Chapter 11: Geological Survey of Denmark and Greenland - Targeting Current 3D Model Needs

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Sandersen, P.B.E., Vangkilde-Pedersen, T., Kallesøe, A.J., Høyer, A.-S., Andersen, L.T., Pedersen, C.B., Mathiesen, A., Møller, I., and Svennevig, K. 2019. Geological Survey of Denmark and Greenland - targeting current 3D model needs; Chapter 11 *in* 2019 Synopsis of Current Three-Dimensional Geological Mapping and Modelling in Geological Survey Organizations, K.E. MacCormack, R.C. Berg, H. Kessler, H.A.J. Russell, and L.H. Thorleifson (ed.), Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Special Report 112, p. 92–108.

Introduction

In Denmark and Greenland, there is a growing need for 3D geological models within the fields of aggregate prospecting, resources and vulnerability investigations of groundwater, geothermal investigations, urban planning, and geotechnical investigations, and specifically in Greenland, geohazard investigations, mineral prospecting, and mapping. For decades, consultants and authorities have constructed geological models to provide a scientific base for dealing with challenging issues related to the subsurface. Consequently, a large number of models exist – models that are of different types, constructed with different purposes, and for use at different scales. When opting for high 3D model detail e.g., for assessments of contaminant transport, adequate coverage with data that resolves the geological details is required.

The Geological Survey of Denmark and Greenland (GEUS) has over a long period of time developed a range of databases that serve as a repository for data used in 3D modelling (Hansen and Pjetursson 2011). GEUS has produced 3D geological models for several years and has initiated the construction of a national 3D geological model for Denmark with the purpose of making all existing geological interpretations available for relevant end-users and the society in general (Sandersen et al. 2016). The foundation of the model is a 3D database that can manage and present the full potential of the geological data and interpretations. Apart from containing national scale geological model elements, the 3D database will also be able to store a variety of existing local and regional models. The 3D database will act as a repository of geological interpretations capable of maintaining its value and continuously being attractive to a wide range of end-users.

Organizational Structure and Business Model

The 3D modelling activities at GEUS are generally related to research projects, consultancy work, and scientific assistance for other authorities. The geological modelling work is done both in connection with projects related to activities in individual departments as well as in connection with projects across departments. GEUS has a large number of geoscientists working with issues either directly or indirectly related to 3D models targeting subsurface resources or subsurface storage potentials (e.g., groundwater, aggregates, geothermal energy, CCS storage or storage of radioactive waste).

Building a national 3D geological model for Denmark is a highly complex undertaking that activates several departments and requires a high degree of collaboration (Sandersen et al. 2015). No overall national 3D model organization is set up because activities until now have been focused on specific sub-topics in work groups or departments. Work groups and individual departments have worked with, for example, testing of alternative 3D modelling methods and workflows (e.g., Høyer et al. 2015a, Jørgensen et al. 2015), 3D database construction, and creation of a coherent national lithostratigraphy.

GEUS performs and participates in research and consultancy work for private companies, private and public research funds, and the public sector related to 3D geological modelling projects, but currently does not receive governmental funding specifically for 3D mapping and modelling of the subsurface. Thus, funding for work on 3D geological modelling is currently related to research applications and consultancy work on specific projects. In order to establish a detailed and comprehensive national 3D geological model for Denmark, substantial external funding is needed. A large range of both private and public stakeholders is expected to benefit from a national 3D model in a variety of applications. Therefore, it will be important to build a strong business case demonstrating the total cross-sector socio-economic benefits of having such a model to generate the necessary funding.

Overview of 3D Modelling Activities

National 3D Models and Model Elements

Development of a 3D Database for the National 3D Geological Model

As a part of GEUS's 3D strategy (Sandersen et al. 2016), a 3D model database with the aim of storing all publicly available 3D geological models has been developed. The primary objective of the 3D model database has been to store the national 3D geological model, but the database will also be a central storage facility for outputs from other 3D model projects. The database has been designed to meet a platform-independent standard that can secure data in the future and make it possible to better share the models internally as well as externally. The database is able to support different model and feature versions and will therefore be capable of storing models, which will include information regarding development history and all the associated features, attributes, and geometry within a versioning management system.

Initially, a conceptualization of the elements of a 3D digital geological model was described, including all of the related geological principles and properties. The assessment of a platform-independent storage facility for 3D geological models was done with the best-suited technology in mind, including open source possibilities. Testing and implementation phases of different import and export scenarios were executed to validate suitable features for the model storage as well as executing various spatial and topological operations. See Figure 1 for an example visualized directly from the database.

On the technical side, the database is based on a PostgreSQL database with the spatial PostGIS extension. Another extension used is the pg_pointcloud extension by Paul Ramsey from OpenGEO for storing point cloud data (LiDAR). The point cloud extension gives the database a unique possibility to store non-fixed dimensional data, so that in principle, the database can store billions of points with multiple dimensions for various properties like porosity, permeability, lithology, biostratigraphy, chronostratigraphy, gravity etc. This provides great possibilities for voxel data, because voxels are made of regular or irregular XYZ-points. For storing polygons or TIN's, the geometry is stored as separate definitions as vertices points, and the edge definitions of the lines that combine them.

Updating 3D Hydrostratigraphic Input for the National Hydrological Model

In connection with the national groundwater mapping project (e.g. Thomsen et al. 2004, Thomsen 2013), a large number of geological and hydrostratigraphic models have been constructed in areas with special drinking water interests in Denmark. The models were generally made without merging with neighbouring models and without necessarily having the same hydrostratigraphy. However, with the finalization of the national groundwater mapping project in 2015, the models are now being merged into a nationwide, 45-layer, hydrostratigraphic model intended as input for the national hydrological model (DK-model; Kidmose et al. 2011). The work is led by the Environmental Protection Agency and the primary stitching and re-interpretations are being made by a group of consultants. GEUS performs QC reviews of the merging process and is responsible for updating the DK-model. The work was completed in early 2019.

3D Geological Modelling of the Deep Subsurface

The deep geothermal resources in the Danish subsurface are expected to contribute to a mixed energy supply in the future. To facilitate the use of geothermal energy, a part of the initiatives has been to establish an overview of the amount and quality of existing and interpreted geological and geophysical data, as well as to pro-

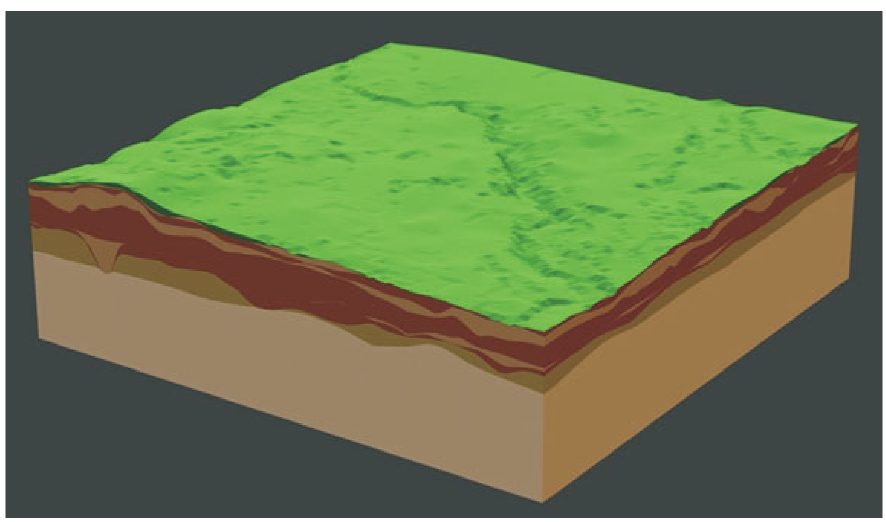

Figure 1. A closed 3D volume model example loaded and visualized directly from the database in a web browser. The volume is located near the city of Odense, measures 10 × 10 km and shows the subsurface down to around 300 m below the terrain surface. The two deepest layers represent Pre-Quaternary limestone and clay (Upper Cretaceous to Palaeocene), whereas the layers above represent a Quaternary succession dominated by clay (dark red-brown colour) and sand (light red-brown colours). The view is towards northeast.

vide an overview of the geological composition of the deep Danish subsurface (Vosgerau et al. 2016).

Data from deep wells and seismic surveys from primarily oil and gas exploration have been used for mapping the depth, thickness, and lateral extent of lithostratigraphical units and for mapping major faults. A number of nationwide maps of important boundary surfaces covering the Danish onshore outlines the structural-stratigraphical evolution from the Top-Pre-Zechstein and up to the Top Chalk Group. The maps are based on patchy and uneven data coverage and constructed to give regional representation of the subsurface and are therefore only meant for regional use. New well and seismic data or refined local geological models may lead to modifications. However, the present depth maps give a good indication of where in Denmark deep geothermal future exploration is relevant. The depth maps can be visualized through an interactive 3D-viewer providing an overview of the subsurface geology; see Figure 2 (http://dybgeotermi.geus.dk).

Mapping and Modelling of the pre-Quaternary Surface

The boundary between the pre-Quaternary and the Quaternary is an important surface in the upper part of the Danish subsurface that is highly demanded by consultants, researchers, and administrators when working with geotechnical issues, groundwater, and aggregates. An update of the existing map of the Pre-Quaternary surface topography (Binzer and Stockmarr 1994) is planned to be one of the important elements of the National 3D geological model (Sandersen et al. 2016). The erosional character and the intricate topography of the pre-Quaternary surface makes it an important element in the National 3D geological model.

National Guidelines

To secure common procedures and workflows GEUS has developed guidelines for constructing 3D geological models (Sandersen et al. 2018a). This guideline is one of a series of guidelines funded by the Environmental Protection Agency to be used primarily when working with projects related to groundwater.

3D Geological Modelling Projects

Examples of Research Projects (Denmark)

GEUS participates in a range of research projects where mapping and modelling of 3D geology is an important element. The projects are typically related to groundwater modelling, contaminant transport modelling, or urban subsurface planning, all of which require detailed interpretations of the geological subsurface architecture. To construct models with a sufficient degree of detail, dense coverage with high-quality data and develop-

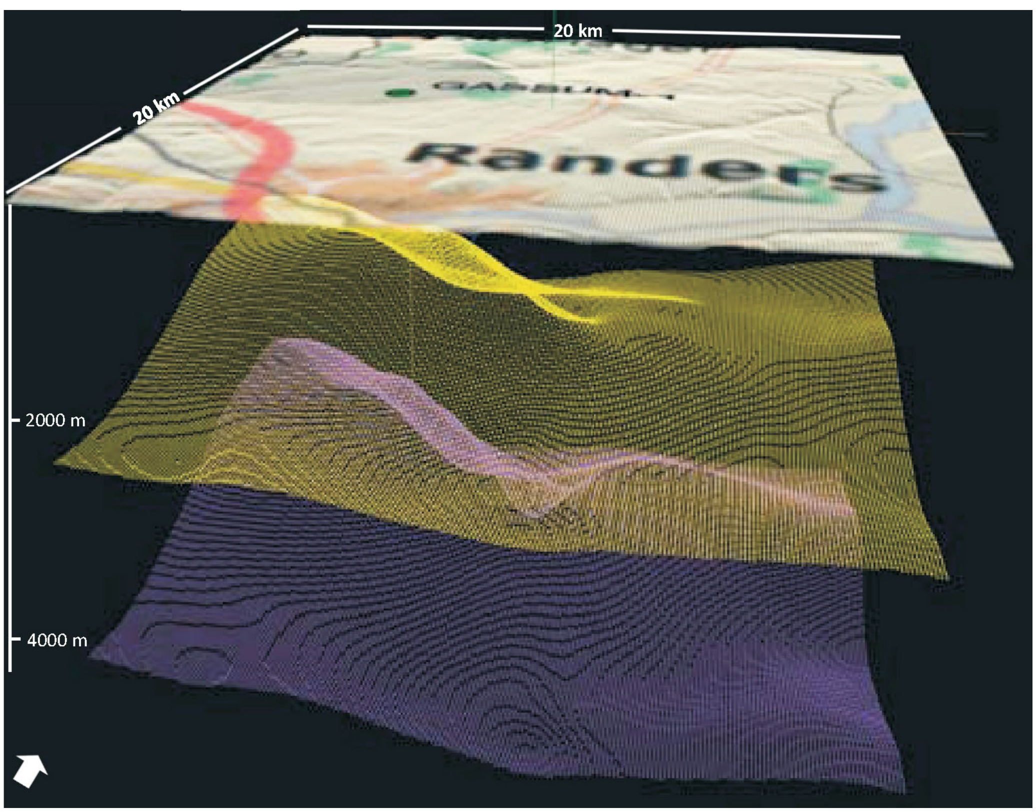

Figure 2. Interactive 3D tool available in the WebGIS portal, visualising selected mapped surfaces. Modified from Vosgerau et al. (2016).

ment of new mapping and modelling approaches are necessary (e.g. Mielby and Sandersen 2017, Sandersen et al. 2018b). At contaminated sites for instance, knowledge about geology and hydraulic properties of the subsurface and the extent of the contamination is needed for risk assessments and for designing potential site remediation.

At a contaminated site close to the city of Grindsted, a local 19-layer 3D geological model was used as a basis for developing a new approach for characterizing contaminated sites through time-domain spectral induced polarization (Maurya et al. 2018). Figure 3 shows the 3D geological

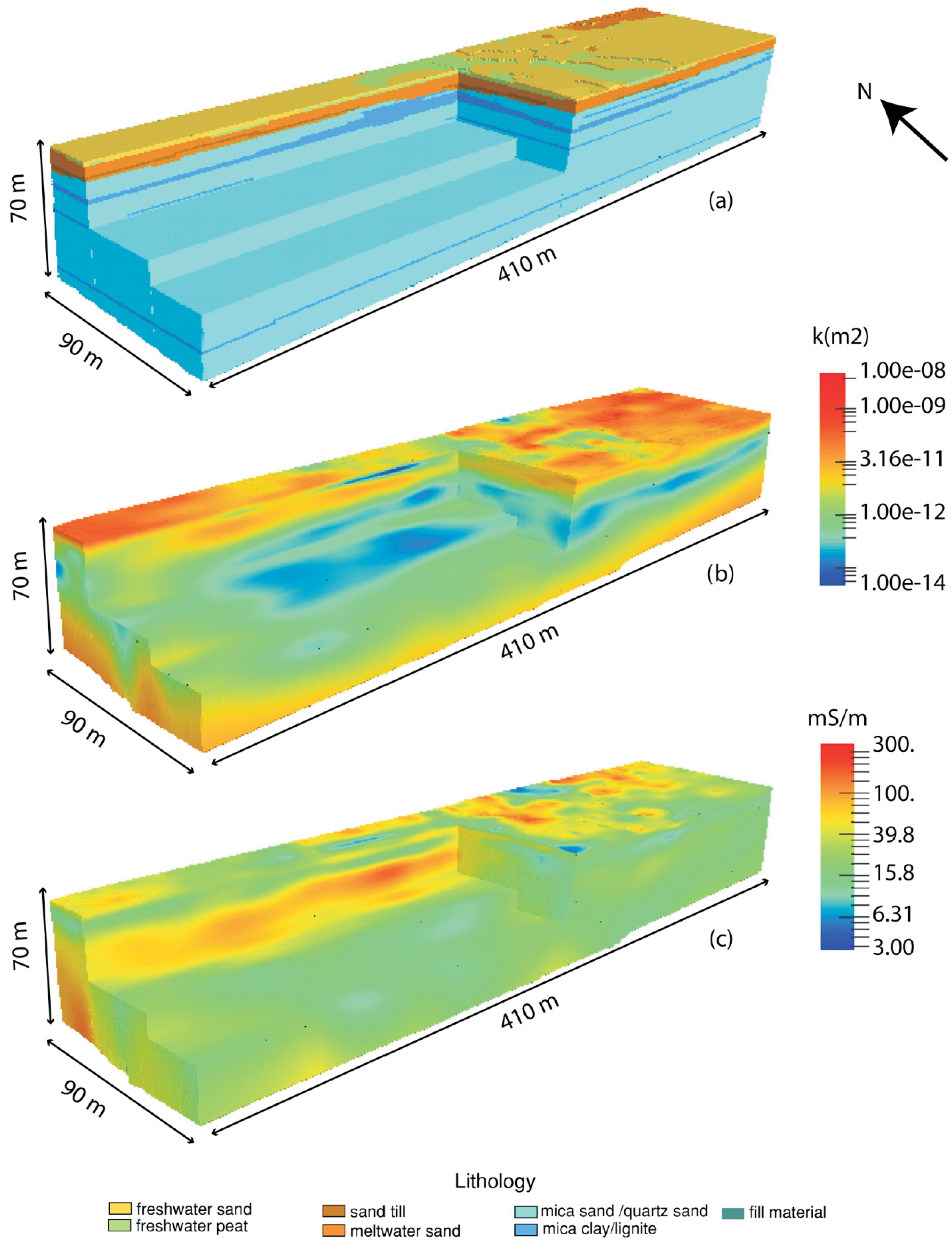

Figure 3. The Grindsted case: (a) 3D Geological model, (b) 3D permeability model and (c) 3D water electrical conductivity model. From Maurya et al. (2018).

model (a) together with a 3D permeability model (b) and a 3D water conductivity model (c). The imaging of permeability and water conductivity allowed for a better discrimination of lithology from the water conductivity, and the geophysical models were actively used as support for the geological modelling.

At a landfill site at Pillemark on the island of Samsø, six different data sources were combined to gain an updated geological understanding of the subsurface (Figure 4; Høyer et al. 2019). A high-resolution 3D geological voxel model was constructed with the purpose of performing a renewed risk assessment in relation to the groundwater resources. The study included analysis of geomorphology data, spear-auger mapping data, near-surface electromagnetic induction data, borehole data, geoelectrical profiling, and Transient Electromagnetic measurements. The 3D geological model was constructed to provide information about the vulnerability of the aquifer below the landfill site.

Buried tunnel valleys are common features in formerly glaciated areas, and because of their abundance and size, they can have a large impact on groundwater recharge and flow. Delineation of the buried valleys and modelling of the infill is therefore very important in relation to groundwater (Sandersen and Jørgensen 2003). Densely covering airborne electromagnetic data in combination with borehole data has proven to be very useful for mapping buried tunnel valleys and their complexity (Jørgensen and Sandersen 2006). A good example is from the Kasted area, where a 3D geological model of a highly complex network of buried valleys has been made based on borehole data and Airborne Electromagnetic data (AEM) (Høyer et al. 2015b). The model includes twenty different buried valleys in a complex cross-cut setting indicating the presence of up to eight valley generations (Figure 5).

In a study area in southwestern Denmark, a novel strategy for 3D multiple-point statistics (MPS) modelling was performed on a succession of Miocene sediments characterized by relatively uniform structures and a domination of sand and clay (see Figure 6; Høyer et al. 2017). The strategy focused on optimal utilization of geological information and the use of 3D training images rather than 2D or quasi-3D training images typically used for MPS modelling. A workflow for building the training images and effectively handling different types of input information to perform large-scale geostatistical modelling was constructed. The study showed how to include both the geological environment and the type and quality of input information in order to achieve optimal results from MPS modelling.

Examples of Research Projects (Greenland)

Compared to Denmark, Greenland has an excellent degree of exposure of bedrock, but a general lack of subsurface data (detailed geophysics, drill-holes etc.). Three-dimensional work has been tied to the application of oblique photogrammetry to map geological structures (faults, and bedding) as detailed 3D polylines (Dueholm, 1992, Svennevig et al. 2015, Sørensen and Guarnieri 2018, Sørensen and Dueholm, 2018). This method has been used in several areas for several purposes, e.g., to produce geological 3D models of complex faulted and folded strata at Kilen in northeastern Greenland mainly for the purpose of structural validation by 3D modelling helping to the restoration of the deformed strata (Svennevig et al. 2016, 2017) (Figure 7). Another application was to produce onshore 3D models for reservoir analogues for offshore basins for the oil industry (Vosgerau et al. 2010, 2015), with the main product being annotated 3D polylines for which the oil industry customers themselves build 3D models. Furthermore, the method has been used to produce high accuracy and structurally validated geological maps (e.g., Svennevig 2018a, b). This work is also ongoing in a large project in the Karat Group of central west Greenland to produce several 1:100,000-scale map sheets (Sørensen and Guarnieri 2018).

Consultancy Work

GEUS is currently producing 3D models in a number of consultancy or partnership projects that have participation by typically waterworks and regional and local authorities. The projects have their focus on solving challenges to issues related to groundwater resources and contamination, groundwater abstraction, and climate change. The 3D geological mapping and modelling is performed at a local scale usually with a high degree of detail.

Resources Allocated to 3D Modelling Activities

Based on activities in 2018, around 12 scientists (man-years) are occupied with activities related to 3D geological modelling.

Overview of Regional Geological Setting

The Danish Kingdom comprises the Danish area (43,000 km^2), the small Faroe Islands in the North Atlantic (1,400 km^2) and the world's largest island, Greenland (2,175,000 km^2). The northern part of Denmark, together with southern Sweden, comprises the boundary between the Fennoscandian Shield and the European sedimentary province (Figure 8). This zone, the Sorgenfrei-Tornquist Zone, is characterized by fault tectonics and horst/graben structures (Figure 9). To the southwest, the Danish basin is an elongated trough, which toward the southeast crosses Poland (Mogensen and Korstgaard 2003). The sediment thickness in the basin is up to 10 km (Vejbæk and Britze 1994). Towards the southwest, the basin is separated from the North German Basin by the Ringkøbing-Fyn

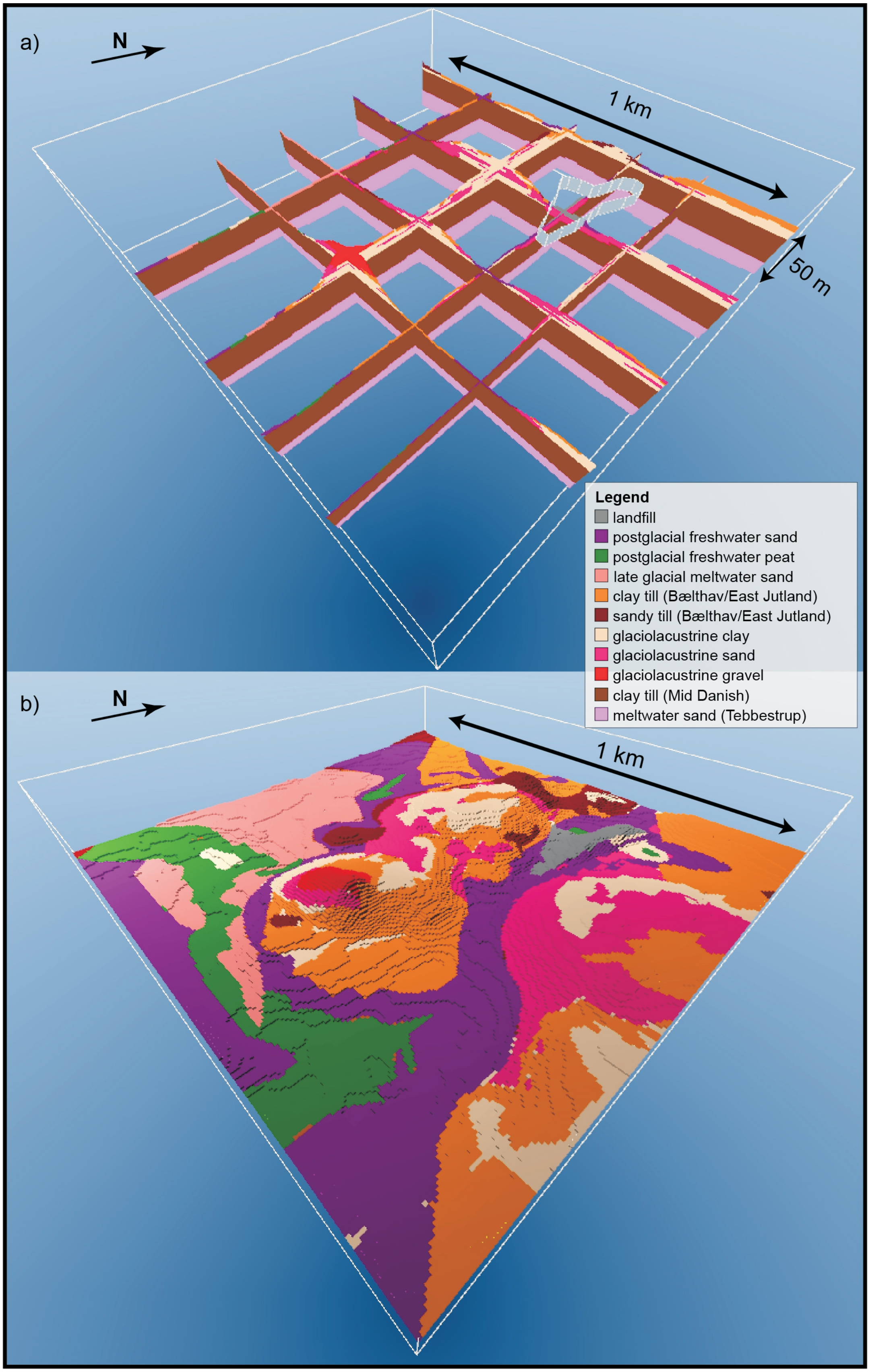

Figure 4. The Samsø case: View of the 3D voxel model a) N-S and E-W slices through the 3D grid. A polygon marks the landfill area, b) The 3D model seen from above. From Høyer et al. (2019).

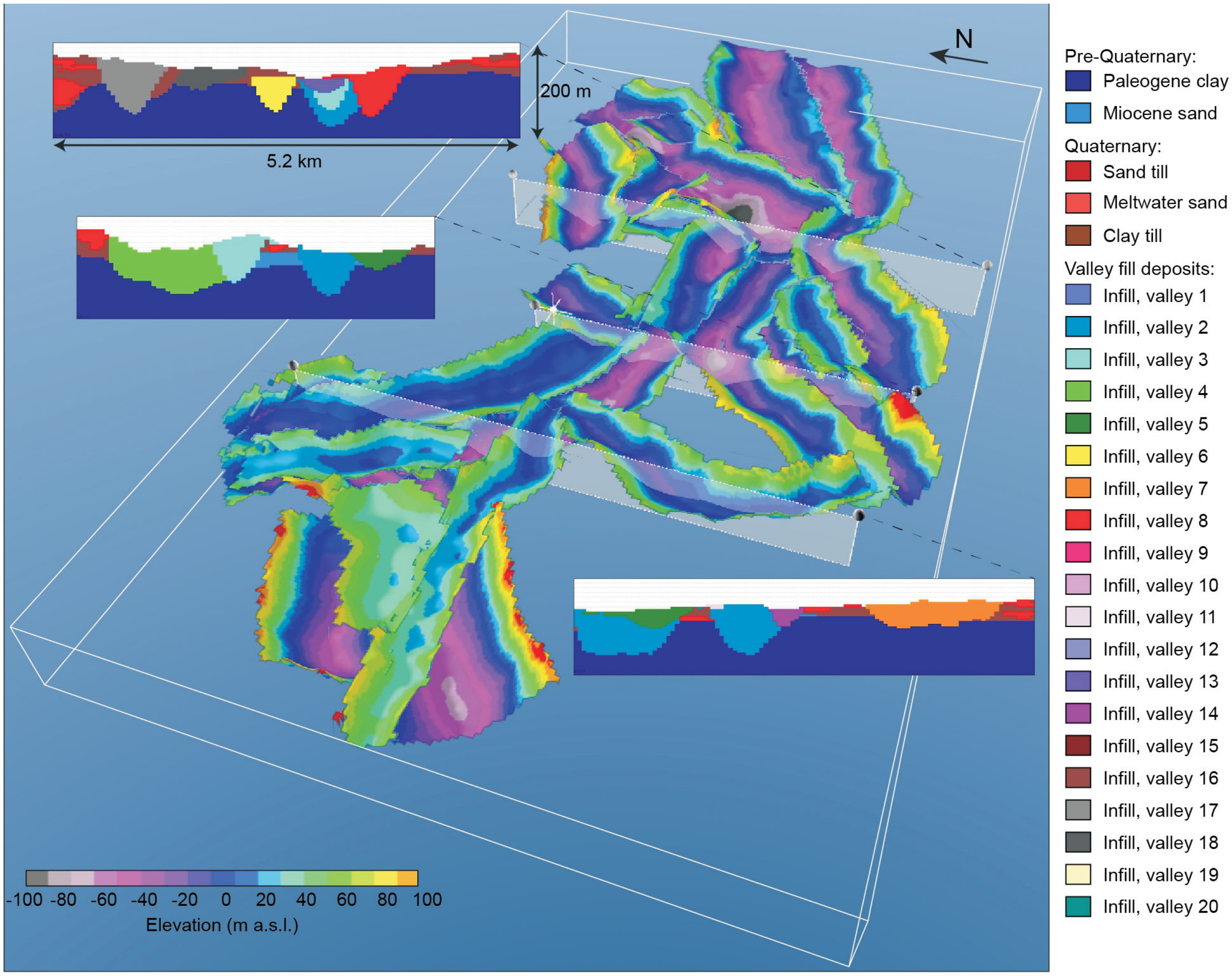

Figure 5. Kasted 3D model: 3D view of the modelled buried valleys. Three slices through the model are shown where the different colours represent the different valley generations. Modified from Høyer et al. (2015b).

High, where the Precambrian basement is found as high as around 1 km below the surface (Nielsen 2003). The southwestern part of Denmark is a part of the North German Basin.

The oldest sediments are Cambro-Silurian sequences (Nielsen and Schovsbo 2007). Devonian deposits have not been found, but occurrences of Carboniferous sediments are present. Above, Permian volcanics and conglomerates form the basis of the upper Permian salt-deposits that can attain thicknesses of ~1 km or more. The Mesozoic sediments consist mostly of marine sands, clays, chalk, and limestone (Nielsen 2003). During the Tertiary, limestone sedimentation was followed by sedimentation of marine clay while sandy materials were more common in the younger Tertiary. The Miocene succession comprises fluvial sand deposits and sand deposited in prograding deltas. Between the sandy units are marine mud-dominated deposits (Rasmussen et al. 2010). The Miocene succession ranges in thickness from a few meters to more than 200 m.

During the Quaternary, glaciers advancing from northerly and easterly directions repeatedly covered Denmark. During the glaciations, deposition of tills and meltwater sediments were dominating, whereas marine and freshwater sediments were mainly deposited during the interglacials. The cover of glacial and interglacial sediments is on average around 50 m thick, but ranges from a few meters to more than 300-400 m in buried tunnel valleys. In many areas, the uppermost sediments were intensely deformed during the numerous ice advances and several occurrences of large glaciotectonic complexes have been found (e.g. Pedersen 2005, Høyer et al. 2013, Jørgensen et al. 2012). The buried tunnel valleys are found as several cross-cutting generations, thus adding to the complexity of the subsurface (Jørgensen and Sandersen 2006).

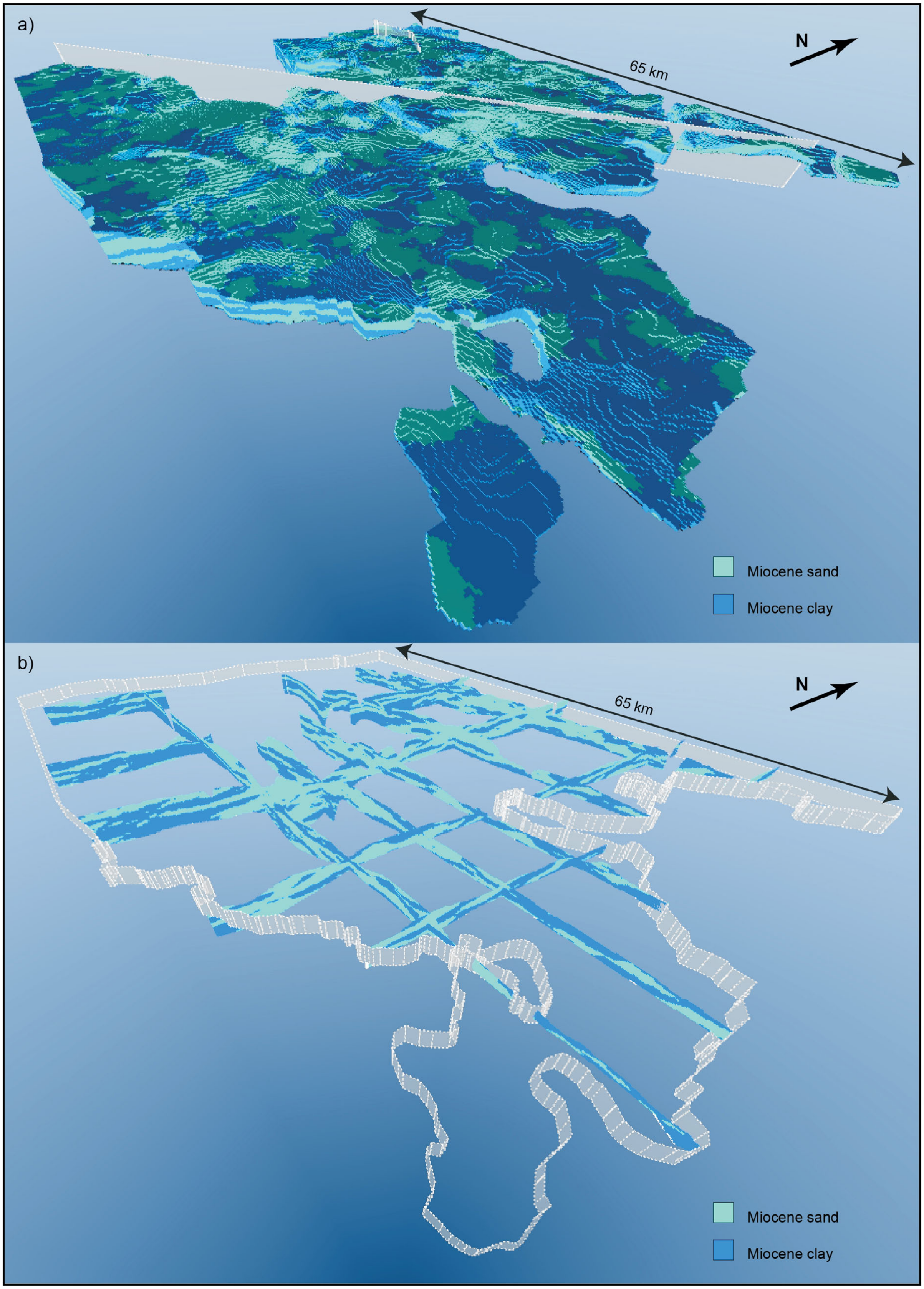

Figure 6. A realization of the Miocene succession in south-western Denmark: 3D-view of one of the final realizations: (a) All voxels, (b) The associated fence view. Vertical exaggeration 10x. Thickness of the Miocene succession is in the order of 100 to 200 m. From Høyer et al. (2017).

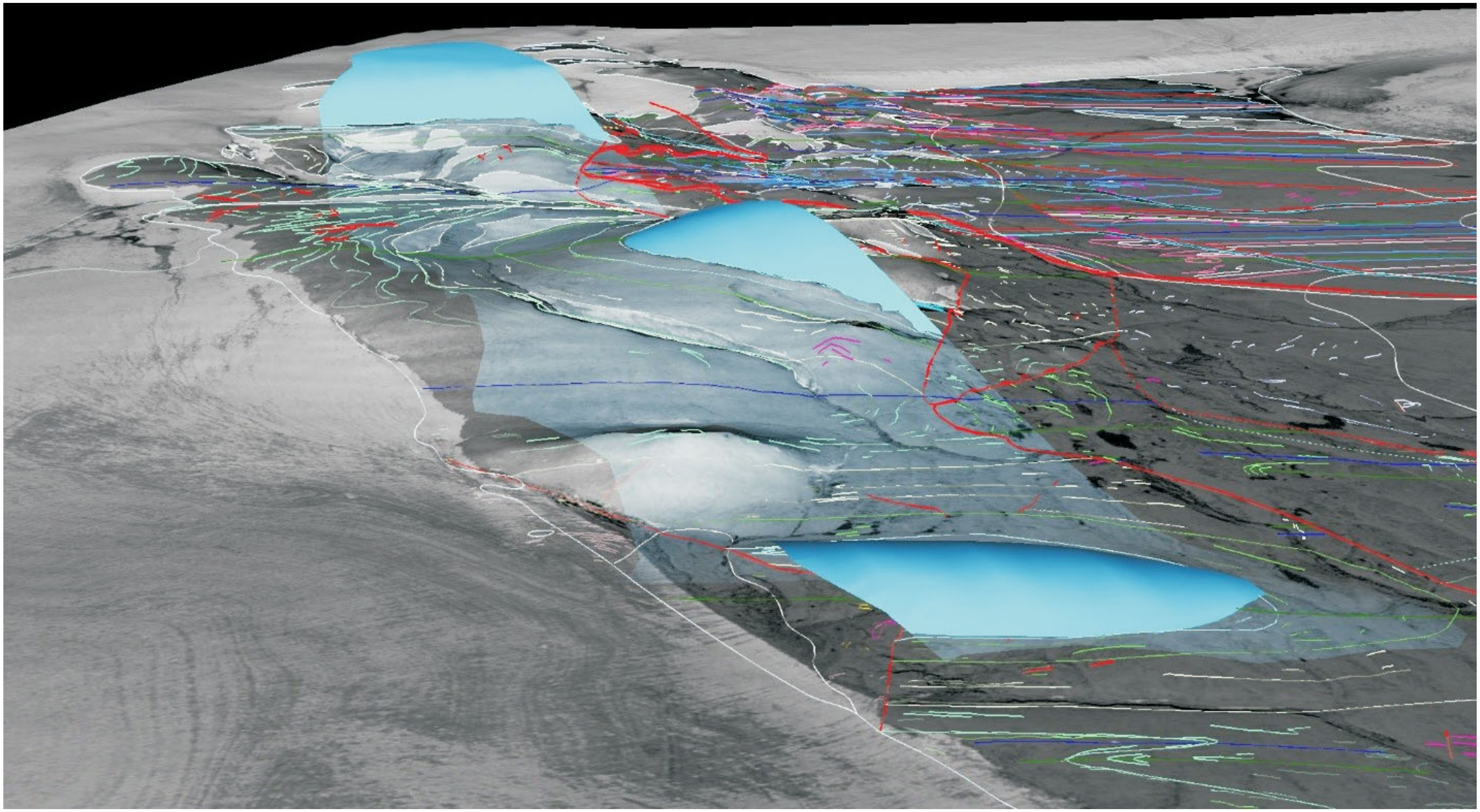

Figure 7. Oblique view of a geological 3D model of Kilen, Eastern North Greenland. Coloured polylines mapped from oblique photogrammetry are shown on a semi-transparent black and white aerial photo draped on a DEM. The various colours refer to different geological units and the bright red lines are faults. The blue undulating surface is a folded Lower Cretaceous marker-bed modelled in 3D based on the 3D polylines and structural measurements. View is towards the north and the distance from the foreground to the background of the image is 20 km. From Svennevig (2016).

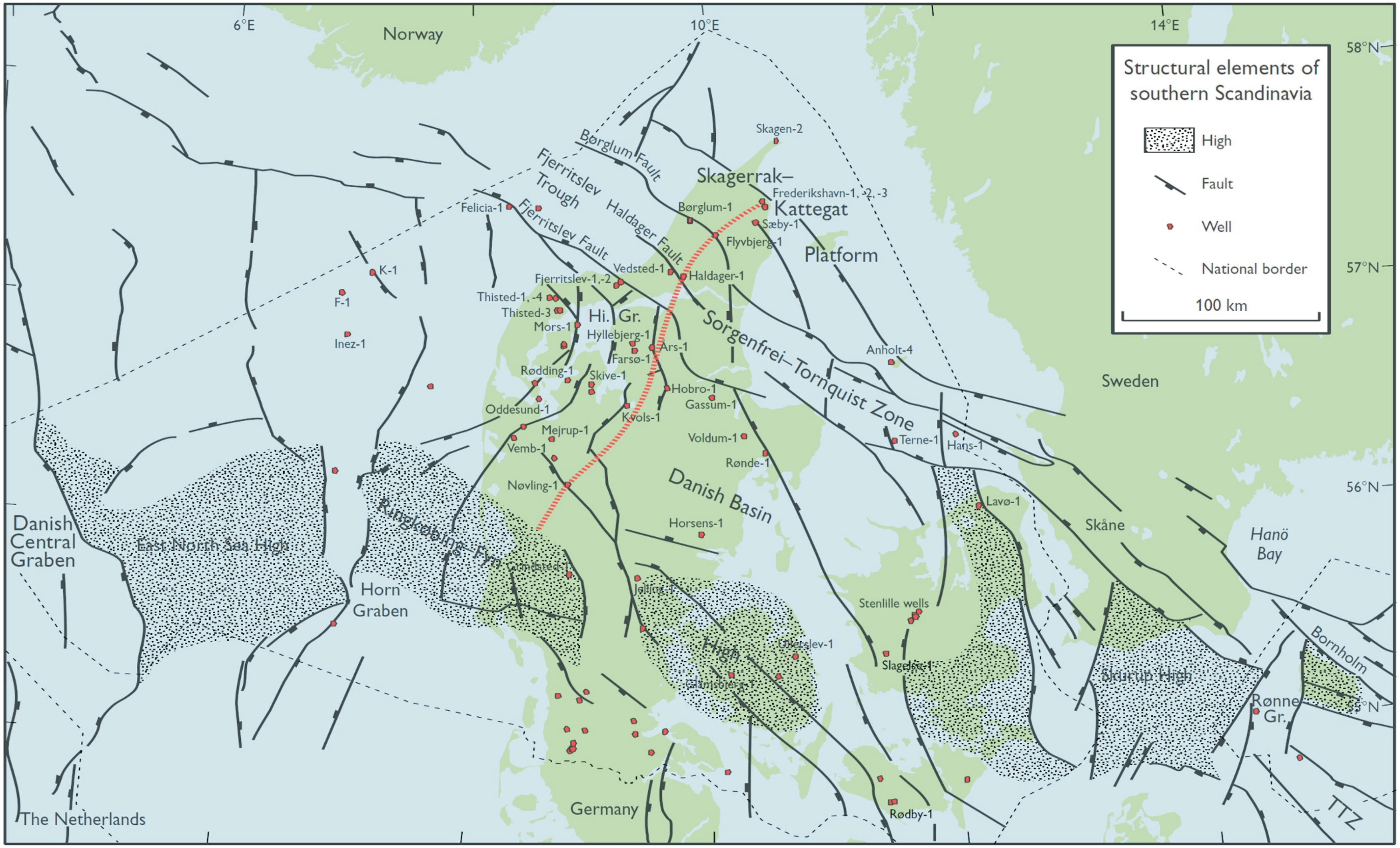

Figure 8. Structural elements of southern Scandinavia. Well locations and principal structural units. The red line indicates the approximate location of the cross-section in Figure 9. From Nielsen (2003).

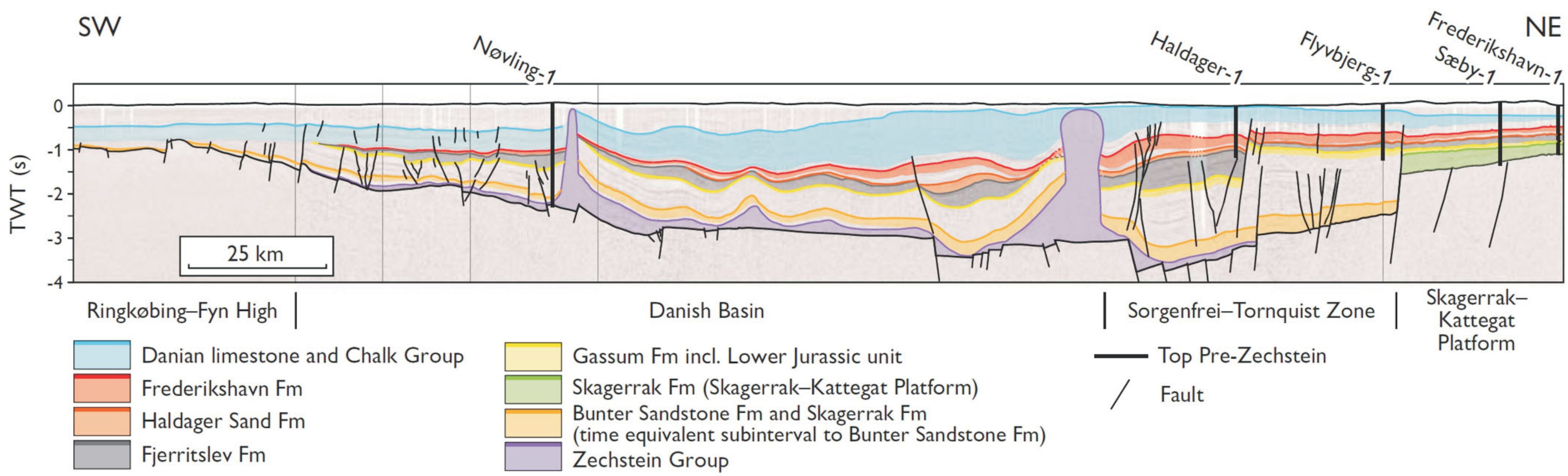

Figure 9. A SW–NE cross section through the Danish Basin and the Fennoscandian Border Zone. For location, see Figure 8. TWT: two-way travel time. From Vosgerau et al. (2016).

The main part of Greenland is covered by an up to 3 km thick ice sheet (the inland ice) with a relatively narrow ice-free zone along the coast. To the west and the southern part of the east coast, Precambrian basement complexes are found, whereas along the northern part of the east coast, the remains of a Caledonian mountain range and a thick sequence of Palaeozoic and Mesozoic sediments are present. In the northernmost part, a fold belt of the Ellesmerian Orogeny deformed a late Proterozoic to Silurian sedimentary basin. Centrally, both to the west and to the east a several kilometers thick sequence of Tertiary plateau basalt rests on Tertiary and Cretaceous sediments. These plateau basalts belong to the same North Atlantic Tertiary basalt province as found on the Faroe Islands (e.g., Esher and Pulvertaft 1995, Henriksen 2005)

Data Sources

As mentioned earlier, GEUS is a national survey and data repository and therefore has the obligation to host and maintain a range of databases for data of national interest (Hansen and Pjetursson 2011). These databases constitute the backbone of GEUS's work with geological interpretations and models.

The national borehole database, JUPITER, contains borehole information dating back more than 100 years. This database contains information on just less than 300,000 boreholes, corresponding to an average of about 7 boreholes per km^2. However, this data density is not enough for detailed geological mapping and therefore other types of data are needed – especially geophysical data. The databases GERDA (Figure 10) and MARTA contains measured data as well as geophysical interpretations for mostly shallow on- and offshore data (e.g., Møller et al. 2009). Other databases host data from oil and gas exploration in the form of reports and data from released 3D surveys and deep exploration and appraisal wells. Apart from confidential data, all other data in the databases are publicly accessible either free or at a specified fee.

The data covering the shallow part of the subsurface originates from investigations for instance at waterworks and in relation to hydrogeological mapping projects performed by consultants and authorities. Legislation in Denmark requires that all data collected in connection with groundwater investigations be sent to GEUS.

In Greenland, as mentioned above, 3D data is mostly gathered in the form of oblique photogrammetry on a local scale for specific projects. Locally, and in some cases regionally, geophysical datasets are available.

3D Modelling Approach

At GEUS, there are different mapping and modelling approaches that are used depending on the area and specific purpose of the model. Some models are supposed to give rough overviews of the geology, while other models need to be highly detailed. Therefore, defining model scale and model detail is important during the initial phases of the mapping and modelling project. An important part of this process is reflections about the capability of the available data to resolve the geology to the required level of detail.

The choice between explicit and implicit modelling depends to a large degree on the end-users needs and in certain cases a combined approach is chosen. In the Danish area, a layer-cake model approach often is used because these models can reflect the overall geological structure of a layered subsurface to a detail that is sufficient in most cases. However, very complex geological successions cannot be built properly using a layer models with interpolated layer boundaries. Therefore, in some cases voxel-modelling and geostatistical methods are used – sometimes with a combined voxel/layer approach. When high detail is needed, modellers seek to intensify the mapping for instance by making the data coverage denser or by using new types of data in selected areas. For example, traditional layer modelling has been used in a local model at Odense, where the general purpose was to provide detailed input for groundwater modelling to be used for assessments of groundwater flow and contaminant transport (Sandersen et al. 2018b). Although the sedimentary succession was rather complex, a layer modelling approach was chosen. In this case, highly specialized data in specific local areas paved the way for the construction of a geological model containing new and more detailed geological information.

A traditional layer model was also constructed at the Norsminde site (Høyer et al. 2015a), but for this project, three different model approaches were chosen for comparison (Figure 11). In the study, a manually constructed layer-cake model was evaluated against two automated modelling approaches. The automatic methods were “clay fraction modelling”, where borehole and AEM resistivity models were integrated through inversion (Foged et al. 2014) and a stochastic approach based on transition probability indicator statistics. The models possessed different strengths and weaknesses, and it was clear that the purpose of the models should be taken into careful consideration when choosing the modelling approach.

The layer approach and the voxel approach can be combined in models where parts of the model area is highly complex and others are not. For example, this has been done in the southwestern part of Denmark, where voxel modelling of glaciotectonically deformed parts of the model area was combined with traditional layer-modelling (Jørgensen et al. 2015). Based on the conceptual model of this study, Multiple Point Statistic (MPS) simulations were per-

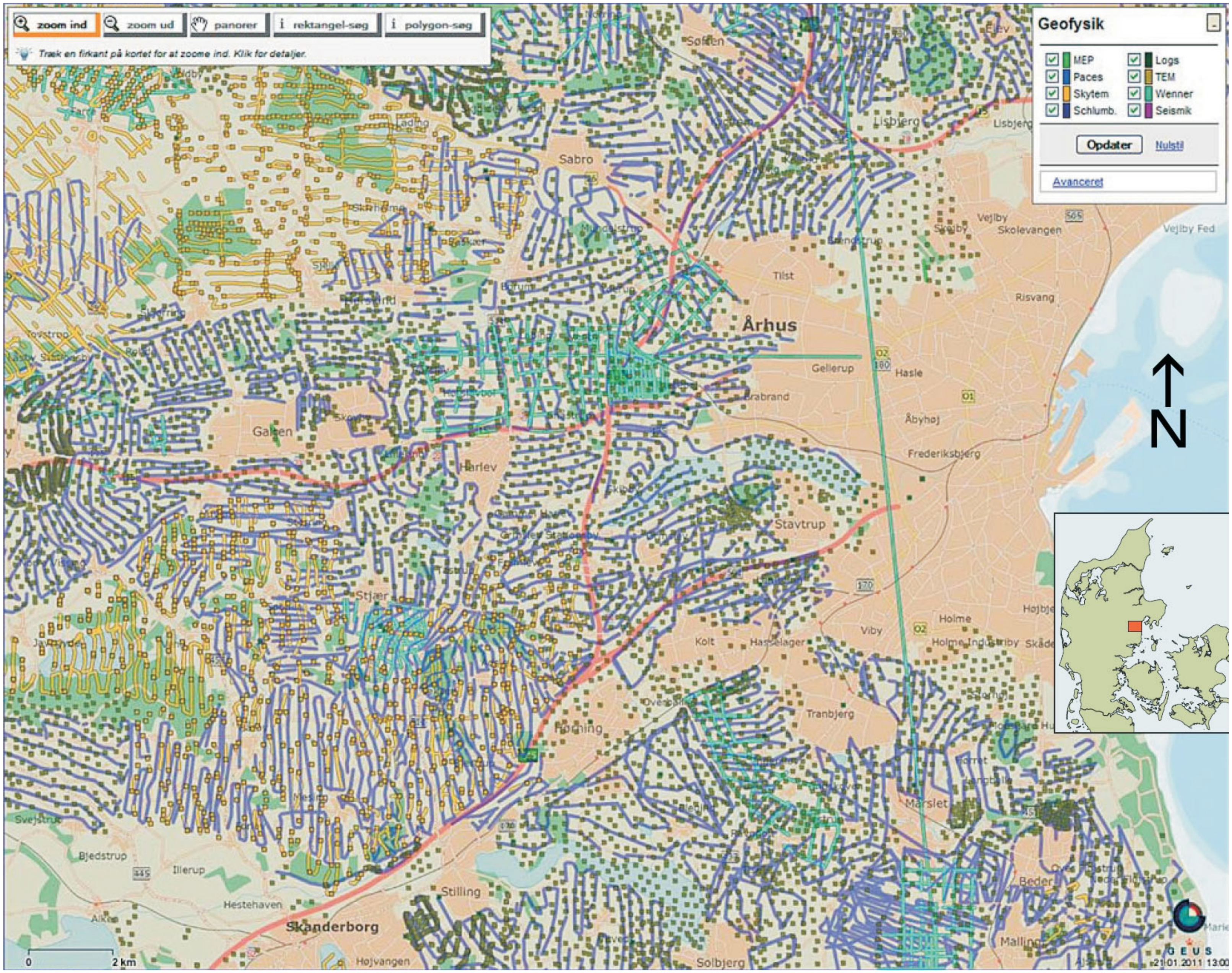

Figure 10. The GERDA database: A close-up of an area west of Aarhus showing data coverage of different geophysical data types. From Hansen and Pjetursson (2011).

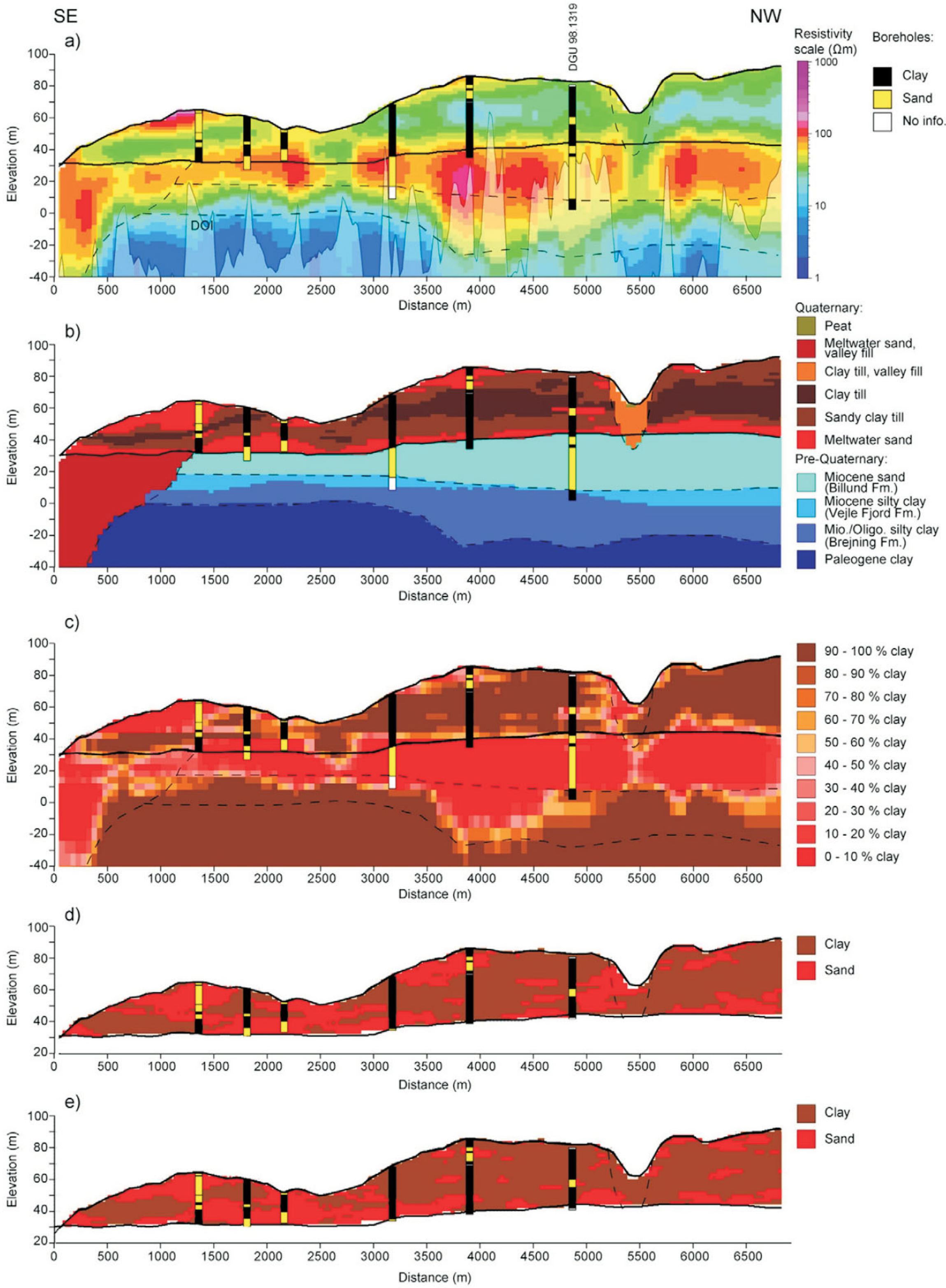

Figure 11. The Norsminde case: A NW–SE cross-section example shown with resistivity grid and model results. Boreholes are shown as vertical rods. The bottom of the Quaternary is shown as a thick line in all the sections. In a–c the bottom of the valleys, the bottom of the Billund Sand and the Top Palaeogene are marked with dashed lines. a) Resistivity grid. The colours are faded below the gridded DOI (depth of investigation). b) The Manual Cognitive Geological model results from which the dashed boundaries are derived. c) Result of the Clay Fraction modelling. d-e) Two of the TProGS simulations. The TProGS simulations are only conducted for the thick glacial deposits. From Høyer et al. (2015a).

formed on the deep Miocene succession (Høyer et al. 2017; see Figure 6). The project presented a practical workflow for building training images and a means to effectively handle different types of input information for large-scale geostatistical modelling. MPS modelling has been studied by Barfod et al. (2018a, b) using the Kasted dataset and the Kasted voxel model (Figure 5) as training image simulating hydrostratigraphic models. In Barfod et al. (2018b) a number of different modelling setups were tested to study the influence on the uncertainty of the hydrostratigraphic model ensembles.

For Greenland, 3D models have mainly been produced with TIN-surfaces representing geological boundaries and faults. This vector-based approach is suitable for the raw data of 3D polylines digitised in oblique stereo photos (Svennevig and Guarnieri 2012, Sørensen 2012, Svennevig et al. 2015) and for the structural complexity encountered in Greenland (e.g., Svennevig et al. 2016, 2017).

Clients

GEUS provides geological models to a wide range of clients – both private and non-private. The clients/stakeholders include public authorities (governmental, national, regional, municipalities), private and public research funds, consultancy companies, oil and gas companies, developers of geothermal projects, water utility companies etc.

GEUS generally encourages clients to participate actively during the mapping and modelling projects. Based on experience, this is the best way to secure that the client is kept continually informed about the modelling progress and the decisions that are made. Using this approach, the client becomes more closely connected to the end product. The geological models of today should be more dynamic compared to models constructed just a few years ago and the value of a model today can be measured in its ability to be continuously updated with new data and knowledge. However, this requires active maintenance and update of databases as well as models. The client should realize that the model most likely is not a one-off, but an active part of their future business that requires continual attention and funding.

Recent Jurisdictional-Scale Case Study Showcasing Application of 3D Models

An example of a 3D geological model that has had an immediate public interest is the Kasted model (Høyer et al. 2015b). A 3D geological model of an area outside the city of Aarhus was constructed based on borehole data in combination with a spatially dense AEM survey. A complex network of buried tunnel valleys characterizes the area and the model was made as a combined layer and voxel model in order to map both the overall structures as well as the lithological variations in the valleys (see Figure 5). The model was subsequently used as input for groundwater modelling (Barfod et al. 2018a, Vilhelmsen et al. 2018). The results of the geological modelling was of high interest for the waterworks in the municipality of Aarhus because the delineation of the complex valley-system could point to new and hitherto unrecognized groundwater resources. Further work to point out new well-fields has been initiated based on the 3D model and the dense geological and geophysical data in the area.

Current Challenges

As mentioned, GEUS is in the process of developing a national 3D geological model for Denmark (Jørgensen et al. 2013, Sandersen et al. 2015, 2016). Building a national 3D model is a large project that requires careful planning and organization. The work has been initiated, but with very little progress until the necessary funding is in place.

Lessons Learned

Based on our 3D modelling activities in recent years, a few of the lessons learned in the process are:

- The planning of a 3D mapping and modelling project should focus on the end-product: Which questions are the model supposed to answer, which types of data, and which type of model approach is needed to reach that goal?
- There is not always a good match between what the end-users and stakeholders think can be modelled and what actually can be modelled based on the available data. Most often we do not have data of the right type or the right amount to obtain the desired model detail
- 3D geological modelling today is a complex task where the best results come from tight collaboration between modellers and other groups of earth scientists
- Too many geological models from a not-so-distant past cannot be reused because of too sparse documentation and lack of maintenance. Consequently, geological modelling often has to be done all over again in the same areas. We should all be aware that 3D geological mapping and modelling is an ongoing and dynamic process and thus strive to keep models alive and readily updateable. Static models should be a thing of the past and we must ensure that this message is properly conveyed to stakeholders and end-users
- The demands for geological 3D models in Denmark and Greenland are very different and so are the approaches, tools, and workflows.

Next Steps

The next steps will focus on:

- Development of a strong business case for establishing adequate funding for the National 3D model
- Continued work on 3D geological modelling in research and consultancy projects with a focus on development of new methods and approaches
- Increasing the awareness among clients and end-users on the importance of keeping 3D geological models dynamic and up-to-date

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