Terp composition in respect to earthquake risk in Groningen

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General Introduction

The ground acceleration experienced as a result of the earthquakes induced by the production of gas from the Groningen field is locally dependent on the shallow geological and soil conditions. This is called the site response. Deltares studied the shallow geological and soil conditions and prepared a detailed model of the shallow subsurface below Groningen. The study results and models are described in a report on the quaternary geology of the Groningen area, which is available at the web-site www.namplatform.nl on the "onderzoeken"-page. Additionally, an introduction to the quaternary geology of the Groningen area by Erik Meijles of the Rijksuniversiteit Groningen is available.
However, these studies and models do not address man-made changes to the shallow-subsurface.
An important man-made change to the shallow subsurface in Groningen are artificial dwelling mounds or terps (regionally called 'wierden'. These are especially important because they form village centres with relatively high population densities. In addition, many buildings on the terps are of cultural importance.
As part of the NAM-led studies program, geographers and archeologists of the Rijksuniversiteit Groningen have investigated the lithological composition and geometry of terps in the province of Groningen. This report provides a database with modelled texture classes of the clastic sediment component of all terps in Groningen. Also micro-scale data on anthropogenic lithology of a selection of terps in the province are provided. This work will form the basis for geotechnical investigations and measurements of the response of terps and the buildings on these terps to earthquakes. Based on the results, the prediction of ground motion on terps will be improved.

Title	**Terp composition** **in respect to earthquake risk in Groningen**	**Date**	March 2016
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Organisation	Faculty of Spatial Sciences / Centre for Landscape Studies, Terp Research Centre and Groningen Institute of Archaeology University of Groningen	**Organisation**	NAM
Place in the Study and Data Acquisition Plan	<u>Study Theme:</u> Ground Motion Prediction <u>Comment:</u> The report describes the lithological composition and geometry of terps in the province of Groningen. This will be used to set up a measurement program for the response of terps to earthquakes. Based on the results, the prediction of ground motion on terps will be improved.		
Directly linked research	(1) Hazard Assessment. (2) Fragility assessment of buildings in the Groningen region (located on terpen).		
Used data	Data of the University of Groningen.		
Associated organisation	Deltares (for follow-up measurements).		
Assurance	Internal assurance at University of Groningen.		

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Terp composition
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Table of contents

1 Introduction 5
1.1 Problem description 5
1.2 Aims and end product 5
2 Methodology 6
2.1 Approach 6
2.2 Pilot area definition and description 6
2.3 Data availability & quality 8
2.4 Terp delineation 10
2.5 Assessing texture using soil map data 11
3 Results 14
3.1 Terps in Groningen: some figures 14
3.2 Composition assessment based on archaeological profiles from individual terps 14
3.3 Conceptual lithological models 20
3.4 Composition assessment based on soil map 23
3.5 A comparison between the composition assessment methods 30
3.6 Terp composition variability - additional remarks 31
4 Conclusions 33
4.1 General conclusion 33
4.2 Recommended additional data acquisition 34
5 References 37
6 Appendices 39
6.1 Database definitions 39
6.2 Work process soil map analysis 49

1 Introduction

1.1 Problem description

NAM is developing a hazard model for induced seismicity resulting from gas production from the Groningen gas field. The aim of this model is to reliably predict ground motions (peak ground accelerations; PGA) at the surface. Detailed knowledge of the shallow sub-surface is essential to estimate ground motions and the local variability in the ground motions.

Although the recently developed GeoTOP model is a detailed reflection of the shallow geology, there is lack of data for the terps (dwelling mound; regionally called “wierde”) in the area covered. The terps are currently mapped as small single geological surface units and are classified as of “anthropogenic composition”. This is also the case for terps on the current geomorphological and soil maps. However, the composition of terps could be an important factor in determining the nature of earthquake impacts on buildings situated on these mounds. Some terps appear to have significantly more house damages than other terps in the direct surroundings, which may indicate a substantial difference in composition, and therefore different effects on PGAs. Although the total area of the terps in the province of Groningen is limited, they are high in number and are important residential areas as well as areas with high archaeological and cultural historical heritage values. From archaeological observations, we know that the lithology of the terps is very heterogeneous. Therefore, there is a need to establish the lithology, geometry and elevation of the terps in order to be able to assess earthquake impacts.

1.2 Aims and end product

The aim of the project is to establish an assessment of the lithological composition and geometry of terps in the province of Groningen. We provide a database with modelled texture classes of the clastic sediment component of all terps in Groningen. We also provide micro-scale data on anthropogenic lithology of a selection of terps in the province. The methodology, results and conclusions will be described in this report and we provide recommendations for further work we find useful or necessary.

2 Methodology

2.1 Approach

To establish the lithological composition of all individual built-over terps within the province by lithological core descriptions would provide a detailed overview of the specifics of all individual terps. However, such cores are currently not available, the number of terps in Groningen is high and obtaining these would mean a large effort, even when only taking into account built-over terps. In the current time-frame with continuous earthquake occurrence, this would not be possible. We therefore aimed to develop a terp-typology, in which the different types would give an indication of the characteristics of terp composition, which could be used as a source for information for earthquake effect estimates. The work was carried out using a mixed method approach.

One approach is to use readily available archaeological data, such as lithological profile descriptions and cores, to get micro-scale information on specific terps. As terps reflect a long period of (permanent) living environment, they consist of a large number of built-up structure remnants with resulting small-scale heterogeneity within the terp. This means that many terps do not solely consist of well-defined layers, but that there also many discordant boundaries present. Such boundaries are not only horizontal but also vertical. They are present because of remnants of discrete house "podia" (former house platforms), refilled fresh water basins (Du: dobbe) or canal remnants. As many terps have been partly quarried (excavated) in the early 1900s and sometimes refilled, some house structures are built on plinth-like structures with vertical boundaries that interrupt horizontal layering. Such small-scale non-horizontal discontinuities could cause instability which may be relevant for earthquake risk assessments. By studying archaeological records, we aimed to get an impression of the micro-scale variability of a selection of terps. In addition, by studying these data, a terp typology model was created which was qualitative and descriptive in nature.

The second approach was to use existing soil and geomorphological maps in combination with LIDAR[1] data to assess texture classes of all terps in the province. By assessing terp volumes and based on the assumption that the terps were mainly composed of sods originally taken from close by, we could make an assessment model of terp lithology. Although this does not provide us with detailed, micro-scale data on individual terps, it does give insight into the regional scale variability of the clastic composition of the terps. Initially we aimed for lithoclass definitions according to GeoTOP, but during the course of the project we refrained from re-interpreting original data and used soil map texture definitions instead.

By comparing the results from the archaeological, terp specific approach, we were able to get an assessment of quality and representativity of both methods. In both approaches, a small number of terps were selected as part of three pilot areas, after which the method was extended to the entire area where possible.

2.2 Pilot area definition and description

Because assessment of all known locations from the start would be too time consuming, three 5 x 5 km pilot areas were selected (Figure 2.1). These pilot areas represent the three major geographical landscape regions in which terps occur. The availability of lithological data was an important criterion. Furthermore, the relative high number of earthquake reports from the Middelstum-Rottum area necessitated extra attention to this particular landscape region. The selection was also based on expert-knowledge. For example, the composition of the terp of Ulrum has been very well described

[1] Surveying method using airborne laser technology to establish high resolution elevation data.

in literature. Middelstum is a good example of a terp that is mainly built up of clayey layers, and the Toornwerd terp consists of a number of plinths.

2.2.1 Pilot area A (Leens-Ulrum)

This pilot area represents the western region of the province, and it is centred across the main east-west saltmarsh ridge on which, amongst others, Leens and Ulrum are situated. This saltmarsh bar consists of extremely silty or sandy clays and even clayey fine sand. The surrounding low-lying areas are also less clayey (and more silty) than elsewhere. The pilot area has been selected to incorporate Leens, from which excavation data are available, as well as Ulrum and Leens-Tuinsterwierde where recent coring data are available. It was noted that Ulrum is represented by a single database entry, but in reality consist of two terps close to each other.

Table 2.1: Pilot area A

Leens-Ulrum	
coordinates (RD)	271,000/598,500 (NW) 222,000/593,500 (SE)
number of terps	48
locations with lithological data	Ulrum, Leens-Tuinsterwierde, Leens-Grote Houw

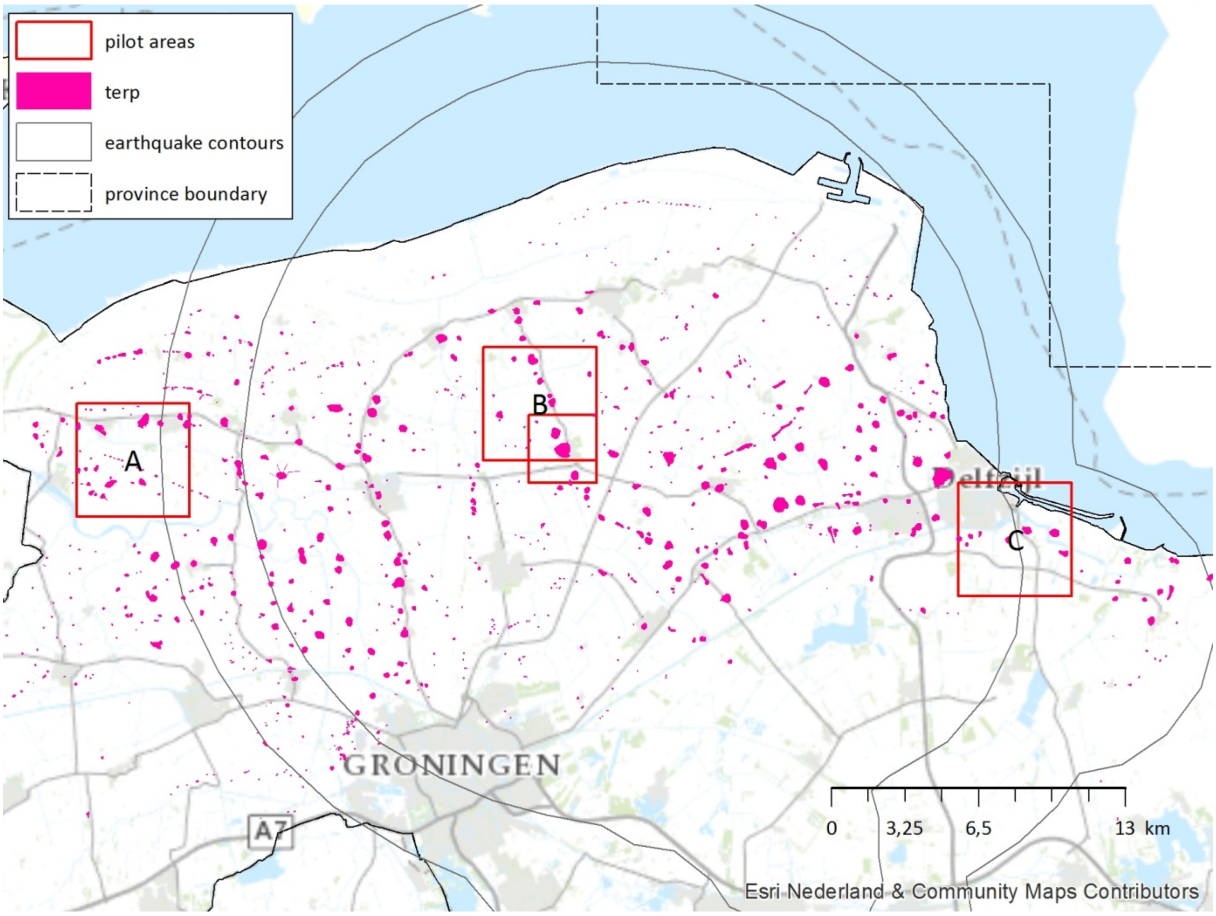


Figure 2.1: General overview of terps in Groningen and the position of the pilot areas

2.2.2 *Pilot area B (Middelstum-Rottum)*

This pilot area is located closest to the centre of the Groningen natural gas field, and as a consequence the number of earthquake reports from this area is relatively high. It also represents the more clayey central region. Kantens, Toornwerd and Middelstum currently consist of multiple polygons in the database; these have been counted as one each in the table below. The pilot area was expanded in the south to fully include Middelstum (Figure 2.1).

Table 2.2: Pilot area B

Middelstum-Rottum	
coordinates (RD)	235,000/601,000 (NW) 240,000/596,000 (SE)
number of terps	24
locations with lithological data	Stitswerd, Middelstum

2.2.3 *Pilot area C (Delfzijl-Heveskesklooster)*

The main difference between this and the other pilot areas is the presence of a substantial peat layer in the Holocene sequence underlying the terps. It is conceivable that this has an effect on the transmission of seismic waves. Although the area contains comparatively few locations, it does encompass part of the Delfzijl industrial zone.

Table 2.3: Pilot area C

Delfzijl-Heveskesklooster	
coordinates (RD)	256,000/595,000 (NW) 261,000/590,000 (SE)
number of terps	9
locations with lithological data	Heveskes, Heveskesklooster

2.3 Data availability & quality

2.3.1 *Provincial terp databases*

The main data source used for the analyses is an internal database containing cultural heritage objects provided by the Groningen provincial government. It contains 527 locations across the entire province. Not all of the locations are real terps; for instance several manors are included that may or may not have an earlier (medieval) raised precursor. The major advantage of this database over the soil and geomorphological maps (see below) is that locations are represented as polygons directly derived from the land registry data, thus providing far more accurate positions and outlines. On the other hand, several locations such as Toornwerd (Figure 2.2 and section 2.4) are represented by multiple polygons, because only “existing” objects are listed; quarried parts of the terps are omitted because they are considered less valuable as cultural heritage. Apart from location data and toponyms, the database also contains some information on the archaeological status of the object as well as a field indicating whether the object is damaged or not. Lithological data are not included.

2.3.2 *Soil and geomorphological maps*

The soil database is based on the soil map of the Netherlands. During several decades in the 20th century, soils were classified on detailed maps based on hand cores and were consequently upscaled to the current 1:50,000 soil map. The soils were classified based on soil pedology and included soil texture and soil texture variations within the top 120 cm of the soil (Stiboka 1981, 1986, 1987; Ten Cate *et al.*, 1995). Soil texture is considered to be a proxy for lithoclasses. Although the maps have been made several decades ago, soil properties relevant to lithoclasses are unlikely to change in such short time periods and therefore, the soil maps are assumed to be of sufficient quality for the purposes of this project. The soil map has not been used to determine terp lithoclasses directly, as on the map the terps are defined as anthropogenic. Details of the method can be found in section 2.5. The geomorphological map was also produced as a regional 1:50,000 scale map, detailing both the relief and shapes of the land surface, including an interpretation of the processes that created the landforms (Koomen and Maas, 2004). In this project, it was expected initially that geomorphological map units (Table 2.4) could be used as a proxy for lithoclass, because local processes determine the composition and grain size of sediments. However, a one-to-one translation from sedimentary environment to lithoclass definition was not possible. We therefore used the geomorphological map as a qualitative tool to check texture consistency. In addition, the map was only used for terp delineation purposes (section 2.4).

Table 2.4: Geomorphological units in pilot areas

type	unit	description (Du)	description
geomorphology	1M35	vlakte van getij-afzettingen	plain with tidal sediments
	2M32	binnendelta-vlakte (+/- klei/zand)	inner delta plain (+/- clay/sand)
	2M35	vlakte van getij-afzettingen	plain with tidal sediments
	2R11	geul van meanderend afwateringsstelsel	former meandering river bed
	2R14	zee-erosiegeul	erosional gully (sea)
	3K31	kwelderwal	salt marsh ridge
	3K33	getij-inversierug	tidal inversion ridge
other	beb	bebouwing	built-up
	T	terp of hoogwatervluchtplaats	terp
	A	afgegraven	quarried/dug
	O	opgehoogd	raised
	V	vergraven	re-dug

2.3.3 LIDAR altitude data

For the province of Groningen, two LIDAR datasets (AHN, Actueel Hoogtebestand Nederland) are available. The AHN1 for Groningen was obtained during 1997-1999 for the coastal region, and 1996-1997 further to the south with a 5-metre resolution, based on a point density of on average 1 point per 16 m^2. The conversion from point to grid data was carried out by an inversed distance interpolation. AHN2, with a 0.5 metre resolution, was obtained in 2009 and was based on 6-10 points per m^2. Grid values were determined only by point measurements within the cell, making the dataset more refined (Van der Zon, 2013). For this project, the filtered products were used, which means that buildings and vegetation are removed from the data. During the course of the project, AHN3 also became available, but which has not been used for this project yet.

2.3.4 Geological data

DINOloket, the Dutch national database for geological subsurface information, was used to obtain the available geological core descriptions for the pilot areas. Table 2.5 shows the number of cores and cone penetration tests (cpt's) per pilot area, as well as the number of cores actually located on one of the terps.

Table 2.5: Overview of available DINOloket data (cores and cone penetration tests) in the pilot areas

pilot area	area (km^2)	cores	density (n/km^2)	cores on terp*		cpt's	density (n/km^2)	cpt's on terp**	
A	25	138	5.5	3	(2.2 %)	42	1.7	1	(2.4 %)
B	25	189	7.6	3	(1.6 %)	31	1.2	4	(12.9 %)
C	25	345	13.8	7	(2.0 %)	297	11.9	3	(1.0 %)

* based on unadjusted terp database (version 7-3-2016) with some manual adjustment; figures in parentheses are percentages of total number of cores

** based on unadjusted terp database (version 7-3-2016); figures in parentheses are percentages of total number of cpt's

From the table it becomes very clear that the geological cores from DINOloket do not form a rich source of lithological terp data. Moreover, because these cores have the specific aim of mapping the natural subsoil, terp layers usually are described as "anthropogenic", for which no further details on the lithological information are provided. In general however, the quality and vertical resolution of the data is good, in particular for the shallower cores, and lithological descriptions are conform the NEN5104 standard (Nederlands Normalisatie-instituut, 1989). Penetration testing results, which potentially provide a better, more detailed picture of terp composition, are also available from DINOloket. However, the usability and usefulness of this dataset have not been explored yet. The number of data points within terp outlines is equally low.

2.3.5 Archaeological data and literature

In addition to the provincial terp database described in section 2.3.1, two major regional inventories of terps and terp-like objects are available. The first inventory by Miedema (1983) was carried out in the area to the northwest of the city of Groningen, and lists a total of 669 archaeological objects. It consisted of an archaeological field survey and description of the locality, often supplemented with one or more hand cores. The lithological description of the cores is not very detailed but often sufficient to get a general idea of terp composition and stratigraphy. Unfortunately, these locations are not referenced to the national coordinate grid (RD) but identified by land registry numbers (Du: 'kadastrale perceelnummers').

A second survey using a very similar method was carried out in the region to the northwest of Appingedam, comprising parts of the (former) municipalities of Appingedam, Bierum, 't Zandt, Loppersum, Stedum and Ten Boer (Miedema, 1990). This study, containing 39 larger and 353 smaller terps, is included in the current research, because an overview map of the locations is provided. Although there are many sites on which archaeological coring has taken place in the past few years, these data have not been used for two reasons. Firstly, the surface covered by these project is generally very small (*e.g.* the size of a planned house or farm building) and the information thus is a mere snapshot of terp composition. Secondly, persisting problems with the accessibility of the national archaeological database ARCHIS during the writing period of the report meant that data regarding these projects could not be analysed. The relevant paragraphs in the results section therefore provide an overview of the locations (the majority of which fall within the pilot areas) for which extensive lithological information, predominantly from excavations, is available.

2.4 Terp delineation

The terp delineations based terp, soil and geomorphological maps were of varying quality. The maps were originally created on the 1:50,000 scale and were mapped mainly on the basis of their location. However, as detailed LIDAR data and aerial photos are currently available, these data were used to define the terp delineation in more detail. In this way, more accurate data on the extent, altitude and volume could be achieved. The delineation of all terps in the pilot areas (around 70) was improved. However, as the total amount of terps in the province is much higher, we only corrected terp delineation in the pilot areas.

The three different source datasets of terps were first merged in a GIS (Figure 2.2). Then for each individual built-up terp, the outline was checked on a 1:10,000 scale approximately and digitally corrected where necessary based on aerial photos, (historical) ordnance survey and altitude maps. As for the lithological analysis the original, unquarried terps were needed, we digitally restored the quarried terps were necessary. In the database a field was entered detailing if parts of the terp were removed.

Figure 2.2: Example of terp outline correction for the terp Toornwerd (pilot area B) with aerial photo (left) and LIDAR image. The red and green lines indicate the geomorphological and soil map definitions, which reflects a 1:50,000 scale representation of the full, original terp. The yellow line comes from the provincial database, reflecting the actual terp status. The pink line is the interpretation used for this study on a more detailed scale, based on aerial photo and LIDAR data. Sources: Aerodata Eelde and AHN.

2.5 Assessing texture using soil map data

When estimating the lithological composition of the terps, it is assumed that the lithology is similar to the direct surroundings of the terp. Since raising a dwelling mound with sods is labour-intensive, it is assumed that material from local saltmarshes was used to build the terp (Postma, 2015). Therefore, we designed a method to use data on the direct surroundings as a tool to estimate terp lithology. We used a combination of LIDAR data (AHN), the soil map of the Netherlands (scale 1:50,000) and the geomorphological map of the Netherlands (scale 1:50,000).

Based on the altitude difference between terp and surroundings, the volume of the terp was estimated. As LIDAR data were either not detailed enough (AHN1) or buildings were not filtered out effectively enough (AHN2), the volume of terps was assumed to be defined mathematically by a cone. The possible altitude difference between the terp "sole" and the surrounding areas (caused by later sedimentation) was ignored in the calculation. We also ignored the possible effects of manure-rich layers. It was assumed that the sods required for the construction of the terp consisted (based on archaeological evidence of sods from the terps) of the top 15 cm of the soil. The volume was converted to an area based on the topsoil definition and then reconverted to a buffer zone surrounding the terp (Figure 2.3).

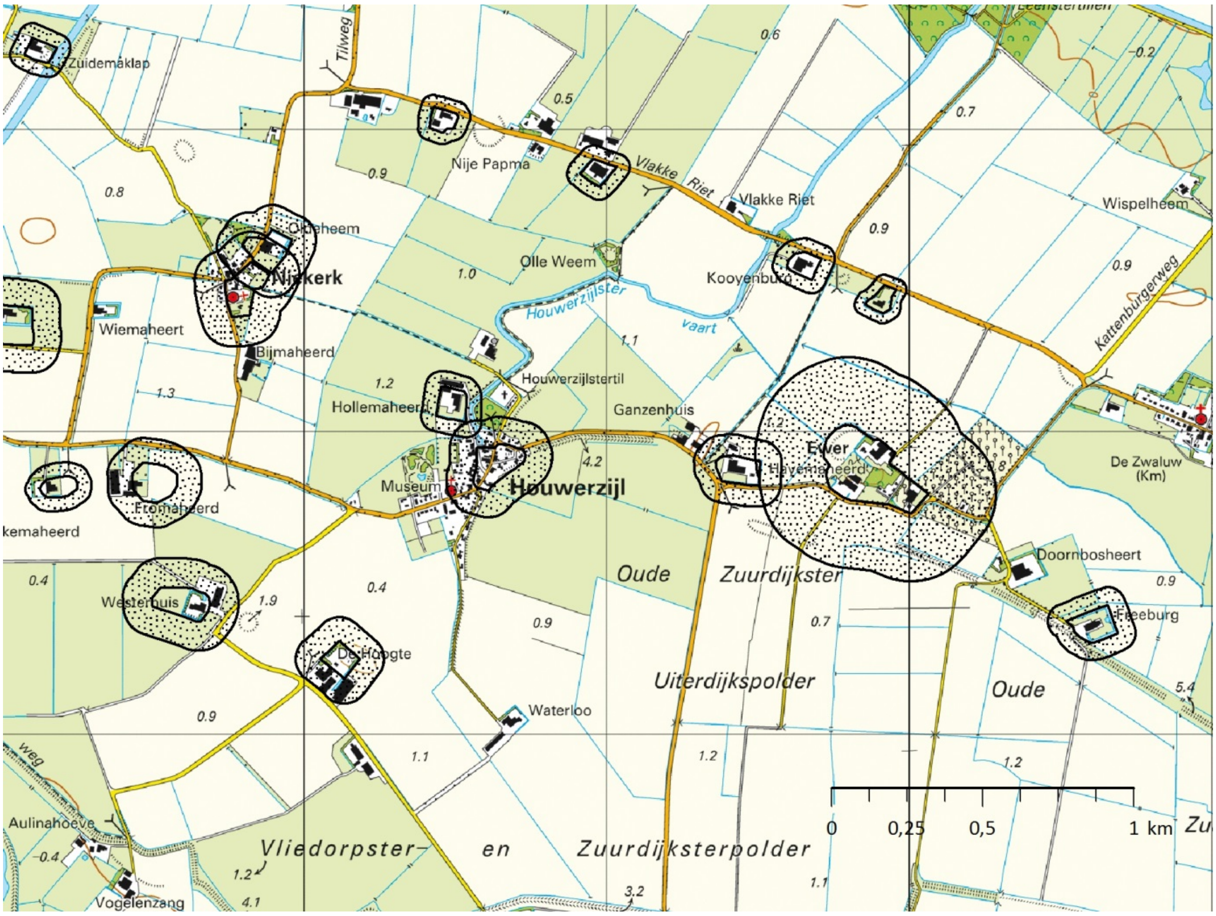


Figure 2.3: Example of volume and buffer calculation around terps (Topographical data: Dutch Land Registry Office, 2009).

With this buffer, a selection was made of the geomorphological and soil maps. Soil texture classes were similar to lithoclasses and regarded as such. The relative proportion of the different lithoclasses were assigned to the individual terps as percentages.

Table 2.6: Litho class definitions according to the GeoTOP en REGISII models (from Stafleu et al., 2013)

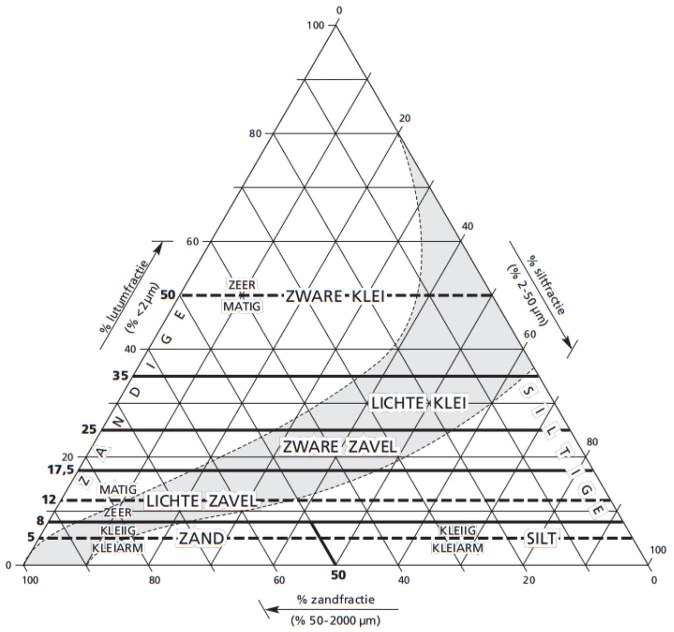
lithoklasse (Du)	lithological class	grain size
antropogeen	anthropogenic	-
organisch materiaal (veen)	organic deposits (peat)	-
klei	clay	-
kleiig zand, zandige klei en leem	clayey sand and sandy clay	-
fijn zand	fine sand	≥ 63 µm & < 150 µm
midden zand	medium sand	≥ 150 µm & < 300 µm
grof zand	coarse sand	≥ 300 µm & < 2000 µm
grind	gravel	≥ 2000 µm
schelpen	shells	-

Table 2.7: Soil fractions as defined in the Dutch soil map (Ten Cate et al., 1995)

fraction	grain size
lutum or clay	< 2 µm
silt	2-50 µm
loam (combined lutum and silt)	<50 µm
sand	50-2000 µm
gravel*	>2000 µm

*not considered as part of the texture.

The soil map contains data per soil unit on topsoil ('bouwvoor') texture, which is comparable but not the same as lithoclass definitions as, for example, in the GeoTOP geological model (Table 2.6). Lithoclasses are classes in a classification of soil composition whereas texture is defined as the soil grain size distribution (Ten Cate *et al.*, 1995) and is based on the proportion of the three main fractions smaller than 2000 µm: lutum, silt and sand (Table 2.7). Although the texture is defined from the soil after removal of gravel, in the case study this is not relevant, as the marine sediments (soil map code M) do not contain gravel. The combined lutum and silt fraction is defined as loam. Gravel (>2000 µm) is not regarded here and left out (Figure 2.4; Stiboka, 1981; Ten Cate *et al.*, 1995). As in this study we deal with marine sediments (Dutch soil map unit M), the latter is regarded as not relevant. The term 'zavel' is a typical Dutch term, defined as mineral material consisting between 8-25% mass fraction of lutum (Ten Cate *et al.*, 1995). As there is no well-defined international definition, we refer to the 'zavel' in this report.



code	class (Dutch)	class (English)	lutum (%)
not in M soil class	kleiarm zand	clay-poor sand	0-5 %
not in M soil class	kleiig zand	clayey sand	5-8 %
1	lichte zavel	light 'zavel'	8-17,5%
2	zware zavel	heavy 'zavel'	17,5-25%
3	lichte klei	light clay	25-35%
4	zware klei	heavy clay	> 35%
5	zavel	'zavel'	8-25%
6	zavel en lichte klei	'zavel' and light clay	8-35%
8	klei	clay	>25%

<table>
<tr><th colspan="2">name</th><th>% lutum</th><th colspan="3">code</th></tr>
<tr><td rowspan="2">zavel</td><td>Light 'zavel'</td><td>8-17,5</td><td>1</td><td rowspan="2">5</td><td rowspan="3">6*</td></tr>
<tr><td>Heavy 'zavel'</td><td>17,5-25</td><td>2</td></tr>
<tr><td rowspan="2">clay</td><td>Light clay</td><td>25-35</td><td>3</td><td rowspan="2">8</td></tr>
<tr><td>Heavy clay</td><td>> 35</td><td>4</td><td></td></tr>
</table>

*'zavel' and light clay (8-35% lutum)

Figure 2.4: Texture classification[2] of non-aeolian sediments. From: Ten Cate et al., (1995, p. 173).

[2] Strictly speaking, this definition holds for non-aeolian sediments only. However, aeolian deposits are not present in the topsoil of the study area.

3 Results

3.1 Terps in Groningen: some figures

There are 993 terps in the province of Groningen (Table 3.1), according to the combined provincial Terp database, the geomorphological and soil maps, of which the majority (> 700) fall within the earthquake risk zone ('red contour line'). This number may be a slight overestimate, because locations from different sources may (partly) overlap, or locations still consist of multiple polygons (see for instance Figure 2.2). The total area of terps is approximately 1600 ha (0.7% of the total mainland area of the province) which means the spatial extent is limited. However, the terps are often built-up, form village centres and have relatively high populations densities. In addition, the terps are rich in archaeological and cultural historical heritage. The villages have a high proportion of monumental buildings, ranging from houses to churches and manors. Built-up terps have an average area of slightly over 2 ha and most of them are relatively small. The size ranges from 0.04 to more than 30 ha (Middelstum). Around 343 terps have a size larger than 1 ha and only 16 are larger than 10 ha. It is estimated that there are around 570 overbuilt terps, which are relatively large in area. We consider a terps as overbuilt, when there is at least one single house built upon. We only take into account these terps.

Table 3.1: Number of built-up terps in Groningen

built-up type		**count**	**total area (ha)**	**average area (ha)**
none		423	464.2	1.1
single	house	369	361.0	1.0
	church	1	2.4	2.4
	manor	4	13.9	3.5
spread		141	584.3	4.1
village		47	206.2	4.4
infrastructure		8	6.3	0.8
Total built-up terps:		570	1174	2.1
Total nr. of terps:		993	1638	1.6
Total area province (mainland): 2400 km^2				

3.2 Composition assessment based on archaeological profiles from individual terps

3.2.1 Introduction

As has been stated above, the main source of lithological information about terp composition are archaeological excavations. Archaeological documentation is available for several locations excavated during the 1920s and 1930s as well as the 1980s and the start of the 21st century. Although the sections from these excavations will always provide insight in the spatial variability within the terp body, it was apparent that the quality of these observations may not meet the standards needed for our research.

The following paragraphs therefore provide an overview of the available lithological information. The focus of this analysis strongly rests on the information that can be gleaned from individual locations, but an attempt will be made at summarising and synthesising the results into models that can be used more widely, including locations for which currently no information is available.

3.2.2 Ulrum (pilot area A)

In 2015 and early 2016, a project aimed at obtaining a provisional archaeological cross-section of the two terps underneath Ulrum was carried out as part of the larger Terpen- en Wierdenland project[3]. To date, 23 hand cores (3 or 5 cm Ø) have been described. Most cores cover the entire anthropogenic layer, which in places can be over 4 m thick. The quality of core descriptions is good, conforming to the NEN5104 standard (Nederlands Normalisatie-instituut, 1989) as far as possible.[4] Although coverage is quite low, the cores do give a good impression of the overall composition of the terp bodies. The eastern terp consists of an up to 2 m thick manure-rich layer, overlain by 2 m thick , almost entirely clastic (strongly silty clay) anthropogenic layer.

The western terp on the other hand consists of a lower (but considerably thinner) anthropogenic manure-rich layer overlain by an up to 0.4 m thick natural flooding layer (clay with sandy laminations) and a second anthropogenic layer, similar in composition and thickness to the upper layer of the eastern terp. Although the differences in lithology between the eastern and western terp probably are not significant (at least not within the framework of the current project), the presence of a presumably continuous intercalated layer may have an effect on the transmission or refraction of seismic waves.

3.2.3 Leens – Tuinsterwierde Zuid (pilot area A)

The excavations at Leens – Tuinsterwierde are famous for their well-preserved remnants of sod houses, probably dating to the 6th and 7th century AD (*e.g*. Van Giffen, 1940). Several cross sections, dating to between 1925 and 1939, are available. Despite being several decades older, their quality is somewhat higher than other excavation sections, because they are annotated with some lithological descriptions. The most important aspect of the sections is the presence of the remnants of sod-walled houses. These remains, which can be up to 1 m or 1.5 m high in total, 1 m wide and between 15 m and 20 m in length, provide a good indication of the scale and extent of lithological and structural heterogeneity of the lower anthropogenic layer here and in other locations. In this respect it is unfortunate that these houses were not build with a preferential orientation (pers. comm. drs. D.A. Postma, GIA), as this would have made incorporation in a (geophysical) model perhaps somewhat easier.

The recorded sequence is as follows:

natural subsoil:	(rooted?) clay, overlain by a shell layer and a second, bioturbated clay layer containing *Phragmites*-remains and a fine sand layer (probably upper marsh or marsh ridge deposits), the top of which appears trampled or ploughed, or contains a paleosoil;
anthropogenic layer 1:	up to 2.7 m thick and 4 m to 6 m wide beds of alternating clay and manure-rich layers, separated by 1 m wide remnants of sod-walled houses. Elsewhere, the layer is more homogenous and contains ashy layers. The entire layer can be seen to decrease in thickness towards the flanks of the terp (e.g. section 1926-19)
anthropogenic layer 2:	found only in section 1926-19, this layer consists of sandy clay and clay with sand lamination but is also labelled “yellow terp soil”. Although on the drawings it appears to be a homogeneous anthropogenic layer, the “clay with sand layers” may point to a (partly) natural origin similar to Ulrum-Oost (see above). Maximum thickness is approximately 1 m, becoming thinner towards the flank but increasing in thickness again, thus more or less levelling the section profile.
top soil:	greenish clay, thickness c. 0.75 m

[3] http://terpenenwiedenland.nl/het-project/; last accessed 8 March 2016

[4] The NEN5104 is designed primarily to describe natural deposits, and as a consequence archaeological layers, such consisting entirely of sods of different lithology, or manure-rich layers, are often very hard to classify properly.

Other than the sod-walled houses already mentioned, the sections show several disturbances and larger-scale features including pond-like depressions, ditches and wells.

3.2.4 Leens – De Houw Oost (pilot area A)

As part of a larger multidisciplinary study into the erosion of terps, part of the location Leens – De Houw, an adjoining raised homestead (location ID 713) and surrounding area was investigated with 23 hand cores on three transects. The western north-south transect shows a similar composition as for instance Ulrum-Oost, with a lower, manure-rich anthropogenic layer and an upper, clayey anthropogenic layer. This twofold division is less clear-cut in the other two transects, suggesting the oldest core of the terp in this case may be considerably smaller than the present-day extent. The homestead is probably only recognizable as a 0.5 m thick layer containing clay lumps and some charcoal in a single core. However, as both terp and raised homestead are currently in use as farmland, it is likely that a substantial part of the uppermost anthropogenic layers has been incorporated into the modern plough soil.

Figure 3.1: The strikingly homogeneous composition of the Wierhuizen terp (near Appingedam) visible during the commercial exploitation of the terp earth in 1916. (Photo: unknown)

3.2.5 Middelstum (pilot area B)

In recent years, a large part of the sewer system in Middelstum has been replaced, during which many archaeological observations have been made. Unfortunately, at the time of writing these data were not published or available yet but in the near future they may contribute significantly to the understanding of this location.

3.2.6 Stitswerd (pilot area B)

In 2011, a coring campaign was undertaken as a pilot project to further refine the archaeological base maps for the area around Stitswerd (Vos, 2011). Two cores are located on the terp of Stitswerd, and are described as having a peat layer underneath the anthropogenic layers. However, full core descriptions are not included in the report, and neither are these available from the DINOloket database.[5]

[5] last checked 15-01-2016

3.2.7 Heveskes (pilot area C)

The 54 m long south section from the 1994 excavation is the most informative drawing from this location. The drawing is coloured but unfortunately a legend or lithological annotations are absent; lithological data therefore are inferred. The average combined thickness of the anthropogenic layers is approximately 2,5 m. The sequence consists of the following:

natural subsoil:	clay (coloured blue), with an apparently trampled top;
anthropogenic layer 1:	brown/stripy coloured layer frequently with labelled sods; thickness between 0.8 m and 1.2 m (average 1.0 m). It remains unclear whether this layer consist of manure-rich material, or of humic clay sods.
anthropogenic layer 2:	rather homogeneous greenish-coloured (possibly clayey) layer; maximum thickness 1.4 m ; average thickness 0.4 m
top soil:	disturbed, contains brick fragments, thickness 1.0 – 1.5 m;

The section shows several recent ditches or similar features cut into the archaeological layers. The widest of these ditches are respectively 8 m and 4 m wide and up to 2 m deep.

Figure 3.2: Excavation Heveskesklooster 1982. From this picture the natural subsoil directly above the megalithic tomb shows cracks due to shrinkage, which is typical for heavy clay with (very) little sand. Directly above the clay, the sods (with intercalated manure) are more sandy as can be seen from the absence of cracks (photo: H.A. Groenendijk)

3.2.8 Heveskesklooster (pilot area C)

In the 1980s, a number of archaeological excavations took place at this location (Figure 3.2 and Figure 3.3) which was to be destroyed to make way for industrial developments. As a result, many excavation plans and sections are available but as with the data from Heveskes (see above) these generally lack in the detailed lithological information required by this project. However, by inference it is possible to use these data, if only because this is the best-documented location in the area. The recorded sequence is as follows (as documented in drawing 88-94, west section expansion WP 9/11):

natural subsoil:	the natural subsoil starts with cover sand from peri-glacial origin, followed by a *c.* 1 m thick basal peat layer, a clay layer, of which the upper half contains many *Phragmites* remains and one or two vegetation horizons;
anthropogenic layer:	only a single, fairly homogenous anthropogenic layer appears to be present.

The section show many disturbances, in particular in the upper part. Many of these disturbances have been caused by the construction and later demolition of Medieval abbey buildings once present on the location. Remains of a later farmhouse are also present.

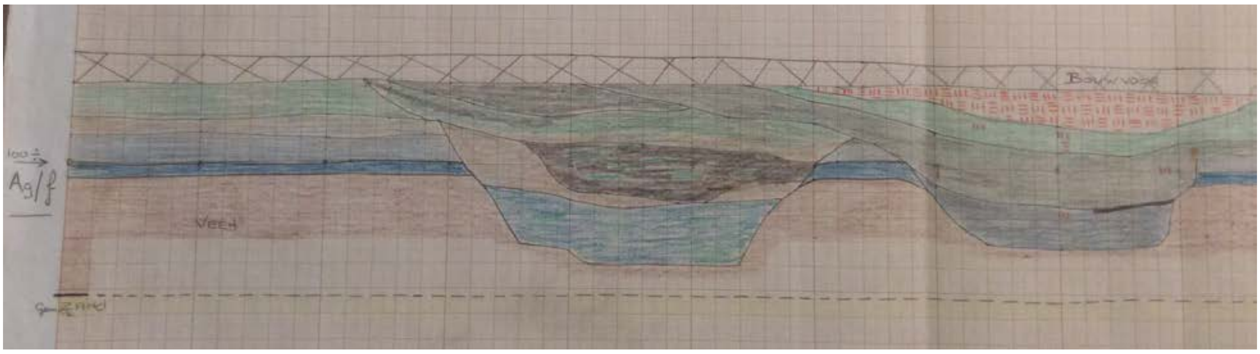


Figure 3.3: Example of an archaeological cross section of the Heveskesklooster terp (north profile, original scale 1:20). The soil is composed of peat superimposed with clay with a darker vegetation horizon. The green section indicates the terp sods (with brick remains in red). It is assumed that the blue layer indicates natural clay deposits. (Drawing: G. Delger, Groningen Institute of Archaeology, University of Groningen)

3.2.9 Lalleweer (outside pilot areas)

A section through the location may be available but has not been located yet. This section could be interesting because Lalleweer appears to be a medium sized terp.

3.2.10 Fransum (outside pilot areas)

For this location, which was partially excavated in 1948, only limited section information exists. Unfortunately, the base of anthropogenic layers was not reached or recorded. The description of the anthropogenic layers itself is, as in other locations, rather minimal, with only a few annotation of layers as terp soil ("terp soil") and manure. The minimum thickness of the anthropogenic layers is 3.75 m at highest part of the location.

Figure 3.4: Photograph (1925) of the Ezinge excavation showing the in-terp variability of sods, manure and house remains. (Photo © Groningen Institute of Archaeology, University of Groningen)

3.2.11 Ezinge (outside pilot areas)

Ezinge is one of the most famous terp excavation in the Netherlands (Figure 3.4). During several campaigns in the 1920s and 1930s many plans and sections were recorded (*e.g.* Van Giffen 1926; 1928) which, in many respects, provide better detail than some of the excavations performed in later years. The sections for instance show a distinction between straw-rich and clay-rich manure (respectively “stroomest” and “kleimest”) as well as different types of clay. From the sections is apparent that a large part of the terp consisted of manure or manure-rich layers, while towards the flanks these become intercalated with clay layers. Later cut features occur regularly, as well as the remains of wooden houses. A more detailed analyses of the sections (field drawings) from this location might provide even better insight in the variability (in occurrence and thickness) of the various anthropogenic layers.

3.2.12 Westeremden (outside pilot areas)

Excavated and documented at the same time and by the same person, Westeremden provides lithological information in the same quality and detail as Ezinge although the number of sections is lower (Van Giffen, 1926). Here too, a basal anthropogenic, manure-rich layer is covered by clay terp layers, which on the flanks become progressively thicker at the cost of the manure layers. On the whole, the sections from Westeremden appear to be more layered than those at Ezinge.

Figure 3.5: Several terps have been (partially) refilled with dredging material. This oblique aerial photo shows the refill of Wierum, with the original terp remainder in the centre. (Photo: H. Breedland, Province of Groningen)

3.2.13 Wierum (outside pilot areas)

This location (Figure 3.5) is perhaps one the first of a “new generation” of terp excavations, and provides some very detailed sections (Nieuwhof, 2006). Although at least 9 occupational phases have been recognised in the sections, the overall lithological composition appears to be somewhat simpler, as the section photographs show. In contrast with older excavations, the report also includes a full list of lithological layer descriptions. The lithological sequence consists of a c. 1 m to 1.25 m thick layer of manure and organic-rich clay, overlain by a second, more clayey anthropogenic layer of a similar thickness. Larger cut features are rare, with the exception of several ditch-like features cut into the natural saltmarsh deposits underlying the terp.

3.2.14 Englum – Lege Wier (outside pilot areas)
An approximately 100 m long section is available for the location Englum – Lege Wier, a terp partially destroyed by quarrying in the early 20th century (Nieuwhof, 2008). Here too, as in Wierum described above, the lower part of the anthropogenic sequence consists of manure- and organic-rich clay layers; the upper part appears less organic but this cannot be verified from the published sections because of a lack of lithological description or clear photographs (Figure 3.6).

Figure 3.6: Englum during archaeological research in 2000, with alternating manure and clay layering visible in the background of the exposure. (Photo: J. Bosboom, Province of Groningen)

3.3 Conceptual lithological models

The previous paragraphs clearly show that, in comparison to the total number of terps, the number of locations with lithological data covering a larger part of the terp is limited, even though the pilot areas have been chosen to incorporate several of the better known locations. However, from the descriptions it may seem as though all terps in the province can be described by a few, relatively simple models.
Since terps are not limited to Groningen, some of the concepts underlying models presented here have been developed in neighbouring areas, mainly Friesland. The models explicitly do not represent an archaeological model with multiple occupation phases; instead they more or less "summarise" (the lithology of) the deposits originating from these occupation phases removing the majority of the temporal depth. Where the lithology of layers is related to a certain period, as it often seems to do, a parallel between archaeological and lithological model obviously remains. Another important aspect to keep in mind is that at this stage the models are unscaled, merely providing an idea of relative size and extent of lithological similar layers. Furthermore, the models have been constructed assuming the top soil is similar in composition and other relevant properties to the underlying layer(s). However, if at any stage it should become apparent that for instance the presence of (brick) foundations does influence seismic wave propagation, then the models should be amended accordingly.

The two main models developed here are a basic single-layer model (section 3.3.1) and a two-layer model (section 3.3.2). However, from the available data, two clear deviations from the two-layer model emerge. Both can be described by a three-layer model, but because of the differing processes leading to the formation of the intercalated layer, they will be discussed separately in sections 3.3.3 and 3.3.4 respectively. The models are drawn schematically in Figure 3.7.

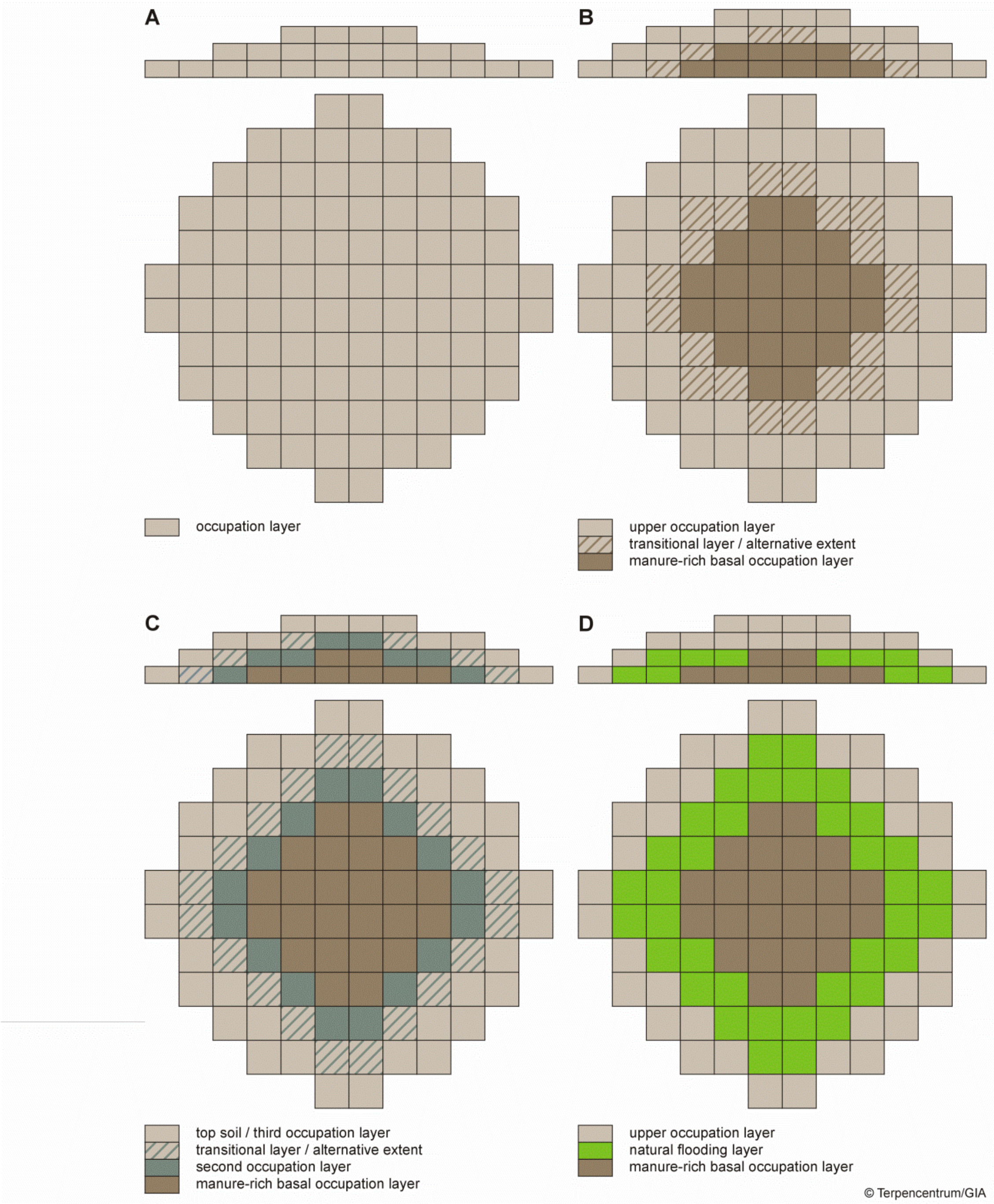


Figure 3.7: Four terp layer models. A: single-layer model; B: two-layer model; C: three-layer model with three occupation layers; D: three-layer model with two occupation layers and intercalated flooding layer.

3.3.1 Single-layer model

Although there is almost no information on the smallest category of terps (historical homesteads) from the research area, recent research in Friesland suggests many of them can be adequately described by a single-layer lithological model. Older homestead terps may have an older occupation layer, often consisting of coarse clay and sometimes peat sods, but in a strictly lithological sense these older layers probably do not differ much from the younger layers. However, depending on the resolution of the seismic model, it may be possible to make such a distinction after all, and in that case a scaled-down version of the two-layer model for larger terps (discussed below) could be used.

3.3.2 Two-layer model

For larger terps, i.e. terps that are large enough to have accommodated several homesteads, it seems a fairly simple two-layer model suffices in most cases. The model (for the moment) only incorporates the larger-scale layers and their overall geometry. It ignores irregularities, incorporated structures (such as the remains of walls of sod houses), later cut features (ditches, ponds, wells) or remains of stone walls and foundations.

Analyses of the available lithological information for the larger (older) terps in the pilot areas show that the general stratigraphy of the terp body can be described by two units, namely a lower unit rich in manure, and an upper, almost entirely clastic unit.

manure-rich unit

composition:	this unit consists either entirely of organic matter (compressed manure) or of an alternation of dm-scale manure-rich layers and more clastic layers (usually trampled sods). The excavation results from Leens-Tuinsterwierde show that the interiors of sod-walled houses are filled by alternating manure-rich and clayey layers. Alternatively, excavations in Friesland have shown that more massive, thicker manure-rich layers can be found next to (flanking) the podia on which houses stood.
discontinuities:	within this unit, the remains of sod-walled houses can be expected, as well as smaller scale features. House plans measure approximately 20 x 6 m (type Leens A; Postma, 2015) or less; remnants of walls are c. 1 m wide but can be up to 1.5 m high. Alternatively, excavations at Ezinge have shown that the remains of wattle-work walls may also be present. Later cut features are relatively rare.
lithoclass:	this unit is, because of its' composition, fairly similar throughout all pilot areas. Any difference in lithology will be due to the clastic component, and to a lesser extent, the ratio between manure-rich and clastic material. In terms of lithoclasses, this unit probably resembles organic deposits, but it is far more compact and, due to the inclusion of sod structures and other archaeological features, far less homogenous. A separate lithoclass may be needed to adequately describe this unit.

upper occupation layer / clastic upper unit

composition:	generally strongly or more sandy clay, without obvious layering. Generally relatively poor in anthropogenic inclusions (such as charcoal or brick fragments).
discontinuities:	this unit is assumed to be a (very) late addition to the terp, and added in a single phase. As a result discontinuities are rare, but remnants (foundations or extraction trenches) of later building may well be present.
lithoclass:	the lithology of the upper unit depends strongly on the source material available at the time of terp construction. In pilot area A (the most westerly of the three) the upper layer thus consists of strongly silty clay or even clayey very fine sand; in the eastern pilot areas the lithology is (as far as it is possible to tell at this stage) more clayey. Lithoclasses probably can be attributed accordingly.

3.3.3 Three-layer model (three occupation layers)
The Heveskesklooster terp is, in terms of documentation, one of the best-known locations in the province. Several cross sections are available, but these unfortunately lack detailed lithological descriptions. However, from the drawings it is apparent that this location is best described by a three-layer model. This is mostly due to the presence of a thicker than usual top soil, containing the remains of the foundations and extraction ditches of the medieval buildings once present on the site. In this respect, it may serve as a test case for other location with older buildings. The lower two layers resemble the manure-rich lower unit and clastic upper unit described above.

3.3.4 Three-layer model (two occupation layers and intercalated flooding layer)
Recent hand coring in Ulrum, a village straddling two terps, showed an interesting difference between the two terps. The eastern terp consists of a sequence of manure-rich deposits overlain by a clastic occupation layer, with a combined thickness of up to 4 meters. The western terp on the other hand shows a sequence of a relatively thin basal manure-rich layer and up to 2 meters of clastic occupation layer. These layers are separated by a layer of flooding deposits (silty clay with thin sandy layers) with a maximum recorded thickness of approximately 0.75 m. Although the flooding deposits may be similar in overall lithology to the overlying occupation layer, their (assumed) continuous presence between the anthropogenic layers may have an effect on the seismic properties of the terp body.

3.3.5 Model applicability
Based on expert judgment and assumptions on subsoil lithology and perhaps age of the terp, it should be straightforward to assign a model to each terp or terp category for which little or no lithological information is available. However, as the neighbouring terps of Ezinge and Englum for instance show, this is clearly not the case. These two terps, dating from the same period and located only 1.4 km m apart in similar landscape environments, have a markedly different composition. As a consequence assigning a lithological model to any terp is fraught with problems, and is therefore not attempted in this project.

3.4 Composition assessment based on soil map

3.4.1 Pilot areas
Figure 2.3 and Figure 3.8 show an example of the resulting zones surrounding terps that were expected to have functioned as a source area for sods for terp construction (section 2.5). The extent clearly increased with the size (volume) of the terp, extending on to the former salt marsh flats or ridges. The composition of the terp was based on the relative proportion of different texture classes within the zone. It has to be noted that this method only resulted in modelled composition of clastic sediments only. It does not provide any information on possible additional layers such as manure or shells, ash and brick remains to a lesser extent.

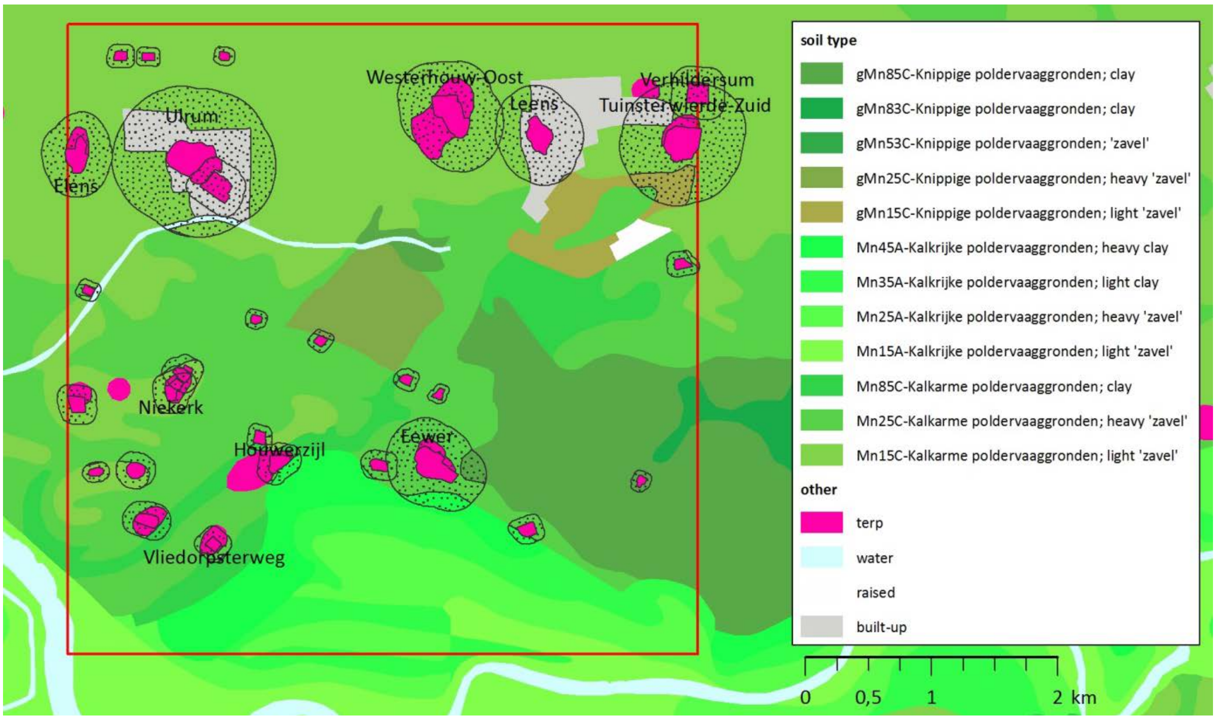


Figure 3.8: Example of soil texture buffer areas (dotted) of built-up terps in pilot area A.

The figures in this section show the different texture proportions of the terps in the pilot areas. Generally speaking, terps show a high proportion of relatively sandy sods in pilot area A (Figure 3.9 and Table 3.2) compared to pilot area B and C. Most terps appear to be composed of light and heavy 'zavel'.There is some variation in modelled terp texture composition between terps, as it can be observed that only the more southerly located terps in pilot area A (the terps Eewer, Houwerzijl and Vliedorpsterweg) seem to have a higher proportion of sods with a higher clay content. This is probably due to a different sedimentary environment during the construction period, which is shown by the geomorphological map (Figure 3.9 bottom). The plains with tidal sediments (the former salt marsh plains) have generally formed by relatively gentle sedimentary processes, in which mostly clayey sediments has been deposited and the proportion of sandy sediments is limited. Terps that are closer to or lie upon the former salt marsh are therefore expected to have a higher clay content. Most of the terps in the area are originally located at the slightly higher salt marsh ridges, which are composed of sandier deposits. In other words: the more northerly terps are on the salt marsh ridge (geomorphological unit 3K31), with light, sandy soils. The terps to the south are in a flat, tidal plain (2M35) with slightly more clayey sediments. This shows, that the geomorphological map can be used in a qualitative way to explain the variety in soil texture.
Some terps have a relative large proportion of unknown ('other') sediments, which means that these areas comes from unmapped soil units in the modelled source area surrounding the terp, such as built-up areas, water, or anthropogenic units: the terp themselves. These units were all combined to a single classification unit 'other' and should be interpreted as 'no data'.

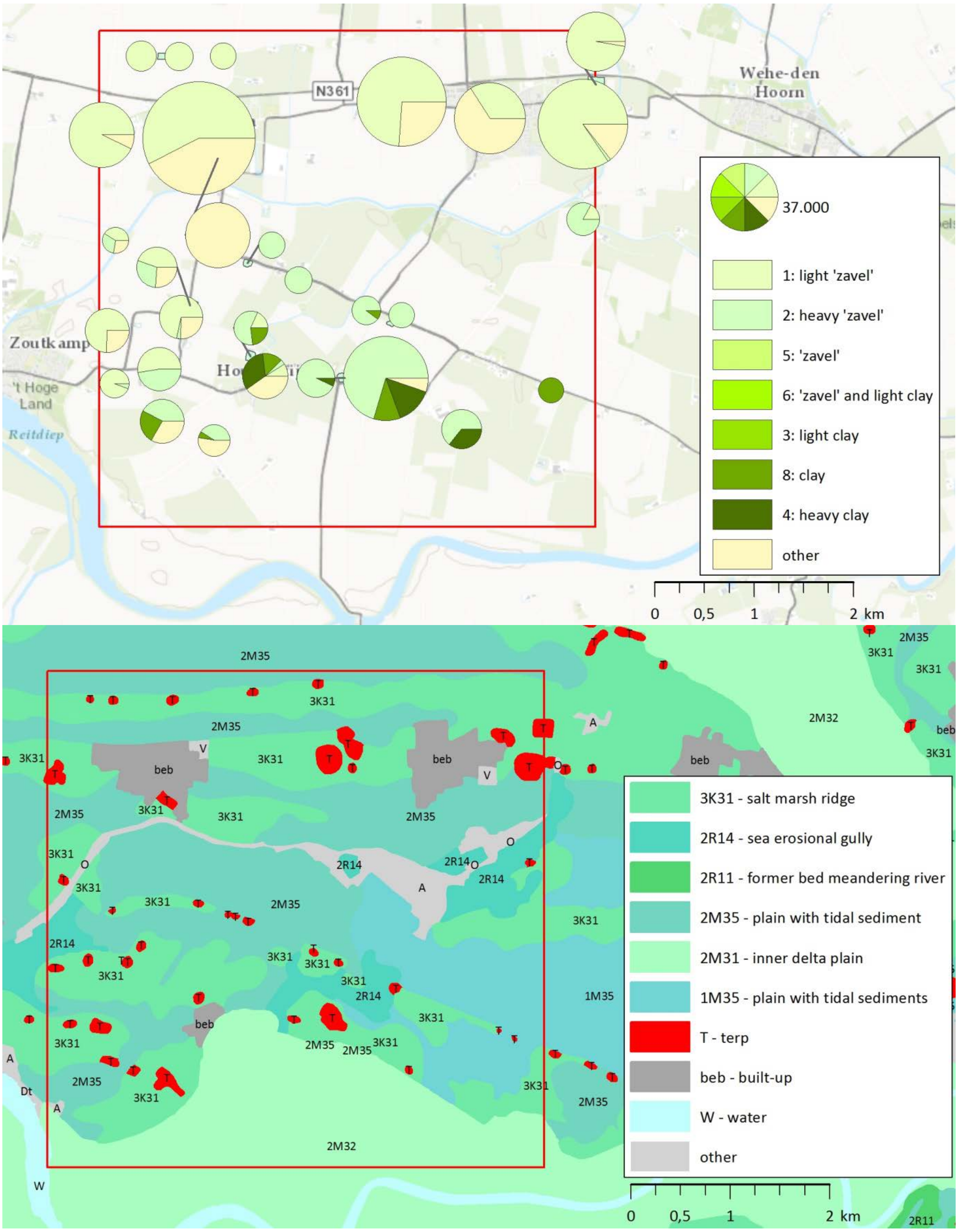


Figure 3.9 Texture proportions for the terps in the pilot area A (top) with the geomorphological map (bottom). The charts are proportioned relative to the terp size. Topographic background: ESRI & Community Maps

Table 3.2: Sample of texture proportion of some terps in pilot areas.

id	pilot area	terp name	area	height surr.	height top	volume	radius sods	texture proportion (code/description)							
			(ha)	(+m NAP)	(+m NAP)	(m^3)	(m)	1	2	5	6	3	8	4	
								light 'zavel'	heavy 'zavel'	'zavel'	'zavel/light clay	light clay	clay	Heavy clay	other
156	A	Eewer	5.8	0.8	3.5	52178	224	0	70	0	0	0	10	14	5
135	A	Elens	3.4	0.7	3.8	34844	187	93	0	0	0	0	0	0	7
146	A	Houwerzijl	1.7	0.9	2.7	9822	89	9	4	0	0	0	14	33	40
170	A	Leens	4.1	1.2	5.2	54048	243	34	0	0	0	0	0	0	66
140	A	Niekerk	1.5	1.0	3.2	11077	99	71	3	0	0	0	0	0	25
6	A	Tuinsterwierde-Zuid	6.5	1.0	5.8	103346	346	84	1	0	0	0	0	0	14
141	A	Ulrum	10.2	0.9	5.5	157447	426	57	0	0	0	0	0	0	42
714	A	Verhildersum	2.8	0.9	2.9	18212	124	97	0	0	0	0	0	0	3
143	A	Vliedorpsterweg	0.8	1.0	3.5	6808	80	0	41	0	0	0	6	0	53
159	A	Westerhouw-Oost	6.4	1.1	4.4	69689	267	74	0	0	0	0	0	0	26
538	B	Bethlehem	1.7	-0.2	2.4	14611	117	0	0	0	0	0	79	0	21
747	B	De Andere Wereld II	0.7	-0.2	1.1	3022	46	0	0	0	91	0	0	9	0
211	B	Eelswerd	4.4	0.2	2.8	38487	191	0	37	0	20	0	31	0	13
214	B	Kantens	8.1	0.3	5.6	143796	414	0	73	0	3	0	21	0	2
691	B	Kantens	3.4	0.6	1.3	8763	67	0	96	0	0	0	0	0	4
695	B	Kokshuis	0.7	0.2	1.8	3978	56	0	0	0	0	0	99	0	0
220	B	Middelstum	36.6	0.4	4.0	436847	681	0	21	0	16	0	50	1	13
723	B	Oosterburen I	1.2	0.3	2.1	7216	77	0	99	0	0	0	0	0	0
539	B	Rottum	13.9	-0.2	5.4	260946	562	0	16	9	1	24	47	0	3
721	B	Siewertsmaheerd	1.3	0.3	1.7	5857	65	0	62	0	0	0	38	0	0
195	B	Stitswerd	4.6	0.2	3.8	55496	243	0	1	0	30	0	64	0	5
222	B	Toornwerd	14.0	0.2	3.3	146443	385	0	40	0	8	0	41	0	11
398	C	Amsweer	2.3	-0.9	2.2	23625	155	0	0	0	0	0	57	26	17
572	C	Geefsweer	6.5	-0.5	1.4	40121	181	0	0	0	0	0	91	9	0
404	C	Heveskes	7.1	0.9	4.1	76236	279	0	49	0	0	0	0	0	51
402	C	Weiwerd	8.2	0.0	3.3	88798	302	0	37	0	0	0	27	1	35

Pilot area B shows more variation within the area which ranges from light 'zavel' soils to heavy clays (Table 3.2 and Figure 3.10), although the clay content on average is higher than in pilot area A. Also in this area there is a clear link with sedimentary environment. The majority of the area is composed of the plain with tidal sediments according to the geomorphological map: the salt marsh flats. The salt marsh ridge is relatively narrow here, which means that – according to our method – the source areas for sods expands from the ridge onto the former salt marshes. Terps on the salt marsh ridge (Rottum, Kantens, Toornwerd en Middelstum) therefore have a mixed texture, in which about half is taken up by lighter texture whereas the other have consists of (heavy) clay. It does not appear that the clastic terp composition of these terps deviates substantially among each other. Terps not situated on the ridge (e.g. Stitswerd, Kokshuis) are almost completely consisting of clay. The variation within pilot area C (Figure 3.11) is large, but because of the limited number of terps (n=4), there is no clear relation with their natural surroundings.

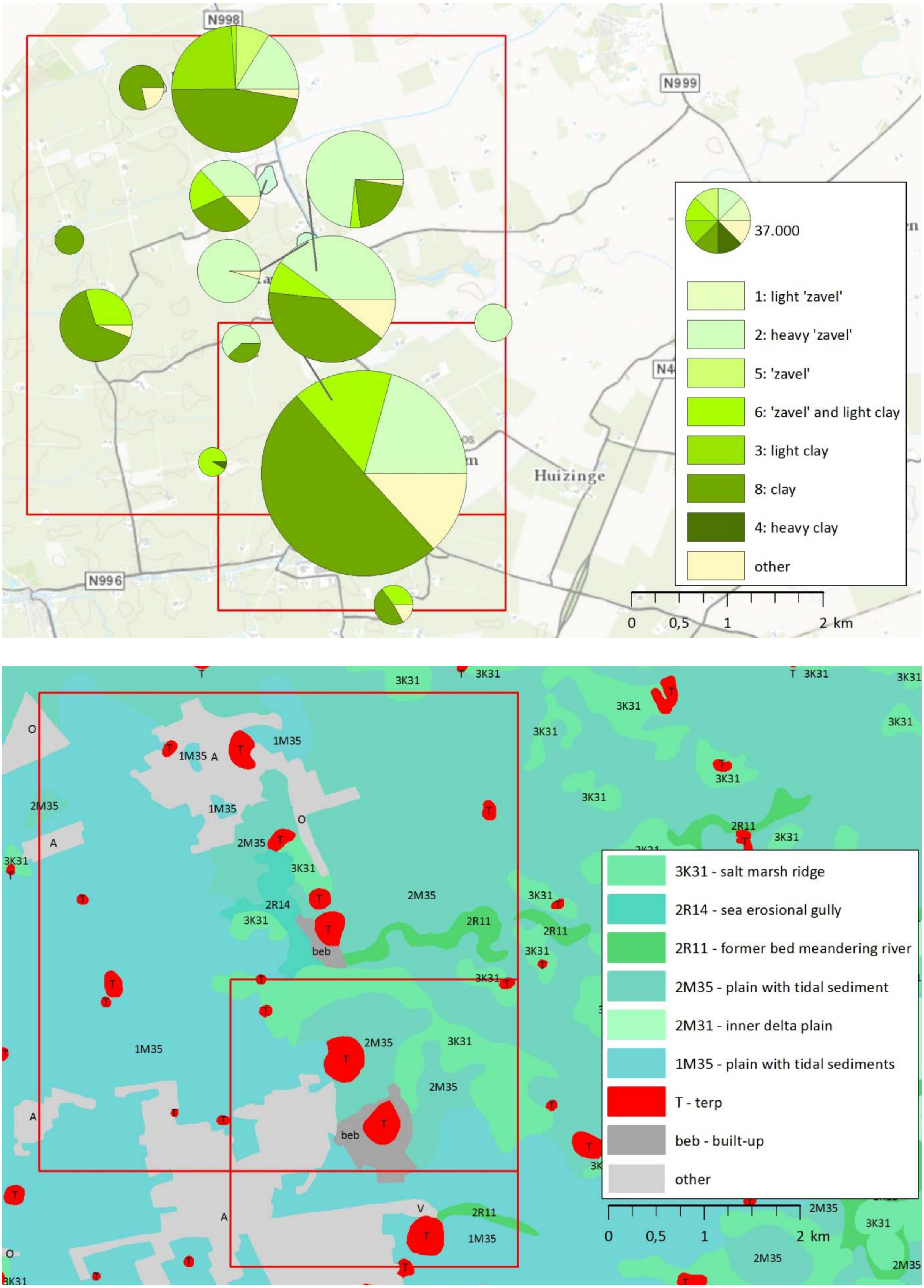


Figure 3.10 Texture proportions for the terps in the pilot area B (top) with the geomorphological map (bottom). The charts are proportioned relative to the terp size. Topographic background: ESRI & Community Maps

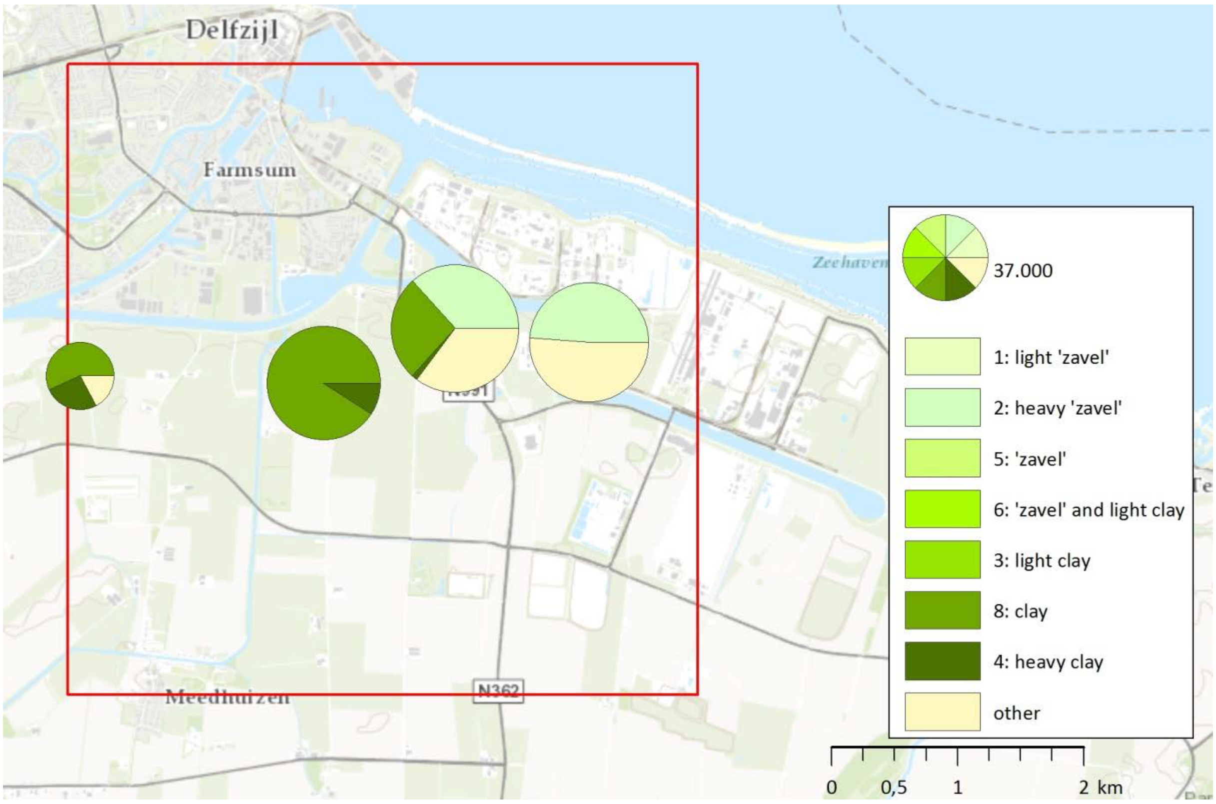


Figure 3.11 Texture proportions for the terps in the pilot area C. The charts are proportioned relative to the terp size. Topographic background: ESRI & Community Maps

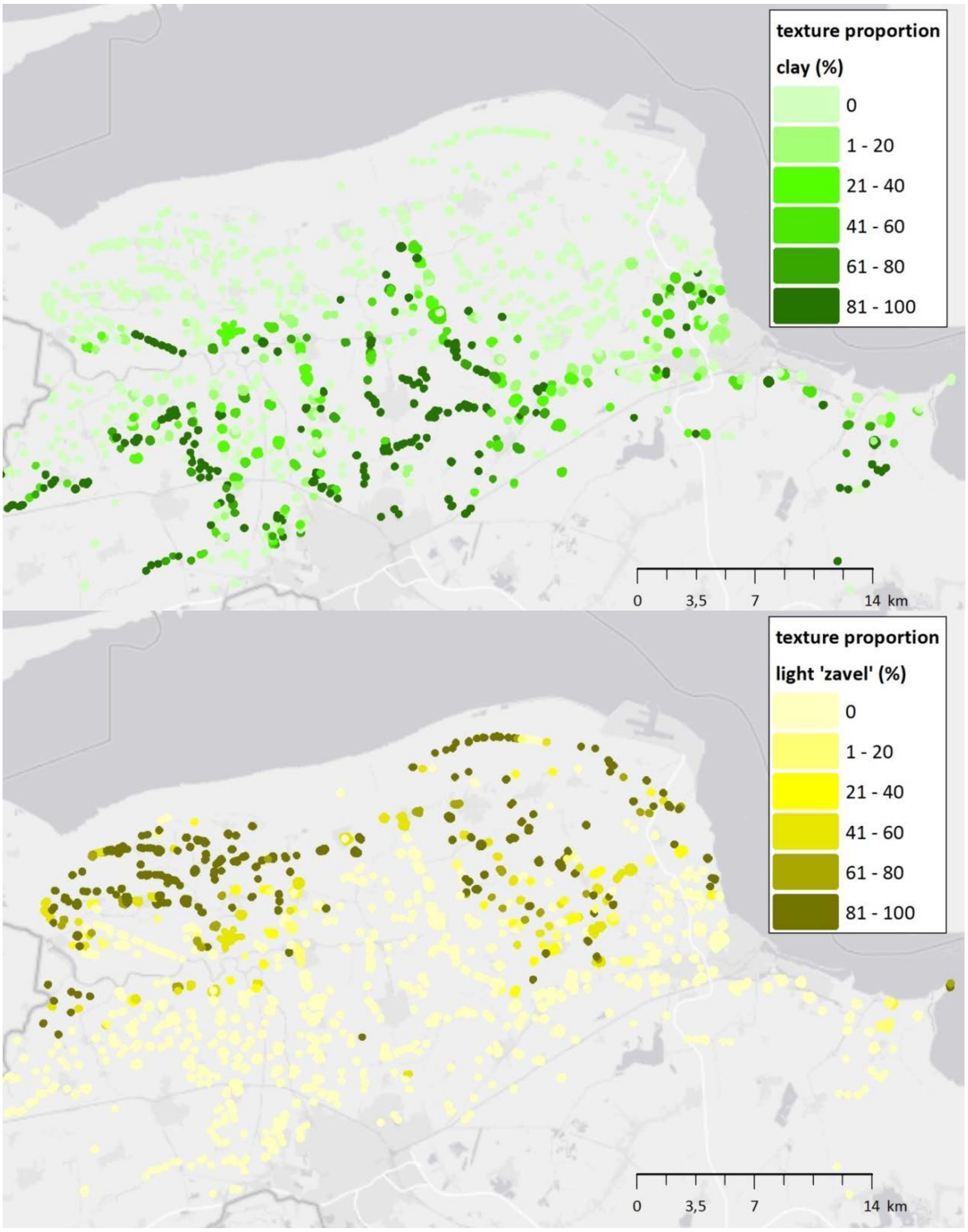


Figure 3.12: Relative proportion of several texture classes based on the soil map for the provincial scale for clay (top) and light 'zavel'. Note that the terps shown are not to scale.

Mapping the terp composition at a regional scale provides us a clear overview of the modelled variation in texture classes. Figure 3.12 shows, that the proportion of clay used for terp construction shows zonation from north to south, in which the clay content increases when moving inland. This corresponds with the notion that former sedimentary conditions in northern regions were influenced more by coastal conditions, whereas further to the south flooding regimes were more gentle. For the light 'zavel' component, the patterns is inversed, with a higher proportion closer to the sea on the former salt marsh ridges.

3.5 A comparison between the composition assessment methods

A comparison between the soil map analyses and the available lithological descriptions from section drawings shows that there is no unequivocal correlation between the two sets of data (Table 3.3). Several reasons can be found to explain these differences.

Firstly, it must be kept in mind that the analyses are made using a modern soil map, which does not necessarily reflect soil conditions or properties at the time of terp construction (*e.g.* the 8th century AD or late medieval period). On the contrary, it can be argued that the removal of soil for terp building has altered the landscape by lowering the surface and thus also changing the sedimentary conditions during later depositional phases. Similarly, current research (Postma, 2015) suggests that the characteristics of sods from various depositional environments were well known and exploited by the people building the terps. For instance, wells were preferably made of clay-rich material because of its waterproof capabilities, whereas more sandy sods were used in house construction. This also means that a buffer surrounding the entire terp may not be the best way to represent the source area of terp material, but since detailed landscape and more importantly lithological information for the time of terp is lacking such an assumption has to be made for the time being.

A second reason lies in the data itself. As has been stated above, almost all section drawings lack detailed lithological descriptions, and sometimes it has been necessary to make assumptions about the lithoclass. Where they are available, descriptions are primarily focused on archaeological properties of a certain layer rather than lithological or pedological characteristics, making comparisons difficult.

Table 3.3: terp texture composition of clastic sediments as derived from the soil map and archaeological data

		terp composition as defined by:	
id	**terp**	**soil map***	**archaeological data**
141	Ulrum	light 'zavel'	eastern terp: strongly silty clay western terp: clay with sandy laminations
6	Tuinsterwierde-Zuid	light ‘zavel'	clay (layer 1) sandy clay and clay with sand (layer 2) clay (topsoil)
713	Leens-De Houw Oost	light ‘zavel’	clayey
220	Middelstum	heavy ‘zavel’ & ‘zavel’ and light clay	not available yet (section 3.2.5)
195	Stitswerd	‘zavel’ and light clay	full core descriptions not available (section 3.2.6)
404	Heveskes	heavy 'zavel'	humic clay? (layer 1) clayey? (layer 2)
573	Heveskesklooster	clay & heavy clay	unknown (layer 2) heavy clay (layer 1; section 3.2.8 & Figure 3.2)
95	Fransum	heavy clay, ‘zavel’ and light clay & clay	‘terp soil’
82	Ezinge	light ‘zavel’ & heavy ‘zavel’	various types of clay
267	Westeremden	‘zavel’, light ‘zavel’ & heavy ‘zavel’	clay
307	Wierum	heavy ‘zavel’, heavy clay & clay	organic rich clay, more clayey to the top
22	Englum – Lege Wier	light ‘zavel’ & light clay	organic rich clay

*Only the soil units have been taken into account here; the class ‘other’ (no data) was ignored in this table.

Another discrepancy is caused by the hitherto necessary assumption that the entire terp volume consist of clastic material, where the section drawings clearly show the presence of manure-rich layers, and to a lesser extent shells, ash and brick fragments. The contribution of these "other" lithoclasses, that do not derive from the soil surrounding the terp, has not been accounted for. Given the substantial thickness of the manure-rich layers in some terps, the contours probably should be smaller. If this makes any difference to the modelled lithological composition is hard to say, and could be subject of a further study.

3.6 Terp composition variability - additional remarks

We have created four different types of terp composition based on archaeological evidence and a regional model of the clastic sediment composition of terps. Based on both methods, we have noted that the variability in terp composition is substantial. Therefore in this section we would like to describe some additional remarks on terp variability that may be important for earthquake risk assessment.

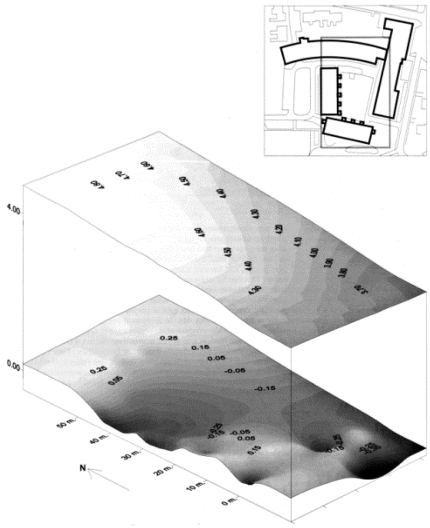


Figure 3.13: 3D model of the terp volume and subsurface of the Ulrum terp, which shows an irregular transition at the terp base (from: Groenendijk, 2005)

First of all, we have noted that the transition from the natural salt marsh ridge or flats to the anthropogenic terp may not in all cases be interpreted as a plain surface. In some cases, the weight of the terp soil has caused a lens-shaped terp 'sole'. This cannot be deduced from the limited archaeological data. It is expected that terp size and composition of the natural subsoil (clay content) may play a role in the shape of the transition. Furthermore, earlier research by Groenendijk (2005; Figure 3.13) has shown, that the transition can be irregular due to the original salt marsh ridge relief or burrows or pits from the terp down into the subsurface, for example for fresh water wells (Figure 3.14).

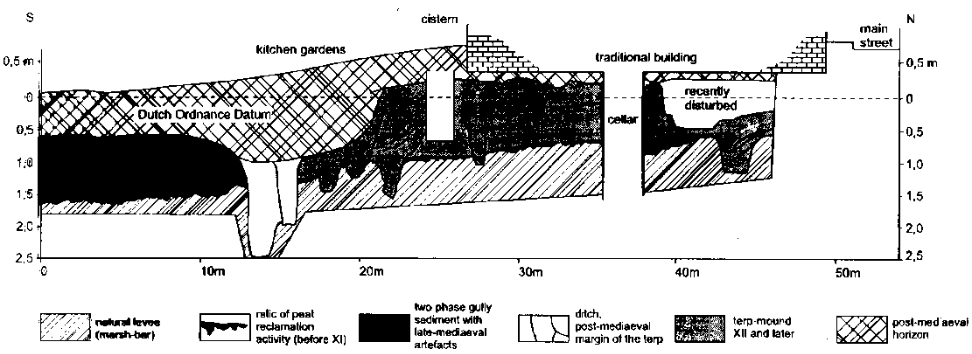


Figure 3.14: a profile of the Bedum terp shows that the terp is situated on a natural salt marsh or levee. The profile also shows the shallow foundations of the traditional houses with several discontinuities by cellars, fresh water wells, etc, typical for village terps (From: Groenendijk 1997)

The continuous process of terp construction in combination with house building and replacing through time has had implications of the terp composition. In some cases, sod houses have become part of the terp, leaving not only different lithoclass composition, but also non-horizontal discontinuities. In addition, until the 1920s, house foundations were relatively shallow and were (partly) built upon older remains, with or without cellars in the terp. We expect this may form a potential (local) weakness in the terp body (Figure 3.15).

Figure 3.15: sod house remains in Leens - Tuinsterwierde, showing near-vertical discontinuities. (Photo © Groningen Institute of Archaeology, University of Groningen).

Finally, after the quarrying of terps in the early 20th century, many terps were left with a steep face. As quarrying the terp was an economic activity at that time and selling the terp soil as fertilizer was profitable, many of such faces are creatively close to the built-up areas. It has been shown, that such steep sides are not stable and suffer from soil creep (), which may be worsened by earth quakes.

Figure 3.16: fence posts show that soil creep is a current process on the steep terp side of Wirdum after quarrying (photo: J. Meijering, Province of Groningen)

4 Conclusions

4.1 General conclusion

The analyses of readily available terp data sources has shown that the total number of terps and terp-like objects in the province of Groningen is approximately 990. Although this total number may be a slight overestimate, due to overlapping locations from different sources or locations consisting of multiple polygons, it is clear that the majority of these locations, well over 700, fall within the earthquake risk zone (‘red contour line’). The fact that terps are often built-up, form village centres, have relatively high population densities, and have a high proportion of monumental buildings, proves the relevance of this dedicated terp composition study.

Within this considerable dataset, it is immediately obvious that the majority of terps are in fact fairly small (so-called house terps); around 343 terps are larger than 1 ha and only 16 exceed 10 ha. Almost no information is readily available on the geometry of the terp body or on the amount of damage by late 19^{th}, early 20^{th} century commercial quarrying and later developments. All these parameters, which may or may not be of influence of seismic wave behaviour within a terp, can be derived from data sources such as the AHN, but these analyses have to be done site by site, and are therefore very time consuming.

Despite the large number of locations, the amount of actual lithological data with any spatial resolution is surprisingly small. Some information can be obtained from the DINOloket and (potentially) ARCHIS databases. Although the quality of these descriptions usually is good, spatial coverage is often very limited or descriptions of anthropogenic layers are altogether lacking. Section drawings are available for a number of excavations. The drawings are usually fairly detailed and give good insight in overall composition of the terp body, the often substantial within-site variability and the presence of discontinuities within the profiles. However, lithological information (if any) is often limited to generic descriptions such as “clay” or “manure” and seldom has the level of detail required by this study.

The soil map analysis shows that it is possible to create a model of the texture of the clastic sediment of the terps. For the pilot areas, it is expected that the results are more reliable than the region outside the pilot areas, because the terps outlines were first corrected based on highly detailed LIDAR data, aerial photos and historical maps. The analysis provides us with a regional view on the spatially varying terp composition. Field checks or comparison to existing soil cores has yet to be taken place. It was also noted that the geomorphological map provides us with a qualitative tool to relate the composition to the sedimentary conditions and hence the clastic component of the terp sediments.

A comparison between the soil map analyses described above and the available lithological descriptions from section drawings shows that there is no unequivocal correlation between the two sets of data. Partly, this can be attributed to a lack of (detailed) lithological descriptions in the sections. Where available, descriptions also are focused on archaeological properties of a certain layer rather than lithological or pedological characteristics. Another discrepancy is caused by the hitherto necessary assumption that the entire terp volume consist of clastic material, where the section drawings clearly show the presence of manure-rich layers, and to a lesser extent shells, ash and brick fragments.

At first glance, it seems that the excavation section data can be simplified to 4 conceptual models. It was hoped that, using a few assumptions based on expert judgment, these models could be extrapolated to locations without lithological data. Currently, validation of the models is impossible due to a lack of sites with lithological data. However, the variability between terps of similar age and in comparable landscape settings is considerable. As a consequence such an extrapolation has not been attempted in this project. The conceptual models however do provide a first approximation of the relative volumes of different materials used in a terp body. As such, they still may be used to improve the soil map analyses. Similarly, calculating the relative contributions of various layers to the

total surface (as a proxy for total terp volume) from digitized excavation sections could provide additional detail and accuracy.
We have seen, that both methods show a high variability in composition. Not only are terps composed of other material than clastic sediments (shells, ash, manure), but also the texture range is large, and also the in-terp micro scale variability is substantial. By using a mixed-method approach based on readily-available data, we have created a first assessment of between-terp and within-terp composition variability, usable for future earthquake assessment.

4.2 Recommended additional data acquisition

4.2.1 Detailed information

With this report we have shown that the composition of terps is variable at the regional scale as well as within the individual terps themselves. Although we are confident that our current models provide a good first assessment of the lithology, more detailed information on lithoclass variability at both scales is necessary. In this section, we provide suggestions for improvements to the models, in order to get a better understanding of the spatial heterogeneities.
We suggest to obtain micro seismicity profiles combined with hand soil coring on a representative number of terps. The aims of this exercise are twofold. Firstly, it will provide insight into the within-terp lithoclass variability. Secondly, the obtained data can assist us in extrapolating lithoclass classification to other terps.

4.2.2 Field data

Micro seismicity data should provide a detailed 2D spatial picture of the seismic properties of terp layers, as reflection is a representation of lithology and lithological boundaries. A representative sample of hand corings along the micro seismicity profiles provides descriptions of the actual lithology as well as depths of layer boundaries, and will be used to calibrate the micro seismicity data. When a good correlation between the seismic and lithological data can be established, it can be used to extrapolate the results to other locations. In addition, hand coring data will be used to test the terp composition models and if sufficient data can be collected, we can statistically test the validity or our regional soil map model. In addition, it will provide useful additional archaeological data.
If necessary, larger undisturbed samples for the testing of geophysical parameters under laboratory conditions can be obtained by mechanical coring at selected locations. Recent multidisciplinary research at Hogebeintum (Frl.) has shown the likely potential of this method.

Cone penetration testing (cpt) to accompany the coring might also be useful. The data will provide us with vertical small-scale lithoclass variation within the terp, including sharp or non-planar boundaries, relevant to the passage of earthquake waves. Similar to the seismic data, the cpt data need to be calibrated by hand or mechanical coring to establish relationships and correlations. Additionally, it may be worthwhile researching the accessibility to the possibly considerable reservoir of existing cpt data held by other commercial companies (e.g. Grontmij).

4.2.3 Location selection

We suggest to carefully select a representative sample of different terps based on expert knowledge and location, using the current terp database as a starting point.
The use of built-up terps has the obvious advantage of a direct link with (potential) earthquake damage. However, they also have significant drawbacks, with the presence of subsurface infrastructure such as sewers potentially hampering measurements and coring location selection.

Furthermore, the selection should include locations in all three geographical regions identified in the report. The research has already shown that inter-terp variability can be very high, even between locations in the same region and of the same age. As an example, Ezinge and Englum, located approximately only 1,5 km from each other, show substantially different compositions, with the lower anthropogenic layers at Englum having a considerably higher manure content than at Ezinge. Simple extrapolation of the terp composition models, even with additional field data, to all locations with a similar age in an area thus seems impossible. A large sample size is recommended.

A preliminary selection should include but not be limited to the following locations:

- Leens – Grote Houw (pilot area A): this location in the western area is not built-up, and used recently for investigations into erosion susceptibility. Coring has shown it to contain manure-rich layers, but not everywhere within the current extent of the terp;
- Middelstum (pilot area B): a relatively intact but completely built-up terp in the central area, with many pre-1920 houses. As houses prior to that date have shallow fundaments, they may be more vulnerable to terp composition than houses built later;
- Helwerd: a terp without any buildings, just to the north of pilot area B;
- Rottum (pilot area B), as it appears that this terp is relatively vulnerable to earthquake damage, which may be (partly) due to its lithological composition. We have indications that this terp has a particularly heavy clay composition.

4.2.4 Further recommendations

In this report, we have used the texture class definitions used for the Dutch soil classification system. We have noted there is a good correspondence between texture and lithoclass definitions, but this is not a one-to-one relationship. When using the data for earthquake models, a translation or transfer functions may be needed. We have shown that there is at least one new lithoclass that needs to defined for earthquake analyses, as many terps have manure layers. Manure be similar to the organic material / peat lithoclass, but depending on its characteristics it me be worth considering defining as a new class. Other anthropogenic terp materials such as shells, ash or brick fragments form relatively thin layers and are less important in terms of occurrence.

During our analysis, we have found that terp extent is currently based on mapping, carried out mainly in the 1960s to 1990s. Although this has provided useful information on the location at the regional scale (1:50,000 as part of the soil, geomorphological and the provincial terp spatial databases), we have shown that this provides us with insufficient detail to characterise the terp relief and therefore has consequences for the quality of the lithoclass establishment based on soil and geomorphology. We therefore recommend to update the available spatial terp database based on the currently available aerial photos and detailed LIDAR data (AHN2). It is advisable to closely cooperate with similar efforts in the Fryslân province to build upon experience there and to keep databases comparable.

It appears that the soil/atmosphere interface may play an important role in the behaviour of seismic waves. This may be particularly important for the (high number) partly quarried built-up terps as they often contain steep unstable slopes. A GIS-based analysis of LIDAR data may be used to obtain data on slopes and gradients. Unfortunately, the current, high resolution datasets (AHN2 and AHN3) may in fact be too detailed, and still contain too many data points representing above-surface structures (e.g. buildings) or vegetation, making automated analysis difficult. Moreover, it is as yet unclear if and how such analysis would deal with partially quarried terps or terps with buildings on plinths. More research into the used of LIDAR data in combination with filtering algorithms might prove useful in establishing slope and gradients in terps.

4.2.5 Additional data acquisition: conclusion

With this report, we are confident that we our current models provide a good first assessment of the lithology. However more detailed information on lithoclass variability at regional and terp scales is necessary. We therefore suggest to acquire a representative sample of micro seismic data calibrated by hand/mechanical coring and cpt data, where possible from readily available sources. A representative sample of terps needs to be selected carefully. In addition, our advice is to currently available high resolution aerial photo and LIDAR data to obtain a more detailed view on extent and relief the soil/atmosphere interface. These data acquisitions would greatly improve our knowledge of terp composition, necessary for future earthquake impact assessment in these man-made structures.

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6 Appendices

6.1 Database definitions

The main data file of the project database is an ESRI personal geodatabase, consisting of several datasets. The datasets are described in detail below.

6.1.1 Pilot area definition: Pilot_areas

This database file contains the outlines of the pilot areas.

field name: id
field type: integer
description: unique numerical identifier for each location
source: n/a (derived from system variables)
values and criteria

field value	criteria	remarks
1 .. 4		

field name: DESCRIPTIO
field type: string [50]
description: short description of the pilot area, containing size and the names of the two major towns within the area
source:
values and criteria

field value	criteria	remarks
3x3 km Middelstum-Toornwerd		this area is not longer used
5x5 km Delfzijl-Heveskesklooster		
5x5 km Leens-Ulrum		
5x5 km Middelstum-Rottum		

field name: LABEL
field type: string [5]
description: contains the letter assigned to each pilot area; field mainly used for labelling purposes
source: n/a
values and criteria

field value	criteria	remarks
A		5x5 km Leens-Ulrum area
B		5x5 km Middelstum-Rottum area
C		5x5 km Delfzijl-Heveskesklooster area
NULL		used for the now defunct 3x3 km pilot area centred on Middelstum

6.1.2 Terp delineation database: terp_outlines

This file contains both the geographical data (polygons) and the most important non-graphical data required by the project analyses for all the objects. In its' current state, it consists of the outlines of all the terp location from the three main data sources, i.e. the provincial terp database, the soil map and the geomorphological map as well as the inventory by Miedema (1990). No attempt has been made yet to reconstruct, merge or split the exact outlines of the locations.
The following paragraph provide a description of the field structure of the dataset. Where possible, field values and the criteria in which those are based are given, as well as examples for specific entries.

field descriptions
field name: id
field type: integer
description: unique numerical identifier for each location
source: n/a (derived from system variables)
values and criteria

field value	criteria	remarks
1 .. n		location identifier

field name: ID_WV
field type: string[8]
description: identifier linking to the provincial terp database; the identifier consists of the prefix "WV" and a numerical part. Duplicate values are possible. Note that identifiers have been added to the digital soil map for this project.
source: provincial terp database
values and criteria

field value	criteria	remarks
WV001		minimum field value
WV527		maximum field value
NULL		location does not occur in source database

field name: ID_BODEM
field type: string[8]
description: identifier linking to the (digital) soil map 1:50,000. The identifier consists of the prefix "BD" and a numerical part. Duplicate values are possible. Note that identifiers have been added to the digital soil map for this project.
source: soil map 1:50,000
values and criteria

field value	criteria	remarks
BD001		minimum field value
BD242		maximum field value
NULL	location does not occur in source database	

field name: ID_GEOM
field type: string[8]
description: identifier linking to the (digital) geomorphological map 1:50,000. The identifier consists of the prefix "GM" and a numerical part. Duplicate values are possible. Note that identifiers have been added to the digital soil map for this project.
source: geomorphological map 1:50,000
values and criteria

field value	criteria	remarks
GM001		minimum field value
GM740		maximum field value
NULL	location does not occur in source database	

field name: ID_MIED90
field type: string[10]
description: identifier linking to the terp inventory by Miedema (1990). The identifier consists of a code referring to the topographical map sheet and a numerical part. Duplicate values are possible.
source: Miedema (1990)
values and criteria

field value	criteria	remarks
7Fn18		location "7Fn" for example refers to the topographical map 1:10,000, sheet 7F, northern half.
NULL	location does not occur in source database	

field name: ID_MIED83
field type: string[10]
description: identifier linking to the terp inventory by Miedema (1983). The identifier consists of a code referring to the topographical map sheet and a numerical part. Duplicate values are possible.

source: Miedema (1983)
values and criteria

field value	criteria	remarks
6Fz22		location “6Fz” for example refers to the topographical map 1:10,000, sheet 6F, southern half.
NULL	location does not occur in source database	

notes: at the moment (7-3-2016) this field does not contain any values yet, because the Miedema catalogue doesn’t provide coordinates or polygons for the locations. See main text for explanation.

field name: PILOTAREA
field type: string[5]
description: field used for easy selection of locations within the pilot areas
source: n/a
values and criteria

field value	criteria	remarks
A	location within pilot area A	
B	location within pilot area B	
C	location within pilot area C	
NULL	location outside pilot areas	

field name: TOPONYM
field type: string[50]
description: name of the location. Preference is given to the name as it occurs in the provincial terp database; for other locations names occurring on the various topographical maps are used. Names prefixed with “#” are unofficial names added during this project.
source: provincial terp database, topographical maps
values and criteria

field value	criteria	remarks
Rottum		example of a location name
#Roetsum		example of a location name added during this project
NULL	location not named yet	

notes: at the moment of writing (7-3-2016) this field is only partially filled, even for the locations from the provincial terp database.

field name: SIZE_QUANT
field type: real [10,2]
description: surface area (in m^2)
source: calculated from digital database
values and criteria

field value	criteria	remarks
1 … n		surface area in m^2
NULL		surface area not known / not determined yet

notes: this field will need to be recalculated after the definitive analysis and adjustment of location outlines

field name: SIZE_QUAL
field type: string[10]
description: qualitative description of location size. This field has been added because absolute size does not always relate to developmental characteristics or composition
source: calculated or classified from the definitive analysis and adjustment of terp outlines
values and criteria

field value	criteria	remarks

farm		historische boerderijplaatsen
small	to be defined	to include “huiswierden”
medium	to be defined	
large	to be defined	
unknown		
NULL		unclassified location

field name: HEIGHT_ABS
field type: real [10,2]
description: absolute (maximum) height of top of wierde relative to Dutch Ordnance Datum (NAP)
source: AHN
values and criteria

field value	criteria	remarks
1 .. n		height in m
-9999	impossible to reconstruct	used for locations that have disappeared entirely
NULL	not calculated yet	

field name: HEIGHT_ABS
field type: real [10,2]
description: relative height (in m) of terp; difference between absolute height and height of surrounding area.
source: calculated from AHN
values and criteria

field value	criteria	remarks
1 .. n		height in m
-9999	impossible to reconstruct	used for locations for which no reliable measurements or estimates can be made, for instance when the entire mound has disappeared
NULL	not calculated (yet)	

notes: The inventories by Miedema (1983, 1990) may contain data for some locations lacking in reliable AHN data

field name: DAMAGED
field type: string[20]
description: qualitative description of the degree of damage by historical terp soil quarrying; also includes more recent activities
source: topographical maps, AHN
values and criteria

field value	criteria	remarks
intact	wierde is intact; no sign of historic quarrying	
partial	segments of wierde removed by quarrying	
plinth	only a small part of wierde remains, usually underneath built-up areas	Toornwerd (Figure 2.2)
entirely	wierde completely removed; usually only an area as high as or lower than the surrounding topography remains	
unknown		
recent	terp topography destroyed or unrecognisable by recent developments	for instance Heveskesklooster
NULL	not assessed yet	

notes: at the moment of writing (7-3-2016), this field has not been used yet, as assessment of the amount of damage is best made after the definitive analysis and adjustment of location outlines.

field name: REFILLED
field type: string[20]
description: describes recent reconstructions of the former terp topography; valid only for locations where (historic) terp soil quarrying has taken place (see field DAMAGED).
source: topographical maps, AHN, relevant project reports
values and criteria

field value	criteria	remarks
intact	terp is intact; no signs of historic quarrying	
partial	part of the quarried segments of the terp have been reconstructed	the location currently consists of "original" and reconstructed segments, as well as parts that have been dug away but not reconstructed
full	all quarried segments reconstructed	location consists of "original" and reconstructed segments
entirely	terp topography completely reconstructed; use for completely quarried terp only	
NULL	not assessed yet	

notes: at the moment of writing (7-3-2016), this field has not been used yet, as assessment of the amount of damage is best made after the definitive analysis and adjustment of location outlines.

field name: BUILT_HIST
field type: string[20]
description: qualitative description of historic amount of building on the location.
source: historical topographic maps, e.g. HisGis (www.hisgis.nl)
values and criteria

field value	criteria	remarks
none	no buildings on location	
centre	buildings grouped together in or near the terp centre	e.g. small hamlet on larger terp
church	one church, chapel or bell tower	
full	fully built up but not as dense as "dorpswierden"	
manor	manor and associated buildings only	
single	one farmstead or house	"single" should not be taken too literal; this category should include associated buildings like sheds, barns etc.
spread	widespread but sparse building	
village	entire terp surface is currently built up	this category is intended to contain the larger terps; may thus include open spaces like parks etc.
NULL	unknown	

notes: at the moment of writing (7-3-2016), this field has not been used yet

field name: BUILT_2015
field type: string[20]
description: qualitative description of the present day amount of building on the location.
source: current topographical maps, GoogleEarth
values and criteria

field value	criteria	remarks
none	no buildings on location	
centre	buildings grouped together in or near the terp centre	e.g. small hamlet on larger terp
church	one church, chapel or bell tower	
full	fully built up but not as dense as "dorpswierden"	
infra	an important part of the terp is covered by major infrastructural works, e.g. roads or bridges	see for instance Paddepoel IV (location 342)

manor	manor and associated buildings only	
single	one farmstead or house	“single” should not be taken too literal; this category should include associated buildings like sheds, barns etc.
spread	widespread but sparse building	
village	entire terp surface is currently built up	this category is intended to contain the larger terps; may thus include open spaces like parks etc.
NULL	unknown	

notes: field should be checked and updated after the definitive analysis and adjustment of location outlines.

field name: DIAMETER
field type: real [10,2]
description: approximate diameter of location; for elliptical and elongated location the longest axis is used; for square or rectangular locations the diagonal is used.
source: AHN or calculated from definitive terp outlines
values and criteria

field value	criteria	remarks
1 … n		
NULL	not calculated (yet)	

notes: at the moment of writing (7-3-2016), this field has not been used yet, as calculations are best made after the definitive analysis and adjustment of location outlines.

field name: DAM_KLOK74
field type: string[15]
description: qualitative description of the amount of damage according to Klok 1974/1975
source: Klok 1974/1975
values and criteria

field value	criteria	remarks
undamaged	legend entry “gaaf”	
local	legend entry “plaatselijk afgegraven”	localized damage
partial	legend entry “gedeeltelijk afgegraven”	terp partially damaged
majority	legend entry “grotendeels afgegraven”	majority of terp damaged
entirely	legend entry “geheel afgegraven”	terp entirely quarried
NULL	unknown / not mapped	

notes: some locations may need checking; the symbol size on the original map means pinpointing the exact location is not always straightforward

6.1.3 Field description geodatabase: terp_composition_soil_entire_region & terp_composition_soil_pilot_areas

The field descriptions below describe the specification, contents, source and calculations of data fields in the terp texture databases and is valid for the entire region. If field names for the pilot area texture database are named different, then they are noted in brackets. Note that many fields are similar to the terp definition databases and can therefore be joined in ArcGIS if necessary. The definitions that are used in both datasets can be found in appendix 6.2.2.

field name: OBJECTID
field type: n/a
description: ArcGIS internal identifier
source: n/a (derived from system variables)
values and criteria

field value	criteria	remarks
1 .. n		location identifier

field name: Shape
field type: n/a
description: ArcGIS internal description
source: n/a (derived from system variables)
values and criteria

field value	criteria	remarks
Polygon		

field name: id
field type: integer
description: unique numerical identifier for each location
source: n/a (derived from system variables)
values and criteria

field value	criteria	remarks
1 .. n		location identifier

field name: HEIGHT_ABS
field type: real [10,2]
description: absolute (maximum) height of top of wierde relative to Dutch Ordnance Datum (NAP)
source: AHN
values and criteria

field value	criteria	remarks
1 .. n		height in m
-9999	impossible to reconstruct	used for locations that have disappeared entirely
NULL	not calculated yet	

field name: Alt_sur_AHN1_m (Alt_mean_surr_m)
field type: real [10,2]
description: relative height (in m + NAP) of terp surroundings (buffer 200 m);
source: calculated from AHN1
values and criteria

field value	criteria	remarks
1 .. n		height in m
-9999	impossible to reconstruct	used for locations for which no reliable measurements or estimates can be made, for instance when the entire mound has disappeared
NULL	not calculated (yet)	

field name: Alt_max_AHN1_m (Alt_max_m)
field type: real [10,2]
description: maximum altitude value on terp (in m + NAP().
source: calculated from AHN1
values and criteria

field value	criteria	remarks
1 .. n		height in m
-9999	impossible to reconstruct	used for locations for which no reliable measurements or estimates can be made, for instance when the entire mound has disappeared
NULL	not calculated (yet)	

field name: radius_terp_m (Radius_m)
field type: numeric
description: radius of terp, calculated by the area and the assumption that the terp is circular

source: terp outlines

values and criteria

field value	criteria	remarks
1 .. n		distance in m

field name: volume_terp_m3 (Volume_m3)
field type: numeric
description: volume of terp, calculated by the area and the assumption that the terp can be defined by a cone
source: terp outlines

values and criteria

field value	criteria	remarks
1 .. n		volume in m^3

field name: area_sods_m2
field type: numeric
description: calculation of the required surface area (source area; m2) for sods to create the terp.
source:

values and criteria

field value	criteria	remarks
0 .. n		Area in m^2

field name: area_terp_and_sods_m2
field type: numeric
description: calculation of the total area of terp and sod source area
source:

values and criteria

field value	criteria	remarks
0 .. n		Area in m^2

field name: radius_total_m (totalradius_m)
field type: numeric
description: radius of terp and source area, based on the assumption that the area is circular
source:

values and criteria

field value	criteria	remarks
0 .. n		Distance in m

field name: radius_sods_m
field type: numeric
description: radius of sod source area surrounding the terp, based on the assumption that all areas surrounding the terp are equally suitable for sods
source:

values and criteria

field value	criteria	remarks
0 .. n		Distance in m

field name: area_m2
field type: numeric
description: sod source area (m2)
source:

values and criteria

field value	criteria	remarks
0 .. n		Area in m^2

field name: lichte_zavel_1 (light_zavel_1)

field type: real (10,2)
description: Proportion of sods surroundings with texture of soil unit texture code 1 (light 'zavel')
source: soil map
values and criteria

field value	criteria	remarks
0-100		% area

field name: zware_zavel_2 (heavy_zavel_2)
field type: real (10,2)
description: Proportion of sods surroundings with texture of soil unit texture code 2 (heavy 'zavel')
source: soil map
values and criteria

field value	criteria	remarks
0-100		% area

field name: lichte_klei_3 (light_clay_3)
field type: real (10,2)
description: Proportion of sods surroundings with texture of soil unit texture code 3 (light clay)
source: soil map
values and criteria

field value	criteria	remarks
0-100		% area

field name: zware_klei_4 (heavy_clay_4)
field type: real (10,2)
description: Proportion of sods surroundings with texture of soil unit texture code 4 (heavy clay)
source: soil map
values and criteria

field value	criteria	remarks
0-100		% area

field name: zavel_5
field type: real (10,2)
description: Proportion of sods surroundings with texture of soil unit texture code 5 ('zavel')
source: soil map
values and criteria

field value	criteria	remarks
0-100		% area

field name: zavel_en_lichte_klei_6 (zavel_and_light_clay)
field type: real (10,2)
description: Proportion of sods surroundings with texture of soil unit texture code 6 ('zavel' and light clay)
source: soil map
values and criteria

field value	criteria	remarks
0-100		% area

field name: klei_8 (clay_8)
field type: real (10,2)
description: Proportion of sods surroundings with texture of soil unit texture code 8 (clay)
source: soil map
values and criteria

field value	criteria	remarks
0-100		% area

field name: other

field type: real (10,2)
description: Proportion of sods surroundings with other soil units (i.e. built-up, water, dike, etc).
source: soil map
values and criteria

field value	criteria	remarks
0-100		% area

field name: shape_length
field type: numeric
description: perimeter length of polygon
source: internal
values and criteria

field value	criteria	remarks
0 .. n		Area (m2)

field name: shape_area
field type: numeric
description: area of polygon
source: internal
values and criteria

field value	criteria	remarks
0 .. n		Area (m2)

6.2 Work process soil map analysis

1. Correct delineation built-up terps (in pilot areas only) by re-interpretation based on AHN2, aerial photos and historical cartography (parcels and canals);
2. Create buffers (200 m) around each terp;
3. Zonal statistics as table (spatial analyst): establish maximum altitude terp and average surroundings (200 m buffer) based on AHN1
4. Join output table to terp database and copy maximum and surrounding altitude;
5. Calculate terp radius (assumption: terp is circular; r=sqrt(area/pi));
6. Calculate terp volume (assumption: terp is a cone-shaped). Volume = pi*radius^2*(height/3);
7. Calculate potential source area (topsoil for sods; assumption: sod thickness = 15 cm). Area = volume terp/0,15;
8. Calculate total terp + sod source area;
9. Calculate radius of terp and sod source area (r=sqrt(total area/pi));
10. radius terp minus total radius = radius source area;
11. Buffer source area, based on field radius source area;
12. Intersect output buffer with soil map;
13. Carry out dissolve on resulting database based on identifier (“ID”) and soil unit (“EERSTE_BOD”). Use option “create multipart feature”. Export attribute table;
14. Create pivot table based on ID, add areas, with settings on “sum” (Excel). Restructure file to have single id field and texture proportions per terp;
15. Join result with terp database.