Predicting archaeological site locations based on fluvial geomorphology of the Zuidplas near Gouda, The Netherlands

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Content

Abstract

The relationship between landscape dynamics and human needs has been a consistent determinant of human habitation strategies. This research applied an improved version of Kempf's Bottom-Up Model to see if studying past environments combined with regional archaeological information can predict the likelihoods of prehistoric habitation and finds at different depths below the land surface. The model consists of 4 input layers: topography, river-bed reconstruction, stratigraphic units and habitation patterns. Combining these layers created the model's output layer, which is displayed in maps. Including not only the likelihood of habitation but also the likelihood of finds adds an extra dimension that can help optimize archaeological investigations and cultural resource management. A first attempt to use the model in the Zuidplas region of the Netherlands showed promising results. Nonetheless, the gaps and inaccuracies must be addressed before the model can be optimally used.

Introduction

The landscape is, and always has been, one of the most important drivers of the habitation patterns of the human population in most parts of the Netherlands. The river and delta landscape were part of the most densely populated areas around the world through most of the archaeological periods (Kooijmans, 1974; Sanchez-Arcilla et al. 1998; Arnoldussen, 2008; Syvitski et al., 2009; Pierik & van Lanen, 2019; Van Lanen & Pierik, 2019). Not only did cultural processes like politics and economics influence the habitation patterns, but also environmental factors such as avulsions, flooding, and landscape elevations (e.g., Butzer, 1982; Brown, 1997; Von Nagy, 1997; Guccione, 2008; Funabiki et al., 2012; Howard et al., 2015). Natural and human-caused landscape elevations are significant factors in habitation patterns. Rivers (levees) and humans (mound buildings) created a higher-situated area that served as a safer location, protecting against flooding and potential avulsions (Pierik & Van Lanen, 2019).

The primary process, sedimentation, is linked to processes such as flooding and avulsions and the resulting landscape elevations. In addition, the sedimentation caused the soils in many fluvial landscapes to be of high quality and provided a fertile substrate (Van Laanen & Pierik, 2019). The abundant natural resources created a large network of long-distance transport routes over water and land (e.g., Cunliffe, 2004, Van Es and Verwers, 2010, Van Lanen et al., 2016). Changes in flood regimes, for instance, influenced habitat patterns (e.g., UK: Macklin, 1999; Gila River, Arizona: Waters, 2008; Elbe, Germany: Schneeweiss and Schatz, 2014; Nile delta: Marriner et al., 2013; Macklin et al., 2015). Observing events on a larger scale, changes in flooding frequency can affect the fall and rise of civilizations (*Yangtze delta:* Zhang et al., 2005; *Shanghai area*: Wu et al., 2014; Lajia Site, Qijia: Yang et al., 2003). The studies mentioned above link environmental processes with habitation patterns, indicating that archaeological sites' locations are highly correlated with landscape dynamics.

The province of Zuid-Holland, The Netherlands, (Fig. 1) provides a unique insight into the correlation between habitation patterns and landscape dynamics. The region underwent large changes in the transition from the Late-Pleistocene to the Holocene (Fig. 2) (e.g., Zagwijn, 1986; Van den Berg, 1986; Van der Spek, 1994; Cleveringa, 2000), as the Rhine and Meuse rivers created a wide river valley with fluvial deposits. The sandy deposits were from the braiding river system (Krefteheye Formation), which made room for a more clay deposit in the late Pleistocene due to the multiple floodings (Berendsen & Stouthamer, 2000; Cohen et al., 2012; Ouwekerk & Paré, 2022). The habitation patterns during Late-Pleistocene (c. 127,000 BCE to 9,700 BCE) (archeology; Paleolithic) consisted out of nomads that traveled from Germany to the Netherlands, depending on the season (Fig. 2). The nomads (hunters and gatherers) were the inhabitants of the Netherlands. The Netherlands consisted, during the Late-Pleistocene, out of mostly cover sands. During this period to the Holocene the winds created higher sand dunes from the sand of the cover sands and the Krefteheye Formation (Berendsen & Stouthamer, 2000; Cohen et al., 2012; Ouwekerk & Paré, 2022). At the beginning of the Holocene era, extensive peat was formed in Zuid-Holland due to the rising sea levels (Berendsen & Stouthamer, 2000; Cohen et al., 2012; Ouwekerk & Paré, 2022). In this period, the meandering river patterns came into existence and formed different channels

Figure 1 Location of the province of Zuid-Holland in the Netherlands shown in blue (created with ArcGIS)

throughout Zuid-Holland. The Late Paleolithic (end c. 8,800 BCE) and the Mesolithic (c. 8,800 BCE-4,900 BCE) were archeological periods of that time (Fig. 2). There was a slight change in habitation patterns. The nomads started to enhance their technology and began living in more fixed places. However, it was not until the Neolithic when the nomads changed to society in settlements including different lithic cultures. Between 14,500 BCE and 6,500 BCE the climate changed, and the temperature rose fast, causing deglaciation and global sea-level rise (e.g., Lambeck et al., 2014) (Fig. 2). Around 6,500 BCE, the deglaciation decreased and the steady sea-level was reached (Lambeck et al., 2014) (Fig. 2). Due to the decreased sea-level rise, the current coastline was able to form (Fig. 3) (Beets and Van der Spek, 2000; Vos et al., 2011; Pierik et al., 2017). Between 5000 BCE and 2300 BCE the sea-lever rise diminished, and a beach ridge were created (Fig. 3) (Beets et al., 1992; Pierik et al., 2017) (Fig. 2). Behind the beach ridges, the salty water was replaced by fresh water due to rainfall and supply from the rivers (Beets et al., 1992; Beets and Van Der Spek, 2000; Vos et al., 2011; Vos et al., 2011; Pierik et al., 2017) (Fig. 2). Within the freshwater basins, peat formation was the keenest process of that time and progressed through the Roman Period (Fig. 3). The Bronze Age, Iron Age and Roman Period were significantly affected by the peat formation, which was exploited during the Middle Ages, leading to the removal of many archaeological finds (Fig. 3), mainly deposits, linear and point structures (Ouwekerk & Paré, 2022). Despite human intervention, the impact of the sea on the landscape persisted, with regular flooding causing creation of creek systems (Berendsen & Stouthamer, 2000; Cohen et al., 2012). In sum, throughout the Late-Pleistocene and Holocene, the habitation patterns in the region were shaped by the dynamics of the landscape (Fig. 2). With the introduction of farming, domestication and pottery, the nomadic lifestyle gave way to permanent settlements. However, the precise effect of the landscape dynamics on the habitation of the Zuidplas region remains unclear.

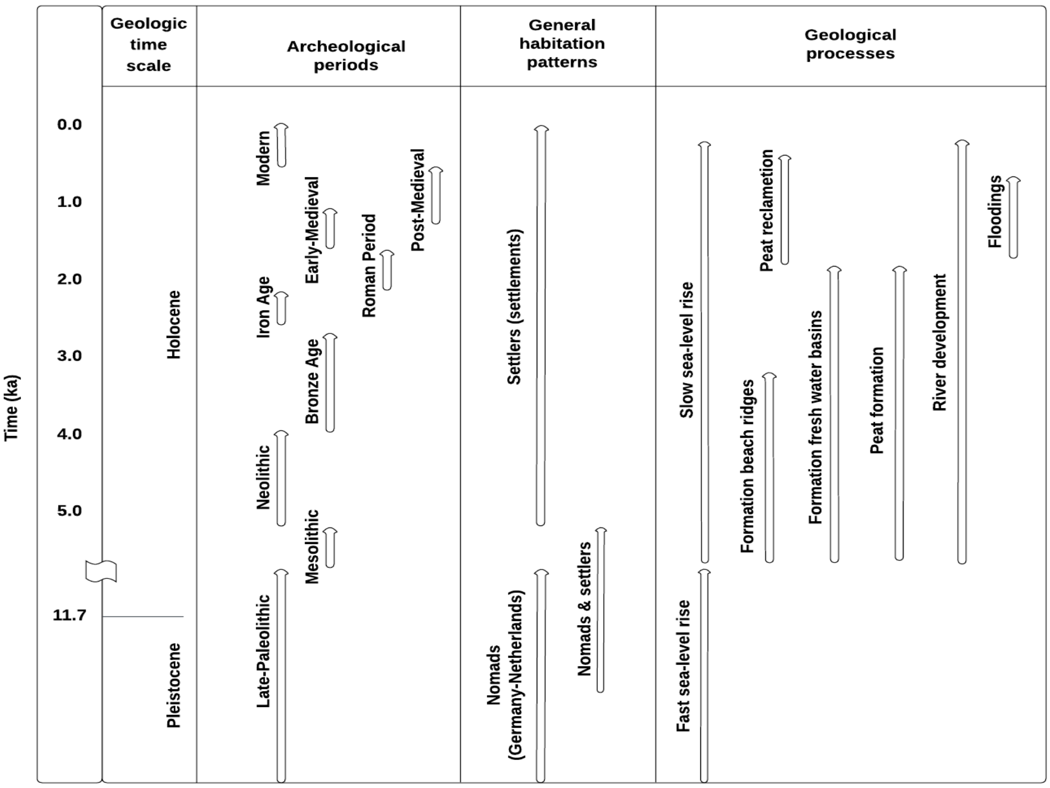


Figure 2 Visualization of archaeological periods, habitation patterns and geological periods over time (Archeologisch Basis Register 1992 - Brandt et al., 1992)

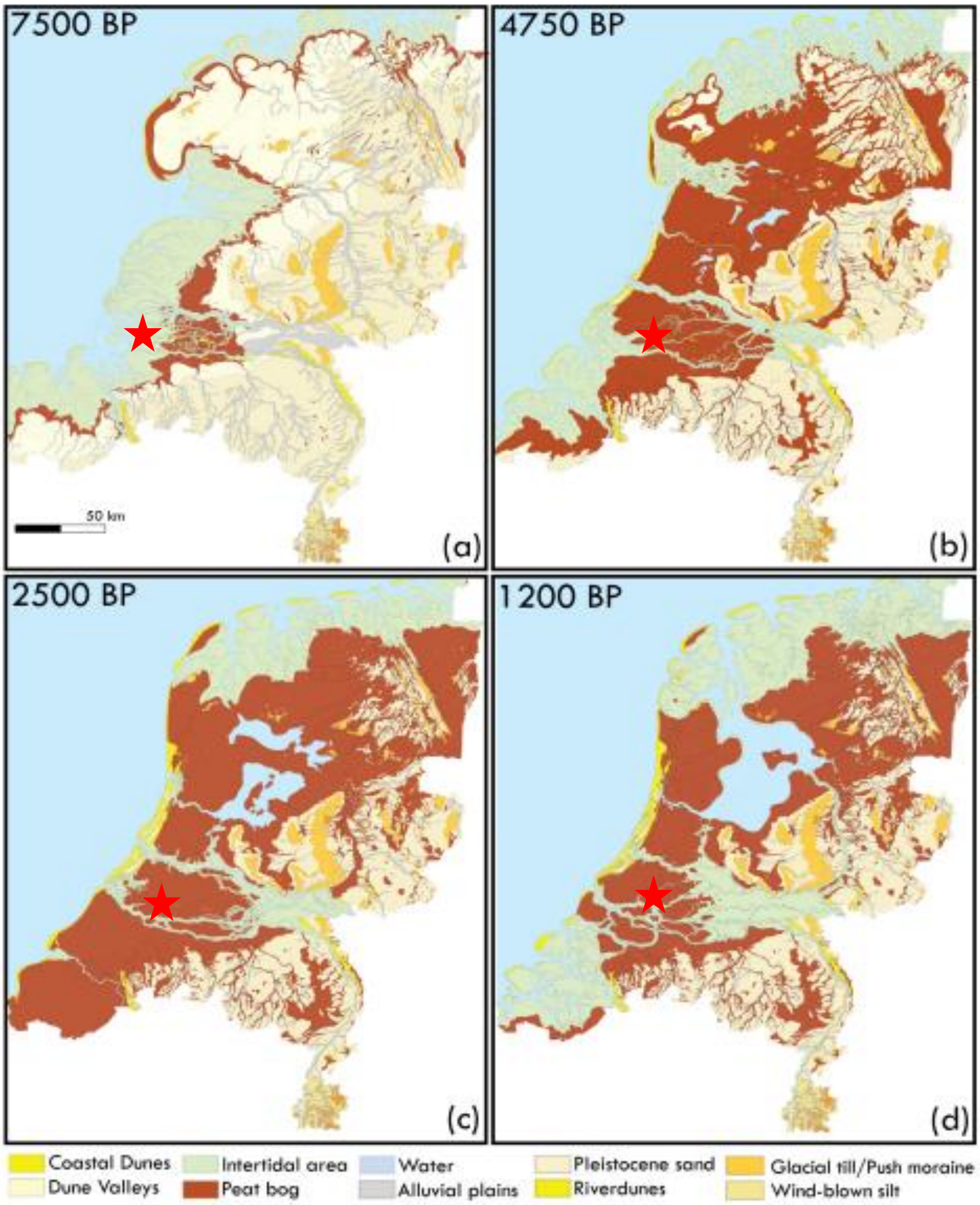


Figure 3 Evolution of the Netherlands between 7500 BP and 1200 BP (from Vos et al., 2011). Red star shows the location of Gouda.

The correlation between landscape dynamics and archaeological sites can be instrumental in conducting archaeological research. By reconstructing an area, one can gain insight into humans' potential habitation patterns. It is widely known that human habitation often occurred on, for example, the levees of the landscape, as these areas provided higher elevation (e.g. Törnqvist et al., 1996b; Kidder and Balee, 1998; Rodning and Mehta, 2015; Holz, 1969; Louwe Kooijmans and Knip, 1974; Donoghue and White, 1995; Stanley and Chen, 1996; Politis et al., 2011; Pierik and van Lanen, 2019; Chamberlain et al., 2020). Analyzing the patterns of the current ridges in previous landscapes can provide indications as to where habitation occurred and where archaeological sites may be located. Similarly, the patterns of former creek systems can also demonstrate the correlation between landscape dynamics and archaeological sites. In the western region of the Netherlands, for instance, creek systems were abundant. Next to the focus on landscape dynamics, the archeological finds can give indications on possible habitation patterns, such as charcoal, animal remains and botanical macro-remains (Appendix 2). In general, analyzing the interaction between humans and the landscape is a more cost-effective and less labor-intensive approach to conducting archaeological research. This has benefits for cultural resource management because it makes mandatory surveys (e.g., cultural resource management in regions of new construction) more efficient (time and cost) and effective.

Often, information on landscape and habitation patterns is available at only a regional or specific level. However, such information has not yet been fully obtained for the study area near Gouda. Knowledge of large-scale or specific processes can help form a relationship between landscape dynamics and habitation patterns. The hypothesis is that such large-scale processes can link these two parameters and provide insights into the archaeological likelihood of the study area near Gouda.

With the hypothesis that large-scale processes link landscape dynamics and habitation patterns, this study will examine these two aspects in a study area near Gouda called the Zuidplas. The study will predict archaeological likelihood based on the Zuidplas' fluvial geomorphology by using an enhanced version Bottom-Up Model created by Kempf (2021). The Bottom-Up Model in this research is a guideline for combining the geological and archeological information by studying different layers separately and placing them together at the end. That connection will be conceptualized through geological mapping of the study area, archival mapping of past archeology in the Netherlands and the region, and fieldwork validation. The first step is to create a landscape reconstruction of Zuidplas near Gouda (Fig. 4) and map out the former river and creek systems. The study area underwent many dynamic processes over a long period, leading to the current formation of the landscape. Different archaeological periods (Fig. 2; Appendix 1) ran parallel to the landscape's formation. The next goal is to understand the different habitation patterns per archaeological period that are relevant to the study area. Ultimately, combining the landscape reconstruction with an understanding of the habitation patterns results in a probability map of potential archaeological sites in the Zuidplas.

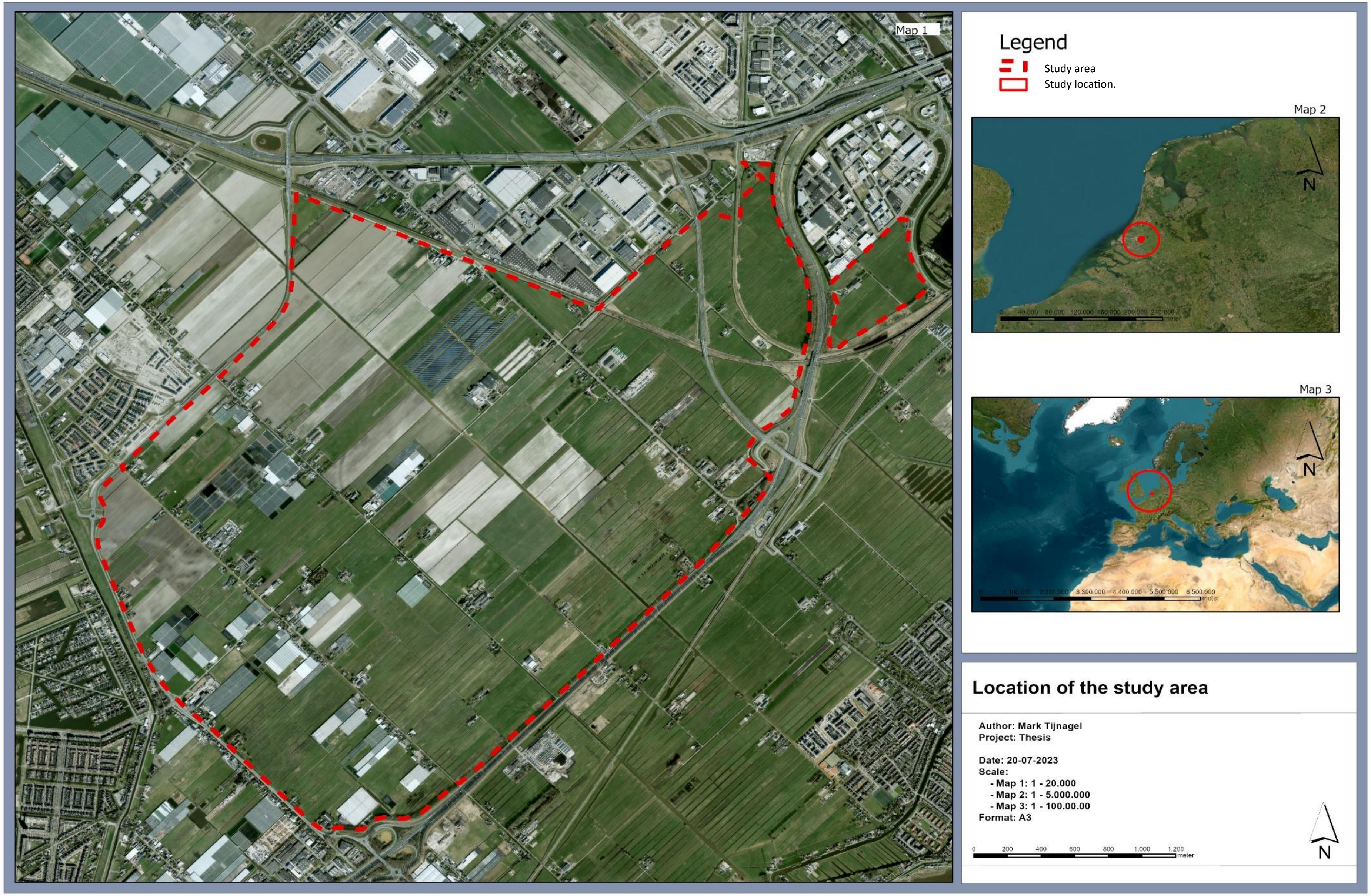


Figure 4 Location of the study area with national and global inset

Research question

This research addresses the question of: Can paleoenvironmental reconstructions coupled with input on regional archaeological periods be used to predict the archaeological probability of a landscape by using the Bottom-Up Model?

- R1. Landscape reconstruction: How can the study of landscape dynamics contribute to the understanding of environmental history? - What are the known landscape systems, and what is their age?
- R2. Archaeological habitation distribution: What types of habitational patterns were employed by humans living near paleo-channels, and how did these strategies change over the different archeological periods?

Methodology

Study design

The thesis included a detailed examination of the study area's paleogeographic and archaeological settings. The basis of the Bottom-Up Model (Fig. 5) comes from the research of Kempf et al. (2021) whose goal was to create a surface cover model that allows a fine-grained land surface classification. In this study, the model forms the basis for creating an archaeological likelihood of the study area by enhancing the input and output layers with the below-mentioned parameters. The model contains four input layers and one output layer. The input layers, namely topography (1), riverbed-reconstruction (2), stratigraphic units (3), and habitation patterns (4), form the input of the model (Fig. 5). The combination of all four input layers creates an output layer containing information on the archeological probability of the study area. The first stage, consisting of the literature study to support the synthesis of the model layers, can be thought of as two different but closely linked parts: geology and archaeology. The landscape reconstruction was created by collecting data from papers and databases (DINOLoket). Maps of the geological units existing in the study area were made with the collected data and their depth and ages. The archaeology segment was created by collecting data from, namely, papers and databases (Archis3). For every archaeological period (Appendix 1) a description of the preferred region and trends in how people lived based were created. After completing both segments, they were combined to create probability maps of the study area. The model output was tested by comparison with eight previously conducted auger drillings by (refs/companies). New fieldwork was intended to further validate the findings; however, it was ultimately not possible due to the unwillingness of the inhabitants to participate in this research. All the collected data were combined into a single report that answers all the research questions.

The study is part of an ongoing project and survey in Zuidplas executed by Sweco, a European engineering, architecture, and consulting firm offering services in sustainable design, planning, and project management. The purpose of the survey is to analyze the interaction between humans and the landscape and identify any archeologically significant sites before proposed modern developments start. By addressing the goal in this way, the archaeological research becomes more cost-effective and less labor-intensive. It brings benefits for cultural resource management because it makes mandatory surveys (e.g., cultural resource management in regions of new construction) more efficient and effective.

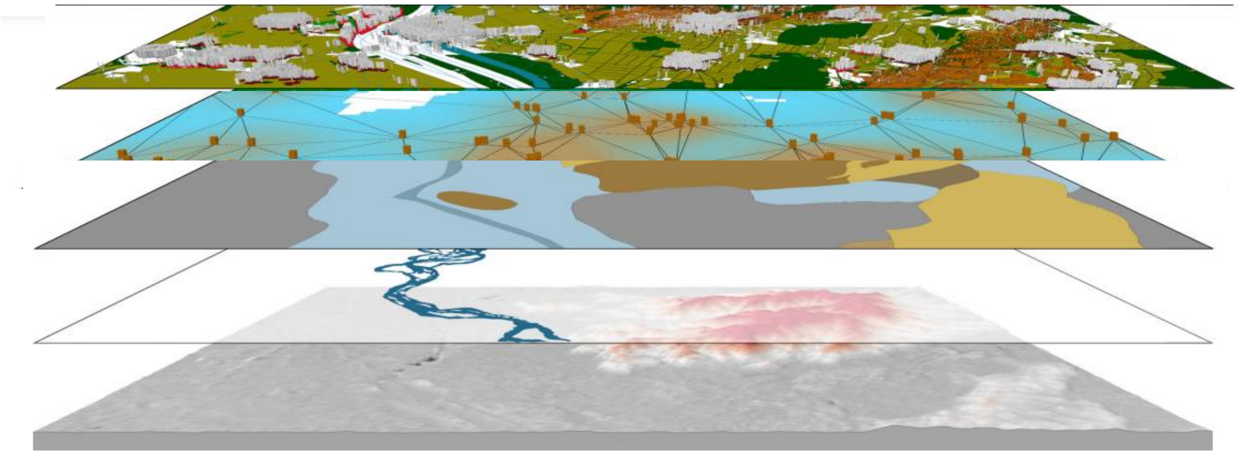


Figure 5 Example of bottom-up model for the reconstruction of paleo-landscapes and human-landscape interactions. The layers from bottom to top consists of topography, riverbed-reconstruction, geology, probability, habitation (adapted from Kempf, 2021)

Data collection

Available data

In the Netherlands, there is high data availability concerning geological processes and settings, which facilitates studies linking cultural and geomorphic processes. In addition, databases such as DINOLoket are publicly available. Underneath is a description of the various sources containing information about geological processes that were used in this study (Fig. 6):

- DINOLoket consists of publicly available data on shallow, deep, and underground soils. It is a collection of a large number of auguring's done around the Netherlands. The database collected information on the geomorphology (Appendix 3) and soil type distribution (Appendix 4) of the Netherlands.
- Peer-reviewed journal articles contain a variety of data that describe the origins of the Netherlands and the coastal region. Examples include papers like *"Paleogeographic development of the Rhine-Meuse delta", "The Netherlands", "Roman and early medieval habitation patterns in a delta landscape: The link between settlement elevation and landscape dynamics", and "Rhine-Meuse Delta Studies' Digital Basemap for Delta Evolution and Paleogeography".*
- The Digital Terrain Model (DTM) is used rather than the Digital Surface Model (DSM) because the DTM is devoid of the natural or synthetic objects located on the earth's surface, such as vegetation and buildings. In addition, unlike the DEM, the DTM has its points regularly spaced and includes natural features (e.g., Ridgelines, coastlines, faults, passes, and drainage lines). The collection of very high-resolution LiDAR data from the Netherlands created the DTM and stored it in the database of Actueel Hoogebestand Nederland (AHN) (Appendix 2).

In addition to gathering geological data, the collection of archeological data is crucial to answering the research question. Various sources, such as the Archeologische Monumentenkaart (AMK), Archis3, and the archeological policy maps, were consulted to obtain an overview of the archeological values in the region (Fig. 6).

- The Archeological Monument Map (Rijksdienst voor het Cultureel Erfgoed Amersfoort, 2003-2009 consists of information on the important archeological terrains in the Netherlands. The maps show locations classified in four categories, ranging from low to high archeological expectancy. However, since 2014 the Rijksdienst voor het Cultureel Erfgoed (RCE) has not updated the AMK. The RCE advised using a static map.

- Archis3 (Rijksdienst voor het Cultureel Erfgoed) is an information system by RCE and consists of information about archeological sites, tracks and finds, the status of the terrain (legal protection), and areas where archeological research was executed.
- Archeological policy maps are maps created by the local or provincial governments. It shows how the government would like to see archeology in their region managed. The policy maps are based on the region's expectation maps.
- Archeological research refers to peer-reviewed articles that describe archeological finds and the habitation patterns in the Netherlands over the different archeological periods. Examples include papers such as *"Paleogeographic development of the Rhine-Meuse delta", "The Netherlands", "Roman and early medieval habitation patterns in a delta landscape: The link between settlement elevation and landscape dynamics", and "Rhine-Meuse Delta Studies' Digital Basemap for Delta Evolution and Paleogeography".*

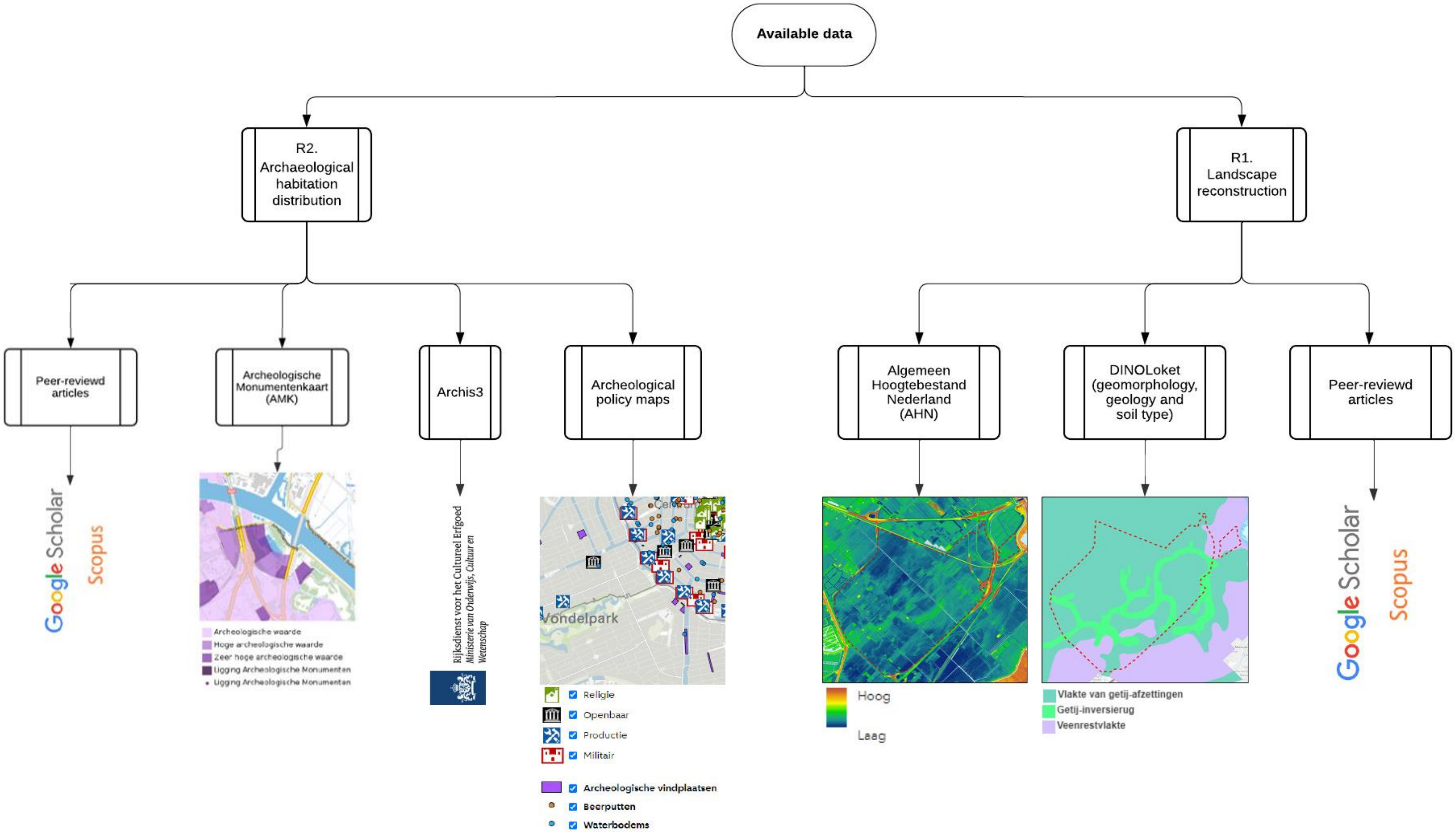


Figure 6 Available data for this study including examples and connections to the specific research questions. The sources provide data to construct the input layers of the Bottom-up Model, used to predict the archeological probability of the Zuidplas study area.

Model construction and output

This section details the construction of the Bottom-Up Model, including its four layers, and the generated output of an archaeological probability map coupled to the expected surface and underlying geologic properties. The area over which the model input and output were generated is 10,6 km^2 and the depth of the Pleistocene deposits is circa 8 meters below surface.

Model input

Layer 1 - Topography

The first layer of the model contained present-day land-surface topographical information. The data was collected using the AHN's database DTM. With the information, a map was produced in ArcGIS PRO that shows the elevation differences within the study area.

Layer 2 - River-bed reconstruction

The second layer consists of the riverbed-reconstruction of the region. The river-bed reconstruction was taken separately from the other geological units and processed because of its general high probability of archeology and the highly detailed reconstruction. The data was mostly collected through peer-reviewed papers (Table 1) and DINOLoket's database. DINOLoket contains the borehole information on which the geomorphological reconstruction was based. DINOLoket provided maps of the former channel belts' locations. In addition, the cross-sectional data shows the depth of these former channel belts. The data was visualized on a map in ArcGIS PRO, showing all of the different riverbed systems. The DINOLoket Model was named BRO GeoTop and contains a detailed three dimensional image of the subsoil to a depth of circa 50 meters below NAP. Within the model the subsoil is divided into voxels (grids) of 100 by 100 meters and 50 cm in depth (*BRO GeoTOP: Detaillering Van De Bovenste Lagen | BROloket*, n.d.). The inclusion of both sources, DINOLoket and peer-reviewed papers, was crucial as it provided a more comprehensive understanding of the river-bed systems in the study area, which would have been otherwise lacking. The combination gave the exact location, both horizontally and vertically including their ages and the origins of the channel systems in the study area. Together they form an image of the landscape dynamics which contributes to the understanding of the environmental history of the study area.

Table 1 Sources used for the river-bed reconstruction

Peer-reviewed paper	Data
Berendsen & Stouthamer; 2001	Reconstruction of landscape, including the study area
Cohen, 2012	Reconstruction of landscape, including the study area

Layer 3 - Stratigraphic units

The third layer contained data on geological processes, excluding riverbed processes, spanning from the 8.800 BCE to 1500 CE, with depths ranging from circa 14 meters (Normaal Amsterdams Peil) to the surface. The data was collected using the same method as the geomorphological data, using peer-reviewed articles (Table 2) as mentioned above and DINOLoket data. The layer contained information on the different sedimental formations (e.g. Krefteheye Formation and Nieuwkoop Formation). Furthermore, the depth information for different formations, such as Nieuwkoop and Krefteheye, was collected using cross-sectional data on DINOLoket. Maps were produced and received in ArcGIS PRO using the data, which depicted the different geological units (formations and members) in the study area, along with their depths. Like the reconstruction of the river-bed, both DINOLoket and the peer-reviewed articles were necessary to receive a full overview. DINOLoket shows the exact location and depth of the stratigraphic units, and the peer-reviewed papers complete it by giving information about the origin of these systems to fully understand how and where they came into existence. Together, they form an image of the landscape dynamics, which contributes to the understanding of the environmental history of the study area.

Table 2 Sources used for the stratigraphic units reconstruction

Peer-reviewed paper	**Data**
Berendsen & Stouthamer; 2001	Reconstruction of landscape, including the study area
Cohen, 2012	Reconstruction of landscape, including the study area
Paré, 2022	Reconstruction of landscape, including the study area
Zonneveld 1959	Information Krefteheye Formation
Doppert et al. 1975	Information Krefteheye Formation
Schokker et al. 2007	Information Boxtel Formation
Ouwekerk & Paré, 2022	Reconstruction of landscape, including the study area
Jelgersma et al., 1970	Reconstruction of landscape, including the study area
Van der Valk, 1992	Reconstruction of landscape, including the study area
Busschers & Weerts 2003	Information Krefteheye Formation, Wijchen Member, Information Nieuwkoop Formation, Echteld Formation
Törnqvist et al. 1994	Information Wijchen Member
Makaske & Nap 1995	Information Wijchen Member
Busschers 2008	Information Wijchen Member
Autin, 2008	Information Wijchen Member
Schokker et al. 2005	Information Boxtel Formation
Pruissers & De Gans	Reconstruction of landscape, including the study area
De Mulder & Bosch, 1982;	Reconstruction of landscape, including the study area
Vos, 2015	Reconstruction of landscape, including the study area

Layer 4 - Habitation Patterns

The fourth layer contains archeological information on habitation patterns, which was almost entirely collected through a literature review (Table 3). For the study, ARCHIS, AMK, and local maps were used to extract archaeological data on habitation patterns, archaeological sites, and other information. For the study area, the dataset was extended with the archaeological data published in the literature. For the study area itself, no publications were available; however, around the study area, publications on archaeological finds were available. Besides local data, broader and regional information was consulted to create the input layer. The broader information focused mostly on lifestyles and how to recognize archeological remains in the field. The ARCHIS, AMK, and external data were collected in a single dataset to achieve maximum chronological resolution on the habitation patterns, encompassing technological innovations, cultural aspects, and lifestyle. Next, a theoretical framework was developed, as specified by the Archeologisch Basis Register (Brandt et al., 1992), that outlines the key habitation patterns per archaeological period (Fig. 2; Appendix 1). Next, a theoretical framework, as specified by the Archeologisch Basis Register (Brandt et al., 1992), was developed that outlines the key habitation patterns per archaeological period (Fig. 2; Appendix 1). The habitation pattern data was compiled for nine periods (Fig. 2; Appendix 1) which covered roughly 8.000 years. The large time interval is chosen to include all important archaeological periods of human habitation that can occur in the research area.

Table 3 Sources used for the reconstruction of habitation patterns for all archeological periods

Peer-reviewed paper	**Data**
Heyse, 1979; Kooijmans et al., 2005; Crombe et al., 2011; Jochim, 1983; Mellars, 1973; White, 1982; Gaudzinski, 1995; Van Kolfschoten & Roebroeks, 1985; Roebroeks & Sier, 2015; Amkreutz et al., 2016	Information about the Late-Palaeolithic Period including habitational information, use of techniques and location of habitation
Heyse, 1979; Kooijmans et al., 2005; Crombe et al., 2011; Verhart, 2000; Elston et al., 2002; Goebel, 2002; Groman-Yaroslavski et al., 2020; Kooijmans 2001a, 2001b; Mol & van Zijverden, 2007; Dasselaar et al., 2005	Information about the Mesolithic Period including habitational information, use of techniques and location of habitation
Bakker & Van Gijn, 2005; Heyse, 1979; Kooijmans et al., 2005; Crombe et al., 2011; Kooijmans, 1986; Modderman, 1988; Van Regteren Altena, 1962 & 1963; Van Gijn, 1989; aemaekers, 2001	Information about the Neolithic Period including habitational information, use of techniques and location of habitation
Kooijmans et al., 2005; Fokkens, 1998; Arnoldussen, 2008; Arnoldussen & Fokkens, 2008; Willemse & Groenewoudt, 2012	Information about the Bronze Age including habitational information, use of techniques and location of habitation
Kooijmans et al., 2005; Wijngaarden-Bakker & Brinkkemper, 2005; Fokkens & Jansen, 2004; Van der Vaart & Van Doesburg, 2011; Van Dijk & Groot, 2013; Van Spelde et al., 2020	Information about the Iron Age including habitational information, use of techniques and location of habitation
Heyse, 1979; Kooijmans et al., 2005; Van Es, 1981; Van Dierendonck, 1998; Groenhuijzen, 2018; De et al., 2017; Van Dinter, 2017;	Information about the Roman Period including habitational information, use of techniques and location of habitation and Limes
Pfister, 1992; Fagan, 2000; Lamb, 1995; Grove, 2001; Barker, 1985; Duby, 1974; White, 1962; Duby, 1974; Verhulst, 1999; Van de Noort, 2004; Cunliffe, 2004; McCormick, 2007; Van Es and Verwers, 2010; Van Lanen et al., 2016; Verhulst, 1999; Stabel, 2001; Henderikx, 1986; Borger, 1992, Gerding, 1995; Borger et al., 2011; Van Lanen, 2020; Lanen et al., 2015	Information about the Roman Period including habitational information, use of techniques and location of habitation and Network-friction information
Brandt et al., 1992	Information about the start and end of different periods

Model output

The output of the model is the fifth layer, which contained information of the likelihood of archaeological sites/finds at different locations and depths, relating to the surface and underlying geology

The data gathered from the four input layers was combined. Firstly, the geological information was placed in ArcGIS Pro. This created a map that contained all the stratigraphic and river-bed units with a density of 100 x 100 meters grid size in the Bro GeoTop Model. A table was used to display the output of the habitation patterns. The theoretical framework revealed the inhabitants' most suitable and most used (geological) locations per archeological period. Each geological unit is assigned a relative importance to archaeological potential. For example, landscape dynamics might have more potential in regions where geomorphological features significantly influence human settlement patterns. With the information on the most used and suitable (geological) location, the map was created by highlighting the regions with different colors that showed the likelihood of the specific area per archeological period. The uncertainty of the model was tested by comparing model predictions with known archaeological research locations, which validated the model and allowed it to adjust for uncertainties in the future.

The likelihood of habitation map contained a color scheme for archaeological likelihood in five stages. The color scheme started with yellow, indicating a low likelihood, and went to a dark red color, indicating a high likelihood (based on classification of general Dutch probability maps)(e.g.

(*Emmen, Emmerdennen: 3.1 Archeologie en Monumenten*, z.d.; Noordervliet & Omgevingsdienst Midden-Holland, 2017; RAAP, 2021; Paalman, z.d.)

Utilizing only the likelihood of habitation maps presented a challenge for translating the results to what could be expected of an archaeological field survey. When combining the information on different archeological periods, the likelihood of habitation maps causes an inequality. The likelihood of archeological habitation for different time periods depends not only on the paleoenvironment but also on the size of settlements, population and what materials were produced and left behind. For example, Paleolithic settlements consisted mostly of small hunting camps that produced little archaeological remains. In contrast, the Middle Age settlements featured larger constructions and different economies and land use strategies, which resulted in a larger surface area with more relict material. In practice, this means that with an auger survey into both periods, the likelihood of finding archeological remains is higher for the Middle Ages than the Paleolithic. To visualize this information next to the likelihood of habitation map so that it can be useful for fieldwork predictions, a map of the likelihood of finds (likelihood of any archeological indication) was produced per archeological period. The different periods were classified based on the likelihood of finds (Table 4) with the Paleolithic as the lowest likelihood and the Middle Ages as the largest likelihood based on settlement and population sizes, as explained in Chapter Results – Layer 4 - Habitation Patterns (e.g. Roebroeks & Sier, 2015; Verhart, 2000; Modderman, 1988; Fokkens, 1998; Fokkens & Jansen, 2004; Van Es, 1981; Stabel, 2001). The same color scheme was used in the maps to indicate the likelihood of artifacts being found. The yellow color showed a low change in finds, increasing to dark red, indicating a high likelihood of artifacts from archaeological finds.

Table 4 Likelihood of finds per archeological period

PERIOD	LIKELIHOOD OF FINDS
MIDDLE AGES	Likely
ROMAN PERIOD	Very likely
IRON AGE	Moderate
BRONZE AGE	Moderate
NEOLITHIC	Moderate
MESOLITHIC	Unlikely
LATE-PALEOLITHIC	Very unlikely

The above-mentioned maps showed the horizontal likelihood of habitation and the likelihood of finds for the study area per archaeological period. However, the overall likelihood of habitation and likelihood of finds are hardly visible on the maps. To visualize the overall likelihood of habitation and likelihood of finds, a map of the study area was produced on a grid (460 m x 460 m) (Fig. 7). Using a large grid size in this study offers several advantages. It allows for the identification of broad patterns and trends, reduces data complexity, and makes data collection more feasible and cost-effective over large areas. Nonetheless, this approach still provides a comprehensive overview and captures significant variability, ensuring that key regional features and trends are effectively highlighted. For every grid, a generalized bore profile was created that contained the most related information on the specific grid. Next to the bore profile, a graph was generated showing the probability and likelihood of finds related to depth (Fig. 8).

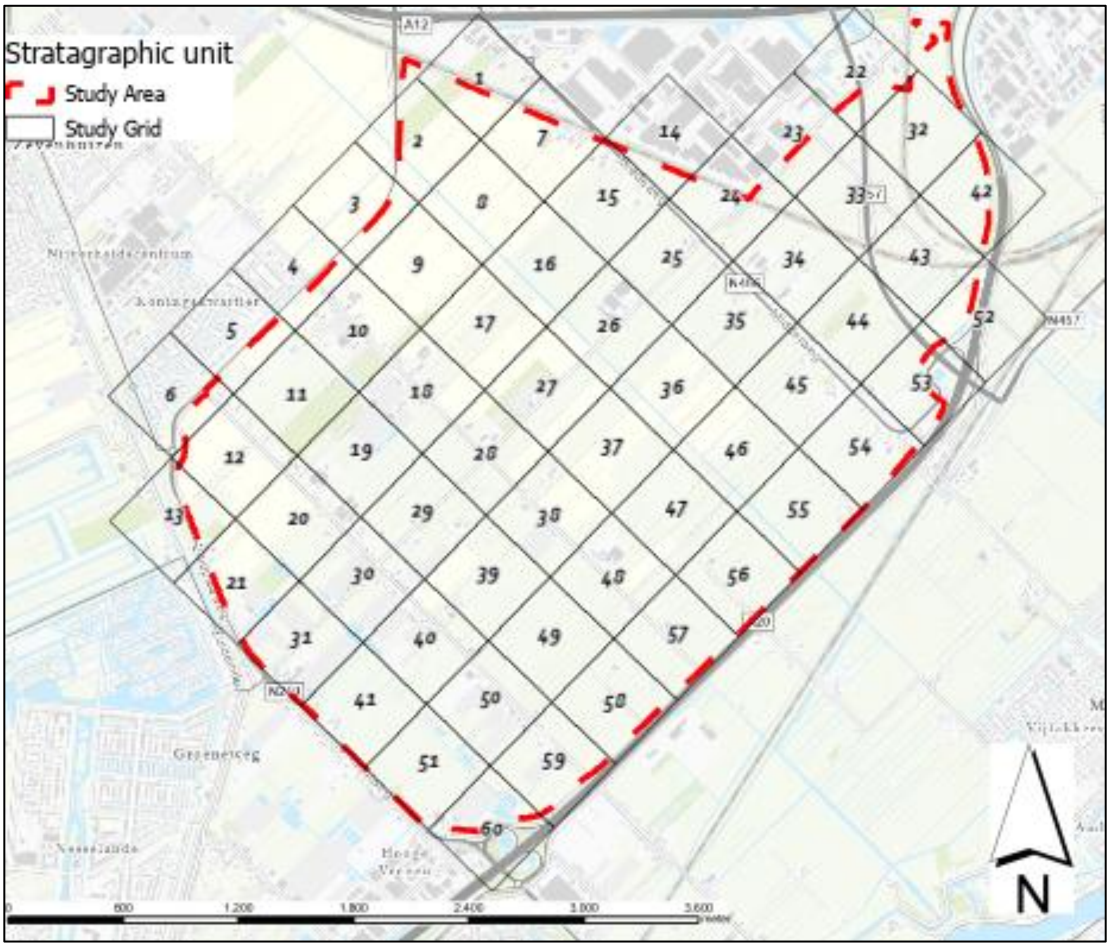


Figure 7 Study grid

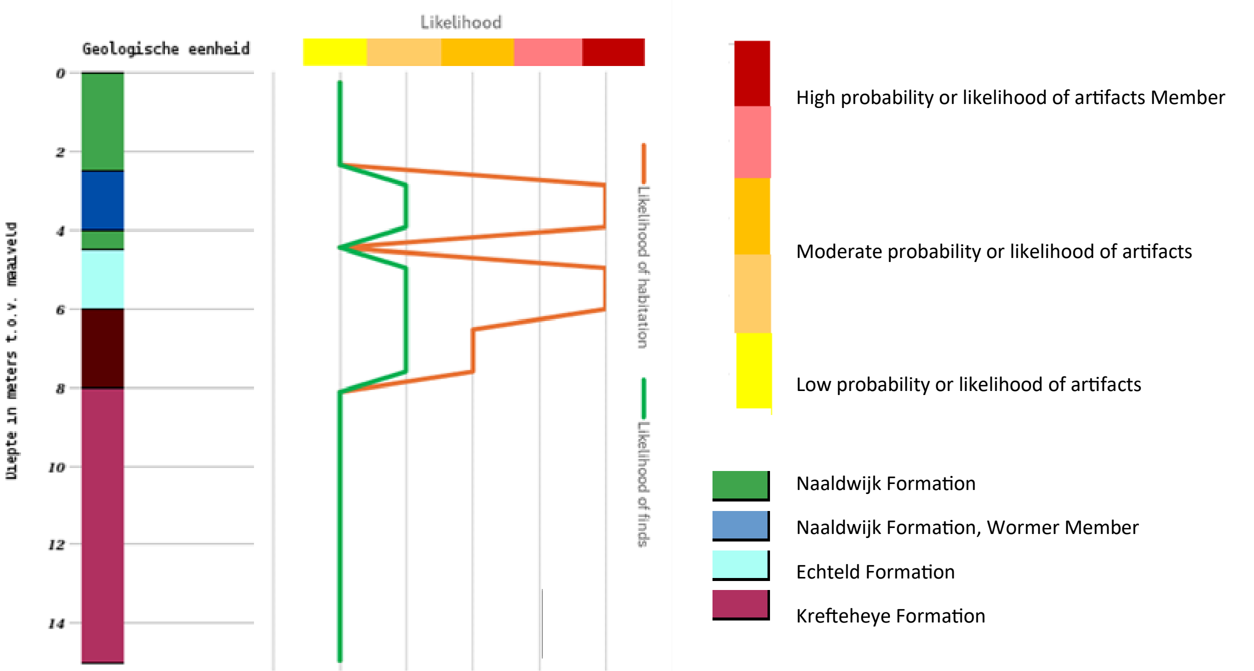


Figure 8 Example of data visualization on the probability and likelihood of artifacts in the vertical profile. The orange line shows the likelihood of habitation for the specific geological unit. The green line shows the likelihood of finds for the specific geological unit.

Model verification

To test the accuracy of the model, field validation was performed using previously collected borehole data from previously executed archeological research (Table 5). The previously collected boreholes (n=7) were obtained in between 2009 and 2020 by auguring to depths up to 6 m. The information on lithology and possible artifact assemblages was recorded by the prior researchers. The location of these boreholes is shown in figure 9.

Table 5 References to the archeological researches used for the verification stage of this study

Reference	Title	Auguring number
Van Putten, 2020 (BAAC)	Gemeente Zuidplas. Plangebied Tweede Tochtweg 127 te Nieuwekerk aan de IJsel	18254-11
Ten Broeke, 2019 (Econsultancy)	Archeologisch bureauonderzoek en gecombineerd verkennend en karteren booronderzoek Middelweg (ong.) te Moordrecht Gemeente Zuidplas	05
Miedema, 2012 (BAAC)	Gemeente Zuiplas Plandgebied Zuidelijke Dwarsweg P7 te Zevenhuizen	11287-28
Leuvering & Nillesen, 2012 (Synthegra)	Bureauonderzoek en inventariserend veldonderzoek, verkennend bodemonderzoek, Tweede Tochtweg 54 te Nieuwerkerk aan den IJsel	3
Kerkhoven & Wilde, 2012 (Adviesbureau Noordam BV)	Archeologisch bureauonderzoek en verkennend booronderzoek Knibbelweg 97, Zevenhuizen	5
Izendoorn & Engelse, 2009 (ArcheoMedia)	Archeologisch onderzoek aan de Bierhoogtweg 11 te Zevenhuizen	001
Coppens, 2012 (Van Westreenen Adviseurs B.V.)	Plangebied Zuidelijke Dwarsweg 17 in Zevenhuizen	ZEZU2-1

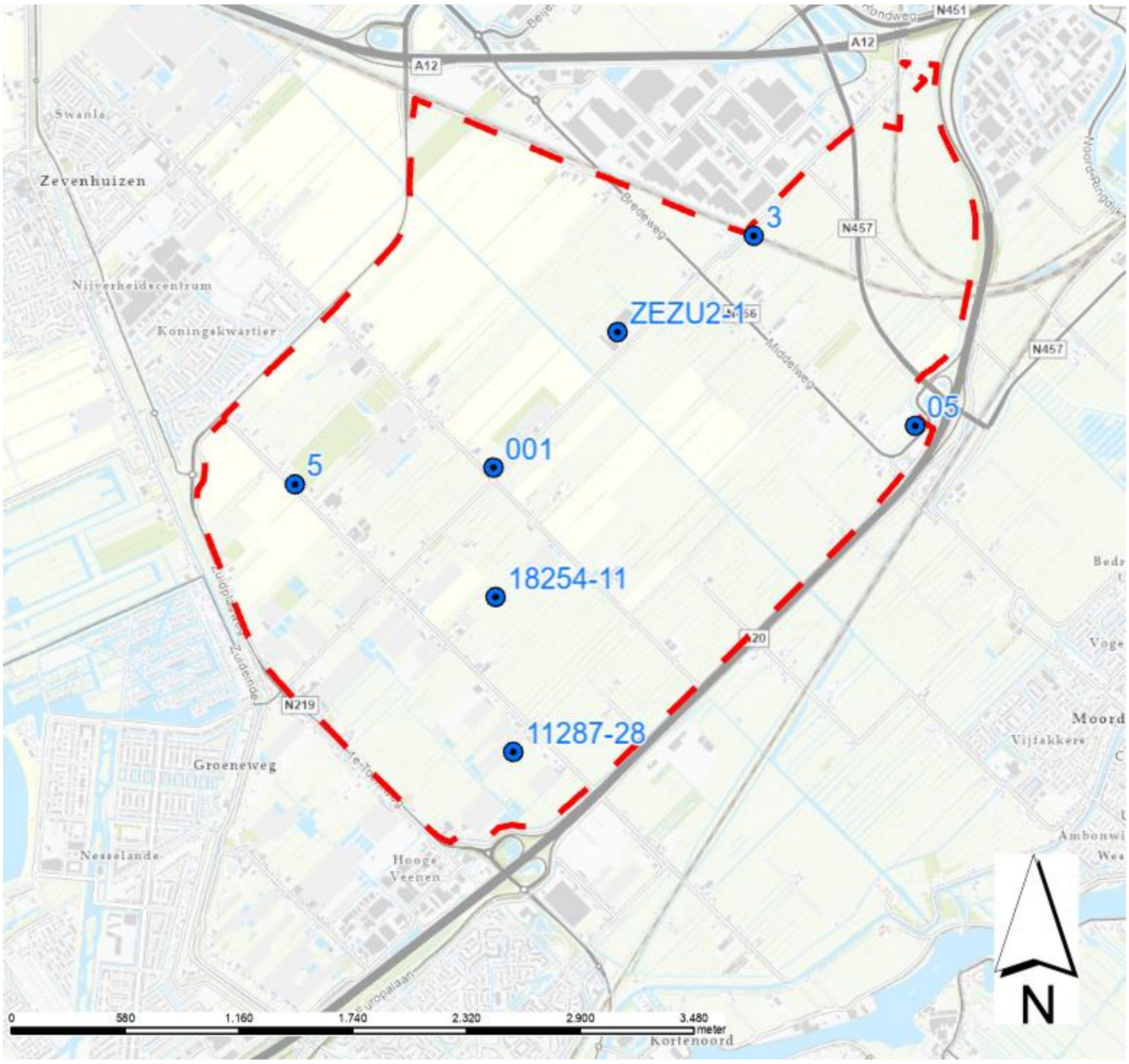


Figure 9 The auguring's shown are previously collected during different archeological researches in the study area.

Results

Model input

Layer 1 - Topography

The study area's land surface is currently relatively low, approximately 6 meters below the Normaal Amsterdams Peil (NAP), according to topographic maps derived from data in the Actueel Hoogtebestand Nederland (AHN) (Fig. 10). It is evident that the study area was influenced by a meandering channel system that is located at a higher elevation, circa 4.3 meters below NAP (Fig. 13).

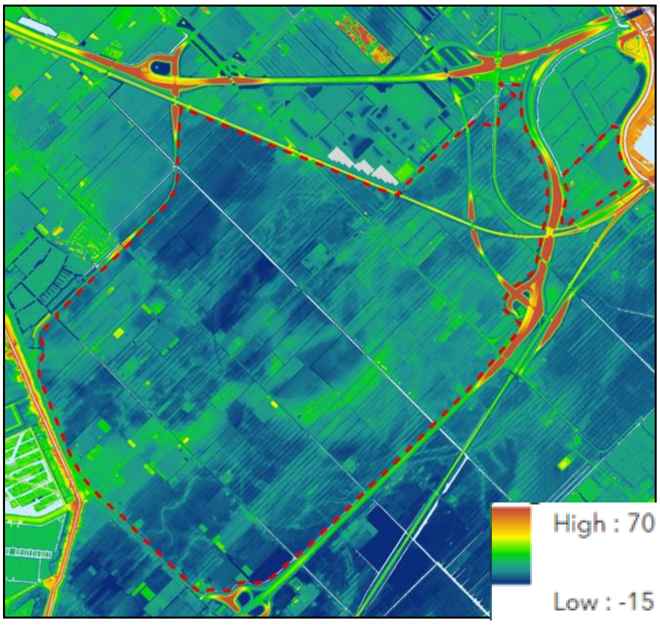


Figure 10 Input layer 1 topography: the topographical information (meters) (AHN) (Appendix 2)

Layer 2 - Riverbed-reconstruction

During the shift from the Pleistocene to the Holocene epoch, multiple meandering rivers wound their way through the peat-rich (Nieuwkoop, basal peats) Formation. The three main river channels were the Delft, Gouderak, and Zuidplas (Fig. 11 & Table 6). The highest point of these former river channels can be found at the upper part of the Echteld Formation, positioned at elevations ranging from 8.4 to 13 meters above the Nieuw Amsterdams Peil (NAP) (Fig. 11 & Table 6). The depth of the sand layer in the Gouderak area varies from 6.5 to 15 meters below NAP (approximately 0.5 to 9 meters below ground level) (Fig. 11 & Table 6). In the Zuidplas area, these depths range from 8.5 to 11 meters below NAP (approximately 2.5 to 5 meters below ground level), and the exact depth for the Delft channel remains unknown but is likely deeper than the Zuidplas ridge (Fig. 11 & Table 6). For the three former channels, the age is known (Table 6) by dating the material (radiocarbon dating) from the specific layers (Cohen et al., 2012).

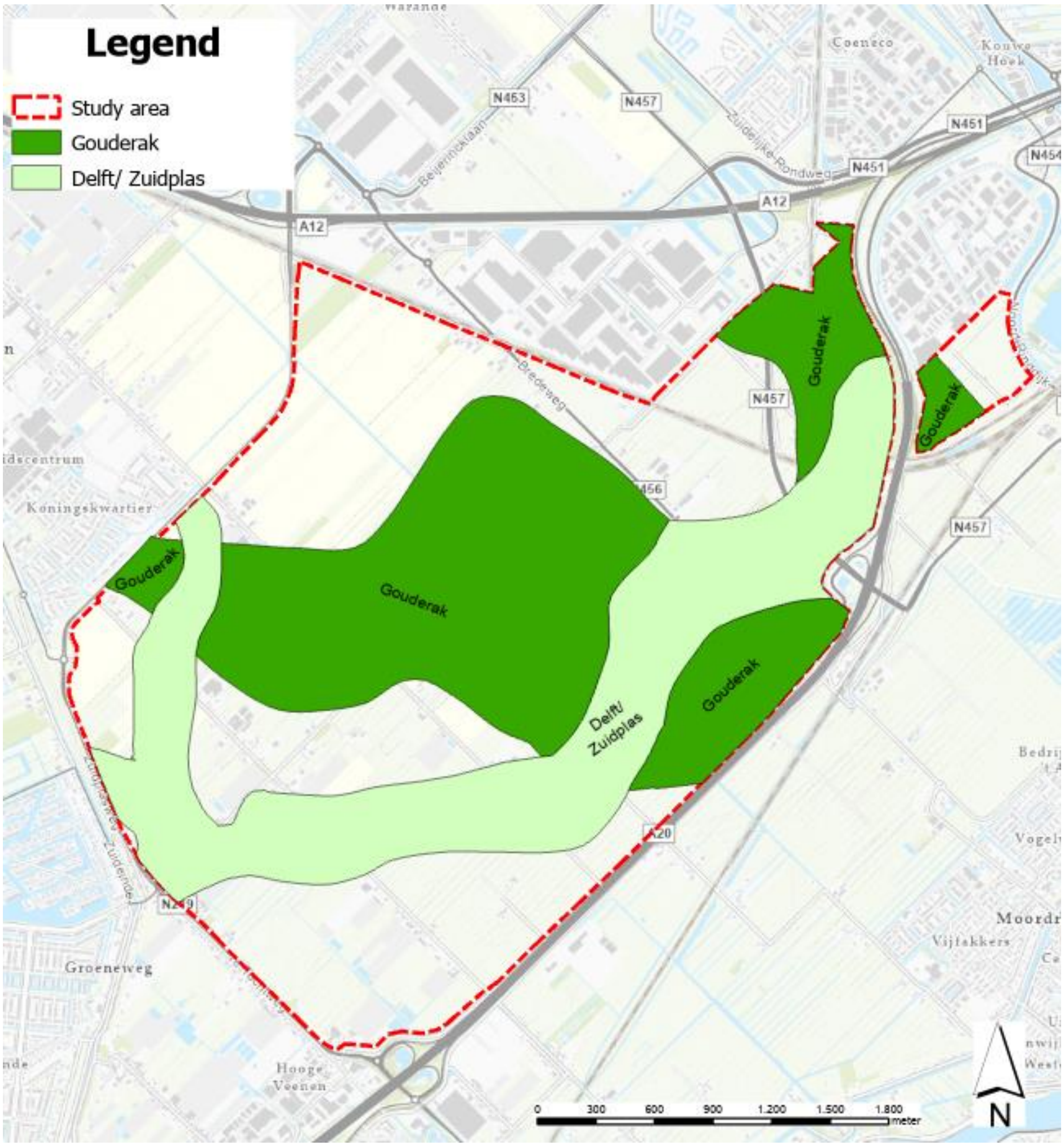


Figure 11 Overview of the ridges in the area. Data regarding the end date and depth are sourced from Cohen et al. (2012)

Table 6 An overview of the river ridges that run through the study area. 53 = Gouderak, 376 = Delft, 204 = Zuidplas (DINOLoket; Cohen et al., 2012)

Ridge	End date	Depth of top of sand
Gouderak	6.000 BCE	-6.5 - -15.0 m NAP
Zuidplas	5.400 BCE	-8.5 - -11.0 m NAP
Delft	6.200 BCE	Unknown (probably deeper than the Zuidplas)

After 5,500 BCE, sea-level rise led to lower gradients in the river, fostering fluvial aggradation in the western region near the terrace intersection. Avulsions, the sudden shifts of river channels, were more prevalent in the west than the east, attributed to the rising sea levels and associated dynamics (Berendsen & Stouthamer; 2001, Cohen, 2012). This caused the Gouderak, Delft, and Zuidplas to silt up. Following the siltation, the sea's influence created a network of meandering creeks (Fig. 12) with corresponding deposits, notably the Naaldwijk Formation and the Wormer Member, in the study area. The deposits were placed on top of the former channel belts. Over time, floods raised the ridges higher than their surroundings. The long-buried deposits, remnants of the Wormer stratigraphic unit, reappeared in areas depleted of peat and are now lying at the surface. Figure 13 shows the combination of the creek system and the former Zuidplas channel belts. The creek system is situated on top of the channel belts, as shown in the figure.

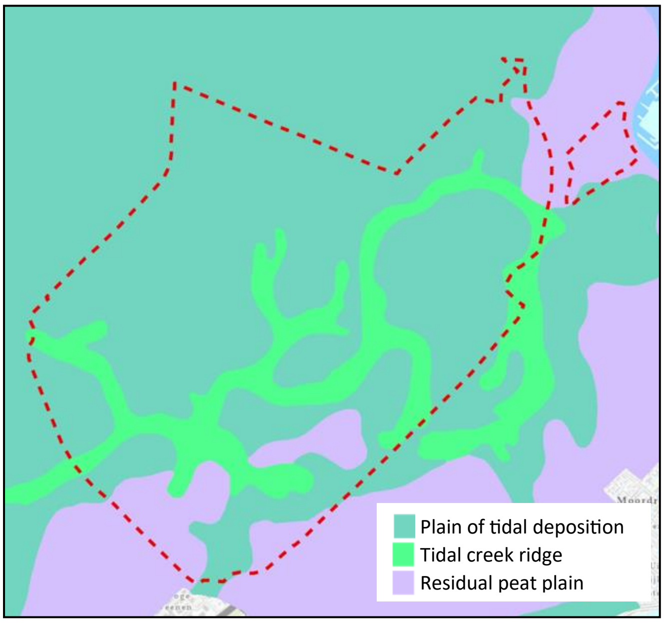


Figure 12 The geomorphology map (DINOLoket) (Appendix 3) of the study area

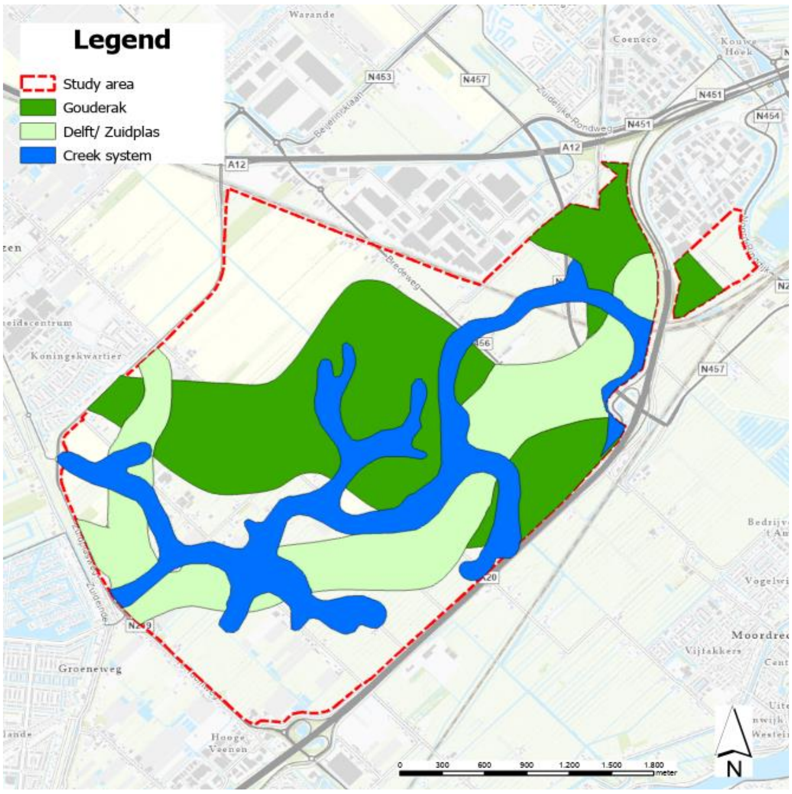


Figure 13 Input layer 2 River-bed Reconstruction: the combination of the creek system channels and former channels belts of the Gouderak, Delft and Zuidplas (created by using date of DINOLoket)

Layer 3 – Stratigraphic units
At greater depths, deposits from the Pleistocene era are seen, which reveal evidence of a vast river valley that formed during the end of the last ice age, spanning a period from 30,000 to 11,700 BC (Appendix 5A). These deposits, mixed with the Kreftehexe Formation (Zonneveld 1959; Doppert et al. 1975; Busschers & Weerts 2003), can be observed at depths ranging from 5.5 to 7 meters (Fig. 14). They consist of various types of sand and gravel, representing remnants of a network of interconnected rivers that once flowed through this area (Zonneveld 1959; Doppert et al. 1975; Busschers & Weerts 2003) (Appendix 6A). Importantly, at the boundary between the Pleistocene and Holocene epochs, we find a layer of dense, grey clay (Wijchen Member (Fig. 12)) (Busschers & Weerts 2003). This clay layer is a trace of the meandering and interconnected river systems (Rhine) that existed at a depth of about 5 meters during that time (Törnqvist et al. 1994; Makaske & Nap 1995; Busschers 2008; Autin 2008). Furthermore, the Boxtel Formation (Delwijnen Member (Fig. 14)) (Schokker et al. 2005; Schokker et al. 2007) was observed on top of the Kreftehexe Formation. The Delwijnen Member consists of finer sands compared to the Kreftehexe formation, which caused the aeolian movement creating drift sand plains and river dunes (Fig. 14).

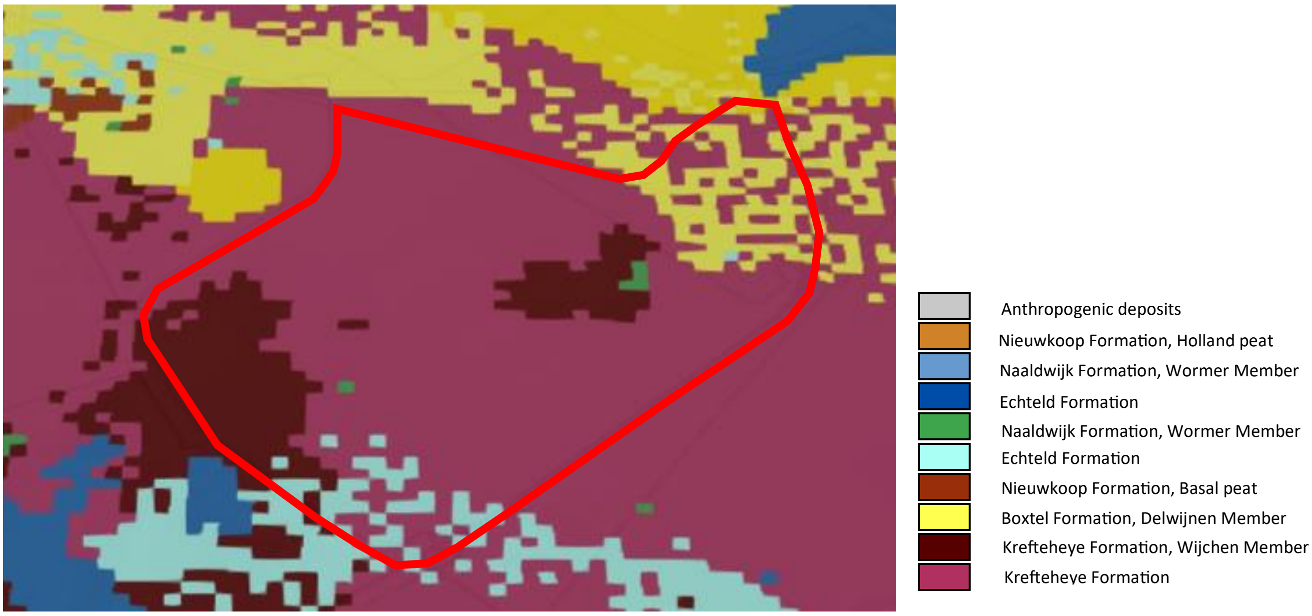


Figure 14 Geological units of the Zuidplas at a depth of -14 meters NAP (adapted from GeoTOP Voxel Scene Layers of DINOLoket)

At the beginning of the Holocene, the ice caps melted and the sea-level rose, accompanied by the groundwater levels near the coast (Berendsen & Stouthamer, 2000; Cohen et al., 2012; Ouwekerk & Paré, 2022). The region's wet conditions produced basal peat, also known as the Nieuwkoop Formation (Weerts & Busschers 2003). During the shift from the Pleistocene to the Holocene epoch, multiple meandering rivers (Echteld Formation) (Weerts & Busschers 2003) wound their way through the Basel Peat and the Wijchen Member (Figs. 15 and 16) (Appendix 6A). The three main river channels were the Delft, Gouderak, and Zuidplas (Fig. 11 & Table 6). The highest point of these former river channels can be found in the upper part of the Echteld Formation, positioned at elevations ranging from 8.4 to 13 meters below NAP (Fig. 11 & Table 6). In the northeast region of the study, small patches of the Delwijnen Member are shown in Figure 13. The higher sandy ridges can indicate river dunes, which were located higher in the region. The sandy outcrops rise higher than the channel of the Gouderak at the same location (Fig. 15). Furthermore, the Kreftehexe Formation is still visible, indicating higher sand ridges compared to the rest of the Kreftehexe Formation (Figs. 15 and 16).

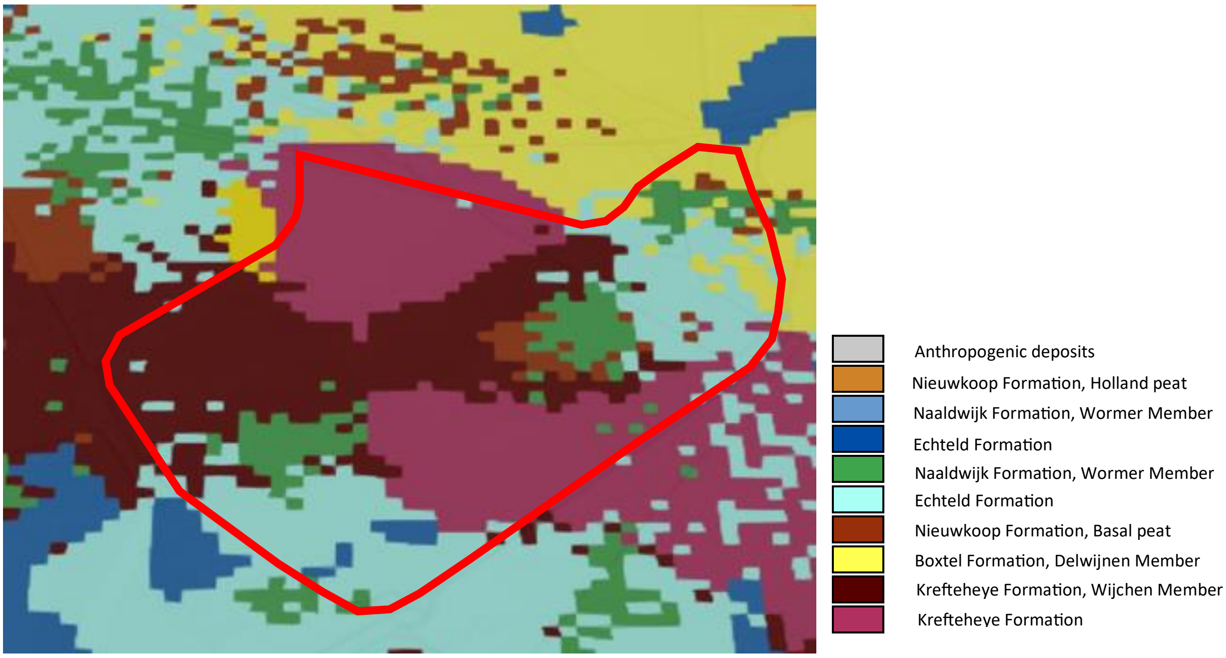


Figure 15 Geological units of the Zuidplas at a depth of -13 meters NAP (adapted from GeoTOP Voxel Scene Layers of DINOLoket)

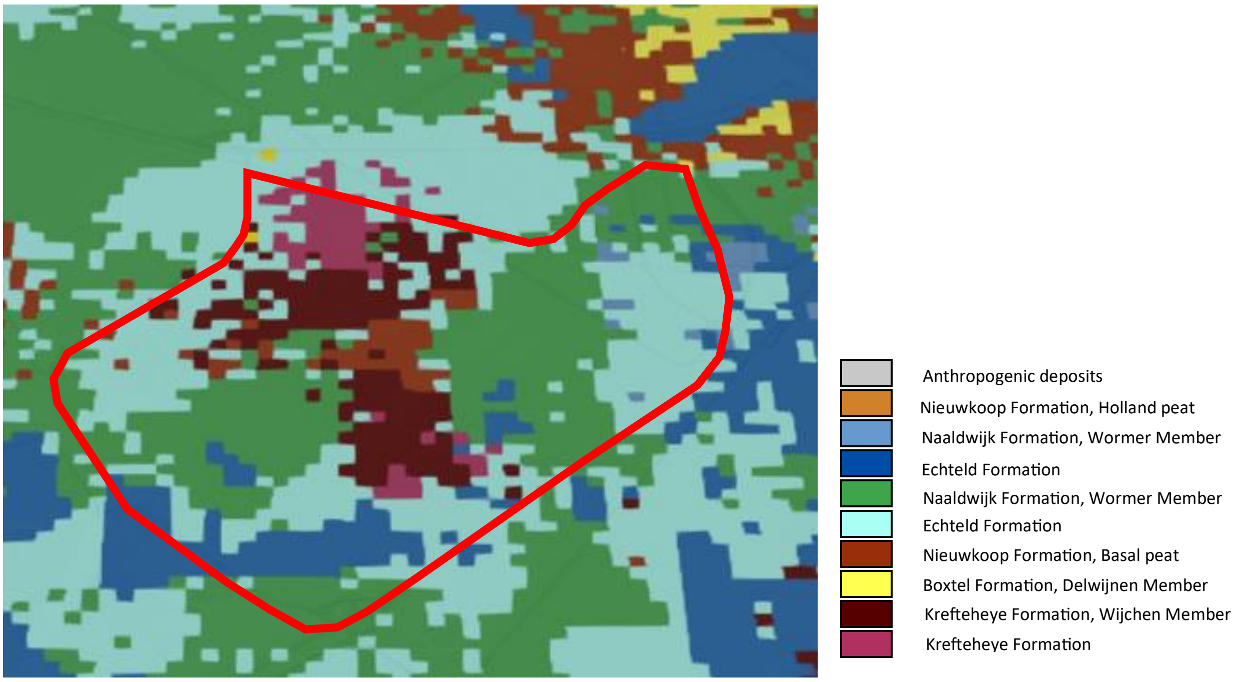


Figure 16 Geological units of the Zuidplas at a depth of -12 meters NAP (adapted from GeoTOP Voxel Scene Layers of DINOLoket)

Around 5,500 BCE, the sea's influence intensified. This transformation created a network of meandering creeks with tidal flat deposits (Appendix 6B), notably the Naaldwijk Formation, specifically the Wormer Member (Fig. 17 and 18). Over time, flooding raised the ridges surrounding the creek system higher than their surroundings. The creation of the creek system and further siltation of the Delft and Zuidplas river systems are shown in figures 17 and 18. In addition, the clay deposits (Fig. 18) covered the older and deeper geological units such as Wijchen, Basel Peat, and Boxtel.

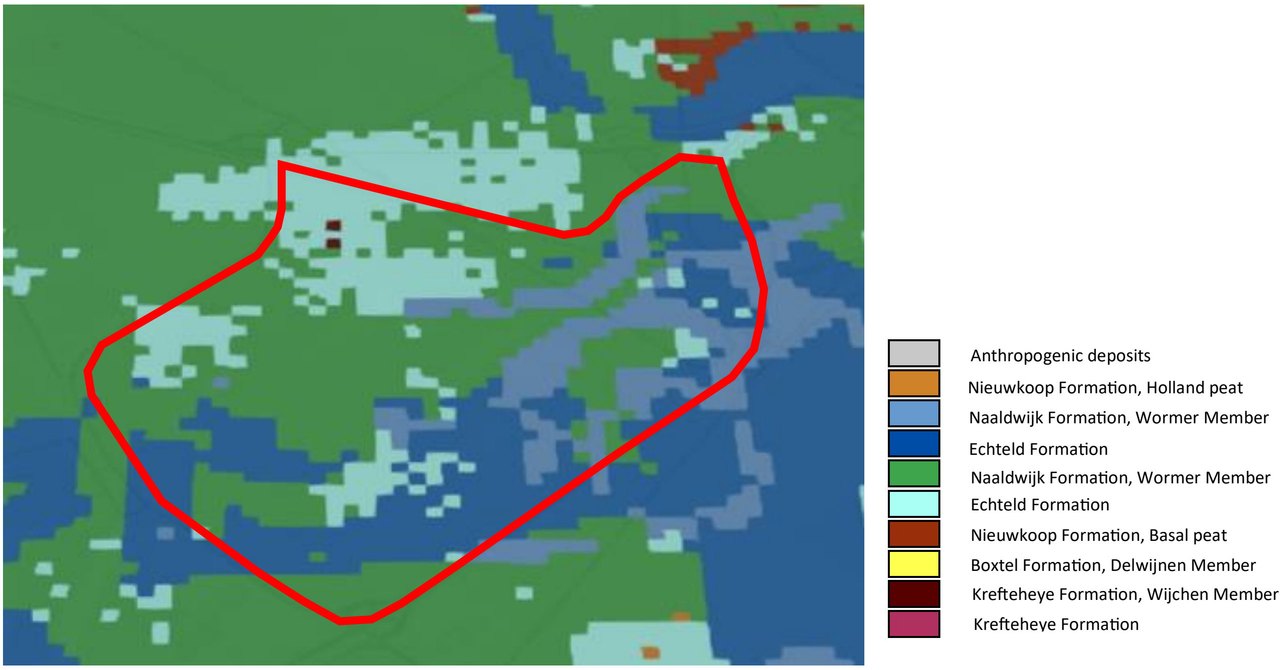


Figure 17 Geological units of the Zuidplas at a depth of -11 meters NAP (adapted from GeoTOP Voxel Scene Layers of DINOLoket)

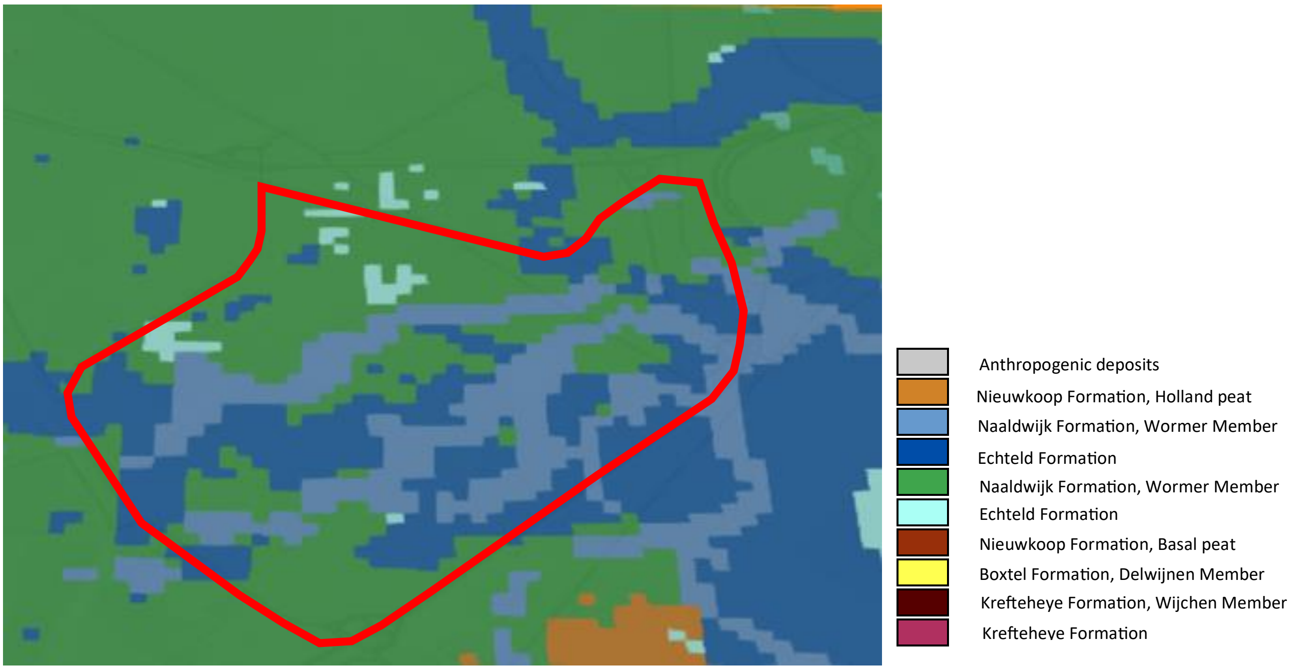


Figure 18 Geological units of the Zuidplas at a depth of -9,5 meters NAP (adapted from GeoTOP Voxel Scene Layers of DINOLoket)

Following 3850 BCE, the western Netherlands' coastal barriers shifted seaward. By approximately 2750 BCE (Appendix 6C), the positions of these barriers corresponded to those depicted on the maps (Appendix 6C) (Pruissers & De Gans, 1985; Jelgersma et al., 1970; De Mulder & Bosch, 1982; Van der Valk, 1992; Vos, 2015). Behind these barriers, extensive peat formation took place.

During the medieval period, the geological patterns in this area underwent a change. The region's drainage system depended on an elaborate network of peat streams, which were subsequently used for a large-scale land reclamation project, accompanied by extensive peat extraction (Appendix 6E, F & G).

The persistent efforts to reclaim land and extract peat played a significant role in the 18th century. The water submerged large portions of the area. However, the echoes of the past were destined to resurface. The ambitious land reclamation endeavours of 1839 revealed the long-buried deposits and remnants of the Wormer Member in areas depleted of peat (Fig. 19).

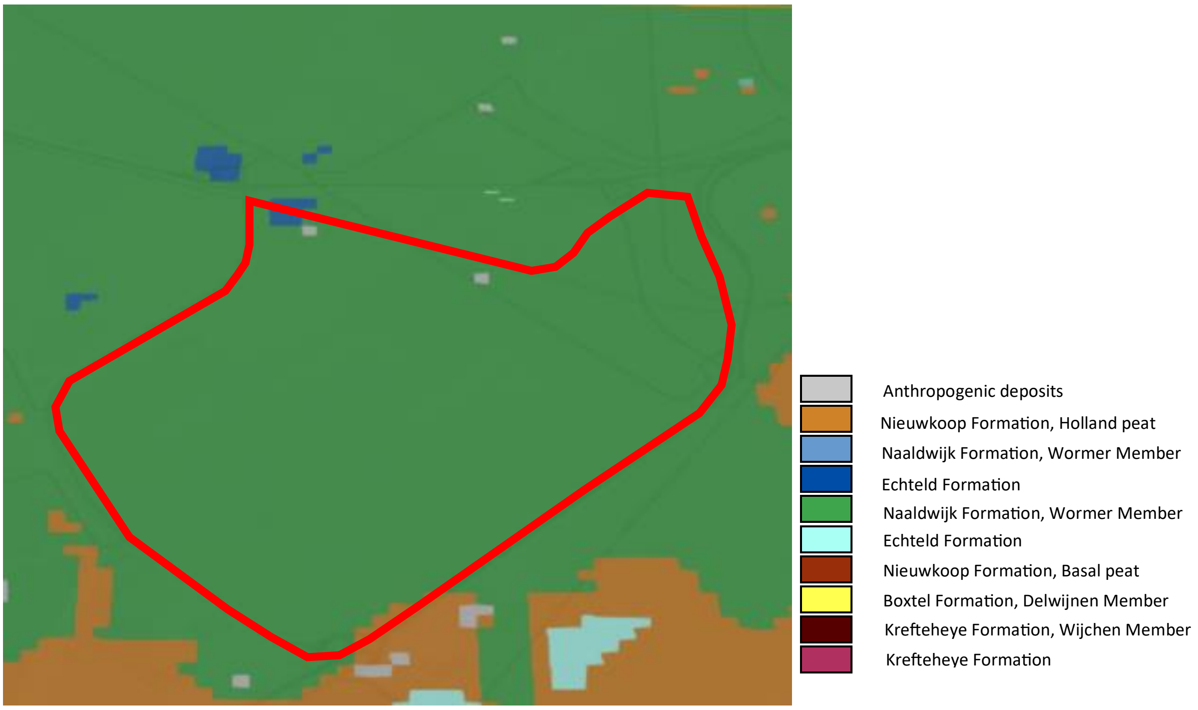


Figure 19 Geological units of the Zuidplas at a depth of -8 meters NAP (adapted from GeoTOP Voxel Scene Layers of DINOLoket)

Layer 4 - Habitation Patterns

Archis

The Archis database showed the location of specific archeological finds. Within the study area, one artifact from the Roman Period is known; however, the reports on Archis3 did not specify what kind of artefact it was. The remainder of the study area is devoid of findings. The region surrounding the study area contained multiple finds from different periods. The New Era (green dots) is most common in the surrounding region. However, the New Era is not taken into account for this study. Next is the Middle Ages, with finds such as coins, bricks, and ceramics. The Mesolithic Period is most interesting in terms of finds. Three locations are indicated to have possible habitation (Fig. 20). Finds such as bone remains, charcoal, flintstone, and fish scales in the former channel belts of the Gouderak indicate possible habitation. According to the data collected from the Archis database, the former channels in the study area are most interesting for habitation and artifact discovery.

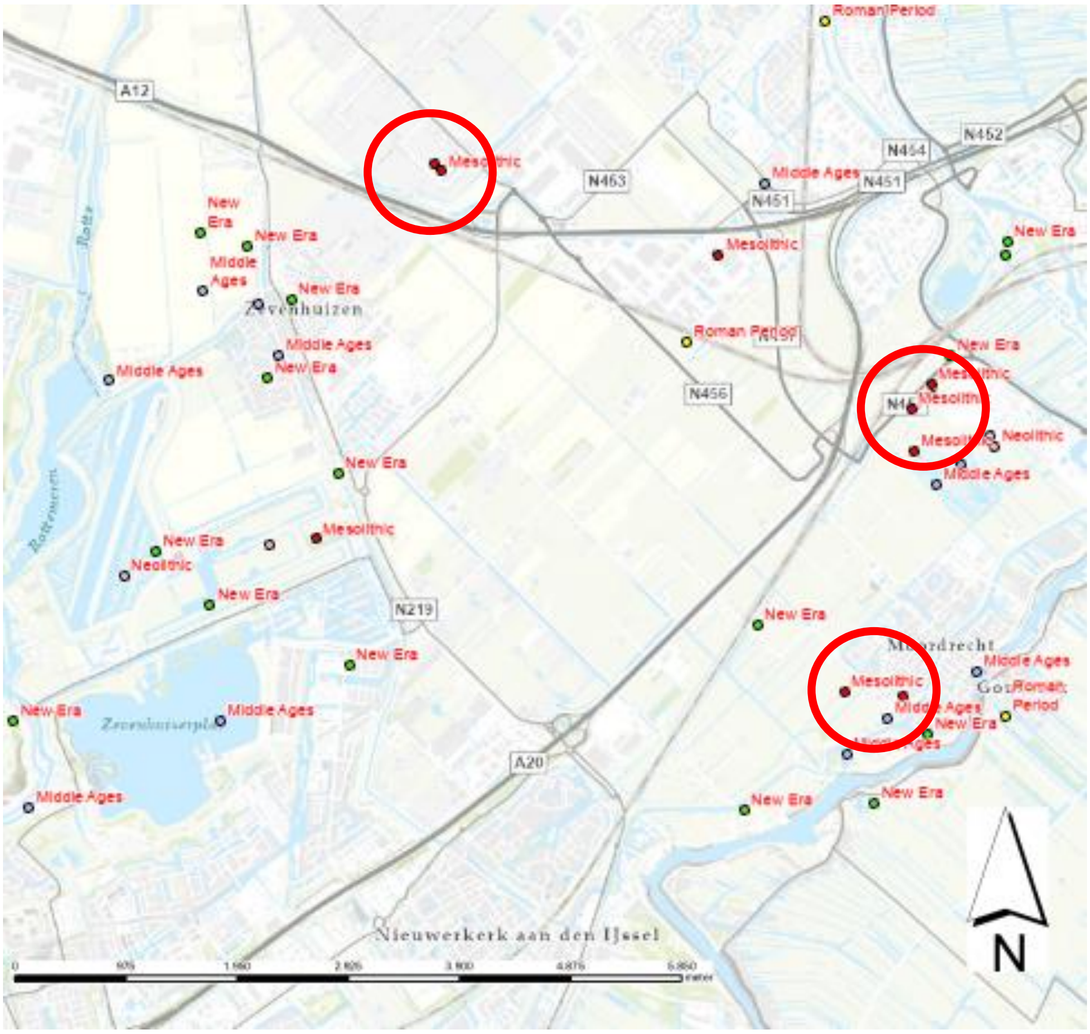


Figure 20 Found artifacts in and around the study area based on the data of the Archis3. The red circles show the locations where, according to research, possible habitation took place.

Late-Paleolithic

The Paleolithic Period, spanning approximately 2.5 million years ago to circa 8,800 BCE (Brand et al, 1992), witnessed significant climatic changes. Improvements in climatic conditions around 12,500 BCE caused the reintroduction of human populations, marking the start of the Late-Paleolithic era. Throughout the Paleolithic, the climate was characterized by cold conditions and open vegetation (Crombe et al., 2011; Paepe, 2022), gradually transitioning as temperatures began to rise after 8,800 BCE (Heyse, 1979; Kooijmans et al., 2005; Crombe et al., 2011).

Human populations in the Netherlands during the Paleolithic consisted of hunter-gatherers (Stavros), with a high mobility pattern (Kooijmans et al, 2005). The distribution, seasonal availability, and density of food resources played important roles in determining the mobility patterns (Kooijmans et al., 2005). Notably, the presence of large mammal species, such as horses and reindeer, which lived in herds, contributed significantly to the nomadic lifestyle (Jochim, 1983; Kooijmans et al., 2005). Moreover, in the Late-Paleolithic, there was an increase in the exploitation of specific species, further increasing mobility dynamics (Mellars, 1973; White, 1982; Gaudzinski, 1995). Due to the high mobility, habitation took place in (hunting) camps on small scales and were temporarily used, rarely exceeding a few hundred square meters (Van Kolfschoten & Roebroeks, 1985; Roebroeks & Sier, 2015)

Technological advancements during the Paleolithic era included the use of flint stones and hand axes, essential tools for various activities like hunting and gathering (Kooijmans et al., 2005; Van Ginkel & Verhart, 2009). These tools facilitated a nomadic existence, enabling efficient exploitation of scattered and seasonally available resources.

Describing the habitation patterns of Paleolithic populations presents challenges due to their nomadic lifestyle. However, information from archaeological site discoveries in the Netherlands sheds light on settlement patterns. Notably, the presence of fire pits and stone structures suggests habitation sites, as evidenced by small hunting camps. These camps were strategically located on elevated Krefteheye ridges or sand dunes, particularly prevalent on the southeastern slopes, providing dry and sheltered environments while offering protection against prevailing north-westerly winds (arts, 1988; Bos et al., 2006; Grimm et al, 2019). The research of Crombé et al. (2011) showed that the habitation of the Late-Paleolithic population was often located on the southern flanks (Fig. 21) of the Krefteheye ridges (1-2 m to a mean of 5 m) and often close to water bodies, such as rivers and lakes (Appendix 7A). However, site locations were also found on clay outcrops and alluvial sediments (Fig. 21) (Appendix 7A). The topographic position, soil texture, and soil drainage were of importance. The elevation between 0,10 and 1,00 m was more often occupied than the lower-laying areas (Appendix 7B). Sandy soils, which were moderately dry, favored the Late Paleolithic site locations (Appendices 7C and D).

Seasonal migration was crucial, with populations moving in due to the availability of resources such as animals and plant foods. The most interesting indications of late-Palaeolithic habitation include charcoal remains, stone toles, and animal remains. In the west, Palaeolithic indications are more scarred than in the west or the south, due to the greater depth. The remains in the south are often seen at the surface, while the remains of the Palaeolithic in the west are often seen in the deeper underground (e.g. Amkreutz et al., 2016). Even though there is a lack of finds, that does not mean habitation did not take place in the west and the study area. study area's drier conditions made it suitable for potential habitation.

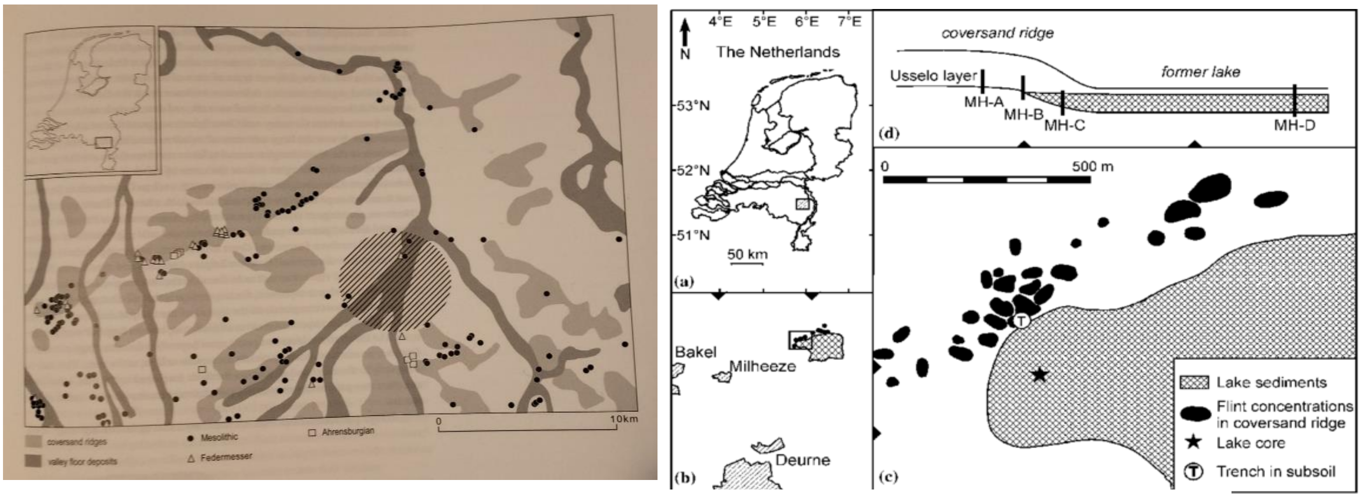


Figure 21 Late Paleolithic and Mesolithic habitation remains in the Netherlands (Kooijmans et al., 2005)

Mesolithic

The Mesolithic period started when the temperature rose from around 8.800 BCE to 4.900 BCE (Brandt et al., 1992). The open vegetation made room for new forests, and the reindeer no longer traveled through the Netherlands but moved more north. Instead, sedentary wild animals lived in these forests, such as boars, deer, bears, and beavers (Heyse, 1979; Kooijmans et al., 2005; Crombe et al., 2011).

The populations changed from hunting and eating reindeer to hunting and eating sedentary wild animals, which still included gathering. These animals remained within their own territories, leading to a decrease in population travel compared to the Paleolithic era. The population only travelled with the seasons to find the best places for food (Kooijmans et al., 2005). The overall mobility of the population was significantly lower compared to the Paleolithic Period; however, hunting and gathering were the main purposes (Kooijmans et al., 2005). With hunting and gathering still being the main aspect relating to mobility, the (hunting) camps were comparable with the camps of the Paleolithic Period. However, due to the slightly lower mobility compared to the Paleolithic, the camp sizes were slightly more stable, but they did not vary substantially (Kooijmans, 1974; Verhart, 2000).

Microlites were the general tools used in the Mesolithic period. They are small, sharp-cut pieces of flintstone, adapted in different forms. This technical advantage had positive effects on both the manufacturing process (standardization, material exploitation, and maintainability) and the use process (haft ability, reliability, and transportability) (Elston et al., 2002; Goebel, 2002; Groman-Yaroslavski et al., 2020). In addition, finds such as the canoe of Pesse (7.500 BCE), indicate the technical advances of that time.

The canoe indicates the locations of such "hunting camps" from the Mesolithic period. In the western part of the Netherlands, there are indications that Mesolithic camps existed. The most well-known sites are the Hardinxveld-Giessendam (Polderweg 5450 - 5050 BCE and De Bruin 5250 - 4500 BCE, Louwe Kooijmans 2001a, 2001b; Mol & van Zijverden, 2007) and the fish traps at the Bergschenhoek site. Researchers discovered habitation remains at the Hardinxveld-Giessendam site, including graves and human remains. Both the Hardinxveld-Giessendam and the Bergschenhoek were located on river dunes, due to their high elevation in the surrounding area. In addition, the Mesolithic population took over many of the habits of the Paleolithic period. Additionally, researchers found different sites on the southern face of the high sand ridges near water (Fig. 22, Appendices 7A, B, C, and D).

In the region surrounding the study area, more archeological remains were found. ArcheoMedia executed research in the region of the study area. The research indicated three locations of archaeological finds (Figs. 20 and 22). The first location, called the Westergouwe, indicated two large and one small concentration of charcoal remains (Appendix 7E) (Dasselaar et al., 2005 The second (Hoge Zuidplaspolder, 5800 BCE) and third (Sportlaan, 5500 BCE) locations indicated charcoal remains besides the burned bone remains and fish scales (Verkennend en waarderend archeologisch onderzoek Hoge Zuidplaspolder te Zevenhuizen, ArchoMedia, A03-216-z & A03-529-z; Verkennend archeologisch onderzoek Moordrecht Sportlaan, ArcheoMedia, kemerk A04-240-z). The remains together indicate a higher chance of anthropogenic influences. The thought was that the remains pointed out a temporary hunting camp found on the Gouderak stream belt (part of the Benschop stream belt).

Figure 22 Location of remains of three locations (Hoge Zuidplaspolder, Westergouwe and Sportlaan) (source: Dasselaar, 2005)

Neolithic

The Neolithic period started around 5.300 BCE in the south of Limburg and around 3400 BCE in the west when the Vlaardingen Culture took habitation (Bakker & Van Gijn, 2005) and lasted until 2.000 BCE (Brandt et al., 1992). The climate was warmer than what we know today. Large parts of the Netherlands, such as the west, were inaccessible for the population due to the wet conditions. Forests made up the majority of the vegetation, but arable land began to take its place due to deforestation. Sedentary wild animals, including species like deer and boars, continued to live in these regions (Heyse, 1979; Kooijmans et al., 2005; Crombe et al., 2011).

This period marked a change from the high-mobility hunter-gatherer lifestyle to a more settled, agrarian way of life brought by a different population to the Netherlands. During this period, farmers created farms on agricultural lands, cultivating crops like emmer wheat, einkorn, and peas (Kooijmans et al., 2005). They kept animals like goats, sheep, cattle, and pigs (Kooijmans et al., 2005). They cleared the forests to create arable land. With the agriculture and keeping of the animals, the lifestyle of high mobility ended (Kooijmans et al., 2005). Nonetheless, hunting and gathering remained important to the food security of Neolithic populations. Due to the decrease in mobility to a more settled habitation, the habitation changed from (hunting) camps to larger permanent "houses". The first small villages came into existence (Siwfterbant and Hazendonk sides) (Kooijmans, 1986; Modderman, 1988).

In the Neolithic Period, the population created a large diversity of sites (Van Regteren Altena, 1962 & 1963; Kooijmans, 1986). The geographical locations of former habitations revealed the diversity. The population was generally known to live on coastal dunes, river dunes, near rivers, levees, and salt marsh ridges on the western side of the Netherlands (Vlaardingen Culture)(Fig. 23). Coastal dune settlements were among the most enduring, with archaeological evidence indicating the presence of structured floor plans, domestic animal remains, and grain storage facilities, suggesting a stable, year-round occupation. These sites provided a reliable food supply from both agriculture and coastal resources, such as fish and shellfish.

Van Gijn (1989) found evidence of semi-permanent habitation on the levees, where they found house structures and used fewer flintstone tools. Furthermore, the discovery of fewer animal remains suggested that cattle breeding held less significance (Raemaekers, 2001). The habitation on these levees indicated a more seasonal habitation with specific tasks, such as hunting, agriculture, and fishing.

The third group is found on the river dunes. Researchers did not find floor plans, and the animal remains indicated wild animals showing a more hunting-based camp.

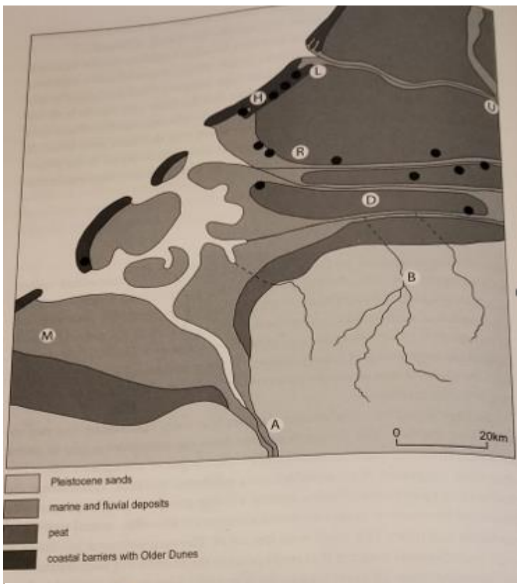


Figure 23 Palaeogeography of the western part of the Netherlands in the Neolithic period. The site locations (Vlaardingen Culture) are on dunes behind the former coastline, along streams and on the outcroppings of river dunes in the peat regions (Kooijmans et al., 2005).

Bronze age

The Bronze Age, spanning from approximately 2000 BCE to 800 BCE (Brandt et al., 1992), marked a period characterized by climatic conditions exhibiting aridity and colder temperatures compared to previous epochs, coupled with elevated sea levels (Kooijmans et al., 2005). Despite these environmental challenges, human populations employed techniques such as the construction of didges and deforestation for agricultural purposes, resulting in the conversion of wooded areas into arable land and heathlands (Kooijmans et al., 2005).

Transitioning from the Neolithic era, the Bronze Age saw the development of mixed farming practices, integrating plough-based agriculture with cattle husbandry. This period marked a significant advancement in agricultural technology, including the use of ox-drawn plows and vehicles, which increased agricultural productivity and efficiency (Kooijmans et al., 2005). During this period, the evolution of farmsteads became notable, with residential areas increasingly incorporating spaces for livestock, reflecting a closer integration of human and animal life. The settlement grew more advanced and had an increase in size compared to the Neolithic (Fokkens, 1998; Arnoldussen, 2008)

Pollen analysis from this period indicates significant landscape transformation, with forests becoming heathlands and podzolic soils developing. These changes are indicative of intensified agricultural activity and human habitation. Additionally, there was a notable cultural shift in burial practices from collective graves to single-corpse interments, reflecting evolving societal norms and beliefs (Kooijmans et al., 2005).

In the Netherlands, the introduction of bronze production, originating from Germany, brought significant social and economic changes. The advent of copper and gold forging led to the establishment of extensive exchange networks, facilitating the trade of materials and finds and reshaping social dynamics (Kooijmans et al., 2005). Settlement patterns during the Bronze Age were predominantly concentrated along relief-inverted riverbeds intersecting peat areas, where the landscape's topography and soil conditions were favorable for agriculture and habitation (Kooijmans et al., 2005; Arnoldussen & Fokkens, 2008; Willemse & Groenewoudt, 2012).

Evidence of human activity during this period has also been found on river dunes, where elevated landforms provided strategic locations for settlements and agricultural use (Fig. 24). However, the frequency of habitation on crevasse-splay deposits was notably higher, suggesting that these areas offered advantageous conditions for settlement compared to the higher, less fertile levees and dunes (Kooijmans et al., 2005; Arnoldussen & Fokkens, 2008; Willemse & Groenewoudt, 2012). In contrast, peat regions were largely avoided for habitation due to their challenging wet conditions and less fertile soils, making them unsuitable for agriculture during the Bronze Age (Fig. 24).

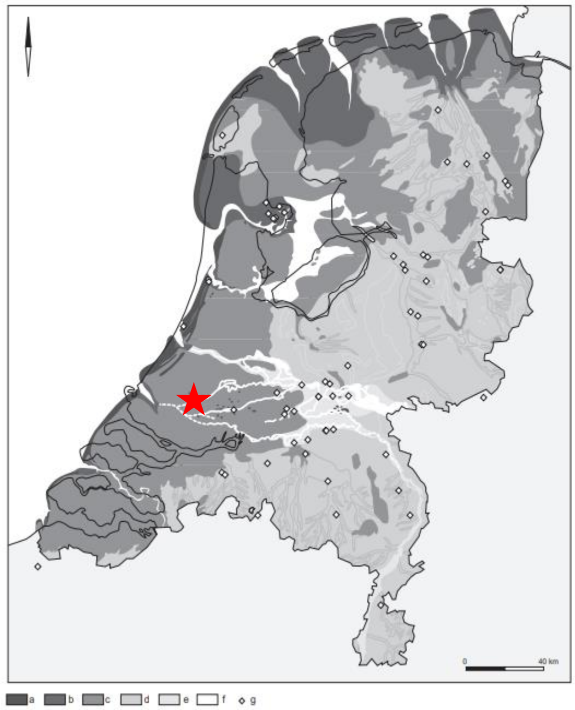


Figure 24 Simplified palaeogeographical map of the Netherlands directly prior the Bronze Age (c. 3800 BP: after De Mulder et al. 2004, 228, fig. 143). Legend: a: Coastal dunes and river dunes; b: Estuaries and tidal flats; c: Peat; d: Flood basin deposits; e: Sand; f: Open water; g: Settlement site with Bronze Age house plan(s) (source: Arnoldussen & Fokkens, 2008). Red star indicates the location of the study area.

Iron age

The Iron Age, spanning from approximately 800 BCE to 12 CE (Brandt et al., 1992) , was marked by climatic conditions that were slightly colder and wetter than those of the Bronze Age. The landscape during this period was mostly covered by forests and peat swamps, with large areas of wetlands (Kooijmans et al., 2005). The fauna continued to include species such as deer, boars, bears, wolves, and beavers. While hunting still existed, most of the food came from agriculture and cattle breeding, leading to a decline in wild fauna as human settlements and agriculture increased.

Agriculture in the Iron Age stayed important, with a continued emphasis on cereal production. Basic crops included einkorn, emmer, barley, millet, and spelt. Spelt, in particular, emerged as an important new grain, showing advancements in agricultural practices (Kooijmans et al., 2005). Alongside grains, the cultivation of various legumes such as beans and peas was common, and there was also the production of flax and other fiber crops, possibly for oil or textile purposes (Wijngaarden-Bakker & Brinkkemper, 2005). The settlements formed villages that were more advanced in clusters with the inclusion of fortified structures (Fokkens & Jansen, 2004; Van der Vaart & Van Doesburg, 2011).

Iron Age settlements were characterized by deforestation, as large tracts of forest were cleared to create these agricultural fields. The construction of homes and farms continued to improve, with buildings typically constructed from wood, wickerwork, and clay (Kooijmans et al., 2005).. Early Iron Age houses were often three-aisled, including two rows of posts supporting the roof. By the middle and late Iron Age, two-aisled structures became more common, with a single row of posts supporting the roof independently of the walls. This architectural design, which included external roof supports, improved the structure and drainage of the buildings, allowing them to be more durable and better suited to the wetter climate (Kooijmans et al., 2005).

Iron Age houses were relatively large, typically ranging from 5 to 8 meters in width and up to 20 meters in length. These dwellings were often accompanied by multiple outbuildings, which included storage structures known as spiekers, as well as individual stalls and workshops. Excavations of Iron Age sites showed additional features such as ditches, fences, and burial grounds, indicating a complex and organized settlement structure (Kooijmans et al., 2005)..

Habitation in the western part of the Netherlands often took place on coastal dunes (Van Dijk & Groot, 2013). However, the peat regions close to the coast were equally important. Well-drained peat areas were very variable locations for habitations in the west (Fig. 25) (Van Dijk & Groot, 2013). These peat regions near the study area were home to Iron Age settlements (Van Dijk & Groot, 2013; Van Spelde et al., 2020). Furthermore, proximity to a water body was critical. However, the analysis of the geological dynamics reveals that the study area was extremely wet. Subsequently, the peat nearly completely disappeared from the area, thereby eliminating any potential for habitation.

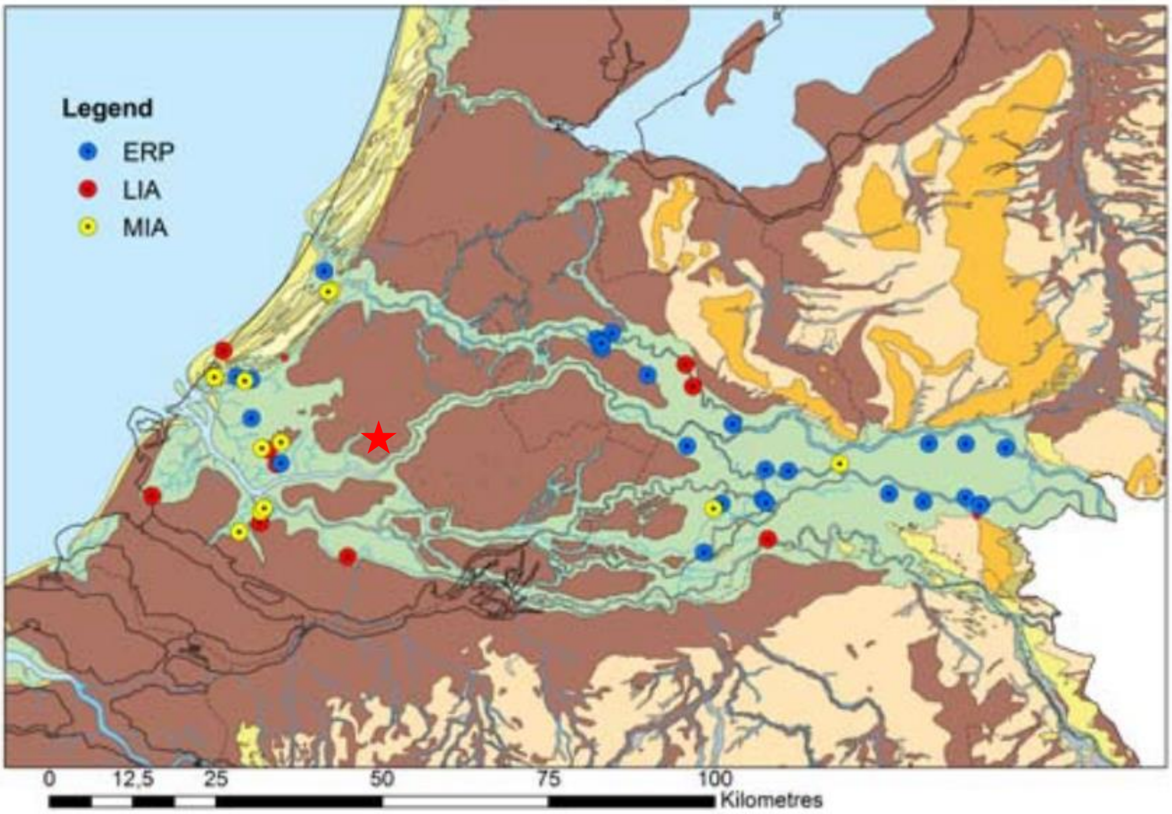


Figure 25 Iron Age and Roman Period habitation in the Netherlands (Van Dijk & Groot, 2013). Red star indicates the location of the study area.

Roman Period
The Roman Period, from 12 BCE to circa 450 CE, had a climate with moderate summers and rainy winters. The period has a favorable climate with stable and warm conditions, making it ideal for agriculture. At the end of the Roman Period, the climate became colder and drier, creating less stable weather patterns (Kooijmans et al., 2005). The region consisted mostly of swamps and forests, including deer, boars, bears, wolves, and beavers (Kooijmans et al., 2005). Despite the continued hunting of these animals, agriculture and cattle breeding emerged as the primary food sources during this period. The abundance of natural resources and fertile land facilitated the flourishing of human settlements (Heyse, 1979; Kooijmans et al., 2005).

The Romans brought important technological advancements, especially in infrastructure and agriculture. The construction of road networks and fortifications, such as the Limes along the Rhine River, marked an important development. The Limes served not only as a defensive line but also created trade routes and the movement of troops, thereby enhancing the strategic and economic integration of the region (De et al., 2017).

Roman agricultural practices included mixed farming, incorporating both crop cultivation and animal husbandry. Key crops included cereals such as wheat and barley, along with the cultivation of beans and peas. The Romans introduced new techniques such as crop rotation and the use of animal-drawn ploughs, which significantly increased agricultural productivity. Additionally, the establishment of large-scale farmsteads combined residential and livestock areas, reflecting a more settled lifestyle compared to earlier periods (Kooijmans et al., 2005). The settlements grew significantly larger, including towns, military camps and rural villages, creating large regions with habitation (Van Es, 1981; Van Dierendonck, 1998).

Roman settlements in the Netherlands were primarily concentrated along the major rivers, particularly the Rhine (Fig. 26). As a result, population density increased in the regions adjacent to these rivers, where the benefits of proximity to waterways outweighed the challenges posed by the environment. The modelling of probable Roman settlement locations in the western Netherlands indicates that these settlements were closely linked to channel systems (Groenhuijzen, 2018; see Fig. 26). Archaeological evidence reveals that Roman settlements were strategically located on elevated terrain, such as river dunes and levees, which provided protection against flooding and other environmental hazards. In addition, these levees were fertile locations for agriculture (De et al., 2017; Groenhuijzen, 2018) and created strategic regions due to the natural barrier of the river and the control of the trade along these routes (Kooijmans et al., 2005; Van Dinter, 2017).

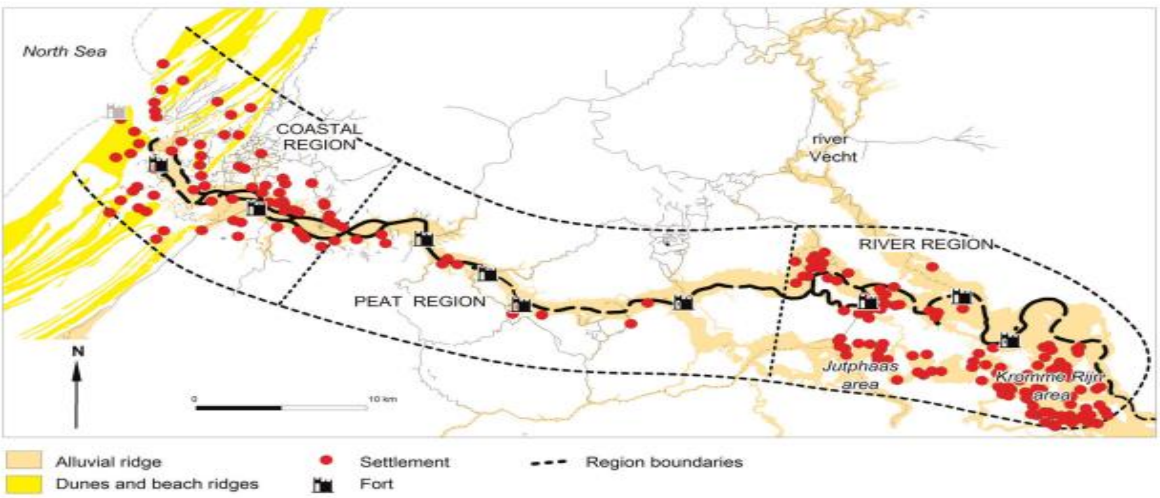


Figure 26 Reconstructed settlements in the western Lower Rhine limes zone based on ARCHIS database (2009)

The peat bogs, which characterized much of the western Netherlands, were largely uninhabited due to their wet and inaccessible nature (Van Dinter, 2017). However, there were occasional findings of Roman activities in these areas, suggesting sparse and transient use compared to other regions (Kooistra et al., 2013). The peat regions, while presenting challenges for habitation, were significant for their role in the broader environmental context of the Roman Period. Figure 27 illustrates the distribution of settlements in relation to the peat bogs, highlighting the limited human presence in these wetland areas.

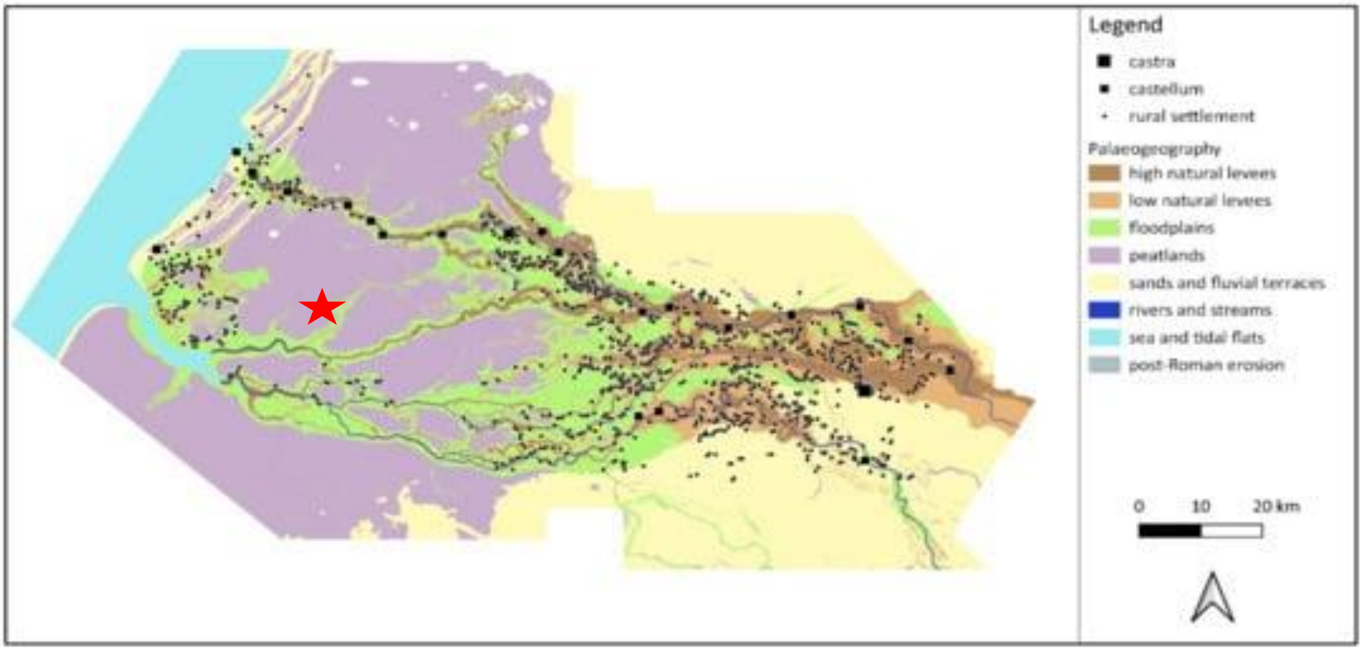


Figure 27 Modelled settlement density of the Roman Period in Western Netherlands (Groenhuijzen, 2018). Red star indicates the location of the study area.

Middel Ages

The Middle Ages, from circa 500 CE to 1500 CE, had a variety of climate conditions. Two main phases exist, namely, the Early Medieval Warm Period (900-1300 CE) and the Little Ice Age (1300-1500 CE). During the Early Medieval Warm Period, the climate was warm and stable, similar to the present day. The climate conditions created a large agricultural expansion. The warmer temperatures and extended growing seasons allowed for the cultivation of a wider variety of crops, contributing to population growth and economic development (Pfister, 1992; Fagan, 2000). The climate began to cool from the 14th century on, creating shorter growing seasons, increased precipitation, and harder winters. These conditions created important challenges for agriculture, resulting in crop failures and food shortages (Lamb, 1995; Grove, 2001). Human activity, including deforestation, agriculture, and the creation of new settlements, largely shaped the landscape of the Middle Ages (Barker, 1985; Duby, 1974).

The Middle Ages showed many technological advancements, mostly in agriculture. The heavy plough for cultivation in heavier soil and the three-field system for an increase in soil fertility created increased production (White, 1962; Duby, 1974). The construction of water mills and windmills ensured the execution of new mechanical labor, including grain grinding and water pumping (Verhulst, 1999; Van de Noort, 2004).

In the Early and Middle Roman periods, a major demographic increase occurred due to the Roman occupation (Fig. 28). The environment of the fluvial landscape was very fertile, rich in natural resources, and useful for transportation over the rivers (e.g., Cunliffe, 2004; McCormick, 2007; Van Es and Verwers, 2010; Van Lanen et al., 2016). However, after the Limes fell around 270 CE a huge demographic decline (78-85%) occurred in the river region (Fig. 28) (Van Lanen et al., 2018). The number of population rose in the Early Middle Ages again, however, never reached the same number as in the Roman Period anymore. This caused the Medieval settlements to vary largely in size. In the rural regions often small dispersed villages occurred and in the habituated regions large cities were created (Verhulst, 1999; Stabel, 2001). The study area was according to the geological reconstruction based in a more rural region, expecting smaller habitation, compared to the Roman Period.

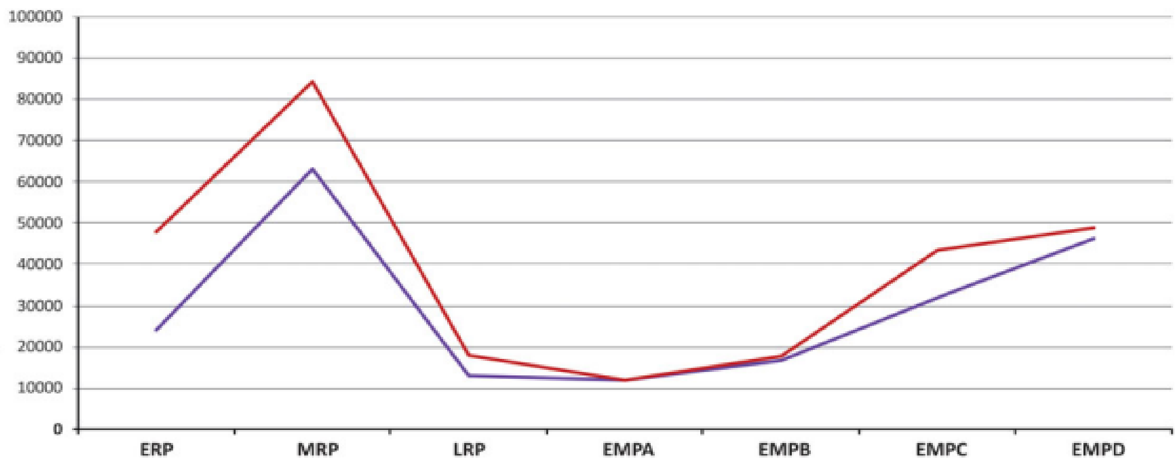


Figure 28 Reconstruction of paleo demographic trends in the Rhine-Meuse delta with blue line the rural inhabitants and the red line the total inhabitants (Adapted from Van Lanen et al., 2018). ERP, MRP & LRP the early, middle and late Roman Period. The EMPA, EMPB, EMPC & EMPD are the different stages of the Early Middle Age Periods.

Throughout the first millennium, large parts of the Netherlands were extremely wet and covered by extensive peat. This created locations that were largely inaccessible (Fig. 29, red). Large-scale reclamation of these peat lands started in the 10th–12th centuries (Henderikx,1986; Borger, 1992; Gerding, 1995; Borger et al., 2011). In the midst of these Holocene and Pleistocene soils, the rivers

Rhine and Meuse strongly influenced (pre)historical natural and cultural developments. Besides providing fertile substrates for agricultural land use, since the Bronze Age (2000–800 BCE; Arnoldussen, 2008) these rivers facilitated long-distance transport on the European mainland (Cunliffe, 2004). In the Middle Ages, the locations of habitation took place, like in the previous period, alongside the rivers, such as the Rhine. The study area itself, located in the peat region (red) is seen as a very inaccessible location for habitation (Van Lanen, 2020).

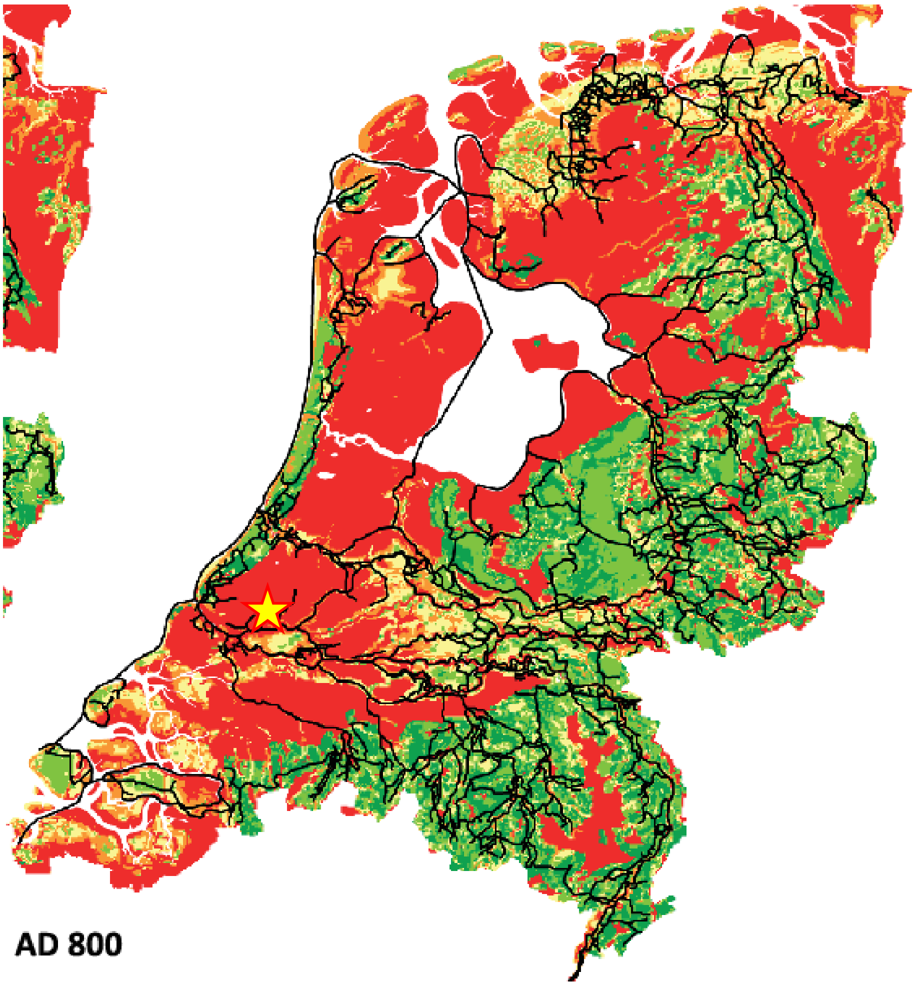


Figure 29 Network-friction maps and calculated route networks for CE 100 and 800 in the present-day Netherlands. The network calculations by Van Lanen et al. (2015) clearly show areas that were inaccessible (in red), moderately accessible (in yellow) and accessible (in green). Based on this integrated method, geoscientific and archaeological data were used to reconstruct early-medieval land and water routes (800 CE). These networks were convincingly validated with archaeological finds not previously included in the model: infrastructural and isolated finds (cf. Van Lanen et al., 2015) adapted from Van Lanen et al. (2015)

Synthesis

Table 7 Synthesis of archeological period with their climate, mobility, possible locations and types of evidence

Archaeological Period	*Time range*	*Climate*	*Seasonal and Migratory Behavior*	*Description of Habitation Sites*	*Artefacts*
Late-Paleolithic	Till 8.800 BCE	*Cold and dry conditions*	*High mobility*	*-Sand ridges (southeast side)* *-Close to water bodies (Wijchen Formation)*	*Fire pits, stone structures, lithics, charcoal remains, and animal remains.*
Mesolithic	8.800 BCE - 4.900 BCE	*Warmer conditions*	*High mobility*	*-River dunes* *-River levees*	*Fire pits, stone structures, lithics, charcoal remains, and animal remains. In addition, the canoe.*
Neolithic	5.300 BCE - 2.000 BCE	*Warm and wet conditions*	*Low mobility*	*-Coastal dunes -River dunes - Along rivers, levees, and salt marsh ridges,*	*The presence of structured floor plans, domestic animal remains, and grain storage facilities, pottery, lithics.*
Bronze Age	2.000 BCE - 800 BCE	*Arid and cool climate*	*Low mobility*	*-Relief-inverted riverbeds* *-River dunes. -Explained the avoidance of peat regions due to their unsuitable conditions for habitation and agriculture.*	*The presence of structured floor plans, domestic animal remains, plough marks, tools, pottery.*
Iron Age	800 BCE - 12 BCE	*Cool and wet climate*	*Low mobility*	*- Coastal dunes* *-Well drained peat*	*The presence of structured floor plans, domestic animal remains, plough marks, tools, pottery.*
Roman Period	12 BCE - 450 CE	*Warm summer, Rainy winter*	*Low mobility*	*- Along rivers on the levees* *- Explained the avoidance of peat regions due to their unsuitable conditions for habitation and agriculture.*	*The presence of structures, infrastructure domestic animal remains, ground marks, tools, pottery.*
Middle Ages	450 CE - 1.500 CE	*Early Medieval Warm Period (900-1300)* *Little Ice Age (1300-1500 CE)*	*Low mobility*	*- Along rivers on the levees* *- Explained the avoidance of peat regions due to their unsuitable conditions for habitation*	*The presence of structures, infrastructure domestic animal remains, ground marks, tools, pottery.*

Model output

The model output firstly consists of the maps per archeological period to get an idea of the likelihood of habitation and finds. The Paleolithic period mostly consists of four main geological units with a higher probability (Fig. 30). It consists of the river dunes in the northeast, the Krefteheye formation, the Wijchen Formation and the Basel peat. The habitation of the paleolithic took place close to a water body and on the southeast slopes of sand ridges. The Wijchen Formation indicates river deposits, which indicates a body of water. Next to the Wijchen Formation, the higher Krefteheye Formation have a higher likelihood of habitation. The Boxtel Formation are former river dunes which are located higher in the surrounding area like the Krefteheye outcrops. The Krefteheye outcrops are, compared to the southern Netherlands, less substantial, hence the lower likelihood of habitation. The cover sands (red) in the northeast of the study area had the highest probability, according to the research (Kooijmans 2001a, 2001b; Mol & van Zijverden, 2007). The Wijchen Formation has an intermediate likelihood of habitation, due to the proximity of water, however, in less combination than they are seen in the southern Netherlands. The likelihood of finds is low for the Paleolithic due to the small camp sizes, which causes the chance of finding finds to be low (Fig. 31). The Basel peat has a low moderate likelihood, due to the closeness of a water body and possible higher elevation in the surroundings and

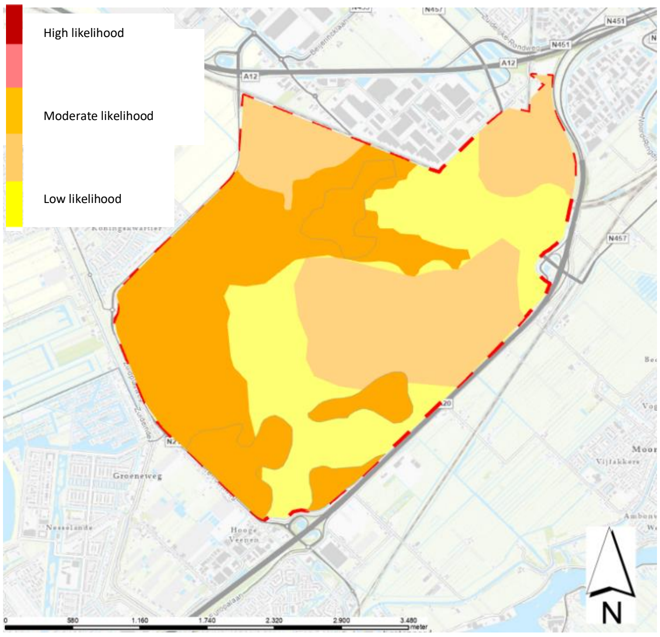


Figure 30 Likelihood of habitation for the Paleolithic Period

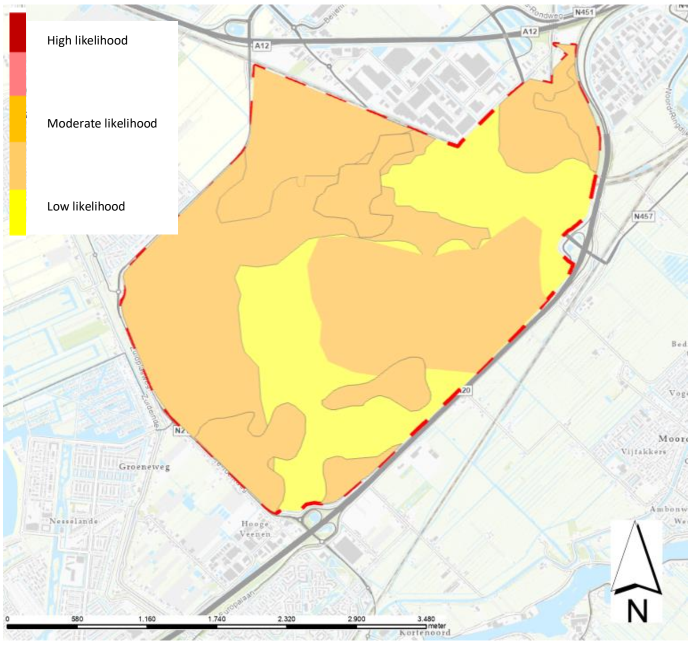


Figure 31 Likelihood of finds for the Paleolithic Period

The Mesolithic Period contained, like the Paleolithic Period, three main geological units. Nonetheless, the Mesolithic units are different: with the Wijchen Formation, Krefteheye Formation, Boxtel Formation, and, in addition, the former channel belts of the Gouderak, Delft, and Zuidplas (Fig. 32). The likelihood of habitation for the Boxtel, Wijchen, and Krefteheye formations corresponds with the likelihood of habitation from the Paleolithic Period, since the habitation patterns for both periods are uniform. The former channel belts have a relatively high likelihood of habitation because of the finds surrounding the study area on the specific channel belt of the Gouderak (Fig. 33). It indicates that habitation in the study area is likely on the channel belts. Contrary to this, the likelihood of finds (Fig. 33) is low for all the geological units in the study area for the Mesolithic Period due to the small-scale habitation.

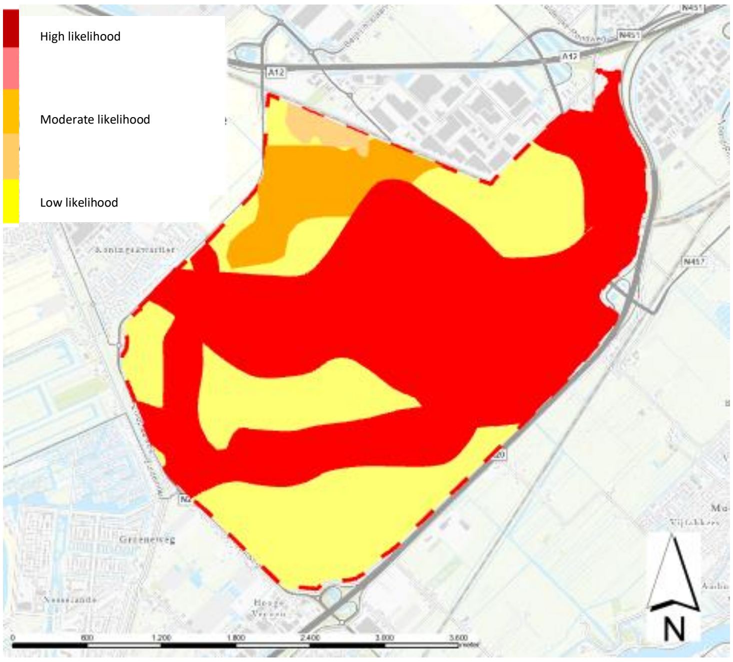


Figure 32 Likelihood of habitation for the Mesolithic Period

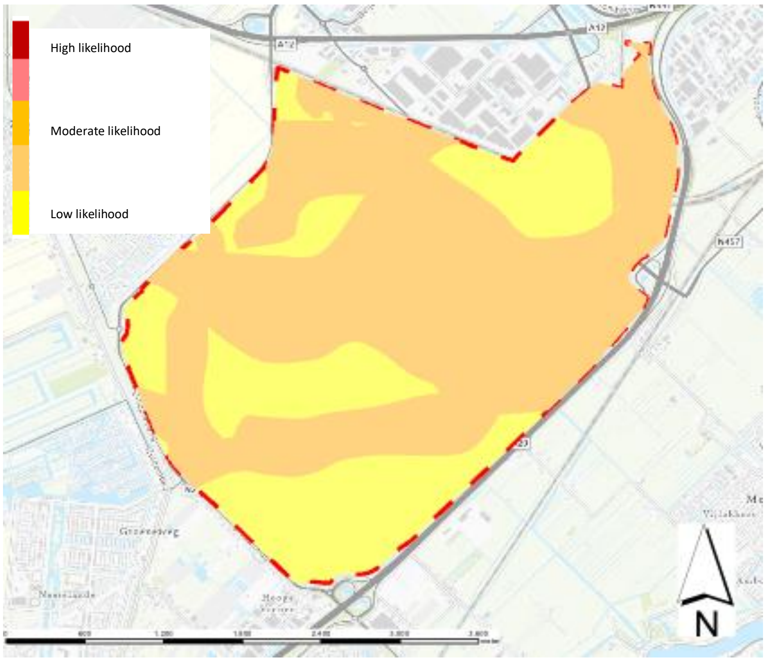


Figure 33 Likelihood of finds for the Mesolithic Period

The Neolithic Period only contained one geological unit with a higher likelihood, the creek system (Fig. 34). The creek system was largely influenced by the working of the sea water. The creek system itself is expected to have a higher elevation then the surroundings, creating a better environment for habitation, hence the moderate likelihood of habitation of the creek system. The surroundings of the creek system were too wet for habitation creating a very low likelihood of habitation. The likelihood of finds is higher compared to the previous two archeological periods. The habitation patterns changed in this period from a nomad lifestyle with high mobility to a more settled lifestyle, which created larger settlements, hence a larger likelihood of finds (Fig. 35). The change of finding such a settlement (or indications of one) with one auguring is larger compared to the Paleolithic and the Mesolithic with their small hunter camps.

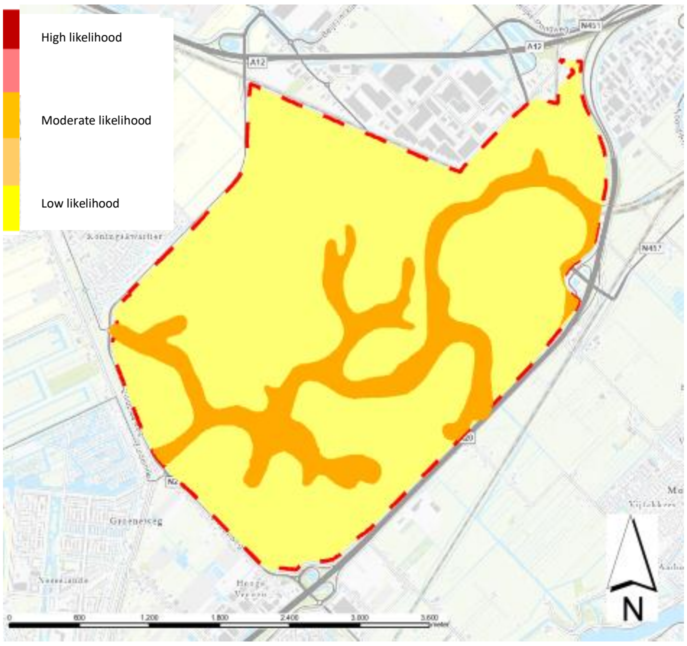


Figure 34 Likelihood of habitation for the Neolithic Period36

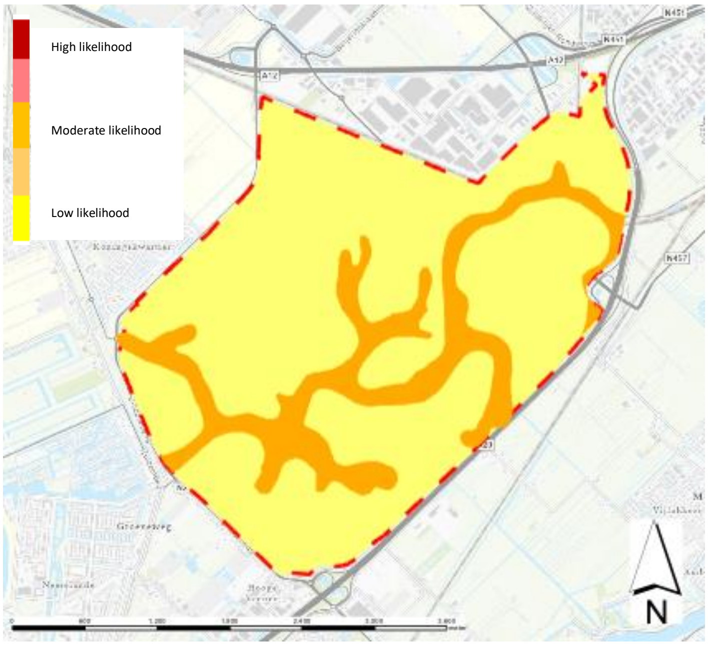


Figure 35 Likelihood of finds for the Neolithic Period

The Bronze Age, the Iron Age, the Roman Period and the Middle Ages are combined in the study. After the Neolithic Period the conditions became wet and peat formation took the upper hand. Due to the wet conditions that persisted until the late Middle Ages, the habitation of the region was less too nonexistent. After the Middle Ages, in the Modern Era, the Zuidplas was reclaimed. Overall, the periods from the Bronze Age to the Middle Ages have all a very low to no likelihood of habitation, hence the map of the likelihood of habitation (Fig. 36). The likelihood of finds for these periods is much larger than the previous periods. The settlements became larger and larger overtime. However, the peat extraction caused all of the geological units of this period to be removed creating a very low likelihood of finds. Only a small patch in the southeast of the study area contains some peat with a higher likelihood of finds (Fig. 37).

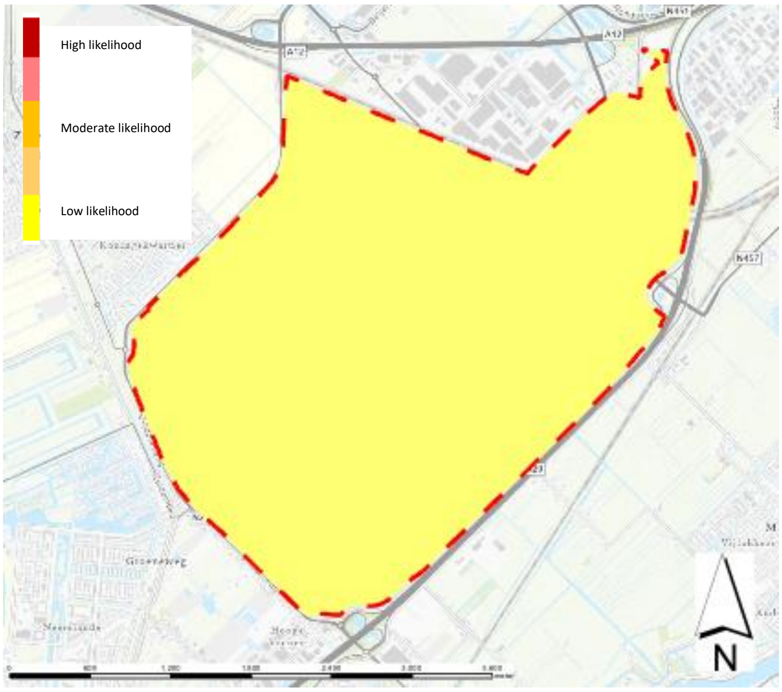


Figure 36 Likelihood of habitation for the Bronze Age, Iron Age, Romand Period and Middle Ages

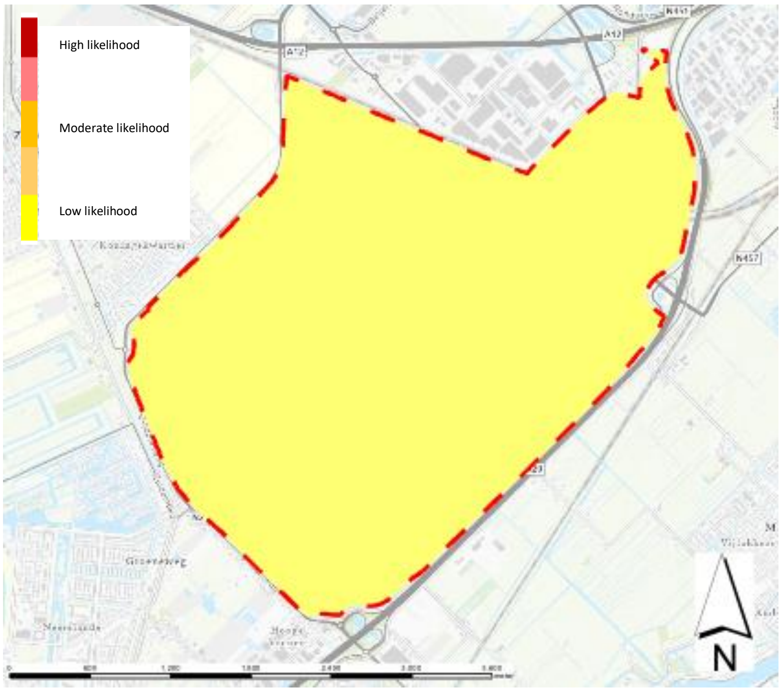


Figure 37 Likelihood of finds for the Bronze Age, Iron Age, Romand Period and Middle Ages

To provide an overview of the entire study area, the maps from each period are combined into two maps (Figs. 38 and 39), one for the likelihood of habitation and one for the likelihood of finds. The grid division generated 60 grids for the entire study area (Figs. 38 and 39). For every grid, there is a bore profile with its likelihood of habitation and finds. The relatively large grid size was applied to make analysis feasible in both time and output. However, the large grid size resulted in some grids containing zones of high and low probability due to variance in the geology within the grid. In such cases, more than one bore profile was synthesized to capture the different geological units. In other words, relatively low resolution makes the analysis feasible, and higher resolution can be applied to areas of high interest or variance. Furthermore, the combined map displays layers stacked on top of each other, ranging from the oldest to the youngest. The yellow geological units are the exception to this rule. The yellow area shows the locations where no geological units manifest with high likelihoods. To ensure that the map is clear, the yellow units are placed at the far end.

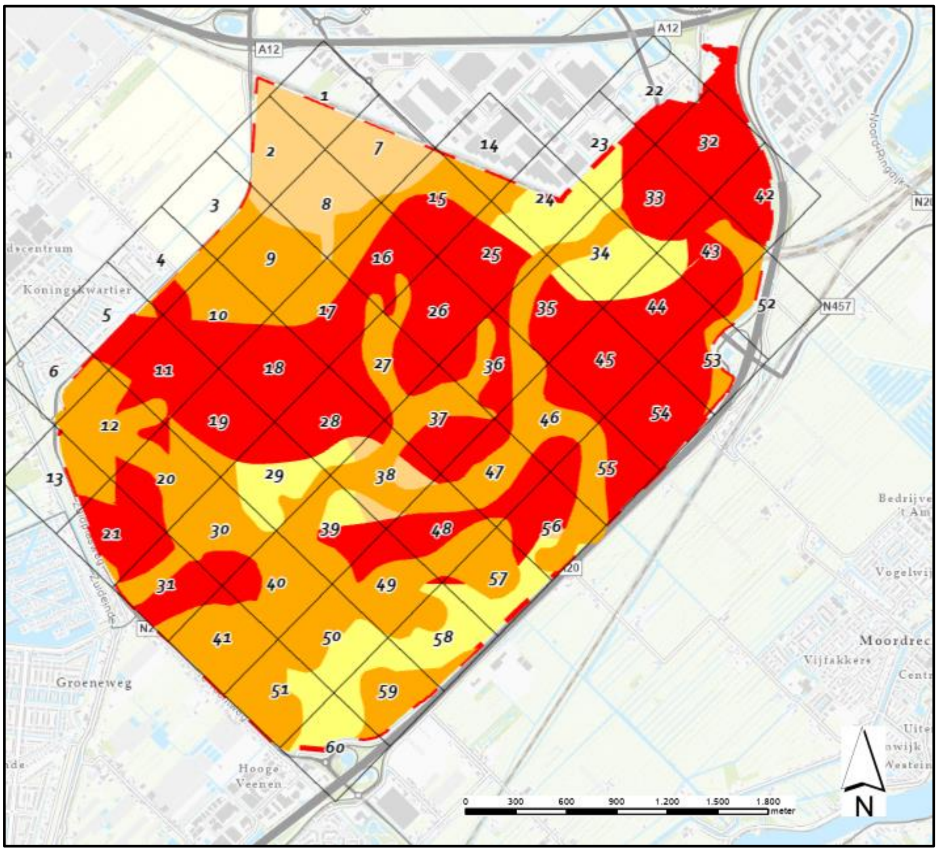


Figure 38 Combined map with the likelihood of habitation for the whole study area including the division in grids

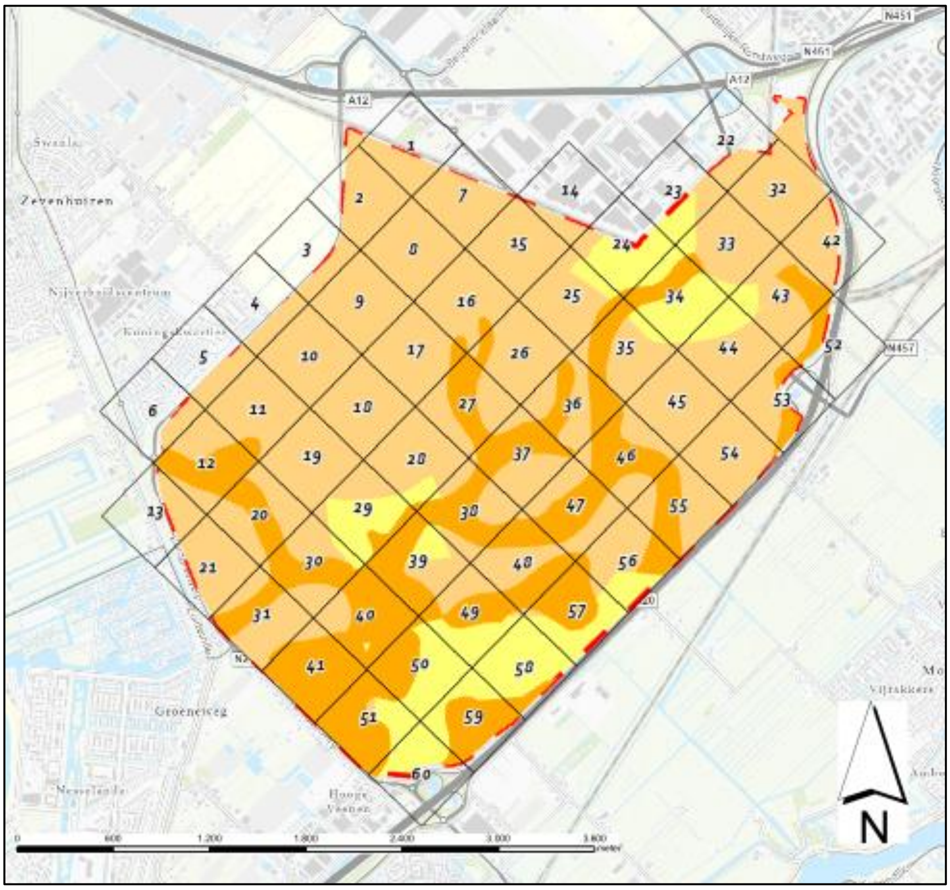


Figure 39 Combined map with the likelihood of finds for the whole study area including the division in grids

Model verification

For the verification of the model, in total 7 auguring's (Fig. 40) were taken out of the data base of Archis3. The auguring's are divided over the region from the high likelihoods to the low likelihoods to give an overview of all locations. The location of the auguring's is shown in figures 40 and 41 below. The auguring's represent a range of conditions due to the distribution in the study area including high- and low-likelihood systems. The legend of profiles collected in this study is shown in figure 41. The verification auguring's are based on NEN 5104 with standardized legends which apply to all profiles in the verification. Extra information, such as geological units or archeological finds are discussed in the comment section next to the profiles of the verification auguring's. The legend with its layer indications is shown in figure 42.

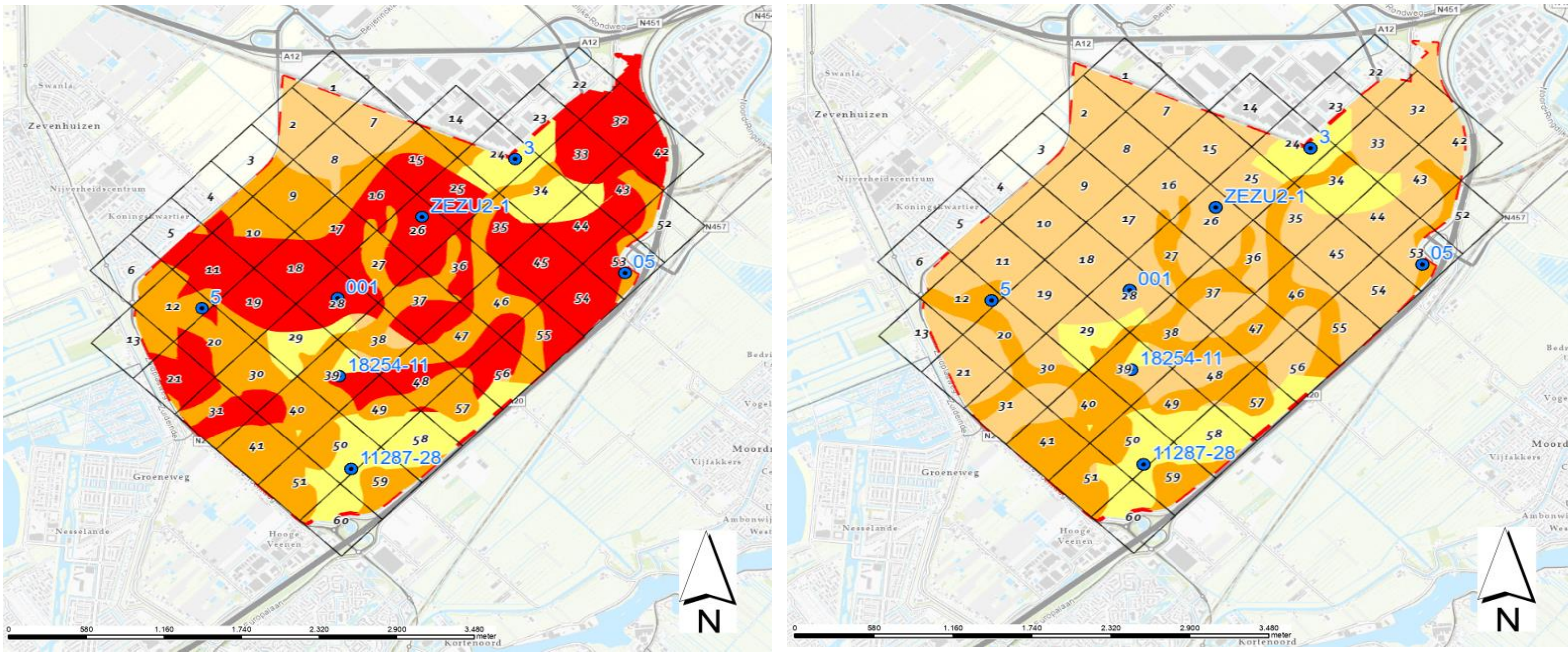


Figure 40 Location of verification auguring's on the likelihood of habitation and likelihood of finds maps

Figure 41 Legend of profiles from this study

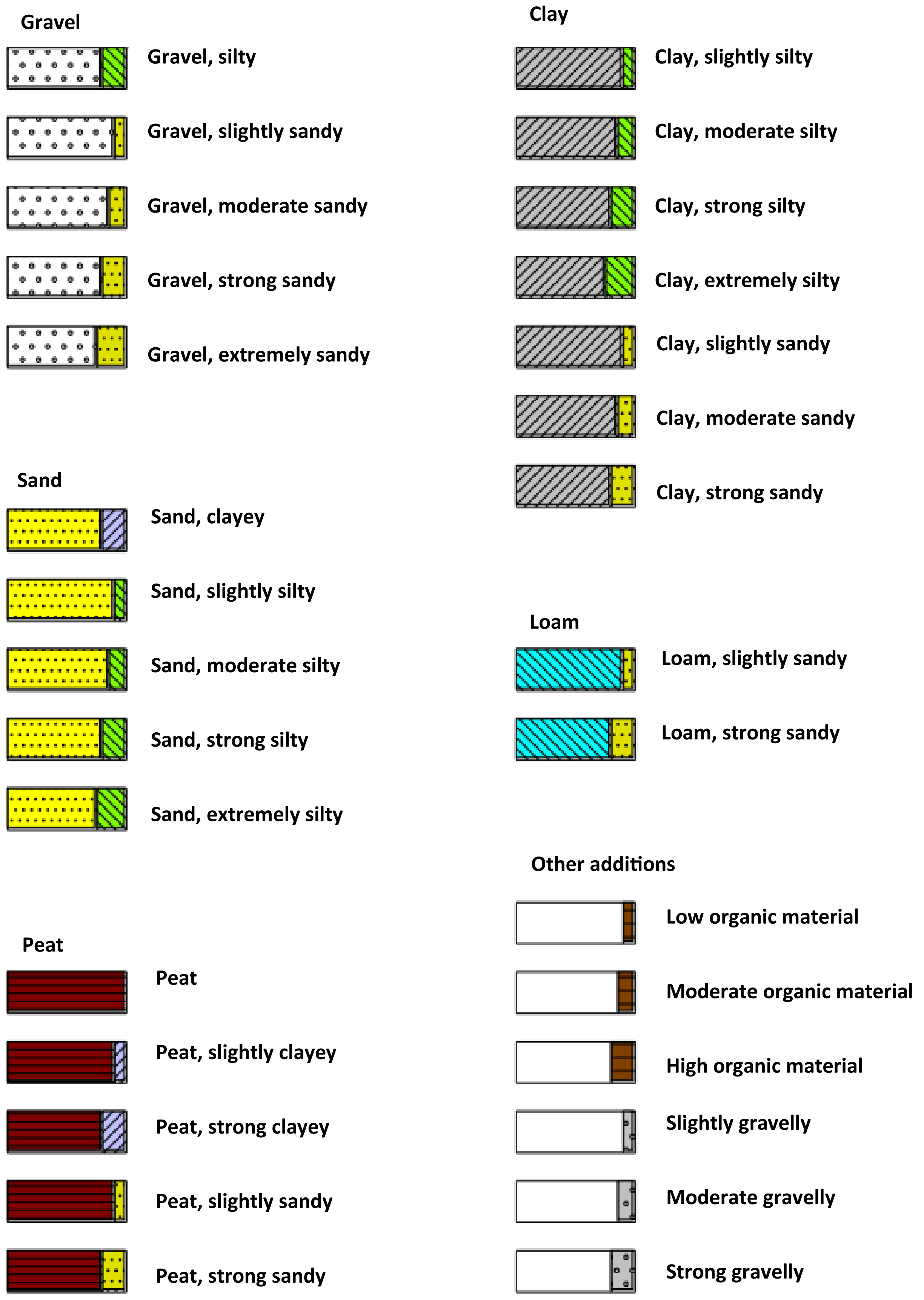


Figure 42 Legend of the verification auguring's based on the NEN 5104 guidelines ((NEN 5104:1989 Nl, z.d.)

Auguring 18254-11 is located in grid 39 (Fig. 43). The verification auguring is located on the edge of the former channel belt, in an area with low likelihood. The auguring primarily consists of clay with a low silt content, originating from the Naaldwijk Formation, up to 2,70 m below the surface. Around 2,70 m below the surface, a peat layer occurs. Hereafter, at circa 3,80 m below the surface, a clay layer, including a silt fraction and plant remains, occurs. The larger amount of silt in this layer indicates a levee deposition, or, based on the plant remains, a basin deposit. However, both, the basin or levee deposit, belong to the Echteld Formation. Within the verification auguring no signs of archeological artefacts were found, except for the clay layers without calcium; however, this does not indicate that archeological remains always occur. This research profile (Fig. 44) shows a clay deposit belonging to the Naaldwijk Formation until around 3,80 m below surface. Under the Naaldwijk Formation, the Echteld Formation is visible. Both the verification audit and the profile from this study largely align with each other. The layer until around 3,80 m below the surface consists of the Naaldwijk Formation, and after that, the Echteld Formation continues. Nonetheless, the peat layer is not visible on the study profile.

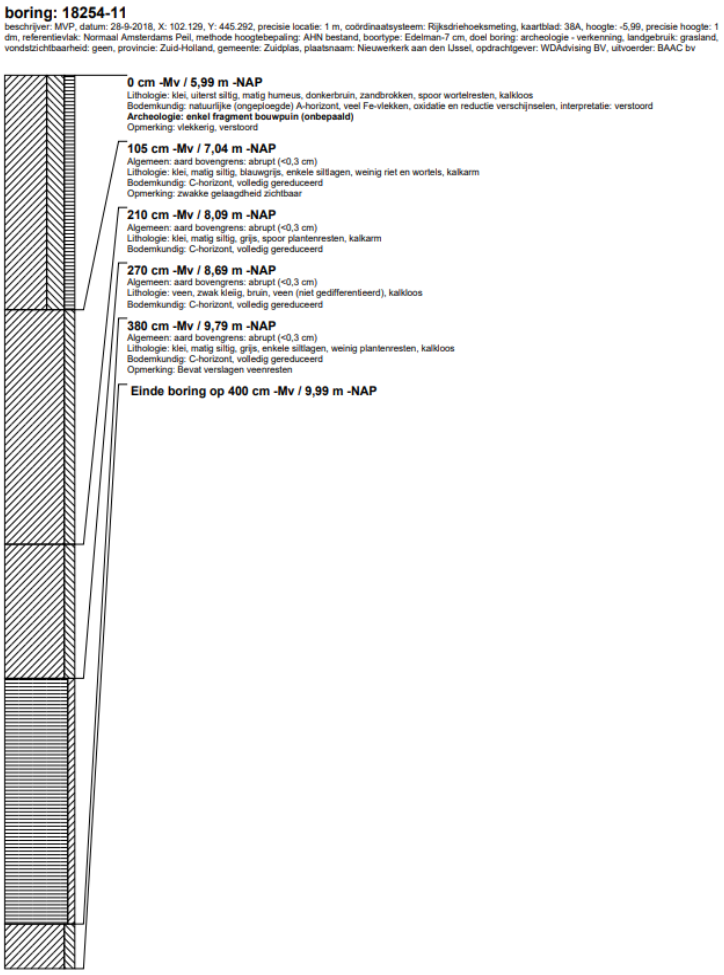
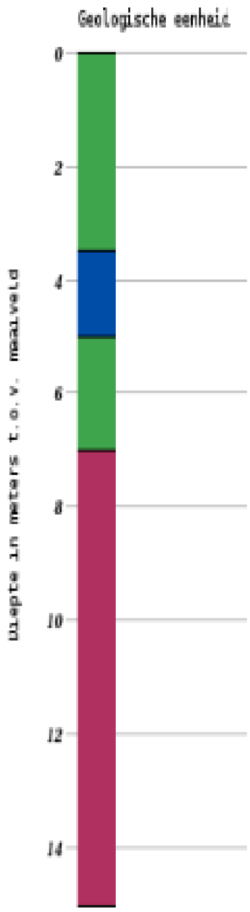


Figure 43 Verification auguring of grid 39



39B

Figure 33 Profile from grid 39 from current study

Verification Auguring 05 (Fig. 45) is located to the north-east of the study area on top of the stream belts of the Gouderak. The stirred top layer makes up the profile. Under the top layer, the clay deposits take over, belonging to the tidal environment of the Neolithic period and after. At a depth of around 4 m below the surface, a change in materials occurs. Clay with a high silt content was identified, indicating a levee deposit. The levee deposit belongs to the former Gouderak channel, according to the report. The peat under the channel belongs to the basal peat, according to the research. No lacquer layer or vegetation horizon is visible at the top of the levee embankment settlements, indicating the absence of buried paleo-soil. This implies that the narrow levees never occupied a relatively high position in the landscape. Subsequently, as the sea level and groundwater continued to rise, the area became waterlogged, leading to rapid peat growth. The research did not show any signs of archaeological remains. The research profile (Fig. 46) reveals the Naaldwijk Formation up to a depth of 4 m below the surface, after which the former channel belts become the primary geological units. Comparing both profiles, it appears that they correspond to each other based on the depth of the Gouderak channel and the thickness of the Naaldwijk Formation. Nonetheless, basal peat does not appear in the profile of this study.

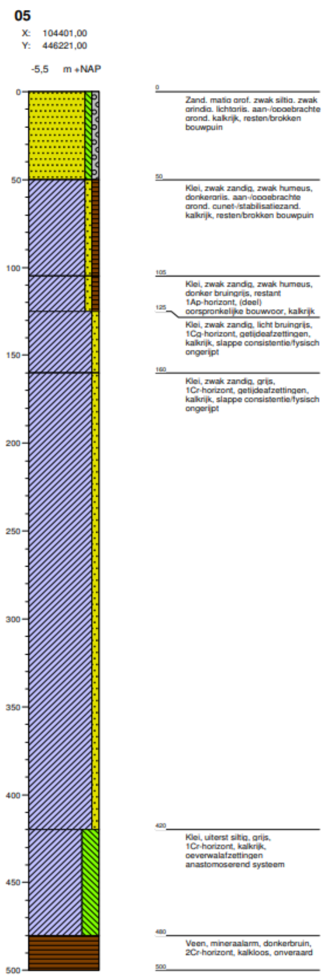


Figure 45 Verification auguring of grid 53

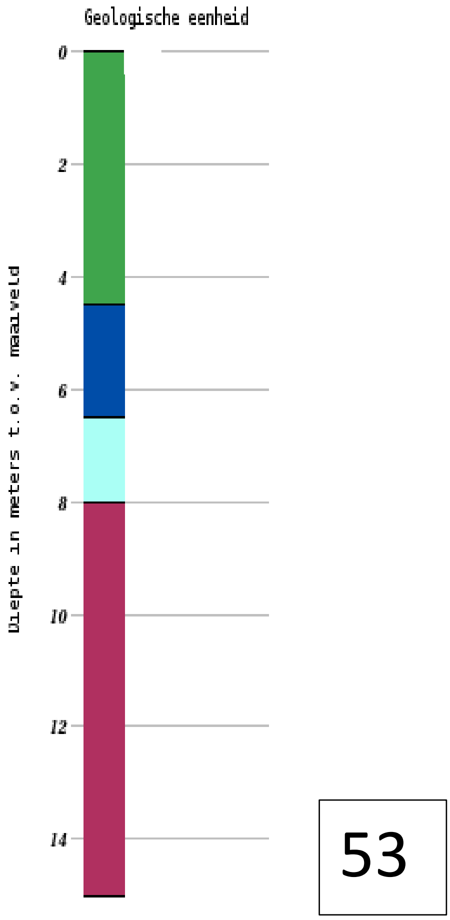


Figure 46 Profile from grid 53 from current study

In grid 50 the verification auguring 11287-28 (Fig. 47 took place. This auguring profile consists mainly of clayish material with a strong silt content. The clayish material, according to the research, originated from the region's tidal influences after the Neolithic Period and belongs to the Naaldwijk Formation. Within the clay layers, peat layers form. Till 6 m below surface level, the texture does not change abrubly, except for the peat layers. Within the verification auguring no signs of archeological artefacts were found, except for the clay layers without calcium; however, this does not indicate that archeological remains always occur. The profile from this research (Fig. 48 shows a Naaldwijk Formation to a depth of 8 m below the surface containing clay. Comparing the profiles, they correspond with each other up to 6 m below the surface. Both materials match each other and belong to the Naaldwijk Formation. However, the peat layers do not appear in the profile from this study.

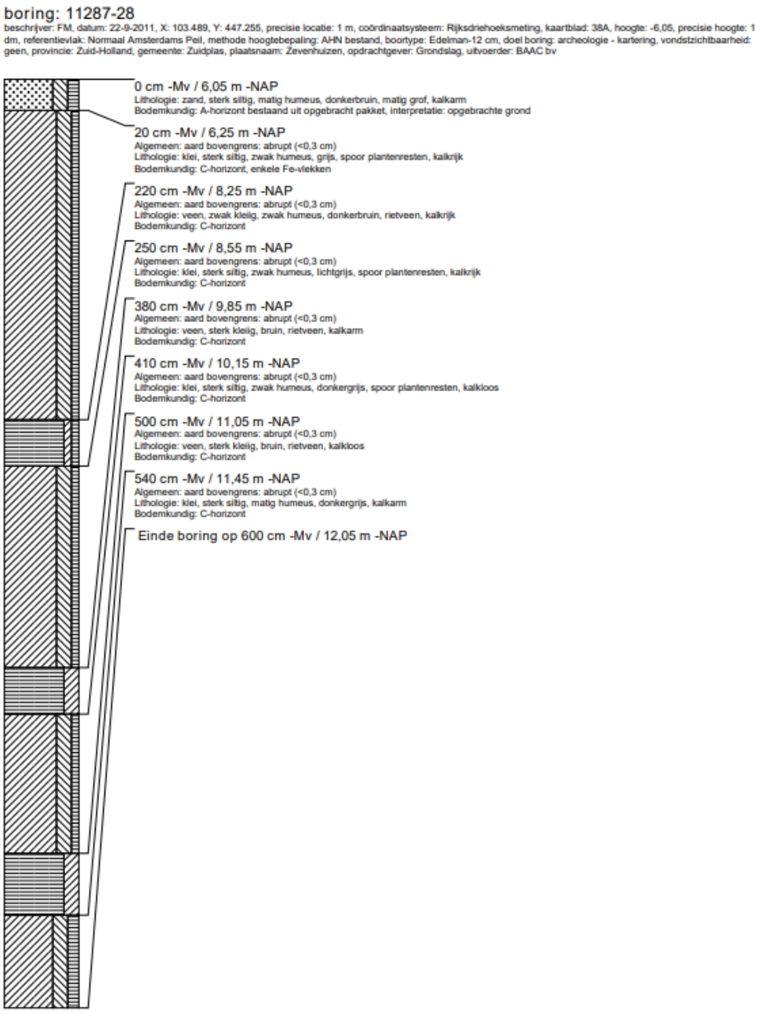


Figure 47 Verification auguring of grid 50

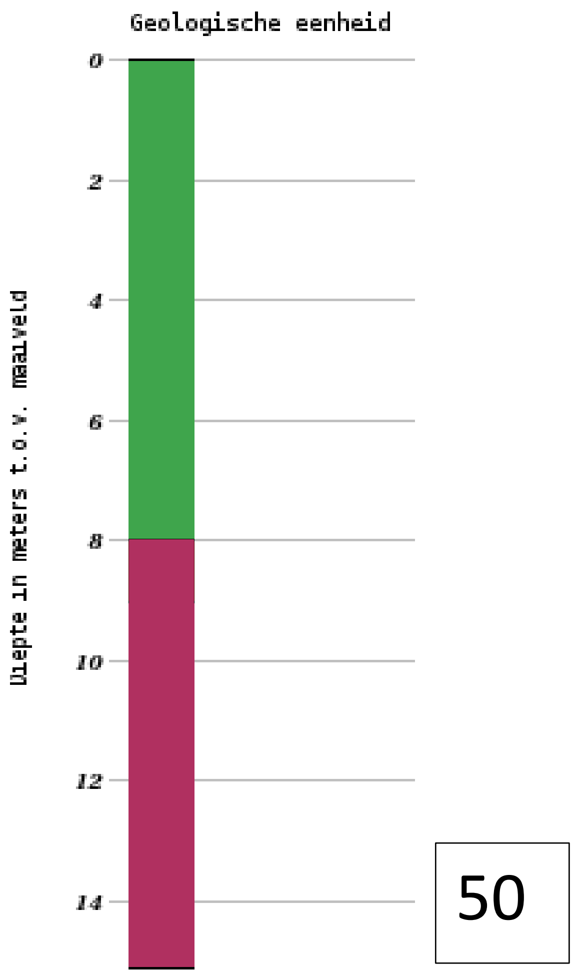


Figure 48 Profile from grid 50 from current study

The profile (3) of the verification auguring (Fig. 49) is located in grid 24. The profile consists, except for the top stirred layer, of clay with a high silt content. The clay belongs to the tidal influences after the Neolithic Period and is part of the Naaldwijk Formation. In between these clay layers, peat occurs. The peat layers vary in depth and occur locally. The research did not indicate any archeological remains within the study area. This research profile (Fig. 50) consists of clay from the Naaldwijk Formation up to 8 m below the surface. Comparing both profiles, the peat layers are again not shown on this study's profile. Overall, both profiles show till 3 m below surface, the Naaldwijk Formation containing clay deposits from the tidal influences.

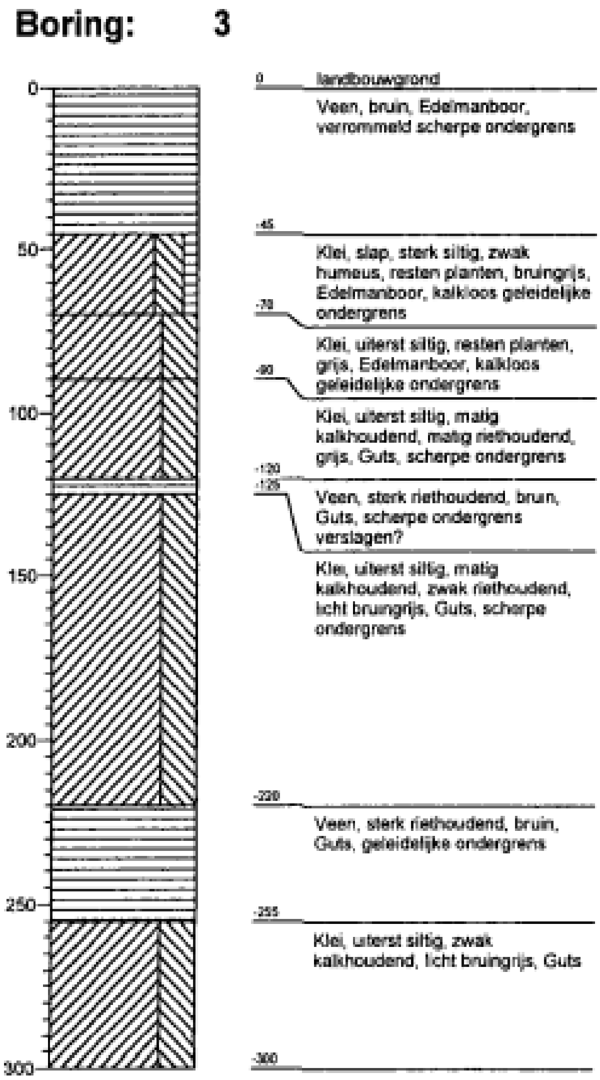


Figure 49 Verification auguring of grid 24

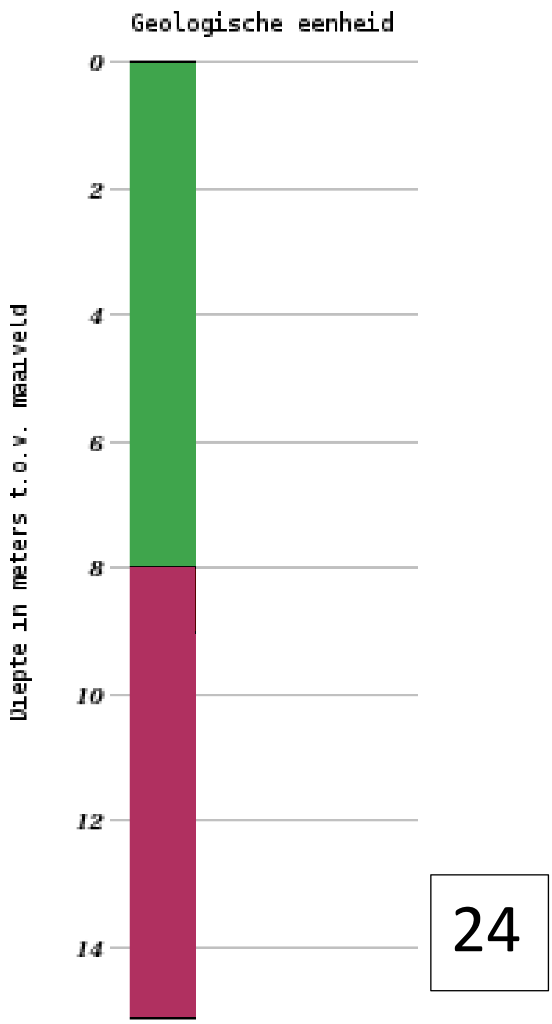


Figure 50 Profile from grid 24 from current study

The profile of the verification bore (5) (Fig. 51) shows a clay-on-peat package. It consists of clay (skewed lines) with peat layers (horizontal lines). According to the research, tidal influences form clay. This clay layer belongs to the Naaldwijk Formation. The research did not indicate any archeological remains within the study area. According to this research profile (Fig. 52), the Naaldwijk Formation extends to 7 m below the surface. Comparing both profiles, they show a large correlation with each other. The Naaldwijk Formation is present in both profiles, with a depth of at least 3,80 m. Nonehtles, like all of the other profiles, shows the peat layers in the profile of this study.

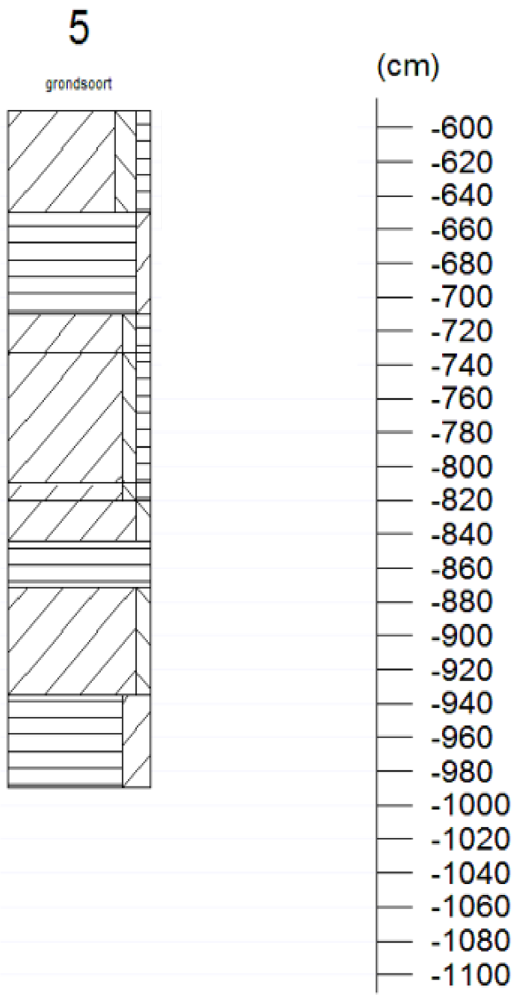


Figure 51 Verification auguring of grid 28

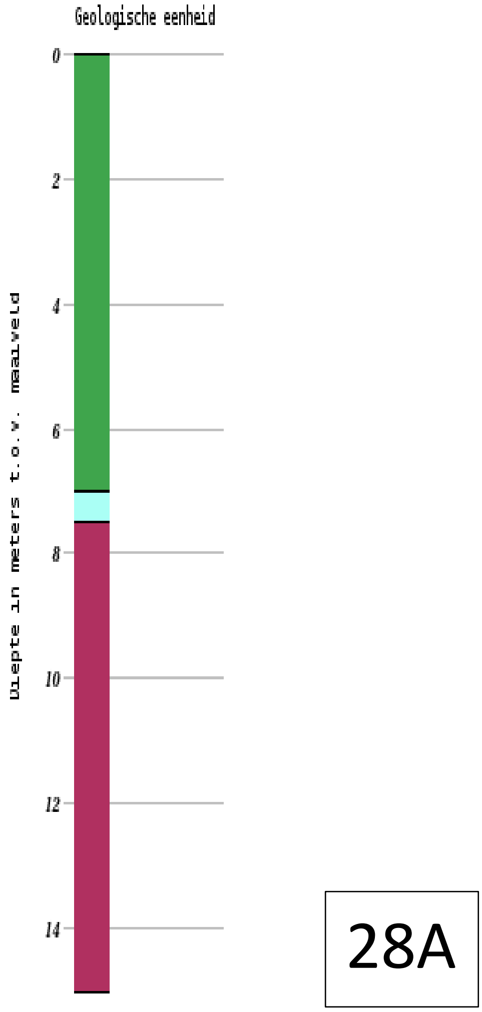


Figure 52 Profile from grid 28 from current study

Verification auguring 001 (Fig. 53) is located at grid 12. The profile is mostly clayish material with a small amount of silt, which belongs to the Naaldwijk Formation. In between the clay layers, peat from the Nieuwkoop Formation is found. Except for the peat layers, the overall profile does not change abruptly. The research did not indicate any archeological remains within the study area. The profile from this research (Fig. 54) shows the Naaldwijk Formation until approximately 4 m below the surface. Underneath the creek system and the Echteld Formation,. Comparing the bore profiles, they correspond, like the other bore profiles, with each other when it comes to the Naaldwijk Formation. The Naaldwijk Formation does not display the intermediate peat layers. Furthermore, the verification auguring's depth stops at 4 meters below the surface. The creek system, the first geolgoical unit with a higher likelihood, starts around 4 meters below the surface.

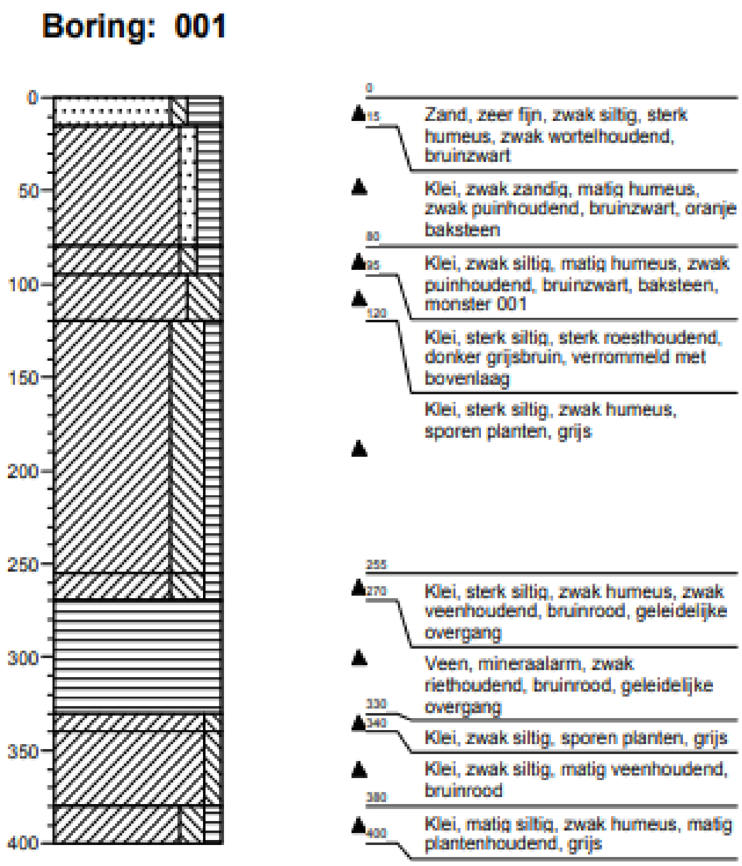


Figure 53 auguring of grid 12

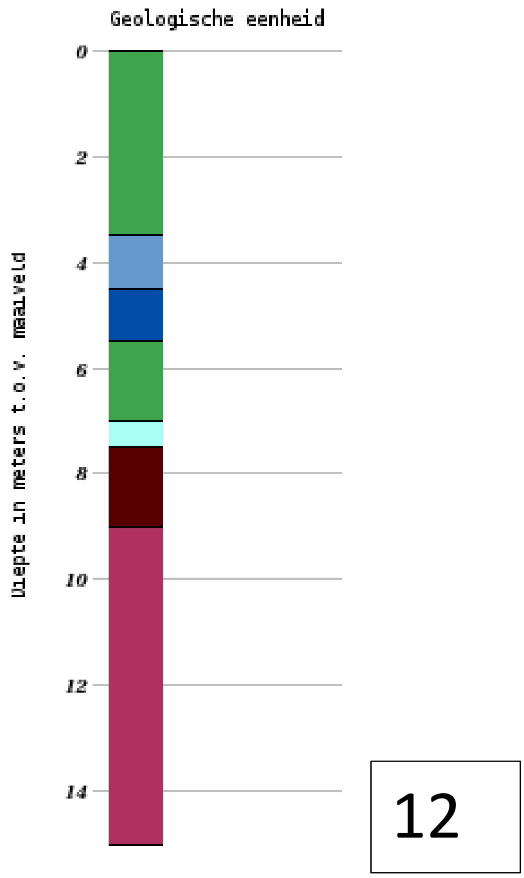


Figure 54 Profile from grid 12 from current study

The last verification auguring ZEZU2-1 (Fig. 55) is located in grid 26. A clay package was found beneath the disturbed package in almost all auguring's. The clay is predominantly limeless, humusy, and soft and contains reeds or plant remains. The clay is characterized by humus layers that transition into peat layers, or a peat package that includes some clay layers. The peat is predominantly clayey and mineral-poor. The clay package is thought to contain tidal flat deposits. However, it cannot be ruled out that they are (partly) basin deposits. The research did not indicate any archeological remains within the study area. Comparing both profiles (Figs. 55 and 56), it appears that the top layers are both clay deposited by tidal influences. At around 2,5 to 3,0 m below the surface, a peat layer occurs in the verification, and the Echteld Formatin occurs in the profile of this study. They do not align; however, the report mentioned that the peat, including clay, might be part of a basin deposit.

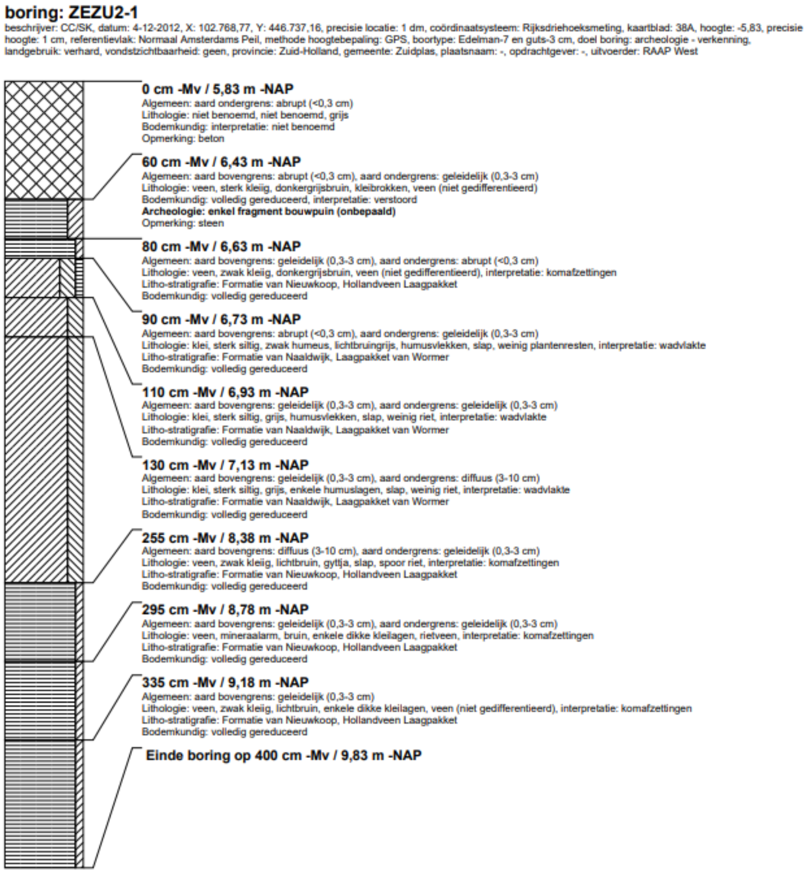


Figure 55 Verification auguring of grid 26

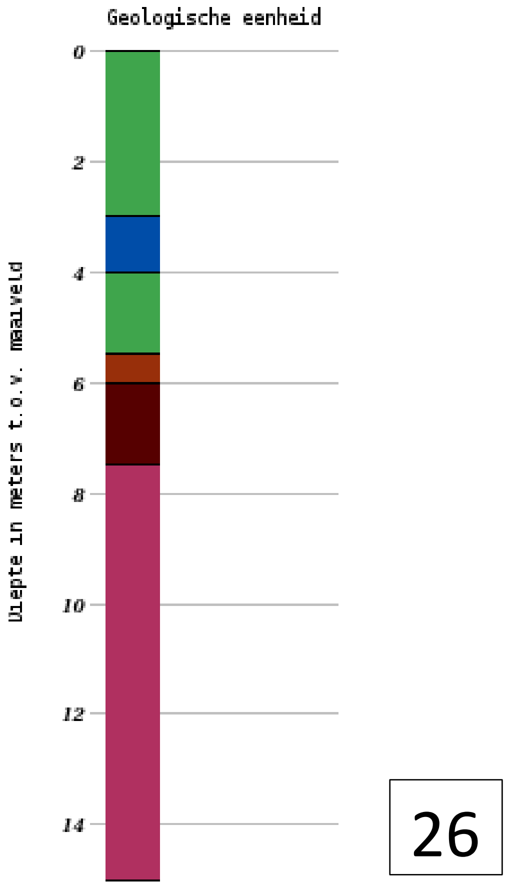


Figure 56 Profile from grid 12 from current study

Discussion

For this research an enhanced version of the Bottom-Up Model of Kempf was applied to answer the question if paleoenvironmental reconstructions coupled with the input on the regional archaeological periods can be used to the predict the archaeological likelihood of a landscape by showing the results in an "interactive map". To answer the question, the research was divided into two sections. First and foremost, landscape reconstruction entails interpreting how the study of landscape dynamics can contribute to understanding environmental history and determining which landscape systems existed, including their age. Secondly, the archaeological habitation distribution was determined by observing what types of habitation patterns were employed in the study area, including understanding the changes in strategy over the different archaeological periods. The research was based on the well-known connection between landscape dynamics and archaeology or habitation patterns. It is the basis of numerous research projects all over the world, and is possible to test in detail in the Dutch landscape due to the large amount of prior work on both archaeology and geology in this deltaic setting. Based on the research herein, I arrive at the following insights.

Landscape reconstruction

The study of landscape dynamics is the basis for understanding environmental history. It allows for the reconstruction of past landscapes, creating a framework for how the landscape has changed over time due to natural processes and anthropogenic influences. By analysing the topography, river-beds, and stratigraphic units, it can be interpreted what system caused large influences and created the region (e.g. Van den Berghe, 2003; Vos & De Vries, 2013). This knowledge is critical for identifying long-term trends in landscape development, such as periods of stability and disturbance, which help to understand the underlying causes of environmental patterns. Landscape reconstruction also provides insights into how past human activities, such as agriculture, deforestation, and urbanization, have shaped the current environment, which is essential for developing sustainable land management practices (e.g. Verheul and Theunissen, 2010).

The reconstruction of the landscape dynamics for the study area in the Zuidplas gave multiple geological units/ landscape systems. All the landscape systems together formed the region as of today. These systems include various formations such as: (1) Formation of Krefteheye created by a braided river system with the top layer forming in the Late-Pleistocene Period; (2) Wijchen Member formed due to floodings of the braided river systems, originating from the Late-Pleistocene to the Early-Holocene Period; (3) Basel Peat Member originating from a rising sea level in wet environments from around the Late-Pleistocene to the Early-Holocene Period; (4) Boxtel Formation (Delwijnen Member), also known as river dunes, were formed by aeolian processes creating higher area close to rivers consisting of sand, from circa the Late-Pleistocene to the Early-Holocene Period; (5) Echteld Formation, consisting of the former channels dating back between 6.200 BCE to 5.400 BCE; (6) Naaldwijk Formation (Wormer Member) created by the influences of the sea that entered the land and was formed around 5.500 BCE to 3850 BCE after the beach barriers closed; (7) Nieuwkoop Formation, consisting of peat that was formed under the wet conditions from 3850 BCE to 1500 BCE.

Archaeological habitation distributions

Populations living close to paleo-channels had various habitation patterns that later evolved over different archaeological periods. These changes reflect adaptations to environmental conditions and shifts in strategies. Below, it is outlined how these patterns changed across different historical periods for the Zuidplas study area. During the Paleolithic and Mesolithic periods, human habitation was characterized by small, temporary camps due to nomadic lifestyles, with settlements often on the southeast slopes close to water bodies, levees, or river dunes. The Neolithic period brought a change to agriculture, causing more permanent and larger settlements, typically located on coastal or river dunes and levees. In the Bronze and Iron Ages, settlements grew in size and complexity and became regional centers with a strong focus on agriculture and trade, situated on well-drained locations like river dunes and levees. The Roman period introduced urban development with towns, military camps, and villas supported by advanced infrastructure, mostly located along the Rhine river. The peat regions were seen as unsuitable for habitation and agriculture due to the wet conditions. During the Middle Ages, following a population decline, habitation patterns shifted to smaller, dispersed rural communities, often in regions favorable for agriculture, while peatlands were still uninhabited.

The difference between the likelihood of habitation and the likelihood of finds originates from their main focus. The likelihood of habitation refers to the probability that a specific geological unit was used for habitation by past populations. It is based on the most favourable locations, such as well-drained, fertile or strategic locations. It is an evaluation of how likely it is that habitation took place on a specifc geological unit. The likelihood of finds is the probability of discovering physical remains left by the population at that time, such as tools, pottery, charcoal, animal remains, structures and marks. An area with a high likelihood of habitation might not necessarily have a high likelihood of finding artifacts if, for example, the population lived nomadic with only small (hunting) camps. Conversely, an area might have a low likelihood of habitation but still have a high likelihood of finds if during the period, the habitation took place at larger scales, which causes more finds to be scattered at a specific location.

Utility and insights from the bottom-up model

The results demonstrate a clear distinction between the likelihood of habitation and the likelihood of finding. The former river channels and the Boxtel Formation have a high likelihood of habitation because, in the region, there were signs that habitation occurred at these specific locations. However, the camps of the Palaeolithic and Mesolithic were small, sizing up to a maximum of a few hundred square meters, compared to the Roman camps that went up to a few hectares (Van der vin, 2002; Kooistra et al., 2013). The likelihood of finding finds from such small Palaeolithic or Mesolithic camps is much lower than findings from the large camps of the Roman Period. The likelihood of finds changed in the Neolithic because the camps started to become farms and reach larger sizes; however, compared to the later periods, the camps were small in size, hence the moderate likelihood. From the Bronze Age to the Roman Period, however, the likelihood of finds and habitation was very low. Due to the already wet conditions, there was no habitation in the region. Findings are more likely to appear at larger campsites than at smaller (hunting) camps. Fokkens (2005) highlighted a significant issue in archaeological research, noting that it often emphasizes drilling while neglecting broader cultural landscape contexts. This focus can overlook important aspects of archaeological finds in the landscape. Papers such as those by Tol et al. (2006) and Verhagen et al. (2013) predominantly focus on the probability of discovering artifacts. Additionally, a central objective of archaeological research is often to identify regions with a high probability of containing archaeological remains and to initiate investigations based on the likelihood of habitation. This approach is prevalent in archaeological research conducted by companies, which typically concentrate on identifying geological units where potential habitation sites may exist and conducting investigations accordingly (e.g. Van Putten, 2020, BAAC; Ten Broeke, 2019, Econsultancy; Miedema, 2012, BAAC; Leuvering & Nillesen, 2012, Synthegra; Kerkhoven & Wilde, 2012, Adviesbureau Noordam BV; Izendoorn & Engelse, 2009, ArcheoMedia; Coppens, 2012, Van Westreenen Adviseurs B.V.). However, the likelihood of finding artifacts is often overlooked, despite its significance compared to the likelihood of habitation. This oversight is crucial, particularly in terms of improving efficiency and reducing costs. By focusing fieldwork on more specific locations with a higher likelihood of finds rather than researching entire regions or geological units, the process can be significantly streamlined and resource use optimized.

Over time, the demand for more modern methods in archaeological research has grown, leading to the development of various innovative ideas and models (e.g. Balla et al., 2014; Paradis et al., 2019; Wang et al., 2023). The drive for efficiency in archaeological methods is crucial, particularly for applications within society where cost-effectiveness and labour-extensive approaches are highly valued. This emphasis on efficiency is a key selling point for archaeological companies seeking to attract clients and increase research demand. This study represents an effort to implement a novel methodology that promises to be more cost-efficient and labour-extensive, aiming to enhance the overall effectiveness of archaeological investigations. The Bottom-Up Model, as developed by Kempf (2021), was enhanced for this study to create a higher efficiency and applicability. By refining the model to focus on relevant geological and archaeological layers, it filters out less significant layers, thereby streamlining the analysis process. This improvement not only increases the model's efficiency but also makes it highly practical for use by archaeological companies, enabling them to provide more accurate and client-specific insights.

The primary goal of this study was to investigate the development of a Bottom-Up Model and gather initial data for the case study. Given the novelty of the approach, our priority was to establish a foundational understanding before moving on to detailed verification. Next to the deliberate decision, unforeseen circumstances occurred. The inhabitants of the study area were less willing than expected. Due to the unwillingness of the inhabitants to agree on Auguring’s, the decision was made not to include the fieldwork as verification. However, the Archis database was used for some verification. The region has already undergone extensive archaeological research, indicating that excavations have taken place. Six of these auguring’s were taken out and placed next to their specific bore profile from the specific grid number on the map. Comparing the verification bore profiles against the bore profiles from this research shows that they partly correspond with each other. When it comes to depth, the Naaldwijk Formation agrees most of the time, from top to bottom. However, the peat layers in between the Naaldwijk Formation are not shown in the bore profiles from this research. An explanation could be that the sea's influence changed per region, creating peat formation at calm times and peat erosion at stormy times Peat occurs very locally, and the density of the auguring’s within DINOLoket does not reveal the layers of peat in between. Another explanation is that the Naaldwijk Formation is known for its discontinuous layers of peat. DINOLoket does not account for the local and unpredictable discontinuous layers of peat. The peat layers belong to the Naaldwijk Formation, not the Nieuwkoop Formation. Besides the peat layers, a bore profile (ZEZU2-1) did not show Echteld Formation, which was observed in the verification auguring. In contrast, this study's bore profile revealed the Echteld Formation precisely at the same depth as the verification auguring (18254–11). Overall, this study's bore profiles largely match the verification's, with the exception of the peat layers found in between.

Implications for cultural resource management.

The Bottom-up Model is an interesting way to look at an archaeological request by combining the geological information with the archaeological information into one single "interactive map". With the bottom-up model, a more specific reconstruction is made of the region in which all the geological units are taken into account, whether they have high or low likelihoods. The combination of the likelihood of habitation and the likelihood of finds gives a better interpretation of how interesting a specific location is for archaeological research in the public sector. Incorporating both likelihoods can lead to cheaper and more specific research. In addition, the bottom-up model provides guidance for archaeological research. Including the likelihood of finds gives an extra dimension to possible fieldwork. A decision can be made on whether fieldwork is profitable. With a very low likelihood of finds, the question can be asked if any fieldwork would result in the finds. Based on this, it can be concluded that auguring in other locations with a higher likelihood of finds might be more useful and provide more information. This research suggests that a standardized Bottom-Up Model, which incorporates the likelihood of habitation and the likelihood of finds, could enhance the execution of archaeological research, resulting in more cost-effective and detailed research.

Often, companies like Sweco work for the same client multiple times. To incorporate the Bottom-Up Model, there is one straight line to follow and an overview. The research creates an "interactive map" to display the bore profiles and their likelihoods. Partly, the input layers can be standardized. The input layer of archaeology often corresponds to a whole region or municipality. Once a region conducts such archaeological research, it becomes standardized, necessitating only geological analysis. When a model is standardized, it can save time and money. An interactive map can be created for the whole municipality or region by analysing both the habitation patterns and the geological reconstruction from a great perspective. It only has to be done once. For future archaeological research, the "interactive map" can be the basis. Point a location on the interactive map, and it shows the bore profile with its likelihoods for that specific location. Following a standardized bottom-up model creates unity, for example, for municipalities that require uniformity when it comes to research.

Opportunities for future work.

The first step in future research is to add more verification to the Bottom-Up Model, as initial tests did not fully explore its capabilities. While initially applied in the fluvial landscapes of the Zuidplas region, the model needs to be tested in regions that do not contain a fluvial landscape. Fluvial landscapes are the easiest geological units to incorporate due to the highly detailed reconstructions available. Nonetheless, the model should be tested in regions with the fluvial systems, such as the coversand regions. In addition, the mountainous regions in the south should be tested due to their different topography and landscape. This broader testing will ensure the model's adaptability and aplicability across different geographical contexts, enhancing its value as a tool for archeological research. To focus on the archeological research executed by companies, the vetting of the model needs to be cost- and labour efficient. Even though, Fokkens (2005) and Brandt & Bakker (1977) are advocates for using small trench research, the cost of these is to high for general archeological research. This shows that a much higher density of coring needs to happen to see what the model does in the study area and different regions.

To focus on the client base, it is beneficial to see how the model performs when parts of it are standardized, creating an interactive map for entire regions that can serve as a standardized product for future research. Such a tool would provide clear guidelines for identifying areas of archaeological interest and combining them with the likelihood of finds. This not only promotes scientific value but also improves efficiency and cost-effectiveness in archaeological research, making the model a practical choice for varied landscapes.

Conclusion

This study successfully applied an enhanced version of Kempf's Bottom-Up Model to investigate the viability of using paleoenvironmental reconstructions and regional archaeological inputs to predict a landscape's archaeological likelihood, presenting the results through an interactive map. The study was divided into two main components: landscape reconstruction and the examination of archaeological habitation patterns. The landscape reconstruction provided insights into historical environmental dynamics as well as the existence and age of various landscape systems. Meanwhile, the investigation of habitation patterns across different archaeological periods allowed for an understanding of how settlement strategies evolved in response to environmental changes.

The findings underscored the significant potential of combining geological and archaeological data to enhance the precision of archaeological predictions. Notably, the former river channels and the river dunes were identified as high-likelihood areas for habitation, especially in older periods. These areas were chosen for settlement due to their favourable conditions, which shows the model's capability to identify locations with high archaeological likelihoods. The difference between the likelihood of habitation and the likelihood of finds was clear, with smaller camps from the Palaeolithic and Mesolithic periods presenting lower artifact retrieval chances compared to the larger Roman and Neolithic sites.

The Zuidplas region research served as a test case for the Bottom-Up Model, showing some local differences, especially in the detection of peat layers, despite a good overall correspondence between the research and verification bore profiles. This shows the importance of considering regional variations in geological formations when applying the model. Despite these variations, the model proved effective in showing high-likelihood areas for archaeological finds.

Furthermore, the study demonstrated that this model has the potential to streamline and standardize archaeological research processes, offering a cost-effective and detailed approach that can be particularly beneficial for municipalities and other clients requiring uniformity in archaeological assessments. The interactive map developed through this research represents a valuable tool for future archaeological investigations, providing a user-friendly interface to visualize areas of high archaeological potential based on a comprehensive integration of geological and archaeological data.

In conclusion, the enhanced Bottom-Up Model, by incorporating both the likelihood of habitation and the likelihood of finds, provides a robust framework for predicting archaeological likelihoods across different landscapes. This approach not only enhances the efficiency and precision of archaeological research but also offers a scalable solution that can be standardized for broader application, thus creating better-informed decisions in archaeological fieldwork and resources. To fully realize the model's potential, future research should focus on further verification and exploration of its applicability in different geographical locations.

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Appendix

Appendix 1 – Overview archaeological and geological periods

Appendix 1, table 1 Overview of archaeological periods (Archeologisch Basis Register 1992 - Brandt et al., 1992)

PERIOD	TIME		
INDUSTRIAL/ MODERN	1.500 CE	-	Present
POST-MEDIEVAL	1.050 CE	-	1.500 CE
EARLY-MEDIEVAL	450 CE	-	1.050 CE
ROMAN	12 BCE	-	450 CE
IRON AGE	800 BCE	-	12 BCE
BRONZE AGE	2.000 BCE	-	800 BCE
NEOLITHIC	5.300 BCE	-	2.000 BCE
MESOLITHIC	8.800 BCE	-	4.900 BCE
LATE-PALEOLITHIC		till	8.800 BCE

Appendix 1, table 2 Overview of Chronology (Archeologisch Basis Register 1992 - Brandt et al., 1992)

CHRONOLOGY		YEARS AGO		
HOLOCENE	Subatlanticum	3.000	-	Current
	Subboreal	5.000	-	3.000
	Atlantium	8.000	-	5.000
	Boreal	9.000	-	8.000
	Pre-boreal	10.000	-	9.000
PLEISTOCENE	High	130.000	-	10.000
		120.000	-	10.000
		130.000	-	120.000
	Middle	800.000	-	130.000
		200.000	-	130.000
		400.000	-	315.000
	Early	2.400.000	-	800.000

Appendix 2 – Archeological indications

Finds

Finds are important for determining whether habitation occurred and to what period they belong. The most vital indication of habitation overall in archeological periods, the charcoal remains (Kooistra, 2006; Kooistra & Brinkkemper, 2016; Kubiak-Martens et al., 2019). Wood was an important fuel not only for campfires but also for the mining of iron (Deforece et al., 2021). Burned wood produces charcoal as a waste product. Almost all conditions preserve charcoal excellently, making it easy to recognize in the field and a suitable indicator to demonstrate human presence in the past (Kooistra, 2006; Kooistra & Brinkkemper, 2016; Kubiak-Martens et al., 2019). In an archaeological investigation, charcoal can provide information about the function of hearths, ovens, or other activities in which fire played a role. Charcoal also provides information about nearby forests and shrublands. The material category is also suitable for 14C dating research (Kooistra, 2006; Kooistra & Brinkkemper, 2016; Kubiak-Martens et al., 2019). Nonetheless, charcoal is a secondary archeological indicator, because it can occur naturally in, for example, natural fires (e.g. Caromano et al., 2014)

Next to charcoal, animal remains are an indicator of habitation (Lauwerier, 2011; Carmiggelt & Schulten, 2002; Ervynck, 2004; Ervynck, 2012). People hunted, ate, and bred animals in the past. The inhabitants consumed meat and gave skeletal remains, tendons, skins, horns, and antlers a second life as finds. In many cases, this practice left behind residues in the form of slaughterhouse waste, kitchen and meal remains, objects made from animal products and the waste resulting from them, and, for example, 'vermin' (Lauwerier, 2011; Carmiggelt & Schulten, 2002; Ervynck, 2004; Ervynck, 2012). In addition, this category of finds also includes the carcasses of (ritually) buried animals (Lauwerier, 2011; Carmiggelt & Schulten, 2002; Ervynck, 2004; Ervynck, 2012). The species of animal can give an indication of what period of possible habitation took place. In addition, age determination provides clarity on the time span.

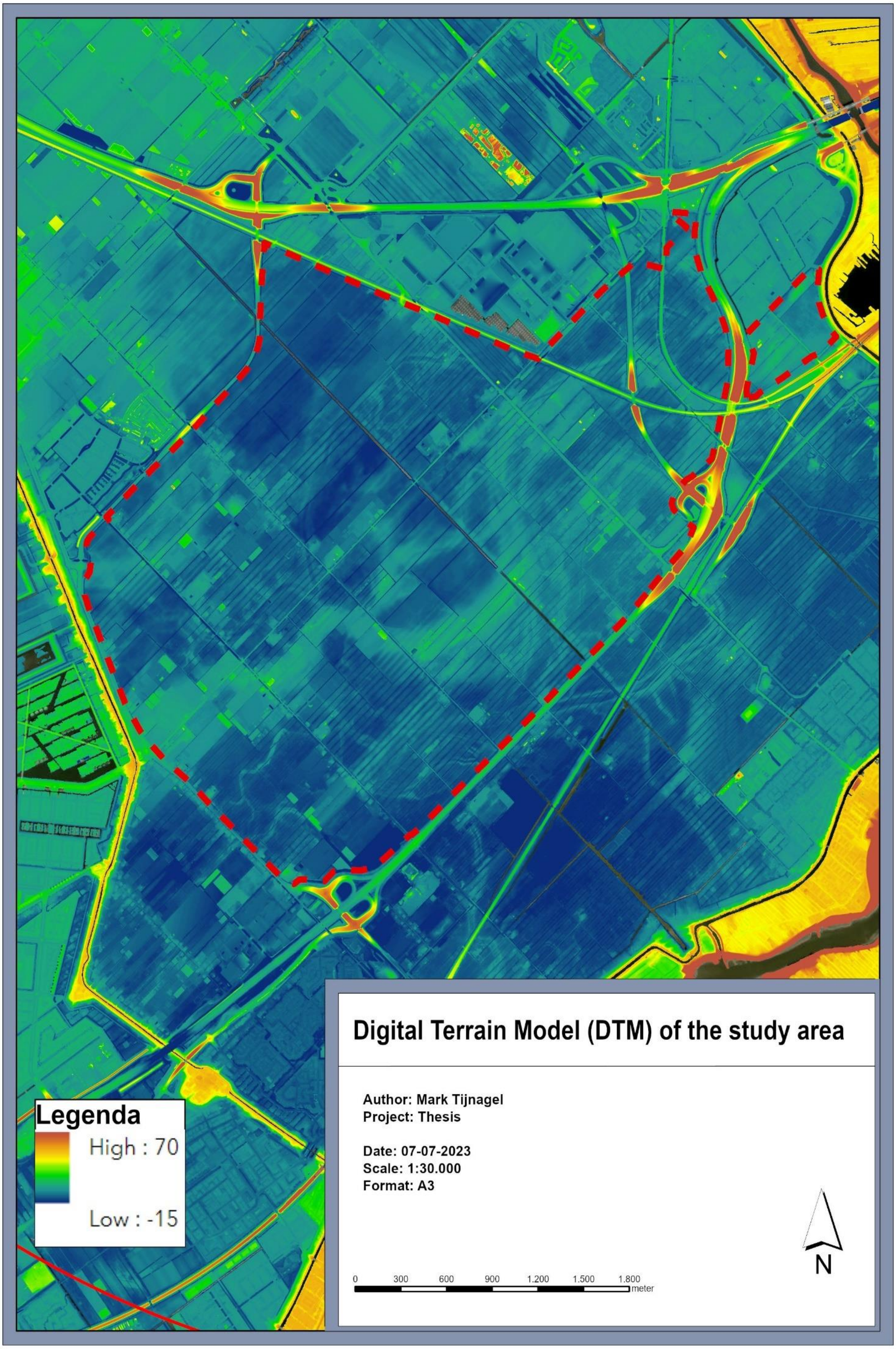
Botanical macro remains thus provide insight into and contribute to answering research questions about the variety of (plant) foods that people consumed in the past, cultivated crops that were introduced and grown, and agricultural and craft activities that people developed (Kooistra, 2021; Kooistra & Brinkkemper, 2016; SIKB, 2018). From Roman times onwards, macro remains offer a glimpse into the trade and status of people as they engaged in large-scale and long-distance food trade (Kooistra, 2021; Kooistra & Brinkkemper, 2016; SIKB, 2018). Furthermore, macro remains shed light on the vegetation and environmental conditions surrounding a site, the collected wild plants, and the impact of humans on the environment (Kooistra, 2021; Kooistra & Brinkkemper, 2016; SIKB, 2018).

Furthermore, remains such as pottery, stone artefacts or even (partly) construction are as important. Any of these finds can almost immediately classify from which period they originate. It gives information on how they lived in for example farms or villages (Cleijne et al., 2017; Dijk & Viersen, 2019; Kort & Zweers, 2016). In addition, the tools, such as pottery, can show the advancements within the period and often is a distinguisher between period or cultures (Cnuts et al., 2021). Ground mark is next to the tangible remains, an important factor. At the microscopic level, traces are still visible and can provide insight into processing hides, chopping wood or cutting vegetable material (Gijn, 2010, 2014; Verbaas et al., 2019).

Soil

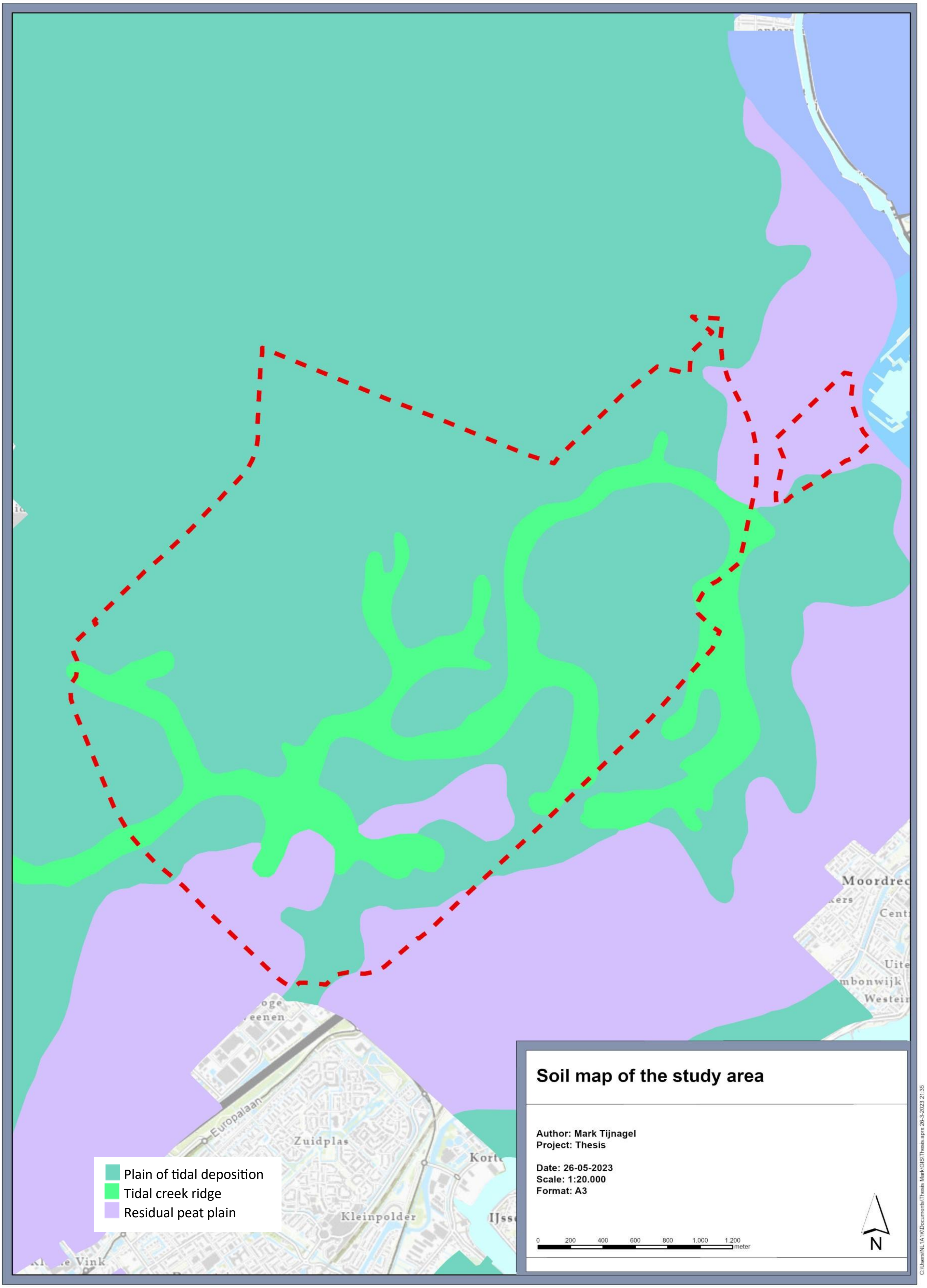
Soil, in addition to finds, indicates higher archeological possibilities. To focus on the region, the deposits consist mostly of clay or peat. The clay deposits on their own do not have an indication; however, when silt occurs, the indication changes. A clay soil with a high amount of silt can indicate a levee deposit. When plant remains are present in the soil, next to clay and silt, there are indications of a basin deposit. The peat occurs in locations that are wet (swamps) where plants grow faster than the environment can decompose, creating a layer of dead plant remains (peat). When sand occurs in the top of the peat layer it indicates that the layer was once at ground level. Next to the soil textures, calcium gives an indication of the time the soil was in contact with the surface. Rain removes the calcium from the soil. When the soils are at the surface for a long period, the calcium content in the soil is low to none, indicating a profitable location for habitation. A large calcium content in the soil suggests long-term burial, making it a less favorable location for habitation.

Appendix 3 – AHN map



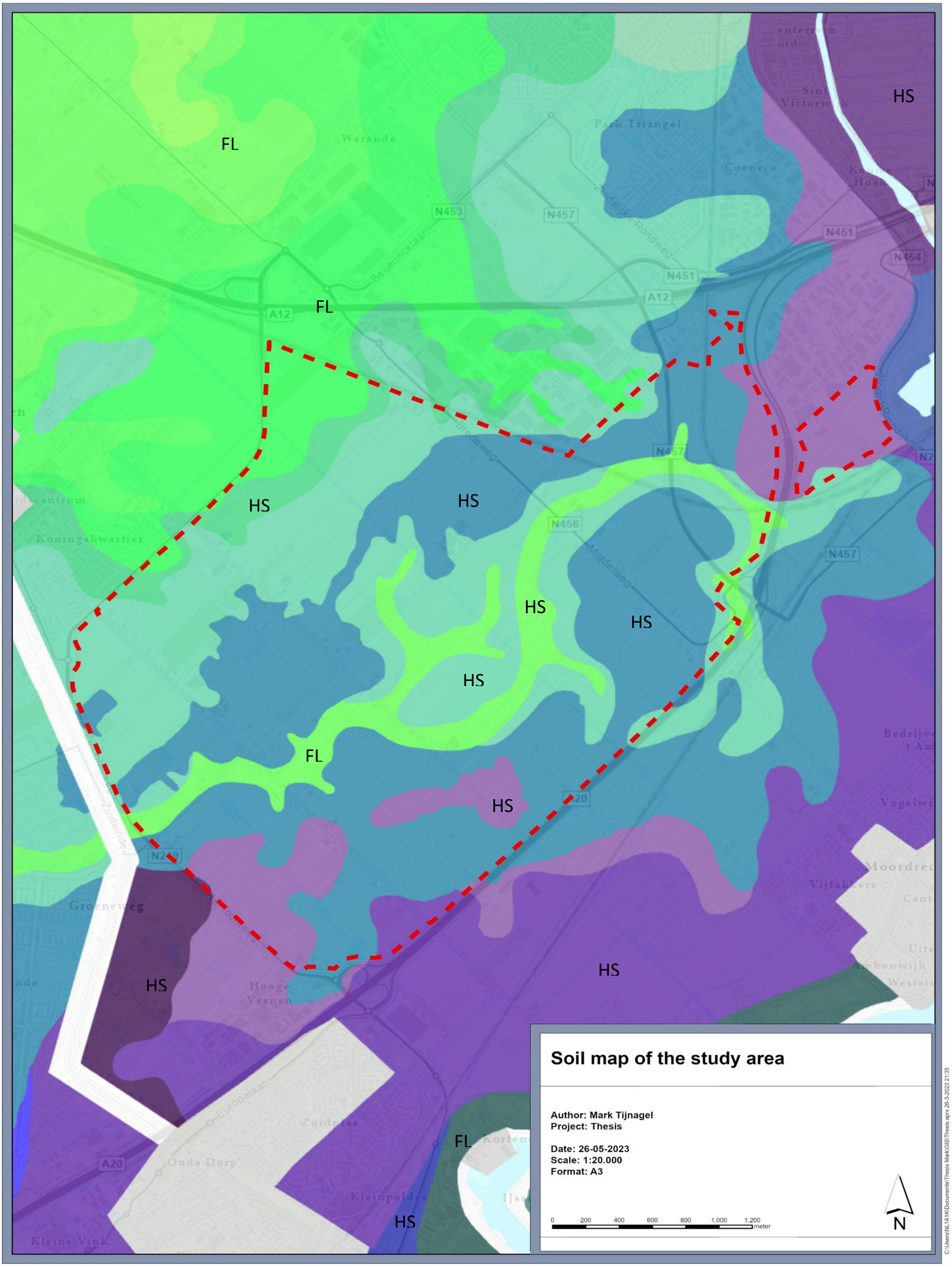
Appendix 3 Digital Terrain Model of the study area

Appendix 4 – Geomorphological map



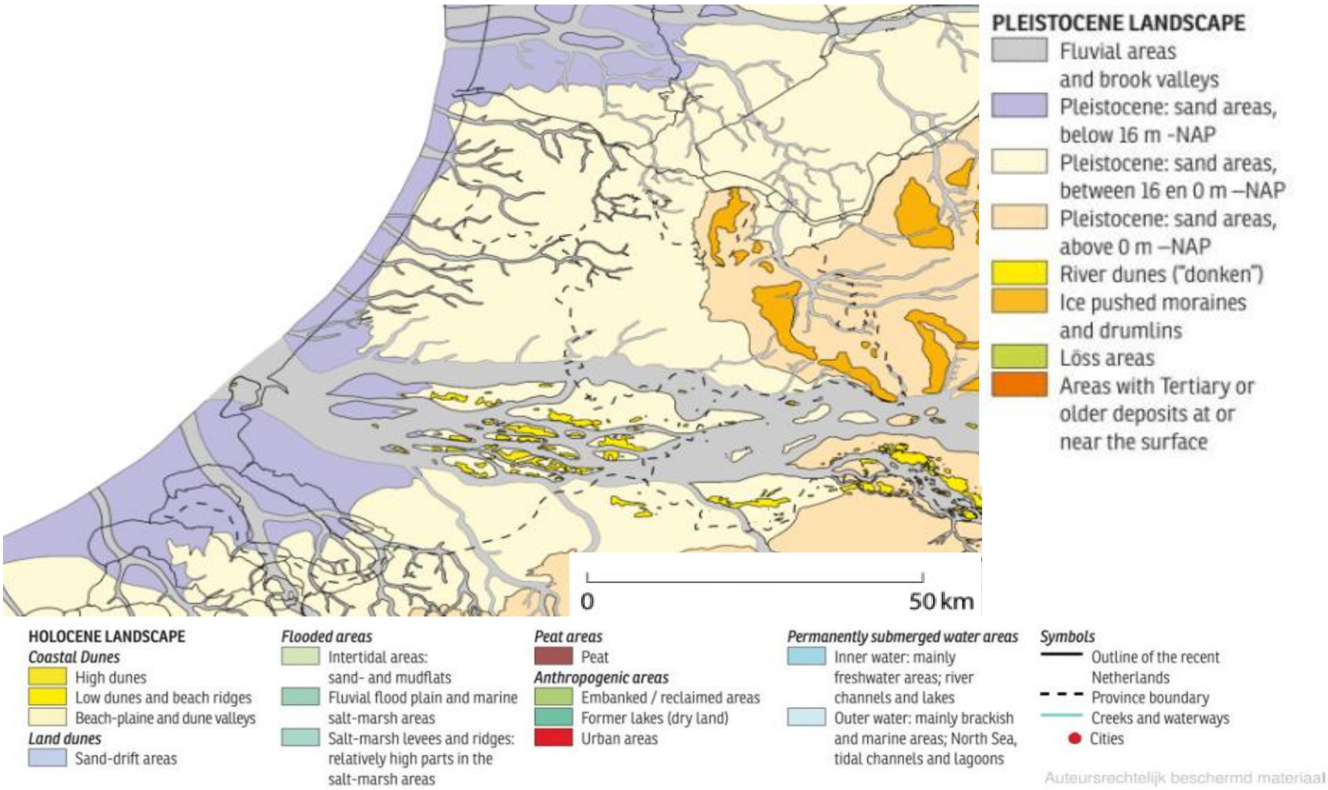
Appendix 4 Geomorphological map of the study area

Appendix 5 – Soil map

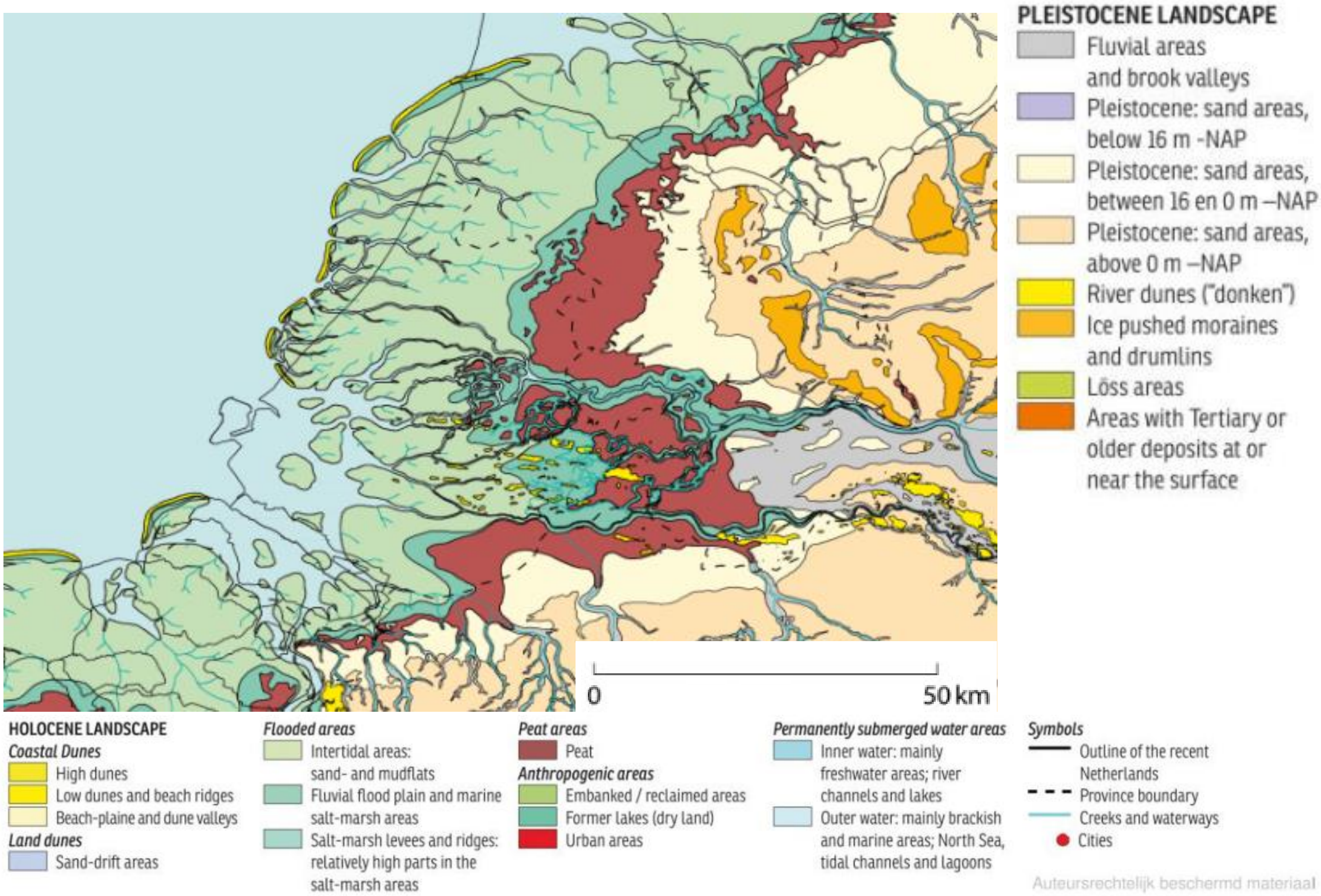


Appendix 5 Soil map of the study area; HS: histosol, FL: Fluvisol

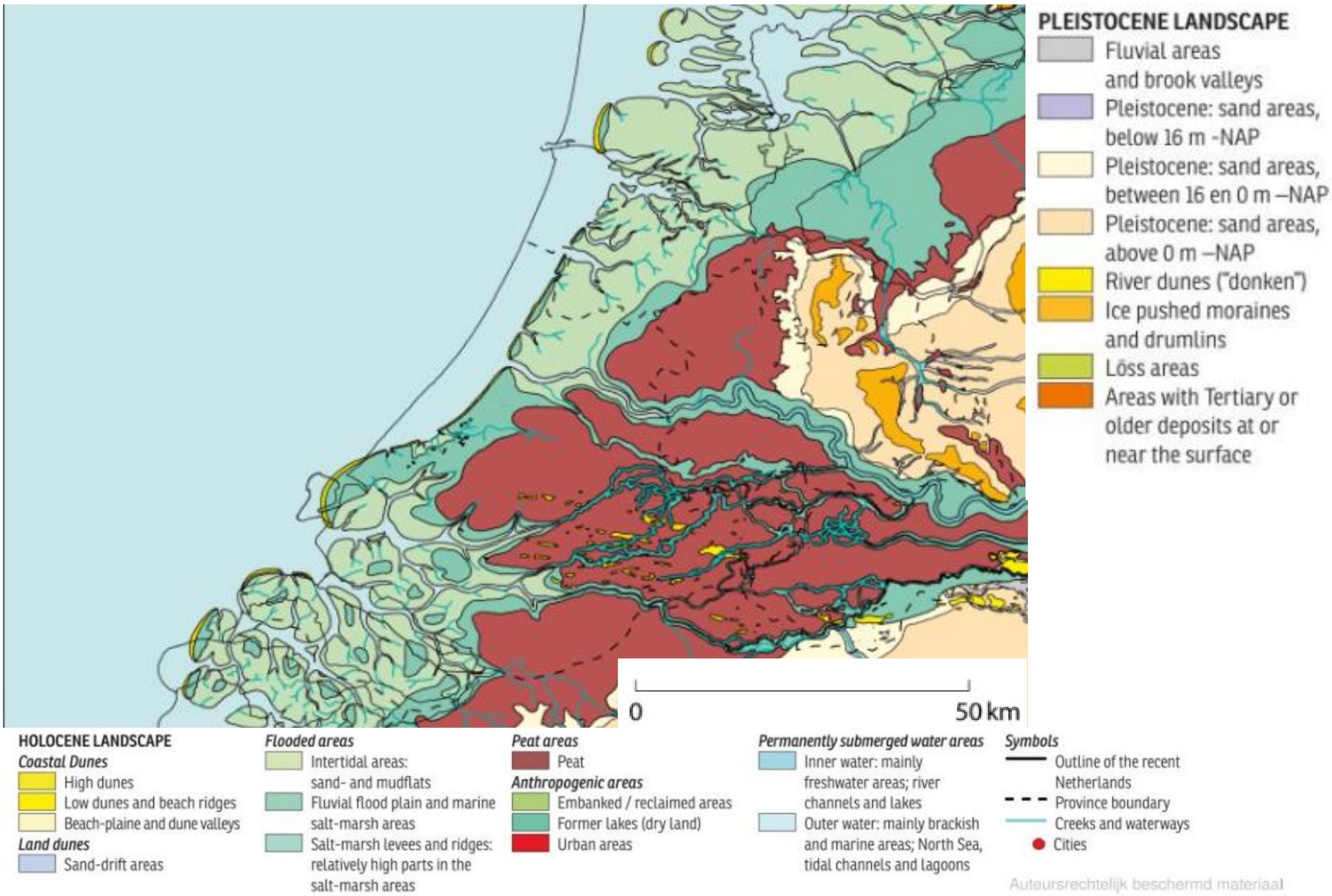
Appendix 6 – Palaeogeographical reconstruction of the Western Netherlands



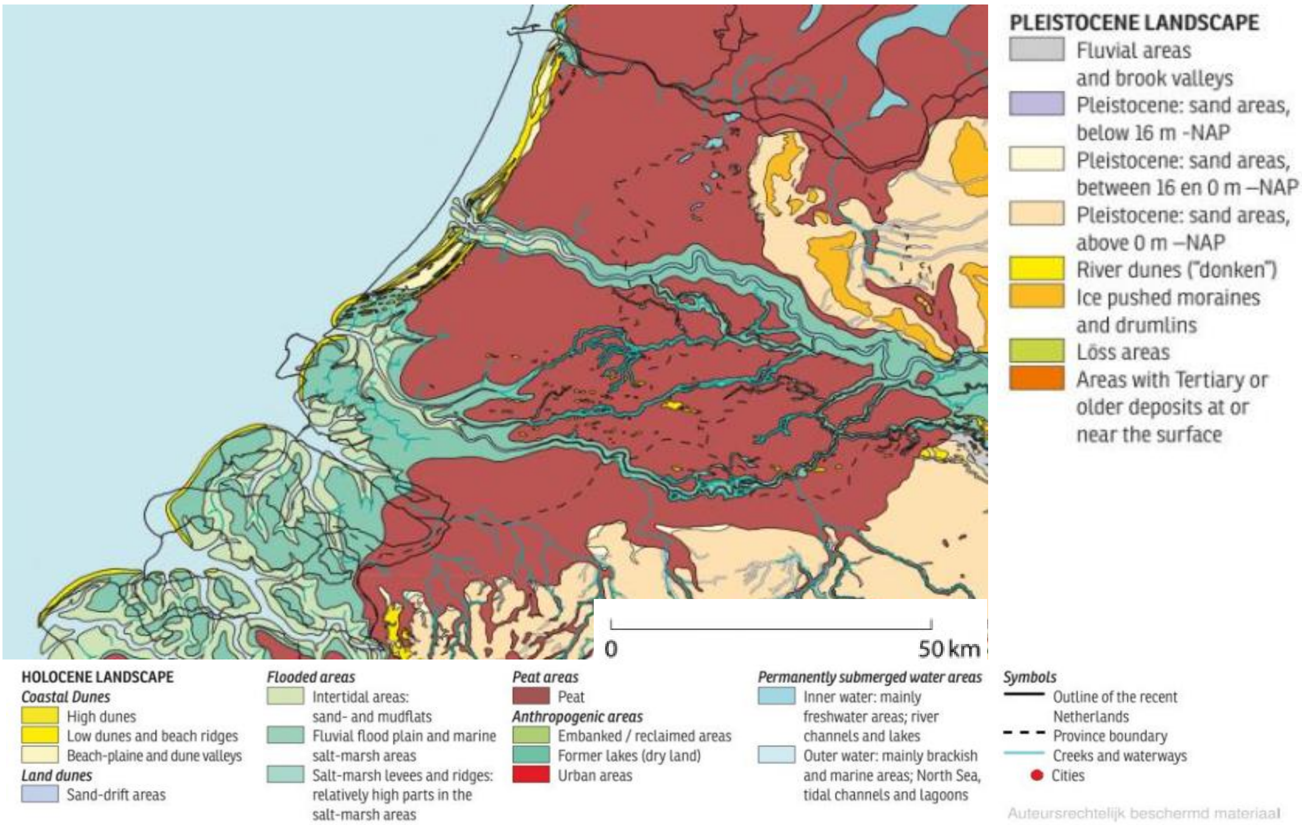
Appendix 6A Reconstruction of Pleistocene Landscape around 9000 BCE (adapted from Vos, 2015)



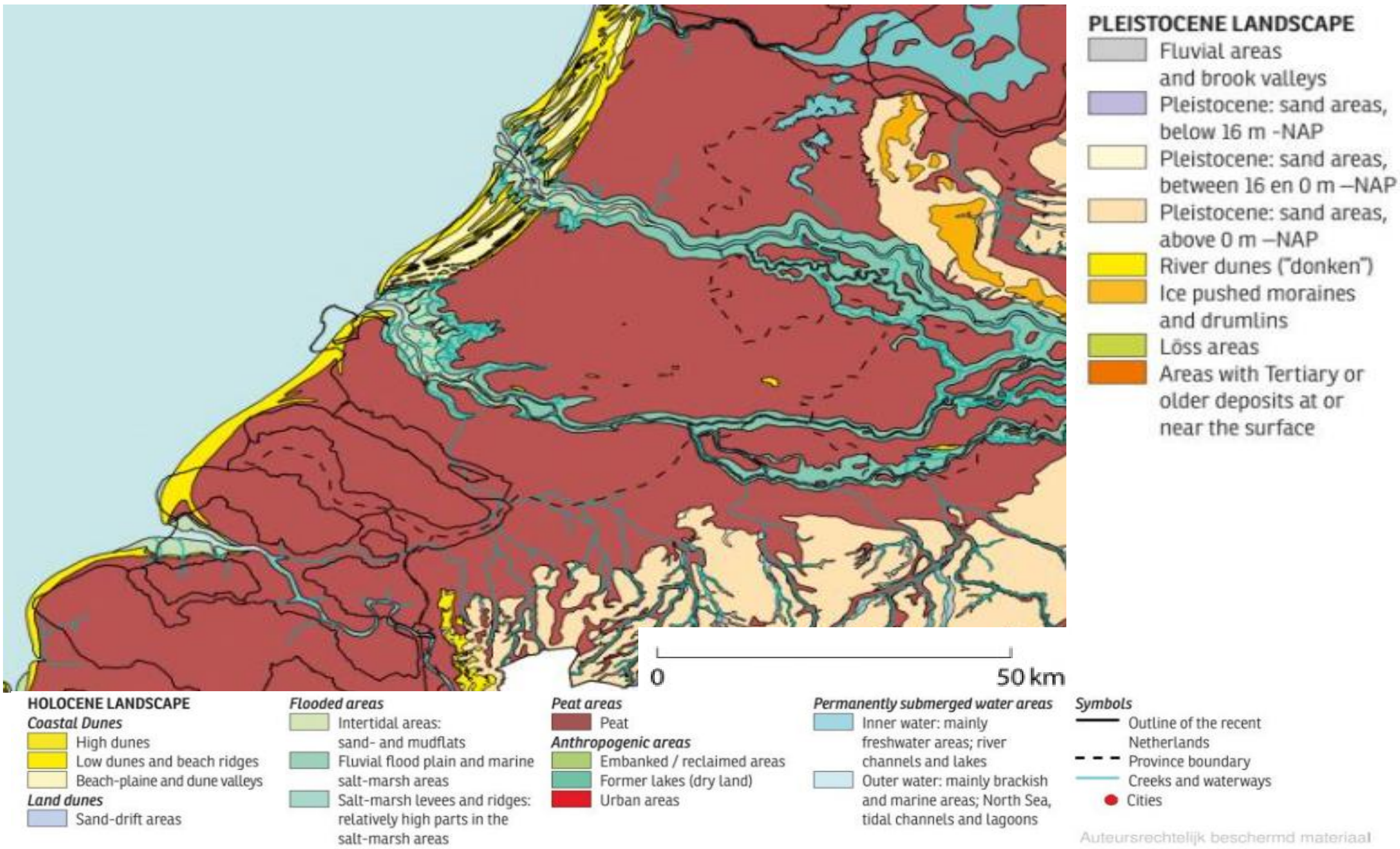
Appendix 6B Reconstruction of the Landscape around 5500 BCE (adapted from Vos, 2015)



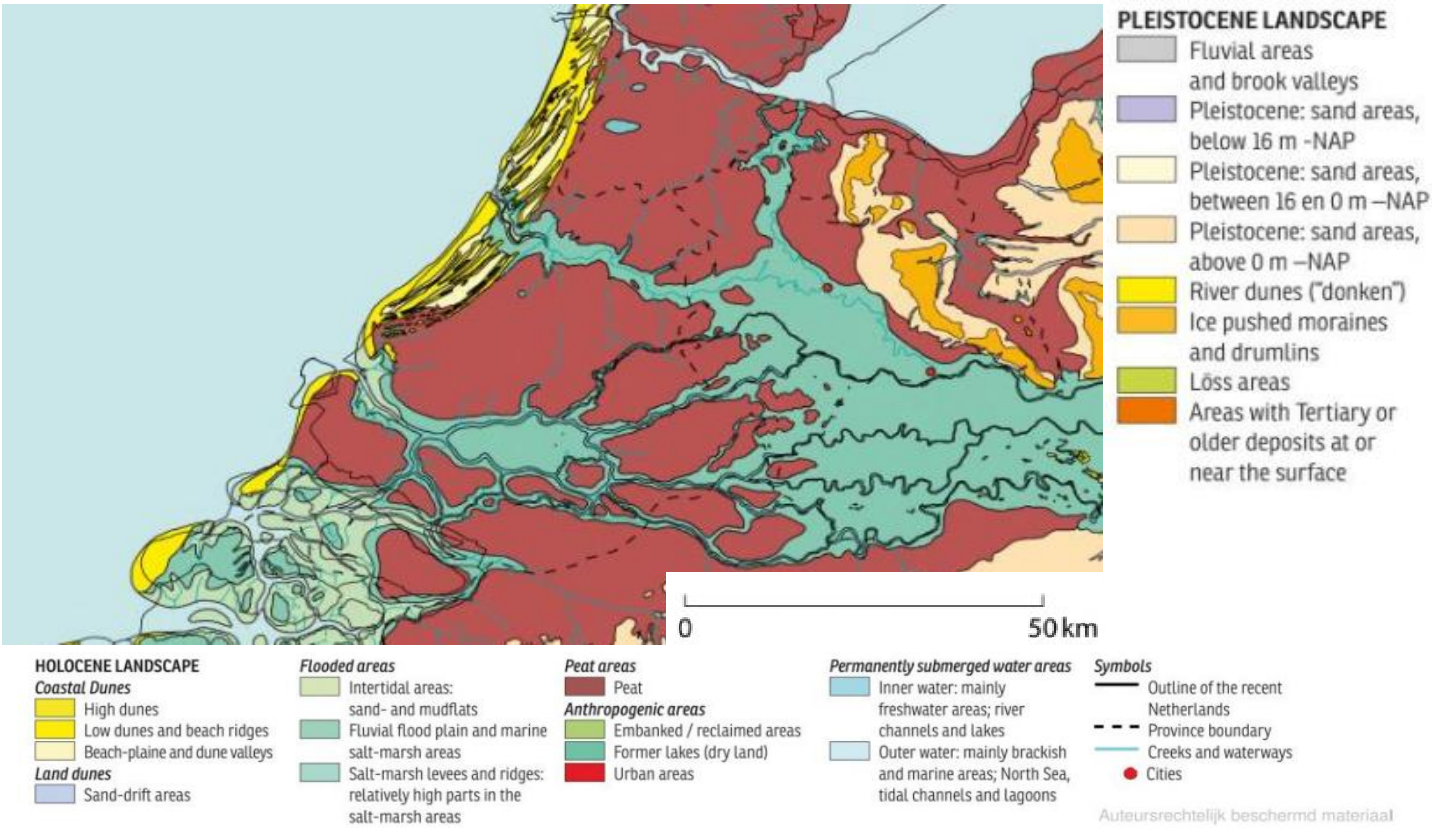
Appendix 6C Reconstruction of the Landscape around 3850 BCE (adapted from Vos, 2015)



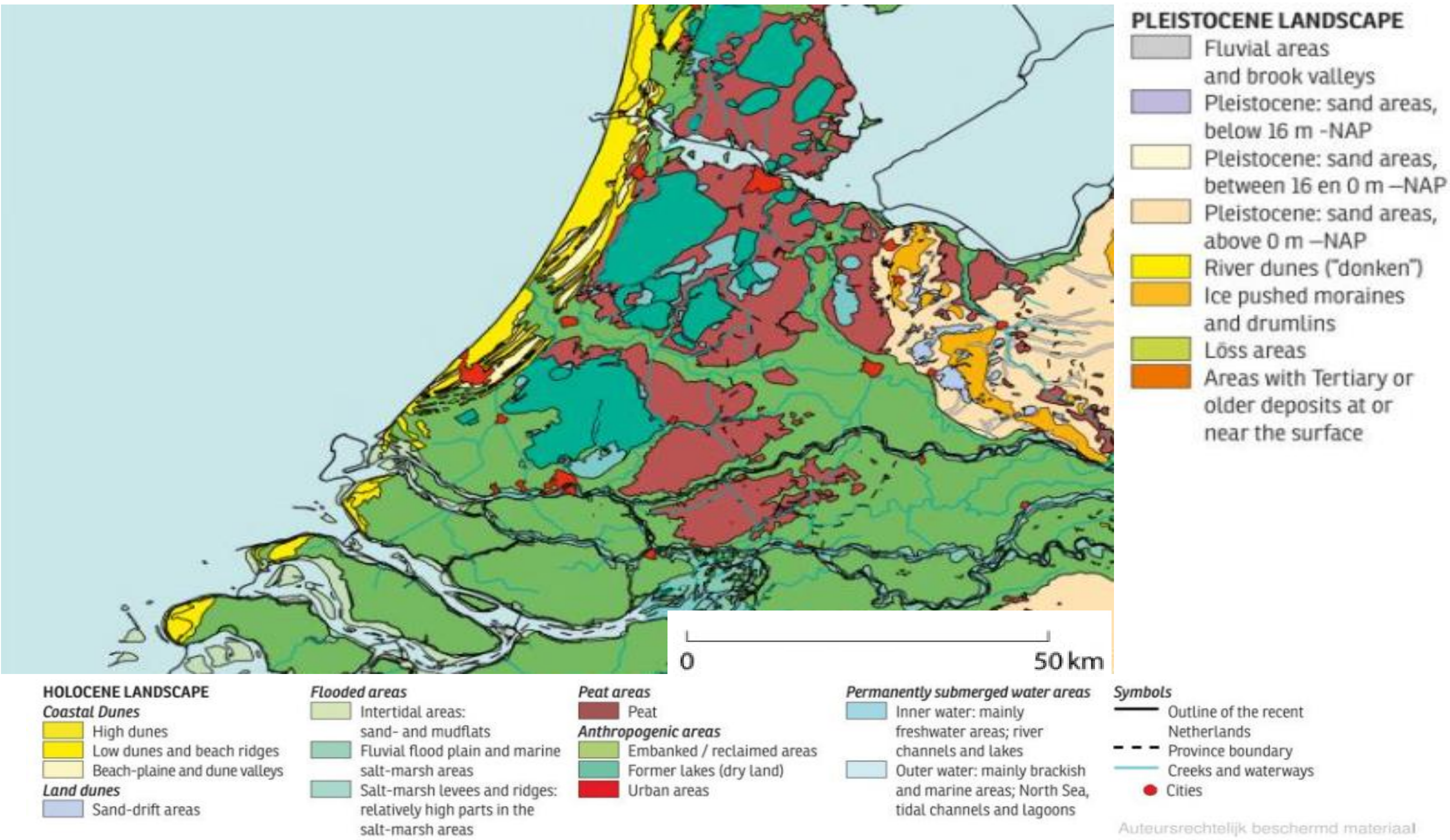
Appendix 6D Reconstruction of the Landscape around 2750 BCE (adapted from Vos, 2015)



Appendix 6E Reconstruction of the Landscape around 1500 BCE (adapted from Vos, 2015)



Appendix 6F Reconstruction of the Landscape around 800 CES (adapted from Vos, 2015)



Appendix 6G Reconstruction of the Landscape around 1850 CE (adapted from Vos, 2015)

Appendix 7 – Archeology

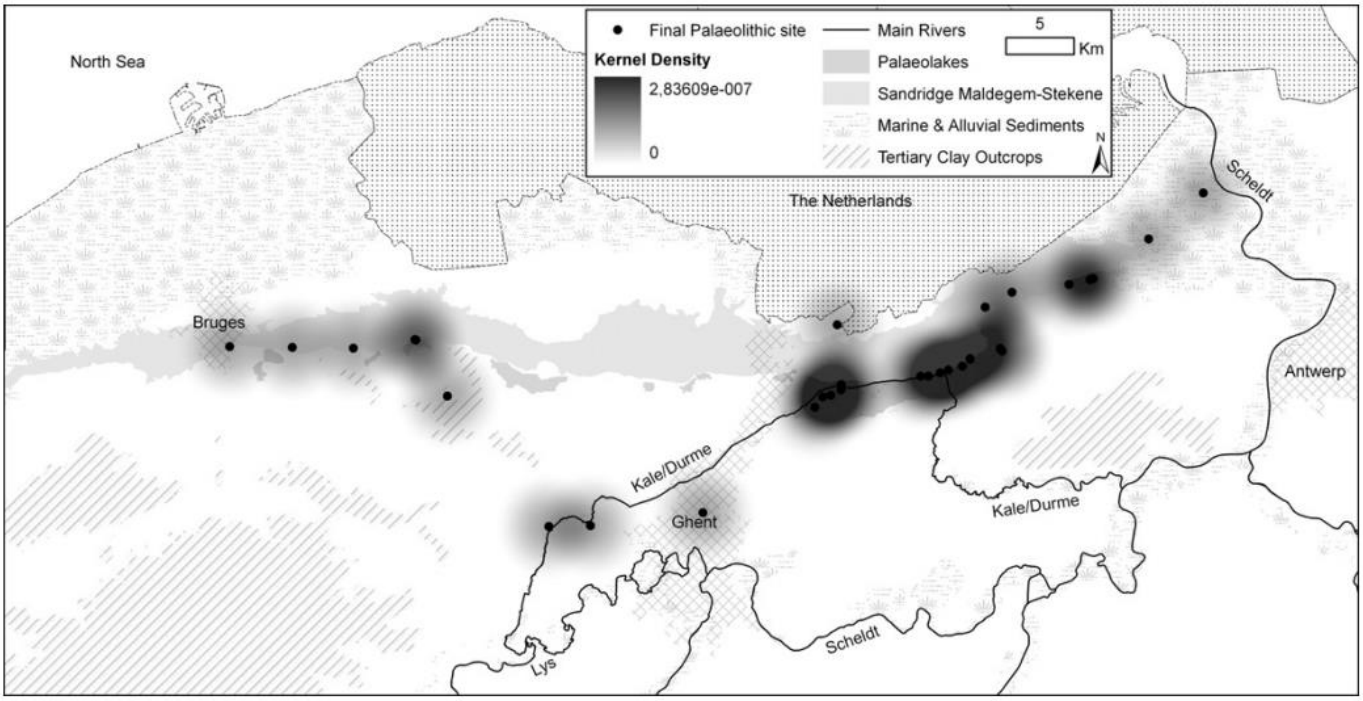


Figure 7A Spatial distribution of Final Palaeolithic sites (Federmesser Culture) using kernel density estimates (Crombé et al., 2011)

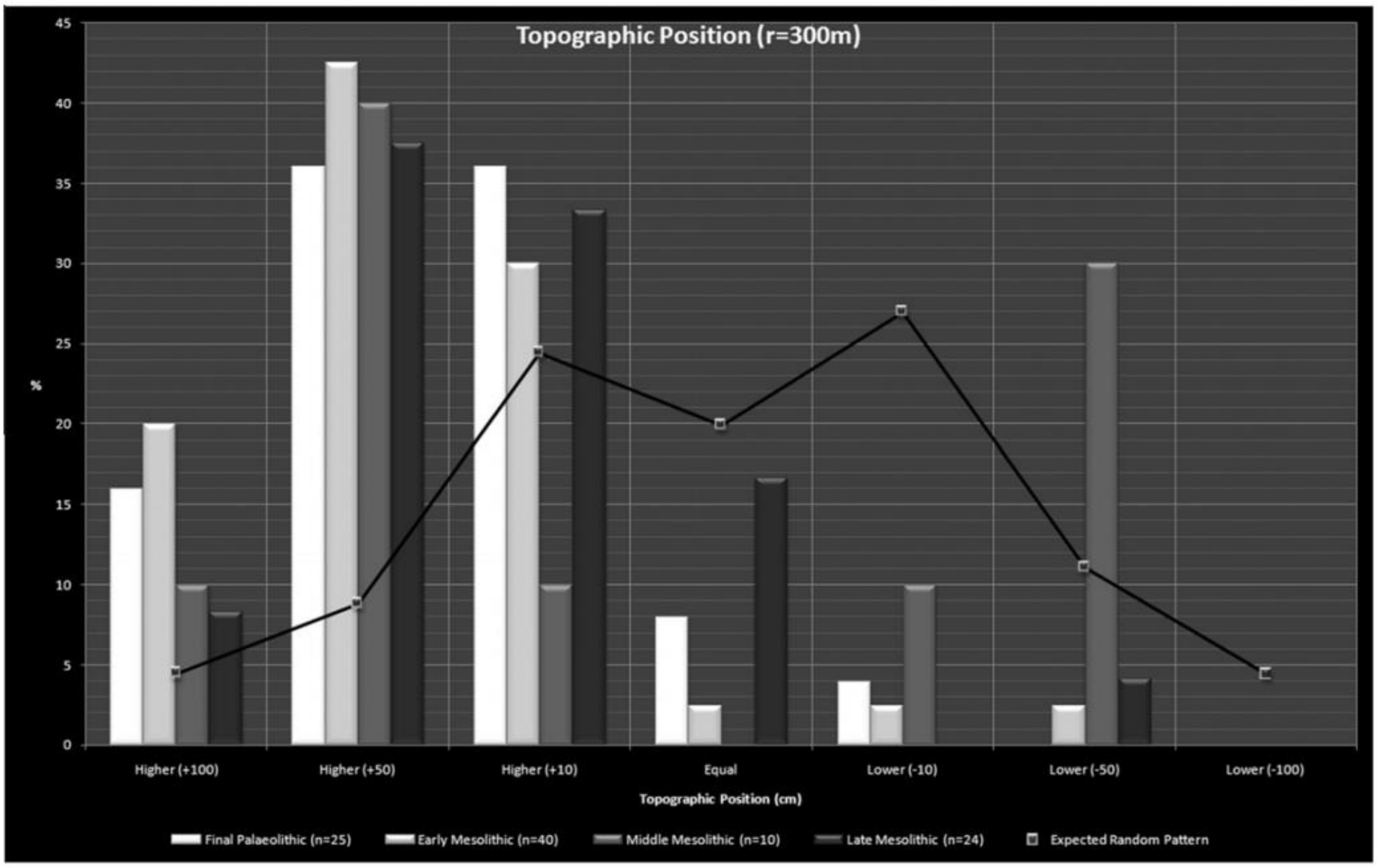


Figure 7B Spatial analysis of the topographical position (difference between the height at the site location and the average height of the surrounding areas, in this case within a radius of 300 m) of sites for each chronological stage, compared with the expected ramdom pattern (generated out of 100 sets of random distributed points) (Crombé et al., 2011)

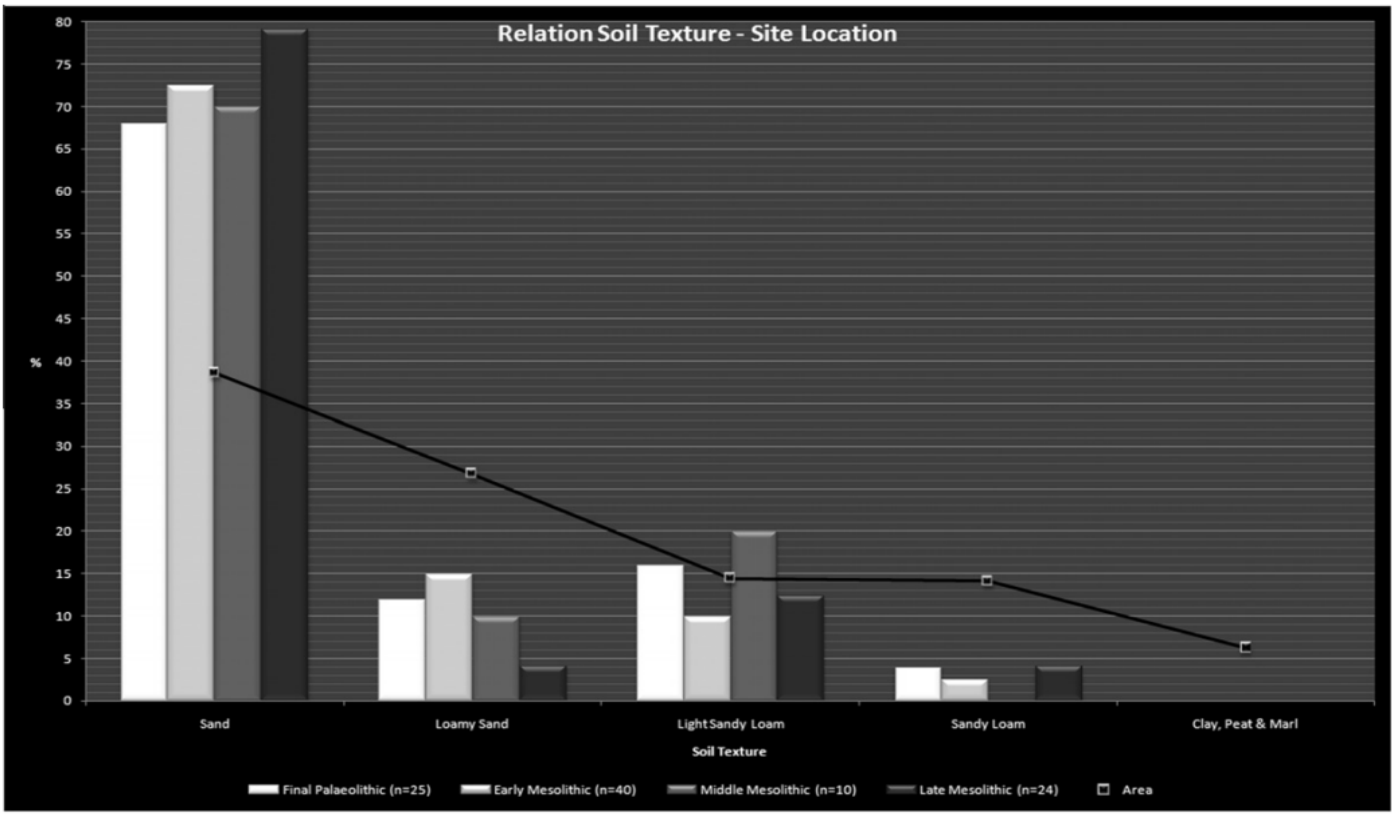


Figure 7C Spatial analysis of soil texture of sites for each chronological stage, compared with the expected ramdom pattern (generated out of 100 sets of random distributed points) (Crombé et al., 2011)

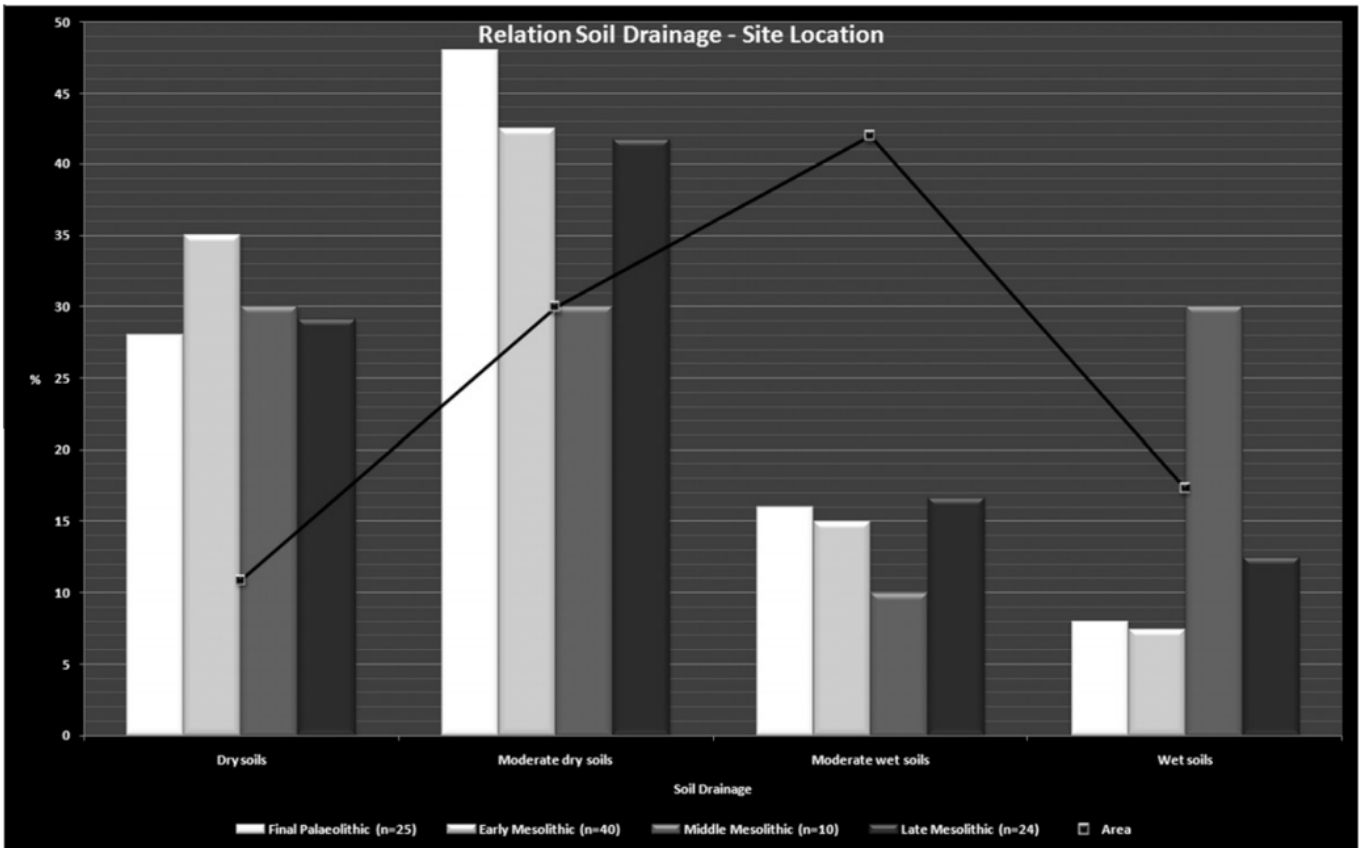


Figure 7D Spatial analysis of soil drainage of sites for each chronological stage, compared with the expected ramdom pattern (generated out of 100 sets of random distributed points) (Crombé et al., 2011)

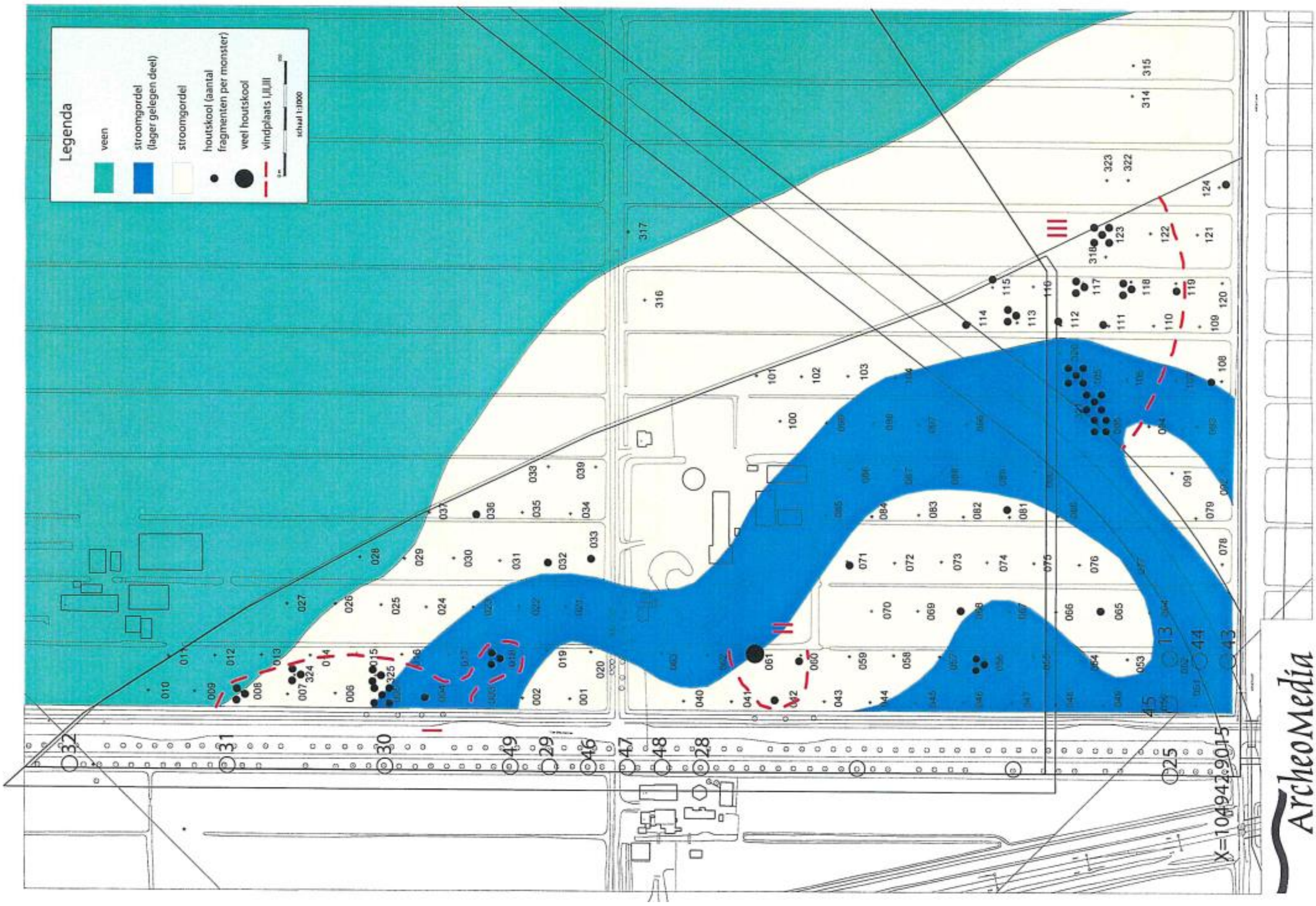
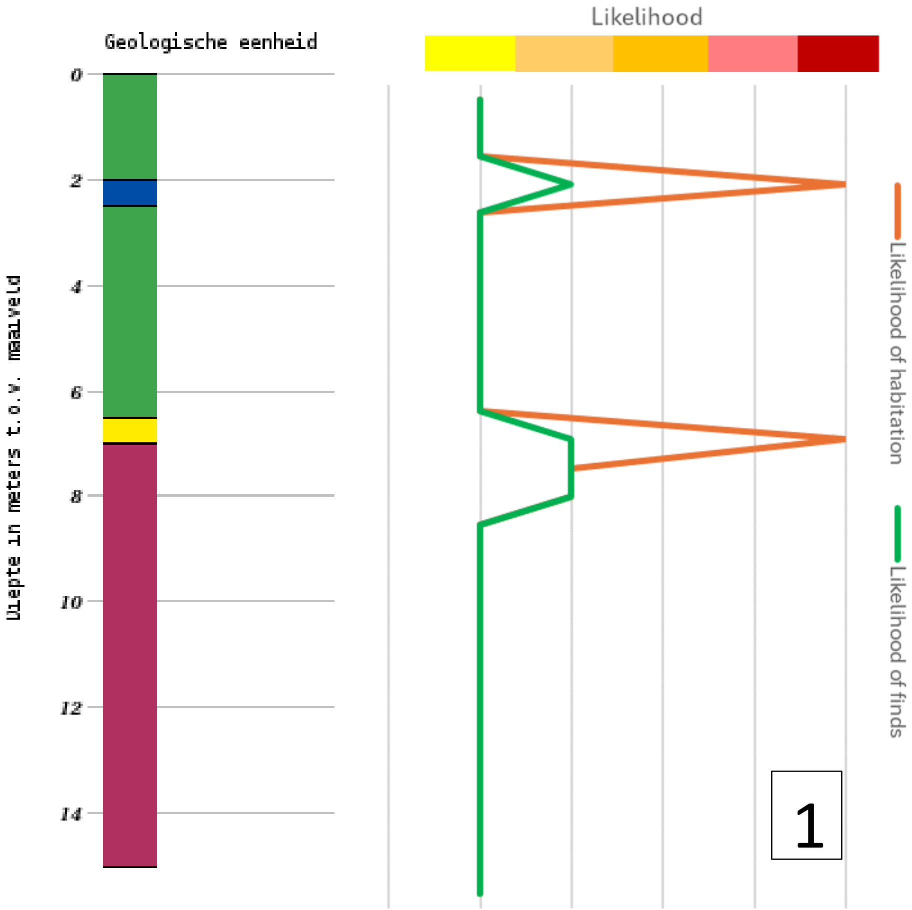


Figure 7E Auguring resulst of the Moordrechtse Tiendeweg with the charcoal remains (Dasselaar et al., 2005).

Appendix 7 – Model output

Legend

- Anthropogenic deposits
- Nieuwkoop Formation, Holland peat
- Naaldwijk Formation, Wormer Member
- Echteld Formation
- Naaldwijk Formation, Wormer Member
- Echteld Formation
- Nieuwkoop Formation, Basal peat
- Boxtel Formation, Wierden Member
- Krefteheye Formation, Wijchen Member
- Krefteheye Formation


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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Likelihood of habitation
Likelihood of finds
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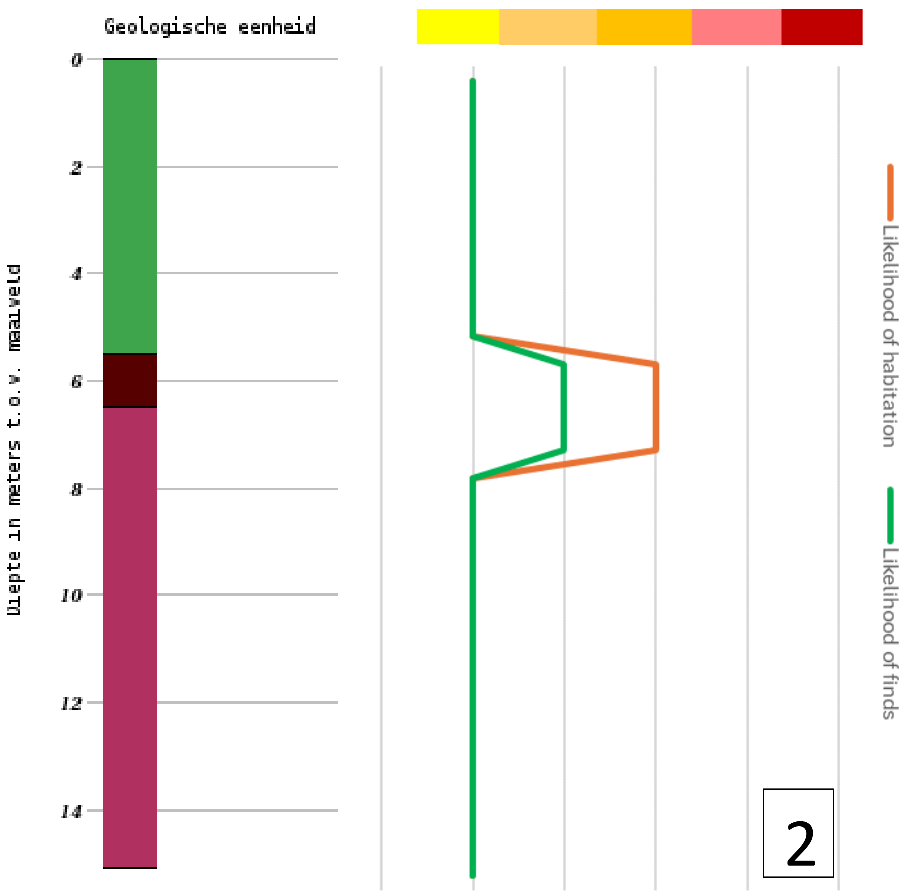
Geologische eenheid
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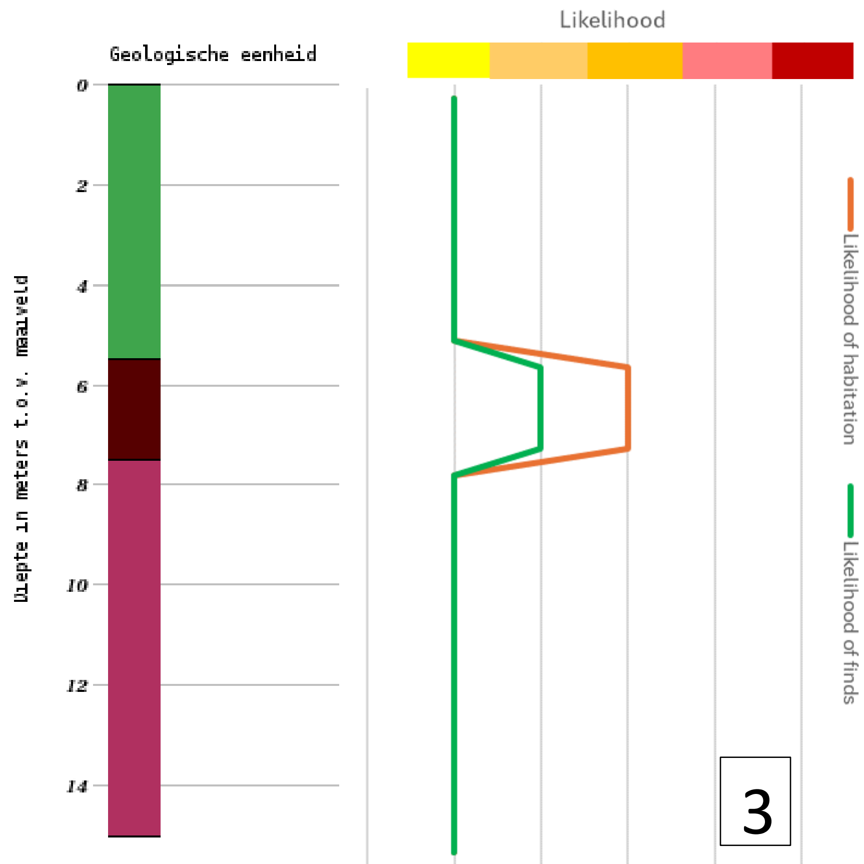

Likelihood
Geologische eenheid
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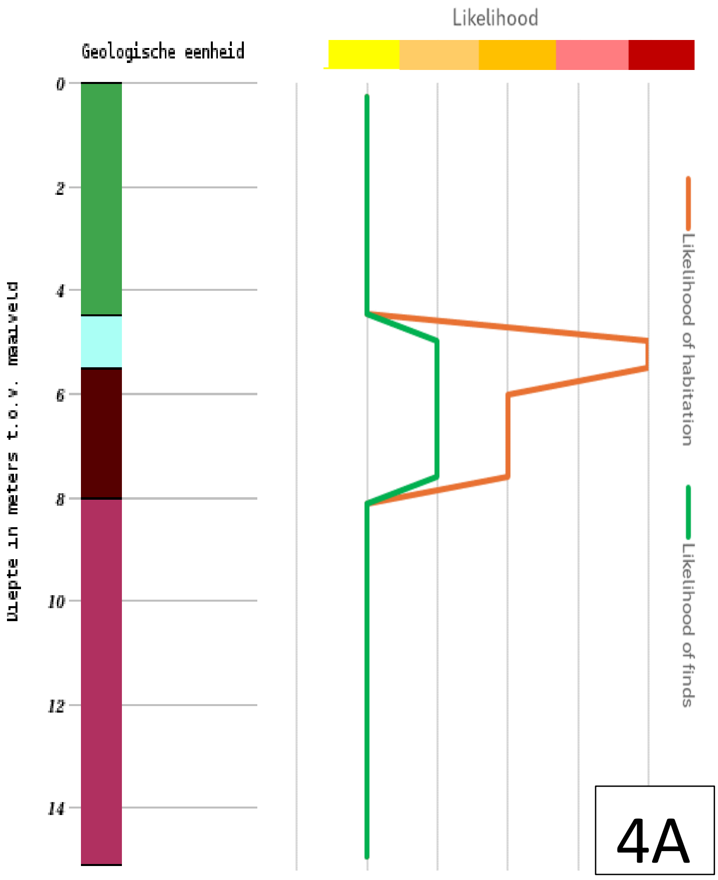

Likelihood
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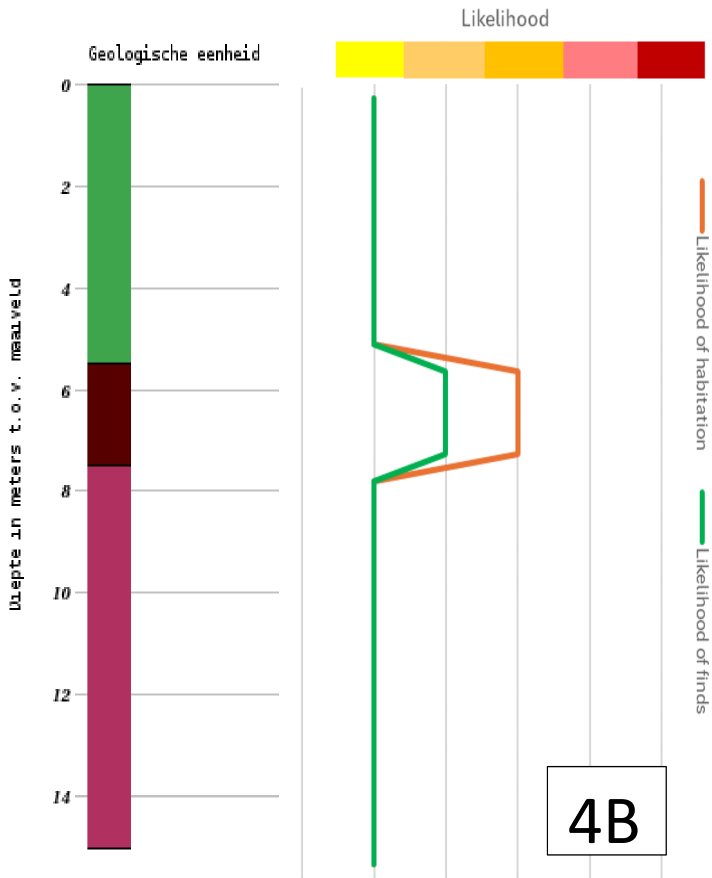

Likelihood
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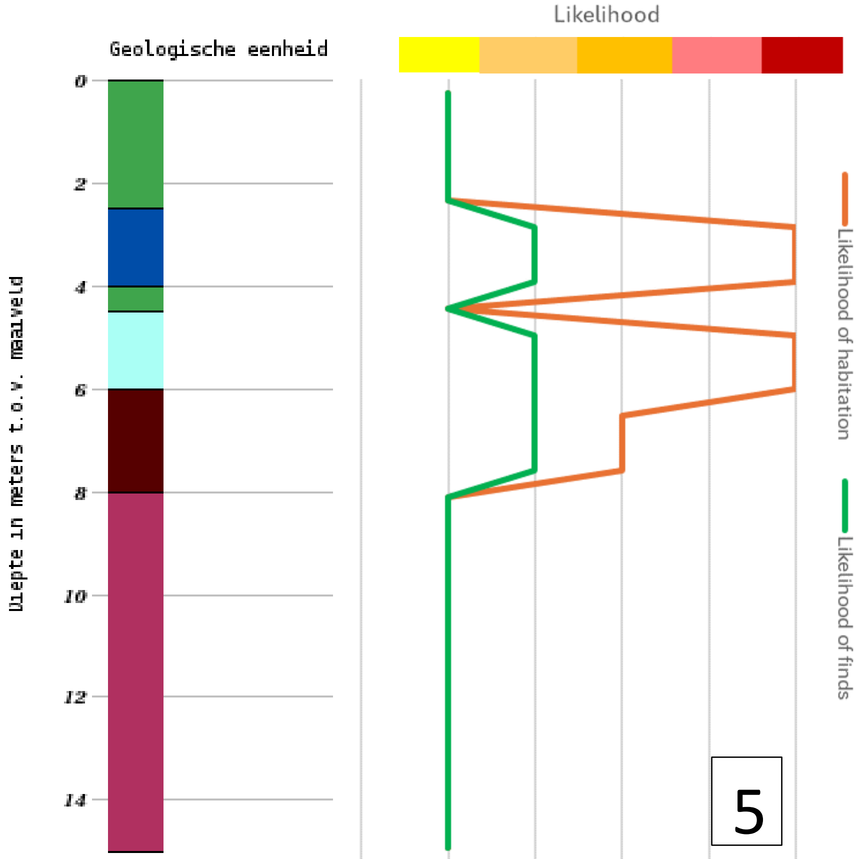
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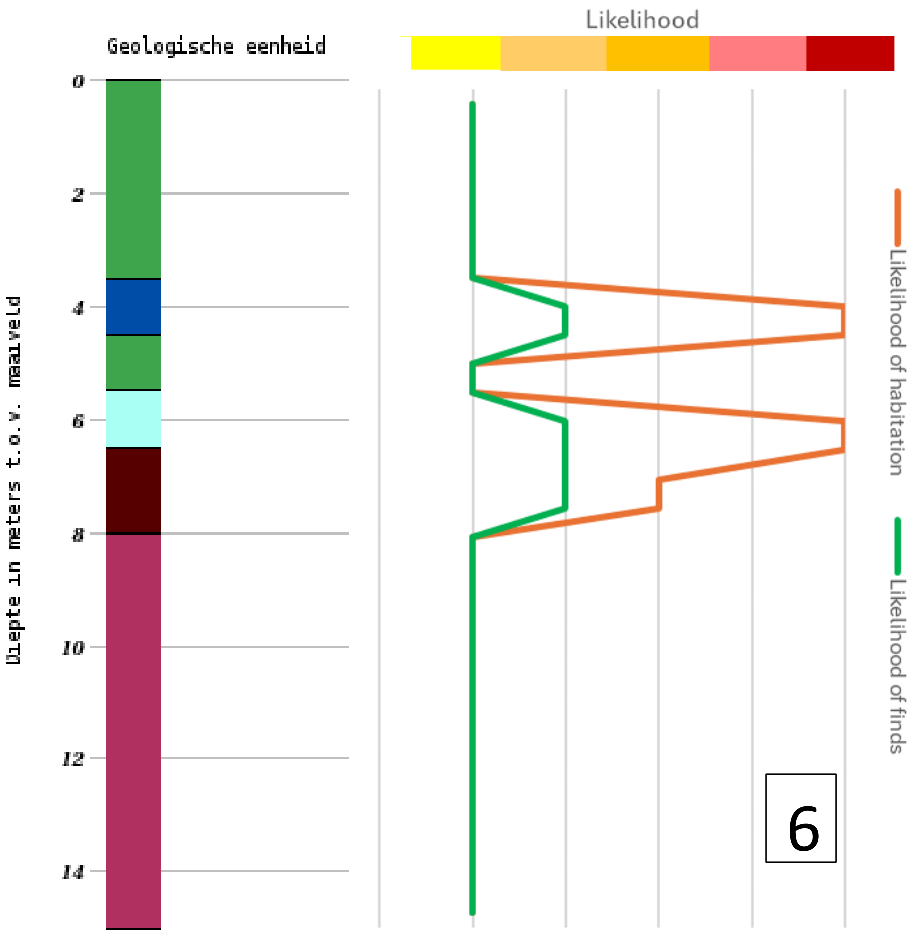
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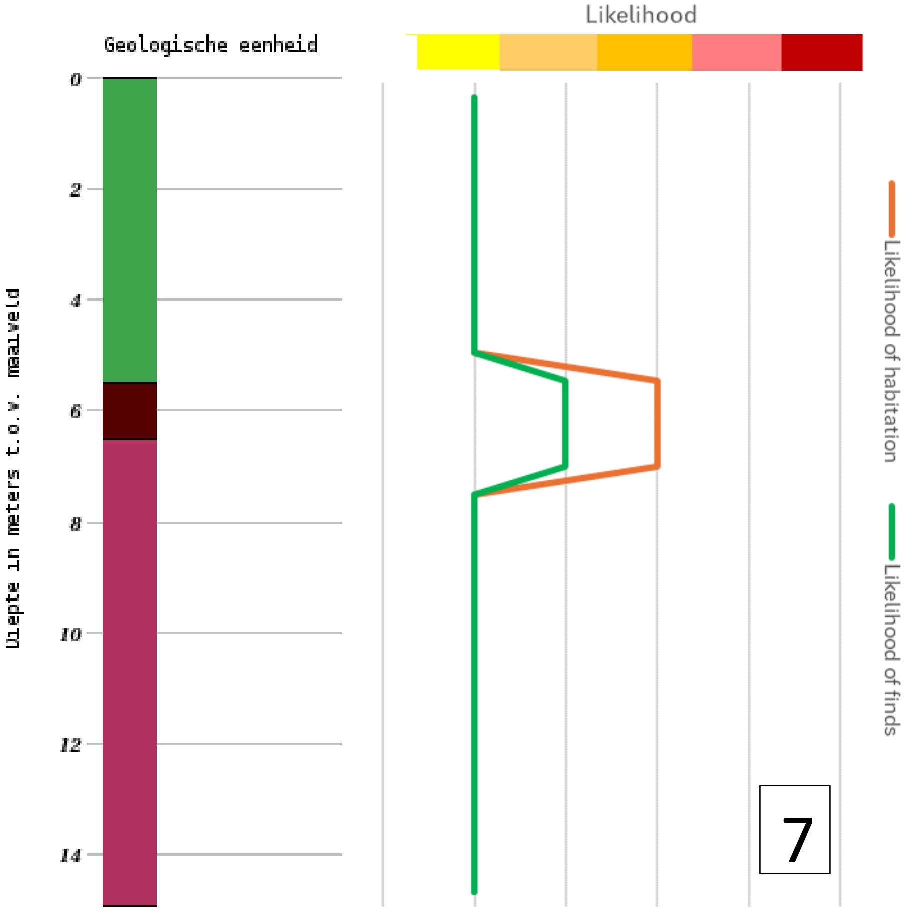

Geologische eenheid
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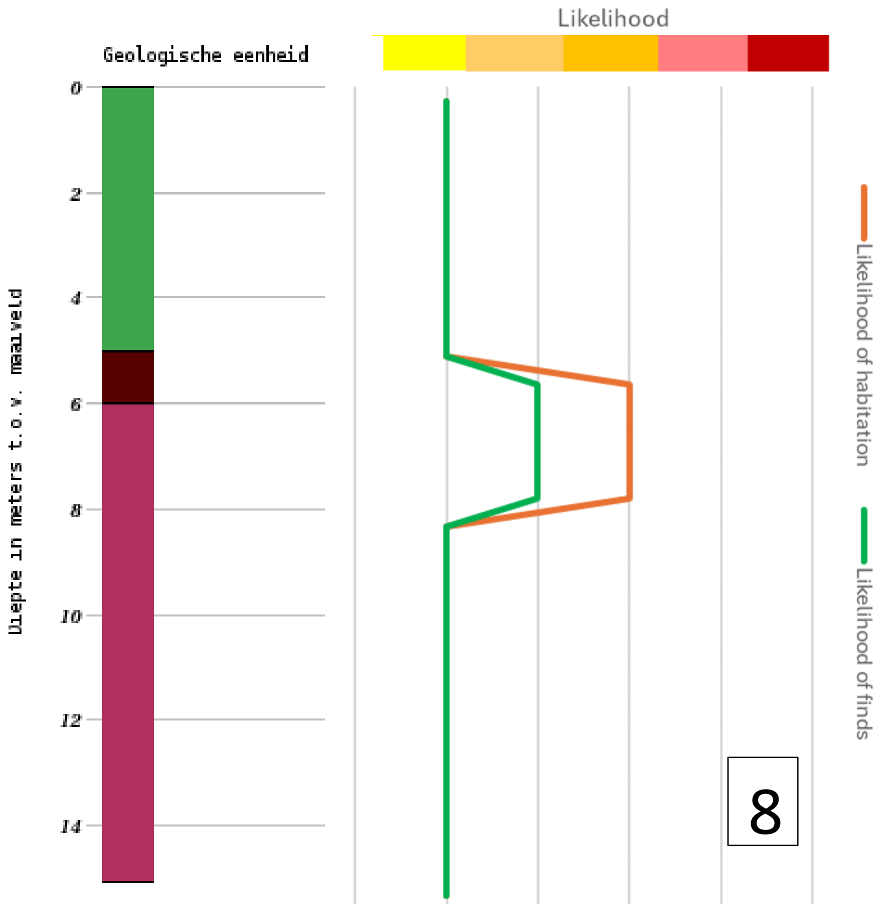

Geologische eenheid
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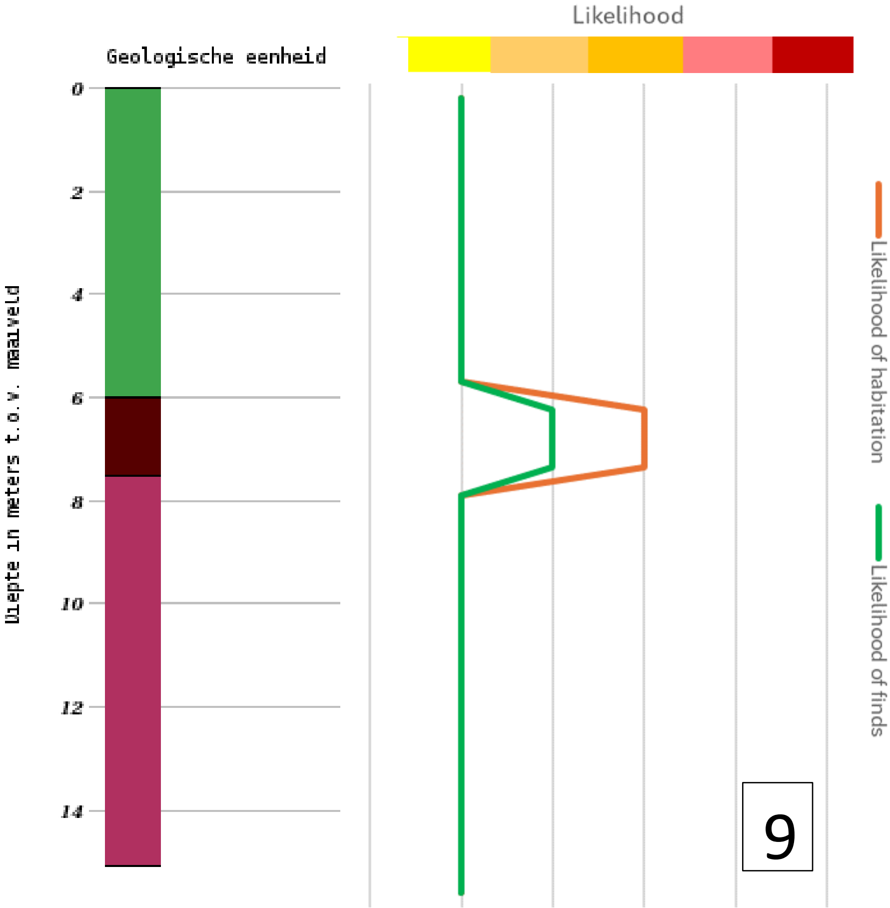
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Geologische eenheid
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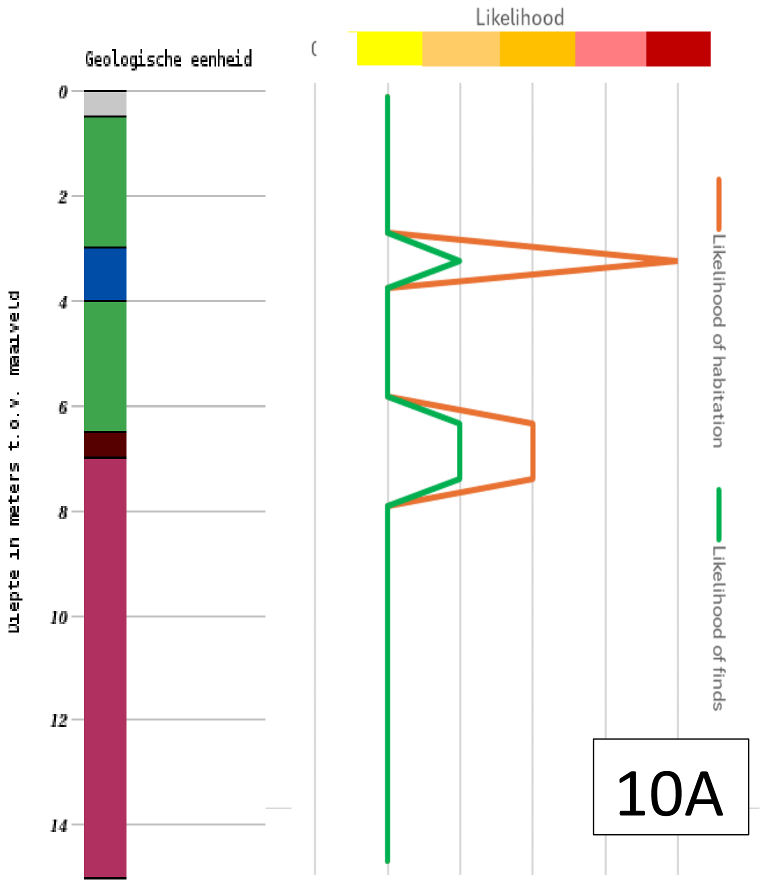
Likelihood
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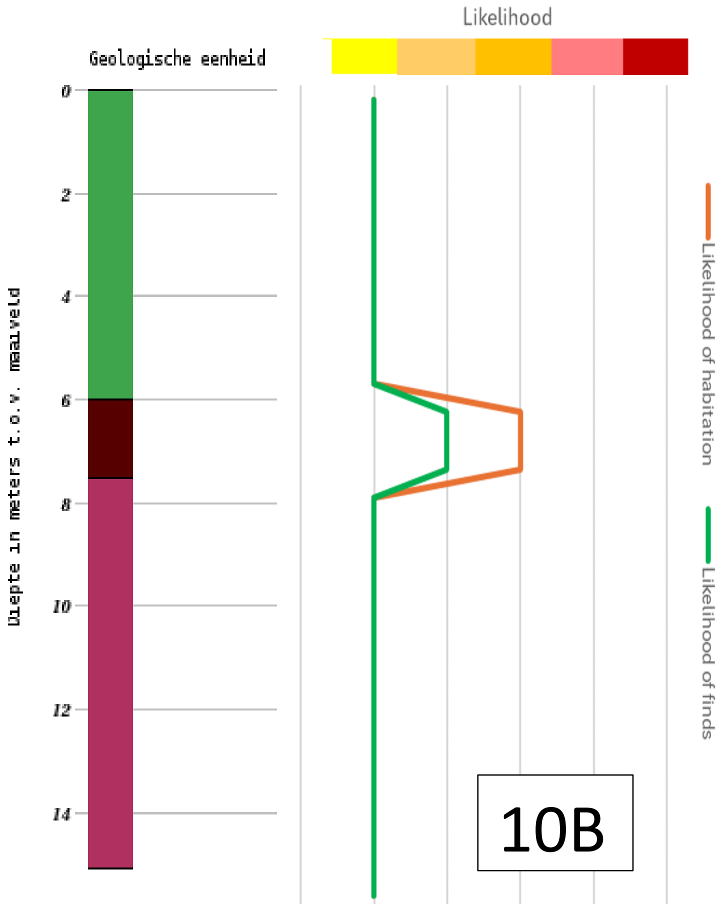
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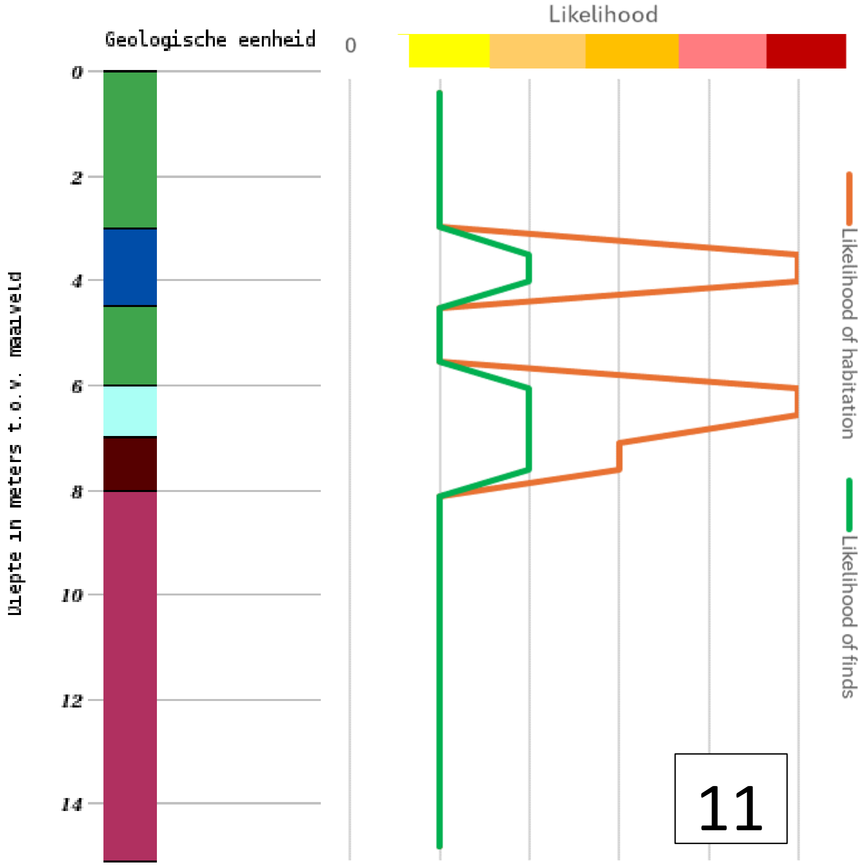
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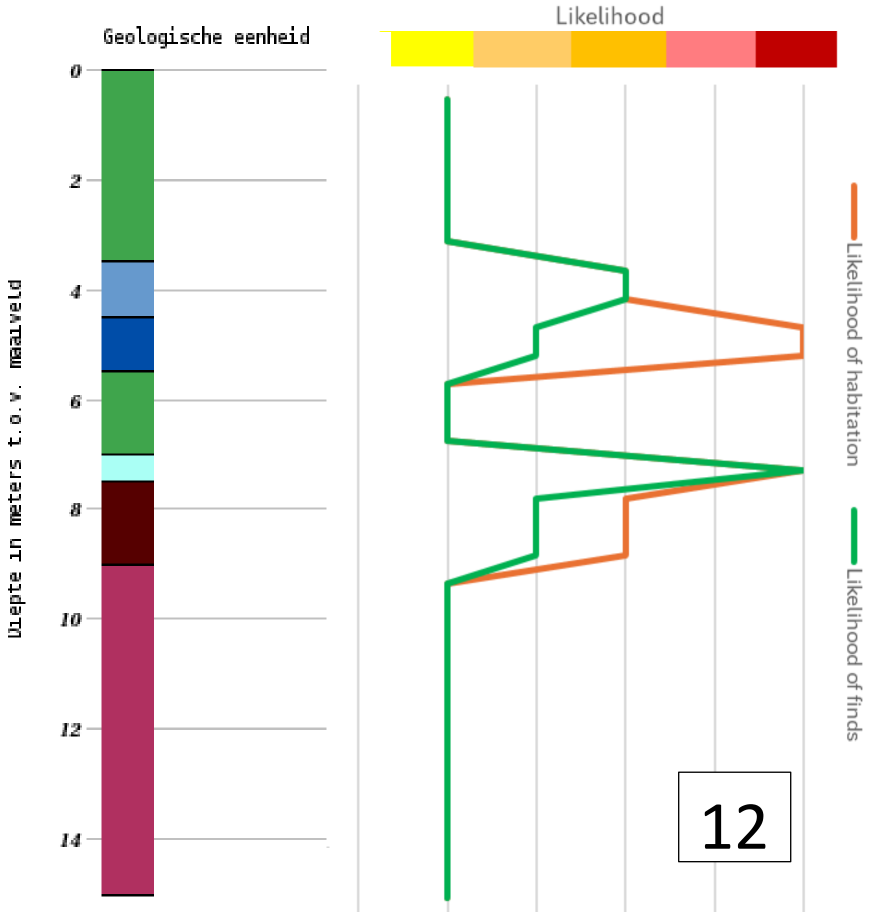
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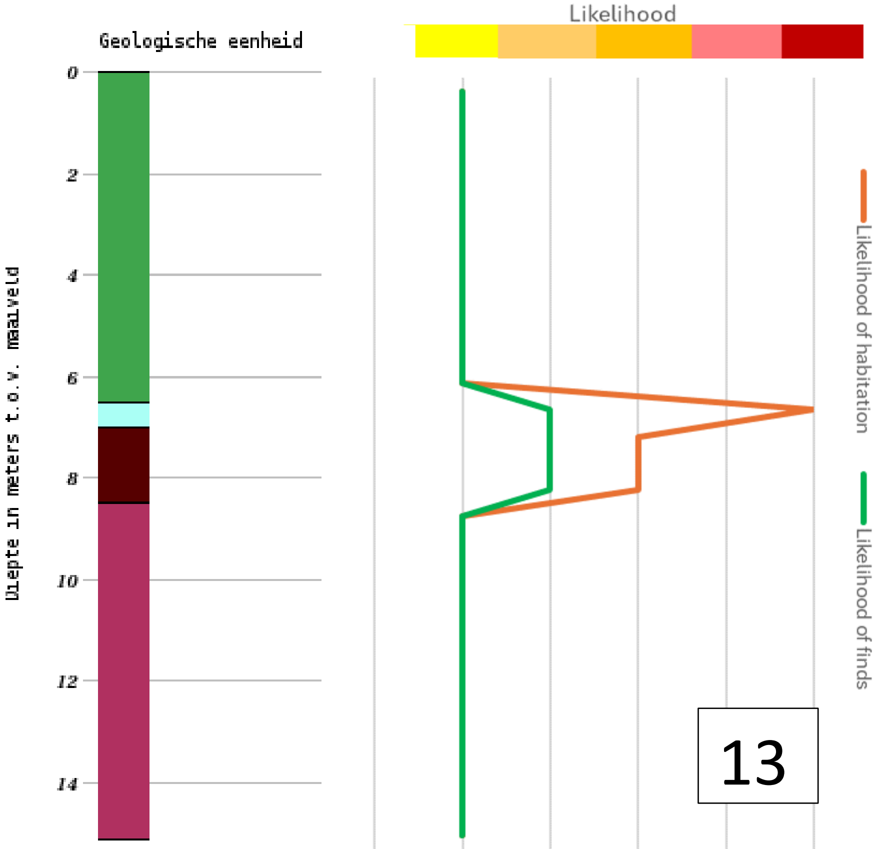
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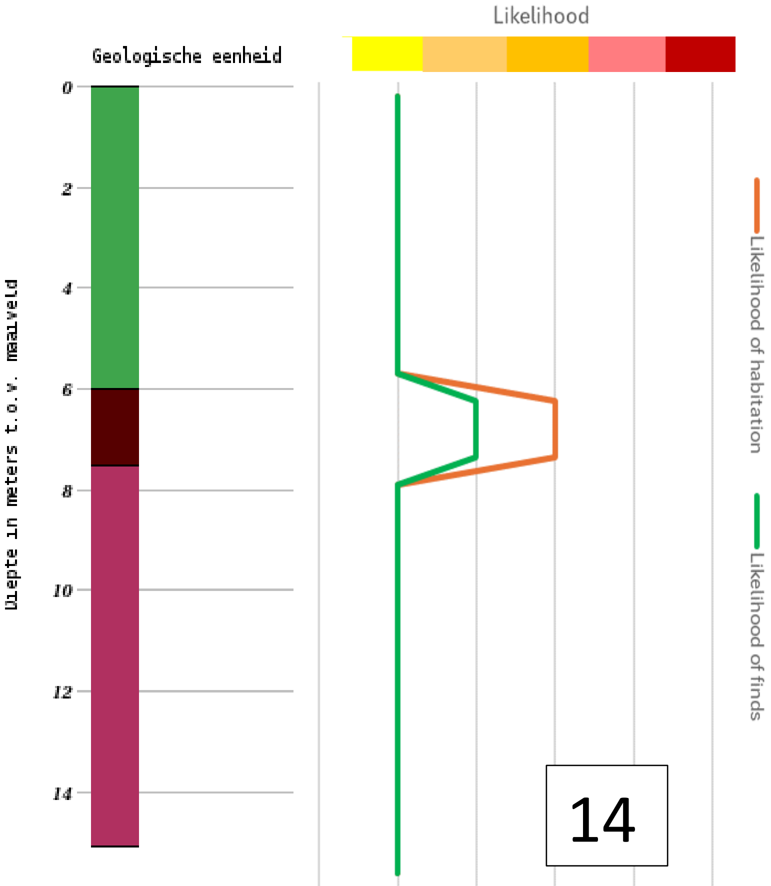
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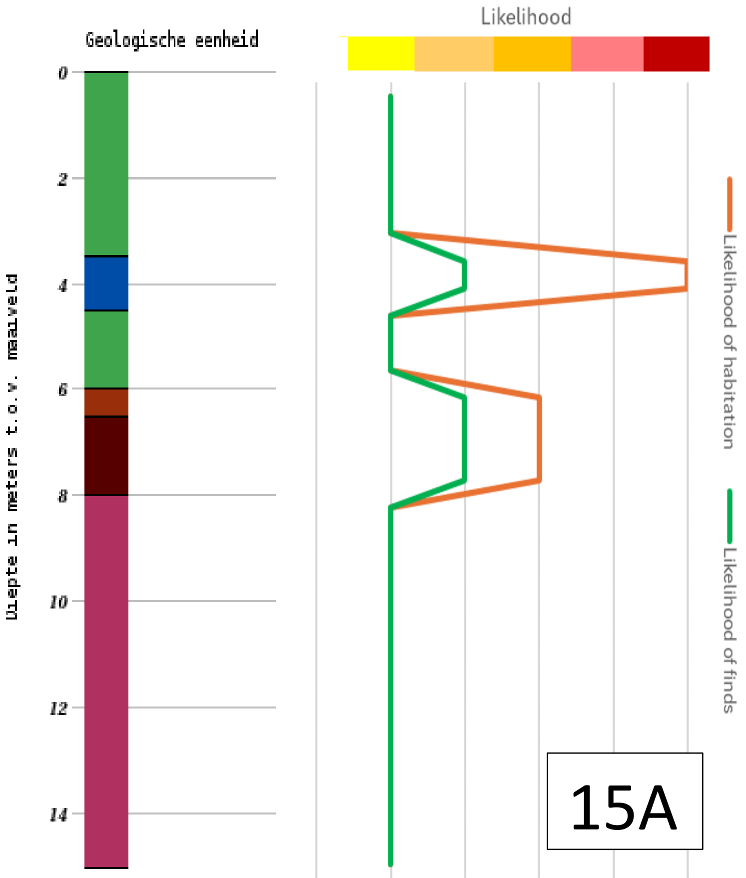
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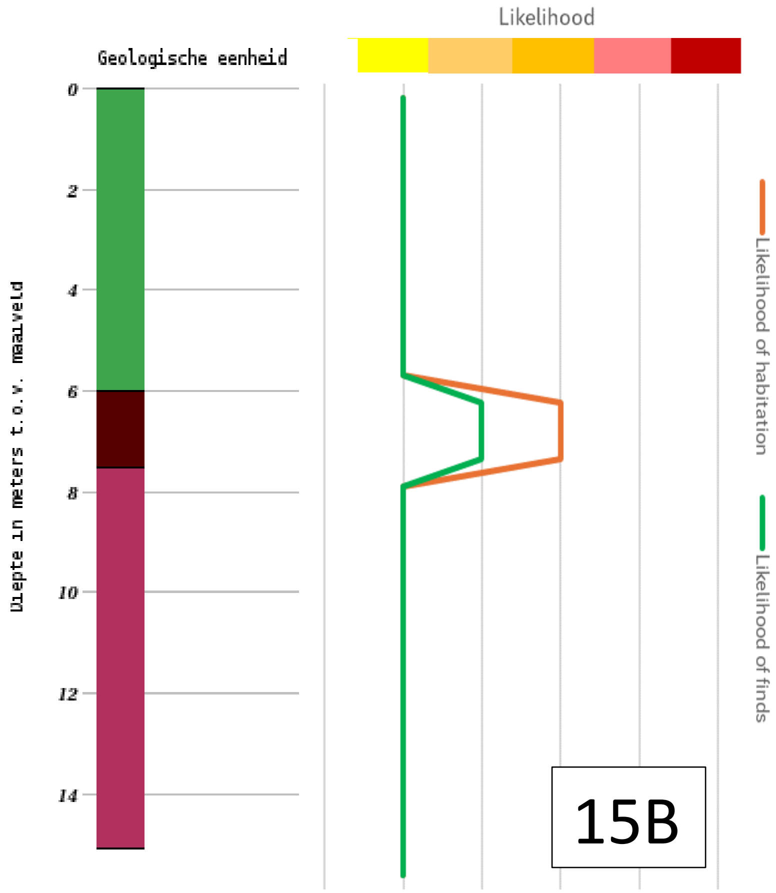
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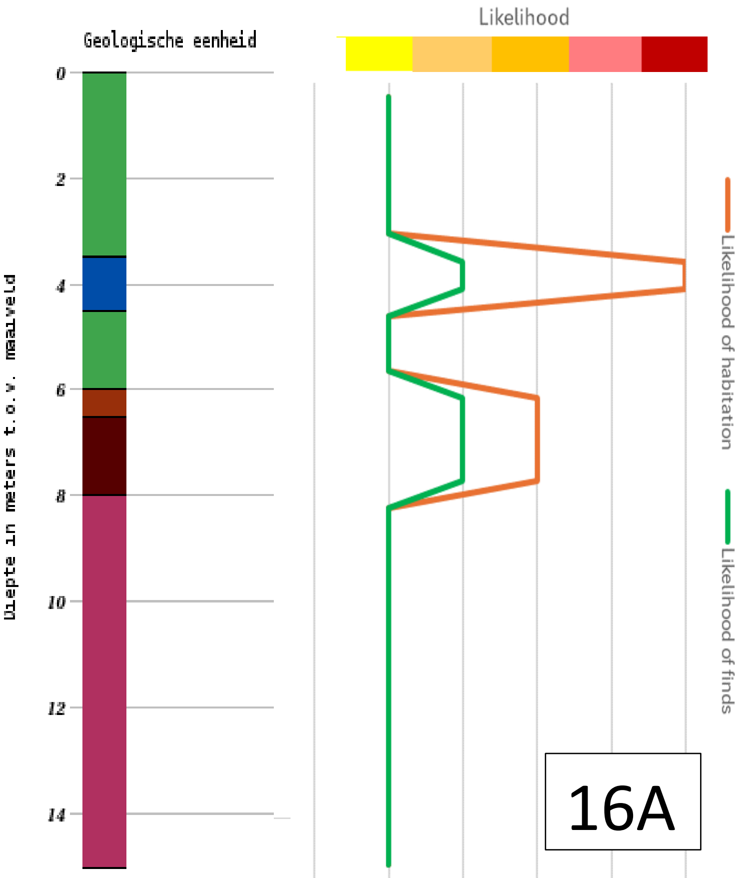
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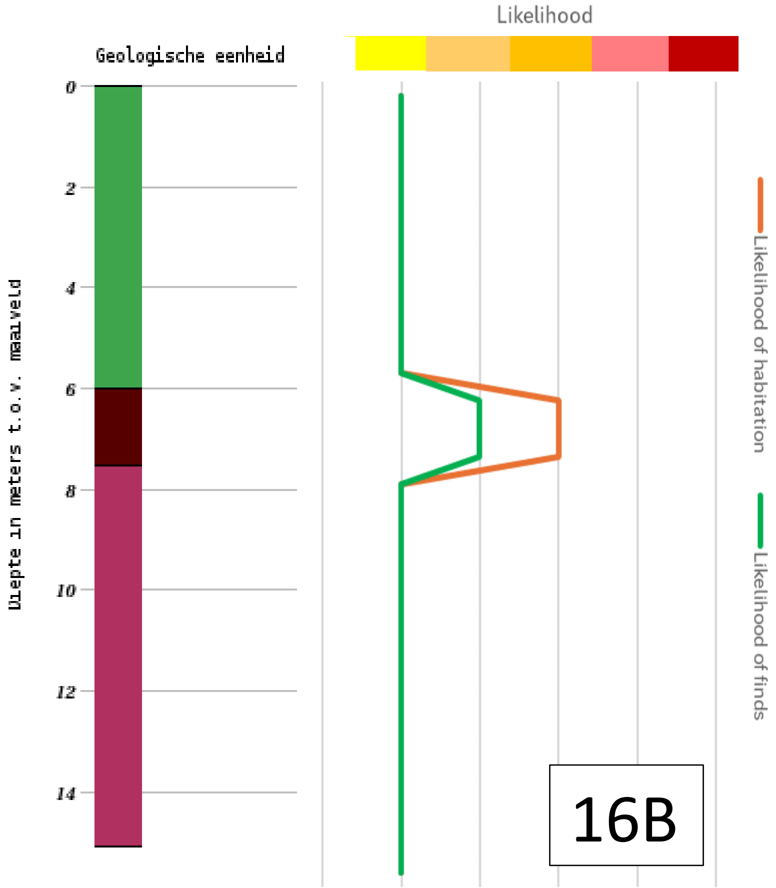
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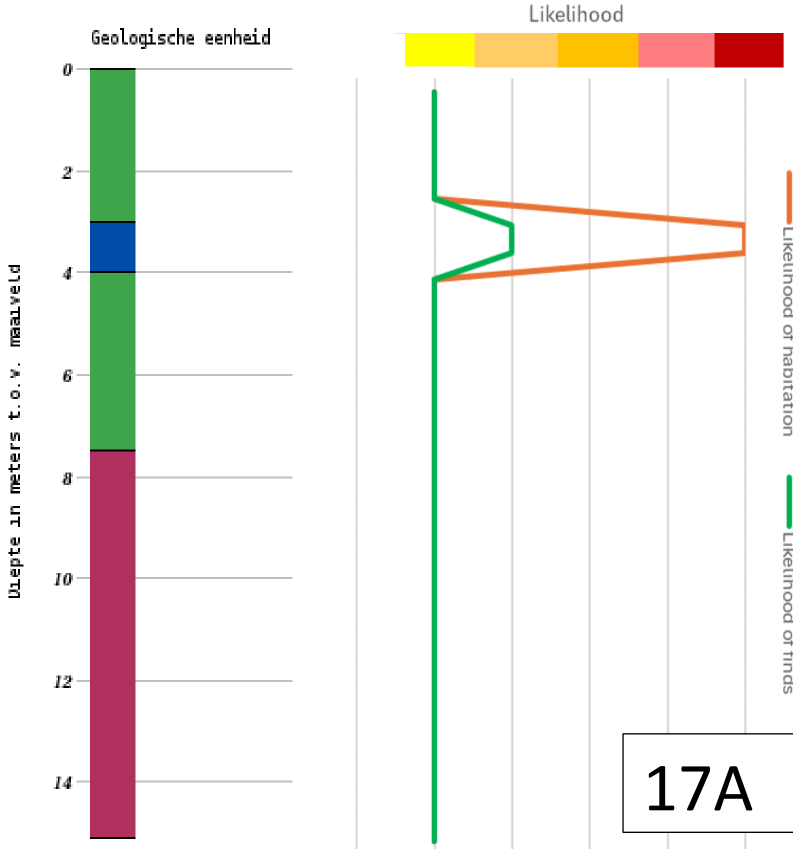
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Likelihood of habitation
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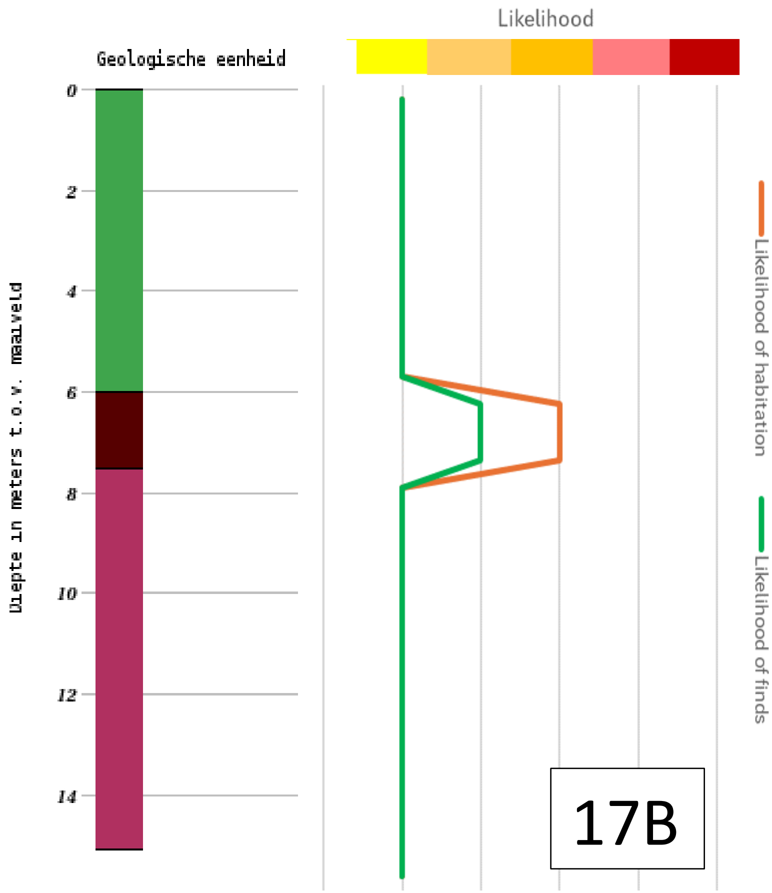
Geologische eenheid
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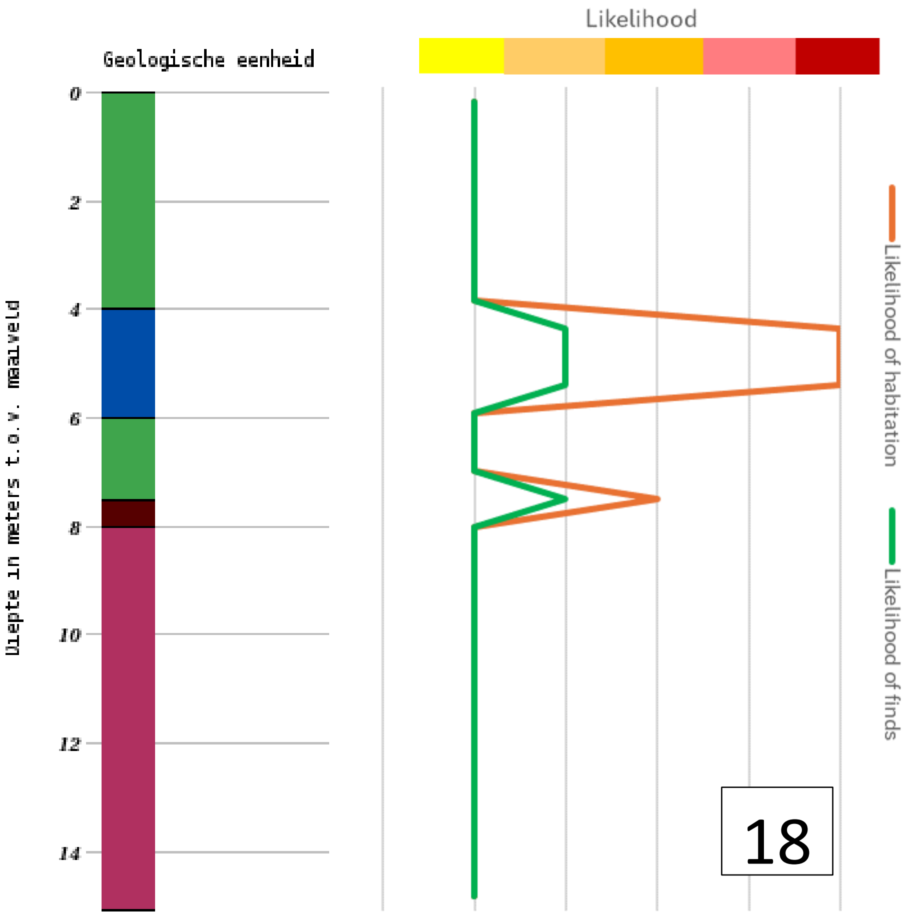
Geologische eenheid
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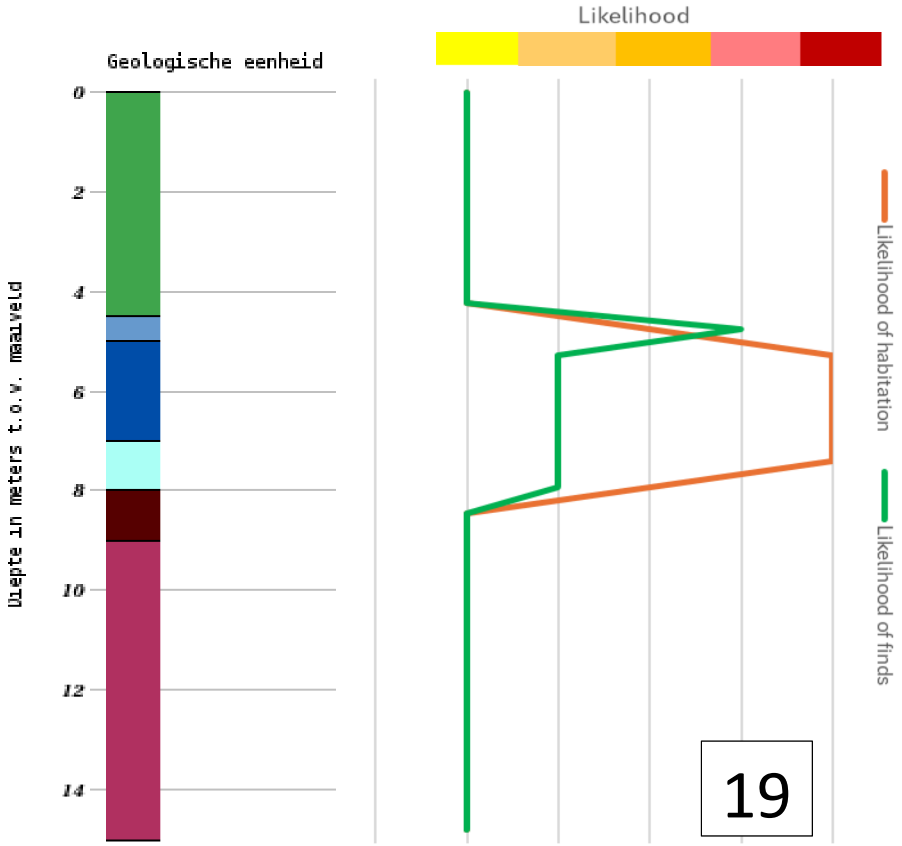
Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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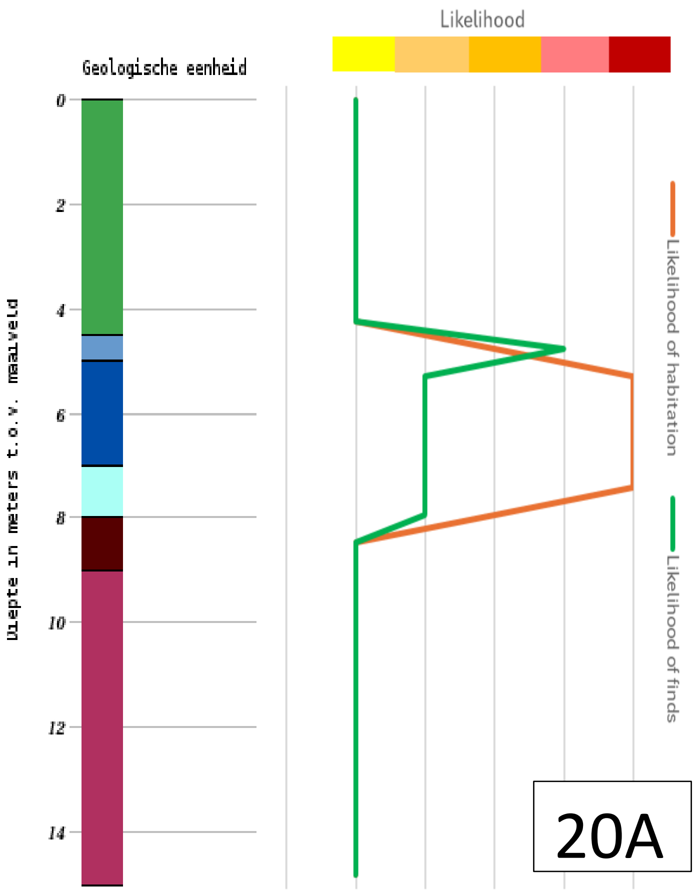
Likelihood of habitation
Likelihood of finds
19


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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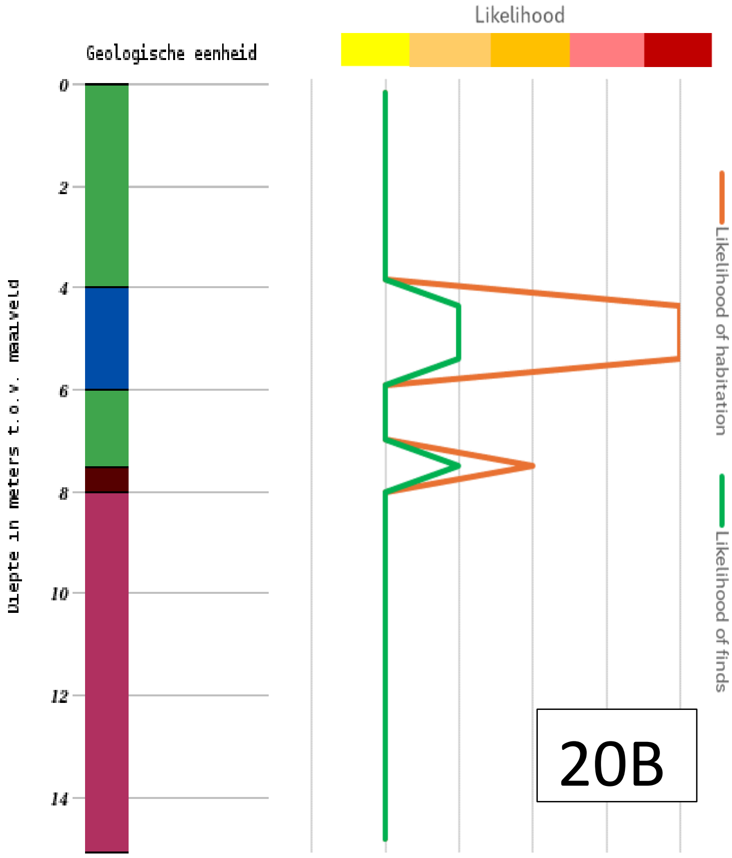
14
Likelihood of habitation
Likelihood of finds
20A


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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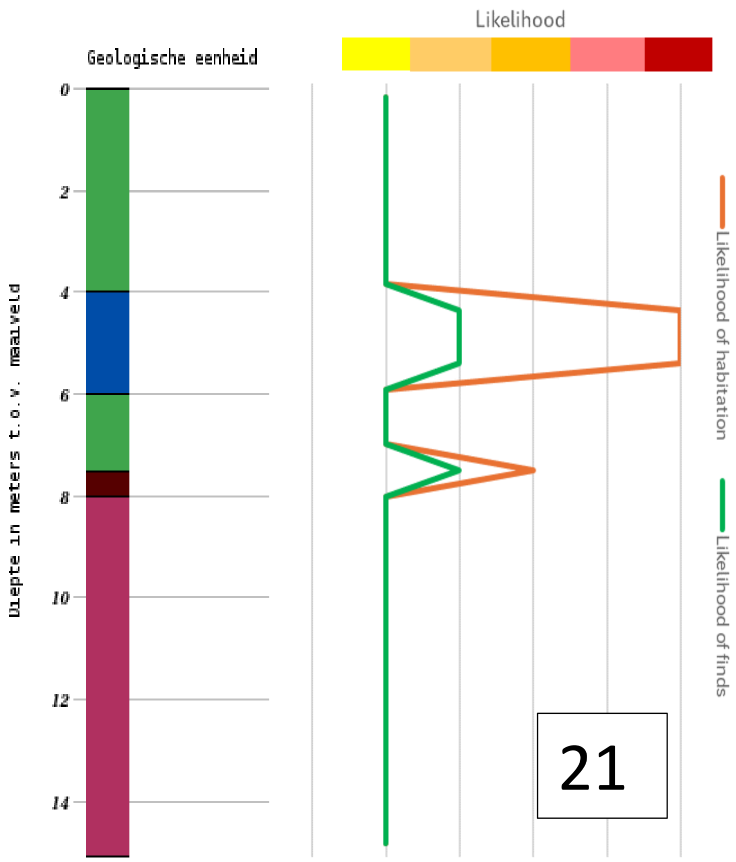
14
Likelihood of habitation
Likelihood of finds
20B


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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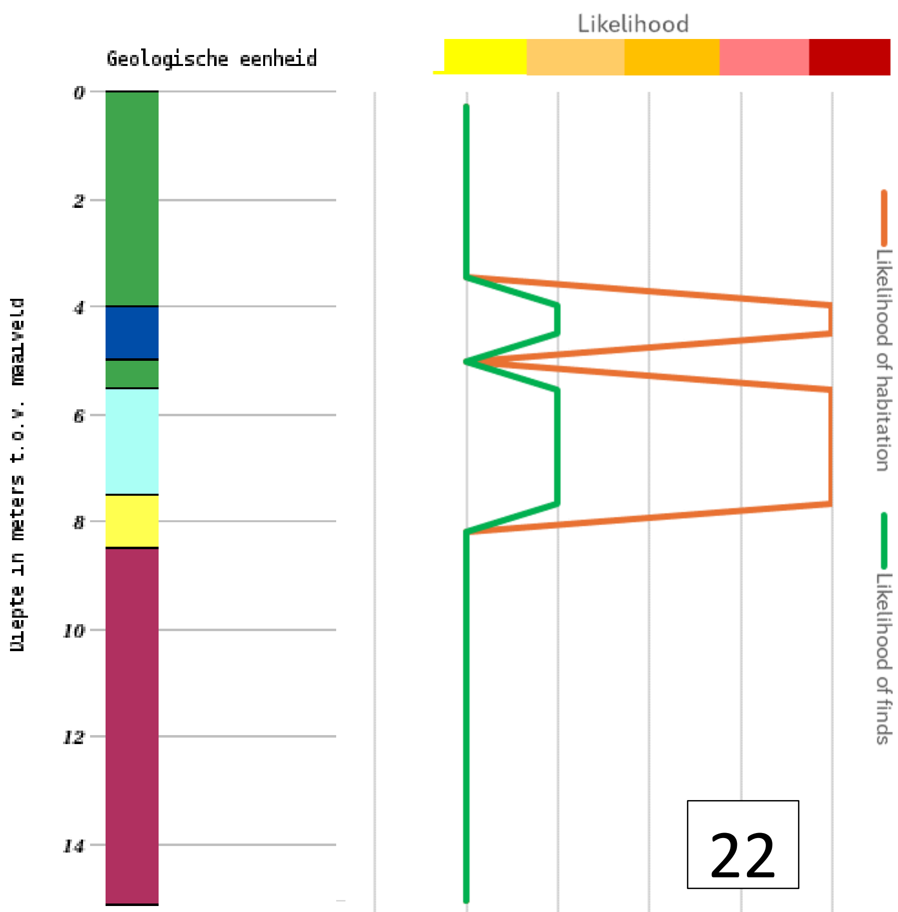
Likelihood of habitation
Likelihood of finds
21


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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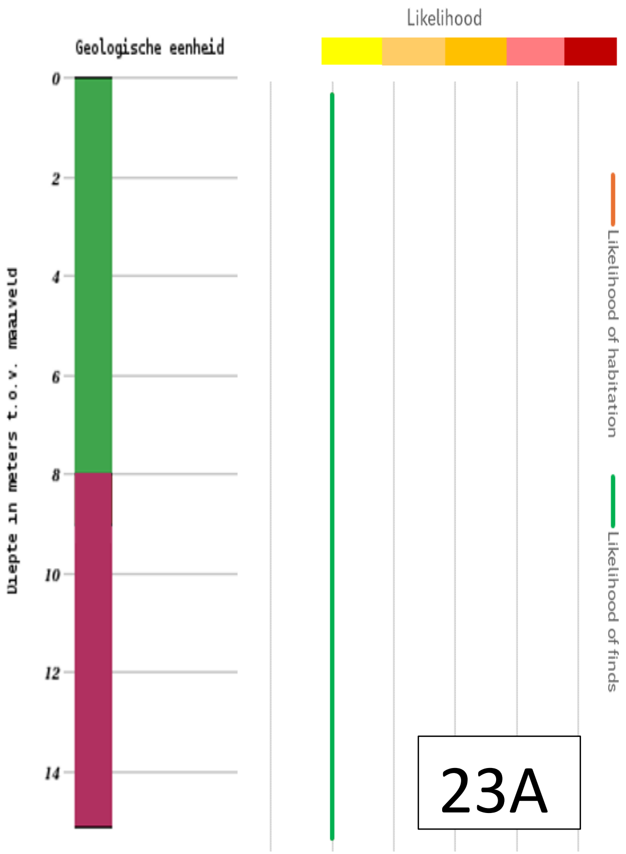
Likelihood of habitation
Likelihood of finds
22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Geologische eenheid
Diepte in meters t.o.v. maaiveld
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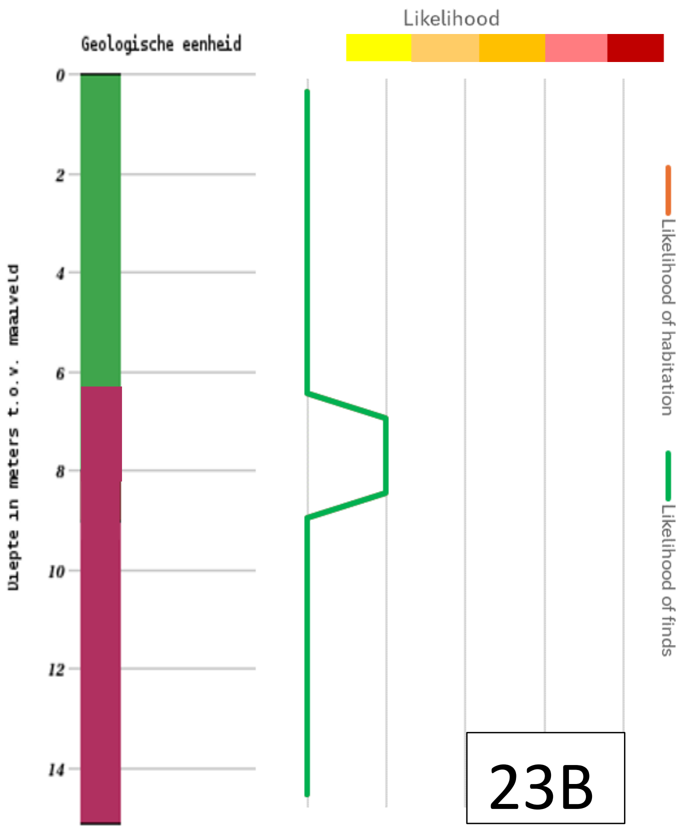
Likelihood of habitation
Likelihood of finds
23A


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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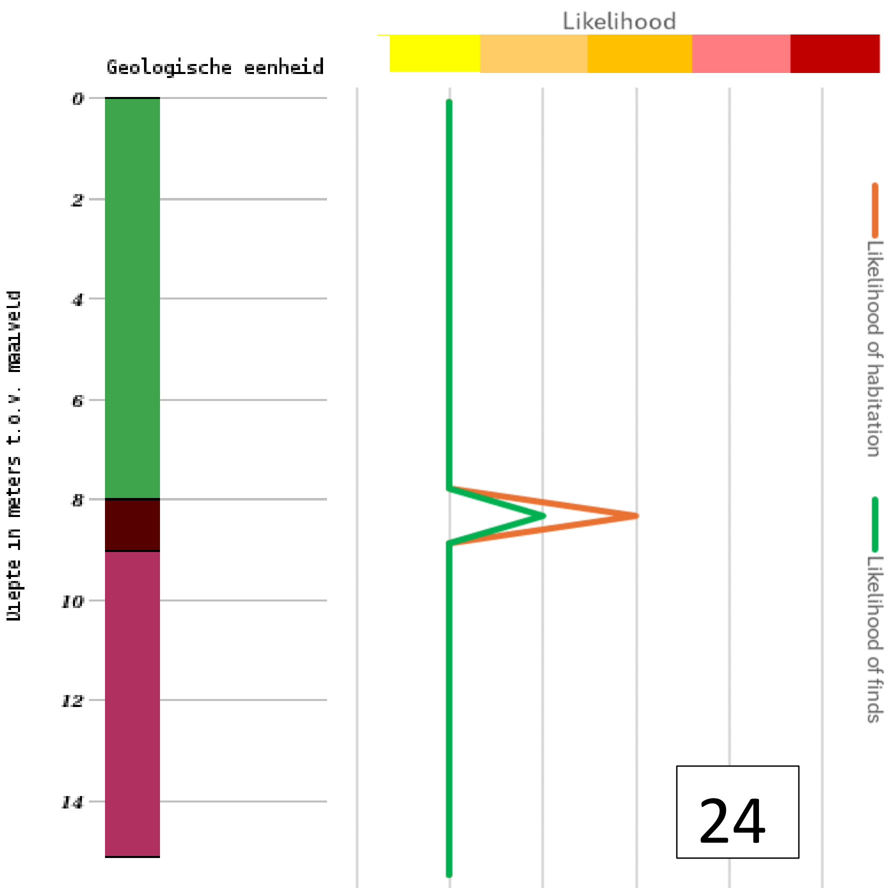
Likelihood of habitation
Likelihood of finds
23B


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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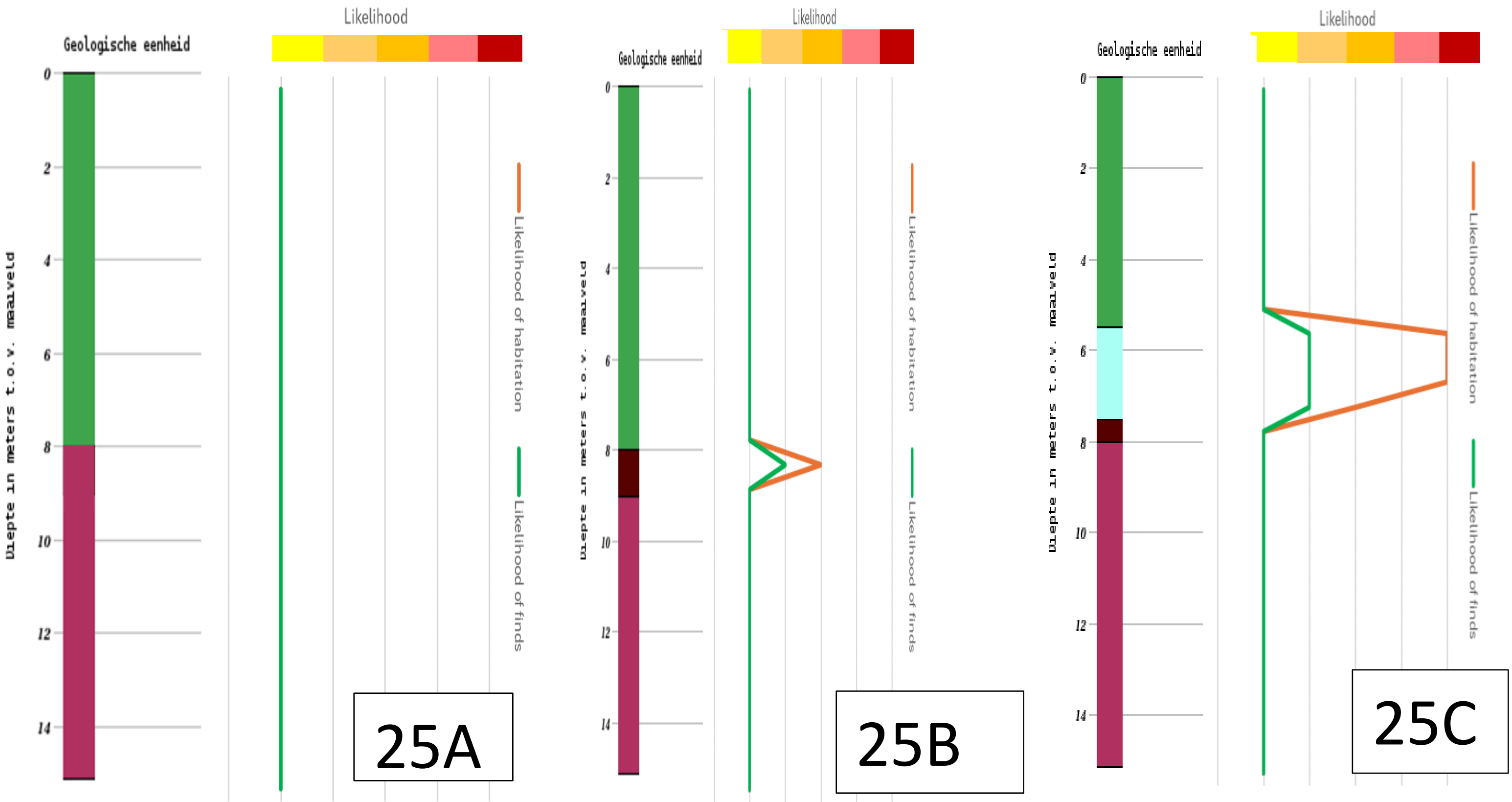
Likelihood of habitation
Likelihood of finds
24


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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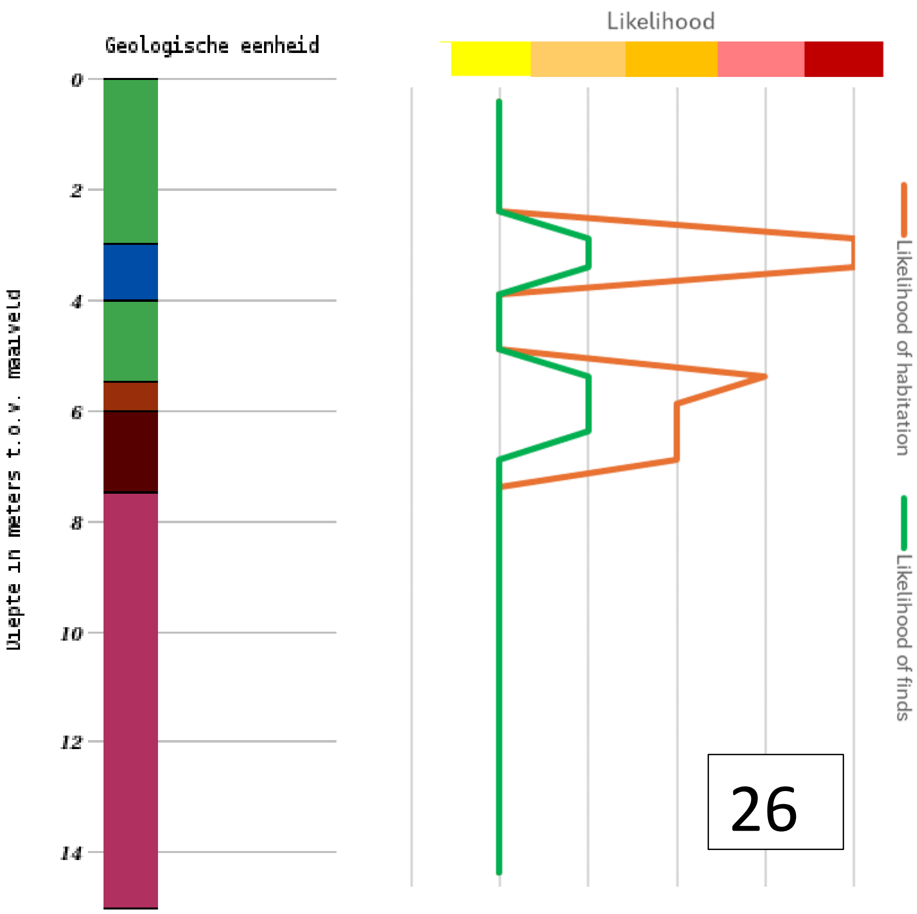
14
Likelihood of habitation
Likelihood of finds
25A
25B
25C


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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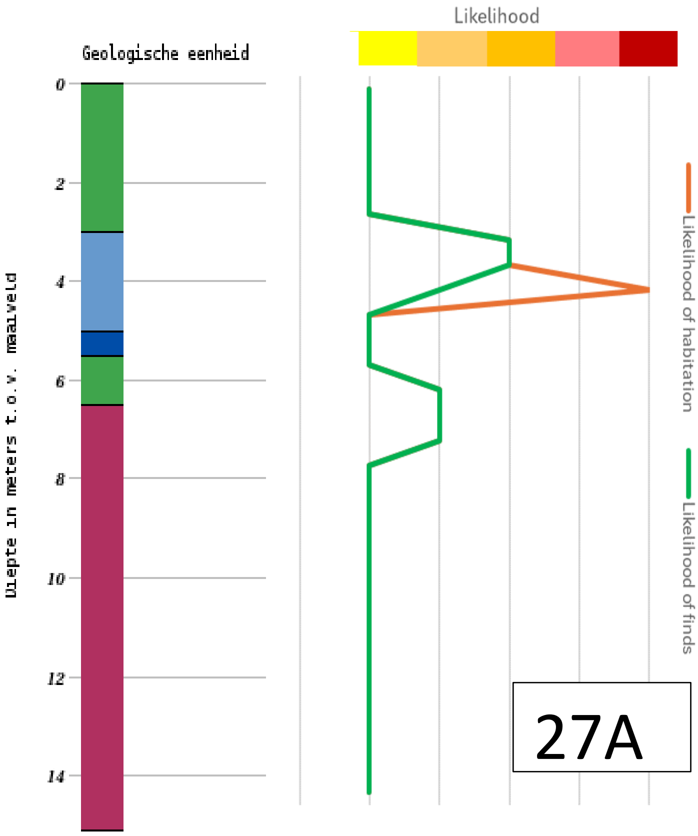
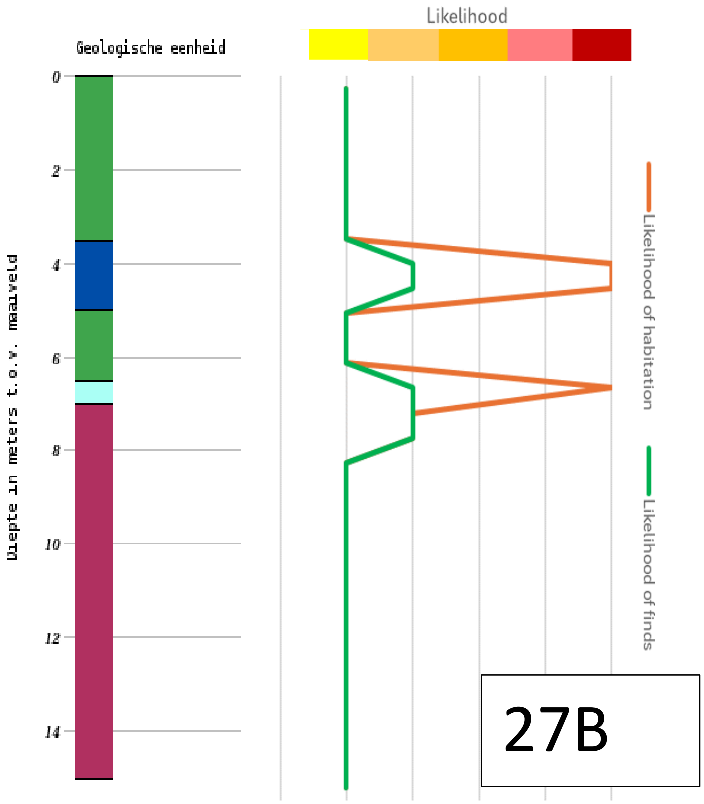
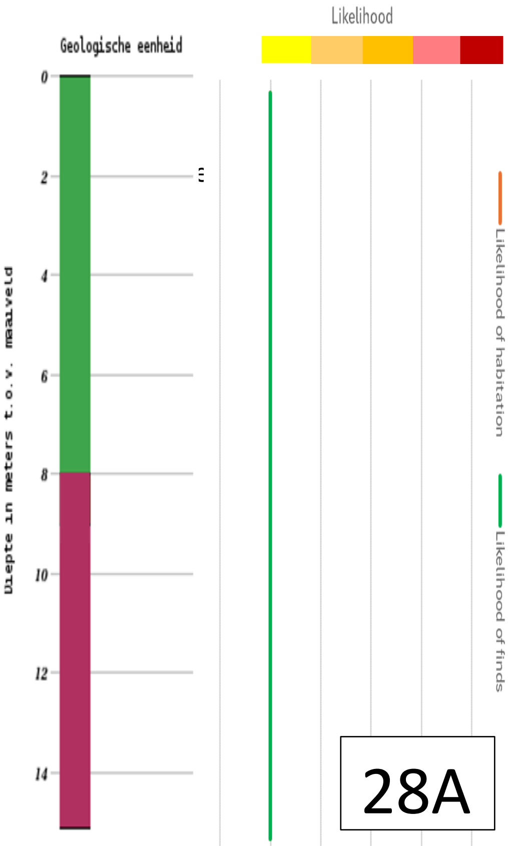
Likelihood of habitation
Likelihood of finds
26



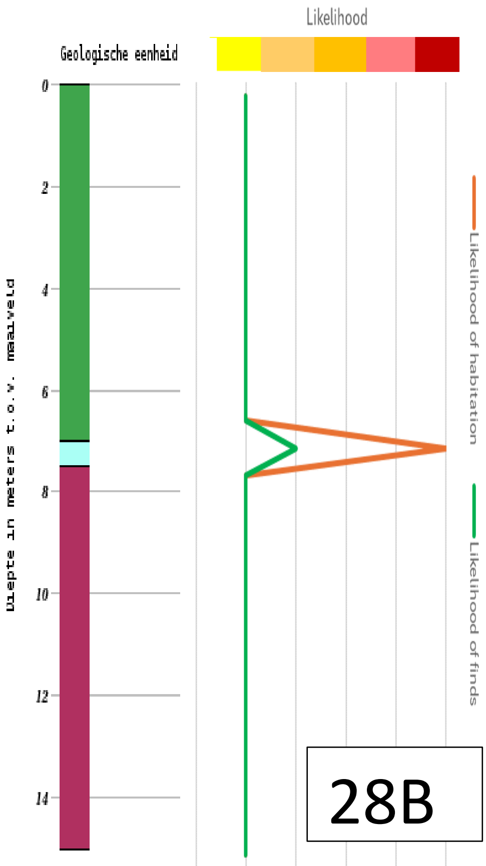
27A



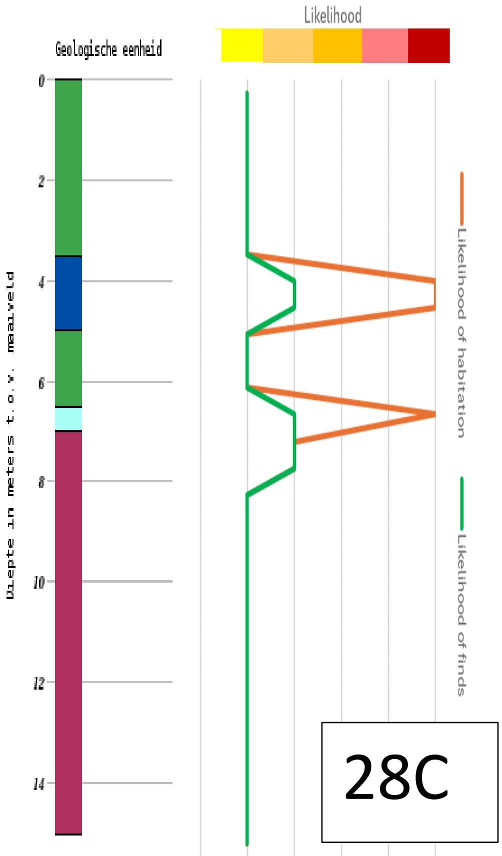
27B



28A



28B



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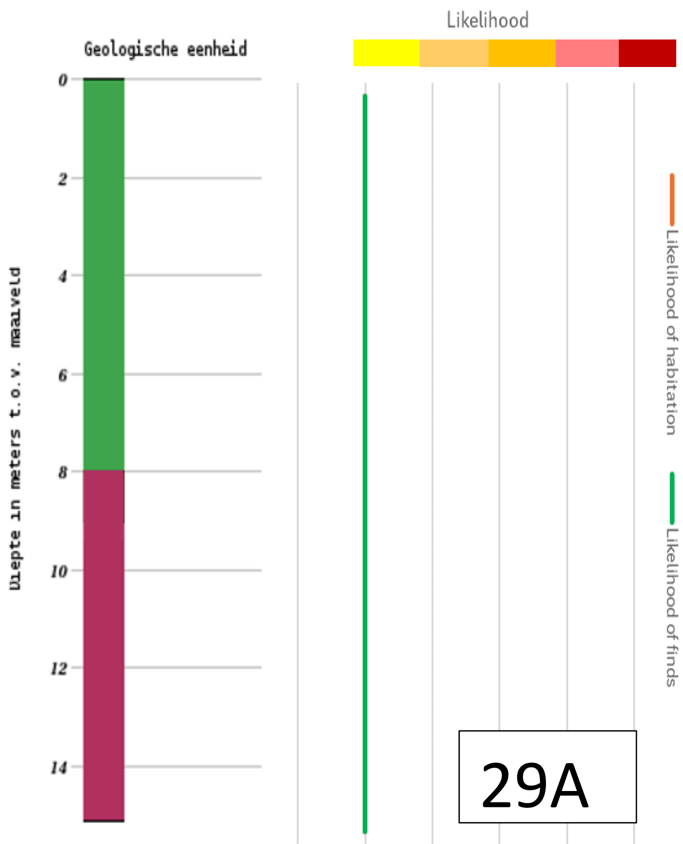
Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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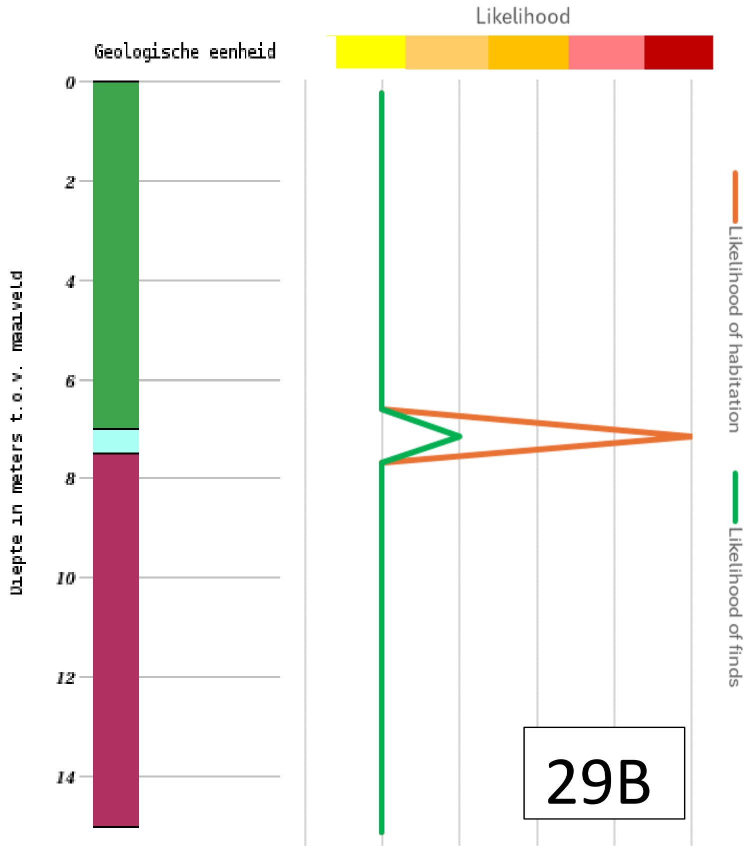
Likelihood of habitation
Likelihood of finds
29A


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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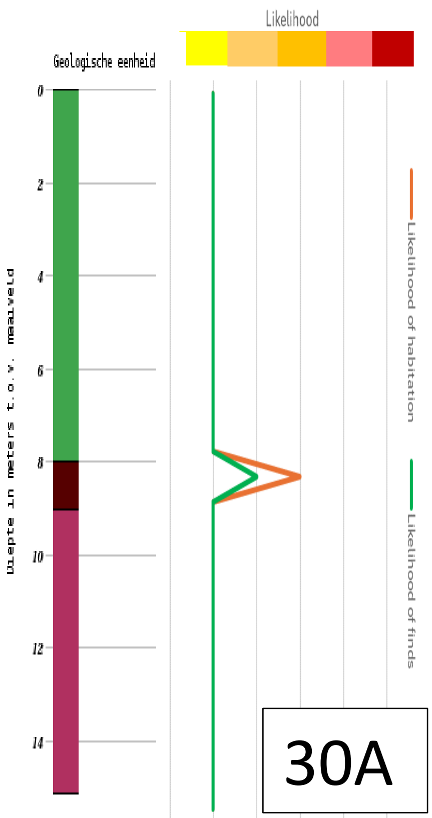
Likelihood of habitation
Likelihood of finds
29B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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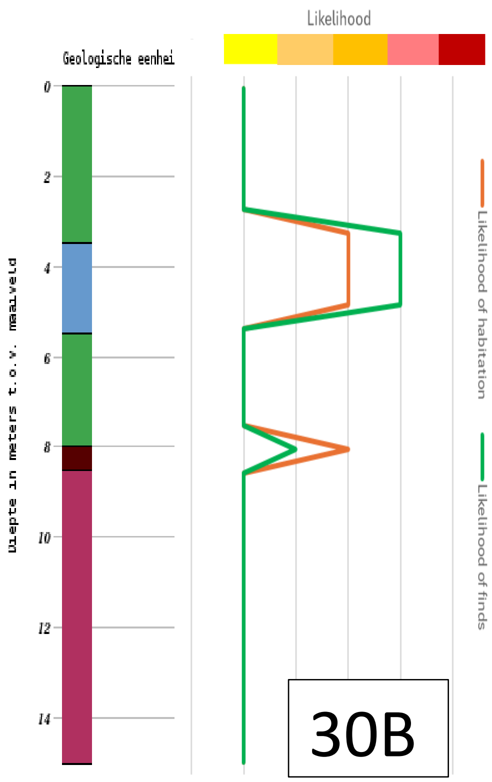
Likelihood of habitation
Likelihood of finds
30A


Geologische eenhei
Likelihood
Diepte in meters t.o.v. maaiveld
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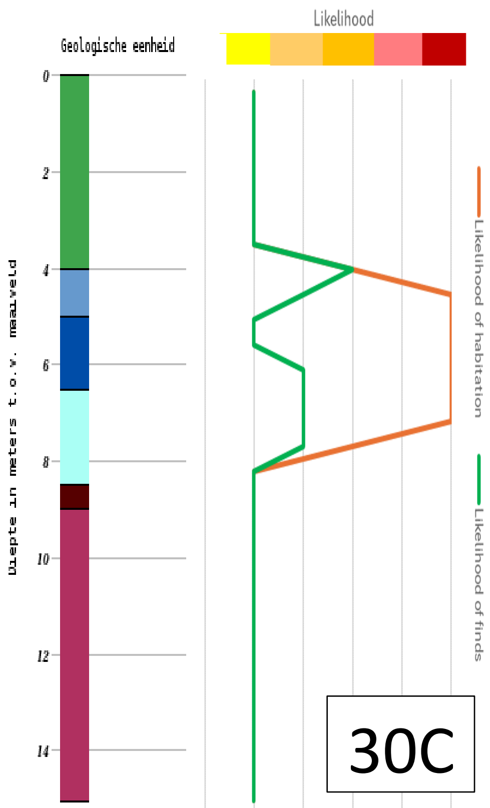
Likelihood of habitation
Likelihood of finds
30B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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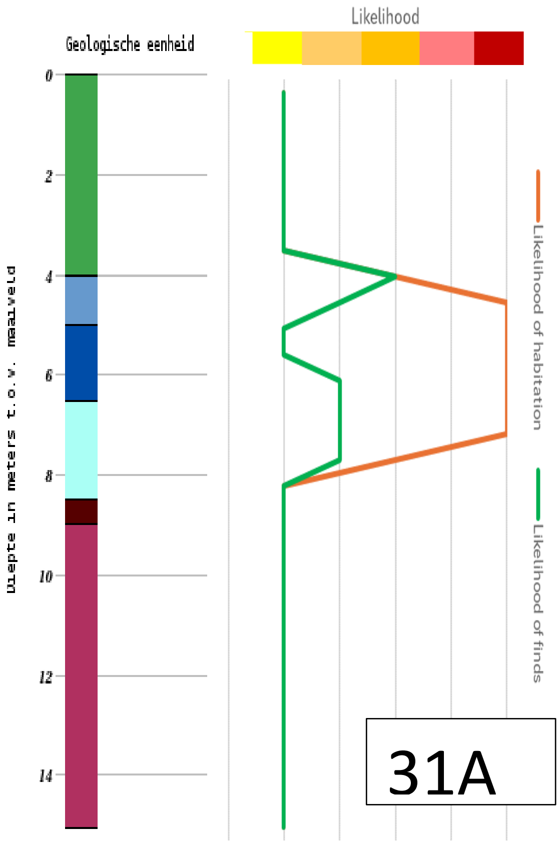
Likelihood of habitation
Likelihood of finds
30C


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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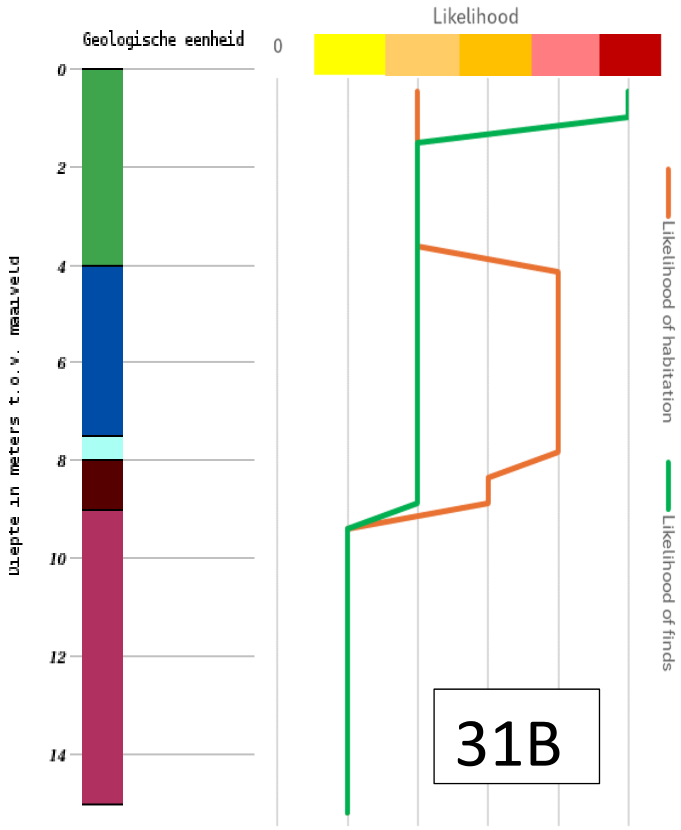
Likelihood of habitation
Likelihood of finds
31A


Geologische eenheid
Likelihood
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Diepte in meters t.o.v. maaiveld
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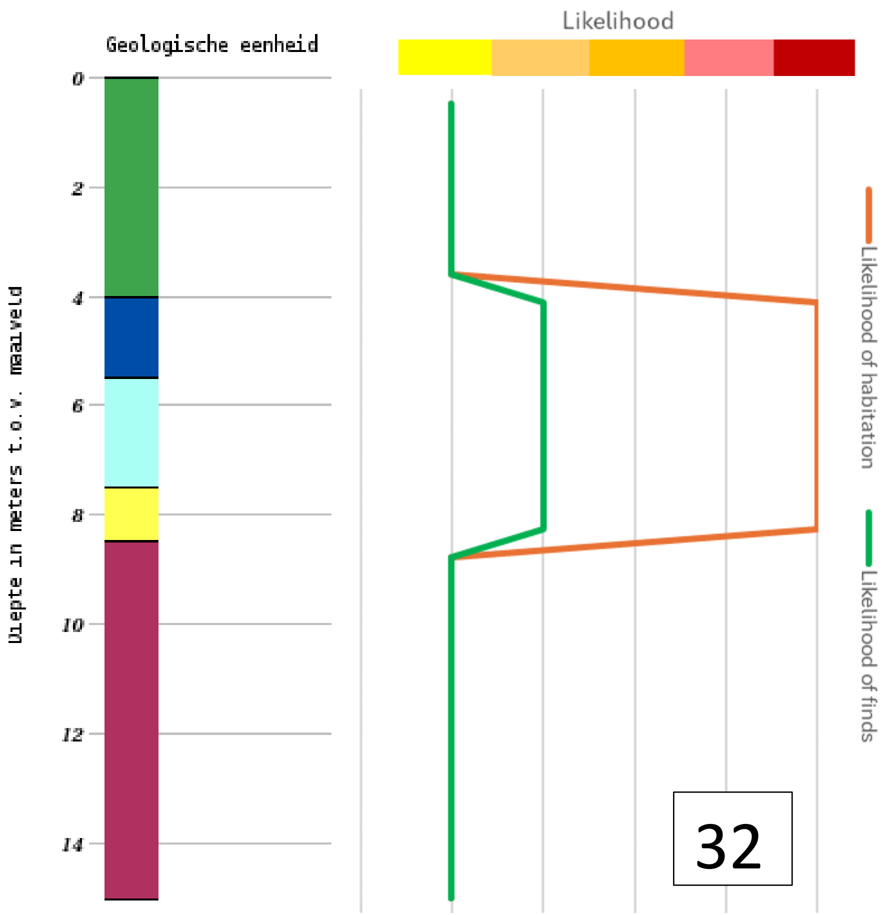
Likelihood of habitation
Likelihood of finds
31B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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Likelihood of habitation
Likelihood of finds
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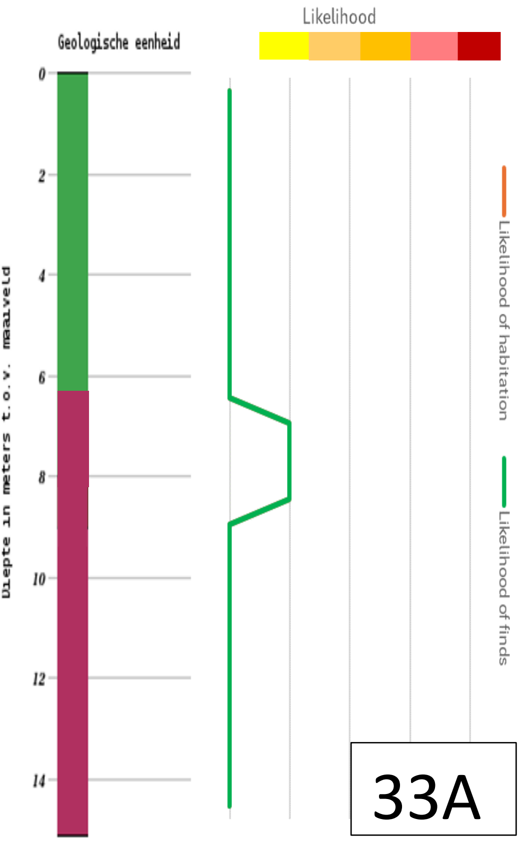
Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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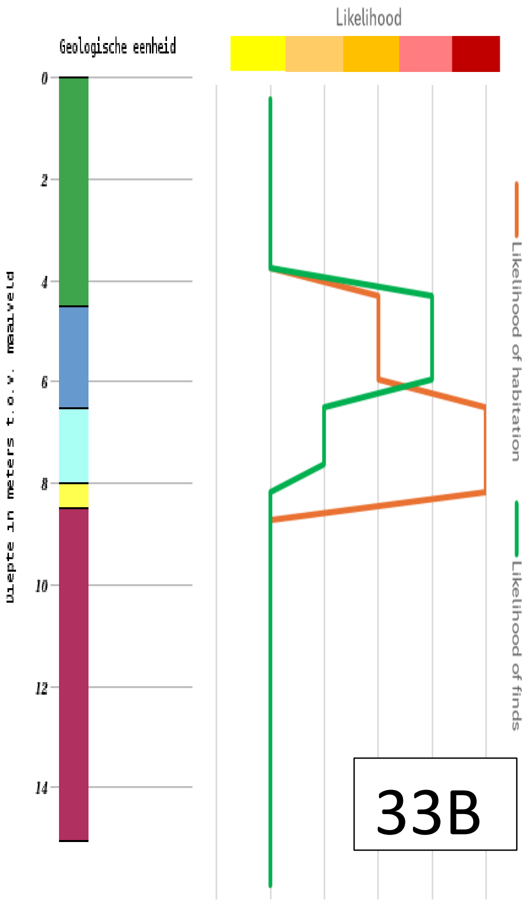
Likelihood of habitation
Likelihood of finds
33A


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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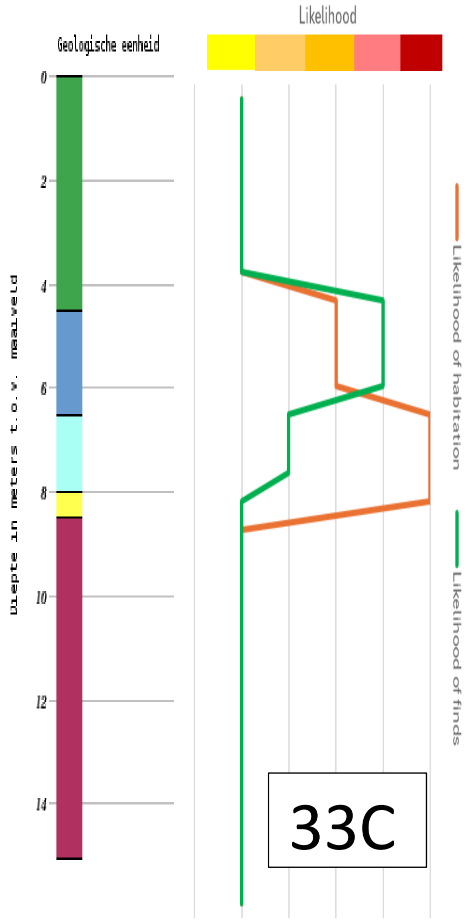
Likelihood of finds
33B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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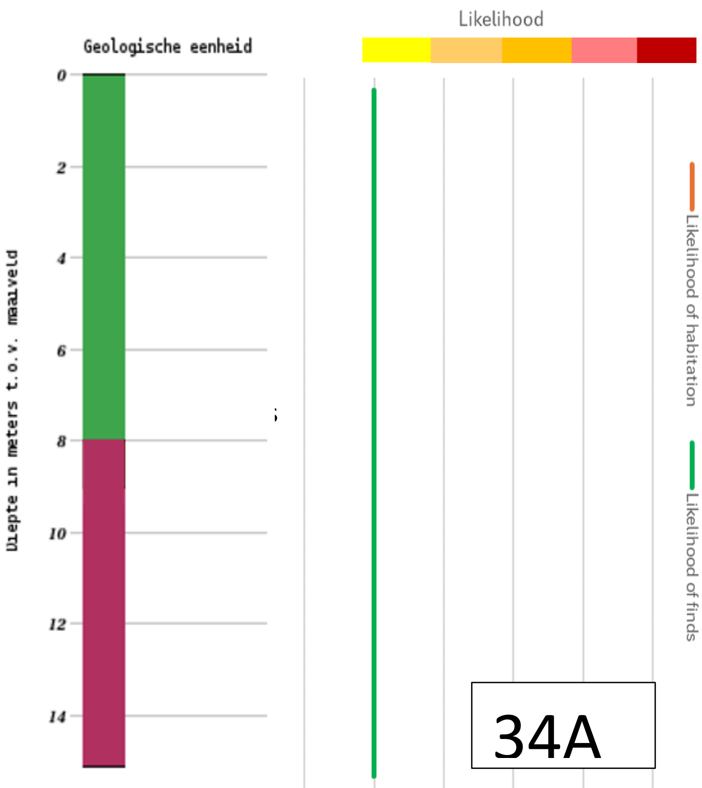
Likelihood of habitation
Likelihood of finds
33C


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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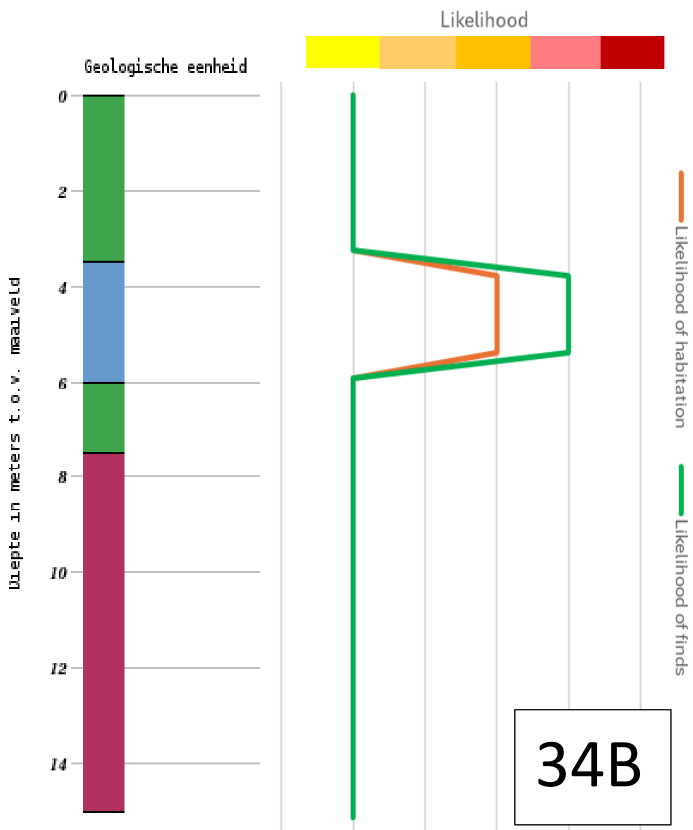
Likelihood of finds
34A


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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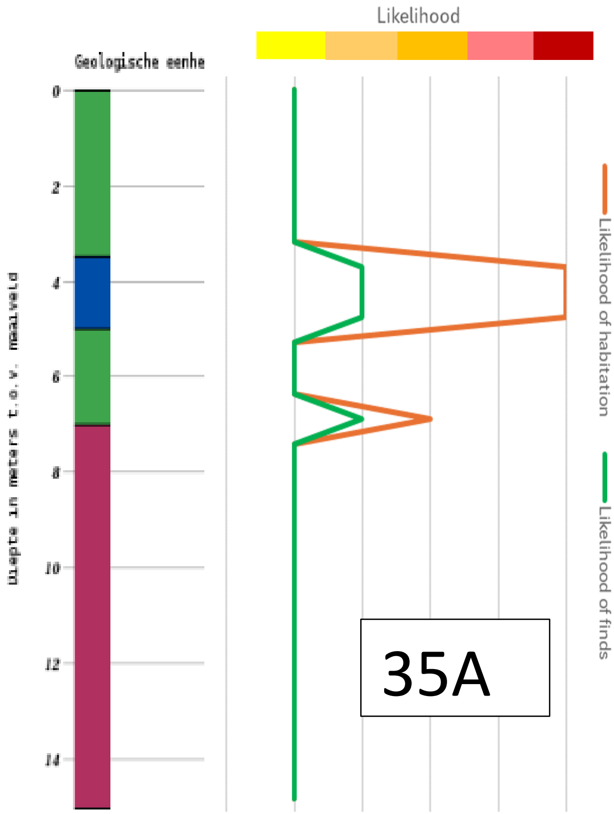
Likelihood of finds
34B


Likelihood
Geologische eenhe
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Diepte in meters t.o.v. maaiveld
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Likelihood of finds
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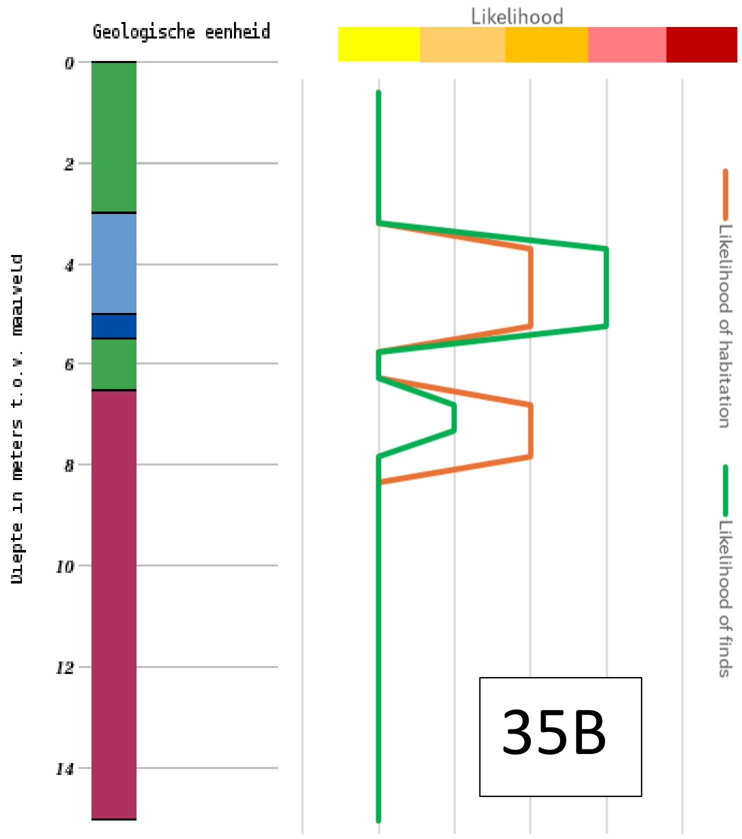
Geologische eenheid
Likelihood
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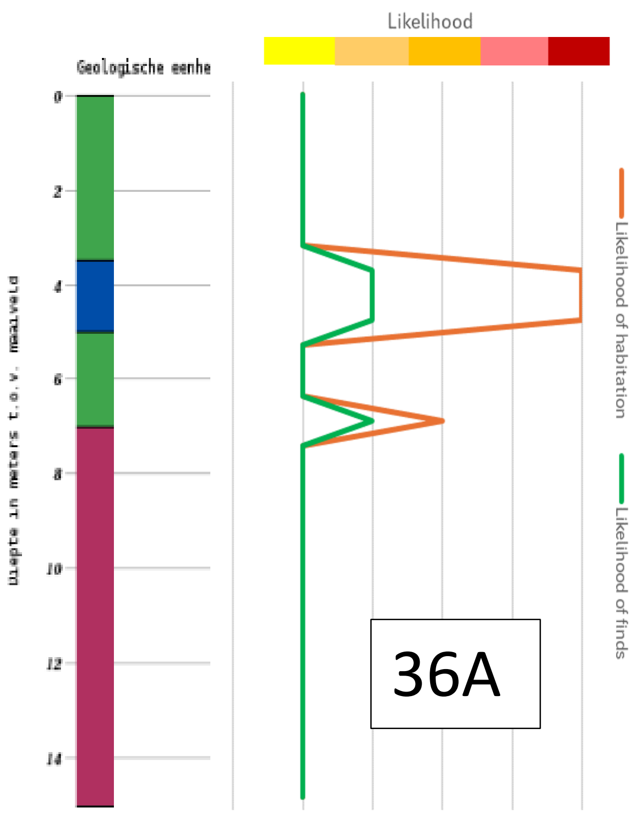
Diepte in meters t.o.v. maaiveld
Likelihood of habitation
Likelihood of finds
35B


Likelihood
Geologische eenhe
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Diepte in meters t.o.v. maaiveld
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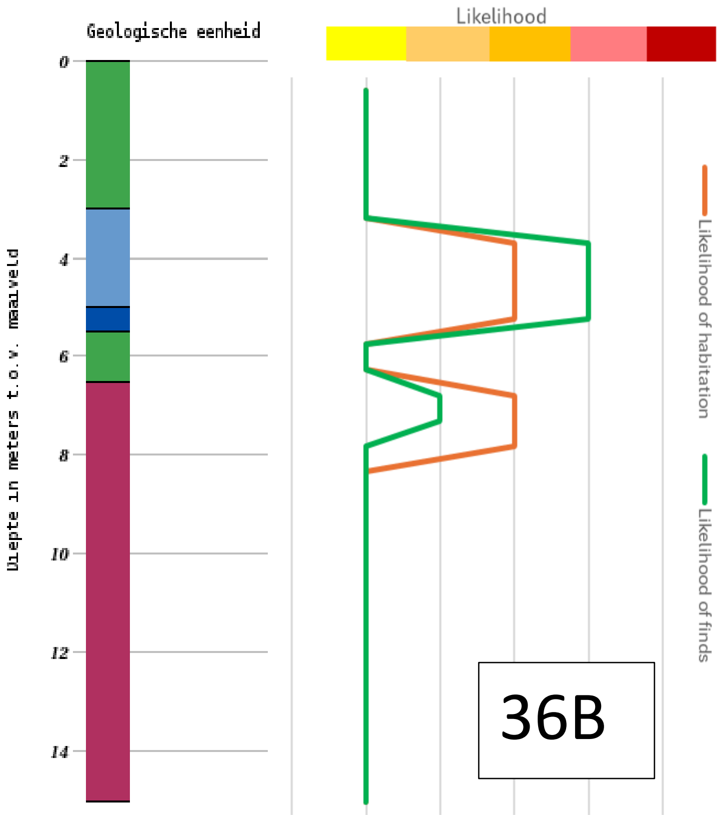
Likelihood of finds
36A


Geologische eenheid
Likelihood
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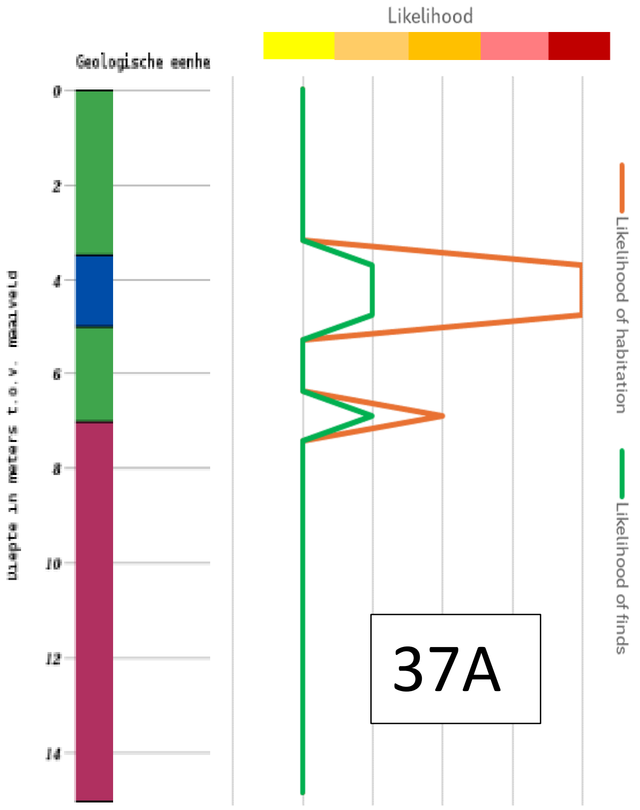
Diepte in meters t.o.v. maaiveld
Likelihood of habitation
Likelihood of finds
36B


Likelihood
Geologische eenhe
Diepte in meters t.o.v. maaiveld
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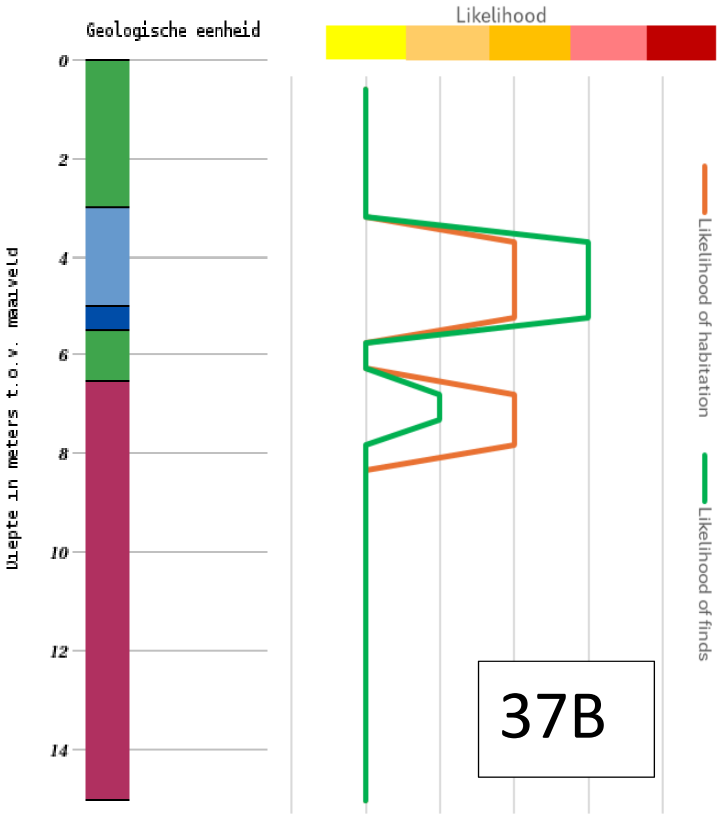
Likelihood of habitation
Likelihood of finds
37A


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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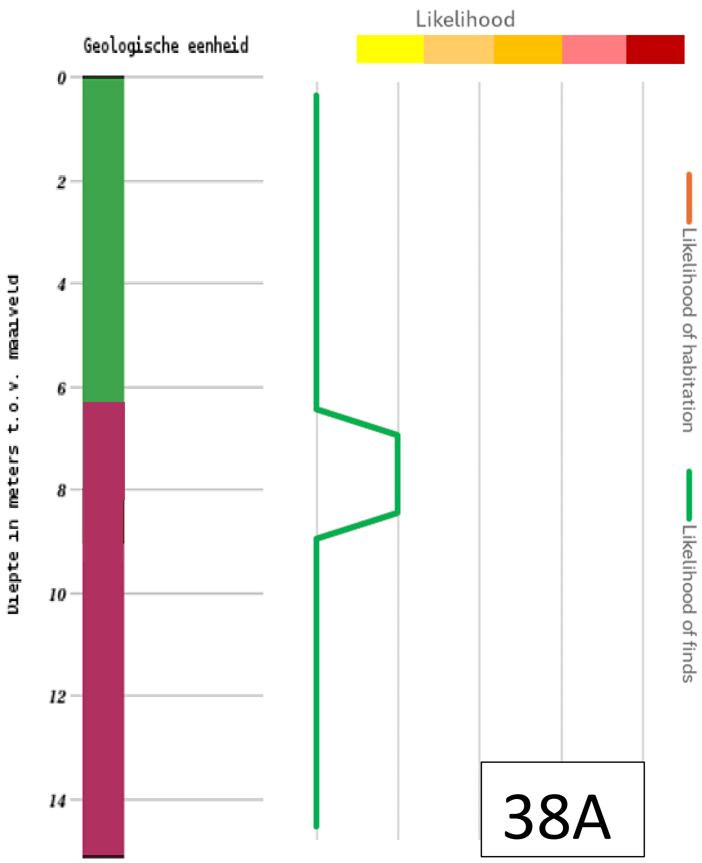
Likelihood of habitation
Likelihood of finds
37B


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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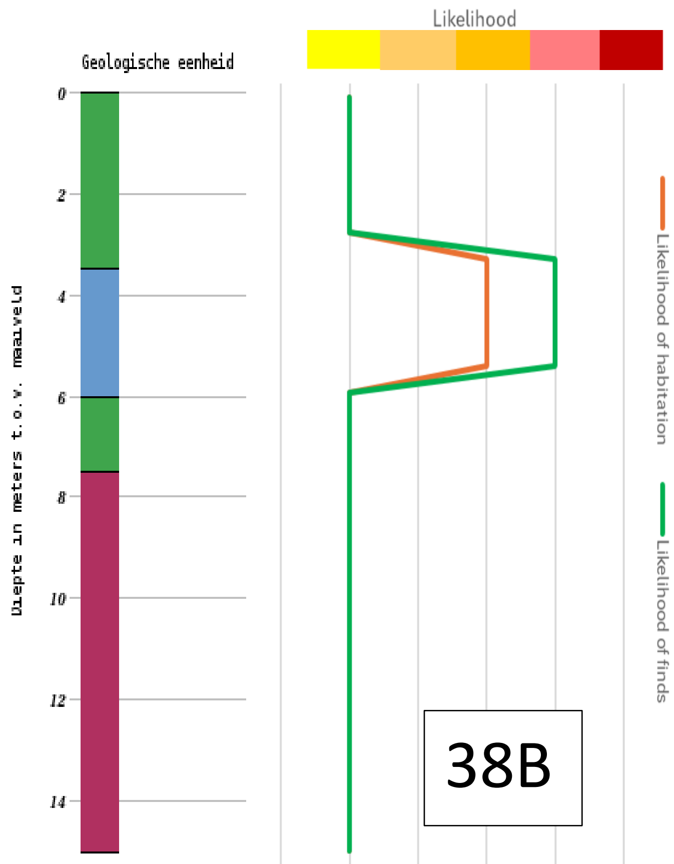
Likelihood of habitation
Likelihood of finds
38A


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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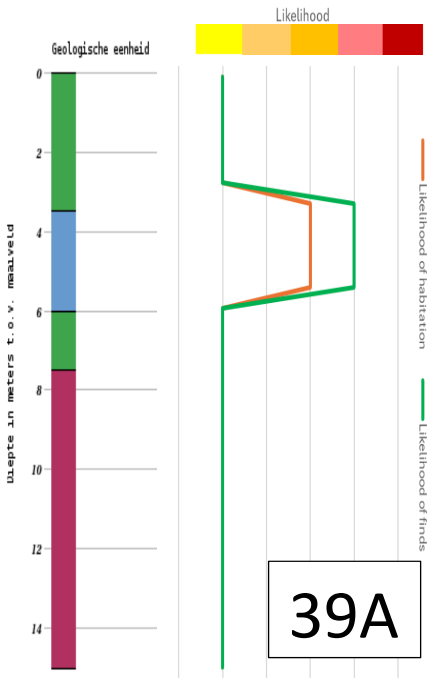
Likelihood of habitation
Likelihood of finds
38B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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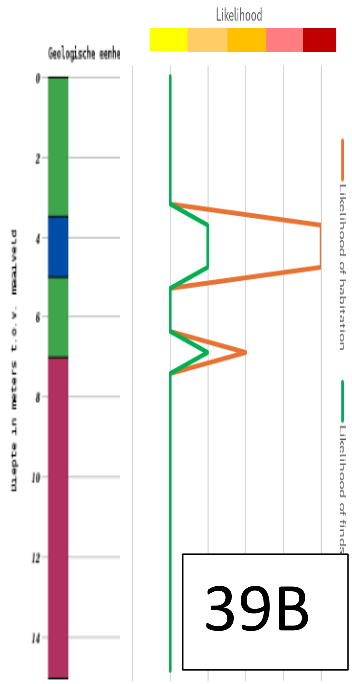
Likelihood of habitation
Likelihood of finds
39A


Geologische eenhe
Likelihood
Diepte in meters t.o.v. maaiveld
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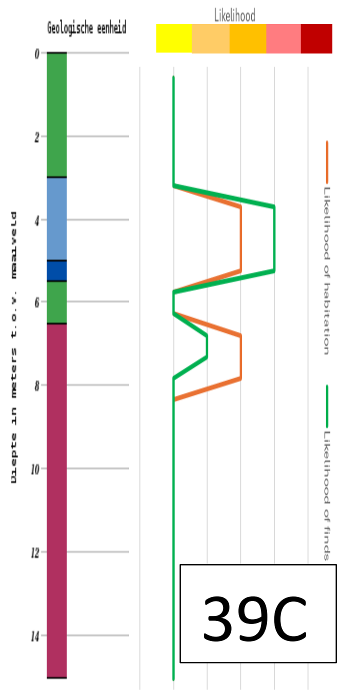
Likelihood of habitation
Likelihood of finds
39B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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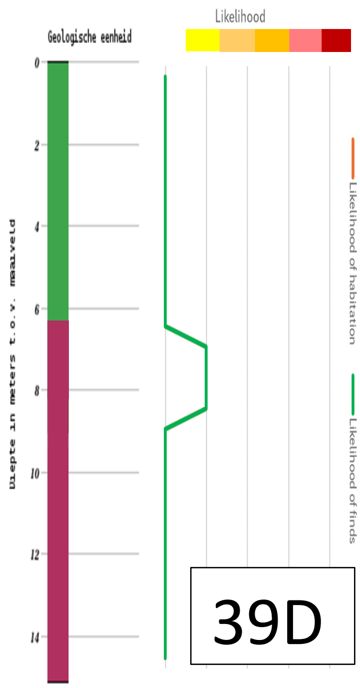
Likelihood of habitation
Likelihood of finds
39C


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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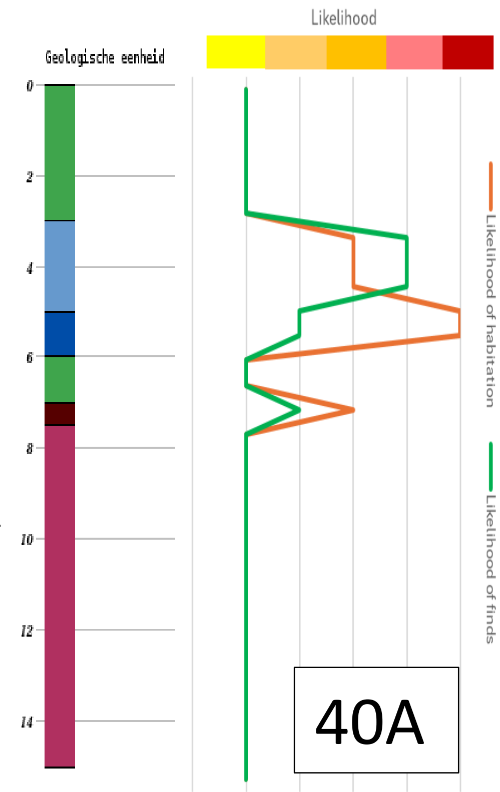
Likelihood of habitation
Likelihood of finds
39D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Likelihood
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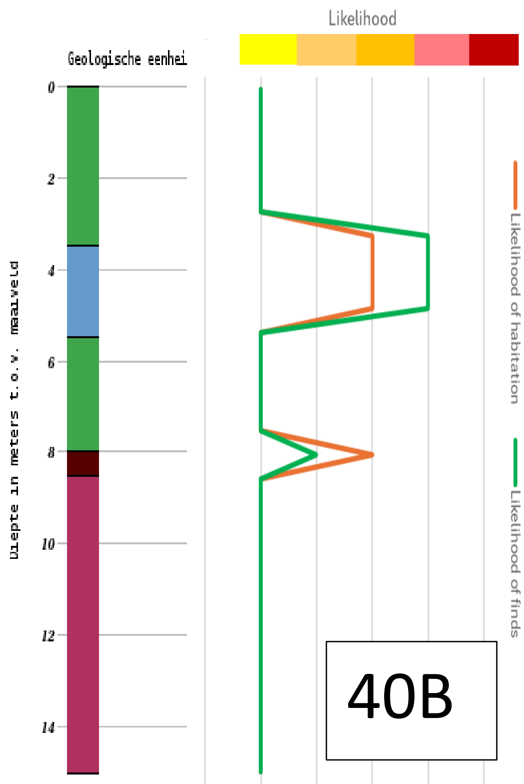
Likelihood of habitation
Likelihood of finds
40A


Geologische eenhei
Likelihood
Diepte in meters t.o.v. maaiveld
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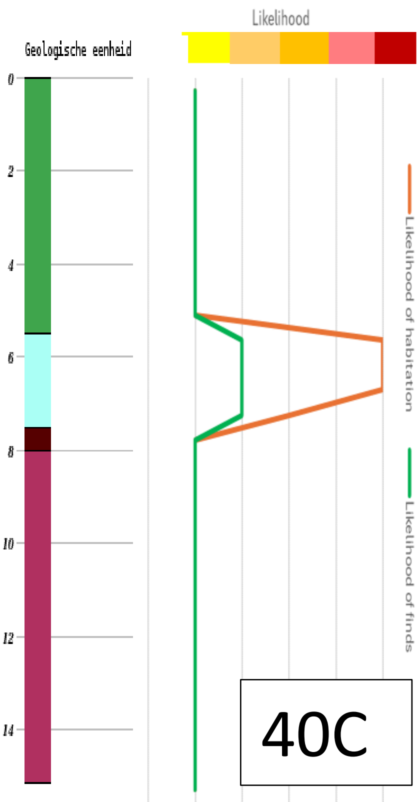
Likelihood of habitation
Likelihood of finds
40B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Likelihood
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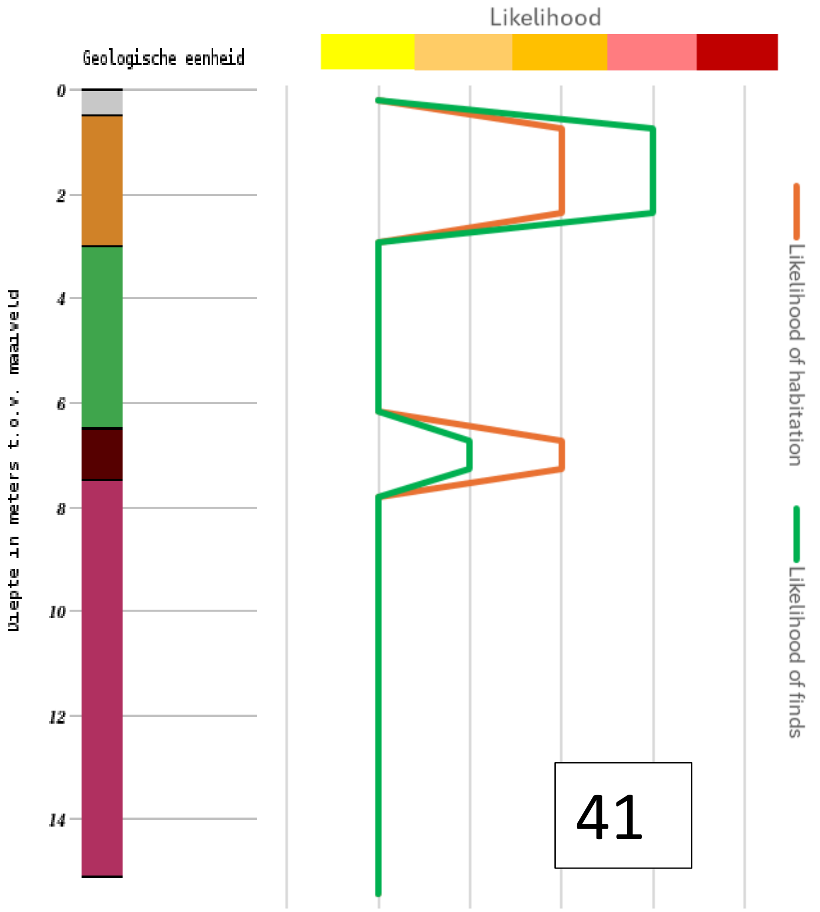
Likelihood of habitation
Likelihood of finds
40C


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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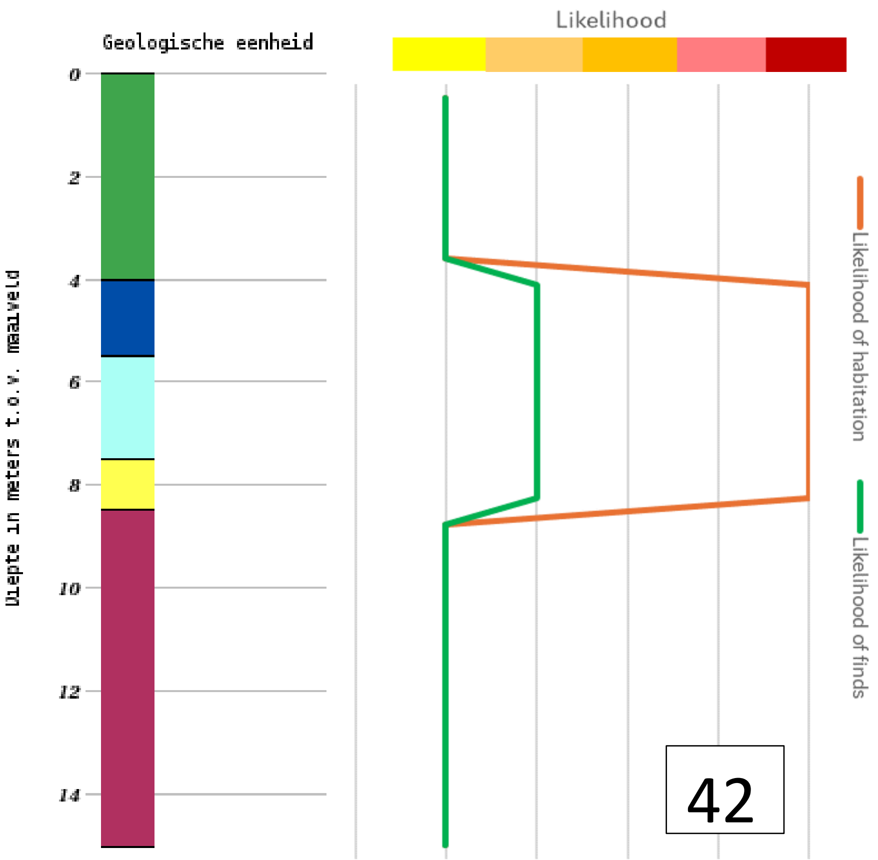
Likelihood of habitation
Likelihood of finds
41


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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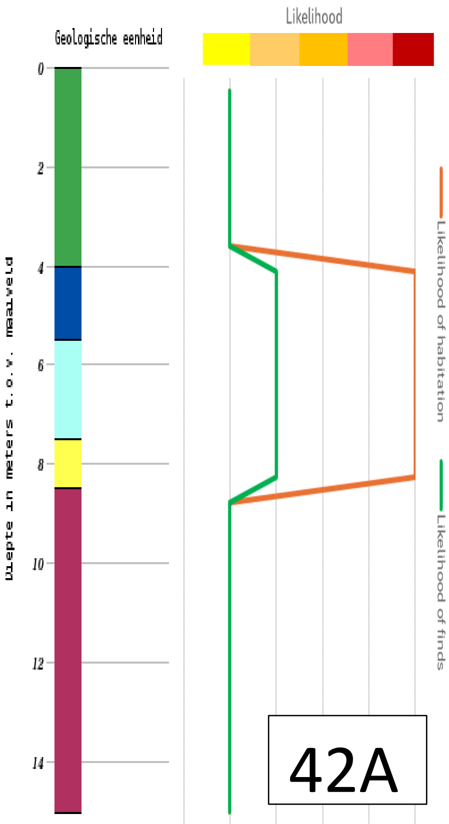
Likelihood of habitation
Likelihood of finds
42


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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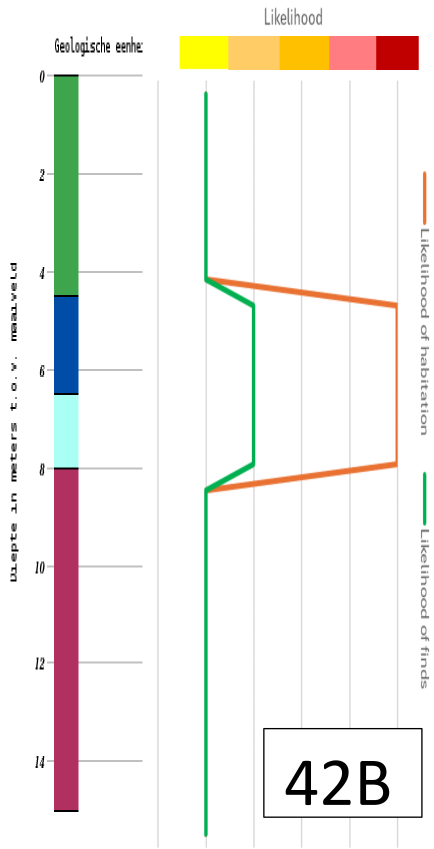
Likelihood of habitation
Likelihood of finds
42A


Geologische eenhe
Likelihood
Diepte in meters t.o.v. maaiveld
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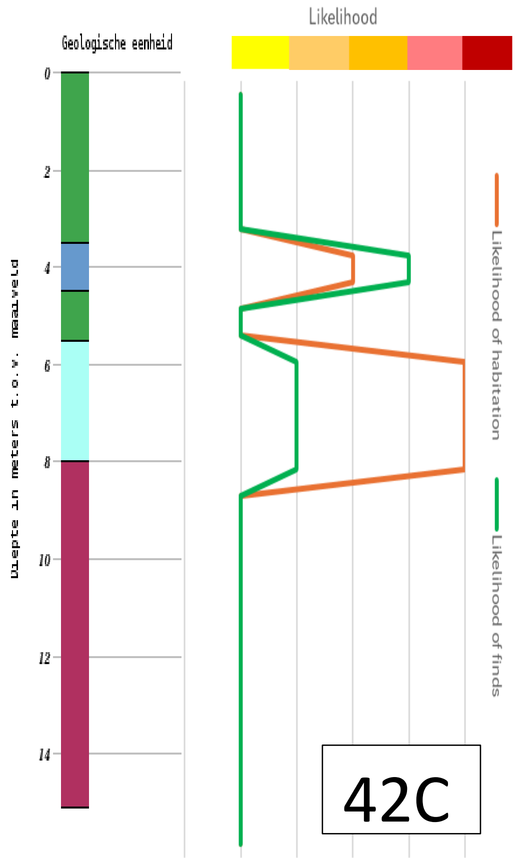
Likelihood of habitation
Likelihood of finds
42B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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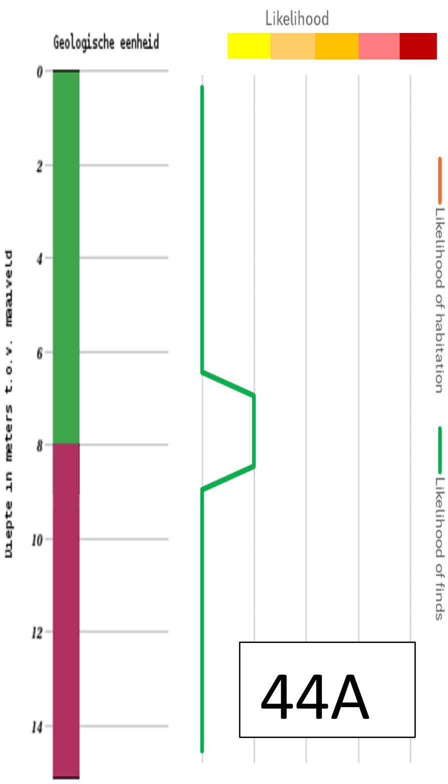
Likelihood of habitation
Likelihood of finds
42C


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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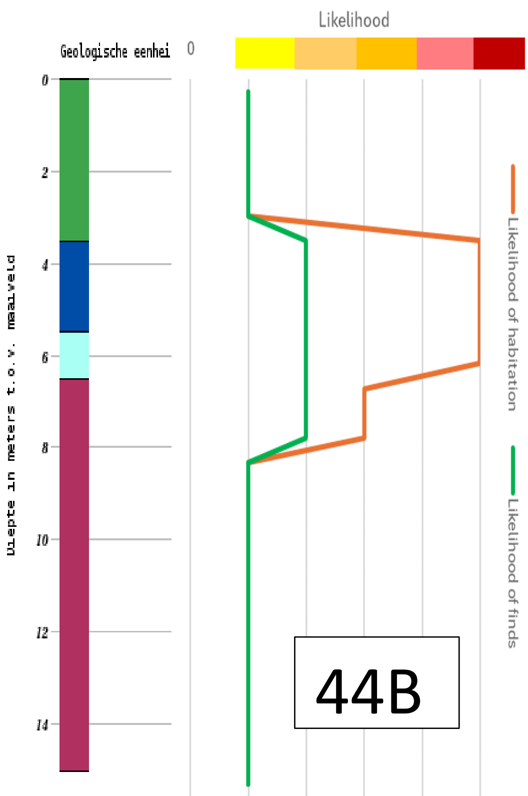
Likelihood of habitation
Likelihood of finds
44A


Geologische eenhei
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Likelihood
Diepte in meters t.o.v. maaiveld
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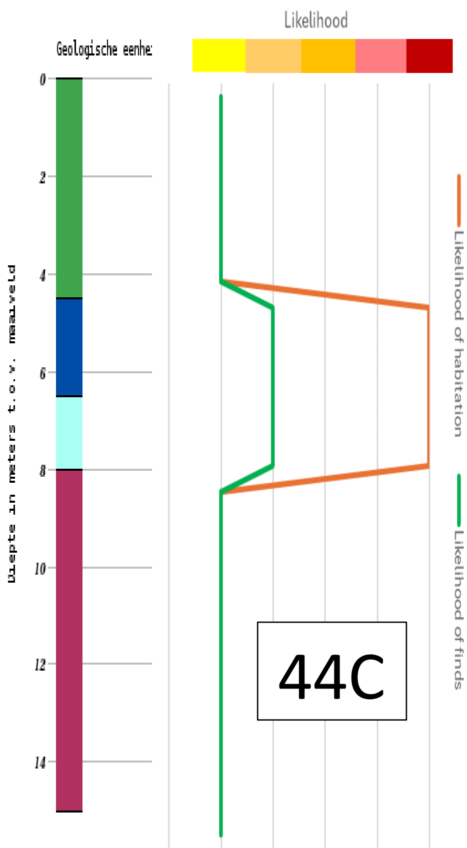
Likelihood of habitation
Likelihood of finds
44B


Geologische eenhe
Likelihood
Diepte in meters t.o.v. maaiveld
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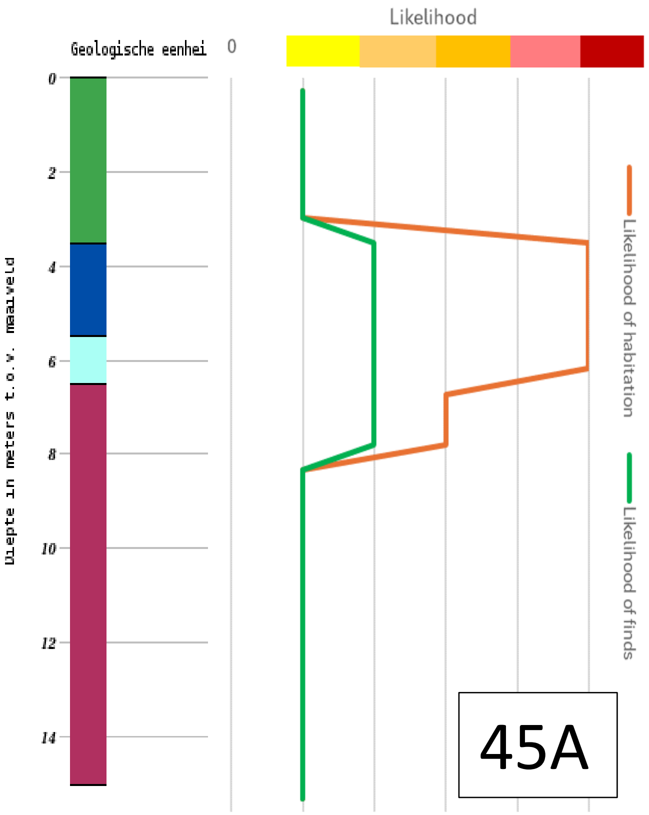
Likelihood of habitation
Likelihood of finds
44C


Likelihood
Geologische eenhei
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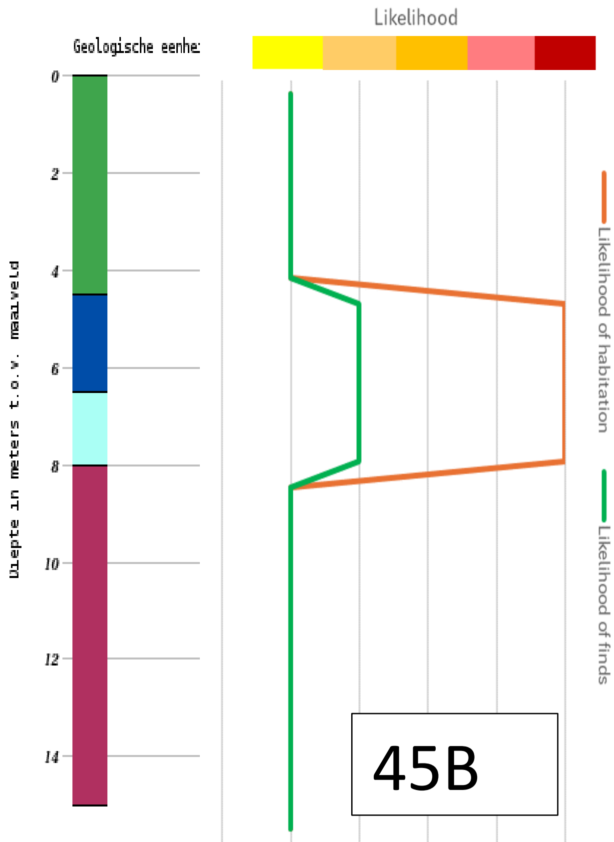
Likelihood of habitation
Likelihood of finds
45A


Likelihood
Geologische eenhe
Diepte in meters t.o.v. maaiveld
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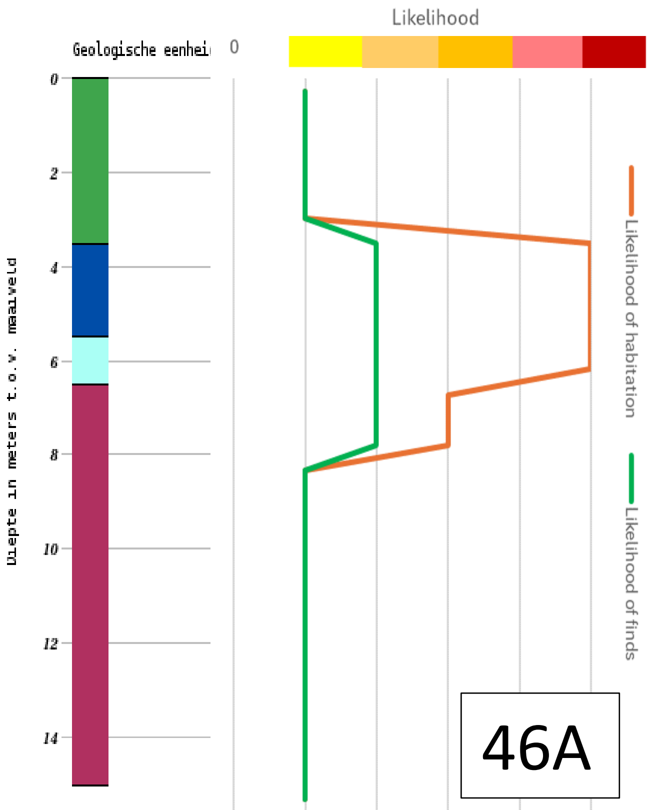
Likelihood of habitation
Likelihood of finds
45B


Likelihood
Geologische eenhei
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Diepte in meters t.o.v. maaiveld
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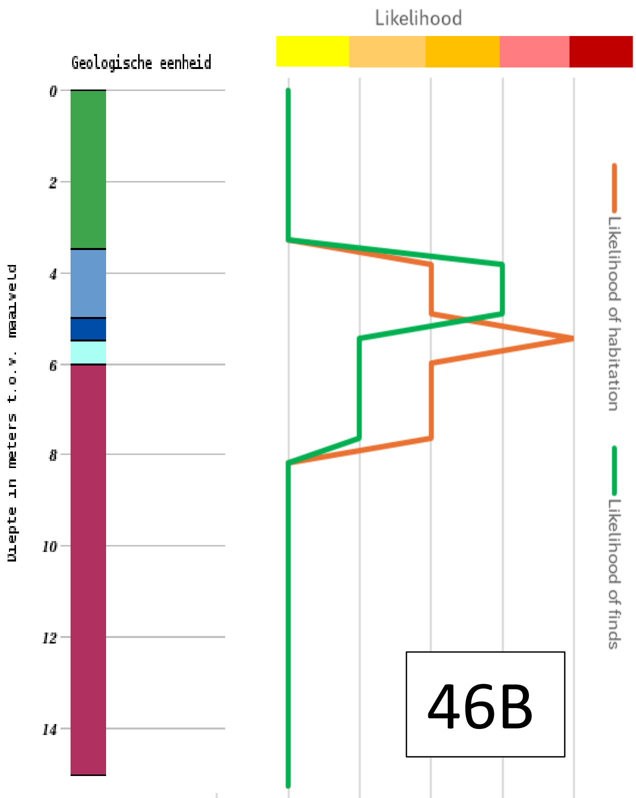
Likelihood of habitation
Likelihood of finds
46A


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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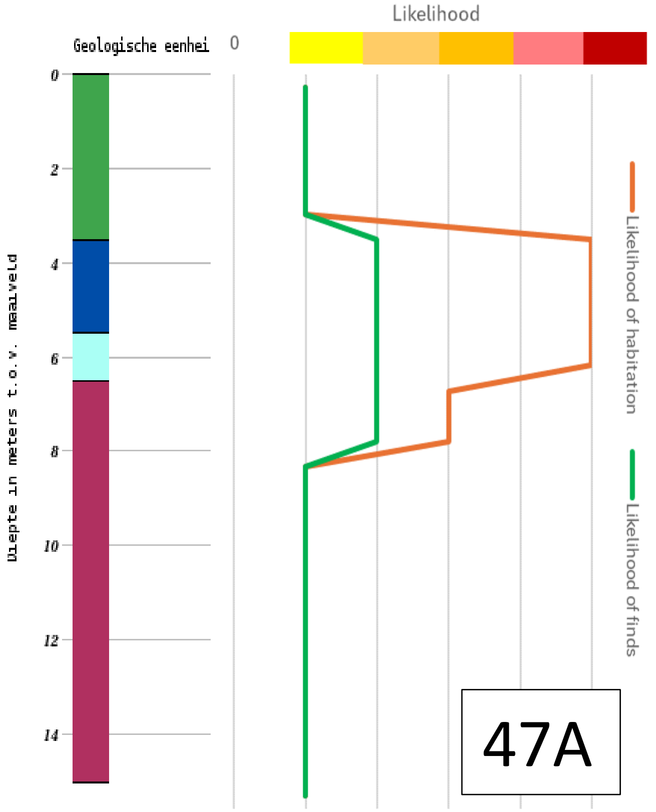
Likelihood of habitation
Likelihood of finds
46B


Likelihood
Geologische eenhei
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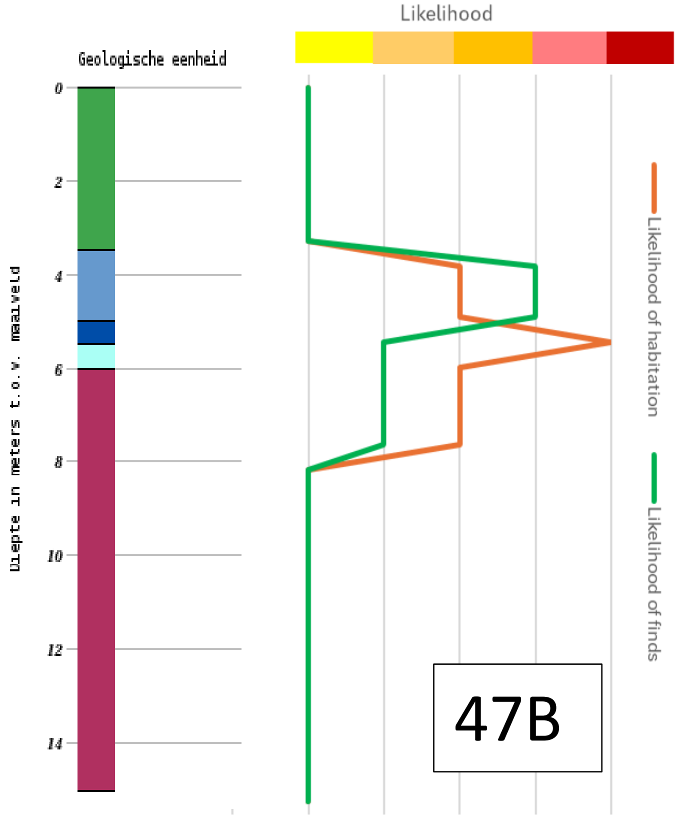
Likelihood of habitation
Likelihood of finds
47A


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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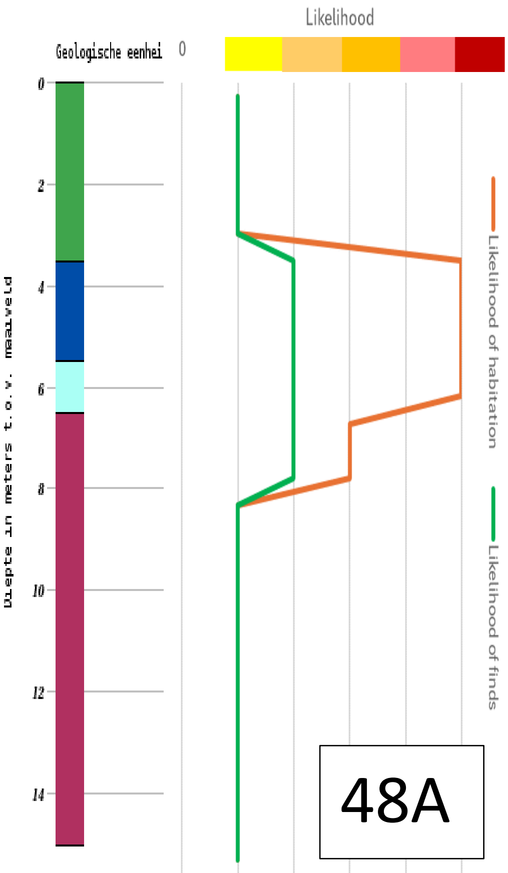
Likelihood of habitation
Likelihood of finds
47B


Likelihood
Geologische eenhei
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Diepte in meters t.o.v. maaiveld
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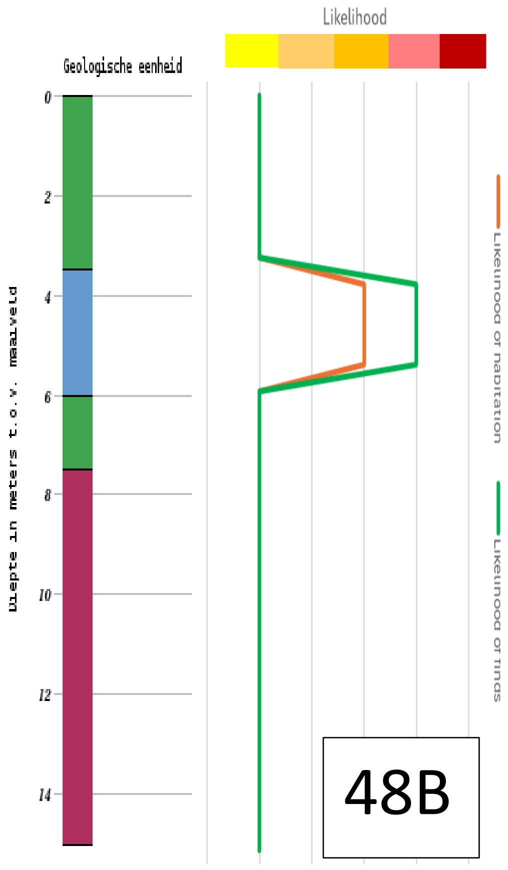
Likelihood of habitation
Likelihood of finds
48A


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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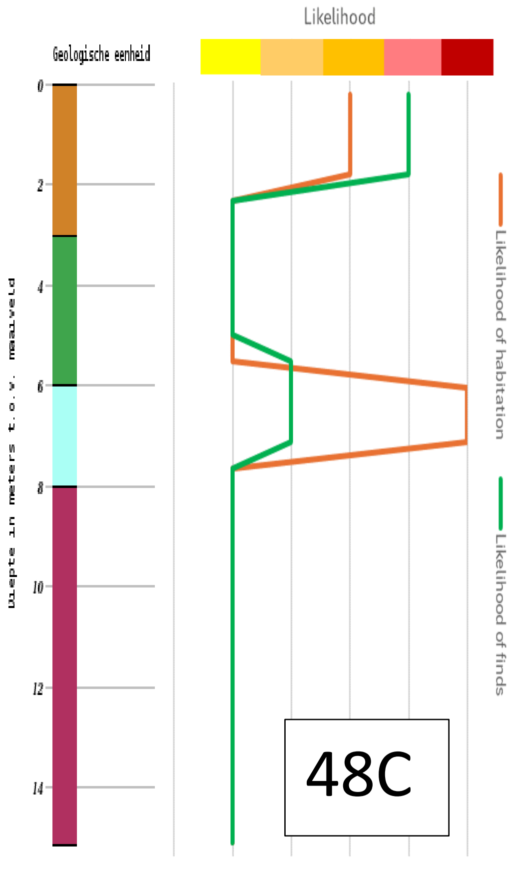
Likelihood of habitation
Likelihood of finds
48B


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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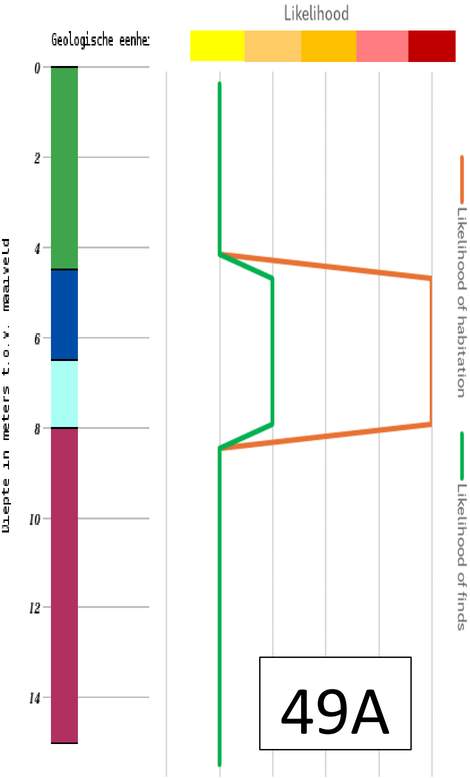
Likelihood of habitation
Likelihood of finds
48C


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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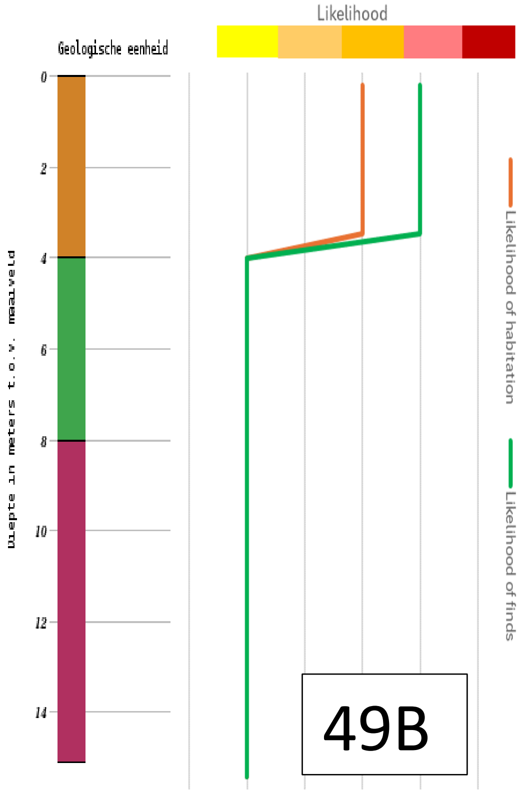
Likelihood of habitation
Likelihood of finds
49A


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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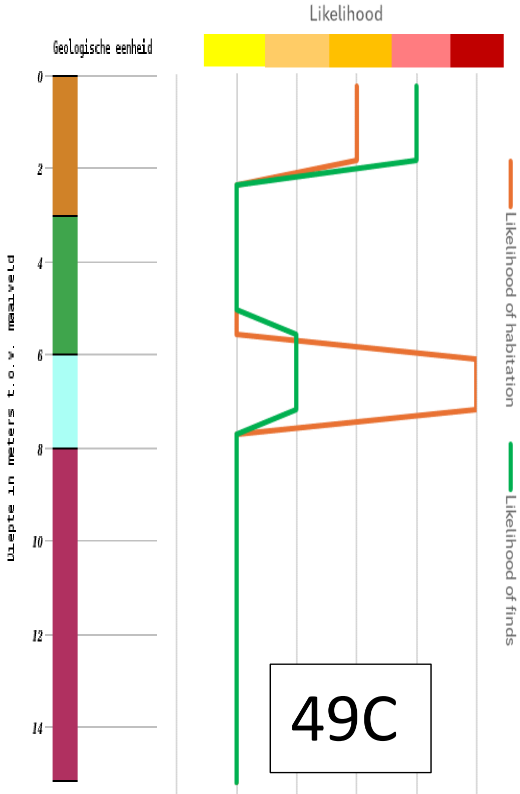
Likelihood of habitation
Likelihood of finds
49B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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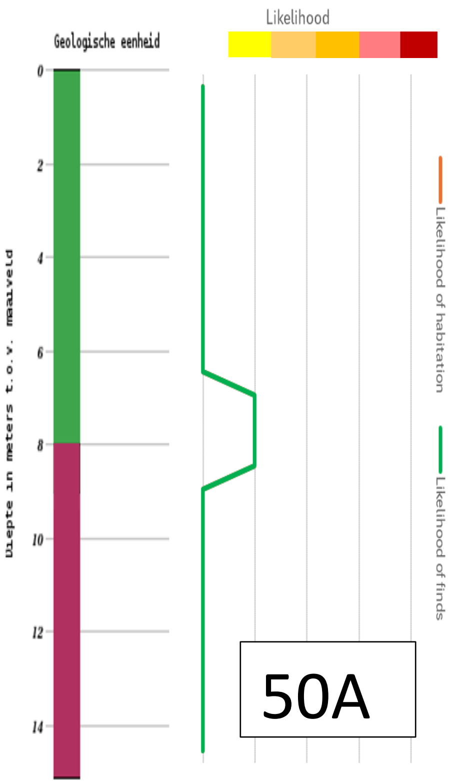
Likelihood of habitation
Likelihood of finds
49C


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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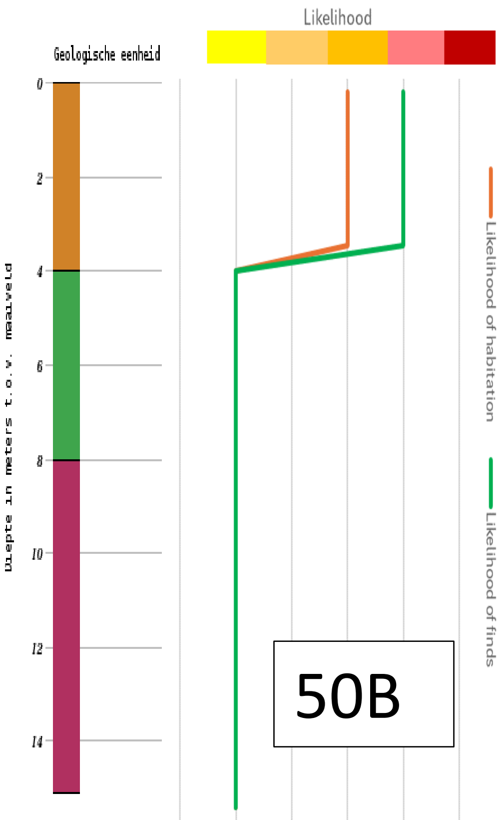
Likelihood of finds
50A


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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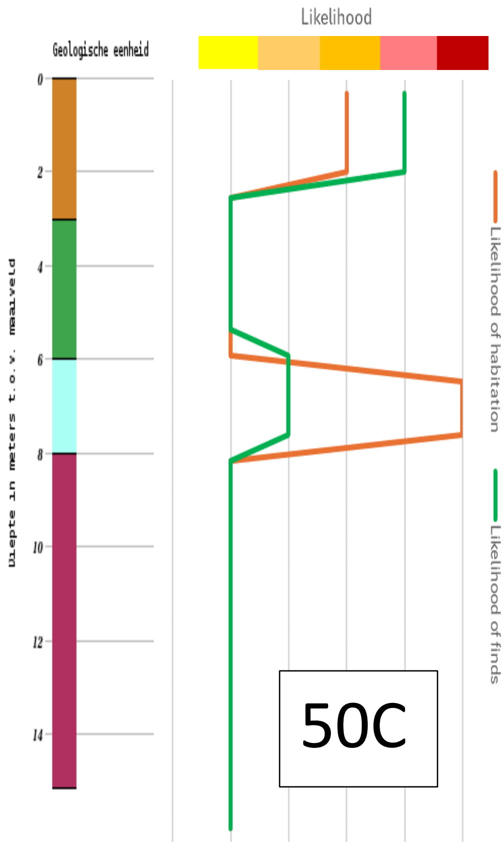
Likelihood of habitation
Likelihood of finds
50B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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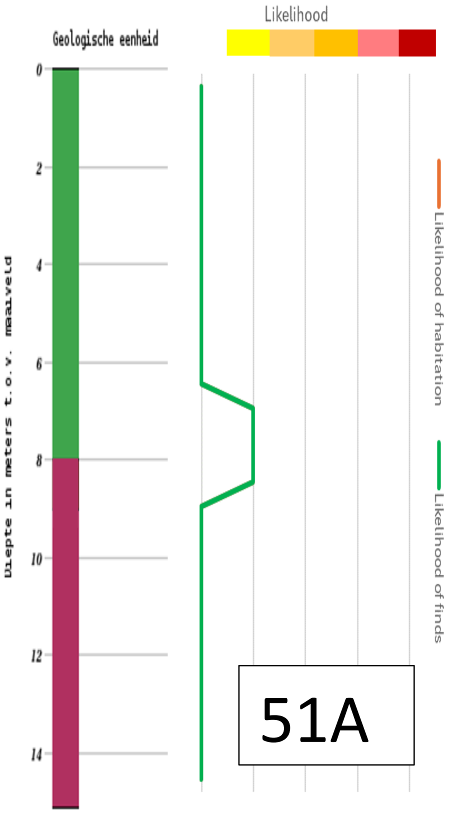
Likelihood of habitation
Likelihood of finds
50C


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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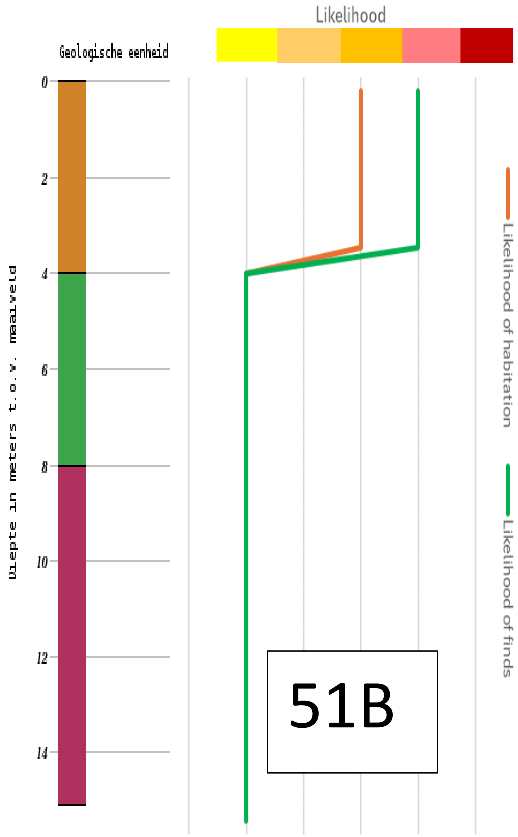
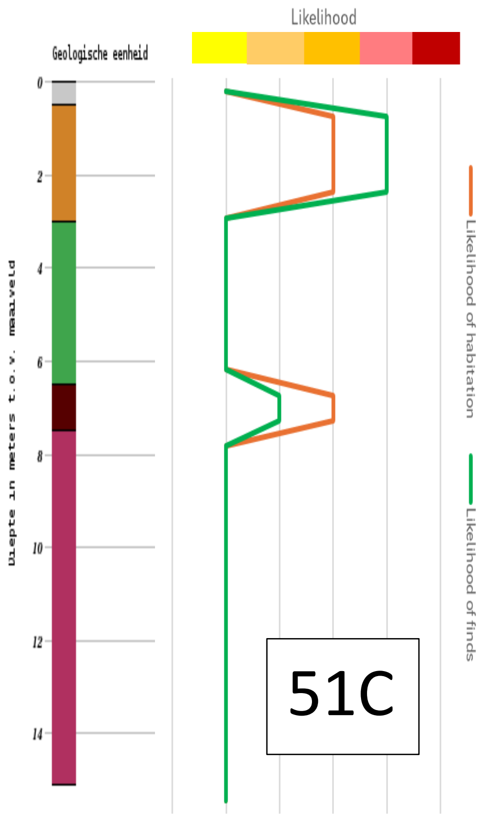
Likelihood of habitation
Likelihood of finds
51A


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
0 2 4 6 8 10 12 14
Likelihood of habitation
Likelihood of finds
51B


Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
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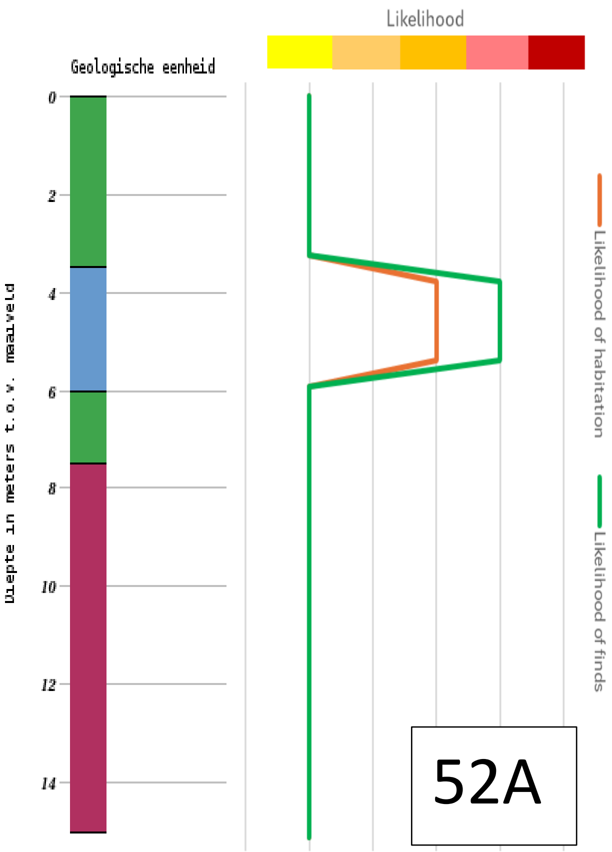
Likelihood of habitation
Likelihood of finds
51C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Likelihood
Diepte in meters t.o.v. maaiveld
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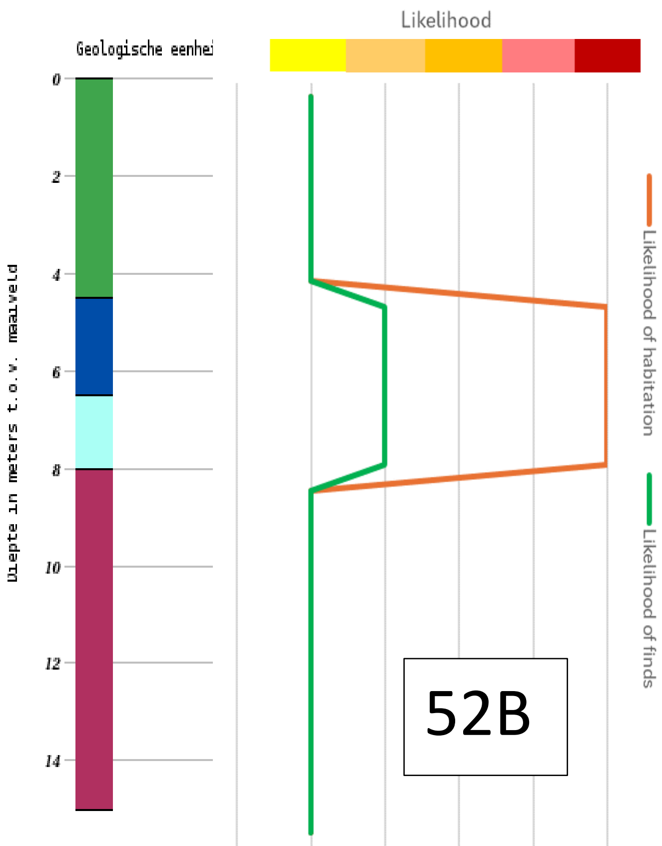
Likelihood of habitation
Likelihood of finds
52A


Geologische eenhei
Likelihood
Diepte in meters t.o.v. maaiveld
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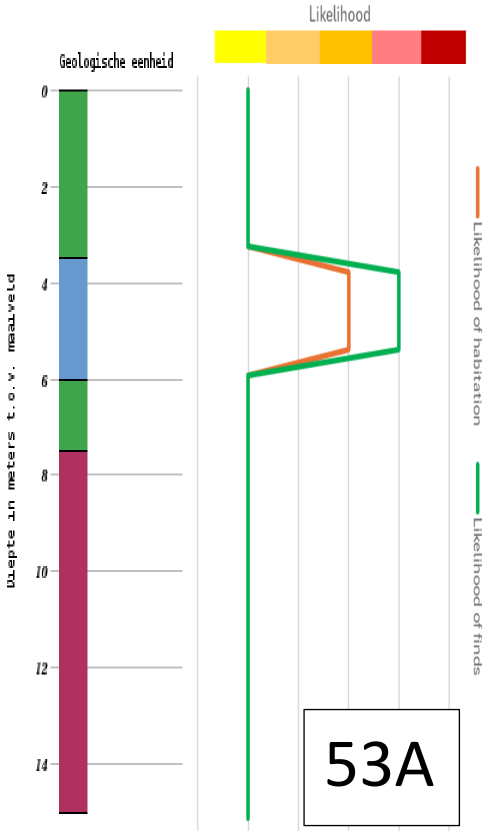
Likelihood of habitation
Likelihood of finds
52B


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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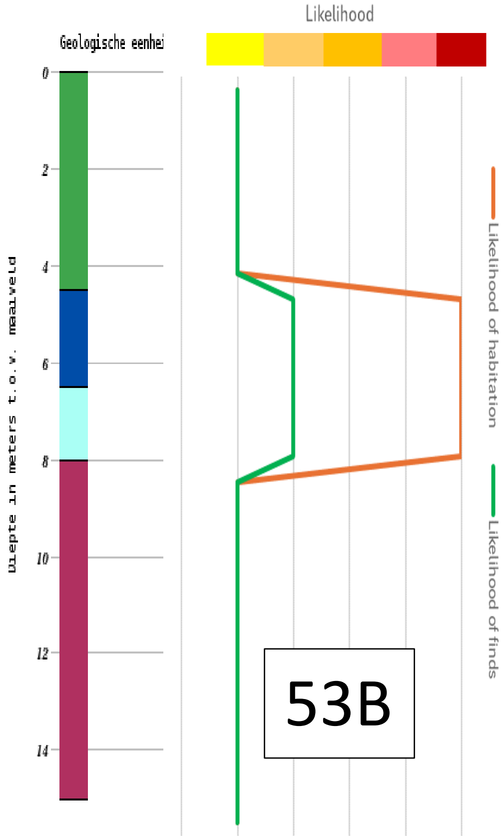
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Geologische eenhei
Diepte in meters t.o.v. maaiveld
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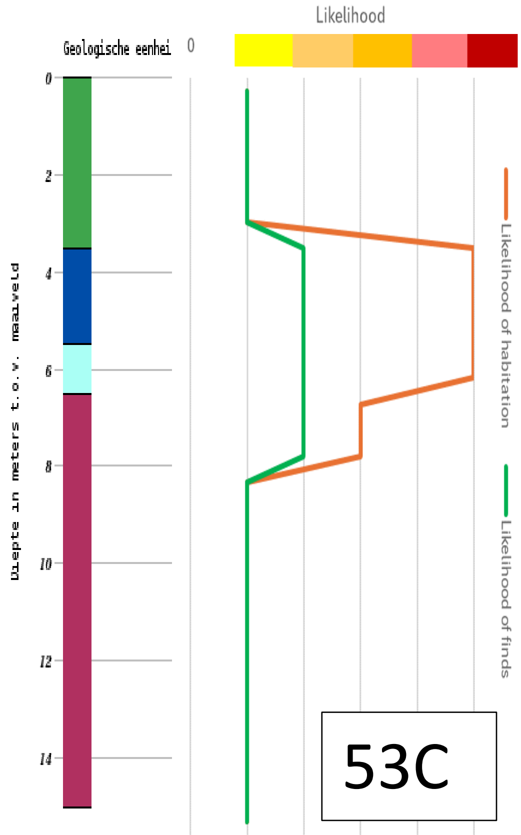
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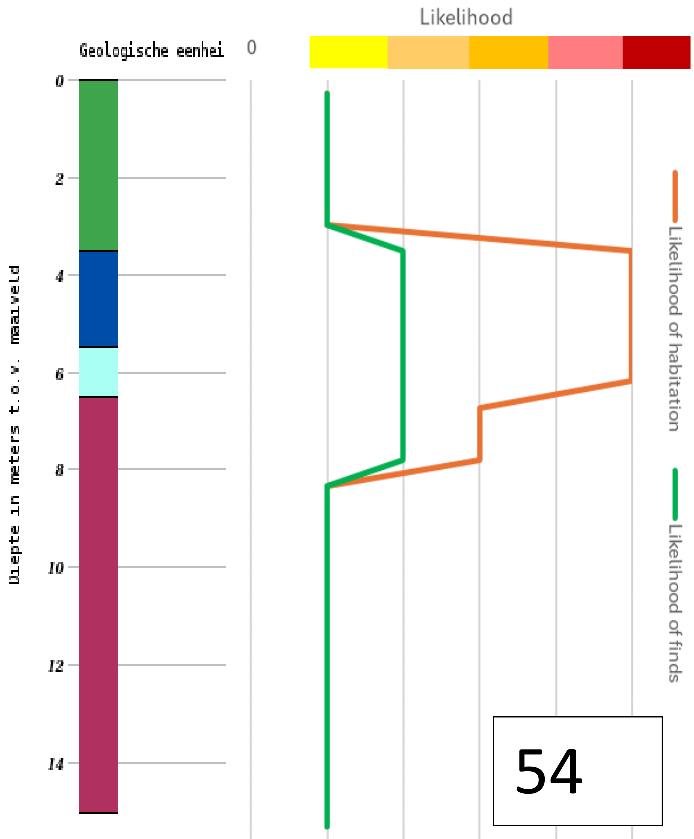
Likelihood
Geologische eenhei
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Diepte in meters t.o.v. maaiveld
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Likelihood of habitation
Likelihood of finds
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Likelihood
Geologische eenhei
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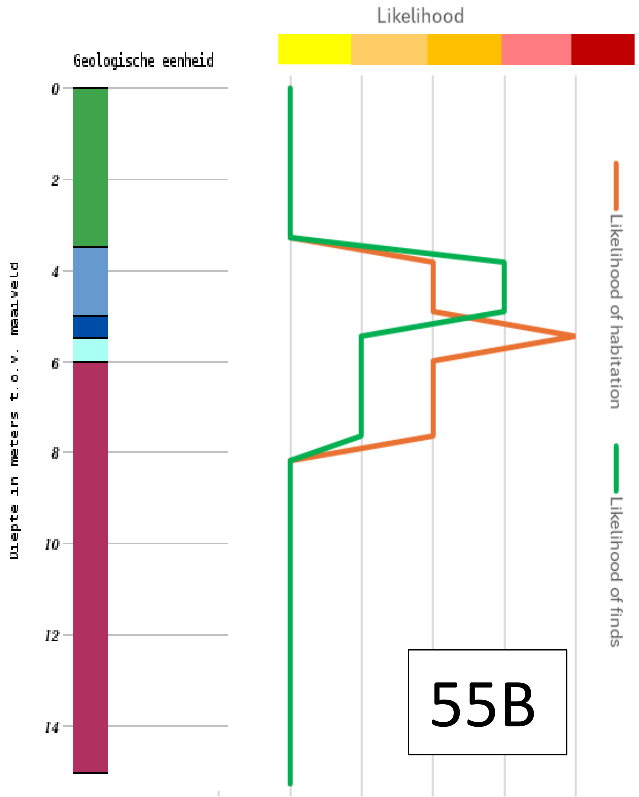
Diepte in meters t.o.v. maaiveld
Likelihood of habitation
Likelihood of finds
55A


Likelihood
Geologische eenheid
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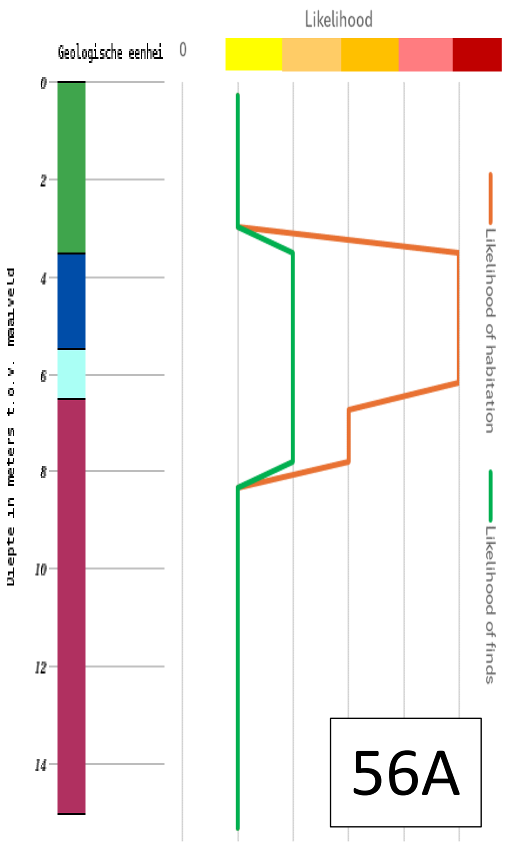
Diepte in meters t.o.v. maaiveld
Likelihood of habitation
Likelihood of finds
55B


Likelihood
Geologische eenhei
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Diepte in meters t.o.v. maaiveld
Likelihood of habitation
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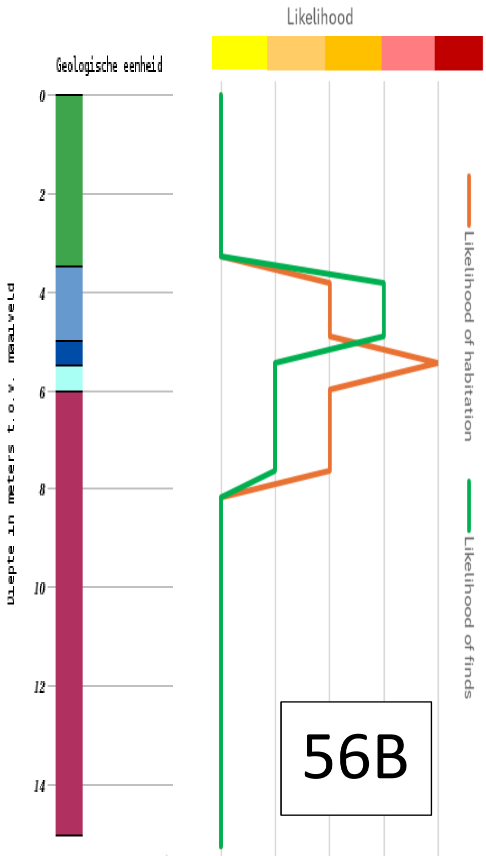
56A


Likelihood
Geologische eenheid
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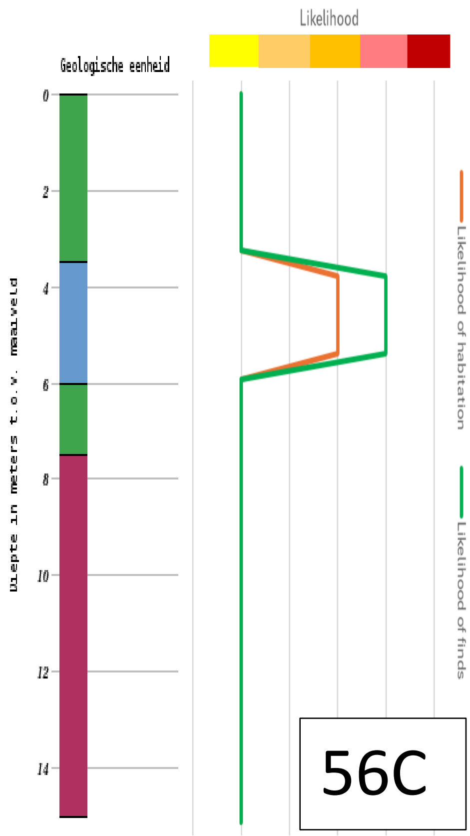
Diepte in meters t.o.v. maaiveld
Likelihood of habitation
Likelihood of finds
56B


Likelihood
Geologische eenheid
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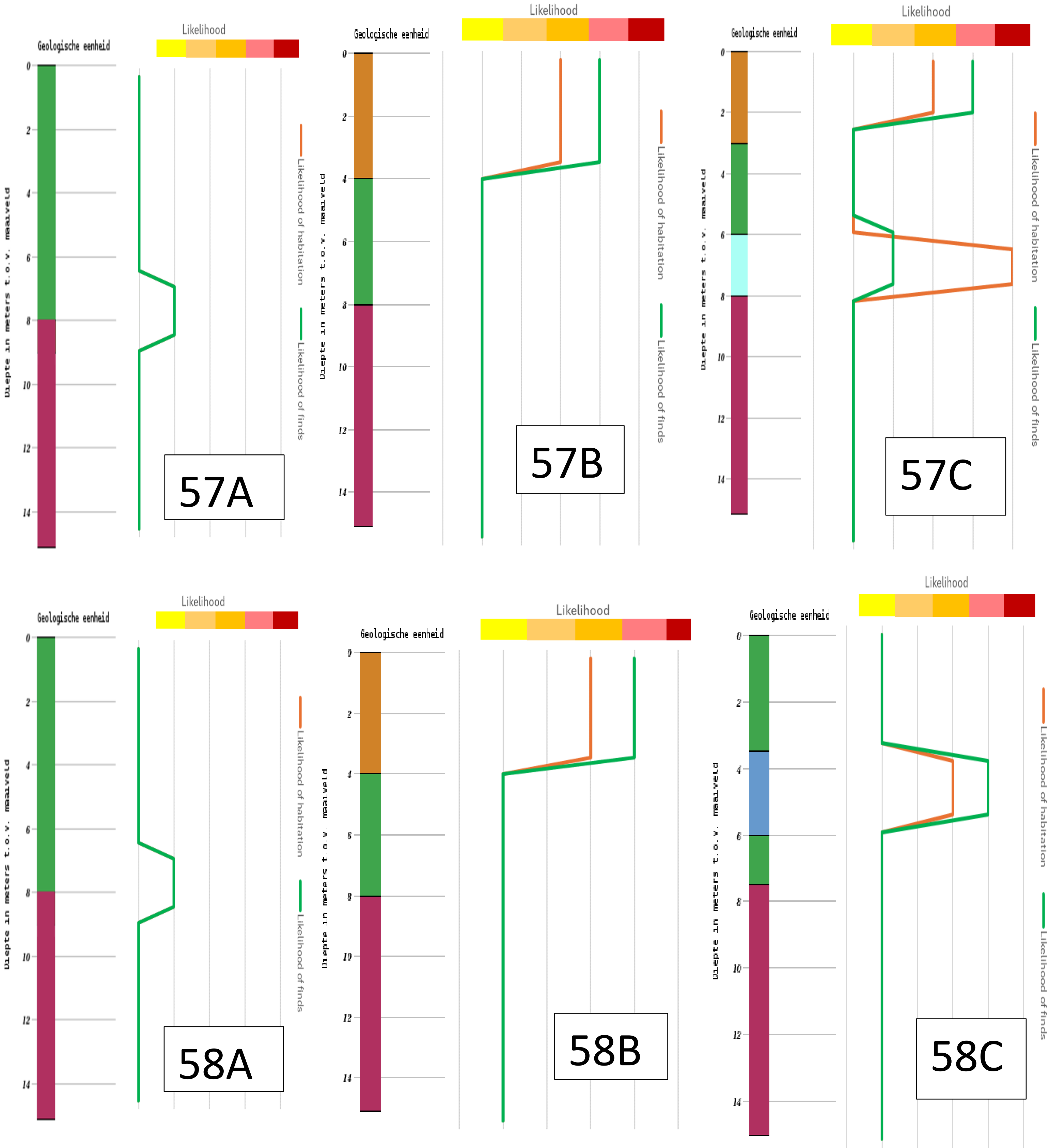
Diepte in meters t.o.v. maaiveld
Likelihood of habitation
Likelihood of finds
56C


57A
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58A
58B
58C
Geologische eenheid
Likelihood
Diepte in meters t.o.v. maaiveld
Likelihood of habitation
Likelihood of finds
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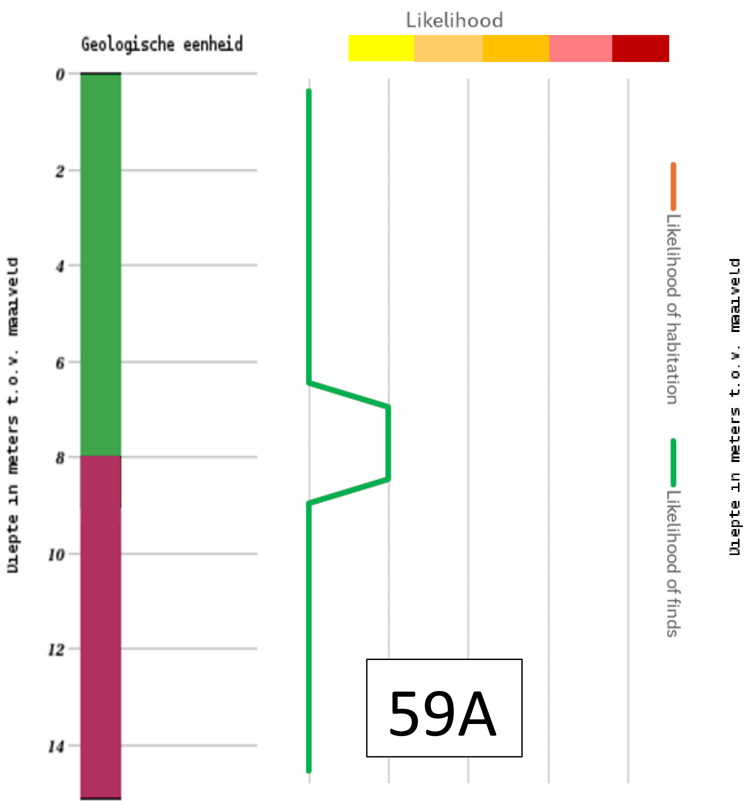
Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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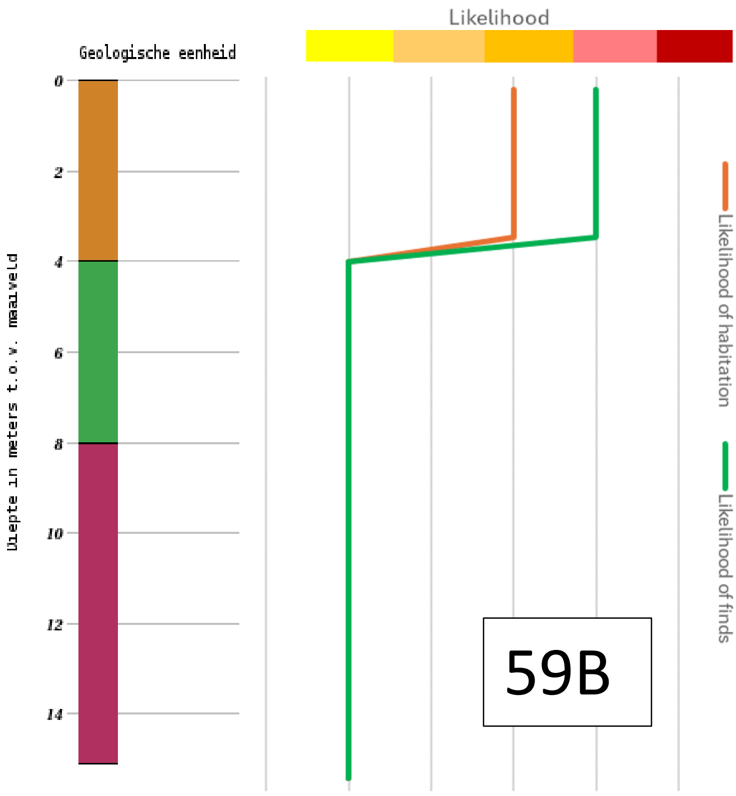
Likelihood of habitation
Likelihood of finds
59A


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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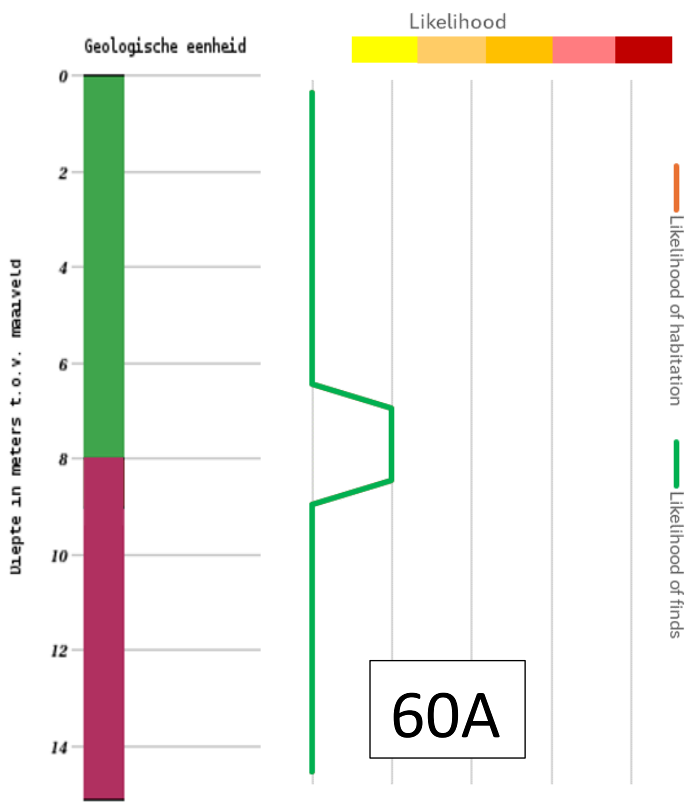
Likelihood of habitation
Likelihood of finds
59B


Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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Likelihood of habitation
Likelihood of finds
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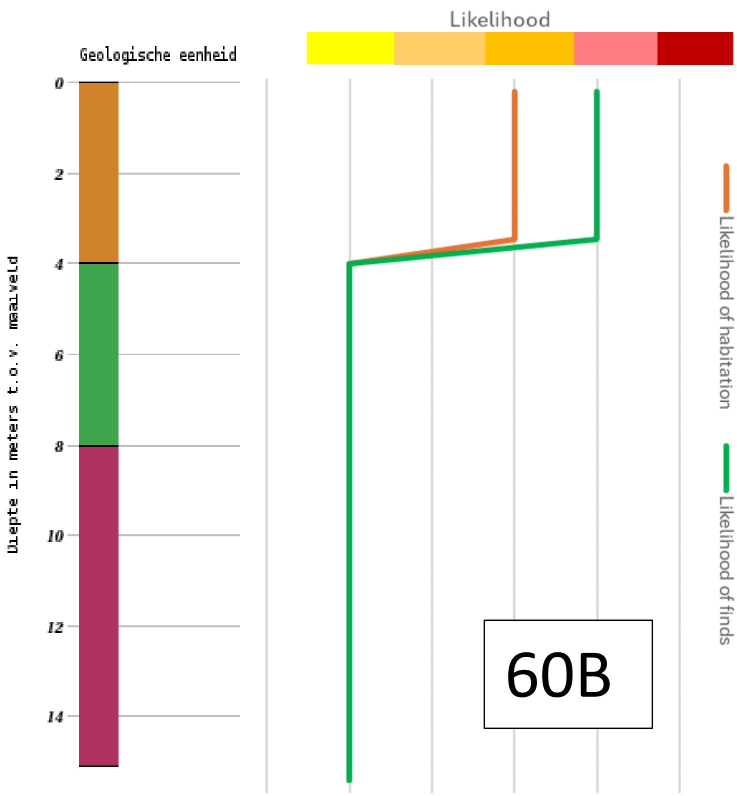
Likelihood
Geologische eenheid
Diepte in meters t.o.v. maaiveld
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Likelihood of habitation
Likelihood of finds
60B