The numerical spatial model (3D) of geological structure of Poland — from 6000 m to 500 m b.s.l.

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A b s t r a c t. The article describes the methodology and the results of the pilot stage of a project, aimed at representing the deep geological structure of Poland from 6000 m to 500 m b.s.l. as a 3D numeric spatial model in scale 1 : 500,000, in the "1992" geo-reference system.

Key words: *deep geological structure, Poland, 3D numerical modelling*

The progress in the field of geomatics, as well as the fast development of computer graphics, methods of numerical modelling and GIS, opens completely new possibilities for description, analysis and visualization of geological data. It allows imaging the geological structure as interactive numeric spatial models.

We participate in the first Polish project, which aims at imaging the deep geological structure of the entire country as a numerical spatial model. This paper presents its methodology as well as the results of its pilot stage, focused on the geological structure from 6000 m to 500 m below sea level (b.s.l.), represented in 1 : 500,000 scale, in the "1992" geo-reference system.

The present model is based on geological horizontal section maps at depth intervals of 1000 m (Kotański et al., 1997), drilling data, the archival geological-geophysical data and the information from other existing databases. Original methodology was created for elaboration of the model. Input data were verified, considering primary the compatibility between different data sources. These allowed construction of an interactive GIS database including borehole data, raster and vector data obtained from digitalized maps. The model was created using the package *GeoGraphix Exploration System v 7.7* (GES) (Małolepszy & Chybiorz, 1996), applying optimized and verified procedures of geometric and geologic processing.

The pilot stage led to the following effects:

❏ numeric spatial model in the GES format coupled to geological horizontal section maps;

❏ interactive GIS database including of 4000 drill holes, as well as various maps *http://web2.pgi.gov.pl/website/cbdg_3d/viewer.htm*;

❏ interactive presentation including: 3D animations and scenes, geological map and cross-sections *http://www.pgi.gov.pl/3d*.

The project team led by Professor Krystyna Piotrowska (Piotrowska et al., 2005) included employees of the Polish Geological Institute (K. Piotrowska, Z. Kotański, M. Rossa, T. Mardal, I. Duliban), the Faculty of Earth Science, University of Silesia (S. Ostaficzuk, Z. Małolepszy, E. Kurowska, R. Chybiorz, E. Biały, D. Jura), the Mineral and Energy Economy Research Institute, Polish Academy of Sciences (Z. Heliasz), the Institute of Geophysics — Polish Academy of Sciences (E. Osuch) and the Faculty of Geology, Warsaw University (P. Karnkowski). The project has been commissioned by the Ministry of the Environment and funded by the National Fund for Environmental Protection and Water Management.

Discretization of the model

The lower boundary of the model is the surface at 6000 m b.s.l., and the upper boundary is the surface at 500 m b.s.l. The vertical outline of the model is the border of the country. The space of the model was discretized to the regular mesh with cell size of ~ 500 m according to the georeference coordinates system "1992". Due to the system requirements each geological unit upper and lower was represented as a volume constrained by two surface. Hence, the grid consists of 1419 columns, 1341 rows on 2 surface, making up over 3.8 million computational elements for each geological unit of the model.

Geological units

It was accepted, that the model will consist of 14 units: 12 stratigraphic units: Neogene; Upper and Lower Cretaceous; Upper, Middle and Lower Jurassic; Upper, Middle and Lower Triassic; Upper and Lower Permian, Palaeozoic (without Permian) and 2 structural units: Carpathian flysh and Precambrian with crystalline basement.

Input materials

❏ geological horizontal section maps (Kotański, 1997) in scale 1 : 750,000 (printed version) and in scale 1 : 500,000 (original maps with supplements) corrected by the authors;

❏ drill hole database including 10,000 wells deeper than 500 m b.s.l., stored in the Central Geological Database (CBDG);

❏ archival and published data from the Polish Geological Institute, University of Silesia and Polish Academy of Sciences.

Geoproccesing of input materials

Verification and processing of input data was done according to the scheme originally worked out by for three

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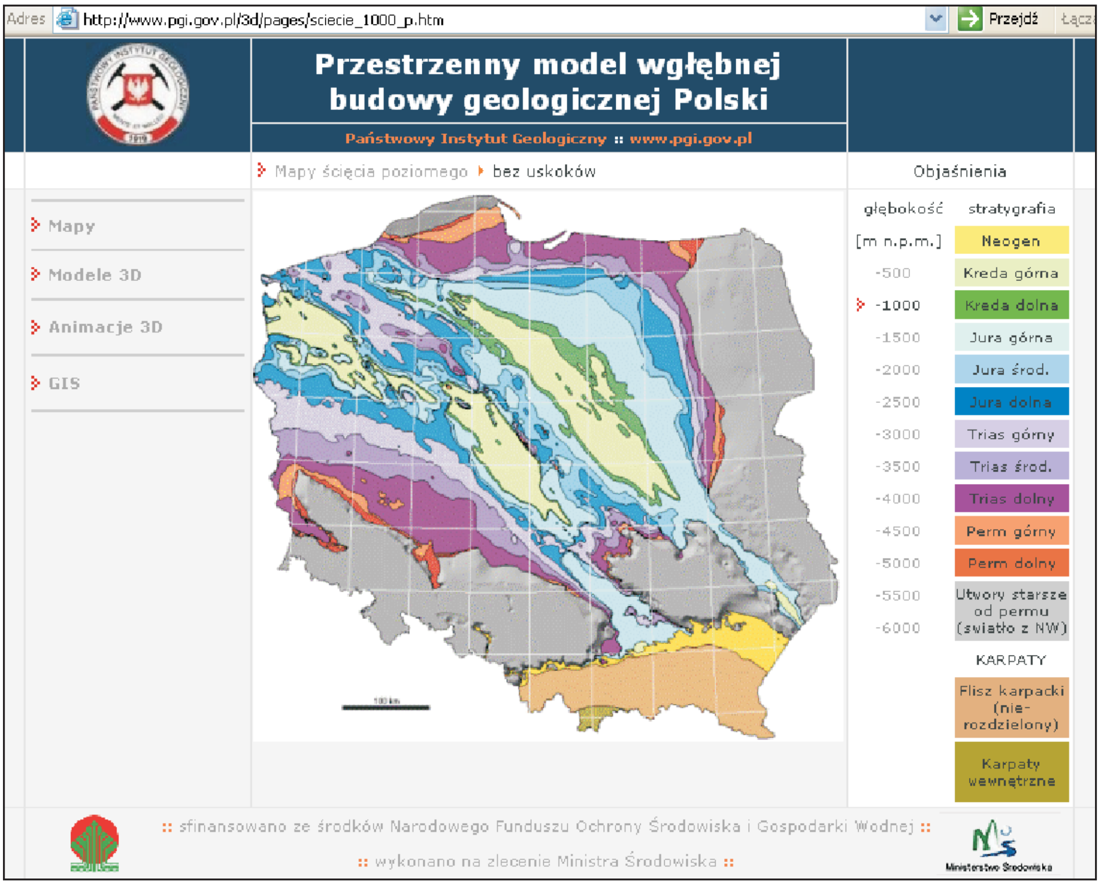

Fig. 1. Screenshot of website with animations and 3D images of the model, geological map and cross-sections, accessible at *Geological horizontal section map for 1000 m b.l.s.*

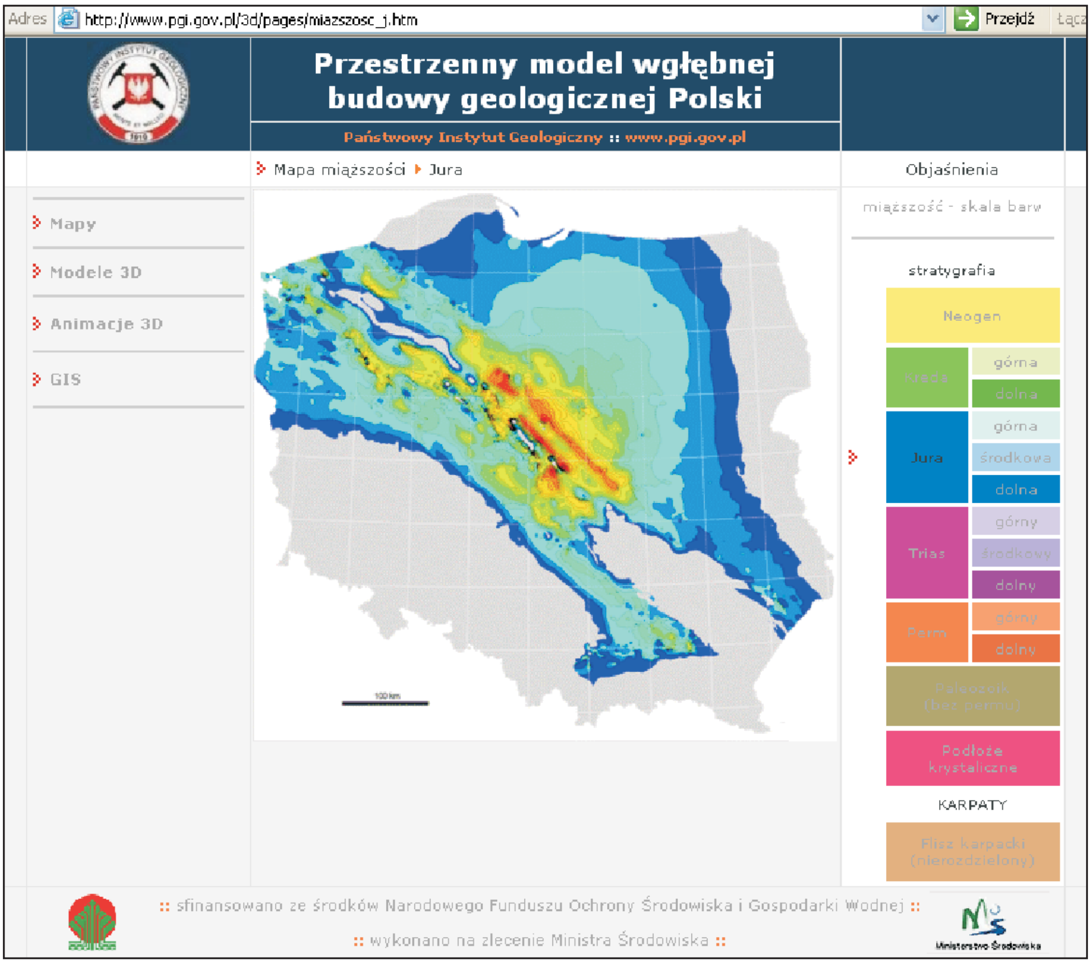

Fig. 2. Screenshot of website with animations and 3D images of the model, geological map and cross-sections, accessible at *Geological thickness map of the Jurassic*

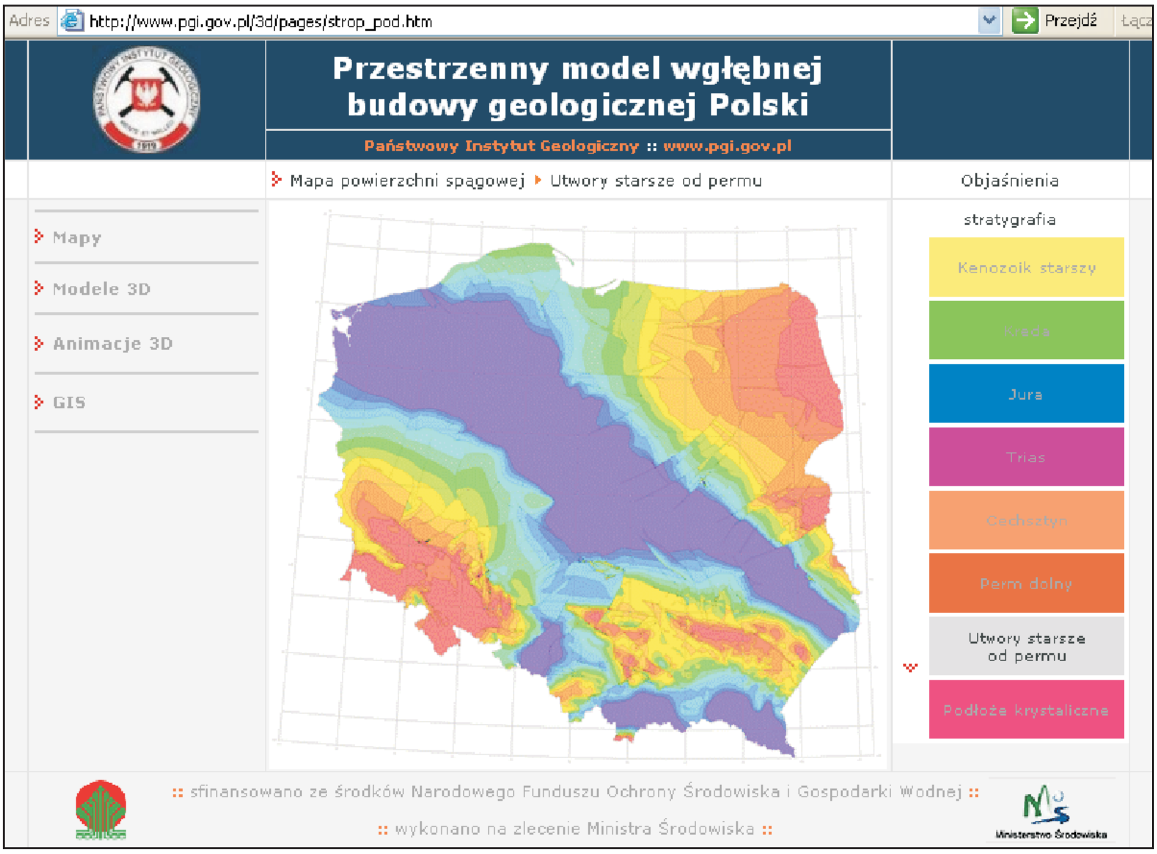

Fig. 3. Screenshot of website with animations and 3D images of the model, geological map and cross-sections, accessible at *Palaeozoic (without Permian) basement surface map*

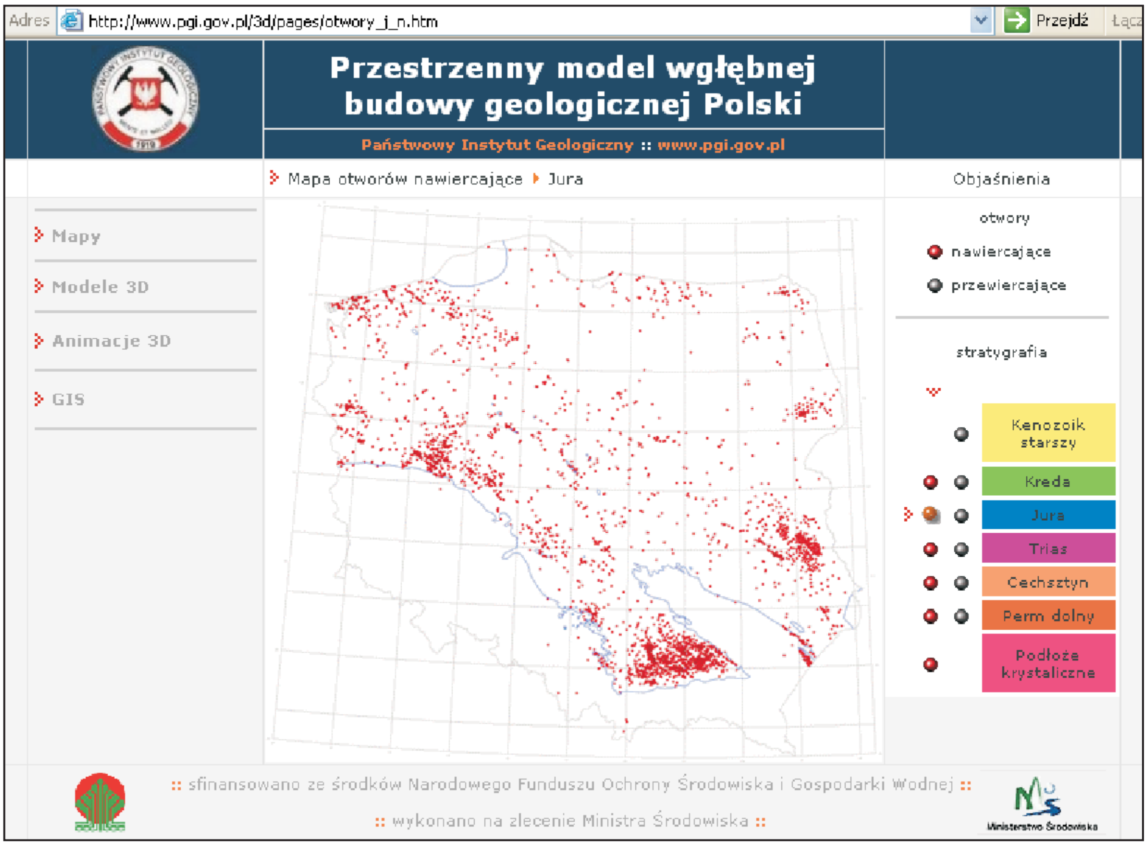

Fig. 4. Screenshot of website with animations and 3D images of the model, geological map and cross-sections, accessible at *Localization maps including drillings deeper than the Jurassic*

dimensional geologic mapping (Małolepszy, 2005) and evaluation of geothermal resource in NE Poland (Kurowska, 2005), modified for the aims of this project and called *MaPIG*.

MaPIG consists of the following stages:

1) preparation of cartographic base map in 1 : 500,000 scale, used for model elaboration and final product;

2) digitisation of geological horizontal section maps, using the package *Discovery Suite GES* — geological units were outlined and their ranges were corrected at this stage;

3) correction of the geological horizontal section maps on the basis of N- and E-striking cross-sections, generalization and unification of stratigraphic units as well as achieving consultants' agreement on position of axes of different geological structures and unit limits at different depths;

4) analysis of the databases' content, including the 10,000 drill holes from the CBDG, using GIS tools and the data verification tools. Location, Z-coordinate and stratigraphic sequence of drilling cores were analyzed. Z-coordinate were compared with the digital terrain model (DTM)

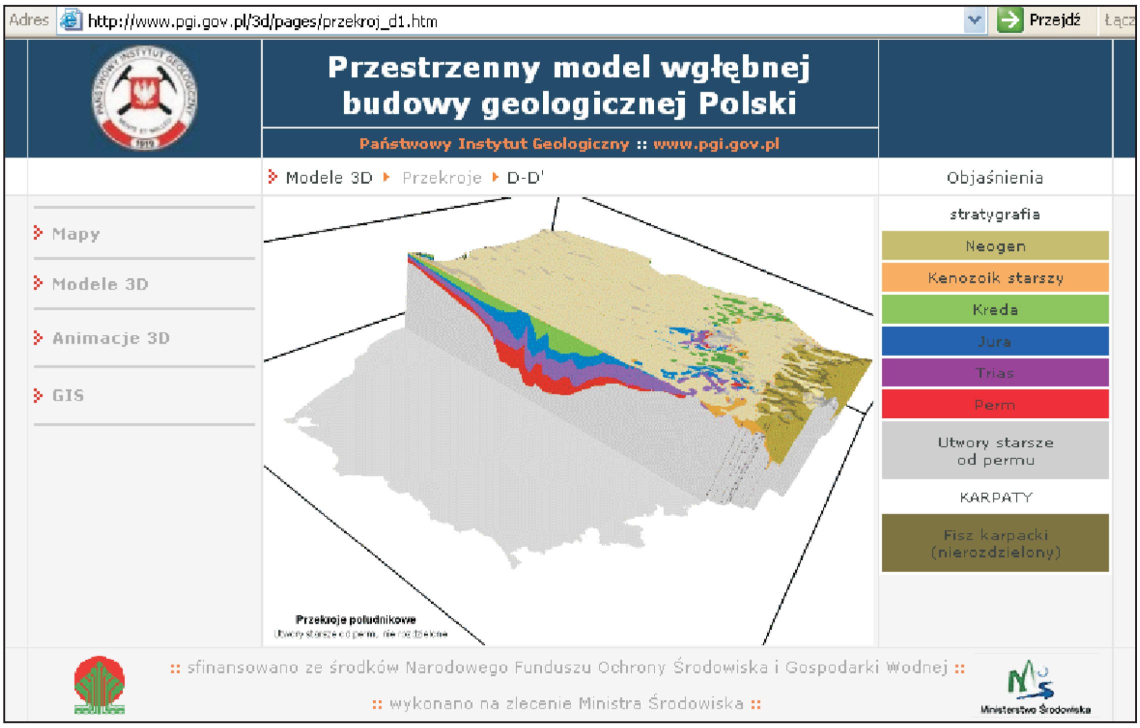

Fig. 5. Screenshot of website with animations and 3D images of the model, geological map and cross-sections, accessible at *N-striking geological cross-section*

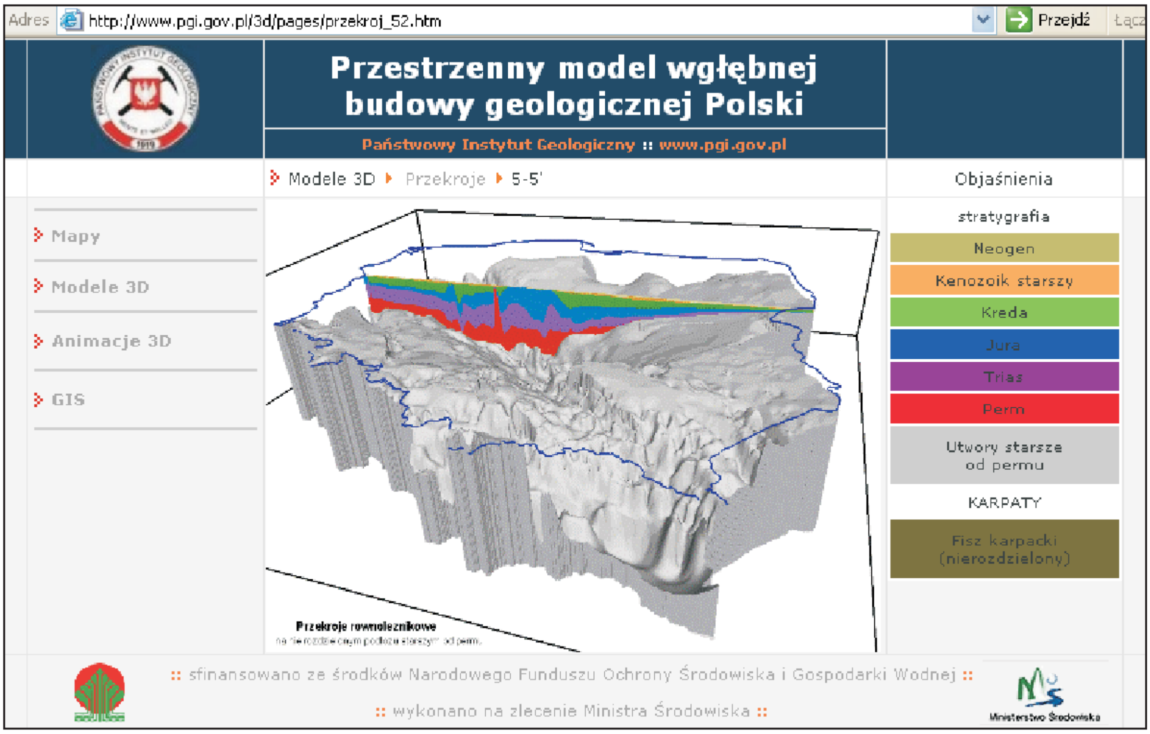

Fig. 6. Screenshot of website with animations and 3D images of the model, geological map and cross-sections, accessible at *E-striking geological cross-section*

and topographic map (in 1 : 100,000 and greater) control points. Stratigraphic sequences of drill holes were compared to the regional geologic cross-sections and the cartographic materials. This analysis allowed us to select 4,000 drilling cores that were used for model elaboration.

Generation of the model

The model was created with *GES* package which supports the database including the data geoprocessed in *MaPIG*.

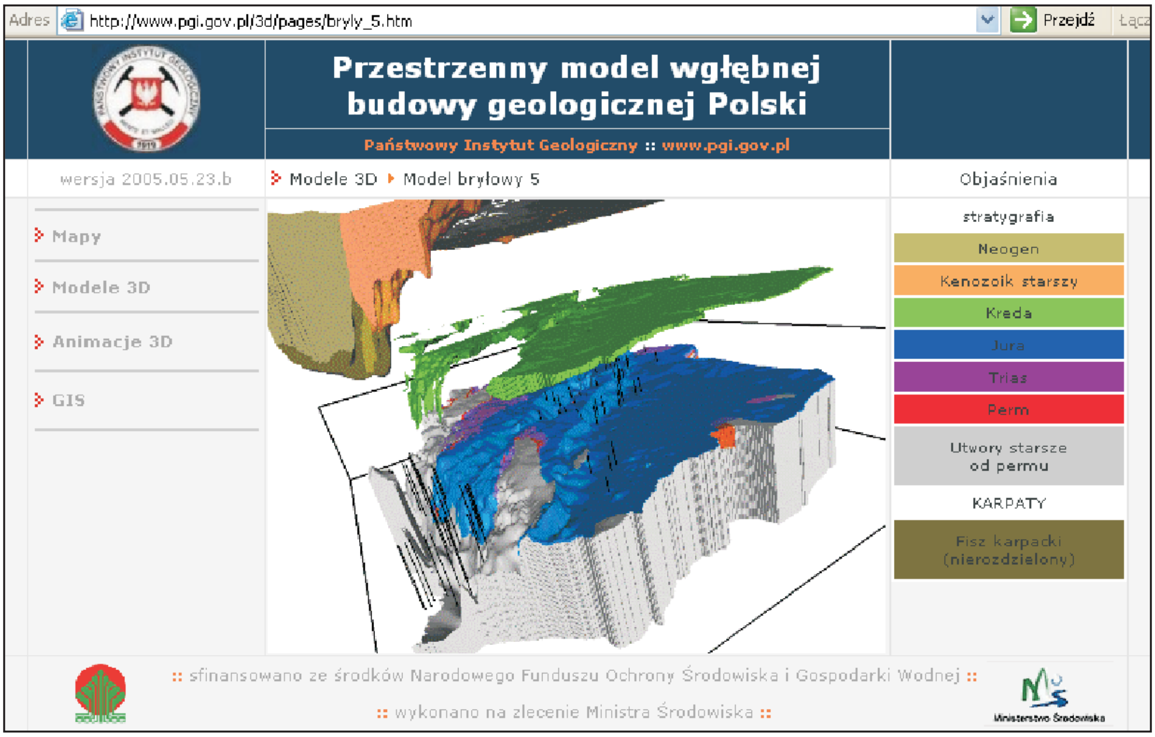

Fig. 7. Screenshot of website with animations and 3D images of the model, geological map and cross-sections, accessible at *Raising and sinking geological units (Cretaceous) along the drillings*

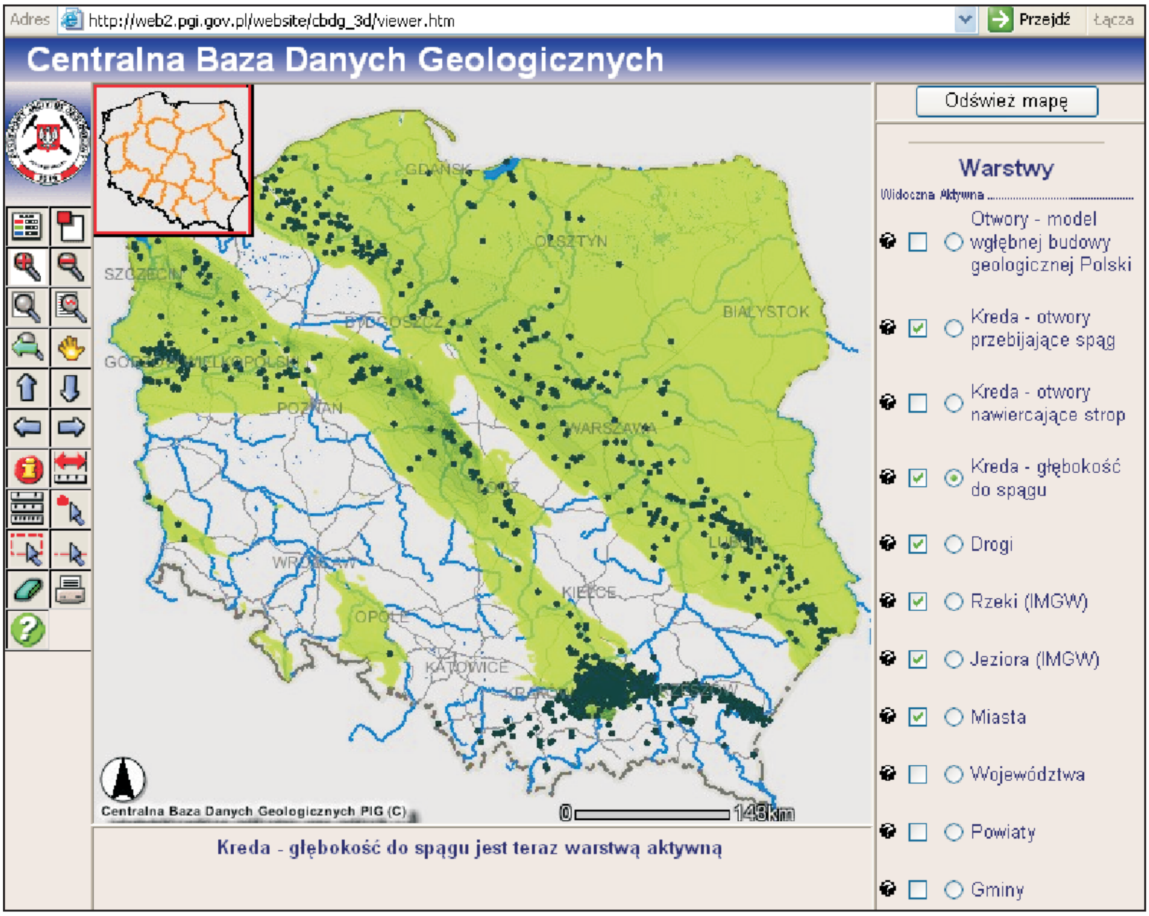

Fig. 8. Screenshot of interactive GIS with the database including 4,000 drillings and selected maps, accessible through the CBDG geosite accessible http://web2.pgi.gov.pl/website/cbdg_3d/viewer.htm.

First, the lower limits (surfaces) of the geological units, and the upper limit of the crystalline basement were generated. Then, the meshes representing these surfaces were exported to the *Volume* package developed by Z. Małolepszy. Each unit limit was joined to the extend neighbouring limit. These, and the surfaces representing lateral distribution of the units plus model boundary allowed construction of the solids representing the geologic units. These solids were exported as ASCII files to the visualization software TecPlot.

Modelling was done in top-to-bottom direction (starting with the youngest sequences). Better recognition of the younger sequences, as well as their age-limited borders allow the single-cycle interpolation. Such procedure cannot be applied to the majority of the present-day surfaces, where the ages differ laterally.

Visualization of modelling results

The *TecPlot* is a flexible software for visualization, includes advanced imaging tools and a wide range of animations in many dimensions (1, 2, 3 and 4D). Besides perspective views, TecPlot permits construction of vertical and horizontal cross-sections along any surface. Selected cross-sections can be joined and displayed as animations in internal TecPlot format (the Framer) or the AVI format (after conversion).

Limitation of model

The horizontal resolution of the model (~500 m) is its main limitation — even modern PC workstations were capable to study no more than 14 geological units at the given resolution within GES package.

The impossibility to generate upturned surfaces is the next limitation of model — *GES* software do not accept two Z values for the same surface at a given XY coordinates. Hence all overturned structures sequence were represented as vertical ones.

Given the huge quantity of the data and the limited computer capacity, significant generalization of the model was necessary. Hence complex tectonic elements were treated as single units: North-East Poland, Carpathians, Upper Silesia Coal Basin and its border, Sudetes. Additional geological horizontal section maps were produced for these units, but the final model includes only part of these data.

Results

Output products of this study are the following:

❑ numeric, interactive spatial model made up of 14 three-dimensional solids of geologic units;

❑ database of 4,000 verified drilling cores from CBDG;

❑ new numeric geological horizontal section maps — from 500 m b.s.l. to 6000 m b.s.l., at intervals of 500 m, in scale 1 : 500,000, and plotter printouts (Fig. 1);

❑ GIS layers in *MapInfo* and *ArcGIS* formats:

— the maps of geological sequence thickness — from 500 m b.s.l. to 6000 m b.s.l. (Fig. 2);

— the maps of geological sequence ranges — from 500 m b.s.l. to 6000 m b.s.l.;

— the maps of base surface of geological units — from 500 m b.s.l. to 6000 m b.s.l. (Fig. 3);

— drilling core localization maps including drillings deeper than 500 m b.s.l. (Fig. 4);

— geological cross-sections: N- and E-striking cross-sections and SW-striking cross-sections and geological block-diagrams — from 500 m b.s.l. to 6000 m b.s.l. (Fig. 5 and 6),

❑ 3D animations (in perspective view):

— raising and falling base surfaces of geological units along the drillings;

— raising and falling geological units along the drillings (Fig. 7);

— E-striking geological cross-sections moving in S–N direction;

— N-striking geological cross-sections moving in W–E direction;

— NE-striking geological cross-sections moving in NW–SE direction;

— geological horizontal sections maps moving in vertical direction.

In order to make the model available to the general public, simplified model images, possible to view with a PC and an internet browser, were also produced. They were made accessible through the PGI webpage:

❑ website with animations and 3D images of the model, geological map and cross-sections, accessible in and on CD;

❑ interactive GIS with: the database including 4,000 drillings and selected maps, accessible through the CBDG geosite (Fig. 8) *http://web2.pgi.gov.pl/website/cbdg_3d/viewer.htm.*

The horizontal resolution of presentation materials was limited to 1200 points, that is to the monitor screen resolution .

Conclusions

❑ presented model is the first Polish digital study of deep geologic structure at the scale of the entire country;

❑ the model is a new form of recording and presenting the geological knowledge;

❑ to fully evaluate geological structure of Poland, it is necessary to prepare the model from 500 m b.s.l. to the terrain surface and detailed models of individual units. This task will be realized in PGI as a continuation of present model;

❑ with time, it will be necessary to establish a separate working group within the PGI for development, maintenance, and administration of the model;

❑ *GES* software with additional modules is suitable for managing the model at the present stage. However, further developments (model from -500 m b.s.l and detailed models of particular units) require different software with extended capabilities;

❑ The final model (up to the topographic surface) should be linked to the natural resources data and used as a tool for strategic decision making respecting energetic and resource security.

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