Modelling The Geological Structure Of Poland – Approach, Recent Results And Roadmap

Zbigniew Małolepszy, Marcin Dąbrowski, Adam Mydłowski, Tomasz Żuk, Ewa Szynkaruk, Marta Tomaszczyk, Marta Adamuszek, Jacek Chełmiński, Tomasz Gogołek, Łukasz Jasiński, Wiesław Kozdrój, Łukasz Nowacki, Piotr Olkiewicz, Marcin Słodkowski, Paweł Sydor, Urszula Stępień, Urszula Wyrwalska;

Polish Geological Institute – National Research Institute, GeoModelling Laboratory, Rakowiecka 4, 00-975 Warsaw, Poland; Marta.Tomaszczyk@pgi.gov.pl

Introduction

Modelling of the geological structure of Poland started ca. 10 years ago at the Polish Geological Institute – National Research Institute (Polish Geological Survey, PGI-NRI). The first model was a low-resolution, nationwide model showing the stratigraphic framework based on published horizontal-section maps and deep boreholes. Since then, several regional and local models have been produced, both structural and parametric, aimed at specific applications such as CCS, geothermal energy (both deep and shallow), urban geology, geological storage or resources. More recently, a systematic program has been launched to model all sedimentary basins of Poland one by one, in a way that would support decision-making at a regional scale. The first model in this series – the model of the Lublin basin – is sufficiently advanced to produce results that will be discussed below. This serial modelling program is a game-changer that is currently driving the development of a systematic workflow for developing models, and probably more importantly a new geological database approach. It is focused on storing geological data in 3D space and area-based data retrieval. Moreover, a model delivery system is being developed within this project, both for easy internal access to data by geomodelers and for external access promoting re-use of available models.

Several other modelling projects are currently being carried out, or have recently been completed, and below we have highlighted the recent activities of the GeoModelling Laboratory at PGI-NRI, including geothermal modelling, imaging sedimentary architecture to construct training images for facies modelling and recently rapidly expanding the activities of the Computational Geology Laboratory, where flow and geomechanical models are being developed.

Lublin basin

The first part of the 3D sedimentary basins modeling program carried on at the Polish Geological Institute is the multiscale static model of the regional structure of the Lublin Basin. It has been built in accordance with the principles of integrated 3D geological modelling, and is based on a large dataset of geospatial data available from all Polish digital databases as well as analogue archives including 420 deep boreholes and several thousands of kilometers of 2D seismic interpretation. The regional structure mapped covers an area of 260 x 80 km located between Warsaw and the Polish-Ukrainian border, along the NW–SE-trending margin of the East European Craton. Within the basin, the Paleozoic beds with the coal-bearing Carboniferous strata underlain by older hydrocarbon reservoir formations and unconventional prospects are unconformable covered by Permo-Mesozoic and younger rocks. The regional model stretches from the ground surface to a depth of 6000 m, reaching the Proterozoic crystalline basement. The project focuses on the internal consistency of models at different scales – from the basin scale (small scale; 1:500000) to the field scale (large scale; 1:10000). The models, nested in a common structural framework, are built using regional geological knowledge, ensuring a smooth transition between the 3D models of different resolution and degree of geological detail.
The model consists of all chronostratigraphic systems from the Ediacaran to the Quaternary, each of them including detailed stratigraphic and lithological information. The distribution of lithofacies and depositional systems has been reconstructed over the entire study area. The lithofacies models for each stratigraphic unit have been created in separate grids generated from the common structural framework. The property modeling was carried out for selected formations in order to assess both shallow and deep regional groundwater systems. The large collection of core samples and wireline data allowed the reconstruction of reservoir properties for groundwater resources.

Figure 1. 3D geological model of the Lublin Basin, Poland.

The model is delivered to the end user through a standalone 3D viewer which is freely distributed as well as a 3D web viewer, which will be launched at the end of 2015.

Uncertainties of the Lublin Model

The major challenge of the multiscale approach to subsurface modelling in the Lublin Basin is the assessment and consistent quantification of various types of geological uncertainties tied to the submodels at different scales. The decreasing amount of available information with depth, with very limited data collected below exploration targets in particular, and the accuracy and quality of data have the most critical impact on the model. At deeper levels of the Lublin Basin, seismic interpretation of 2D surveys is sparsely tied to well data. Therefore, time-to-depth conversion is the major uncertainty when modeling the subsurface, especially below a depth of 3000 m. Furthermore, as all models at different scales are based on the same dataset, we must deal with different levels of generalization of geological structures. The same degree of generalization shall be applied to uncertainties. However, the approach to the uncertainty assessment and quantification may vary depending on the scale of the model. In the small-scale regional and sub-regional models, deterministic modelling methods are used, while stochastic algorithms can be applied for uncertainty modelling at the large-scale multi-prospects and field models. It can be assumed that the 3D multiscale modelling which describes geological architecture with quantified structure uncertainties, presented on standard deviation maps and grids, will allow us to outline exploration opportunities as well as to refine the existing and build new conceptual models. As the tectonic setting of the area is a subject of long-term dispute, the model depicting both structures and gaps in geological knowledge at different resolutions will allow the confirmation of some concepts related to the geological history of the Lublin Basin and the rejection or modification of other hypotheses.
TransGeoTherm

This cross-border, Polish-Saxon project was developed as a tool to support the development of shallow geothermal energy resources, and to make the results of geothermal modelling and mapping available to the public. The secondary goal is to increase and to popularize the use of low-temperature geothermal energy as one of the sources of renewable energy, thus addressing the need to reduce the emission of CO2 as well as the „smog-causing” gases and dusts from using fossil fuels. The success of the project is based on an innovative and advanced technology of analysis and interpretation of geological, geothermal and hydrogeological data as well as on the preparation of a 3D numerical model of the subsurface. The core of the database consists of 5146 selected borehole logs and 5168 virtual boreholes, with rock formations / layers grouped into 75 hydrogeological–geothermal (HGE) units. The boreholes (codified using HGE units) and geological cross-sections are used as a leading reference to construct a 3D numerical model processed using the GOCAD software, down to a depth of 200 m below the ground level (locally down to 340 m) – Figure 2 (http://gst.pgi.gov.pl/gstweb/GSTws/gui2.php).

The GOCAD modelling procedure uses raster datasets consisting of the top and bottom surfaces of every HGE unit as well as its thickness calculated from the model using cells with dimensions of 25 × 25 meters. Based on the geothermal properties of rocks and their groundwater content, a specific value of geothermal conductivity (λ, [W/m*K]) is allocated to each rock type (layer) in every borehole. A depth-weighted mean λ value is calculated for every section of a borehole, belonging to a certain HGE unit of the 3D geological model. The results are presented in the following ways (http://www.transgeotherm.eu/mapy_geoter.html):

- 8 maps of mean geothermal extraction rate [W/m]
- 4 depth-intervals x 2 annual operation hours
- 4 maps of mean thermal conductivity [W/m*K]
- Lambda-distribution for 4 depth-intervals (Figure 3)

The project results are available free of charge, and can be used by all interested parties. The results serve as a decision-making tool for local and regional planning and development, and thus are of special interest.
to the local authorities, planners and the general public as well as to the business sector (for example producers and installers of heat pumps). The geothermal maps can also be used for renewable energy auditing at the local and regional scale.

**Sedimentary architecture of coastal dunes**

Although modelling software is designed for geographically extensive projects which use seismic and deep well data, it is also well suited for modelling based on high-resolution datasets such as ground penetrating radar (GPR), vibrocoring, or trenches. We use GOCAD for display and interpretation of shallow geophysical and borehole data in sedimentological projects which aim to reconstruct the evolution of Holocene landscapes and investigate the sedimentary architecture of depositional systems. Figure 4 shows an example of 3D GPR data from a larger dataset (6 3D grids and several km of 2D lines) collected across the Mrzeżyno dunefield, southern Baltic Sea coast, NW Poland. Geophysical data was calibrated using vibrocores and trenches, while the topography of dunes was reconstructed using LIDAR data. The datasets showed the internal organization of individual dunes to depths exceeding 20–30 m with reflections representing various-scale erosional surfaces ranging from sand-flow cross-strata to interdune surfaces and lithological boundaries. Horizontal slices showed the paleotransport directions which were quantified and compared between the GPR datasets, current dunefield morphology and the wind regime. Quantitative conclusions about the heterogeneity of aeolian deposits across the dunefield can be used to generate training images for facies modeling in similar situations in ancient rock records.

**Geological Processes Modelling**

The Computational Geology Laboratory, a section within the GeoModelling Laboratory, has been established to complement the modelling of the geological structure beneath Poland with numerical models of geological and industrial processes. The core activities of the group include the development of geomechanical models for shales and geothermal systems, the studies of flow and transport in porous media, and the modeling of salt tectonics, shear zone dynamics, and fold-and-thrust belts.

In the presented example, fluid flow in either a rough or a propped fracture is studied using our unstructured mesh finite element code MILAMIN (Dabrowski et al., 2008). In both cases, the fluid flow
Figure 4. One of the high-resolution models from the Mrzeżyno dune field produced using GOCAD based on 3D GPR data (collected with 250 MHz shielded antenna), vibrocores and trenches. The blue surface is the groundwater table at 2.5 m; green indicates an erosional surface separating cross-stratified sets (interdune surfaces); red shows erosional surfaces created due to changes in wind direction and velocity, i.e. reactivation surfaces; yellow represents the bottom of the aeolian sequence (supersurface) underlain by organic deposits; the brown horizon is the top of the glacial till associated with strong signal attenuation and diffraction hyperbolas. All dimensions shown are in meters.

Figure 5. The magnitude of the fluid flow velocity in a pressure driven flow through a fracture with roughness.

Figure 6. The magnitude of the fluid flow velocity in a pressure driven flow through a propped fracture.
exhibits a non-trivial channel-like pattern, which shows that mass transport is strongly heterogeneous in such systems. The obtained results can be directly used to measure the impact of the roughness or the proppants on the effective fracture transmissivity. Our direct numerical simulations of the fracture flow allow us to study transport characteristics such as mechanical dispersion, residence times, and the evolving morphology of incoming fronts. Local wall stresses, which can have an effect on mass exchange between the surrounding porous medium and the fluid in the fracture, can be easily inspected. The numerical model is currently under development towards a direct FEM-based multi-phase flow solver.

Roadmap

In the long term the, Polish Geological Institute is planning to produce a complete 3D map of every regional-scale sedimentary basin in Poland. We are seeking to develop a modelling workflow that will be systematic, but sufficiently flexible to include site-specific requirements related to the scope and detail of representation of each sedimentary basin in question. To accompany this flagship program, we will deliver several, usually smaller-scale projects targeting specific scientific and applied issues, such as salt mobility modelling, coastal zone modelling, resources modelling, geothermal energy and others.

References
