Activity report on postprocessing and evaluation of data model in pilot area Walbrzych - Broumov

Deliverable D.T3.4.1 09 2019

A. JAN JELÍNEK, JAN FRANĚK & THE GEOPLASMA-CE TEAM.

[1] Czech Geological Survey

Contact details of author: jan.jelinek@geology.cz

The involved GeoPLASMA-CE team

CGS (PP05)	J. Jelínek, J. Franěk

Content

1. Executive summary in English language

The experiences gathered during model construction and data pre- / post- processing and related methodical rules set for the Geoplasma model construction were generally very good and led to significant improvement and generalization of 3D geological modelling approach at the Czech Geological Survey. Nevertheless, several decisions and rules defined for Geoplasma model construction were inappropriate by our opinion and should be carefully considered in similar projects in future. In particular, extent of the pilot area was too large compared to detail needed for consideration of individual target users (i.e. often owners of houses, small factories e.t.c.). Further, modelling of Quaternary units with the planned detail was very time-consuming and generally imprecise on this model scale. Modelling of tops of geological bodies is non-intuitive and not natural, we suggest to model bottoms rather than tops in future projects. The Czech Geological Survey is recently developing its own web-viewer. In future, after overcoming recent technical and licensing issues, the 3D geological model of this pilot area is supposed to be presented in this viewer.

2. Executive summary in national language

Zkušenosti získané při konstrukci modelu a pre- / post- processingu dat, a související metodická pravidla stanovená pro konstrukci modelu v projektu Geoplasma byly obecně velmi dobré a vedly k významnému zlepšení a zobecnění metodických postupů 3D geologického modelování na České geologické službě. Přesto bylo podle našeho názoru několik rozhodnutí a pravidel definovaných pro konstrukci modelu nevhodných a tato by měla být v podobných projektech v budoucnu pečlivě zvážena. Konkrétně byl rozsah pilotní oblasti příliš velký ve srovnání s podrobností potřebnou pro jednotlivé cílové uživatele výstupů projektu (tj. často majitelů domů, malé továrny atd.). Dále, modelování kvartérních jednotek v naplánovaném detailu bylo v tomto měřítku modelu velmi časově náročné a obecně nepřesné. Modelování svrchních hranic geologických těles není intuitivní a není přirozené, v budoucích projektech doporučujeme spíše modelovat báze. Česká geologická služba v poslední době vyvíjí vlastní webový prohlížeč. V budoucnu, po překonání stávajících technických a licenčních problémů, by měl být v tomto prohlížeči zveřejněn také 3D geologický model této pilotní oblasti.

3. Introduction

3.1. Aim and scope of this report

This report describes the postprocessing steps performed on model of the pilot area (Walzbrych-Broumov), which have been created within the frame of Activity A.T3.3. These reports summarize activities on postprocessing and evaluation of 3D model of the pilot areas. It identify strong and problematic points of preparation of the model.

This report describes the following postprocessing steps:

General postprocessing steps

- Harmonization of attributes
- Transformation of the reference system and parameter units to GeoPLASMA-CE standards

Geological 3D modelling

- Change the model representation (e.g. 3D/2D, unit tops)
- Change data structure (e.g. grids, triangulated surface)
- Quality control, validation and error estimation
- Visualisation of modelling results and derivation of secondary maps

Numerical modelling

- Quality control, Validation and error estimation
- Changes of the file structure (e.g. ESRI database, shapefile)
- Visualisation of modelling results and derivation of secondary maps (e.g. calculation of mean temperature)

4. General postprocessing steps

4.1. Harmonisation of attributes linked to modelling

The dataset supplied together with the resulting 3D geological model involved hydrogeological data from boreholes and petrophysical data from rock samples. Both these datasets were imported from MS Excel and ArcMap GIS software into the unified and standardized MS Access database designed for the purposes of the Geoplasma project. The database was then checked for possible mistakes by crosschecking the database values with the original values in measurements results from laboratories etc.

4.2. Transformation of the reference system and parameter units to GeoPlasma standards

The Czech data were often originally available in the very inconvenient Czech national coordinate system S-JTSK. In these cases, all the data needed for model construction or import to database were projected into the joint coordinate system UTM 33N agreed for this PA by the Geoplasma team. Laboratory measurements were originally produced in standard SI units and according to the Geoplasma standards.

5. Geological modelling

5.1. Overview of applied prodcuts

The data preprocessing and postprocessing involved use of the following Software: ESRI ArcMap GIS, MS Excel, MS Access, Surfer. For the 3D model construction of the Broumov pilot area the MOVE software was used. In particular, extensive data preparation and some steps of modelling that involved grid calculations were performed in ArcMap GIS because MOVE does not offer extensive tools needed for the grid operations. Tops of the modelled units were directly created using MOVE software. All geological surfaces are represented by triangulated irregular networks (TIN's).

5.2. Changes of the model representation

To prepare the 3D model for the Wałbrzych area the SKUA-GOCAD software was applied. Some initial versions of modelled top surfaces were prepared with a use of the Surfer software. Linear interpolation was used for modelling of the Broumov area in the MOVE SW, which is most suitable for surface construction of irregularly distributed spatial data. In Gocad a regression plane through the data is calculated and splitted into triangles. The data points are applied as interpolation constraints, the interpolation method is DSI. The two national 3D models were then joined in the SKUA GOCAD SW. For that reason, the Czech 3D model was exported in the GOCAD export format, where names and colours of the MOVE objects are preserved during the export and import into SKUA GOCAD. No other specific preparation steps had to be applied before model joining.

5.3. Changes of the data structure

The TINs of the approved 3D geological model were first exported from MOVE SW in DXF file format. The DXF files were subsequently imported into ArcMap GIS as so-called Multipatch type of objects, using internal import tool of the ArcMap SW. The multipatch-type TINs were then transformed into grids using the standardized master grid as defined in the previous Geoplasma guidelines. The resulting grids were then exported in a common 2D grid file format.

5.4. Quality control, validation and errror estimation

As data density and quality changes significantly across this pilot area, the Quality of resulting 3D geological model and its error estimation cannot be estimated in a relatively simple semiquantitative way, but rather detailed qualitative description of the issue must be given as follows.

3D geological models are often created from ambiguous and uncertain data which are subject to error propagation during data acquisition and interpretation. Further the data are often scarce and heterogeneous, so that the modeler depends on model-based interpretation, e.g. by assuming a certain tectonic regime or deformation style. Apart from the small scale models of the resource industries, these uncertainties are often neither evaluated nor shown to the users and stakeholders because there is currently no standardized approach to quantify the uncertainties for such complex and large – scale cases. According to results of this project, the quantification of uncertainty would require compilation of different sources of uncertainty, classification of the different types of uncertainty formulated and data sets for the different types of uncertainty provided. Subsequently these data sets would have to be used to test existing and develop new visualization methods from computer graphics. None of such approaches was published so far for comparable geological 3D models.

In case of this pilot area, the modelling uncertainties are caused by data errors (boreholes, maps and cross-sections), lack of data, and the methodology of modelling. The highest credibility was assigned to the boreholes data and the geological map.

Uncertainties and errors of methodology of modelling:

These errors are derived from the interpolation method used. Linear interpolation was used for modelling in the MOVE SW that is most suitable for surface construction of irregularly distributed spatial data. At small thicknesses of modelled units, the meshes locally crossed each other on a scale of 1-2 m. This problem appeared mainly with Quaternary units, but it also occurred elsewhere, where the dip of the units was very small combined with limited thickness of adjacent units. In these cases, it was decided that the boundary of the underlying model unit was locally shifted by 2 or 3 m downwards manually, to correct this purely artificial inconsistency.

Uncertainties and errors of map:

The geological map used for model construction was created by compiling and simplifying archive geological maps of various scales. Each model unit combines multiple lithological or stratigraphical units displayed in the original geological maps. These maps have been created by various geologists who have different opinions on the geological genesis of the area of interest. The verification of lithological boundaries or fault networks by geological mapping has never taken place thoroughly.

The extent of individual quaternary bodies in the original geological maps seems to be very often imprecise to misleading. The boundaries of the quaternary bodies were strongly corrected using the DTM 4G. Accuracy of these bodies corresponds to the precision of the DTM 4G (grid unit 5×5 m) and the experience of the quaternary geologist. Significant terrain verification could not take place with regard to the project schedule.

The inaccuracies of the model unit boundaries are also related to the inaccuracy of the fault network. The used fault network was created as a compilation of all available tectonic interpretations and maps. Similarly to the maps above, each author had different opinion on the fault network, therefore, the map fault networks do not match when plotted together. The dip or sense of movement has not been established at many faults. Many faults were missing according to the DTM, so that missing major faults were newly complemented by morpho-structural analysis and consultation with responsible geologists for the area.

Uncertainties and errors of cross-section:

The reinterpreted cross-sections were used to create the 3D model. These cross-sections were created by the compilation of cross-sections of many authors (Čech, Gawlikowska 1999; Krásný et al. 2012; Tásler et al., 1979). The differences were again not only in the location of faults but also in their number. Most of the geological work was focused on the Police basin. Only one work includes the Hronov-Poříčí fault zone.

Further uncertainties are in determination of the depth of model units. The cross-sections shows mainly stratigraphic position of layers that do not correspond with the modelled units. Only two the correlation boundaries can be directly used - the base of the Cretaceous sediments and the base of Triassic sediments. After compilation of all cross-sections in 3D it was revealed that many boundaries did not fit to the lithological boundaries in the geological map, or even the cross-sections do not match to each other at their crossing. The error in determining of depth the model unit boundaries reaches locally tens of meters.

Uncertainties and errors of borehole data:

Borehole data contain these three principal types of errors:

1. Determination of the model unit boundaries – particularly in sedimentary sequences this feature represents the most important source of errors, due to often lower quality of borehole description combined with complex (sedimentary) succession. Borehole profiles were reclassified according to the created model legend. Unfortunately, some boundaries of model units in borehole profiles are poorly determined or missing. To recognize model units mainly in Cretaceous or Permian sediments is often difficult.
2. Position of borehole – errors appears relatively scarcely, often of a scale of several meters. The borehole is located in the model unit on the geological map, but in its profile the model unit is missing. There is also a problem with altitude localization. Some boreholes are located a few meters under the terrain (the error is somewhere over 10 meters).
3. Lack of inclinometry – the uncertainty then generally increases with depth. None of the boreholes has inclinometry. Therefore, the boreholes, showed as vertical in the model, pass through faults into another tectonic block and thus into another model unit.

5.5. Visualisation of modelling results and derivation of secondary maps

The PA 3D geological model is visualized solely on the Geoplasma web portal. Despite the Czech Geological Survey is recently developing its own web-viewer with use of the ESRI Arc GSI Pro web functionalities, the viewer cannot process such large areas as this PA covers so far, resp. it cannot handle so huge number of vertexes of the model meshes, as the 3D model is composed of mainly due to areal extent of the PA.

The TINs of the approved 3D geological model were first exported from MOVE SW in DXF file format. The DXF files were subsequently imported into ArcMap GIS as so-called Multipatch type of objects, using internal import tool of the ArcMap SW. The multipatch –type TINs were then transformed into grids using the standardized master grid as defined in the previous Geoplasma guidelines. The resulting grids were then exported in a common 2D grid file format and serve mainly for geothermal potential calculations and for virtual borehole construction. The web-services available for this pilot area include General information, Potential maps - Borehole heat exchangers, Conflict maps, Field measurements and Local contacts for those users, who may need more detailed informations (Professionals, Research institutes and Planning and consultation institutes).

6. Numerical modelling

Numerical modelling was neither planned nor realized in this pilot area.

7. Conclusions and outlook

The experiences gathered during model construction and data pre- / post- processing and related methodical rules set for the Geoplasma model construction led to significant improvement and generalization of 3D geological modelling approach at the Czech Geological Survey. Nevertheless several decisions and rules defined for Geoplasma model construction were inappropriate by our opinion and should be carefully considered in similar projects in future:

- Extent of the pilot area was to large compared to detail needed for consideration of individual target users (i.e. often owners of houses, small factories e.t.c.) Particularly simplifications of lithological units and fault network needed for handling of such large model with presently available hardware equipment may lead to either exaggerated simplification or regular mistakes on a scale of some e.g. 50m deep geothermal borehole planning.
- Modelling of Quarternary units with the planned detail was very time-consuming and generally imprecise on this model scale. The time costs are moreover in contradiction with very low effect of Quarternary sediments on heat extraction potential, due to mainly limited thickness of the Quarternary sediments (not only) in this PA compared to the common depth of geothermal boreholes.
- Modelling of tops of geological bodies is non-intuitive and not natural. In reality, most geological bodies are characterized by well-defined and topologically relatively simple bottom (erosional surface, etc.), but their top boundaries are often affected by several processes and thus neighbouring with several rock units. This causes significant technical problems during model construction and also topological misfits during further model handling. Thus, we suggest to model bottoms rather than tops in future projects.
- The Czech Geological Survey is recently developing its own web-viewer with use of the ESRI Arc GSI Pro web functionalities. In future, after overcoming recent technical and licensing issues, the 3D geological model of this pilot area is supposed to be presented in this viewer.

Activity report on postprocessing and evaluation of data model in pilot area Walbrzych – Broumov

(Polish part of the PA)

Deliverable D.T3.4.1 09 2019

A. G.RYŻYŃSKI[1], A.KOWALSKI[1] & THE GEOPLASMA-CE TEAM.

[1] Polish Geological Institute – National Research Institute

Contact details of author: gryz@pgi.gov.pl

The involved GeoPLASMA-CE team

PGI-NRI (PP08)	G. Ryzynski, A. Kowalski
CGS (PP05)	J. Jelinek, J. Franek

Content

1. Executive summary in English language

The report presents an overview of processing steps performed during preparation of 3D model of Polish part of Wałbrzych-Broumov Pilot Area and postprocessing workflow used to generate the thermal conductivity maps.The 3D model was created with the use of SKUA (GoCAD) with support of Surfer software. The postprocessing of 3D model layers tops into thermal conductivity maps was performed in ArcGIS environment (raster algebra) with the use of Spatial Analyst extension (ESRI) and IE_Geothermie 10.5 extension (LFUlG).

In general the GEOPLASMA CE 3d modelling workflow was very good and efficient approach. The experience and lessons learned through the GEOPLASMA CE 3D modelling process will allow PGI-NRI to implement the essential GEOPLASMA workflow steps into national funded projects (Polish Geological Survey tasks) in the field of shallow geothermal potential mapping. The main conclusion regarding GEOPLASMA modelling approach is, that the modelling of layers bottoms should be used rather than modelling of tops, which is more technically complicated and generally less intuitive.

2. Executive summary in national language

Raport zawiera ogólny opis kroków wykonanych w celu sporządzenia polskiej modelu 3D obszaru pilotażowego Wałbrzych – Broumov. Dodatkowo w raporcie opisano także kroki wykonywane podczas sporządzania generowanych z powierzchni stropowych warstw geologicznych z modelu 3D map przewodności cieplnej na zadanych ścięciach głębokościowych.

Model 3D wykonano w pakiecie SKUA (GoCAD) wspierając się narzędziami do interpolacji powierzchni 3D z pakietu Surfer. Postprocessing modelu 3D w celu wykonania map potencjału geotermalnego (map przewodności cieplnej) wykonywano w środowisku ArcGIS przy wykorzystaniu rozszerzeń Spatial Analyst (ESRI) oraz IE_Geothermie 10.5 (LFUlG).

Podsumowując procedurę modelowania 3D projektu GEOPLASMA CE należy uznać za optymalną i efektywną. Doświadczenia pozyskane w trakcie sporządzania modelu 3D pozwolą PIG-PIB na wdrożenie procedury modelowania 3D GEOPLASMA CE do krajowych projektów (zadań państwowej służby geologicznej) z zakresu wykonywania map potencjału geotermii niskotemperaturowej. Główną sugestią w zakresie oceny procedury modelowania 3D GEOPLASMA CE jest propozycja zmiany modelowania stropów warstw geologicznych na modelowanie spągów, co jest bardziej intuicyjne i technicznie prostsze.

4. Introduction

4.1. Aim and scope of this report

This report describes the postprocessing steps performed on model of the pilot area (Walbrzych-Broumov), which have been created within the frame of Activity A.T3.3. These reports summarize activities on postprocessing and evaluation of 3D model of the pilot areas. It identify strong and problematic points of preparation of the model.

This report describes the following postprocessing steps:

General postprocessing steps

- Harmonization of attributes
- Transformation of the reference system and parameter units to GeoPLASMA-CE standards

Geological 3D modelling

- Change the model representation (e.g. 3D/2D, unit tops)
- Change data structure (e.g. grids, triangulated surface)
- Quality control, validation and error estimation
- Visualisation of modelling results and derivation of secondary maps

Numerical modelling

- Quality control, Validation and error estimation
- Changes of the file structure (e.g. ESRI database, shapefile)
- Visualisation of modelling results and derivation of secondary maps (e.g. calculation of mean temperature)

5. General postprocessing steps

5.1. Harmonisation of attributes linked to modelling

The dataset supplied together with the resulting 3D geological model involved hydrogeological data from boreholes and petrophysical data from rock samples.

Both these datasets were stored in MS Excel and ArcMap GIS software in the unified and standardized tables designed for the purposes of the Geoplasma project

For construction of the Polish part of the model at least 1016 boreholes were used.

Borehole data for use in the model were prepared in the form of two ASCII tables in the *.txt format. The first table contained the name of the borehole, its accurate location (X, Y and Z coordinates) and total depth. The second table contained the individual lithological horizons and their position in the borehole in meters. The depth of the individual horizons was given in re-calculated Z coordinates, or as the depth in meters; the depth in meters was used in practically all cases.

Cross sections as well as other archival data were prepared for import into the modelling with use of SKUA 2011.3 (GoCAD) software. Input data consists of polygons (geological and stratigraphic units), lines (faults), calibrated raster images (archival geological maps) including calibration files such as .prj files, as well as re-classified borehole data.

In the process of the model construction a DEM of cell size of 20 m was used. The project requirement was to ensure that generalization of the geological situation in the Quaternary units was kept to a minimum; the geology was more generalized in the case of pre-Quaternary sediments and crystalline rocks.

5.2. Transformation of the reference system and parameter units to GeoPlasma standards

The Polish data was available in various Polish national coordinate systems (1942, 1965, 1992 and 200). All the data needed for model construction or import to database were projected into the joint coordinate system UTM 33N agreed for this PA by the Geoplasma team. Laboratory measurements were originally produced in standard SI units and according to the Geoplasma standards.

6. Geological modelling

6.1. Overview of applied prodcuts

The data preprocessing and postprocessing involved use of the following Software:

- Data preprocessing: MS Excel, Surfer, ArcGIS,
- Model construction: SKUA (GoCAD) + Surfer.
- Model data postprocessing: ArcGIS + Spatial Anayst Extension and IE_Geothermie 10.5 extension

Tops of modelled units were created in GoCAD. They were represented by triangulated irregular networks (TINS). TIN nodes were then exported in csv files for postprocessing in ArcGIS.

Postprocessing required import of tops in form of point csv, then interpolation to surface by nearest neighbour algorithm.

Further calculation of geothermal potential maps (thermal conductivity) was done within an IE_Geothermie 10.5 Arc GIS extension provided by LFUIG.

6.2. Changes of the model representation

To prepare the 3D model for the Wałbrzych area the SKUA-GOCAD software was applied. Some initial versions of modelled top surfaces were prepared with a use of the Surfer software.

The two national 3D models were joined in the SKUA GOCAD SW. For that reason, the Polish and Czech 3D models were exported in the GOCAD export format, where names and colours of the MOVE objects were preserved during the export and import into SKUA GOCAD. No other specific preparation steps had to be applied before model joining.

6.3. Changes of the data structure

The TINs of the approved 3D geological model were first exported from GoCAD in ts file format. The ts files were subsequently converted into csv files with TIN nodes point clouds. These csv files were imported into ArcMap GIS. Then interpolation to surface by nearest neighbour algorithm was used and final interpolation results were saved as grids using the standardized master grid resolution (25x25 m) as defined in the previous Geoplasma guidelines. The resulting grids were then exported in a common 2D grid file format (ESRI grid) acceptable by IE_Geothermie 10.5 ArcGIS extension used for thermal conductivity maps computation.

6.4. Quality control, validation and errror estimation

As data density and quality changes significantly across this pilot area, the Quality of resulting 3D geological model and its error estimation cannot be estimated in a relatively simple semiquantitative way, but rather detailed qualitative description of the issue must be given as follows.

3D geological models are often created from ambiguous and uncertain data which are subject to error propagation during data acquisition and interpretation. Further the data are often scarce and heterogeneous, so that the modeler depends on model-based interpretation, e.g. by assuming a certain tectonic regime or deformation style. Apart from the small scale models of the resource industries, these uncertainties are often neither evaluated nor shown to the users and stakeholders because there is currently no standardized approach to quantify the uncertainties for such complex and large – scale cases. According to results of this project, the quantification of uncertainty would require compilation of different sources of uncertainty, classification of the different types of uncertainty formulated and data sets for the different types of uncertainty provided. Subsequently these data sets would have to be used to test existing and develop new visualization methods from computer graphics. None of such approaches was published so far for comparable geological 3D models.

In case of this pilot area, the modelling uncertainties are caused by data errors (boreholes, maps and cross-sections), lack of data, and the methodology of modelling. The highest credibility was assigned to the boreholes data and the geological map.

No geostatistical methods were used to validate the model. The 3d model quality was ensured by input data quality checks, including verification of consistency of borehole data set and precise verification of geometry of used geological and hydrogeological maps and cross sections.

6.5. Visualisation of modelling results and derivation of secondary maps

The PA 3D geological model is visualized solely on the Geoplasma web portal. Despite the Czech Geological Survey is recently developing its own web-viewer with use of the ESRI Arc GSI Pro web functionalities, the viewer cannot process such large areas as this PA covers so far, resp. it cannot handle so huge number of vertexes of the model meshes, as the 3D model is composed of mainly due to areal extent of the PA.

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The web-services available for this pilot area include General information, Potential maps - Borehole heat exchangers, Conflict maps, Field measurements and Local contacts for those users, who may need more detailed information (Professionals, Research institutes and Planning and consultation institutes).

7. Numerical modelling

Numerical modelling was neither planned nor realized in this pilot area.

8. Conclusions and outlook

- In general the GEOPLASMA CE 3d modelling workflow was very good and efficient approach. The experience and lessons learned through the GEOPLASMA CE 3D modelling process will allow PGI-NRI to implement the essential GEOPLASMA workflow steps into national funded projects (Polish Geological Survey tasks) in the field of shallow geothermal potential mapping.
- Modelling of Quarternary units with the planned detail was very time-consuming and generally imprecise on this model scale. The time costs are moreover in contradiction with very low effect of Quarternary sediments on heat extraction potential, due to mainly limited thickness of the Quarternary sediments (not only) in this PA compared to the common depth of geothermal boreholes.
- Modelling of layers bottoms should be applied, rather than modelling of tops, which is more technically complicated and generally less intuitive.
- The Polish Geological Survez is recently developing its own web-viewer. The 3D geological model of this pilot area is supposed to be presented in this viewer. The prototype of PGI-NRI 3D model viewer „Geo3D" can be seen here: https://geo3d.pgi.gov.pl/pl. Geo3D has following features:
  - Allows to visualize the geological 3D models with accompanying parameters
  - Simple analyses can be performed, as opacity, vertical exaggeration, camera position.
  - Visualisation of single layer of a set o layers. Layer vertical spreading is also possible.
  - Virtual boreholes and cross sections generation
  - PDF reports generation, in form of cross section and a model view with indicated on terrain surface cross-section line.
  - Allows import of 2D maps in WMS.
  - Models are visualised on the background of dynamically scaled coordinate system meshes.
  - Data streaming of 3D grids is implemented, so different scale and complexity models can be easily visualised.
  - Browser is used for Polish Geological Survey Tasks.