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TNO-report

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Product specification
Subsurface model GeoTOP

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Contents

1 Introduction

The present product specification describes the subsurface geological model GeoTOP, version 1.3, produced by TNO – Geological Survey of the Netherlands. On the basis of this specification the reader can decide whether or not the GeoTOP model is appropriate for his or her applications.

The specification starts with a general description of GeoTOP (Chapter 2). This chapter provides an overview of the main aspects of the geological model: the lithostratigraphical framework, the subdivision into lithological classes and the (future) link to physical and chemical parameters. An example is shown of the model uncertainties included in GeoTOP.

Chapter 3 goes into the aim, applications and limitations to use the GeoTOP model in practice.

Chapter 4 presents the GeoTOP data model: the construction components of the model and a description of the entities and attributes. This chapter contains the formal description of the subsurface model.

Chapter 5 explains the way the model is disseminated to the users. The dissemination includes online-visualizations as well as downloadable software and data files.

Chapter 6 presents important quality issues of the subsurface model.

The product specification ends with an outline of the formal metadata of the model (Chapter 7).

1.1 Related documents

The TNO-report “GeoTOP modellering” (in Dutch; Stafleu et al. 2012) contains a detailed description of GeoTOP. It goes into the source data used to construct the model and into the work flow of the model. In addition the report draws up the products derived from the GeoTOP model that are applicable in analyzing and resolving subsurface problems.

A geoscientific publication that discusses the Zeeland model area can be found in Stafleu et al. (2011). This article deals in particular with the used stochastic interpolation techniques.

Other subsurface models related to GeoTOP and produced by TNO are the Digital Geological Model (DGM, Gunnink et al. 2013), the National Hydrogeological Model (REGIS II, Vernes & Van Doorn, 2005) and Delfstoffen Online (Van der Meulen et al. 2005; Maljers et al. 2015).

GeoTOP version 1.3 contains two new indicators of model uncertainties. A comprehensive explanation to these new attributes is given in the document “Modelonzekerheid in GeoTOP”, available from DINOloket (TNO 2014a, www.dinoloket.nl/en/want-know-more).

2 Product specification (informal description)

2.1 Product name

The product specification explains the subsurface model GeoTOP, version v01r3, produced by TNO – Geological Survey of the Netherlands.

2.2 General description

Knowledge about the composition and properties of the subsurface rock layers is vital to using and managing the subsurface safely and sustainably. Among other available data, TNO - Geological Survey of the Netherlands supplies this information in geological subsurface models. One of these subsurface models is GeoTOP that schematises the geometry and properties of the shallow subsurface up to a depth of 50 m below NAP (Dutch Ordnance Datum). That depth range is the most intensively used part of the shallow subsoil.

The 3D voxel model GeoTOP schematises onshore Netherlands in millions of voxels (grid cells), each measuring 100 x 100 x 0.5 m. Each voxel in the model contains information on the lithostratigraphy (geological unit), the lithological classes (lithological classes, such as sand, peat and clay) representative of the voxel, and a number of attributes that indicate the model uncertainties.

Explanation to lithostratigraphy and lithological classes:

- **Lithostratigraphy**, the logical ordering of rocks into geological units, such as Formations and Members, is based on lithological properties (the constituent material). These properties discern a rock unit from other rock units above, below or lateral from the observed unit (the distribution and position of the rock body). For practical reasons, described in paragraph 4.6.2, GeoTOP uses the term **geological unit** instead of lithostratigraphical unit.

- In GeoTOP lithological properties are described in **lithological classes**, combining lithology and sand grain-size classes in one legend.

GeoTOP has been constructed per region from the available digital borehole logs stored in the DINO database. Each borehole log provides detailed information about the layering of the subsurface at one particular location. As some 430,000 borehole descriptions are available in an area of 41,000 square kilometers, we can conclude that about 10% of the voxels is penetrated by a borehole. This number rapidly diminishes with depth. Therefore, we have to estimate the content of most of the voxels on the basis of nearby borehole logs, using stochastic interpolation techniques.

The first step in the GeoTOP modelling procedure is the interpretation of the borehole logs (Fig. 2.1).This includes the subdivision of the borehole logs into geological units and into lithological classes (lithological classes).

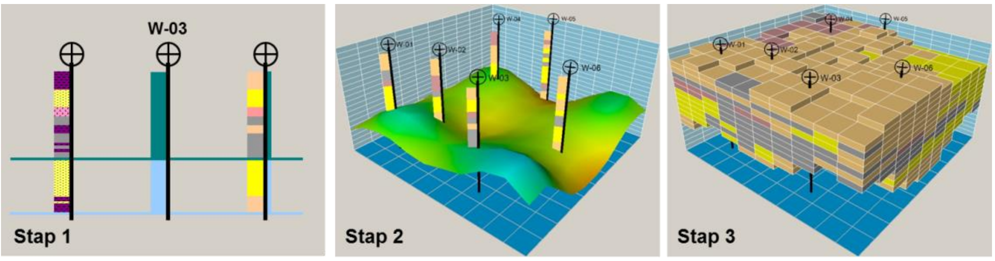

Figure 2.1. Most important steps to construct the GeoTOP model. Step 1: Interpretation of the borehole logs. Step 2: Modelling the base of the geological units. Step 3: Modelling lithological classes (voxels).

Subsequently, the bounding surfaces are constructed. These interfaces represent the base and top surfaces of the geological units. Each voxel in the model can now be placed within the correct geological unit. In the third step stochastic interpolation techniques are used to assign a lithological class to the voxels.

Voxels of the GeoTOP area Utrecht - Gelderse Vallei filled with geological units and lithological classes are presented in Figures 2.2a and 2.2b. The lithological class model shows, e.g., the coarse sands and the gravel content of the ice-pushed ridges around the Gelderse Vallei. The 3D model also clearly shows the oblique position of the originally horizontally bedded sediments. Model depth slices provide insight into the variation in lithology at a chosen depth. As an example Figure 2.3 shows two depth slices in the Zuid-Holland area, one at a depth of 5 m below NAP (Dutch Ordnance Datum) and the other at a depth of 20 m below NAP. The slices clearly show the differences in lithology and grain-size classes between the Holocene and the Late Pleistocene sediments.

The use of stochastic interpolation techniques in modelling enables to compute the most probable occurrence of a lithological class for each voxel. The probabilities are a measure of the model uncertainty. Figure 2.4 shows the results in case of the Rhine floodbasin deposits (Echteld Formation) near Wijk bij Duurstede. The colours indicate the probability of occurrence of the lithological class clay in a voxel. At greater distances of the river courses the probability is high (red is 100%). Close to the river courses the blue and green colours reveal the low probability of occurrence of clay. The probability of occurrence of sand and clayey sand near the channels is much higher. The pattern of sandy sediments in and near the river courses and clay in the flood basins characterizes the Holocene fluvial deposits in the Netherlands.

Physical and chemical parameters will also be included in GeoTOP. The measuring program has been organized in such a way that the results can be assigned to the geological and the lithological class model units. The outcome is a detailed 3D image of the spatial variation of the parameter values in the subsurface. Examples are the horizontal and vertical hydraulic conductivity, crucial parameters in groundwater studies, and the reactivity of the sediment used in the modelling of contaminant plumes. The chosen parameters to include in the model are based on the needs and wishes of the users of GeoTOP.

GeoTOP models individual regions that roughly correspond to provinces. At present, GeoTOP models are available for Zeeland, Goeree-Overflakkee, Zuid-Holland, Noord-Holland, Rijn - Maas gebied (the Rhine–Meuse area), West Wad and East Wad. At present GeoTOP covers about 57% of the onshore Netherlands (Fig. 7.1).

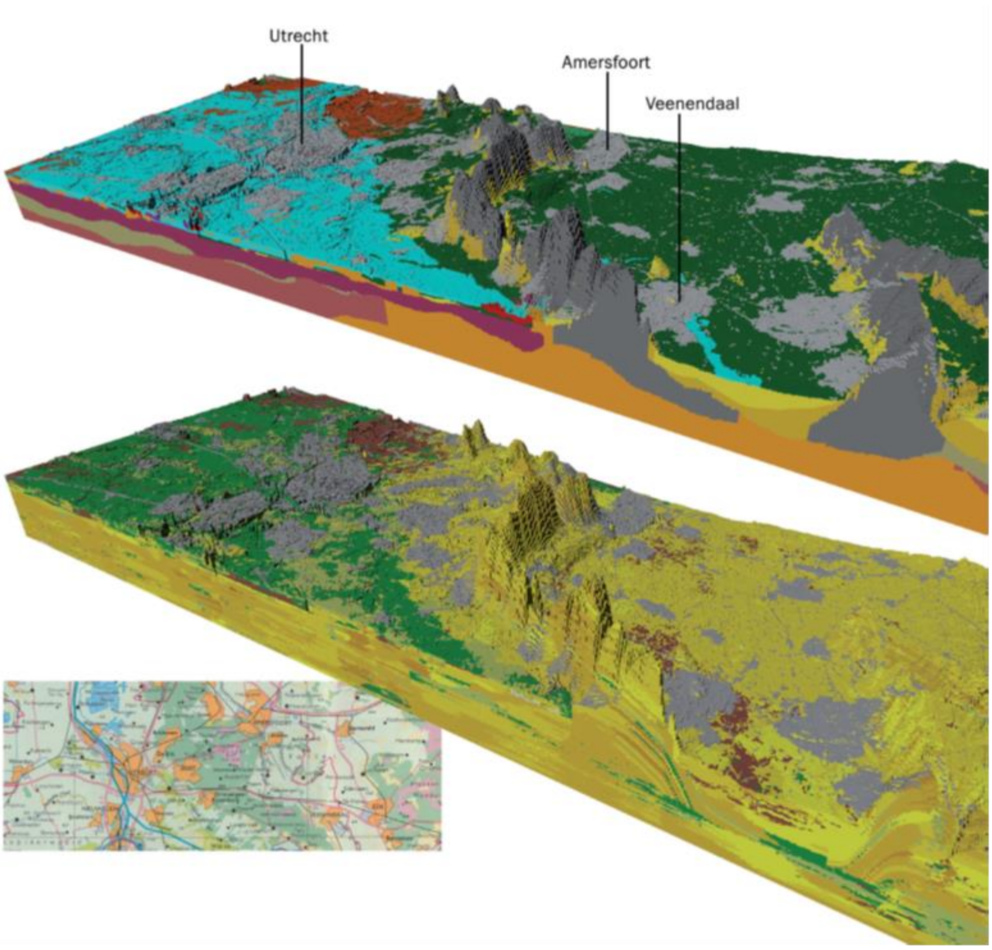

Figure 2.2a. GeoTOP 3D views of the Gelderse Vallei area in the central part of the Netherlands. Geological units (above) and lithological classes (below). Legend is shown in Figure 2.2b. The displayed block measures 62 x 24 km; depth of the base is 50 m below NAP and the vertical is 75 times too much.

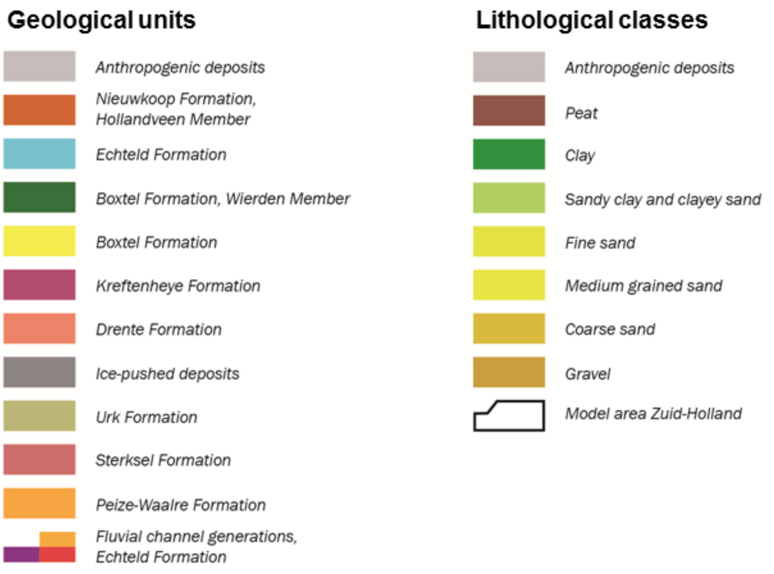

Figure 2.2b. Legend to Figure 2.2.a.

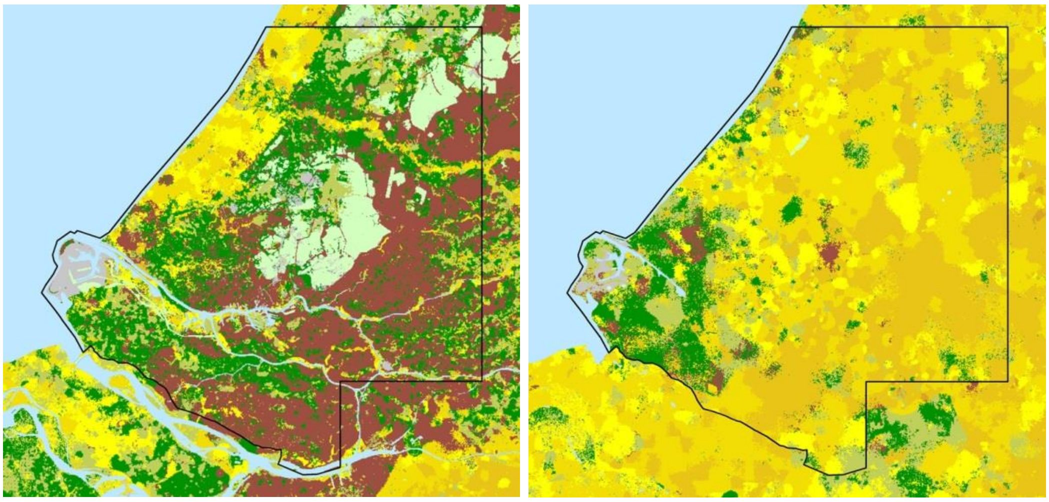

Figure 2.3. Variation in lithological classes at depths of 5 m (a) and 20 m (b) below NAP in the model area Zuid-Holland.

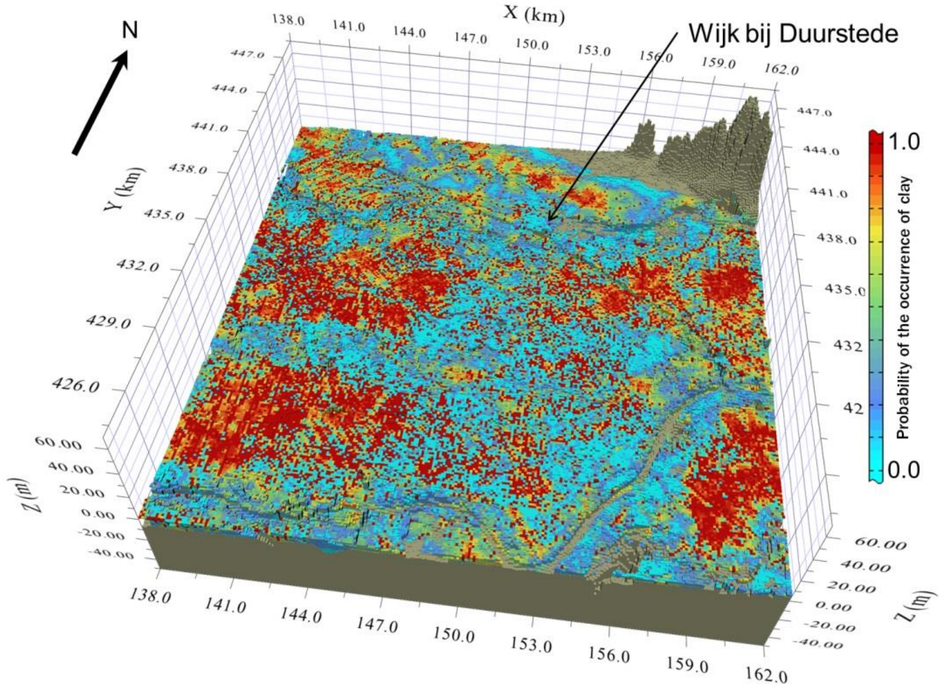

Figure 2.4. Probability of the occurrence of clay in the flood basin area south of Wijk bij Duurstede.

3 Aim, application and limitations of the model output

3.1 Aim and application

The GeoTOP model predicts the geometry and a number of properties of the onshore Netherlands subsurface to a depth of 50 m below NAP. The model contains as much available data and information on the subsurface as possible, summarized in borehole logs with interpretations, a layer model and a voxel model, all of which can be ordered via DINOloket (www.dinoloket.nl).

GeoTOP models the subsurface at a subregional scale that is suitable for applications at the levels of province, municipality and district. This scale is comparable to the 1:50,000 scale used for one of its predecessors, the Geological Map of the Netherlands. If a larger scale is required (when working at the level of streets or individual buildings), GeoTOP can serve as a framework to which more detail can be added.
GeoTOP is broadly applicable for issues to which the shallow subsurface is important. Below are a few examples of model applications.

3.1.1 General use as 3D geological map

GeoTOP can be viewed as a 3D geological map, a follow-up of the 1: 50, 000 paper version of the Geological Map of the Netherlands. The general use is supported by various visualisations shown on DINOloket (Chapter 5) to help the user to make a 3D image of the geometry and properties of the subsurface. In the case of a detailed mapping survey, say at a building site, GeoTOP can serve as a framework. The parts of the model required for a detailed mapping, in particular the layer model and the voxel model, are available via DINOloket.

3.1.2 Groundwater modelling

The spatial variation of physically measurable properties in the subsurface, such as the conductivity of groundwater, in particular depends upon two properties, modelled in GeoTOP: geological unit and lithological class (lithological class). Sand has a different conductivity than clay, but clay in the one geological unit has a different conductivity than clay in another geological unit. Combining geological unit and lithological class to conductivity enables GeoTOP to serve as input for a groundwater flow model.

GeoTOP refines the upper 50 m of the hydrogeological layer model REGIS II (Vernes & Van Doorn 2005). This applies in particular for the Holocene sediments, mapped in REGIS II as one unit (“Holocene complex”). GeoTOP provides a detailed survey of the Holocene sequence, that is subdivided into members, beds and channel belt sediments, each with their own hydraulic properties.

GeoTOP is not appropriate for application in a local groundwater model, for instance an area around a groundwater extraction site. However, the model can serve as a framework for a detailed, local groundwater model to which additional data from borehole descriptions and cone penetration tests are added. An example is the hydrogeological modelling of the Zuiderzee area (the AZURE groundwater model) that uses the GeoTOP model of the Rhine-Meuse area (www.azuremodel.nl).

3.1.3 Geotechnical applications

In the project planning of large infrastructure works, such as the construction of tunnels and highways, GeoTOP provides insight into the expected bearing capacity of the subsurface. Especially in the west of the country, the depth of the Pleistocene sands, the composition of the Holocene sediments and the location and thickness of the channel belt sands are important parameters in the calculation of costs and in the planning of additional subsurface research. The expected composition of the subsoil may also be a factor in the choice of the road section.
Eventually, each infrastructure project will need additional site specific research of the subsoil. The scale of the GeoTOP model is not appropriate in the construction phase of an infrastructure project.

3.1.4 Land subsidence

Land subsidence caused by compaction of clay and peat and by oxidation of peat strongly depends on the lithological composition of the shallow subsurface and on the groundwater table. GeoTOP is an important tool in predicting future land subsidence. The same condition as applied to other applications is valid in this case: the land subsidence estimated in GeoTOP provides trends at a regional scale and is not suitable at local situations. The land subsidence map of Utrecht province is based on the GeoTOP model (Van de Schans 2012). The Flevoland subsidence map (De Lange et al. 2012) is an example of a prediction based on a voxel model similar to GeoTOP.

3.1.5 Natural resources

GeoTOP provides insight into the occurrence of surface mineral deposits such as gravel and sand. Also the volume of the overlying layers, for instance clay, that have to be removed to reach the natural resource can be deduced from GeoTOP. TNO – Geological Survey of the Netherlands has developed Minerals Online, an internet site that displays interactive natural resource maps (www.delfstoffenonline.nl; Van der Meulen et al. 2005). To improve these maps use is made of GeoTOP (Maljers et al. 2015).

3.1.6 Dredging activities

During dredging activities in rivers, for instance the Utrecht Vecht, there is a probability of occurrence of a “hydraulic short circuit” causing seepage of water into the flood basin. Channel belt geometry and composition of the Holocene channel belt sands modelled in GeoTOP can be used to determine which parts of the river course are prone to this phenomenon and whether additional geological research is needed.

3.1.7 Geosciences

GeoTOP data support geoscientific research. An example is the identification of grain-size trends in the Rhine-Meuse delta (Stafleu & Busschers 2014). Analyses of 3D GeoTOP images using the Subsurface Viewer provide new insights into the shallow subsurface geology of The Netherlands (paragraph 5.7).

3.2 Limitations

GeoTOP is currently being developed and does not cover the whole of the onshore Netherlands. Parts of the Netherland that are not covered by GeoTOP can be viewed in the model NL3D (Nederland 3D). NL3D is a lower resolution voxel model (voxels measuring 250 x 250 x 1 m) that covers the whole of the Netherlands.

GeoTOP is not appropriate for use at a local scale, e.g. a building site, individual houses, apartment blocks and water defences. To make a proper estimate of the geometry and properties of the subsurface at a locale scale additional data will always be needed.

4 Data model (formal specification)

4.1 Introduction

GeoTOP consists of the following products and intermediate products created out of a standardized workflow:

- Interpretation of the borehole logs into **geological units** and **lithological class units**. Each borehole log is subdivided into intervals with equal geological units. Within the geological units intervals are discerned with equal lithological classes.
- A **layer model**, comparable to the layer models of DGM and REGIS II, but based on much more borehole logs. In the layer model the subsurface is presented as a stacking of geological units bounded by depth maps of the top and the base of the units. Both surfaces are displayed as a grid or **raster** with grid cells measuring 100 x 100 m. Attributes of each **grid cell** are depth maps of the top and base in m relative to NAP. Grid files of the thickness of the geological unit are derived from the top and base grid files. To conclude standard deviation grids of both top and base are available to represent model uncertainties.
- The actual **voxel model** of the subsurface, each voxel measuring 100 x 100 x 0.5 m. Each **voxel** has a number of attributes, the geological unit, the lithological class and a number of attributes that are a measure of model uncertainty.

The interdependence of the interpreted borehole logs, the layer model and the voxel model is shown in Figures 4.1 – 4.4.

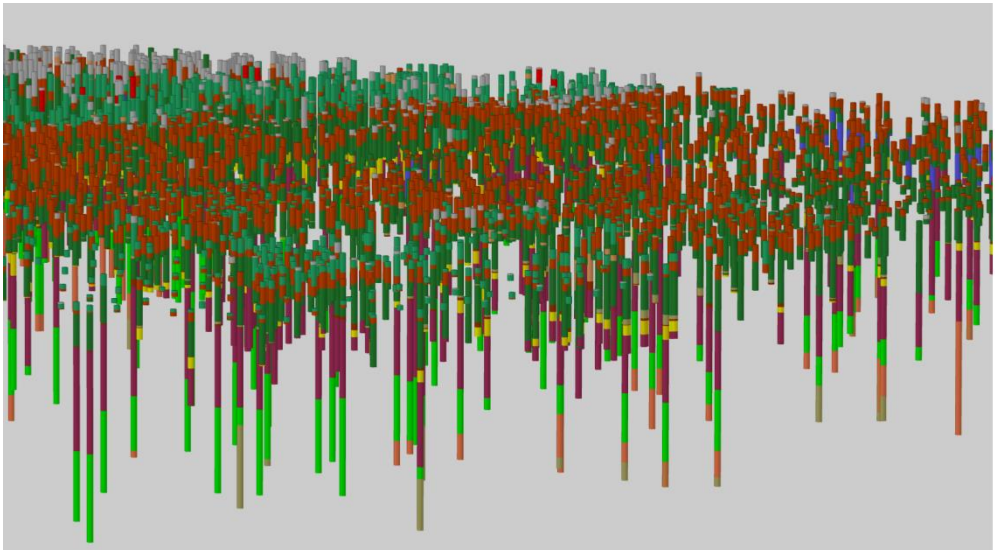

Figure 4.1. 3D view of borehole logs. The colours represent the geological units.

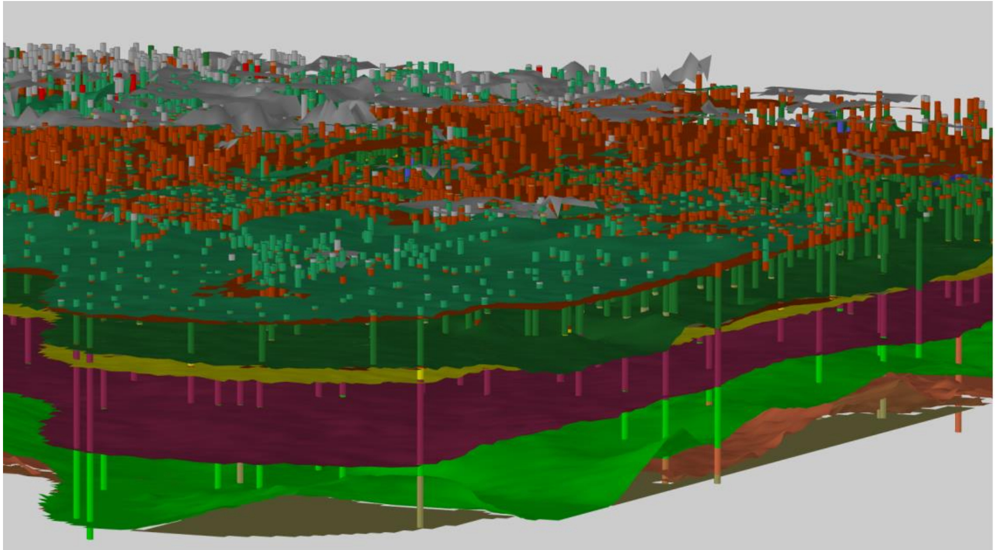

Figure 4.2. 3D view of the layer model based on the interpretation of the borehole logs shown in Figure 4.1. All of the displayed interfaces of the layer model are base surfaces of the geological units. Each base surface is the result of the spatial interpolation of the base of the geological unit indicated in the borehole logs.

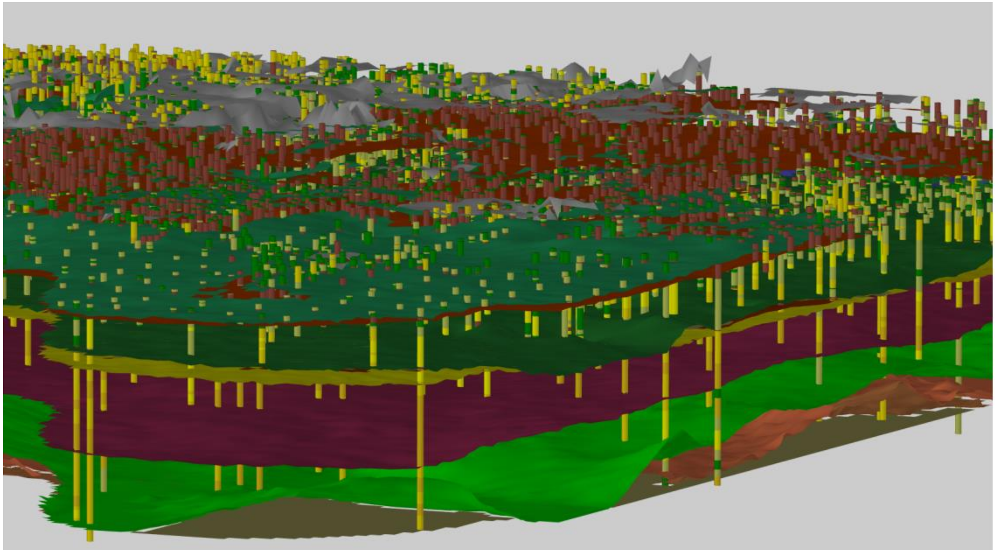

Figure 4.3. 3D view of the layer model shown in Figure 4.2. The colours in the borehole logs represent the assigned lithological classes: coarse to fine sands are displayed with yellow, ranging from dark to light, clay is green, olive green is clayey sand and sandy clay, brown is peat.

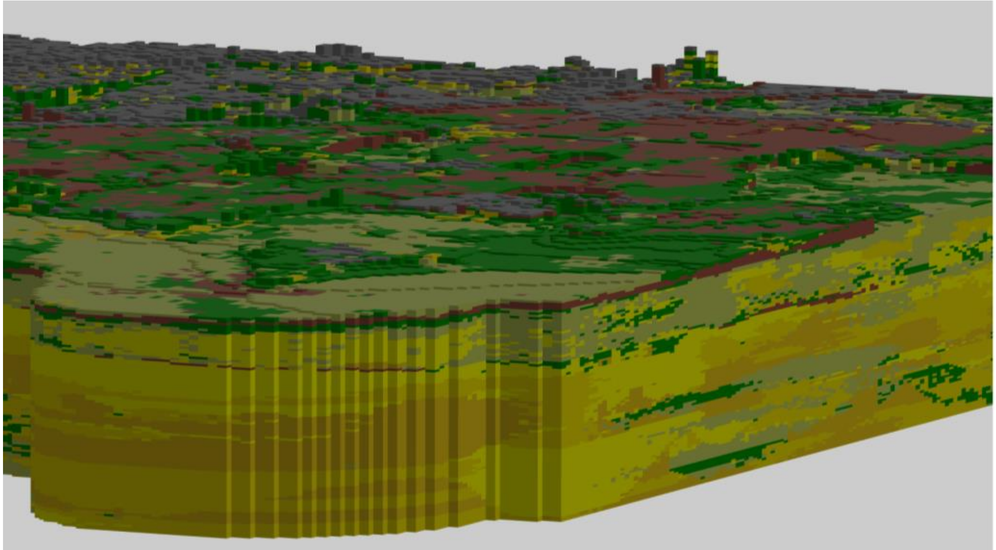

Figure 4.4. 3D view of the voxel model showing lithological classes in different colours. The lithological class arrangement is the result of the spatial interpolation of the lithological class interpretation of the borehole logs. Coarse to fine sands are displayed with yellow, ranging from dark to light, clay is green, olive green is clayey sand and sandy clay, brown is peat.

Another important aspect of GeoTOP is the subdivision into **model areas**. The model is not constructed nationwide but per individual region in a long-term project that was started in 2007. About once a year a new model area is produced. GeoTOP started in the south-western Netherlands (Zeeland, Goeree-Overflakkee and Zuid-Holland) in the period 2007-2010. Models of Noord-Holland, Utrecht and the Rijn-Maas (Rhine-Meuse) area were produced in 2011. From 2012 onwards the models of the northern Netherlands were developed: West Wad (2014) and East Wad (2016).

Version management is applied to GeoTOP. Version management applies both to individual model areas and to the GeoTOP model as a whole. A GeoTOP version consists of a composition of several versions of model areas.

4.2 Model version and model area version

4.2.1 Diagram

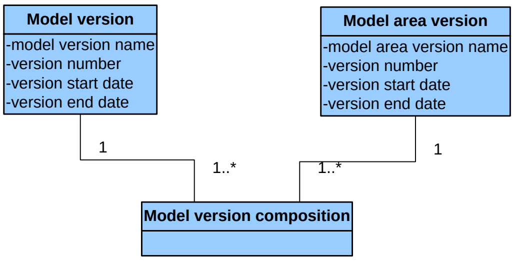

Figure 4.5. Diagram of the data model showing the model version, model area version and model version composition.

4.2.2 Model version

Definition	A version of the subsurface model GeoTOP. A version consists of one or **more model area versions**.
Relations	A **model version** comprises one or more **model area versions**, established in the **model version composition**.
Attribute	**Specification**
Model version name	Model version name. The current version is named “GeoTOP”
Version number	Version number. Number of the current version is “v01r3”.
Version start date	First day the version is actual.
Version end date	Last day the version is actual. The current version has not (yet) an end date.

4.2.3 Model area version

Definition	A version of a model area.
Relations	A model version area is part of one or more **model versions**, established in the **model version composition**.
Attribute	**Specification**
Model area version name	Name of the model area version. For example “Rivierengebied”.
Version number	Version number. For example “v01r3”.
Version start date	First day the model area version is actual.
Version end date	Last day the model area version is actual.

4.2.4 Model version composition

Definition	The model version composition indicates which **model area versions** are compiled in a **model version**.
Relations	A **model version** is composed of one or more **model area versions**. A **model area version** is part of one or more **model versions**.
Attribute	**Specification**
Model version	Reference to **model version**.
Model area version	Reference to **model area version**.

4.3 Interpreted borehole logs, description and interpretation of the intervals

4.3.1 Diagram

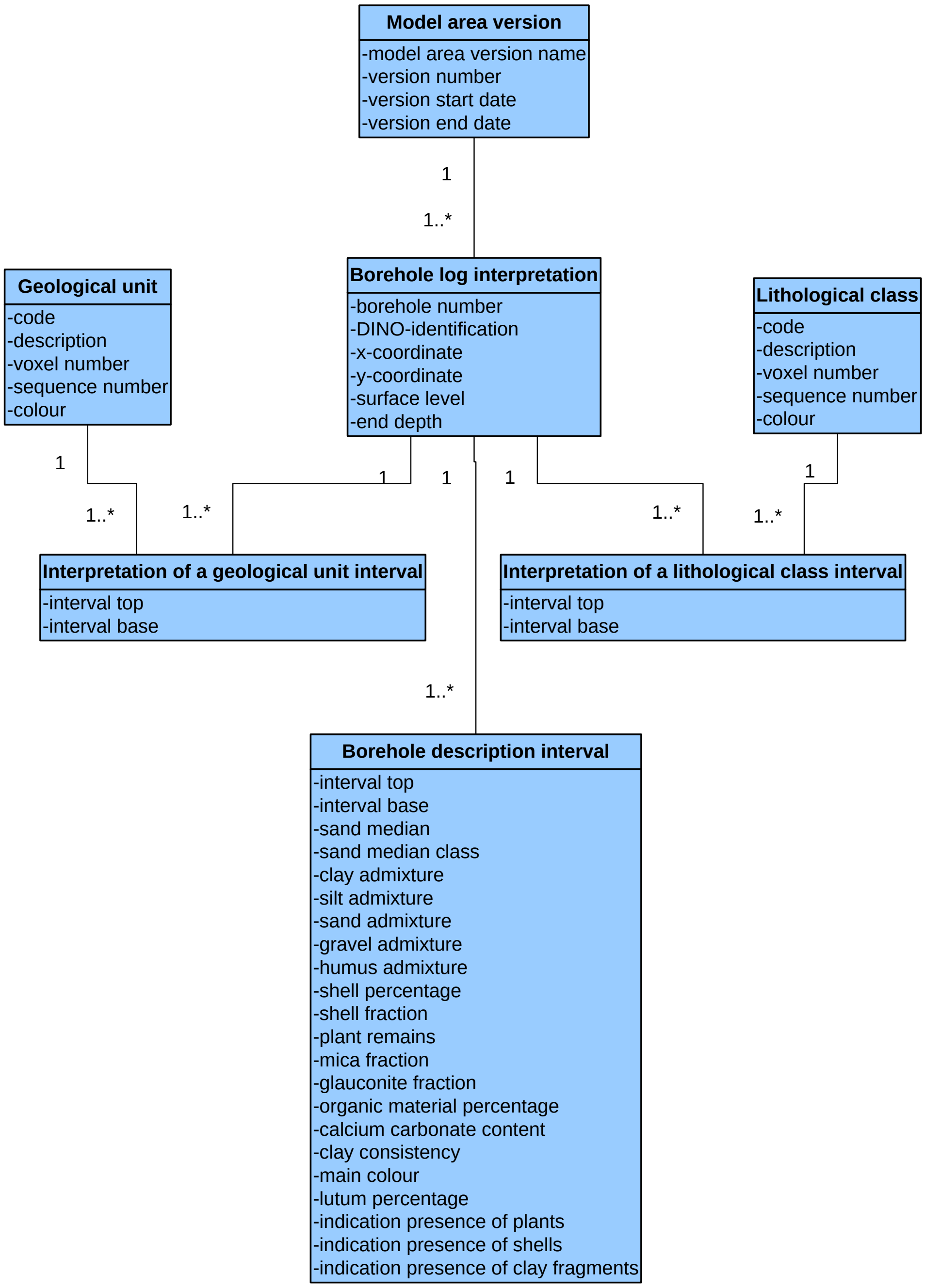

Figure 4.6. Diagram of the data model showing the model area version, the interpreted borehole logs and the description of the interpreted intervals of the geological unit and the lithological class.

4.3.2 Borehole log interpretation

Definition	A borehole log in a **model area version** to which an interpretation of the **geological units** and the **lithological classes** has been added.
Relations	The interpretation of a borehole log comprise one or more **borehole description intervals**, one or more **geological unit intervals** and one or more **lithological class intervals**. The borehole log interpretation belongs to one **model area version**.
Attribute	**Specification**
Model area version	Reference to the **model area version**.
Borehole number	NITG- number of the borehole log.
DINO-identification	Reference to the corresponding borehole log in the DINO database.
X-coordinate	X-coordinate of the location of the borehole log, according to the Dutch National Grid.
Y-coordinate	Y-coordinate of the location of the borehole log, according to the Dutch National Grid.
Surface level	Elevation of the surface level or the waterbed in mm relative to NAP at the location of the borehole log.
End depth	Depth in mm of the borehole counted from the top of the borehole log.

4.3.3 Explanation

At a certain time during the construction of the model area version a snapshot is made of the borehole logs and the related intervals of the borehole descriptions stored in the DINO database. The interpretations of the borehole logs will be based on this snapshot. Any changes made in the DINO database after the snapshot will not be visible for that version of the model area. However, the borehole log in the DINO database is related to the borehole log of the snapshot (the attribute DINO identification). If required the snapshot can be compared with the actual situation in DINO.

4.3.4 Borehole description interval

Definition	Borehole description interval of an **interpreted borehole log** in a **model area version**.
Relations	A borehole description interval is part of **the interpretation of a borehole log.**
Attribute	**Specification**
Borehole number	Reference to the interpreted borehole log that contains the described interval.
Interval top	Top of the interval in mm counted from the top of the borehole log.
Interval base	Base of the interval in mm counted from the top of the borehole log.
Sand median	The grainsize in µm that divides the sand fraction, based on weight, in two parts of 50%.This property is recorded as the

	sand median (number) and the class (sand median class) to which the median belongs.
Sand median class	The class to which a sand median belongs.
Clay admixture	Code that indicates the degree of clay admixture.
Silt admixture	Code that indicates the degree of silt admixture.
Sand admixture	Code that indicates the degree of sand admixture.
Gravel admixture	Code that indicates the degree of gravel admixture.
Humus admixture	Code that indicates the degree of humus admixture.
Shell percentage	Estimated weight percentage of the shell fraction (shells > 2 mm)
Shell fraction	Code that indicates the volume percentage of shells (including shell grit).
Plant remains	Code that indicates the volume percentage of plant material.
Mica fraction	Code that indicates the mica percentage.
Glauconite fraction	Code that indicates the glauconite percentage.
organic material percentage	Estimated weight percentage of the organic material.
Calcium carbonate content	Code that indicates the calcium carbonate content.
Clay consistency	Code that indicates the clay consistency.
Main colour	Dominant colour.
Lutum percentage	Estimated weight percentage of the mineral constituents, mainly clay minerals (grain size < 2 µm).
Indication presence of plants	Indication (y/n) to the presence of plants.
Indication presence of shells	Indication (y/n) to the presence of shells.
Indication presence of clay fragments	Indication (y/n) to the presence of clay fragments.

4.3.5 *Interpretation of a geological unit interval*

Definition	Interpretation of a **borehole log** used in GeoTOP that describes the sequence of intervals of the same **geological unit.**
Relations	The interpretation of a geological unit interval belongs to one interpreted borehole log and to one geological unit. The data model does not display the relation that a geological unit interval is an interpretation of 1 or more consecutive, contiguous borehole description intervals, and that a borehole description interval always exactly belongs to 1 geological unit. An additional relation is the subdivision of the geological unit into 1 or more lithological class intervals, and that a lithological class interval always belongs to one geological unit interval.
Attribute	**Specification**
Borehole number	Reference to **the interpreted borehole log** to which the geological unit interval belongs.
Interval top	Top of the interval in mm counted from the top of the borehole log.
Interval base	Base of the interval in mm counted from the top of the borehole log.

Geological unit	Reference to the geological unit of the interval

4.3.6 *Interpretation of the lithological class interval*

Definition	Interpretation of a **borehole log** used in GeoTOP that describes the sequence of intervals of the same **lithological class**.
Relations	The interpretation of a lithological class interval belongs to one interpreted borehole log and to one lithological class. The data model does not display the relation that a lithological class interval is an interpretation of 1 or more consecutive, contiguous borehole description intervals, and that a borehole description interval always exactly belongs to 1 lithological class unit. An additional relation is that a lithological class interval always belongs to 1 geological unit interval and that a geological unit is subdivided in 1 or more lithological class units.
Attribute	**Specification**
Borehole number	Reference to the **interpreted borehole log** that includes the lithological class interval.
Interval top	Top of the interval in mm counted from the top of the borehole log.
Interval base	Base of the interval in mm counted from the top of the borehole log.
Lithological class	Reference to the lithological class of the interval.

4.3.7 *Technical aspects*

The interpreted borehole logs and the description and interpretation intervals are tabular information. The data are stored in a relational database.

4.4 Layer model

4.4.1 *Diagram*

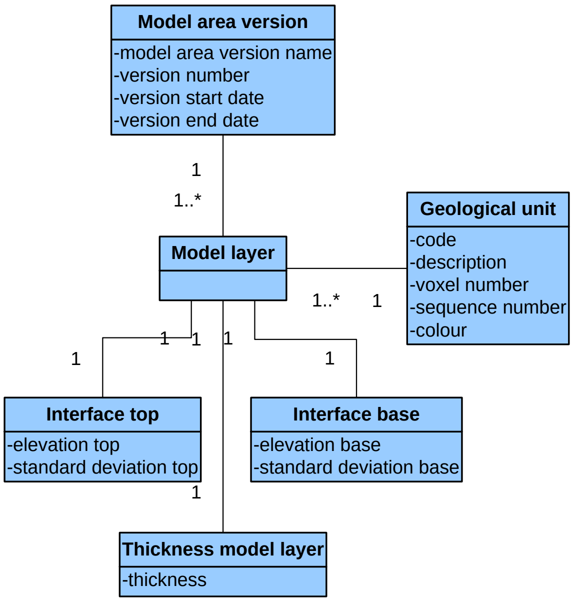

Figure 4.7. Diagram of the data model showing the model area version, the model layer, the interfaces and the thickness of the model layer.

4.4.2 *Model layer*

Definition	A volume of a **geological unit** that is included in a **model area version** and that is bounded by **interfaces** at the top and the base.
Relations	A model layer belongs to one **model area version**. A **model area version** includes several model layers. A model layer describes the volume of one **geological unit**. The data model does not display the relation that a voxel must be located between the interfaces of the model layer.
Attribute	**Specification**
Model area version	Reference to the **model area version**.
Geological unit	Reference to the **geological unit**.

4.4.3 *Interface top*

Definition	The spatial limitation of the top of the **model layer**.
Relations	A **model layer** is always limited by one interface top. An interface top always specifies the top of one **model layer**.
Attribute	**Specification**
Elevation top	Elevation top in m relative to NAP.
Standard deviation top	Standard deviation of the elevation top in m.

4.4.4 *Interface base*

Definition	The spatial limitation of the base of the **model layer**.
Relations	A **model layer** is always limited by one interface base. An interface base always specifies the base of one **model layer**.
Attribute	**Specification**
Elevation base	Elevation base in m relative to NAP.
Standard deviation base	Standard deviation of the elevation base in m.

4.4.5 *Thickness model layer*

Definition	The thickness of a **model layer** derived from the **interfaces top** and **base**.
Relations	A **model layer** always has one thickness. A Thickness always belongs to one **model layer**.
Attribute	**Specification**
Thickness	Thickness in m. Thickness can be derived from top and base.

4.4.6 *Technical aspects*

In technical terms the layer model is saved in grid files. A grid is a regular rectangular frame of square grid cells that determines one property of a model layer. A grid cell is a square area measuring 100 x 100 m in a grid. Each cell has a value of a property that is representative for the whole grid cell.

Each model layer in the layer model has 5 grids. Each grid records one property, such as top, base, thickness, standard deviation top and standard deviation base. The following shows the files of the model layer NIHO (Nieuwkoop Formation, Hollandveen Member):

Grid file	**Explanation**
niho_bcc.asc	Base of the unit.
niho_tcc.asc	Top of the unit.
niho_dcc.asc	Thickness of the unit.
niho_std_bcc.asc	Standard deviation of the base of the unit.
niho_std_tcc.asc	Standard deviation of the top of the unit.

De grids are saved in *ArcInfo ASCII Grid-format* (ESRI), extension*.asc (*ArcAscii-format*). The issue of GeoTOP via DINOloket (Chapter 5) uses the ERDAS Imagine format (extension *.img) to store the grids. Both formats can be opened in nearly all GIS applications, though sometimes they must first be converted. Stafleu et al. (2012) present a detailed description of the ArcAscii-format.

Grids that cover the complete coverage area of a GeoTOP model version are separate model area versions that have been merged to one grid without any adaptations.

4.5 Voxel model

4.5.1 Diagram

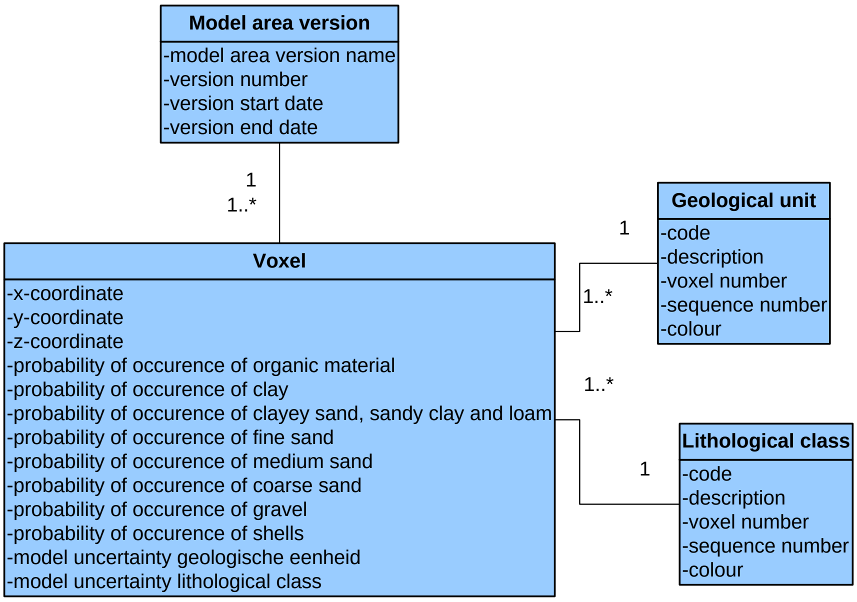

Figure 4.8. Diagram of the data model showing the model area version and the voxel of the voxel model.

4.5.2 Voxel

Definition	A **voxel** is a volume block in the subsurface that has uniform properties. A voxel has a location established by the (x, y, z) coordinates of the centre of the voxel, and a number of attributes. The attribute values are representative not only for the centre, but for the whole voxel.
Attribute	**Specification**
Model area version	Reference to the **model area version**.
X-coordinate	X-coordinate (Dutch National Grid) of the centre of the voxel.
Y-coordinate	Y-coordinate (Dutch National Grid) of the centre of the voxel.
Z-coordinate	Z-coordinate in m relative to NAP of the centre of the voxel.
Geological unit	Reference to the geological unit that includes the voxel.
Most probable lithological class	Reference to the lithological class of the voxel.
Probability of occurrence of organic material (peat)	Probability of occurrence of the lithological class ‘ organic material (peat)’ in the voxel. The probability is given in a real number in values between 0 and 1. 0 = low probability, 1 = high probability.
Probability of occurrence of clay	Idem to lithological class clay.
Probability of occurrence of clayey sand, sandy clay and loam	Idem to lithological class ‘clayey sand, sandy clay and loam’.
Probability of occurrence	Idem to lithological class ‘fine sand’.

of fine sand	
Probability of occurrence of medium sand	Idem to lithological class ‘medium sand’.
Probability of occurrence of coarse sand	Idem to lithological class ‘coarse sand’.
Probability of occurrence of gravel	Idem to lithological class ‘gravel’.
Probability of occurrence of shells	Idem to lithological class ‘shells’.
Model uncertainty geological unit	The degree to which the model is able to give an unambiguous estimate of the geological unit of the voxel. The model uncertainty is given in a real number in values between 0 and 1. 0 = very small model uncertainty, 1 = very high model uncertainty.
Model uncertainty lithological class	The degree to which the model is able to give an unambiguous estimate of the lithological class that is representative to the voxel. The model uncertainty is given in a real number in values between 0 and 1. 0 = very low model uncertainty, 1 = very high model uncertainty.

4.5.3 *Explanation*

In GeoTOP v1.2 both model uncertainties were only available in the voxel model of the West Wad model area. The current version (v1.3) includes model uncertainties in all model areas.

4.5.4 *Technical aspects*

To store the voxel model use is made of two data formats: first, one in which the voxel includes the (x, y, z) coordinates per voxel, and second, one in which the (x, y, z) coordinates per voxel can be derived from the header information (comparable to the ArcAscii-format of the grids mentioned above). Both data formats are in ASCII. Voxel models that are supplied with the Subsurface viewer belong to the second data format. Both data formats are described in detail in Stafleu et al. (2012).

4.6 Property definitions

4.6.1 *Geological unit*

Definition	A **geological unit** is a spatial coherent rock body in the subsurface showing similar lithological and genetic properties.
Attribute	**Specification**
Code	Unique identification code of a geological unit, for instance ‘NAWA’.
Description	Name of the geological unit, for instance ‘Naaldwijk Formation, Walcheren Member’.
Voxel number	Unique, numerical code of the geological unit that is used in many technical implementations of the voxel model.
Sequence number	Sequence number of the preferred stratigraphical sequence of the geological units. Low numbers occur in the upper part of the stratigraphic sequence. Among other things, the sequence number is used in the legend of the geological units.

Colour	RGB value of the colour used to visualize the geological unit.

4.6.2 *Explanation*

In most cases the geological units correspond to the lithostratigraphical units described in the Nomenclature Shallow Subsurface. We use the term geological unit because not all units do correspond exactly with the lithostratigraphical units in the Nomenclature. In the modelling it can be necessary to merge two lithostratigraphical units into one geological unit. As an example the Peize Formation and the Waalre Formation have been combined to one geological unit.

The opposite case, splitting a lithostratigraphical unit into two (or more) geological units, can also be necessary. An example is the Echteld Formation, that is modelled in two units that have a different stratigraphic position relative to other units.
A special case are the channel sands. The Holocene channel belts of the Naaldwijk and Echteld Formations are modelled separately from their lithostratigraphical unit.

A channel sand is characterized by its position in the subsurface relative to other channel sands. They are classified A to E. A, the youngest belt, is the most shallow situated channel sand and E, the oldest belt, is the most deepest situated channel sand. The Holocene channel belts are not distinguished as separate units in the Nomenclature. They are part of the Echteld Formation or, in the case of the Naaldwijk Formation, part of the Wormer Member or Walcheren Member.

4.6.3 *Lithological class*

Definition	A **lithological class** is an individual class in a soil type classification.
Attribute	**Specification**
Code	Unique identification code of a lithological class, for instance 'k'.
Name	Name of the lithological class, for instance 'clay'.
Voxel number	Unique, numerical code of the lithological class that is used in many technical implementations of the voxel model.
Serial number	Among other things, the serial number is used in the legend of the lithological class units.
Colour	RGB value of the colour used to visualize the lithological class.

4.6.4 *Explanation*

GeoTOP uses the classification of REGIS II, added with lithological class 'Anthropogenic':

Name	**Code**	**Voxel number**	**Grainsize (median)**
Anthropogenic	a	0	-
Organic material (peat)	v	1	-
Clay	k	2	-
Clayey sand, sandy clay and loam	kz	3	-
Fine sand	zf	5	≥ 63 µm and < 150 µm
Medium sand	zm	6	≥ 150 µm and < 300 µm
Coarse sand	zg	7	≥ 300 µm and < 2mm
Gravel	g	8	≥ 2mm
Shells	she	9	-

Sand, grainsize unknown	z	-	unknown
Others	o	-	-

The lithological class has been derived from the borehole descriptions on the basis of a set of rules. Stafleu et al. (2012) present the details of this derivation. The lithological class ‘anthropogenic’ only occurs in the voxel model. The lithological classes ‘sand, grain-size unknown’ and ‘others’ only occur in the interpretation of the borehole logs. Note that the particle size ‘medium sand’ (150 – 300 µm) in the present report differs from the commonly used Wentworth particle size scale for medium sand (250 – 500 µm).

4.6.5 Technical aspects

Definitions of geological units and lithological classes are tabular data. The data are stored in a relational database.

5 Dissemination

5.1 Introduction

GeoTOP is released via www.dinoloket.nl, the dataportal of TNO - Geological Survey of the Netherlands.
The following visualisations of GeoTOP are available via the dataportal:

- Map of the GeoTOP coverage area showing the location of he borehole logs used in the construction of the model.
- Real record of each borehole log showing the lithological description in addition to the GeoTOP geological unit and lithological class.
- Virtual record (synthetic borehole) of the voxel model at a chosen location showing the vertical sequence of voxels.
- Vertical transect (cross-section) of the voxel model along a chosen line on the map.
- Map of the distribution, top, base or thickness of the chosen model unit.
- SubsurfaceViewer files of the voxel model, the layer model and the interpretation of the borehole logs of a chosen map sheet area (a rectangular area usually measuring 20 x 25 km). These files can be visualized using the software especially developed for this purpose, including a 3D representation.
- ArcGIS files of the layer model (grid maps).
- ArcGIS files of horizontal slices (grid maps) of the voxel model (both relative to surface level and to NAP).

The GeoTOP visualisations are explained below.
Only the current version of GeoTOP are available via DINOloket. Former versions of GeoTOP can be requested via the Servicedesk.

5.2 Map of the GeoTOP coverage area and location of the borehole logs

5.2.1 Aim and use

The map shows the spatial extent of GeoTOP onshore the Netherlands. The map also shows the location of the borehole logs that have been used to create the model.

5.2.2 Description

A red line indicates the boundary of the present spatial extent of GeoTOP (Fig. 5.1). Within this outline the location of the boreholes used to generate the model is shown. Clicking on an individual borehole will bring up the borehole log.

Figure 5.1. Coverage area of the current version of GeoTOP.

5.2.3 Limitations

The boundary of the coverage area is a polygon while the models are grids measuring 100 x 100 m. Therefore, part of the model may fall inside or just outside the polygon.

To generate the models we also used confidential boreholes. These boreholes are not displayed and cannot be ordered at DINOloket. Use has also been made of a large set of data from Utrecht University. These data result from hand-augered drillings made in the Rhine-Meuse delta and are not displayed and cannot be ordered via DINOloket.

5.3 Actual borehole records with interpretations

5.3.1 Aim and use

The actual borehole record provides insight into the interpretation of the borehole logs.

5.3.2 Description

The actual borehole record (Fig.5.2) shows the vertical sequence of intervals with interpretations: geological unit, lithological classes and lithology.

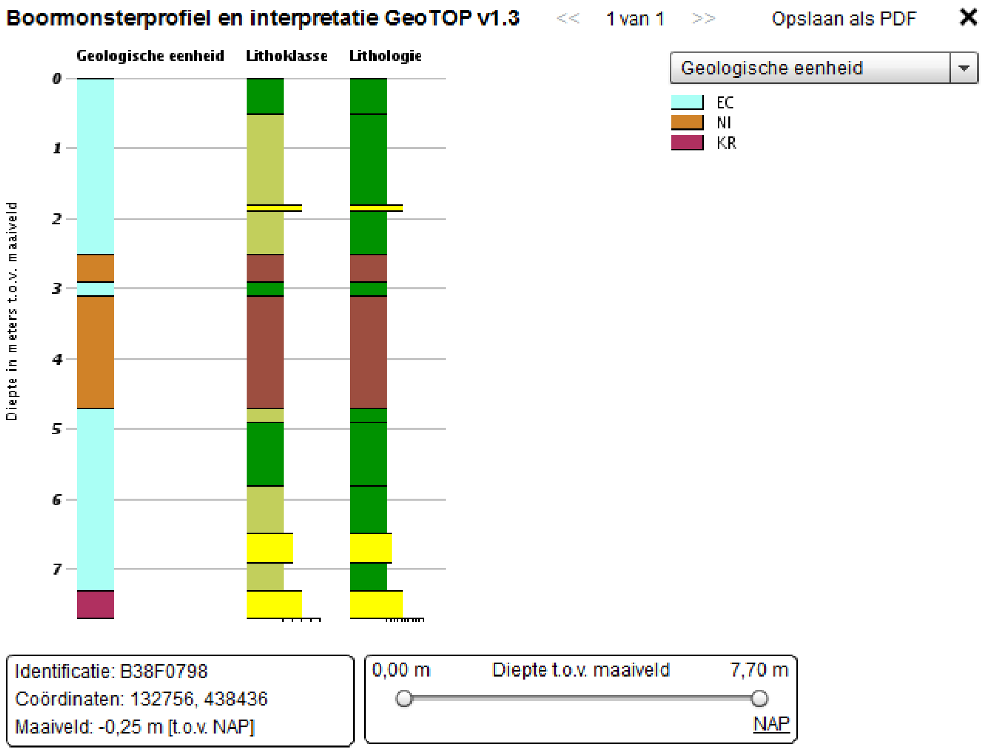

Figure 5.2. Actual borehole record of the interpreted borehole log in GeoTOP.

5.3.3 Limitations

To generate the GeoTOP model confidential boreholes were used. Use has also been made of a large set of data from Utrecht University. These boreholes are not displayed and cannot be ordered via DINOloket.
A borehole log presents a detailed image of the stacked layers in the subsurface at one specific location. The layer model and the voxel model predict the stacking of the layers that is representative for an area of 100 x 100 m which fits to a subregional scale. Therefore, the interpretation of a borehole log may deviate from a synthetic borehole at the same location.

The elevation of the surface level at the location of a borehole log may deviate also from the level in the model. This may have several causes: small differences of the surface level at the location of the borehole log, errors in the measurement of the surface level, or a real change in surface level. In the latter case, for example, the construction of the model took place after raising or levelling of the soil.

5.4 Synthetic borehole (corer)

5.4.1 Aim and use

The synthetic borehole (‘corer’) through the GeoTOP voxel model shows the vertical sequence of the voxels at a selected location on the map and the uncertainty of the model.

5.4.2 Description

The synthetic borehole (‘corer’) through the GeoTOP voxel model shows the vertical sequence of the voxels at a selected location on the map and the uncertainty of the model. The voxels measure 100 x 100 x 0.5 m (x, y, z) and therefore represent layers with a thickness of 0.5 m (Fig. 5.3). Per voxel the following properties are displayed that are representative for the entire voxel:

- The geological unit to which the voxel belongs.
- The model uncertainty of the geological unit (only available in the model area West Wad).
- The most probable lithological class assigned to the voxel.
- The probability of occurrence of the lithological classes in each voxel.

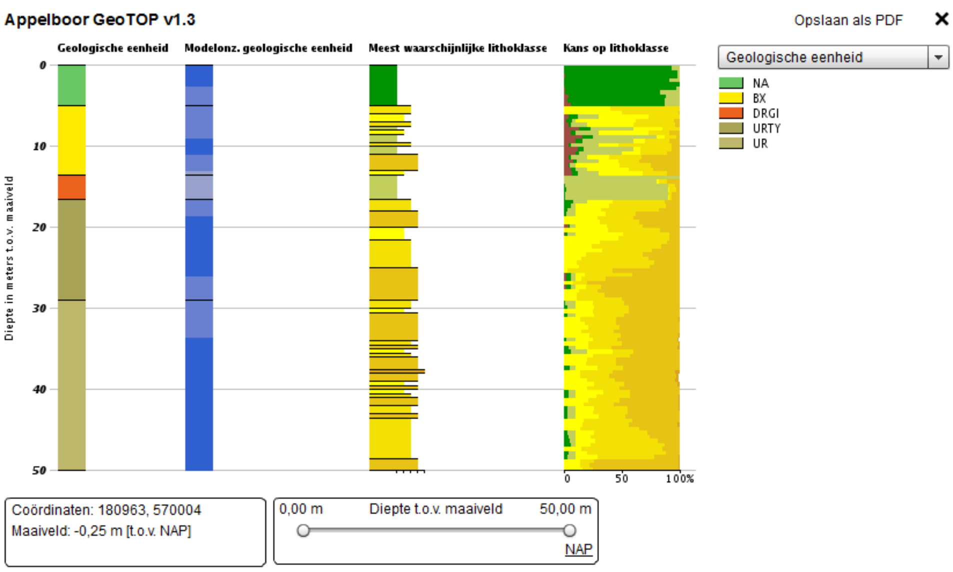

Figure 5.3. Synthetic borehole record of the GeoTOP voxel model.

In GeoTOP the lithological classes are estimated in a stochastic procedure that in addition to estimating the most probable occurrence also estimates the probability of occurrence of each of the discerned lithological classes. The probabilities are a measure of the model uncertainty. For example, if 80% fine sand and 20% clay have been predicted, the uncertainty is low. If, on the other hand, a probability of 35% clay, 40% peat and 25% fine sand has been predicted, then the uncertainty is relatively high. It is important to realise that probabilities are not the same as proportions: a 35% probability of the occurrence of clay means that the *entire* voxel has a probability of being 35% clay and not that 35% of the voxel contains clay.

The subdivision into geological units is also linked with uncertainties. These uncertainties are displayed in the column ‘Model uncertainty of the geological unit’ in the West Wad model area. The ArcGIS files of the GeoTOP layer model contain information about the uncertainties of the geological units in grid maps of the standard deviations.

5.5 Vertical transect (cross-section) through the voxel model

5.5.1 Aim and use

The vertical transect (cross-section) through the voxel model along a chosen line on the map shows the vertical sequence of voxels. To visualise a 3D image of the layering and properties of the subsurface you can make multiple cross-sections through your area of interest.

5.5.2 Description

The user defines a transect by clicking points on the map. These points may be the locations of borehole logs or randomly chosen locations. To follow a line on the map, e.g. a dike transect, one uses the mouse to make several clicks.
The visualisation shows a cross-section through the voxel model along the transect (Fig. 5.4). The voxel model will show the attribute chosen by the user: geological unit, most probable lithological class or the probability of occurrence of a lithological class. In the West Wad model area the model uncertainty of the lithological class or the geological unit can also be displayed.

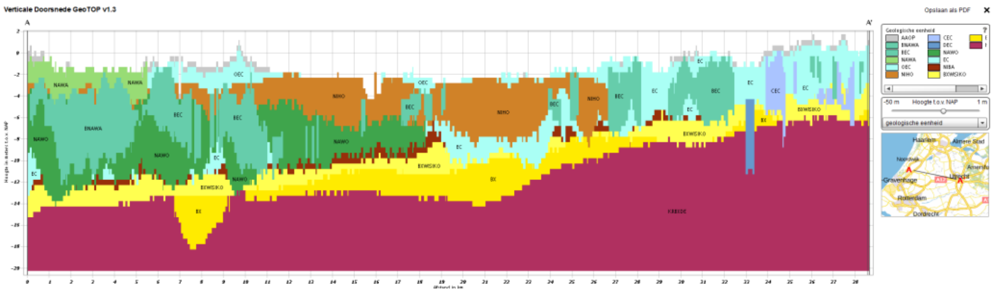

Figure 5.4. Vertical cross-section of the GeoTOP voxel model

5.5.3 Limitations

Faults cutting the cross-section are not displayed. In case of displacement along the fault plane an abrupt change is shown in the boundary plane of the geological unit and/or the lithological class.

5.6 Map of a geological unit in the layer model

5.6.1 Aim and use

The map of the occurrence and top, base or thickness of the selected geological unit provides insight into the spatial distribution of the unit shown in a cross-section. Combining the cross-sections with map images of the geological units, may give a sound 3D image of the stacked layering and properties of the subsurface.

5.6.2 Description

The user clicks on a geological unit in the vertical cross-section and can visualize a map with the distribution and top, base or thickness of the chosen unit (Fig. 5.5).

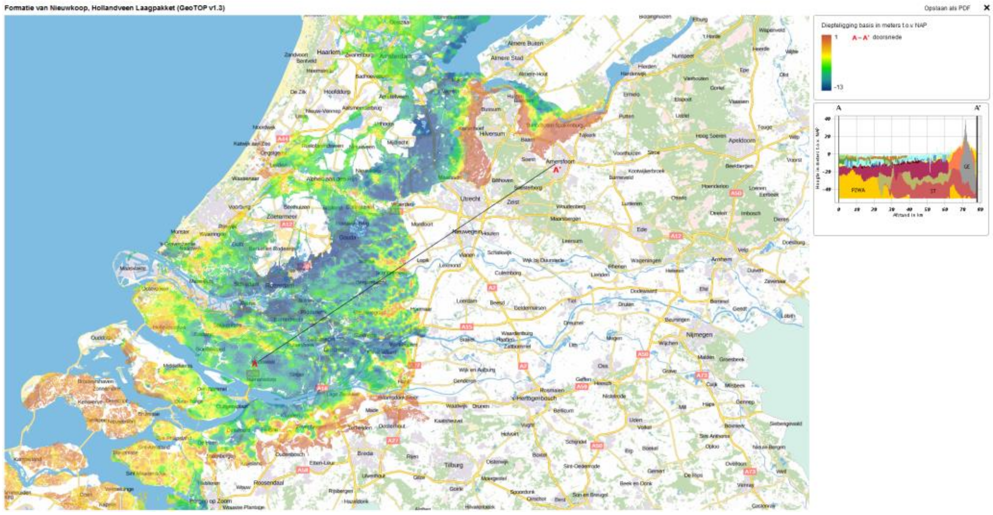

Figure 5.5. Map showing the distribution and depth of the base of a geological unit in the GeoTOP layer model.

5.6.3 Limitations

Faults cutting the map are not displayed. In case of displacement along the fault plane an abrupt change is shown in the top, base and/or thickness of the geological unit.

Map images can only be displayed from a cross-section. The map is a static image that can not be zoomed or panned.

5.7 SubsurfaceViewer files

5.7.1 Aim and use

The SubsurfaceViewer visualises the geometry and properties as estimated in the models, using maps, borehole logs, cross-sections and full 3D views of the subsurface of the Netherlands. The map sheets of the SubsurfaceViewer files also contain the voxel model in ASCII format.

5.7.2 Description

The GeoTOP SubsurfaceViewer is a program to visualize the layer model, the voxel model and the borehole logs with interpretations.
The SubsurfaceViewer has been developed for TNO by the German firm INSIGHT Geological Software Systems GmbH (www.subsurfaceviewer.com) and can be ordered and installed freely via DINOloket. The model data of GeoTOP can be viewed in the SubsurfaceViewer (Fig. 5.6). Further information about the operation and the software can be found in the “Handleiding SubsurfaceViewer 3D (TNO, 2014b)”.

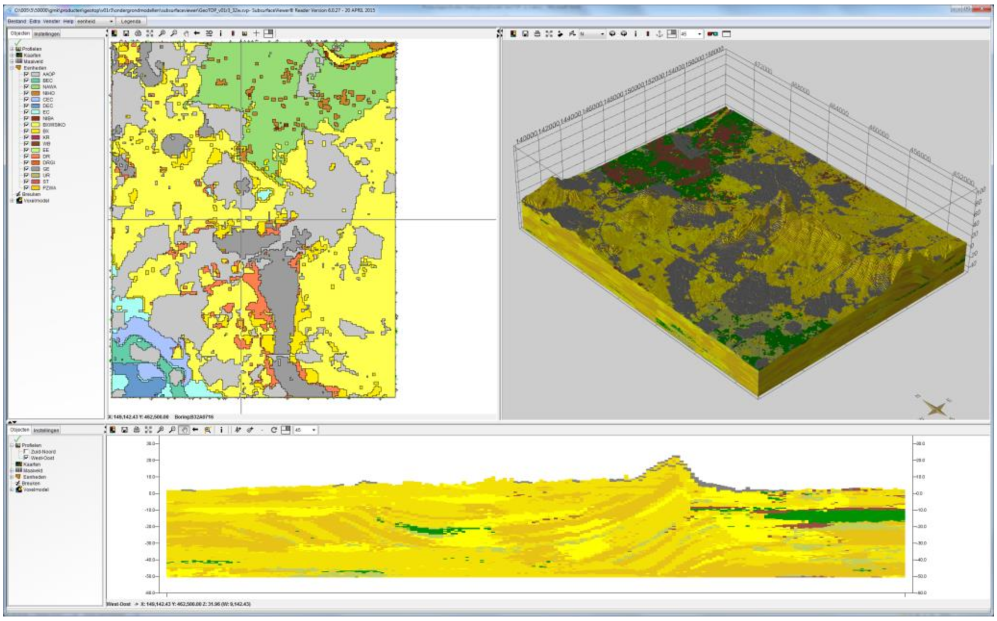

Figure 5.6. GeoTOP map sheet 32 W shown in the Subsurface Viewer. Upper left side: map of the layer model; upper right side: 3D view of the voxel model; below: west – east cross-section through the voxel model.

5.7.3 Limitations

The software of the SubsurfaceViewer makes high demands to the hardware of the PC or laptop and the graphics card.

Files to be used in the SubsurfaceViewer can only be delivered in predefined map sheets, following the TOP50 grid of Kadaster.nl.

5.8 ArcGIS files of the layer model

5.8.1 Aim and use

Five grid maps are available for each geological unit in GeoTOP: top, base and thickness, standard deviation of the top and standard deviation of the thickness. In the current version of GeoTOP the grid files of the separate versions of the model areas are combined. One possible use of the grid files is to develop a framework of a detailed local scale subsurface model, such as a building site.

5.8.2 Description

The ArcGIS files are compiled in one zip file of c. 300 MB. The unzipped files cover about 10 GB. The zip file contains the following files:

- ArcMap document “Holoceen” of the Holocene units supplied with legends.
- ArcMap document “Pleistoceen” of the Pleistocene and older units supplied with legends.
- Per unit:
    - Grid maps of the distribution and depth of the top and the base of the unit (in m relative to NAP).
    - Grid maps of the distribution and thickness of the unit (in m).
    - Grid maps of the standard deviation in the depth of the top and base of the unit (in m).

    - Shape file (points) of the interpreted borehole logs that comprise the unit, supplied with information on the top, base and thickness of the unit in the borehole log.
- General information that supports the use of the model:
    - Schematic topographic map of the Netherlands (shapefile, polygon).
    - Boundaries of the GeoTOP model areas (shapefile, polygon).
    - Relief maps of surface level and waterbed (grid file).
    - Outline of the topographic map sheets. The numbering of the borehole logs has been based on these map sheets (shapefile, polygon).

5.8.3 Limitations

As the grids of several model areas have been merged, some artificial transitions (edge effects) may be visible along the boundaries of the model.

Some units may fall within the depth range of GeoTOP in one model area, while they may fall outside the depth range in another model area. Only the units that fall within the depth range of GeoTOP have been modelled.

The user can open the mxd-files in ArcGIS version 10.0 or higher. Grid files and shapefiles can be opened in nearly all GIS applications, though sometimes they must first be converted. Examples of alternative GIS-packages are Grass (open-source), MapInfo and GeoMedia.

5.9 ArcGIS files with depth slices

5.9.1 Aim and use

Horizontal slices provide insight into the spatial distribution of the geological units and lithological classes at a specific elevation relative to NAP or to surface level.

5.9.2 Description

Horizontal slices are grid files which show a property of the voxel model (e.g. a lithological class) at a specific depth relative to surface level or to NAP. Figures 5.7a and 5.7b show examples of horizontal slices of a lithological class relative to surface level and to NAP.

A zip file with horizontal slices comprises the following files:

- ArcMap document of the compiled maps with legends.
- Per depth, at 50 cm intervals:
    - Grid file of the lithological class or the geological unit (NB: the ArcMap document only shows the grids for 1 m intervals; the download files contain all grids per 50 cm interval).
- General information that supports the use of the model:
    - Schematic topographic map of the Netherlands (shapefile, polygon).
    - Boundaries of the GeoTOP model areas (shapefile, polygon).
    - Map of surface level height and waterbed depth (grid file).
    - Outline of the topographic map sheets. The numbering of the borehole logs has been based on these map sheets (shapefile, polygon).

5.9.3 Naming of the horizontal slices

The names of the horizontal slices of GeoTOP are composed as follows:

Horizontal slices relative to surface level: the name has a prefix “strat” (model units) or “lith” (lithological class) followed by the depth in cm below ground level (4 digits). For example: strat_0000_mv.img means a slice through the model units at a depth of 0 to 0.5 m below ground level. The next grid strat_0050_mv.img provides the slice at a depth of 0.5 to 1 m below ground level.

Horizontal slices relative to NAP: the name has a prefix “strat” (model units) or “lith” (lithological class) followed by a serial number of 3 digits and the depth in cm relative to NAP (4 digits). Serial number 001 is the lowest located slice at 50 m below NAP and it shows the interval from 50 to 49.50 m below NAP. The name is as follows: lith_001_5000_cm_onder _nap.img. An example of a slice above NAP is lith_103_0100_cm_boven_nap.img showing the range of 1 to 1.5 m above NAP.

5.9.4 Limitations

The user can open the mxd-files in ArcGIS version 10.0 or higher. Grid files and shapefiles can be opened in nearly all GIS applications, though sometimes they must first be converted. Examples of alternative GIS-packages are Grass (open-source), MapInfo and GeoMedia.

As the grids of several model areas have been merged, some artificial transitions (edge effects) may be visible along the boundaries of the model.

5.10 Costs

Ordering GeoTOP files via DINOloket is free of charge. Charges may be applied when you request (parts of) the GeoTOP model or when you ask for secondary products.

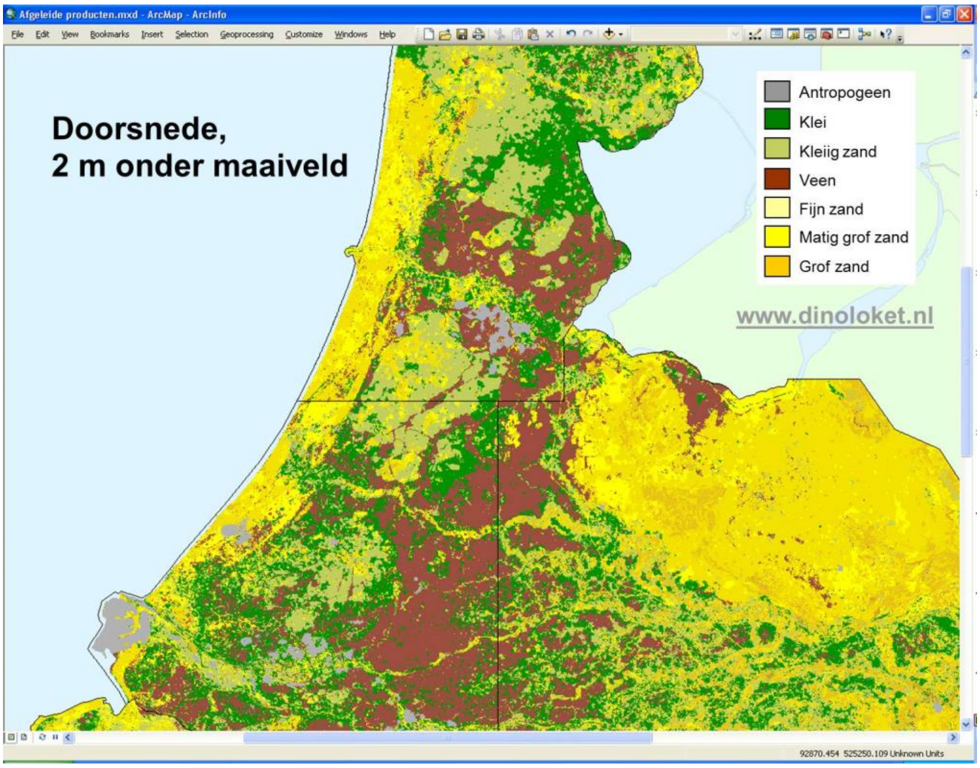

Figure 5.7a. Horizontal slice showing the lithological classes at 2 m below surface level. The thin black lines are the boundaries between the model areas.

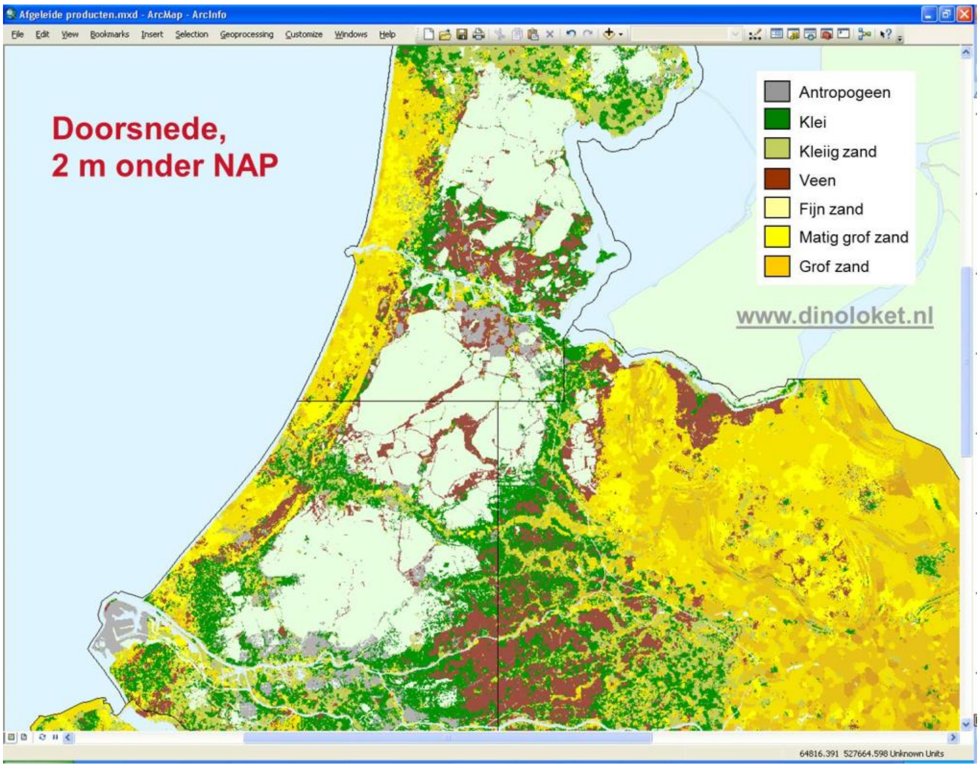

Figure 5.7b. Horizontal slice showing the lithological classes at 2 m below NAP. The thin black lines are the boundaries between the model areas. Notice the position of the large polder areas, showing surface levels situated below 2 m –NAP.

6 Quality aspects

6.1 General

The quality of GeoTOP strongly depends on the following factors:

The *amount of the available borehole logs*. The borehole logs are not equally distributed in the Netherlands. There are areas with a high density of boreholes, e.g. Zuid-Holland and large parts of the Rhine-Meuse area. Other parts of the country, e.g. the Veluwe, have a low density of boreholes. In addition, much more data are available for the shallow parts than for the deeper parts of the subsurface. In general, it can be said that the data density deeper than 30 m below surface level strongly diminishes the quality of the estimate of the lithological class.

The *quality of the borehole logs*. The borehole logs in the DINO database have not especially been collected for use in GeoTOP. The quality strongly varies, depending on the aim and the method used for the drilling.

The *age of the source data*. The reality to be modelled, as it appears in borehole descriptions and on geological maps and soil maps, may have been changed in the meantime. For instance, peat mentioned in a borehole description may have been oxidized in the course of time. Examples of other changes are excavations (e.g. harbours, dredged channels) or the shifting of tidal channels in the Waddenzee.

The *complexity of the geology*. A simple, homogeneous subsurface can be modelled easier and with less borehole logs than a complex, heterogeneous subsurface. Differences in complexity may also occur within the geological units..

The *application* of GeoTOP. Different applications require different quality needs.

The following paragraphs deal with the above mentioned and with other quality aspects.

6.2 Merging the model areas

During the construction of new model areas and the maintenance of existing model areas, the model areas are merged with each other as good as possible. Nevertheless, problems may occur at the boundaries of the model areas. This is due to the time elapse (sometimes several years) between the release of the two model areas. During that time elapse more borehole logs have been collected, a new version of DGM became available, or geological views have been changed. Also, the reality to be modelled may have been changed in the meantime. For instance, the effect of sand digging that is visible in the new model area but not in the older model area.

6.3 Borehole logs

6.3.1 Borehole descriptions

The quality content of the borehole descriptions in the DINO database varies considerably. The applied drilling method and the coupled sampling method to the drilling affect the quality content of the layer descriptions. Drillings disturb the sequence of layers in the subsurface. Depending on the drilling method a small or large degree of admixture of the soil samples will take place. In a cored drilling, the bailer takes undisturbed soil samples per meter interval and the admixture only occurs at the top of the cores. Using water jetting drilling equipment, such as straight-flush drillings, a strong mixing of the sediment layers will take place. Moreover, the added drilling fluid during water jetting lower the quality of the samples. To get a thorough interpretation of the vertical lithological sequence a geophysical well logging is applied to the straight-flush drilling.

The way the borehole samples are described and the professional skill of the person that makes the description are important too. To decide whether or not a detailed borehole description will be made depends on the aim of the drilling and the available financial means. TNO has experienced employees who describe the borehole logs according to the Standaard Boor Beschrijvingsmethode (SBB, Bosch 2000).

6.3.2 *Quality filters*

Basic assumption to GeoTOP is that all borehole logs stored in the DINO database is used for the construction of the model. However, part of the borehole descriptions are of low quality and the use of these borehole data should not improve but instead worsen GeoTOP. To trace and exclude these borehole data a quality filter has been applied. The first filter excludes the borehole logs that only have header data, or that miss the data about the elevation of surface level, the end depth and the location (x- and y- coordinate).

In the next step all borehole descriptions are put through an automated quality control. This is done by looking at the thickness of the intervals in the first 30 m of the borehole description (top of an interval must be situated at a depth less than 30 m below the surface level of the borehole log). Of these intervals the maximum and mean thickness are determined. Borehole logs showing a maximum thickness-interval more than 7 m and a mean thickness-interval of more than 3,5 m do not pass the quality filter. The parameters 7 m and 3,5 m are data acquired from experience.

When the borehole log is located in the coastal area, it is subject to less strict criteria. The reason is that in the dune area thick intervals may occur in high quality borehole descriptions. The criterion in the coastal area is a maximum thickness of more than 9 m. The mean thickness is not relevant in the coastal area. The coastal area is defined in a polygon that displays the boundaries of the dune and beach sands along the North Sea coast. Further adjustments and extensions of the criteria may be done in the future, for instance a differentiation per geological region.

Borehole logs that are excluded are recorded in a list to which a (short) specification of the reason for exclusion is added. This list is manually complemented in a further step in the construction of the model. Depending on the model area about 5% of the borehole logs are excluded based on the automated quality filter. As an example, in the model area Rivierengebied about 4,500 of ca. 80,000 borehole logs stored in the DINO database are excluded (5.6%).

The same automated quality filter used to the DINO borehole logs has been applied to the borehole logs of Utrecht University. Using the quality filter only a few borehole logs of Utrecht University are excluded.

6.3.3 *Snapshot*

At a certain time during the construction of the model area version a snapshot is made of the borehole logs and the related intervals of the borehole descriptions stored in the DINO database. The interpretations of the borehole logs will be based on this snapshot. Any changes made in the DINO database after the snapshot will not be visible for that version of the model area.

6.3.4 *Stratigraphic interpretation*

Due to the size of the dataset (the current version of GeoTOP contains more than 155,000 borehole descriptions) it is not possible to make a manual interpretation of the stratigraphy of each borehole log. Moreover, manual work can create inconsistencies in the interpretation of comparable borehole descriptions. GeoTOP therefore provides automated procedures to interpret the stratigraphy of the borehole logs. A more extensive explanation of this topic is presented by Stafleu et al. (2012).

The stratigraphical interpretation is being tested by experts in the geology of the model region. They use geological cross-sections and borehole logs that have been manually interpreted before the construction of GeoTOP. Plausibility checks are performed to secure that the sequence of stratigraphical units is in the right order. Manual checks of all the individual interpretations are not executed.

The manually executed interpretation of the stratigraphy of Zeeland and Goeree-Overflakkee, the first constructed GeoTOP model areas, were done by experts in the geology of those areas.

6.3.5 *Interpretation of lithological classes*

The lithological class interpretation of the intervals in the bore hole logs is an automated process with relatively simple and unambiguous calculation rules. A detailed description of the calculation rules is presented in Stafleu et al. (2012).

6.3.6 *Differences to DGM*

In most cases the automated stratigraphical interpretation of the borehole logs in the DGM selection set coincide with the manually made stratigraphical interpretations of the DGM units. Due to the differences in the interpretation method differences in stratigraphical sudivisons may occur. The automated process of GeoTOP only includes the analysis of the lithological borehole descriptions, while in the manual interpretation the nearby located borehole logs and/or geophysical well logs also are used.

6.4 Occurrences

Preceding to the stratigraphical interpretation of the borehole logs, the area of occurrence of each geological unit is established. In the construction of GeoTOP the borehole logs located in this area are investigated on the occurrence of the geological unit. The occurrence also functions as the maximum or potential extent of the geological unit in the layer model. Outside the potential extent the unit cannot occur; within the potential extent the unit *may* occur.

To construct the boundaries of the occurrences a map at a scale of 1: 50,000 is used. Small occurrences of the geological unit that do not fit to the resolution of the map scale are not included in the extent of the unit.
Because of the construction of the layer model the boundaries of the occurrences (polygons) are converted to grids, measuring 100 x 100 m per grid cell. The rule applied is that a coverage of 16% of the grid cell is enough to count the whole cell to the geological unit. This implies a small exaggeration of the surface of the geological unit, but it guarantees the connectivity (the extent to which the unit forms a contiguous area) of important units, such as the Holocene channel systems.

6.5 Layer model

6.5.1 Stochastic model

To construct GeoTOP a stochastic procedure is applied to estimate the depth of the base of each geological unit. The procedure results in 100 different, but statistically equally probable realisations. The average of 100 realisations is supplied as the base of the unit. Also the standard deviation of 100 realisations is released as the level of the model uncertainty. The stochastic character of the layer model is shown in the 'noise' of minor deviations superimposed on a regional trend.

6.5.2 Consistent layer model

The layer model is consistent, which means that the top of a unit coincides with the base of one or more units above, or that it coincides with surface level. Vice versa the base of a unit coincides with the top side of one or more units below, or it coincides with the base of the model. As a consequence any point in the space (within the boundaries of the model area) lays between the top and base of one single geological unit. This conclusion is used to determine to which unit the center points of the voxels must be addressed.

An exception to the consistency has been made for the grids of the Holocene channel systems: these grids overlap. For example, a point in space can be located in a Holocene channel as well as in the Echteld Formation. In the voxel model this exception does not apply: a voxel always belong to one geological unit, in which the Holocene channel systems prevail.

6.5.3 Differences to the borehole logs

A borehole log shows a detailed image of the stratigraphic sequence of geological units at one specific point location. The layer model estimates the stratigraphic sequence that is representative for an area of 100 x 100 m (10,000 m^2) and that fits to a (sub)regional scale. Therefore, the interpretation into geological units of a borehole log can differ from the sequence of geological units in the layer model at the same location.

The elevation of surface level at the location of the borehole log may also deviate from the elevation of surface level in the model. This may have several causes, such as small differences of the surface level at the location of the borehole log, errors in the measurement of the surface level or a real change in surface level. For example, a raising or levelling of the soil that took place in the time between the making of the borehole log and the construction of the model. To the elevation of surface level also applies that it is representative for an area of 100 x 100 m in the model and to the specific point location in the borehole log.

6.5.4 Differences to DGM

Compared to DGM, that displays all Holocene sediments in one geological unit, the GeoTOP layer model shows much more detail. GeoTOP includes 12 Holocene lithostratigraphical units and 9 Holocene channel systems modelled as separate units.

GeoTOP is based on more borehole logs. Therefore, the base of the Holocene sequence, and also the top of the Pleistocene sediments can be displayed in more detail in GeoTOP than in DGM and REGIS II.

The deeper units of the subsurface models DGM and GeoTOP have a better match. However, GeoTOP uses more borehole logs and a stochastic modelling procedure in contrast to DGM.

6.6 Voxel model

6.6.1 Stochastic model

Just like the layer model the voxel model uses a stochastic interpolation procedure to estimate the lithological class of the voxels. The procedure results in 100 different, but statistically equally probable realisations. The method used averages the lithological classes to ‘the most likely lithological class’. For each lithological class the probability of occurrence is calculated by dividing the amount of estimates of the lithological class in a voxel to 100.

6.6.2 Differences to the layer model

The voxel model has the same dimensions horizontally as the layer model. The maximum resolution vertically is 0.5 m. This means that the values of top, base and thickness of the geological units are always multiples of 0.5 m.

In the conversion from the layer model to the voxel model the position of the center point determines to which geological unit the voxel belongs. This unit is addressed to the voxel. In case the unit in the layer model has a thickness less than 0.5 m, and there is no voxel center point between top and base, the unit will not occur in the voxel model. When there is a voxel center point between top and base, the unit will get an exaggerated thickness of 0.5 m.

In exceptional cases a unit in the layer model is given a minimal thickness of 0.5 m. This will ensure that the unit is always represented in the voxel model.

6.6.3 Differences to the borehole logs

As in the layer model there may be differences in the lithological classes of the borehole logs and those in the voxel model. The lithological classes in the voxel model are estimates that are representative for an area of 100 x 100 x 0,5 m (5000 m^3) that fits to a (sub)regional scale. Therefore, the interpretation of the lithological classes in the borehole logs may differ from the lithological class in the voxel model at the same location.

7 Metadata

7.1 Identification

The present product specification refers to the subsurface model GeoTOP, version 1, release 3 (v01r3).

GeoTOP includes a number of model areas. These geographical areas are modelled in one procedure using a set of basic data. The model areas have their own version number. GeoTOP version v01r3 includes the following model areas :

Model area	Version
Zeeland	v01r2
Goeree-Overflakkee	v01r1
Zuid-Holland	v01r1
Noord-Holland	v01r0
Rivierengebied	v01r0
Westelijke Wadden	v01r0
Oostelijke Wadden	v01r0

GeoTOP version v01r3 replaces version v01r2. Model area Oostelijke Wadden (East Wad) is included in version v01r3. Two new attributes of the voxel model, the model uncertainty of the geological unit and the model uncertainty of the lithological class, are now available for all model areas.

7.2 Release date

GeoTOP version v01r3 has been published May 2016 via DINOloket (www.dinoloket.nl)

7.3 Resolution

Grid cells in the layer model measure 100 x 100 m. Voxels in the voxel model measure 100 x 100 m horizontally and 0.5 m vertically.

7.4 User scale

The user scale is c. 1: 50,000. See also the explanation in Chapter 3.

7.5 Territory

At present GeoTOP is not yet available for the entire onshore Netherlands. The model is constructed per region in a long-term project that started in 2007. Version v01r3 includes the model areas Zeeland, Goeree-Overflakkee, Zuid-Holland, Noord-Holland, Rivierengebied, Westelijke Wadden and Oostelijke Wadden (Fig. 7.1).

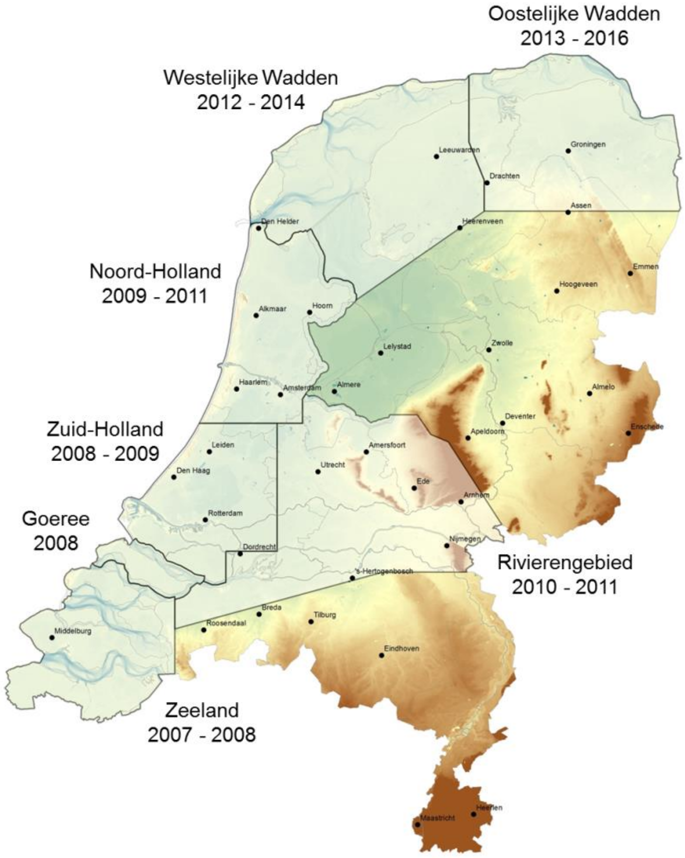

Fig. 7.1: The GeoTOP model areas and the period of construction. GeoTOP version v01r3 includes the model areas Zeeland, Goeree-Overflakkee, Zuid-Holland, Noord-Holland, Rivierengebied, Westelijke Wadden and Oostelijke Wadden. No model areas have yet been established for the other part of onshore Netherlands. Colours indicate the elevation of the surface level and the waterbed.

In future GeoTOP will cover the entire onshore Netherlands. Onshore Netherlands also includes the large waters, such as the IJsselmeer, the Waddenzee and the Westerschelde.

The rectangle around the area, expressed in minimum and maximum coordinates of the model, has been established in the Dutch National Grid (Rijksdriehoekstelsel). The values and the converted values in WGS84 are displayed in the Table below.

Coordinate	**Dutch National Grid (m)**	**WGS84 (degrees)**	**WGS84 (degrees, decimal)**
Minimum X-coordinate	0	E 003 11 40.7450	3.19465
Minimum Y-coordinate	300.000	N 50 40 09.1109	50.66920
Maximum X-coordinate	280.000	E 007 16 30.7336	7.27520
Maximum Y-coordinate	625.000	N 53 35 46.3216	53.59620

7.6 Horizontal boundary

The horizontal boundary has been established per model area in grids measuring 100 x 100 m. Whether the grid cell lays inside or outside the model area is marked with an indicator. With respect to the state boundaries of Belgium and Germany and the land-sea boundary, the grids of the surface level and the level of the water bed are used (Stafleu et al. 2012).

7.7 Vertical boundary

The vertical boundary of the top of the model area is determined by the grids of the surface level and the level of the waterbed (Stafleu et al. 2012). This is a grid file with cells measuring 100 x 100 m. Each grid cell displays the elevation of the surface level and the level of the water bed relative to NAP.
The vertical boundary of the base of the model is determined by a grid file with cells measuring 100 x 100 m. Each grid cell displays the depth of the lower boundary in meters relative to NAP. The model areas in GeoTOP version v01r2 have a fixed value of 50 m below NAP.

7.8 Horizontal reference system

All coordinates in GeoTOP are given in m in the Dutch National Grid, code Rijksdriehoekstelsel_New according to EPSG: 28992.
The coordinates of the interpreted borehole logs indicate the position of the borehole at surface level. To the layer model applies the convention that the position of a grid cell is determined by the lower left corner. To the voxel model applies the convention that the horizontal position of the voxel is determined by the cell center of the voxel.

7.9 Vertical reference system

All elevations in GeoTOP are given in m relative to NAP, code Normaal Amsterdams Peil according to EPSG: 5709. To the voxel model applies the convention that the vertical position of the voxel is determined by the cell center of the voxel.

7.10 Source data

Stafleu et al (2012) present an extensive overview of the source data that differ from the bore hole logs described in the present document.

7.11 The principal

The principal is the Geo-informatie Commissie (GIC) in which the Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs participate.

7.12 Legal aspects

Intellectual property rights of GeoTOP belong to TNO - Geological Survey of the Netherlands. The use of GeoTOP is permitted under the conditions mentioned on DINOloket.

A disclaimer published on DINOloket is applied to the use of GeoTOP.

7.13 Safety

GeoTOP has free access.

7.14 Contact

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9 Signature

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