GENETIC APPROACH TO RECONSTRUCT COMPLEX REGIONAL GEOLOGICAL SETTING OF THE BALTIC BASIN IN 3D GEOLOGICAL MODEL

Konrāds POPOVS, Tomas SAKS, Jānis UKASS, Jānis JĀTNIEKS

University of Latvia, Faculty of Geography and Earth Sciences, e-mail: konrads.popovs@lu.lv

INTRODUCTION

Interpretation of geological structures in 3D geological models is already standardized in many geological branches.

Traditionally, geological concepts complement quantitative as much as qualitative data to obtain a model deemed acceptable, however, available data very often is insufficient and modeling methods primarily focus on spatial data but geological history usually is mostly neglected for the modeling of large sedimentary basins.

A need to better integrate the long and often complex geological history and geological knowledge into modeling procedure is very acute to gain geological insight and improve the quality of geological models.

During this research, 3D geological model of the Baltic basin (BB) was created. Because of its complex regional geological setting and wide range of the collected data sources with multiple scales, resolution and density as well as its various source formats, the study area provides a challenge for the 3D geological modeling.

In order to create 3D regional geometrical model for the study area algorithmic genetic approach for model geometry reconstruction was applied what include simplified prerequisites of geological evolution.

1. GEOLOGICAL OVERVIEW

The Baltic Basin is a large marginal synclinal structure in the southwestern part of the East European Craton situated on the slope of the Belarusian–Masurian crystalline basement. Depth below sea level of the Precambrian basement increases from few hundred metres in Estonia to 2 km in southwestern Latvia and 5 km in Poland.

The Baltic Basin includes the Neoproterozoic at the base and all Phanerozoic systems. In this sedimentary cover four structural complexes area distinguished, seperated from each other by angular unconformity – Baikalian, Caledonian, Hercynian (Variscian) and Alpine complexes.

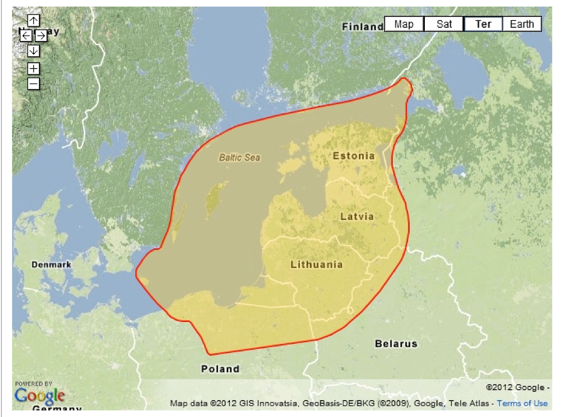

Fig 1. ***Spatial context of research territory.***

Each of these structural complexes are marked by more or less intensive faulting of the basin, where most extensive faulting was in the end of the Caledonian tectonic stage.

Baikalian complex lasted from Vendian till lower Cambrian and are distributed in the eastern part of the Baltic countries and is up to 300 m thick.

Following rest of the Cambrian succession till Silurian constitutes Caledonian complex.

Hercynian complex contains Devonian sequence and the lowermost Carboniferous sediments.

The Alpine complexes include Upper Permian to Cretaceous sequence and in SW part of area Cenzoic sediments.

2. DATA

Table 1. ***Geological data sources that are used in construction of model geometry.***

Territory	Boreholes	Structural maps (Relief data, fault locations and displacement values)	Geological maps (Geological boundaries)	Literature information (Books, publications...)
Latvia	X	X	X	
Estonia	X		X	
Lithuania		X	X	
Russia				
Kaliningrad (RUS)			X	X
Poland			X	X
Baltic Sea		X		X

Collected geological information in many cases are under-sampled. Sufficiently detailed information is available only for territories of Latvia, Estonia and Lithuania. Rest of model area is poorly characterized.

Also, available information are in various formats and types, therefore, standardized modeling methods are not applicable directly.

3. APPROACH

Construction of model geometry is based on assumption that post-depositional deformation produces no significant changes in sedimentary strata volume – the strata thickness and its length in a cross sectional plane remains unchanged, except as a result of erosion (Dahlstrom, 1964).

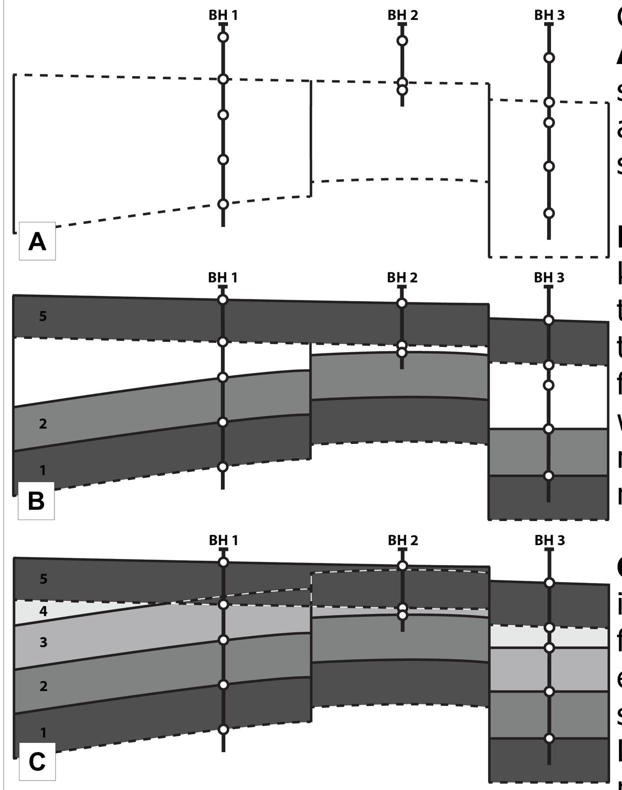

Fig 2. ***Principles of geometrical reconstruction.***

Geometrical interpretation can be divided into:

A – Construction of model framework from stacked base surfaces with known displacement amount along the faults, fault network and erosion surfaces (dashed lines) using all available data.

B – Reconstruction of non-eroded layers with known full thickness (1st, 2nd and 5th) using known thickness interpolation and successive aggregation to the base surfaces taking over slip amount along faults from those surfaces. The full thickness data where was available,was extrapolated to those nearest boreholes, where bottom of the layer was not reached.

C – Reconstruction of eroded layers. After initial thickness restoration of eroded layers with full known thickness (3rd), in places of erosion elevation values are taken over from erosion surfaces.

Layers with unknown full thickness (4th) are reconstructed assuming that they are topographically similar to the underlying layers and layer volume can be reconstructed by filling volume between underlying layer and erosional surface.

4. PROCESS

Modeling environment.

The geological model was created within MOSYS modeling system (Virbulis et al., under revision). Model generation process is abstracted in the system of logical operations (algorithms) written in *Python* where logical operations consist of operations and user defined command systems (Sennikovs et al., 2011).

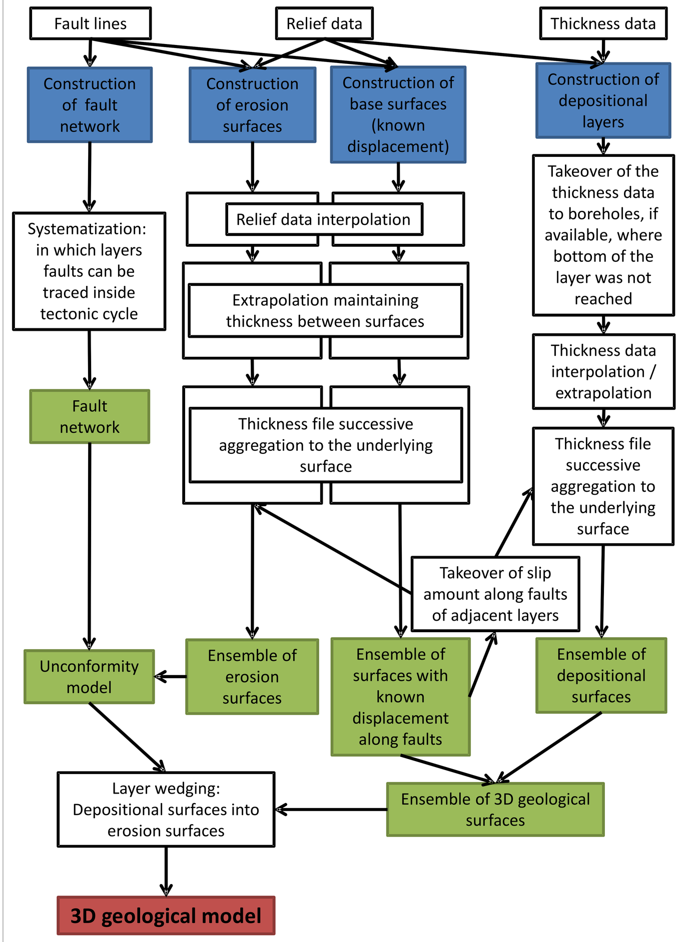

Fig 3. ***Schematic model building procedure***

Model structure

Model layers were divided into several integrated sequences considering:

- Known displacement along faults of the layer surfaces, which were taken over to part of geological section what was formed in one tectonic cycle;
- Influence of erosion to lateral boundaries of layers along faults and erosion surfaces.

Model construction procedure.

Construction of the model geometry include several integrated steps including:

- systematization of fault system accordance to stratigraphical units,
- 3D reconstruction of the structural surfaces with known displacement data along faults,
- 3D construction of the unconformity surfaces including regional erosion surfaces and fault networks which together with structural surfaces form ensemble of base surfaces and further were used in:
- reconstruction of the sedimentary layer geometry.

By **thickness interpolation** and successive thickness file aggregation to the underlying surfaces inside layers belonging to one tectonic cycle, each layer reflects the topography and fault displacement of the underlying layer.

Outside of areas with available data, was performed **thickness extrapolation** with unconformity control and regional thickness maintenance.

5. RESULTS

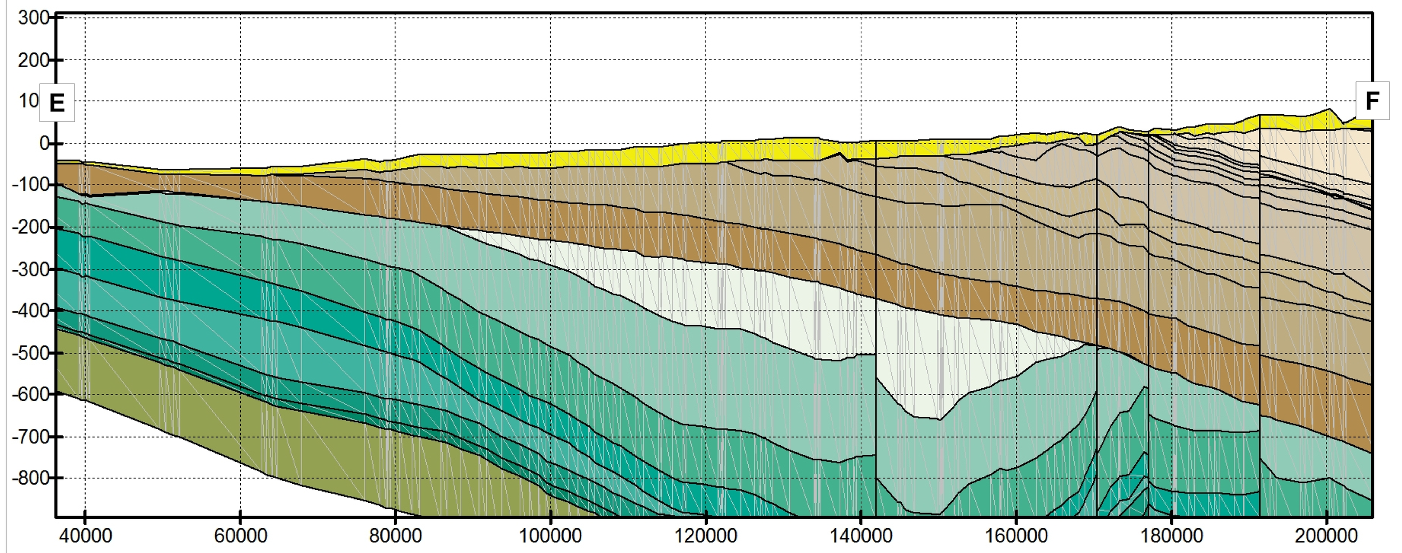

Fig 4. ***Cross section through the territory of Baltic Basin.*** *Profile line in Fig 7. Vertical Exaggeration 1:50. Grey lines – model meshplot.*

Use of the unconformities as a tool for evolution of relationships between model elements and reducing uncertainty along the faults gave an opportunity for geologically believable and topologically correct interpretation of model geometry. Using 3D topological relations between depositional layer, erosion surfaces and fault structures, lateral margins were geometrized and layers wedged out on first intersected mesh node between layer and unconformity.

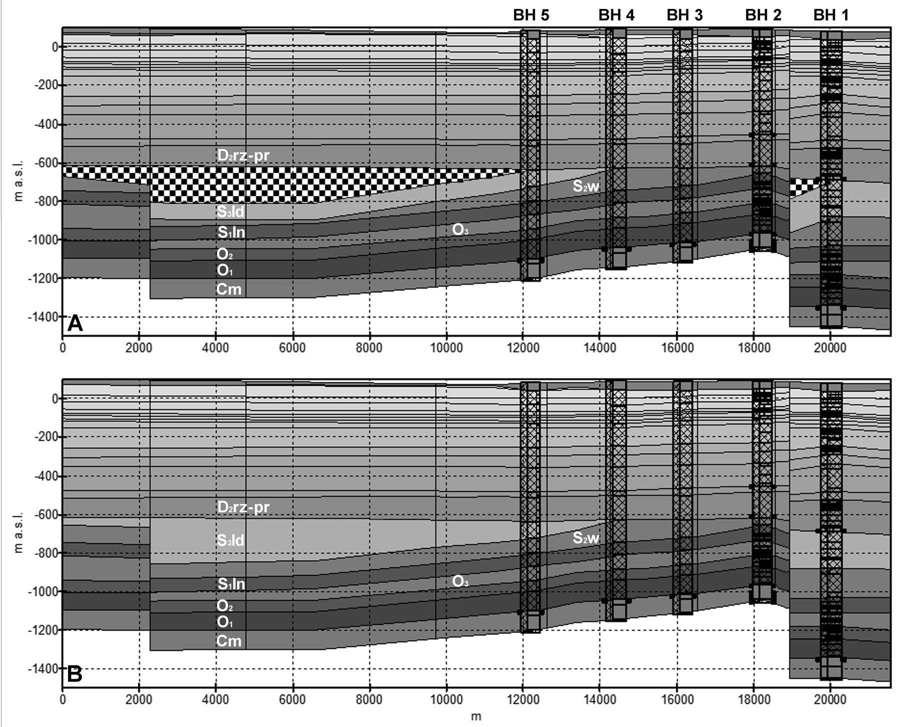

Fig 5. ***Example of reconstruction of volume offset along fault in cross section.*** *A – cross section with offset, B – reconstructed cross section.*

Excluding from data set values that do not describe full layer thickness (example: **Fig 5 A – BH 5 – S3ld, BH4, BH5, BH2 – S2w**), partly is resolved unknown part of section (**dashed area**) by interpolation values from the known full thickness.

However most of the gap was reduced by assuming geological structure which fulfills the geometrical requirements: if the fault displacement values were interpreted reliably, then regional thickness of each stratum has to be maintained (**S3ld**) following the know geological sequence (**BH1**).

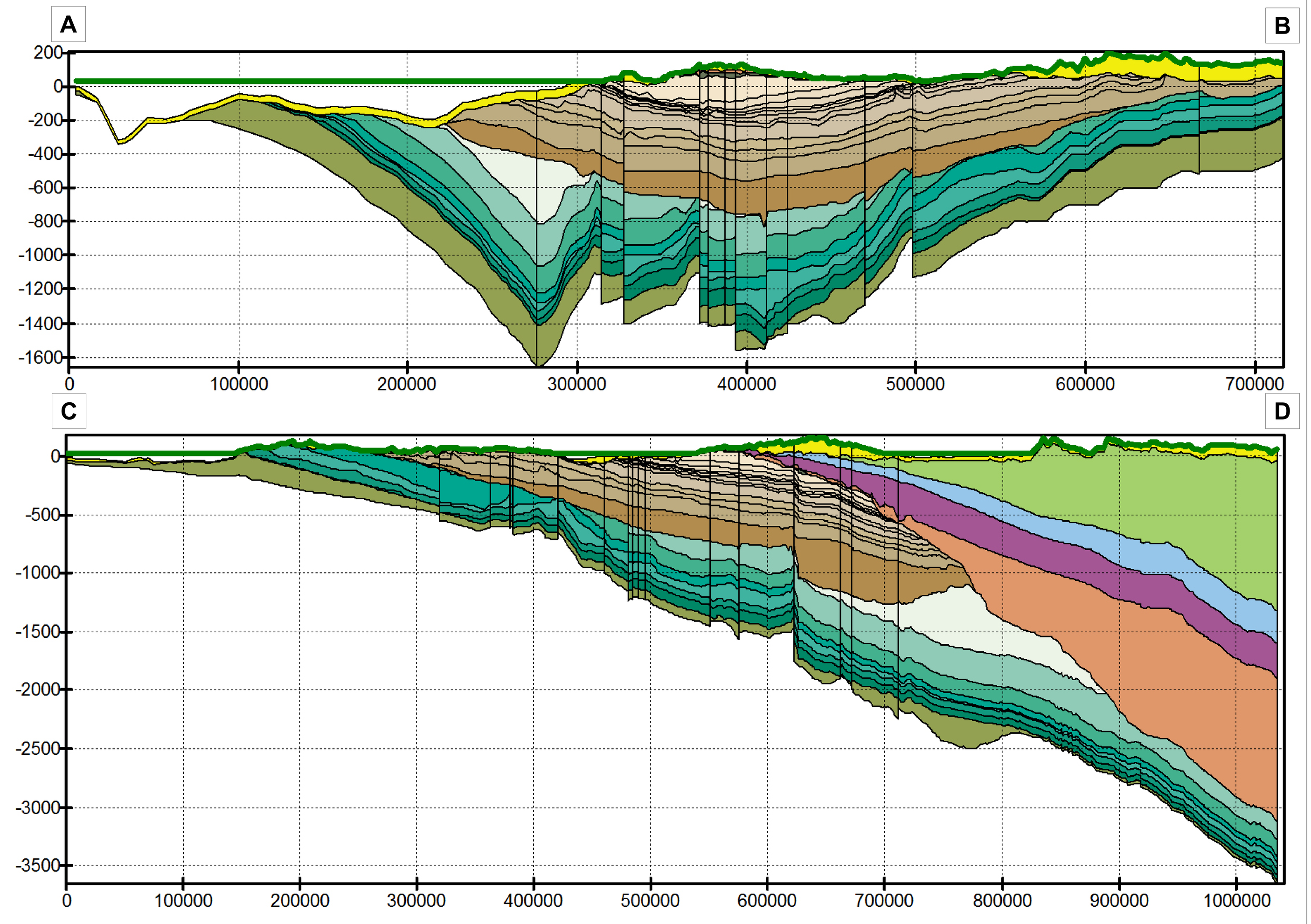

Fig 6. ***Cross sections through the territory of Baltic Basin.*** *Profile lines in Fig X. Vertical exaggeration 1:50.*

Established model well corresponds to the general notions of geological structure of the Baltic basin.

Developed structure highlights coherent interpretation of the geological structure by maintaining the thickness of the whole sedimentary cover where were implemented know fault displacements and extrapolated to the model surfaces with no or sparse data.

In the model structure it was possible to clearly distinguish intraregional, regional and subregional structures of Caledonian, Hercynian and Alpine tectonic stages as well as local structures along the fault lines, including local highs and depressions as well.

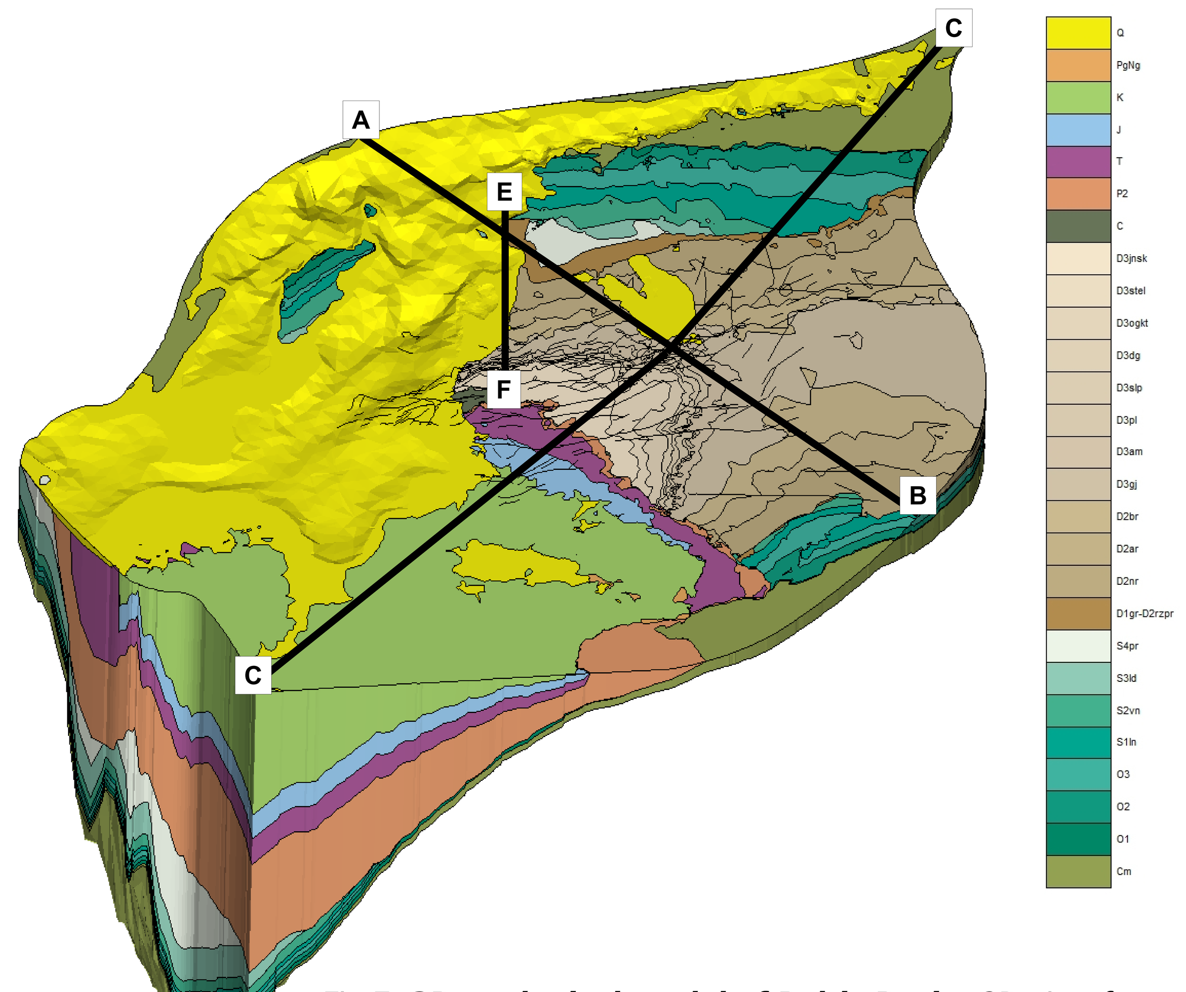

Fig 7. ***3D geological model of Baltic Basin.*** *3D view from South-West to Nort-East. Horizontal slice at -50m a.s.l. Section lines for Fig 4 and Fig 6. Vertical exaggeration 1:50.*

CONCLUSIONS

Applied techniques made possible reliably reconstructing the 3D geological structure of the Baltic artesian basin and allowed to predict surface geometry of the layers in areas of the sparse data. Chosen methodology allowed establishing the geological model that corresponds to the general notions of the Baltic basin geological structure.

Subordinate model creation to the simplified evolution preconditions of geological structure allowed us to reduce uncertainties associated with two aspects – discontinuities of stratigraphic sequence by presence of erosion and interpretation of layer displacement values along the faults.

At the current density of the data used, detalization of the geometrical model is in the maximum possible resolution, however modeling results allow us to quantify areas in the model structure where additional data is necessary to improve the quality of geological reconstruction, especially for territories of Poland and Baltic Sea.

Reconstruction of tectonic structures in current level of detalization do not provide the necessary amount of information, especially for the deepest layers and areas outside of central part of Baltic states. For reconstruction of tectonic structures structural maps were used as only available data set containing interpretations from seismic data, however in some model areas offset between these maps and boreholes were found.

Some inconsistencies and uncertainties in the model structure are mostly associated with limitations of subsurface mapping and interpretation methods that was used in data acquisition and processing of data in previous researches which was used in this research, as well as a lack of data. Results of this study suggest that the borehole logs are the best data source for spatial description, interpretation and prediction of geological structure if the good quality seismic data is unavailable.

Used approach has good potential in development of regional geological models of sedimentary basins and is valid for spatial interpretation of geological structures from heterogeneous and sparse data, subordinating this process to prerequisites of geological evolution.

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