2. 3D Geological Model of the Slovak Republic at Scale 1: 500,000

Zlocha Marian, Vizi Ladislav, Kronome Balázs, Cibula Róbert, Nagy Alexander, Fričovská Jana & Surový Martin

State Geological Institute of Dionýz Štúr, Mlynská dolina, Bratislava, Slovak Republic; marian.zlocha@geology.sk

Abstract: The creation of digital 3D geological models has become relatively common in recent years with the development of computer technology, the deployment of powerful algorithms and the intense work of larger teams. Also at the State Geological Institute of Dionýz Štúr, several geological tasks were carried out in this area: "Upper Nitra Basin - Three-Dimensional Geological Modelling of the Exposed Area" (Kotuľová et al., 2010), as well as the multilateral International Project "TRANSENERGY" (Černák et al., 2012), "Turčianska kotlina Basin - Three-Dimensional Geological Modelling" (Nagy et al., 2014) and in the years 2016-2019 the task "3D Geological Model of the Slovak Republic at Scale of 1: 500,000" (Zlocha et al., 2019).
SGIDŠ's progressive approach to this issue in the last decade has been reflected not only in the use of explicit and implicit approaches to modelling, similarly to the world, but also in the development and application of its own methodological procedures and algorithms, implemented by its own applications.
The 3D geological model of the Slovak Republic at the scale of 1: 500,000 is one of the first national models at all. From commercial softwares, the following were used in its creation: Petrel® 8.4 and ISATIS™, for import / export of data, for creation of virtual boreholes, profiles and sections own applications and for visualization of results ArcScene™ of ESRI® company and own web application on ArcGIS™ Enterprise 10.7.1 platform with API for JavaScript.
In the article we briefly describe the process of creating a 3D geological model, source data and the methodology of their processing, the methodological procedure of the solution and the main results of 3D modelling with a number of attached images are provided.
Keywords: 3D modelling, geological model, virtual borehole profile, cross-section.

2.1 Introduction

In general, it is possible to observe a growing trend in decisions of the professional public based on spatial data. Typical examples include objectives relating to the health and safety of the population, the use of natural resources and wealth, etc. The fulfilment of these objectives requires, among other things, information obtained on the basis of geological research. For this reason, the share of geology in solving problems and finding solutions in the issues of energy, deposits of useful minerals, water resources as well as risks, hazards and infrastructure optimization is increasing. The global trend is to move from established practices to new approaches, which means a shift from classical 2D paper maps and publications to digital 3D models that can be integrated into systematic space-time monitoring.

The goal of today's geological services is the production of 3D computer images (models), which include information and properties such as thicknesses, strike and dip of bedding, heterogeneity of monitored parameters, reliability of results, etc. The renown geological services (e.g. in Poland, the Czech Republic and Austria, United Kingdom, Denmark, Finland, Germany, the Netherlands, Spain, Switzerland, Italy and Sweden and others) today provide not only modelling results within the lithostratigraphic setting of the study area, but also relevant properties and parameters of the rock environment such as petrophysical properties, contents of monitored elements, distribution of fractures of the rock mass and its disintegration and others, which are used for subsequent modelling of heat flow, landslide risk, groundwater quality, spatial planning and the like for sustainable development.

The issue of creating a 3D geological map is relatively new and it is not possible to consider it as a methodologically reliable and unambiguously solvable task. There are practically no 3D solutions for entire territories in a sufficiently detailed scale. In terms of methodology, detail and scale of processing, the British geological survey approach was a suitable inspiration.

At the State Geological Institute of Dionýz Štúr (hereinafter SGIDŠ), several geological tasks were performed in the field of 3D modelling in the past, e.g.: "Upper Nitra Basin - three-dimensional geological modelling of the exposed area" (Kotuľová et al., 2010), "TRANSENERGY" (Černák et al., 2012), "Turčianska kotlina Basin - three-dimensional geological modelling" (Nagy et al., 2014), etc. In the creation of these regional models, the interaction between a 3D expert using specialized 3D software and the geologist himself, whose knowledge was implemented in the model (so-called spatially explicit modelling approach).

The creation of a national 3D geological model of the Slovak Republic at a scale of 1: 500,000 in a relatively short period of time required, in addition to the above approach, significantly greater use of computer algorithms available in specialized software packages, as well as sophisticated geostatistical methods, especially in the field of interpolation and extrapolation of spatial data (so-called implicit modelling approach).

A web application was created to view the results of the 3D modelling, which will be available on the SGIDŠ map portal.

2.2 Methodology of the solution

When creating a 3D geological model of the Slovak Republic at a scale of 1: 500,000, we relied on previous experience gained from the 3D regional modelling and inspiration from published best practices, but last but not least we had to modify and expand the methodology for such a large area, including the development of new algorithms and their applications, test the resulting models on prototype areas and extend the procedures used for the entire area of the Slovak Republic.

A) Literature and archive search

We divided the input spatial data for the creation of the 3D model into 4 groups - map data, geological profiles, data from boreholes and other data.

- Map documents
  - Geological maps were used:
    - Geological map of the Slovak Republic at a scale of 1: 500,000 (Biely et al., 1996);
    - Geological map of the Western Carpathians and adjacent areas at a scale of 1: 500,000 (Lexa et al., 2000) (Fig. 2.1);
    - Tectonic map of the Slovak Republic at a scale of 1: 500,000 (Bezák et al., 2004);
    - Digital geological map of the Slovak Republic at a scale of 1: 500,000 (Káčer et al., 2005);
    - General geological map at a scale of 1: 200,000 (Bezák et al., 2008);
    - Digital geological map of the Slovak Republic at a scale of 1: 50,000 (Káčer et al., 2005).
      - Analog maps at a scale of 1: 500,000
      - Neotectonic map of the Slovak Republic at a scale of 1: 500,000 (Maglay et al., 1999a, b);
      - Map of the Pre-Tertiary basement relief of the Inner Western Carpathians (Plančár et al., 1985);
      - Tectonic map of the Pre-Tertiary basement relief of the Inner Western Carpathians (Fusán et al., 1987);
      - Geological map of the basement of the covered areas of the southern part of the Inner Western Carpathians (Fusán et al., 1972);
      - Geological map of the Quaternary of Slovakia at a scale of 1: 500,000" (Maglay et al., 2009).
- Geological cross-sections
  - Geological cross-sections from maps at scales of 1: 50,000, 1: 100,000 and 1: 200,000 were used for the 3D model creation (Fig. 2.2). A total of 240 profiles from 56 analog maps at the scale of 1: 50,000, 5 cross-sections from maps at the scale of 1: 100,000 and 2 profiles from the map at the scale of 1: 200,000 were processed.
- Data from wells
  For the needs of model creation, its calibration and control, a total of 462 boreholes drilled through Tertiary were used from the territory of the Slovak Republic out of almost 1,000 deep boreholes.
- Other data
  - formed the boundary of the 3D model in space
    - in the direction [X, Y] it was the border of the Slovak Republic.
    - in direction [Z]
      - overburden: digital relief model at scale 1: 50,000 (source: GIS SGIDŠ) generalized to scale 1: 500,000.
      - basement: variable depth range of the 3D model given by the depth of the input data (together with the *buffer*).

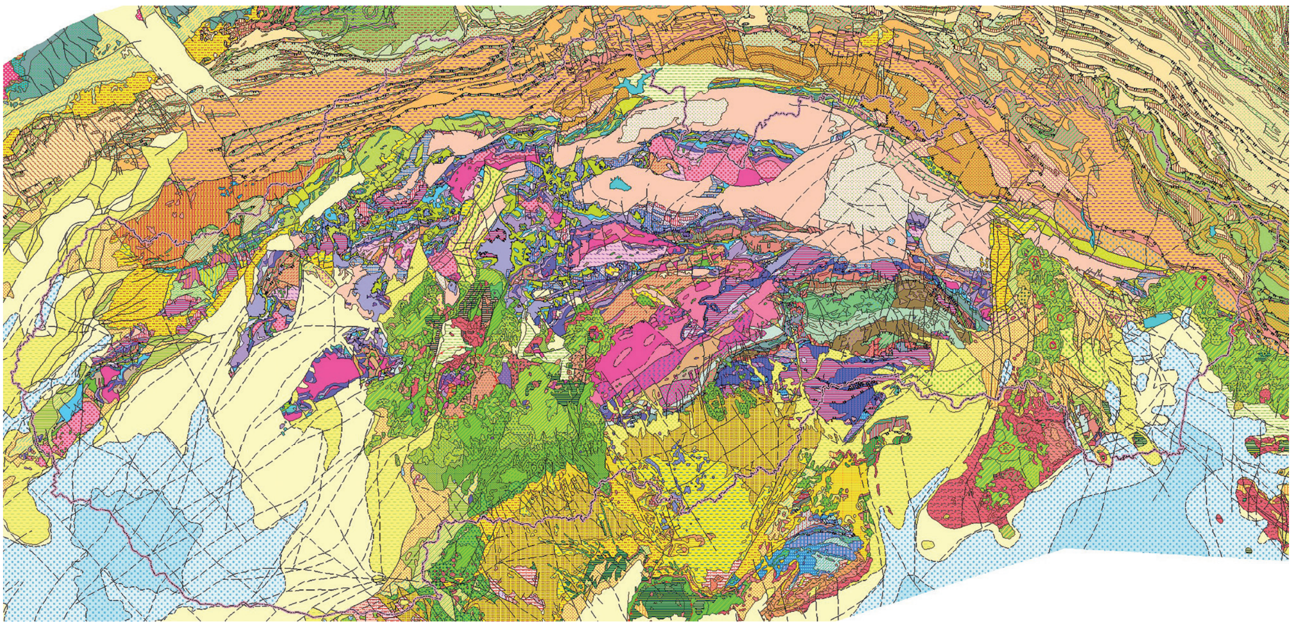


Fig. 2.1. *Geological map of the Western Carpathians and adjacent areas at a scale of 1: 500,000. (Lexa et al., 2000).*

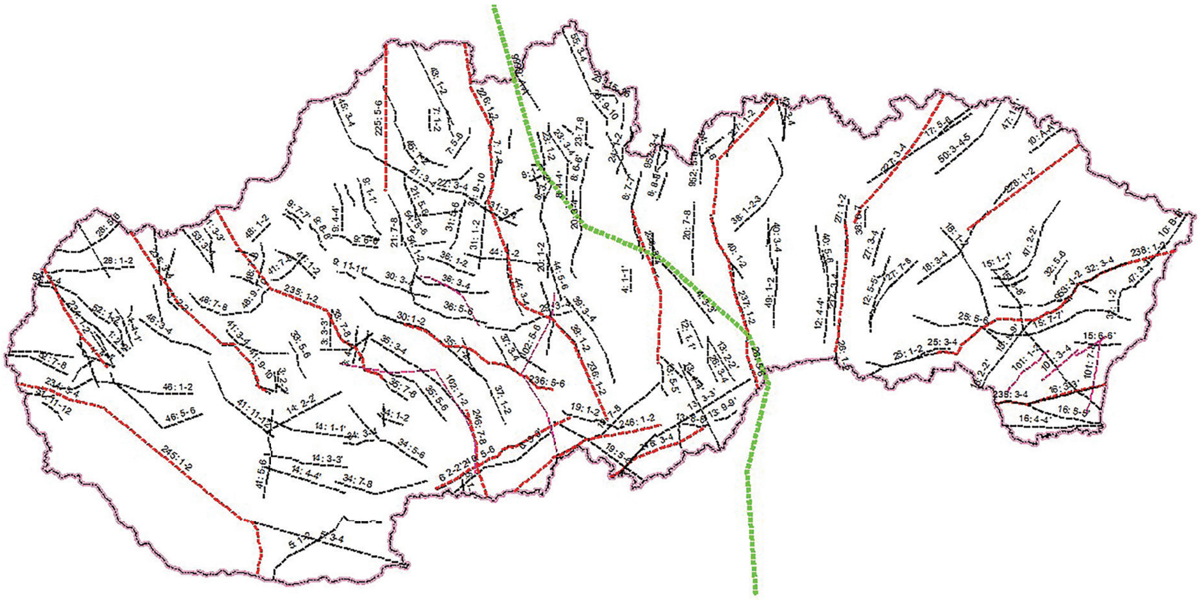


Fig.2.2. *Projection of used geological cross-sections from geological map 1: 50,000 (black), 1: 200,000 (red) and 1:500,000 (green).*

B) Digital processing of spatial data into 3D

- Digital maps were in the S-JTSK coordinate system, their geometries were taken over.
- Analog maps were scanned, georeferenced, selected objects were digitized into line and polygon objects (lines, e.g. depth isolines, tectonics, polygons, for instance geology).
- A separate issue was Geological map of the Quaternary of Slovakia at a scale of 1: 500,000 (Maglay et al., 2009). The attributes of this map existed in the form of intervals (e.g. depth sections 20-50 m, 50-100 m), which had to be recalculated by special geostatistical methods into a regular raster network.
- Data from geological profiles of scale 1: 50,000 were generalized after analysis with respect to the used basement (geological map 1: 500,000). Interface vectorization was performed manually on 3D georeferenced substrates, or by 2D semi-automatic vectorization and rotation of the obtained objects into space based on the known [XYZ] coordinates of the breakpoints vertices (Fig. 2.3). Short programs have been developed for this calculation.
- Data from geological boreholes were filtered for conditions of completeness of data (unambiguous identification by name, archive number, filled in values of collar coordinates, depths, drilling through Tertiary, etc. (Fig. 2.4)
- The legend to the Geological map of the Western Carpathians and adjacent areas (Lexa et al., 2000) was chosen to create a catalogue of attributes. According to this database, values were assigned to individual spatial objects.

C) 3D geological model creation

Even before modelling, the geological model of a large area required the creation of an idea/concept of how to approach spatial data with regard to the complexity of the geological setting on the one hand and the possibilities of 3D modelling tools on the other. This interpretive aspect, the subjective input of the geologist, with the strong support of modelling tools as an objective factor, is the principle for the whole modelling process.

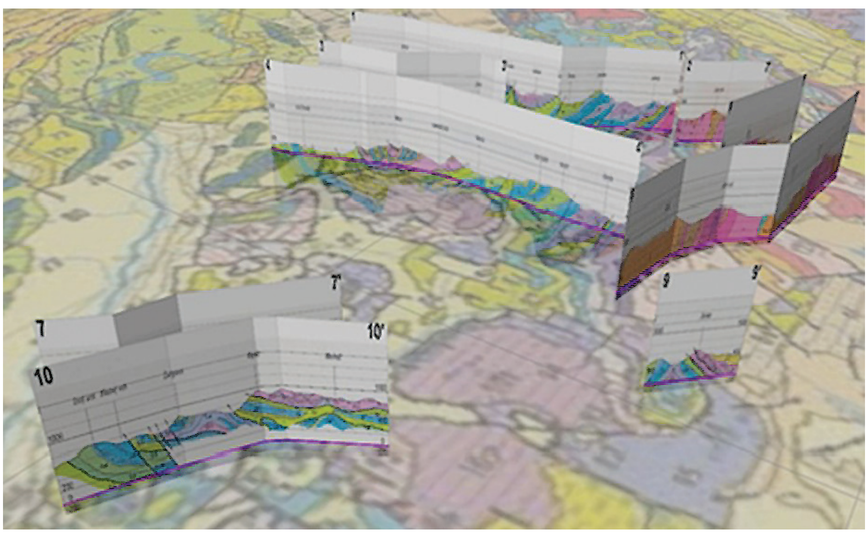


Fig. 2.3. *3D georeferencing of geological cross-sections.*

a) *Model concept*
The concept of the model was based on the tectonic setting, the structure of the input data, the goals and the scale of modelling. It determined which geological elements (units, faults, etc.) were included in the model, in what form and what is their mutual relationship (Fig. 2.5a). Given that the planned model includes the entire territory of Slovakia, we had to significantly simplify the geological setting, both in terms of lithological content and faults pattern. The model created was "hybrid": while in the pre-Cenozoic lower part the principle of tectonic units was used, in the higher Cenozoic, "basinal" part it was built mainly on the stratigraphic principle. A special group consisted of neovolcanics, where we had to distinguish up to three horizons, because especially in the East Slovak part, two periods of volcanic activity are relatively well distinguishable. A special group consists of subvolcanic bodies (Fig. 2.5b). The concept of the model also determined the entry of input data according to the requirements of the model: coalescence of some formations, re-evaluation and re-indexing of drilling data, connection of some faults into one line, etc.

b) *Sequence of geological model creation*
The pre-Cenozoic bedrock as an interface between the lower part of the model and its basinal sedimentary filling was created mainly on the basis of a map of Kilényi and Šefara (1989), but in areas where we had a newer and/or more accurate source, these input data were also used, e.g. Sub-Tatra Basin: (Szalaiová et al., 2008), Vienna Basin: Wessely (1988), Danube Basin: TRANSENERGY results (Černák et al., 2012). The horizon, which has not yet been disintegrated by faults, is shown in Fig. 2.6.

In the following phase, a structural model was created, in which the main fault lines describing the character of the entire failure zone were determined. By integrating tectonic elements into the modelled horizon, the final layer of the pre-Cenozoic bedrock was created (Fig. 2.7). We consider it to be one of the most significant results of the entire 3D geological model.

Other horizons - Neogene base, Palaeogene base, Lower Miocene/Badenian interface and Quaternary base were created gradually from existing elevation data, such as e.g. Map of the Tertiary base Plančár et al. (1985), Map of Quaternary thicknesses (Maglay et al., 2009) supplemented with data obtained from processed geological profiles. The most important information input into the modelling process was drilling data, which served as primary data (mostly from cross-section, partly also from maps) the relevant boundaries have been adjusted to respect drilling data (Fig. 2.8).

The modelling of spatial distribution was preceded by a thorough control of input data and error correction. The models were calculated by several interpolation methods,

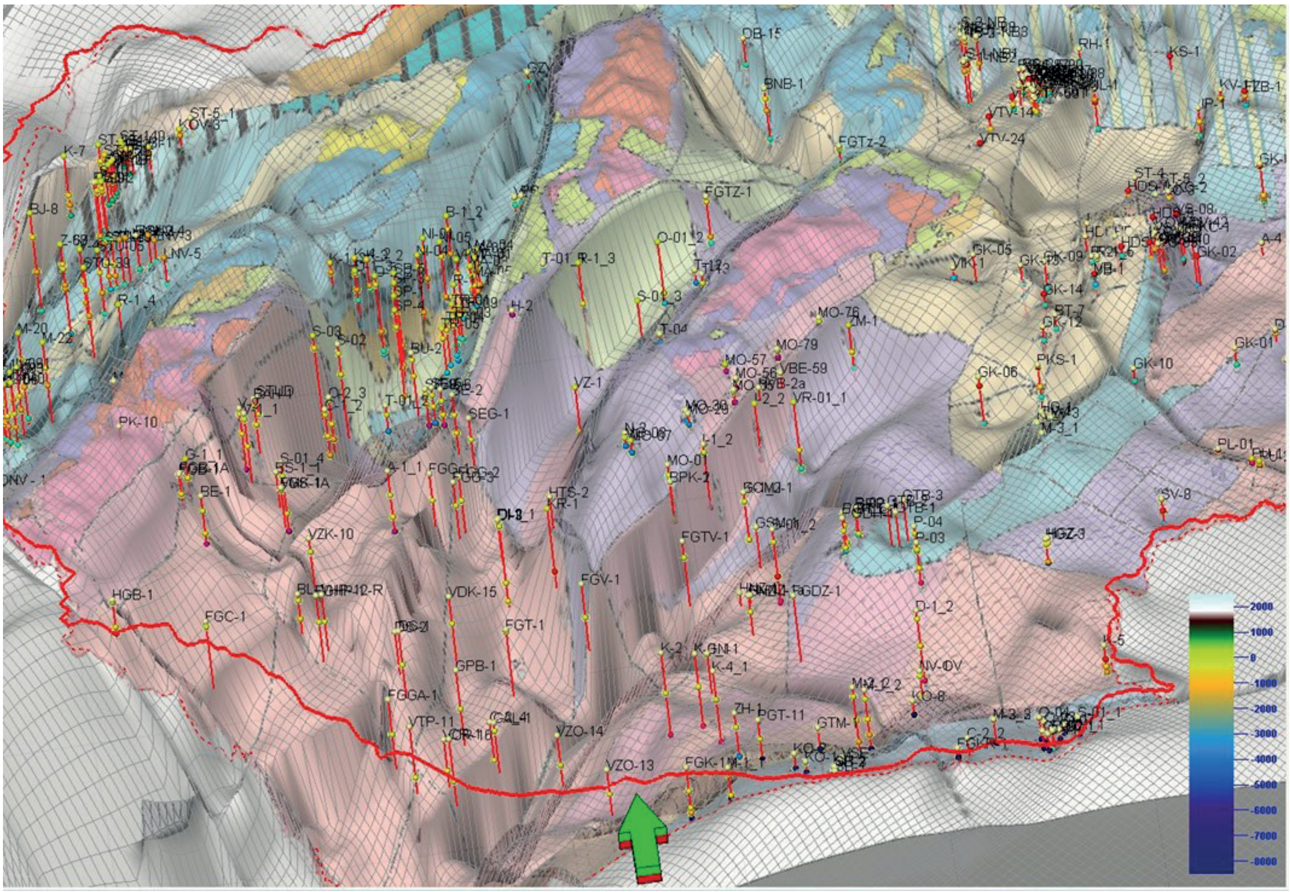


Fig. 2.4. *Deep geological boreholes with an associated legend, map of the interfaces in the Pre-Tertiary basement.*

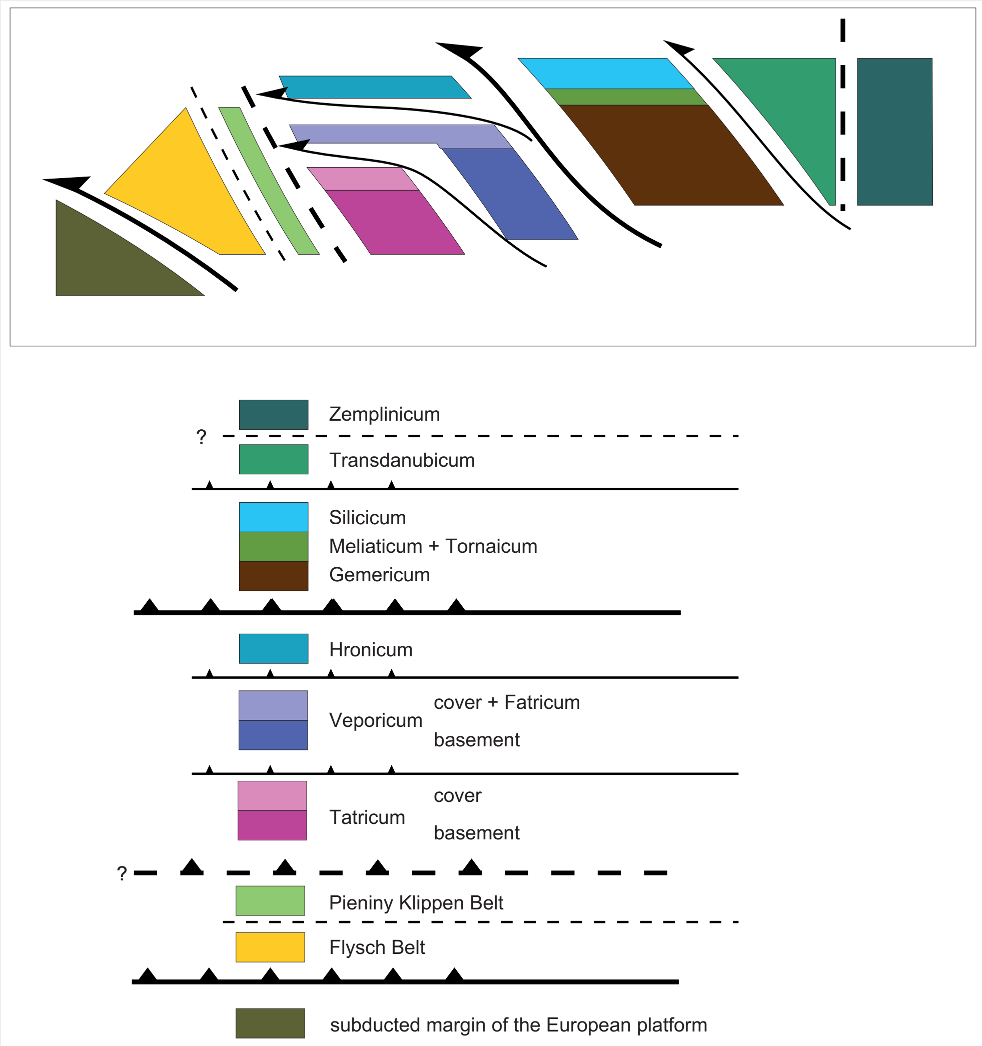


Fig. 2.5a. Concept of the model of the pre-Cenozoic bedrock.

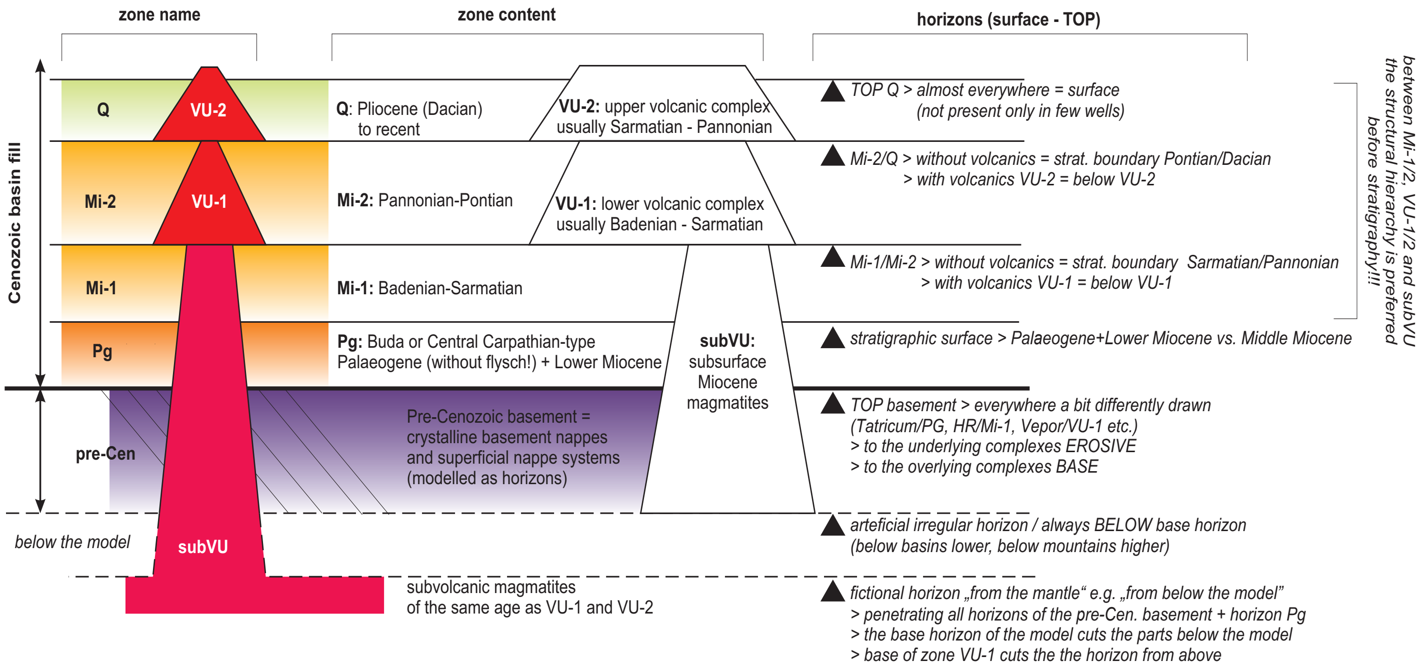


Fig. 2.5b. Concept of the model of the Cenozoic basinal filling, including neovolcanics.

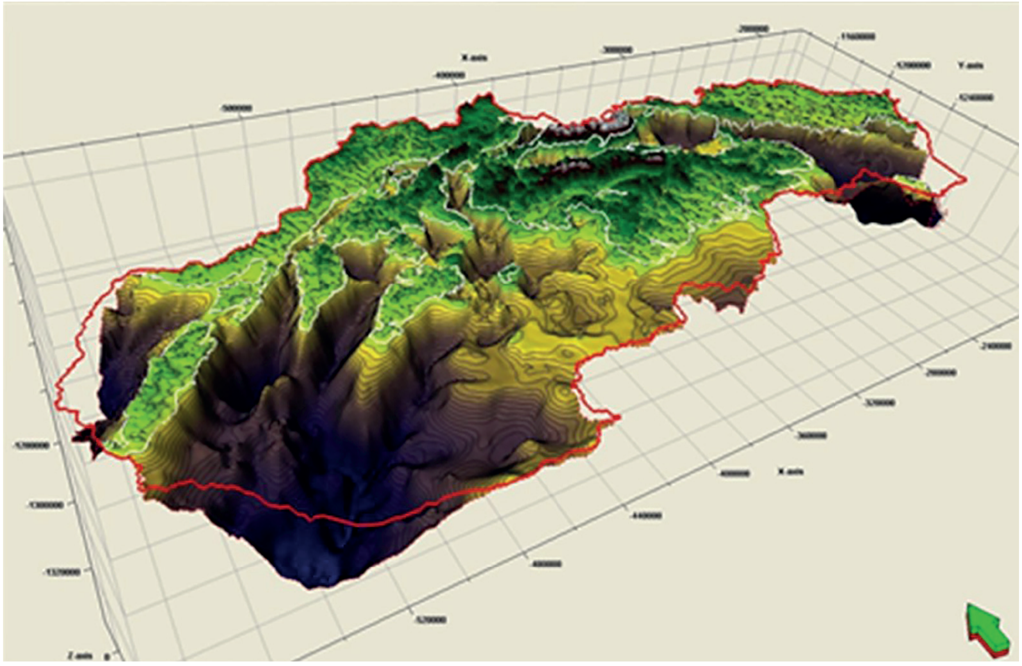


Fig. 2.6. *The "unfaulted" surface of the Cenozoic basement.*

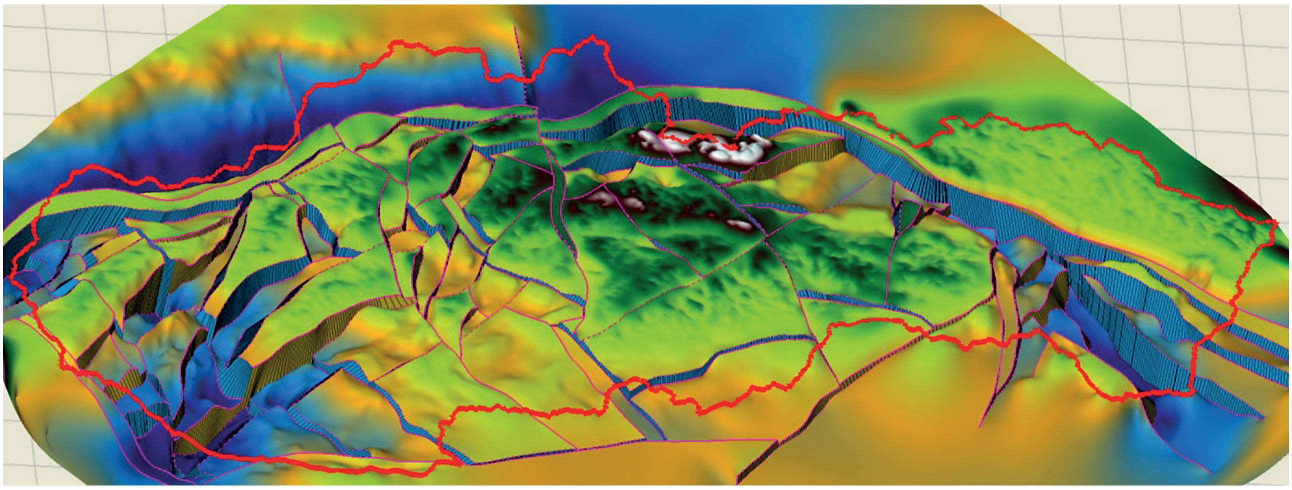


Fig. 2.7. *Fault-segmented horizon of the pre-Cenozoic basement.*

through ordinary kriging with various parameters (simple kriging with isotropic spherical variogram, anisotropic model of spherical type variability, etc.), triangulation method, square distances, splines and minimum curvature methods. However, none of these approaches gave satisfactory results, with undesired ripple of isolines and various computational artifacts in the calculations (Fig. 2.9).

The best results were finally achieved using methods of sliding or local geostatistics, in which the parameters entering the modelling were locally optimized: the direction and magnitude of the axes of the anisotropy ellipse as well as the impact of the autocorrelation of both axes of anisotropy.

The mutual position of individual modelled horizons was confronted with knowledge about their mutual stratigraphic position. For instance, the altitude of the Quaternary base had to be at any point in space *below* the Earth's surface. In general, the relative position of formations can be as follows:

– *Erosional*: the erosive surface at the surface of the modelled complex (e.g. the Earth's surface);
– *Discontinuous*: a layer intersecting all other layers/formations, e.g. erosive surface with hiatus in sedimentation, or the overthrust surface of a nappe;
– *Conformable*: inclined, the layer overlies the underlying stratum without intersecting, continuation of the sedimentation cycle;
– *Base*: the layer on which all other layers/formations of the sedimentation sequence lie, the basal layer.

Knowledge of these rules at individual horizons allowed us to make corrections for inaccuracies that arose due to insufficient density of input data, or as undesirable estimates of some values in interpolation.

The resulting 3D model contained the following *3D surfaces*:

– Digital relief model
– Tertiary basins filling:

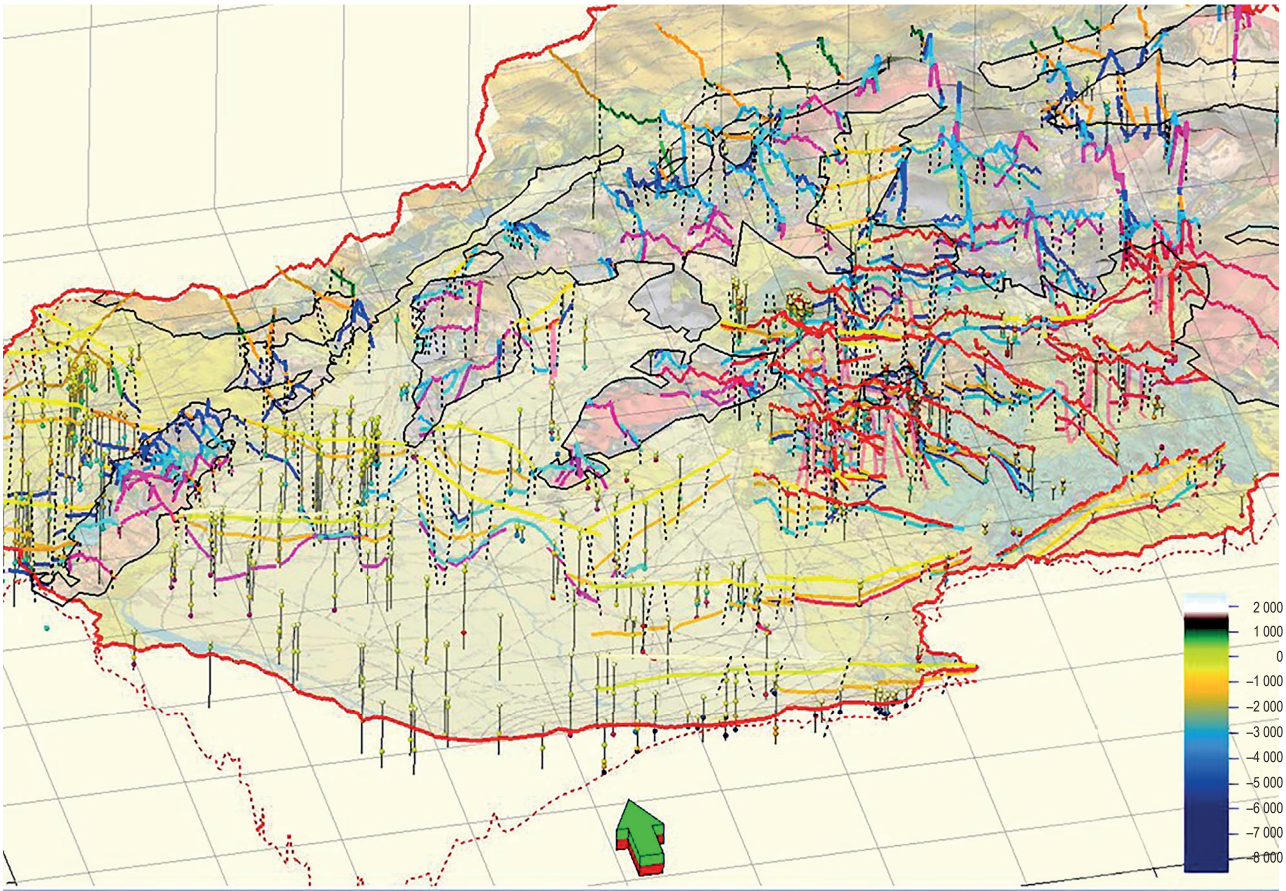


Fig. 2.8. *Deep geological boreholes with an associated legend, digitization of the interfaces. The territory of the western Slovakia.*

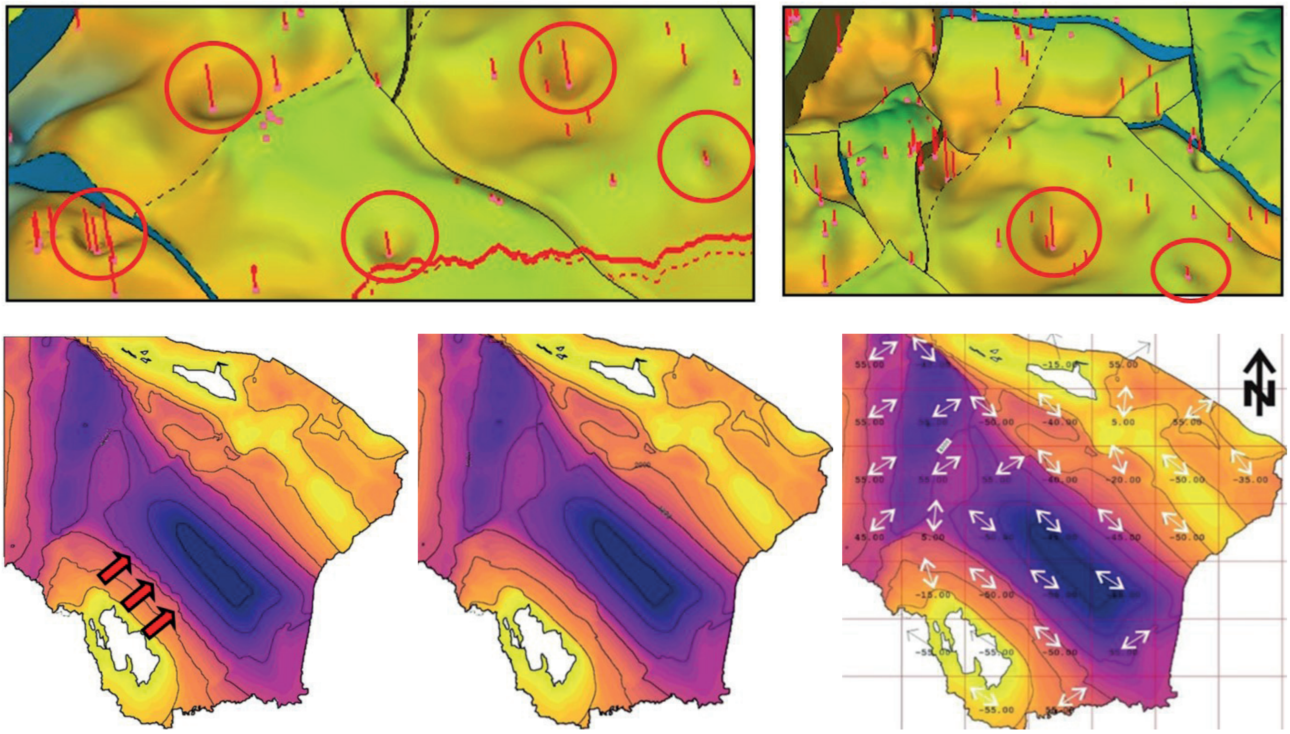


Fig. 2.9. *Artifacts around points created by interpolation (top), the use of sliding geostatistics methods to smooth interpolation curves (bottom).*

- ○ Quaternary base;
- ○ Miocene base;
- ○ Palaeogene base;
- ○ Neogene base (= pre-Tertiary)
- – Tectonic structure
- – Tectonic units subdivided as follows:
  - ○ the Gemericum;
  - ○ the Veporicum with cover;
  - ○ the Tatricum;
  - ○ higher tectonic units;
- – Model base.

D) Voxel model creation

A true 3D model should provide information not only about the interfaces, represented in the form of 3D surfaces, but also information at any point of the modelled space. At this stage, our model was just the so-called box model, more suitable for visualization of buildings, etc. Due to the topological properties of the calculated 3D surfaces (given by their mutual position and interconnection), it was possible to assign to each point of the regular spatial network a value from the catalogue, i.e. determine its affiliation to a particular modelled entity. The set of this information then forms the so-called voxel model. This can be saved in one of the standard ASCII formats (e.g. for GeoModeler™), used as part of the spatial visualization of a real 3D geological model, or as an input parameter to some of the hydrogeological modelling softwares (ModFLOW, etc.) and last but not least as a data warehouse for quick and easy creation of some special geological functions, such as virtual wells, virtual profiles and virtual cross-sections.

E) Virtual functionalities creation: boreholes, profiles and cross-sections (Fig. 2.10)

At this stage the created 3D geological model with integrated 3D interfaces, tectonics and voxel information with a step 600x600 m in the direction [XY] for coarse visualizations, or 200x200 m for fine views, similarly in the direction of the axis [Z] 60 m, or 20 m was used for further calculations and visualizations.

The voxel's stored 3D model allowed simple and fast creation of arbitrarily localized boreholes (actually non-existent, they are "boreholes" in the sense of the perpendicular from the model overburden to its subsoil, so we term them *virtual*) with almost instant display of drilled formations in full volume and the appropriate legend, *virtual profiles* (defined by 2 points at the surface and then displayed in 3D with the appropriate legend) and *virtual cross-sections* (defined by the corners of the rectangle and the required altitude). These functionalities can be combined with each other, create e.g. *block-diagrams*, *radiator-like-diagrams* and other common visualizations. All layers were saved locally in ESRI® 3D SHP format.

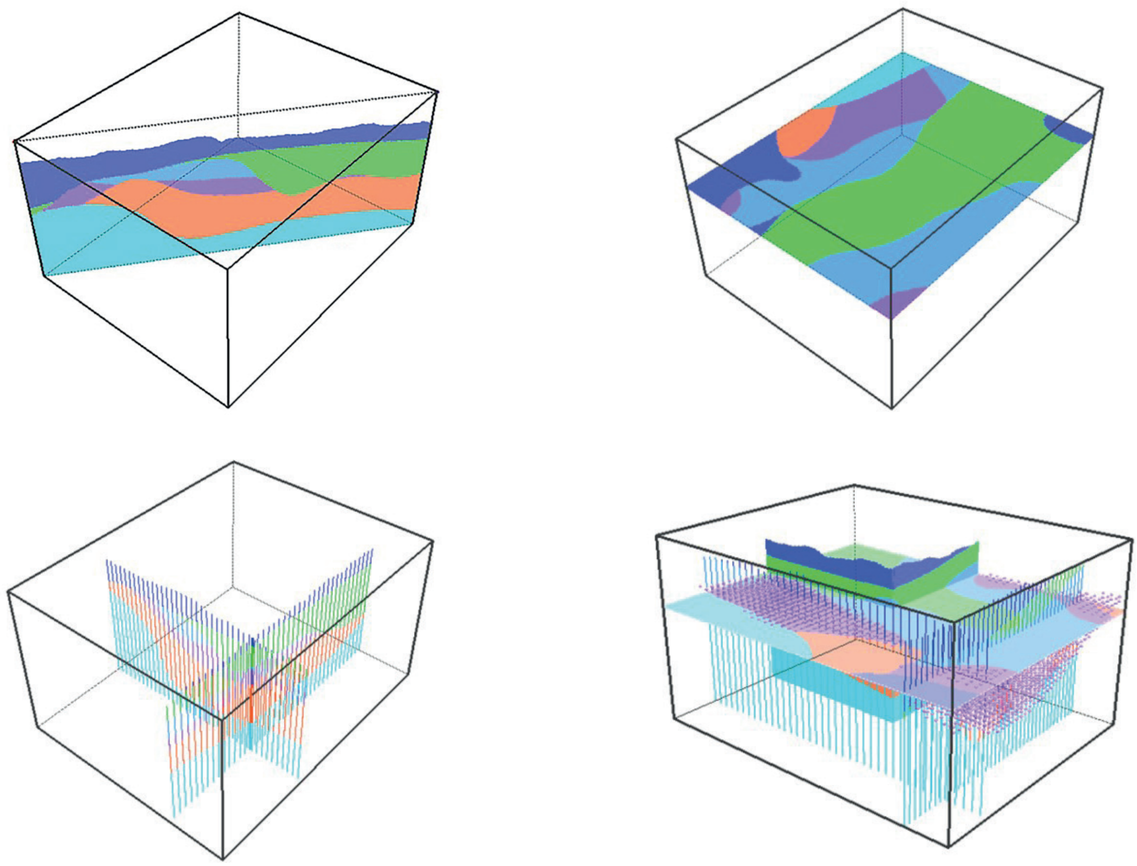


Fig. 2.10. *Virtual functionalities created from the voxel model: 3D profile (top left), 3D horizontal cross-section (top right), a set of boreholes in planes passing through a selected point (bottom left), a combination of several forms of 3D display (bottom right).*

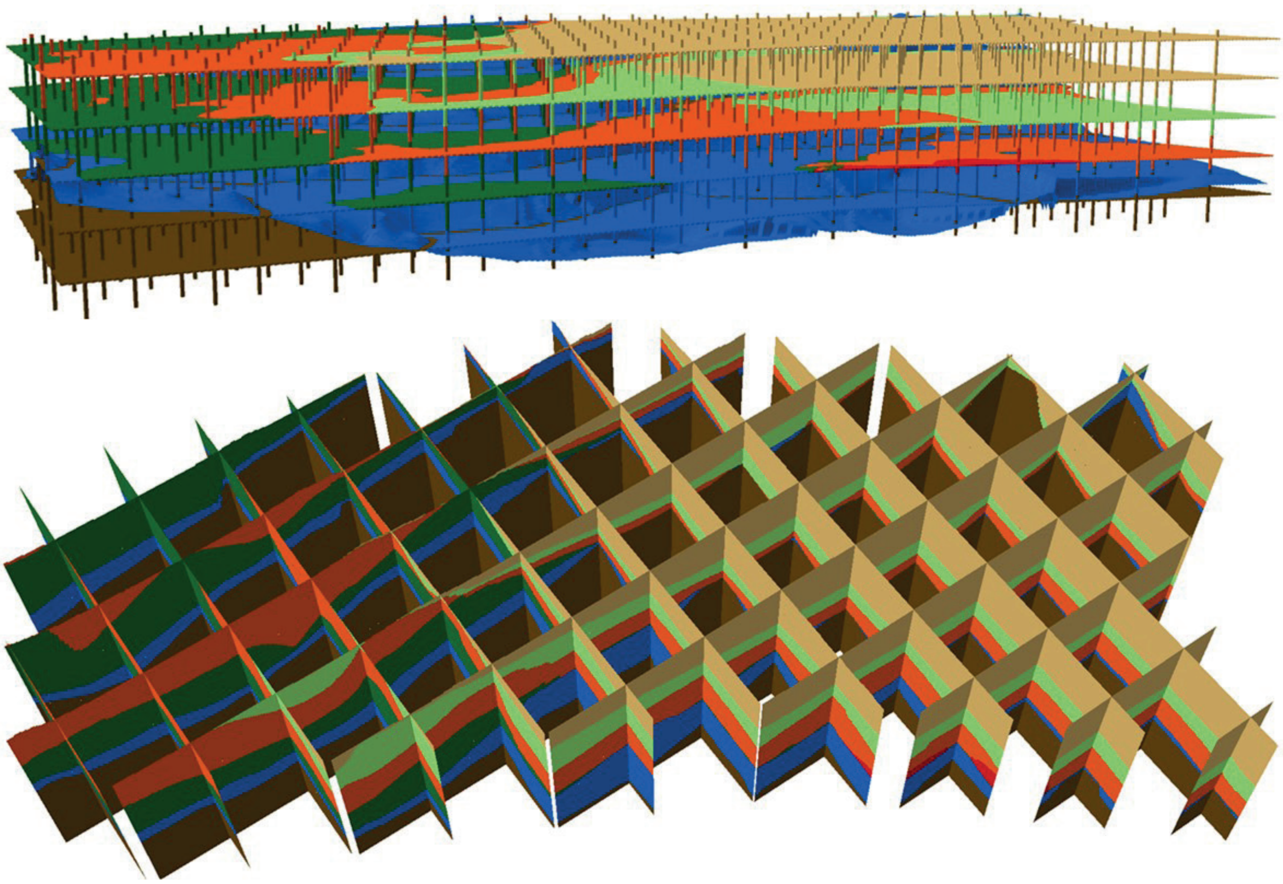


Fig. 2.11. *3D model of the test area (Východoslovenská nížina Lowland), visualization using a set of horizontal sections, boreholes and a selected surface (top), or sets of profiles in the direction of the X and Y axes (bottom).*

For the needs of visualization of the resulting model, a web application was created, which will be available on the website www.geology.sk. It currently offers a 3D interface display, tectonics, individually selected virtual borehole, profile or cross-section. The combination of individual views is being prepared for the future.

2.3 3D modelling results

The developed methodology of spatial geological data processing for the purpose of creating a 3D geological map was tested in selected already modelled regions, such as Turčianska kotlina Depression, Podunajská rovina Flat and Východoslovenská nížina Lowland (Fig. 2.11), solved in previous tasks: "Upper Nitra Basin - three-dimensional geological modelling of the exposed area" (Kotuľová et al., 2010), "TRANSENERGY" (Černák et al., 2012), "Turčianska kotlina Depression - three-dimensional geological modelling" (Nagy et al., 2014). The aim was to verify the methodology in these areas, testing the process steps from data pre-processing, through 3D modelling to visualization of results. The individual steps were used to fine-tune the display, response, testing and development of the functionality of the web application.

The results were very satisfactory. Users, limited in the past to working with specialized 3D modelling software packages, will be able to view the results of their work in real time with excellent response in a commonly used licensed ArcGIS™ environment (when ArcScene™ serves essentially only as a 3D viewer), or can easily visualize the calculated models using a web application on a regular PC and under a common internet connection speed.

Podunajská rovina Flat (TRANSENERGY)
/example of a regional 3D model for testing 3D methodology/

The territory of the Podunajská rovina Flat and adjacent areas (as part of the international project TRANSENERGY) was modelled in the environment of SW Petrel® 8.4. To create a 3D model of the area, 8 modelled horizons were defined, while the main fault lines were respected to during modelling. The individual modelled interfaces were (Figs. 2.12, 13):

- Earth surface;
- Upper Pannonian;
- Lower Pannonian;
- Sarmatian;
- Badenian;
- Badenian – volcanics;
- Palaeogene-Lower Miocene;
- pre-Cenozoic.

The result of the new modelling methodology was, in addition to 3D surfaces, also the voxel model, from

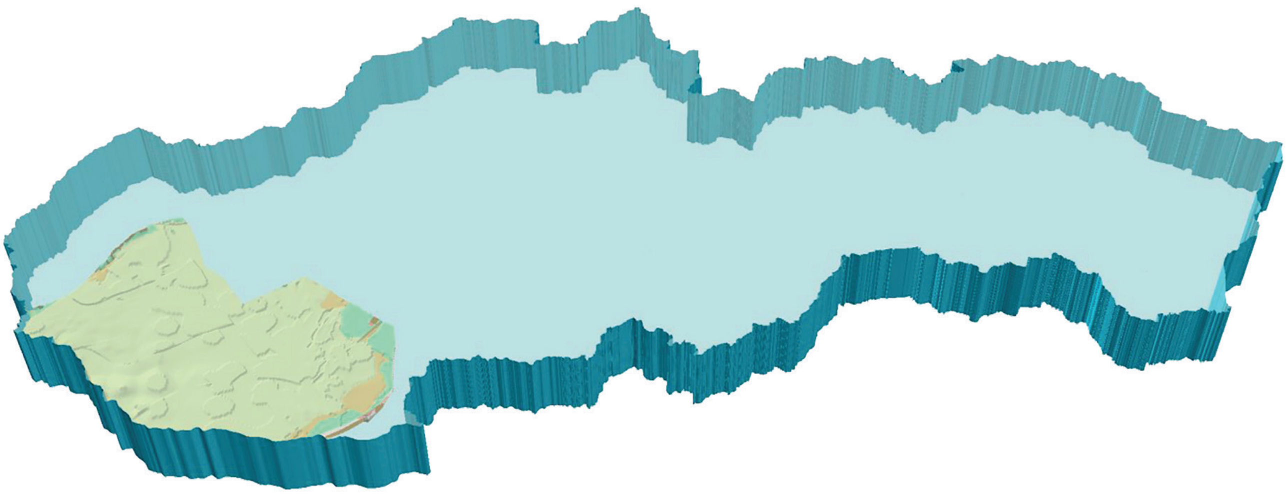


Fig. 2.12. *Localization of the modelled area of the Podunajská rovina Flat within the 3D space of the Slovak Republic.*

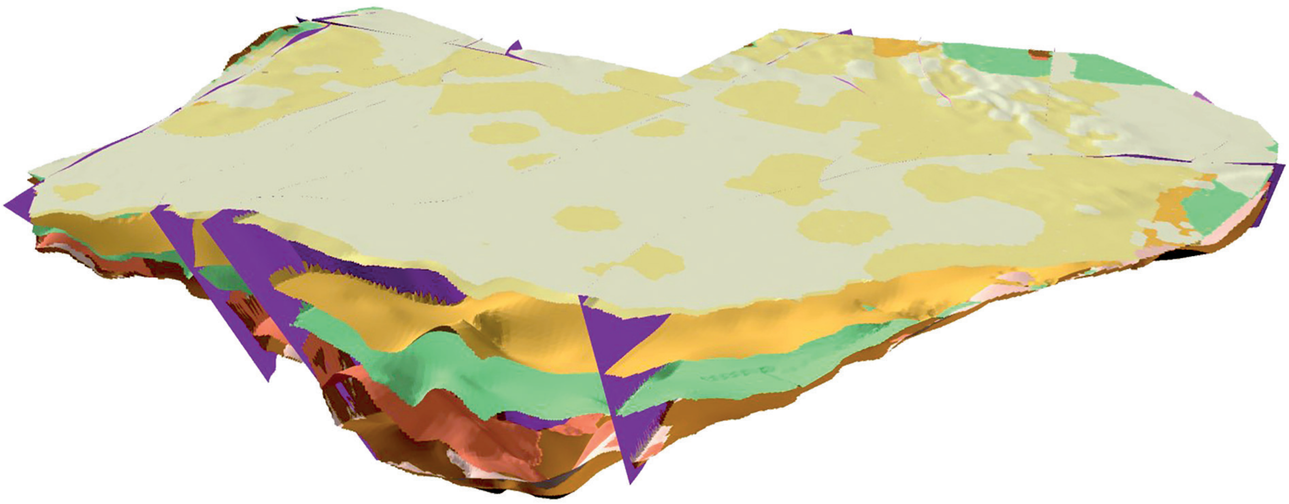


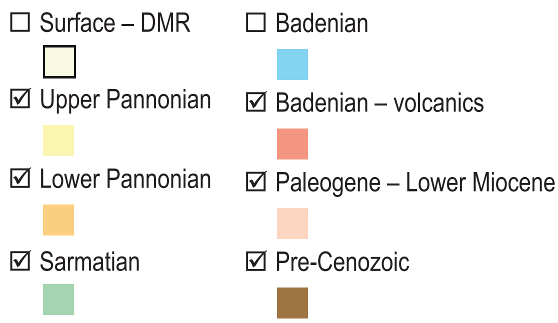
Fig. 2.13. *3D model of the Podunajská rovina Flat (TRANSENERGY), see legend below.*

which we present some extended visualization options, such as a set of sections in the direction of the X axis, or the Y axis, combined with the display of selected interfaces and tectonics (Fig. 2.14), or a combination of a set of horizontal sections, a cloud of virtual boreholes and selected interfaces (Fig. 2.15). The voxel model was calculated in a network of 500x500 m in vertical detail with a step of 50 m.

As can be seen from the attached images, the proposed methodology of data processing into a voxel model and derived virtual boreholes, profiles and sections, even at a voxel resolution of 500x500x50 m, illustrates spatial information about the spatial geological setting of the area, complements the display of information in the entire volume of the modelled 3D territory.

2.4 3D geological model of the Slovak Republic territory at scale of 1: 500,000

- The methodological part presented the method of creating a 3D geological model for the whole territory of the Slovak Republic. The boundary surfaces of the 3D model were:
- state border of the Slovak Republic;



- the Earth’s surface represented by a digital relief model (DMR);
- variable depth range of the model (according to the availability of input data calculated at the time of the model creating).

In the first step, the tectonic structure of the Slovak Republic was modelled as reliably as possible, with the support of the key experts in this field when drawing out the main fault lines (failure zones). The objects of faults were often edited, repaired not only for professional geological reasons, but the intersection of faults below the base also brought computational problems to correctly model the

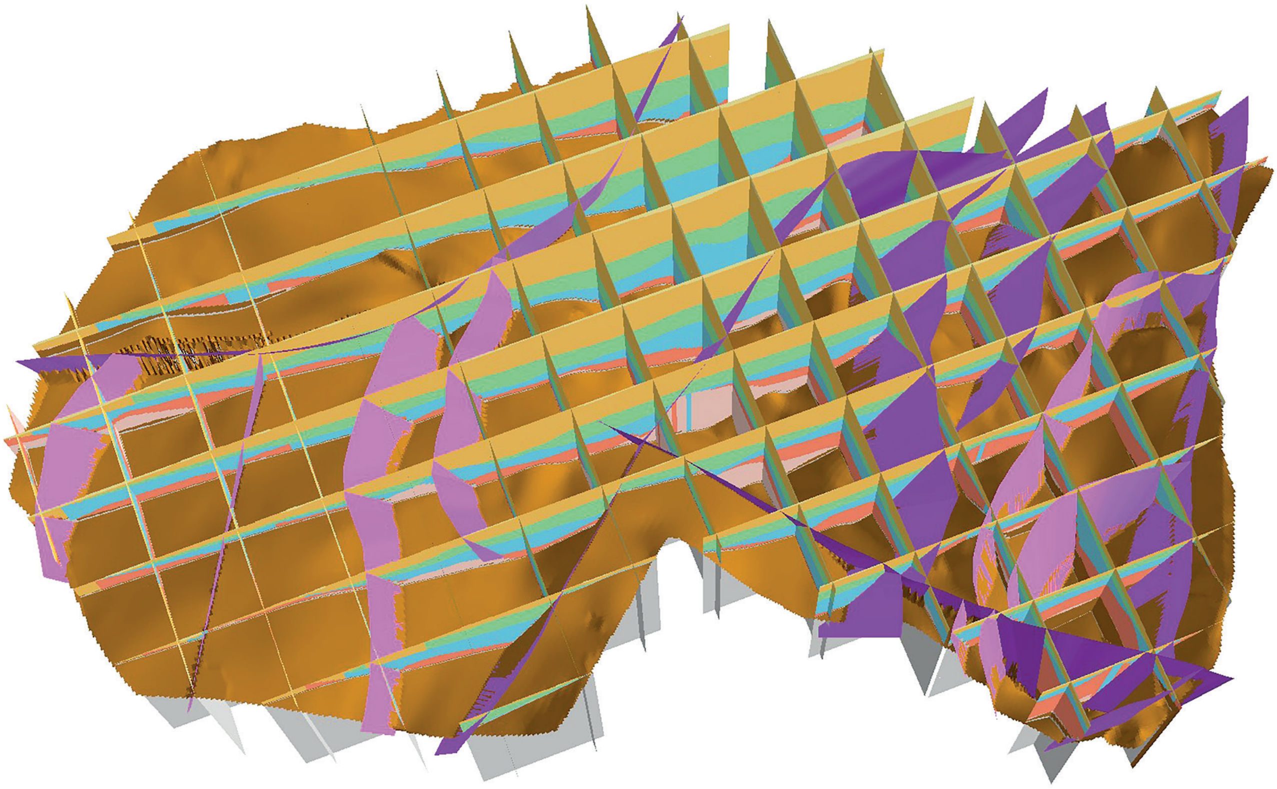


Fig. 2.14. *3D model of the Podunajská rovina Flat area with tectonics. Visualization using a set of profiles in the direction of the X and Y axes.*

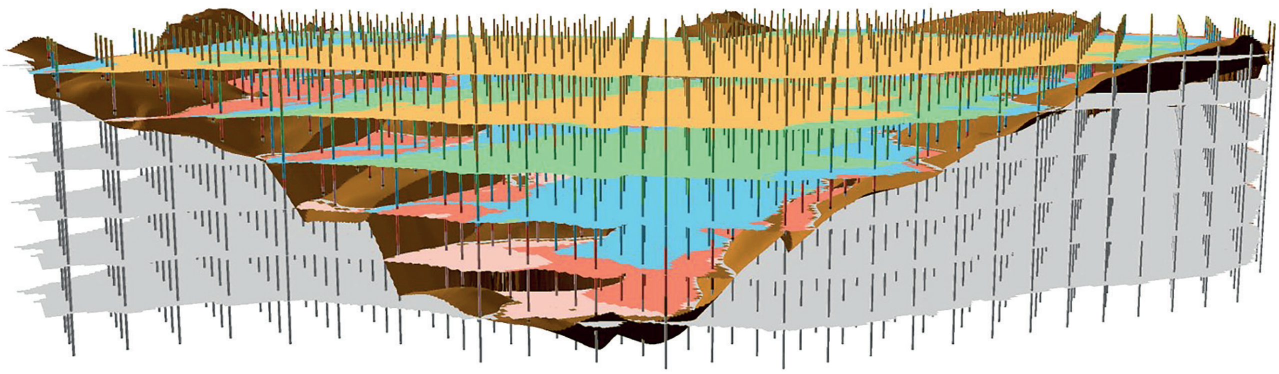


Fig. 2.15. *3D model of PR territory (TRANSENERGY). Visualization using a set of horizontal sections, boreholes and the surface of the pre-Cenozoic basement.*

spatial grid in these segments. This part of creating the 3D model was solved in the environment of the program Petrel® 8.4 of the company Schlumberger. The integrated methodology forced us to work in precisely defined steps and the internal logic of the Petrel® program, which brought many advantages, but also certain limitations.

The 3D tectonic structure of the territory of the Slovak Republic at a scale of 1: 500,000 forms the skeleton of further 3D modelling and we assume that in the future it will form the supporting structure of 3D models of this scale (e.g. when refining, updating the calculated model, but also when creating specialized geothermal models, etc.; Figs. 2.16a, 16b):

During the modelling of the course of 3D surfaces within the created tectonic structure, the individual segments were evaluated separately, or in a sophisticated way so as to respect spatial fault planes (Fig. 2.17).

The modelled space was divided in the depth direction by a layer of pre-Cenozoic basement. The layers below the pre-Cenozoic basement were modelled in the Petrel environment, the layers above this layer in the ISATIS™ program.

The very structural layer of the pre-Cenozoic basement was the main output of the solution of the 3D geological model of the Slovak Republic at the scale of 1: 500,000.

The resulting model was the spatial integration of all modelled 3D surfaces across the vector segments (Fig. 2.18, 19, 20, 21). Each layer was formed by a set of spatial triangles, integrated into a single spatial object with one attribute. Performance tests have shown that this form of

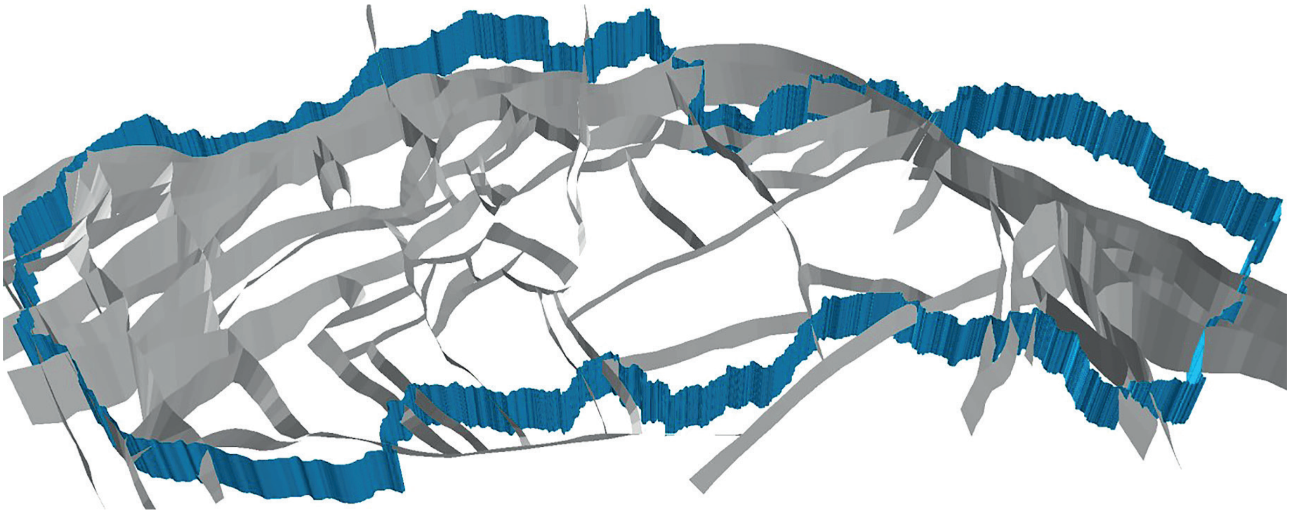


***Fig. 2.16a**. 3D tectonic structure of the Slovak Republic.*

***Fig. 2.16b.** 2D projection of 3D tectonic structure of the territory of the Slovak Republic.*

storage has been optimal. For the purposes of visualization, the spatial objects obtained in this way were divided into smaller parts on the basis of regional division.

A voxel structure was created from a set of spatial planes with a selected step. The resulting 3D grid was used to display a selected set of virtual functionalities, such as the creation of virtual boreholes, profiles and sections (Fig. 2.22, 23, 24). The selected set of objects is stored locally in a *multishape* format based on the query, similar to 3D surfaces. Separate applications have been created to create these functionalities.

In the future, direct support for the ESRI® platform for displaying voxel data is expected. Created applications are ready for this extension.

2.5 Discussion and Conclusions

The resulting 3D model of the geological setting of the Slovak Republic in the form of 3D surfaces (Fig. 2.24) will be available through a web application and in the form of a binary 3D voxel grid, from which it is possible to generate selected boreholes, profiles, sections and display them in one scene.

The 3D voxel model was calculated in a 200x200 m network and in a 600x600 m network with an optional depth resolution interval, e.g. 20 m for detailed views or 60 m for general views.

During modelling, it was found that the source data need to be re-evaluated applying a uniform methodology and using a single legend. A number of differences and inaccuracies were found in the mutual spatial superposition of the calculated surfaces. This was caused by the interpreted data themselves (e.g. the existing Pre-Tertiary basement map), which were formed as separate outputs without connection to other formations, or their surroundings. We have to note that opinions on the geological setting have also changed over time (the range of interpreted maps creation is up to 50 years). It is similar to the creation of classical geological maps, but in 3D there

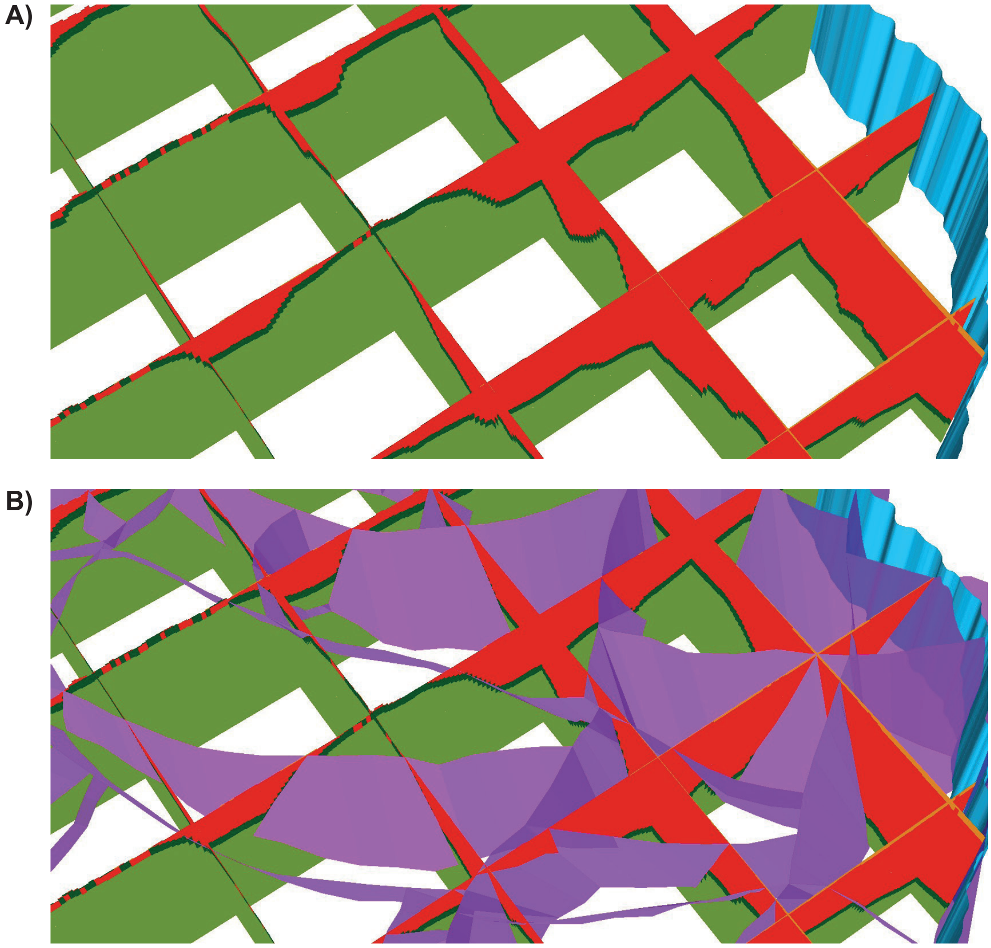


Fig. 2.17. *Comparison of the situation of imaging of the pre-Cenozoic basement with tectonics. A: tectonics off, B: tectonics displayed.*

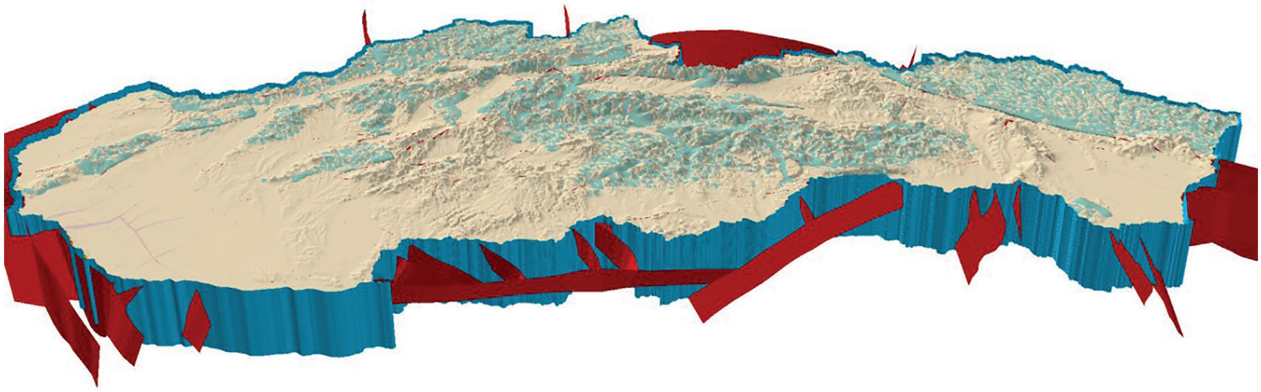


Fig. 2.18. *3D digital relief model in 600x600 m network. The faults are cut to their surface projection.*

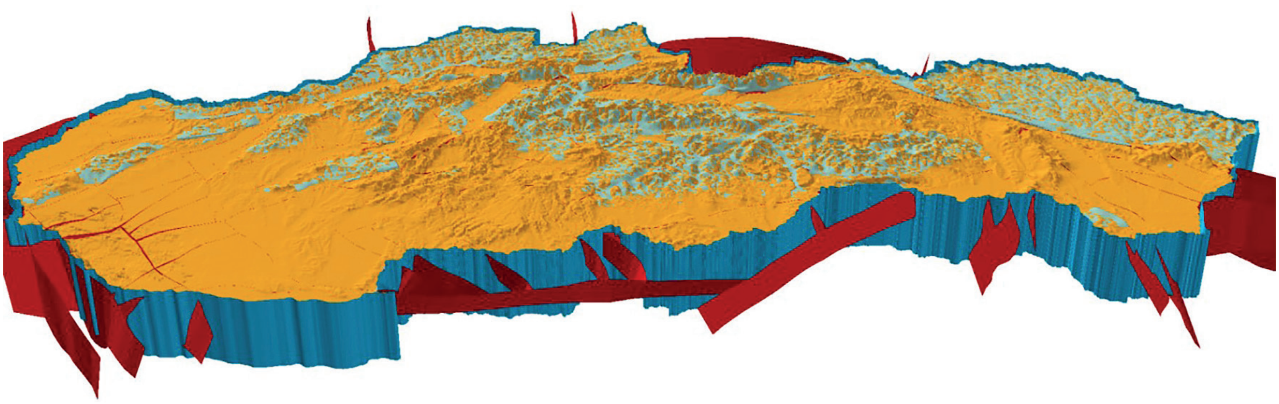


Fig. 2.19. *3D model of Quaternary depths in a 600x600 m network. The faults are cut to their surface projection.*

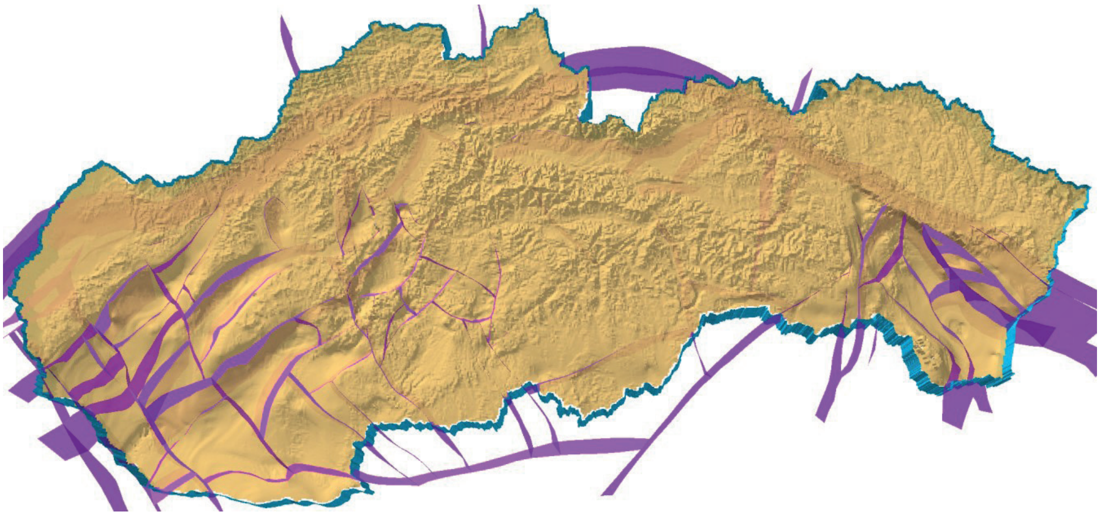


Fig. 2.20. *3D model of the depths of Neogene in a 600x600 m network. The faults are cut to their surface projection.*

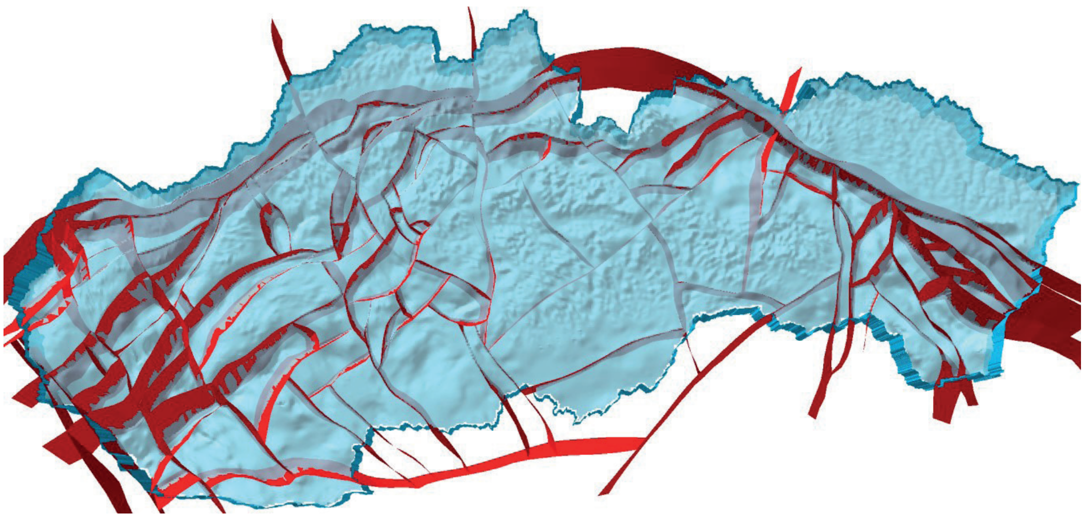


Fig. 2.21. *3D model of the pre-Cenozoic basement of the territory of the Slovak Republic with faults displayed.*

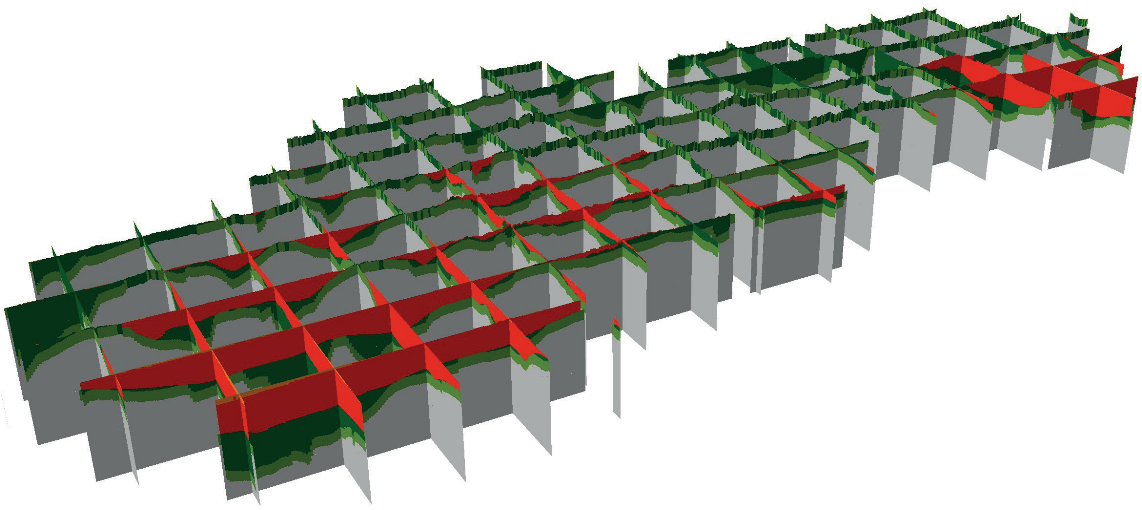


Fig. 2.22. *3D geological model with Neogene base.*
Layers: relief, Quaternary, Neogene base, pre-Cenozoic basement with tectonics, model base (1,000 m below the pre-Cenozoic), in a 600x600 m network. Displayed using virtual geological profiles in the direction of the X and Y axes.

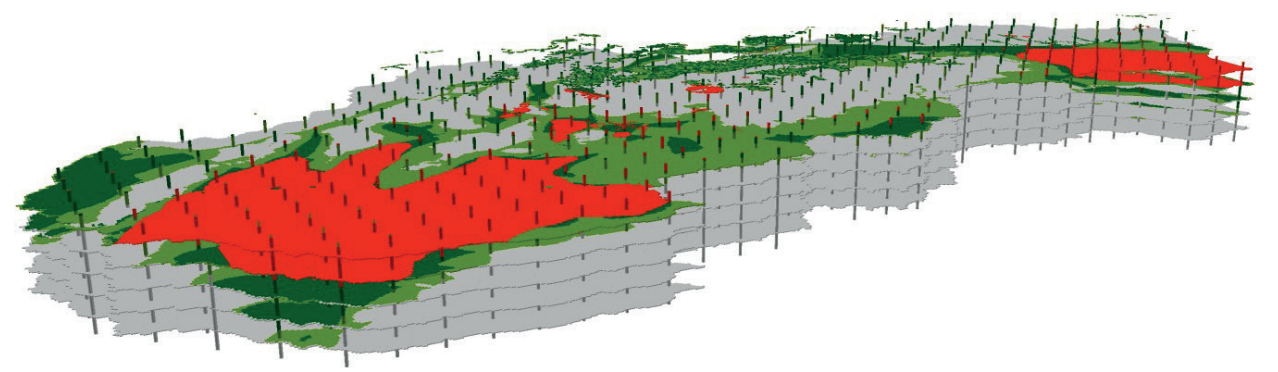


Fig. 2.23. *3D geological model with Neogene base, imaging using horizontal sections and boreholes.*
Layers: relief, Quaternary, Neogene base, pre-Cenozoic subsoil with tectonics, model base (1,000 m below the pre-Cenozoic), in a 600x600 m network.

Fig. 2.24. *3D geological model with geological situation in the basement.*
Layers: pre-Tertiary basement, tectonics, geological situation in the basement.

are even more systematic and random inaccuracies and ambiguities in the data, very uneven spatial distribution of input data (boreholes), etc.

We encountered a number of problems at work, some of which we were unable to solve. The created 3D model corresponds in quality and accuracy to the input data from which it was created. We had the smallest amount of data in the northeastern part of Slovakia, as well as in the Outer Carpathians as such (Flysch Zone), the complicated geological structure of the Central Slovakia Neovolcanics Field (with typical younger dikes, penetrating through the older formations) had to be simplified. In the future, geophysical methods will also need to be applied for more reliable 3D modelling: VES, seismic sounding, etc.

The display of source data in space revealed all these discrepancies, which were more pronounced in 3D. In the case of intersecting profiles, it was clear whether the interfaces were drawn correctly or were bounced off, in the worst case non-coherent. A similarly created model compared to the drilling data had to correspond in a geologically acceptable way, it could not be a so-called *bull-eyes* (naming taken from 2D methodologies), etc. Troubleshooting was relatively easy, but the errors eradication was very complicated.

During 3D modelling, it was found that the 3D modelling packages we use (Petrel®, ISATIS™) could not create all the required functionalities so that they could be used in the web interface. Applications had to be created for data import/export, for the creation of virtual boreholes, profiles and sections, various forms of 3D model display had to be designed and tested (locally, but especially via a web application). The optimized procedure was tested on already completed regional models in various stress tests.

The result of the work was the creation of a comprehensive methodology from collection, through data processing, creation of tectonics scheme, structural map, modelling of individual 3D surfaces, creation of a voxel model, creation of boreholes, profiles and sections on request, creation of a web application to publish calculated results. In addition, the web application created over the ESRI® libraries will also support the voxel views themselves in the future.

The created 3D geological model of the Slovak Republic at a scale of 1: 500,000 represents the first attempt to provide a comprehensive 3D geological map for the entire territory of the Slovak Republic and is the most modern expression of a spatial geological setting. The 3D model may in the future be one of the bases for economic and administrative activities of the Slovak Republic and in addition to basic information on the geological setting of the region may provide data for compiling a wide range of purpose, thematic and general geological maps of scales 1: 500,000, 1: 1,000,000. Its selected layer - "3D model of the pre-Cenozoic basement" with a marked geological structure, can be printed plastically as a wall-hung exaggerated (or overlaid) 3D map.

By creating a 3D geological model at the state (national) level, we have become more widely involved in leading positions in this area. In the future, it will be appropriate to participate in international expert commissions and actively participate in the creation of catalogs and methodologies. Such possibilities would provide space for the creation of transnational 3D models in initiatives and projects of *OneGeology, GeoERA, GEOSS*, etc.

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