TNO | Knowledge for business

GeoTOP

Three-dimensional modelling of the upper 30 meters of the Dutch subsurface

GeoTOP is a detailed three-dimensional model of the upper 30 meters of the subsurface of the Netherlands. It provides the user with a cell-based description of the spatial variability of geological, physical and chemical parameters in the subsurface. In this way, GeoTOP provides a sound framework for subsurface related questions on groundwater management, land subsidence, natural resources, and infrastructural projects.

The Geomodelling department of TNO focuses on the sustainable use and management of the upper 500 to 1000 meters of the Dutch subsurface. The department's most important task, as commissioned by the Geological Survey of the Netherlands (GSN), is the characterisation and modelling of geological deposits. It develops and maintains three models: DGM (Digital Geological Model), REGIS II (Regional Geohydrological Information System) and GeoTOP (3D model of the upper 30 meters). REGIS II emerged from separate mapping tasks commissioned by the Provinces in collaboration with the Directorate-General for Public Works and Water Management.

Geological model

GeoTOP schematises the subsurface in millions of grid cells (blocks), each measuring 100 by 100 meters in the horizontal directions and 0.5 meters in the vertical direction. Several parameter values are estimated for each grid cell. These parameters include geological characteristics, such as lithostratigraphical and lithofacies units, as well as physical and chemical parameters, such as hydraulic conductivity and chloride content. The geological model is used as a basis for the parameterisation of physical and chemical properties, resulting in a reliable estimation of the spatial variability of these properties.

Lithofacies:
All sediment characteristics (for example the lithology, type of layering and the dimensions of the sedimentary unit) that result from the depositional environment in which the sedimentary unit was formed. For example, in a river sands are deposited in channels and bars ('channel belts'), whereas thick layers of clay accumulate in the adjacent flood basins. In addition, channel belts have other dimensions than flood basins. Therefore, both the channel belt and the flood basin deposits are considered as distinctive lithofacies units within a sequence of river deposits.

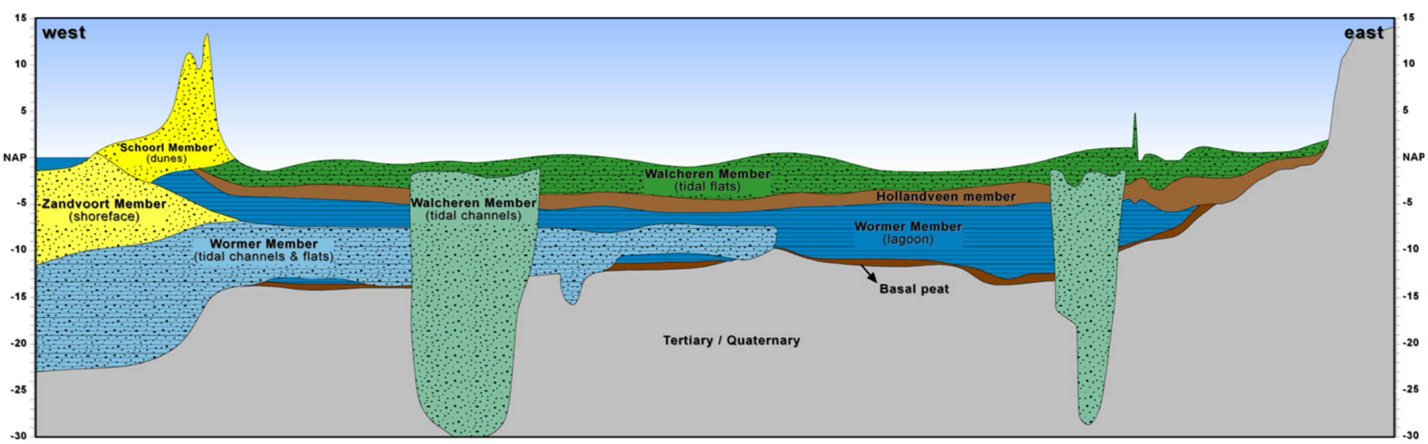

Figure 1. Schematic cross-section through the Holocene deposits in the Province of Zeeland. The horizontal distance is about 70 km, the vertical distance runs down to 30 meters below Ordnance Datum.

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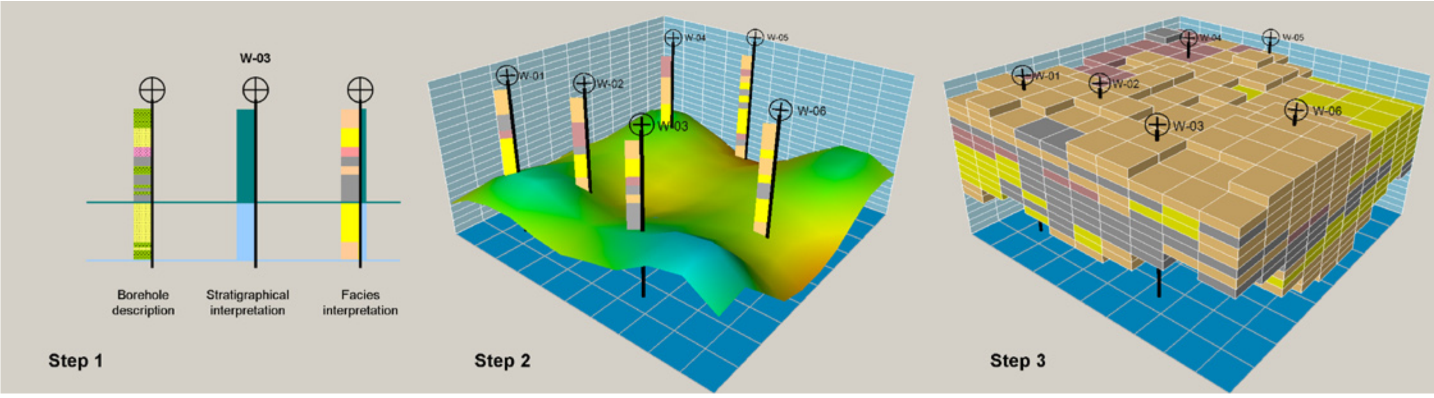

Figure 2. Step 1: Schematisation of boreholes. Step 2: Modelling lithostratigraphical bounding surfaces. Step 3: Modelling lithofacies.

Modelling

The Province of Zeeland (SW Netherlands, covering an area of approximately 70 by 75 km) was chosen as the starting point for the GeoTOP modelling. After completing the Zeeland model, we continued with the Province of Zuid-Holland, with major cities like Rotterdam and The Hague. A model of the Province of Noord-Holland, with the areas of Amsterdam and Schiphol Airport is currently under construction.

The Province of Zeeland is positioned at the southern rim of the North Sea basin. The shallow subsurface geology mainly consists of gently northward dipping Tertiary and Quaternary strata that were formed under shallow marine, estuarine and fluvial sedimentary conditions. The upper part of the sequence (Figure 1) is formed by Holocene deposits consisting of tidal channel, tidal flat and lagoonal sediments that alternate with peat beds and coastal shoreface, foreshore and dune deposits.

From borehole to model

Starting point for the GeoTOP models are the borehole descriptions stored in the DINO database, the Dutch national database for Data and Information of the Subsurface. For the Province of Zeeland, this database provides us with some 23,000 borehole descriptions while over 50,000 borehole descriptions are available for Zuid-Holland. Each borehole description reveals detailed information of the subsurface at one particular location. Cone penetration tests will be incorporated in the near future, resulting in an even more extensive dataset.

The modelling procedure involves a number of steps (Figure 2). The first step is a geological schematisation of the boreholes into units that have uniform sediment characteristics, using both lithostratigraphical and lithofacies criteria. Examples of lithostratigraphical units are the Walcheren Member (green colours in Figure 1) and the Wormer Member (blue colours in Figure 1), both belonging to the Naaldwijk Formation. These lithostratigraphical units can be further subdivided into lithofacies units. For example, the Walcheren Member is further subdivided into sandy tidal channel deposits and clayey tidal flat deposits.

During the second modelling step, 2D bounding surfaces are constructed. These surfaces represent the top and base of the lithostratigraphical units and are used to place each 3D grid cell in the model within the correct lithostratigraphical unit.

In the third and last modelling step, 3D stochastic interpolation techniques are used to assign a lithofacies unit to each grid cell. After this step, a cell-based (100*100*0.5 meter) three-dimensional geological model is obtained.

Tidal channels and tidal flats

17 lithostratigraphical units were modelled in Zeeland and the total number of lithofacies units amounts to 41. Figure 3 shows part of the lithofacies model in the central part of Zeeland. The Walcheren Member is represented by the green, yellow and dark blue colours. In the foreground of Figure 3, we can see a large sandy channel system which follows the present-day outline of the Westerschelde estuary. Blue colours in the channel indicate the presence of shells and shell-rich sands. On the islands of Walcheren and Zuid-Beveland, the Walcheren Member mainly consists of thin layers of clayey tidal flat deposits.

Holocene channel belts

In contrast to Zeeland, the Holocene deposits of Zuid-Holland are characterized by complex fluvial channel systems of the Rhine and Meuse rivers. By using detailed maps of the position of the channel belts and series of Python-based scripts, a 3D model of the geometry of the channel belts (lithofacies) was constructed (Figure 4). The colours in Figure 4 represent channel belt generations (relative ages): the youngest generation is A, the oldest one is E. Generation A is the present-day main course of the Rhine and Meuse rivers, and generation B, for example, corresponds to the course of the Rhine in Roman times. Figure 5 zooms in on the youngest channel belt (generation A) in the Rijnmond area (Port of Rotterdam). The grid cells are filled with lithology and sand-grain size classes rather than lithofacies, providing more insights into the internal buildup of the channel belts.

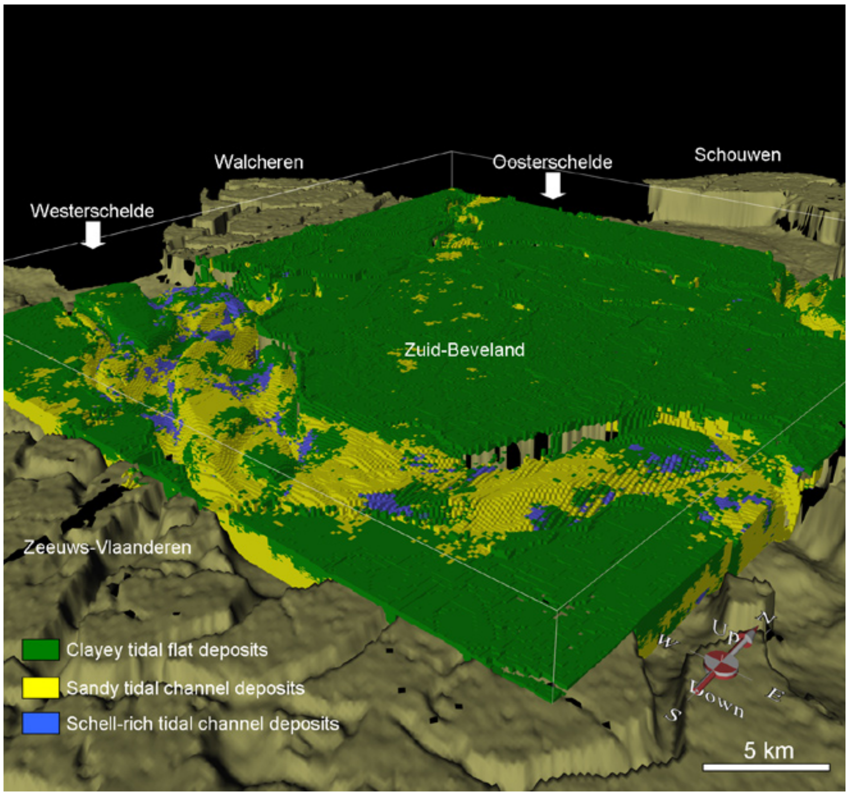

Figure 3. Part of the 3D lithofacies model of the central part of Zeeland.

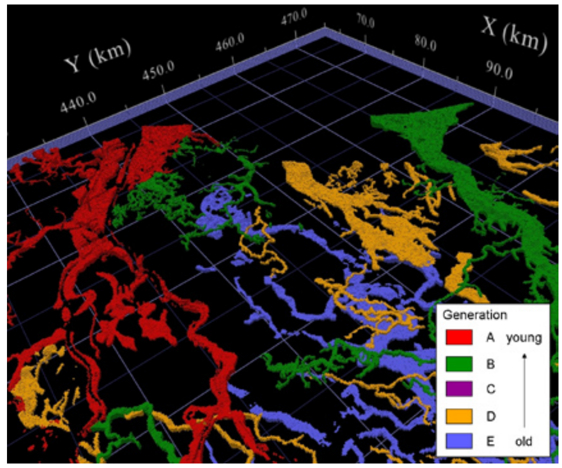

Figure 4. Holocene channel belt systems in Zuid-Holland. The colours represent generations (relative ages) of the channel belts. The youngest generation is A, the oldest one is E.

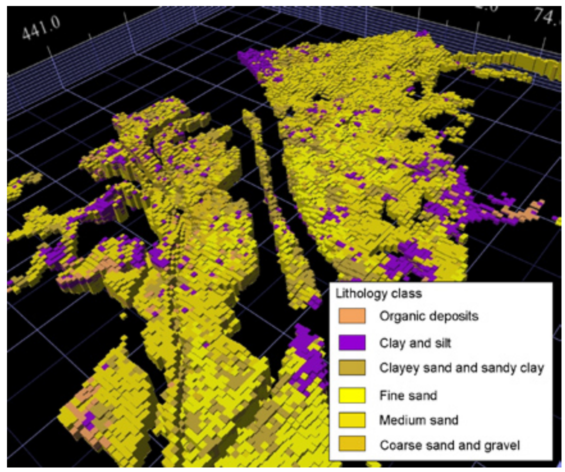

Figure 5. Detail of Figure 4, where the grid cells of the youngest channel belt system in the Rijnmond area (Port of Rotterdam) are filled with a lithology class representing the type of sediment.

Uncertainty

The use of stochastic techniques during modelling allowed us to compute probabilities for each grid cell for both lithostratigraphy and lithofacies. These probabilities provide a measure of model uncertainty. Figure 6 shows the results for a tidal channel in the Walcheren Member in the province of Zeeland. The colours indicate the probability that a grid cell contains the sandy tidal channel lithofacies. At the centre of the channel, this probability is high (100%). In the upper part of the channel, the green and yellow colours reveal much smaller probabilities. In this upper part, we expect more clayey tidal flat deposits. Similarly, we see lower probabilities at the bottom of the channel, where we would expect shells and shell-rich sands.

Physical and chemical parameters

In addition to the modelling described above, we collect and measure physical and chemical parameters. The sampling strategy is such that measured values can be assigned to lithostratigraphical and lithofacies units, making it possible to obtain insights into the spatial variability of physical and chemical properties in three dimensions. Examples of physical and chemical parameters include horizontal and vertical hydraulic conductivity, which are crucial in groundwater models and the reactivity of sediments, which is used in the modelling of contaminant plumes. The choice of parameters to include in the models is based on the needs of researchers at TNO, Deltares and other organizations.

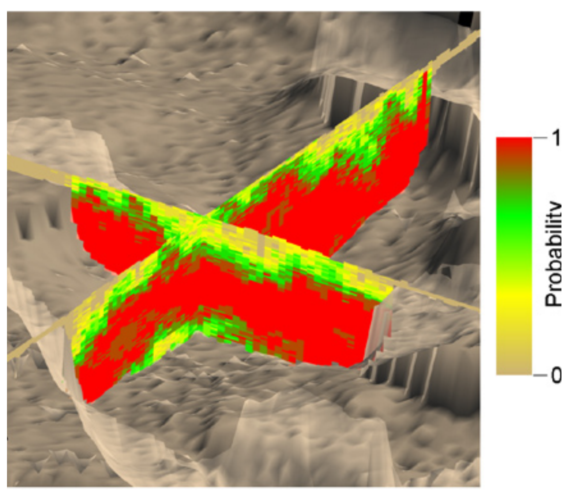

Figure 6. Cross-section through a tidal channel in Zeeland showing the probability that a grid cell belongs to the tidal channel lithofacies.

Model applications

The GeoTOP models are the first fully 3D regional-scale lithofacies models of Tertiary, Quaternary and Holocene strata in the Netherlands. The models show the architecture of lithostratigraphical surfaces and the 3D spatial distribution of lithofacies and lithology. It provides the user with an accurate description of the spatial variability of physical and chemical parameters in the subsurface. Using the model, we are able to study the effects of human activities as well as natural changes on the physical and chemical behaviour of the subsurface.
In the future, TNO will extend the models towards the north, east and south of the Netherlands, ultimately leading to a full model cover of the Netherlands.

More information

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Subsurface and Water

TNO Built Environment and Geosciences – *Geological Survey of the Netherlands* is the central geoscience centre in the Netherlands for information and research to promote the sustainable management and use of the subsurface and its natural resources.

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