Structural geological mapping of the Cenozoic sediments of the Brest region using GIS technologies

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Abstract. Cenozoic sediments of the territory of the Brest region is the object of research in this work. The aim of this work is to detail the structure of the Cenozoic stratigraphic deposits by creating a set of structural geological maps. The process of creating maps included several sequential stages implemented using the ArcGIS 10.5 software product. In general, a set of maps for each period of the Cenozoic era was made according to the implemented method. As a result of mapping, the features of the geological structure of the Cenozoic sediments were detailed (based on the use of the most complete materials on the drilling exploration of the territory during the construction). The use of geoinformation systems in the process of building will allow for quick updating of cartographic materials in the future.
Keywords: Brest region, cenozoic sediment, gis mapping, big data, structural-geological maps.

Introduction

Cenozoic deposits have become quite widespread within the territory of the Brest region, which due to their lithological diversity can be considered as a promising regional resource base of minerals, primarily building materials. This necessitates a serious detailing of the nature of the surface of the buried horizons of the Cenozoic as a basis for a qualitative forecast and assessment of the prospects for the development of the mineral resource potential of the territory as well as optimization of the organization of engineering and construction activities.

It is possible to obtain information about the nature of the surface of buried geological horizons by analyzing structural-geological maps. However, the present cartographic materials reflecting the nature of the surface of the horizons of Cenozoic sediments made for the territory of the Republic of Belarus and covering the territory of the Brest region as well as maps made for separate tectonic structures located within the boundaries of the region [1–4] have a number of disadvantages. First, the preparation of cartographic

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materials was carried out at different time periods using different construction methods. Secondly, the creation of structural geological maps was often carried out manually with subsequent digitization which does not exclude the presence of distortions on such maps associated with the subjective vision of the compilers. Thirdly, the use of traditional methods of drawing up structural maps limited the ability to use the entire amount of available data in the construction and identify errors at intermediate stages of modeling. Fourth, updating the existing cartographic materials due to the peculiarities of their creation is a laborious process. All of the above indicates the impossibility of using existing cartographic materials to obtain high-quality and reliable information about the relief structure of the Cenozoic stratigraphic units within the territory of the Brest region.

At present, in the work of a number of Belarusian authors we can find examples of creating structural geological maps using GIS technologies. But in these works, the structural-geological maps are compiled for the territory of separate regions of Belarus and do not include the territory of the Brest region [5, 6]. In the works, where the territory of Belarus was the object of mapping, the maps were implemented for the horizons of the Quaternary system of the Cenozoic era which does not allow getting an idea of the nature of the relief structure of the Paleogene-Neogene deposits [7].

Based on the foregoing, the creation of a set of digital geological maps of the Cenozoic deposits of the Brest region is becoming urgent, implemented according to a unified technique using geoinformation systems allowing to obtain a high-quality detailed picture of the structure of the underground relief of the Cenozoic stratigraphic units.

Analysis of a number of literary sources in the field of creating digital geological models showed that at present there are many examples of the implementation of structural geological maps for various territorial levels and areas of tasks being solved [8–15]. However, there is no unified approach in the literature regarding the methodology for creating such maps. As a rule, the preliminary stage of modeling is the collection of all available thematic information and its introduction into the GIS-shell which allows you to create a universal structured data model with the preservation of topological integrity as well as a properly organized subordination of geological units [16, 17].

In the future, the construction of structural geological maps using well data is carried out with the help of various interpolation methods which are used to solve a wide range of geographic problems [18, 19]. At the same time, in most of the works describing the methodology for constructing structural geological maps the main emphasis is placed on the algorithm for constructing interpolation models, on the features of the choice of the interpolation method taking into account the specifics of the available data [6, 20]. Less common are methods that include, along with the description of approaches to surface modeling, stages associated with the preparation of data for construction including the processing of initial information [21]. When modeling underground geology, 3-D construction and various proprietary methods are actively used today which are mainly aimed at solving rather highly specialized problems (for example, solving problems in the oil geology of a particular field). At the same time, such methods are quite difficult to implement and require the collection of a significant amount of diverse geological information [22–23].

In this paper, on the basis of approaches existing in the literature using GIS technologies, a method for creating structural geological maps in the geoinformation system ArcGIS 10.5 is proposed. The presented technique has been tested on the example of creating a set of digital geological maps for separate horizons of Cenozoic sediments in the Brest region. The difference between the proposed approach and those existing in the scientific literature is as follows. This technique is a sequential series of stages of creating structural geological maps from the stage of data preparation to the implementation of the finished layout. When developing the methodology, the fact was taken into account that geological data are large amounts of information and the amount of initial information can

increase over time, i.e. the developed methodology is focused on working with large amounts of information. Data processing is carried out both at the "input" in order to eliminate distortions associated with errors in the source materials and at the "output" to assess the correctness of the implemented models. While in most studies, processing is carried out only at the stage of data preparation.

In general, the algorithm presented in this work simplifies the process of drawing up structural geological maps while allowing to qualitatively visualize the features of the relief structure of buried stratigraphic horizons and can be used to create structural geological maps for other territories.

The implemented digital cartographic material has a high-precision spatial reference and can be quickly changed taking into account the latest literature data, information from engineering and geological surveys which will significantly simplify the procedure for mapping geological deposits based on drilling knowledge. Various operations can be carried out with the surfaces obtained in the course of the worked out technique including the combination of several maps in order to perform subsequent analysis.

Methods

Initial data. The initial data for the compilation of a set of structural geological maps presented in this work were the materials of drilling exploration of the territory of the Brest region provided by the State Scientific Institution "Institute of Nature Management of the National Academy of Sciences of Belarus" and the State Enterprise "Research and Production Center for Geology".

The information presented in the initial database is characterized by rather large volumes and can be classified as geospatial data obtained as a result of prospecting and exploration work [24–26].

The original database is presented in Microsoft Access format and includes several related tables: well assignment, work objectives, lithology, stratigraphy, wells. In addition, coordinates are presented for each record in the table which allows it to be embedded in software GIS shells. In this case, the desktop software ArcGIS 10.5 was used. The preliminary stage of importing the database into the GIS environment was the selection of information by building a query in the query designer on the basis of which a pivot table was created containing the information selected most necessary for the subsequent construction of maps from various tables presented in the database.

In general, the database implemented in the GIS contains 40,590 records providing information on more than 5,000 wells. Several records are associated with each well on the map for each of the Cenozoic era horizons that were penetrated by this well. The database also contains 22 fields which provide information about the number of the well, the date of drilling, the local structure to which it is confined and its territorial and administrative affiliation, coordinate reference, marks of the mouth, bottom hole and depth of the well, the purpose of its drilling, stratigraphy and lithology.

It is worth noting that the database contains indicators of the depths of the horizons but at the same time the absolute marks of the top and bottom of the layers which form the basis for building maps of the deep geological structure have not been calculated. The absolute marks of the bottom of the horizons were calculated by subtracting the marks of the depth of the well from the marks of its mouth; the level of the base of the overlying layer is taken as the mark of the top of the stratigraphic units. It should also be noted that the network of wells drilled within the territory of the Brest region is uneven. In some areas, it is quite dense, in others - sparse (Fig. 1).
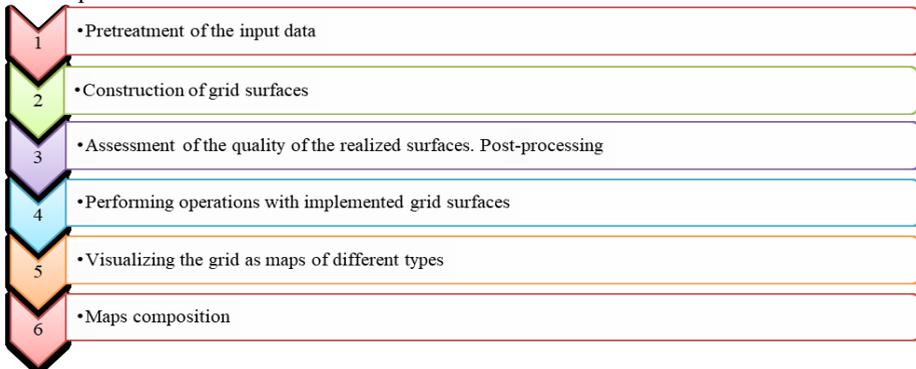
Considering the significant volumes of initial data as well as their belonging to the type of geospatial information their qualitative processing is possible with the use of geographic

information systems which will allow: 1) to perform a preliminary analysis of data and identify errors that are present in them; 2) carry out interpolation in automatic mode with minimal time costs despite the large amount of data presented; 3) apply various construction methods to the available data and compare the resulting models; 4) carry out mathematical operations with the constructed surfaces 5) perform high-quality design and layout of the resulting maps.
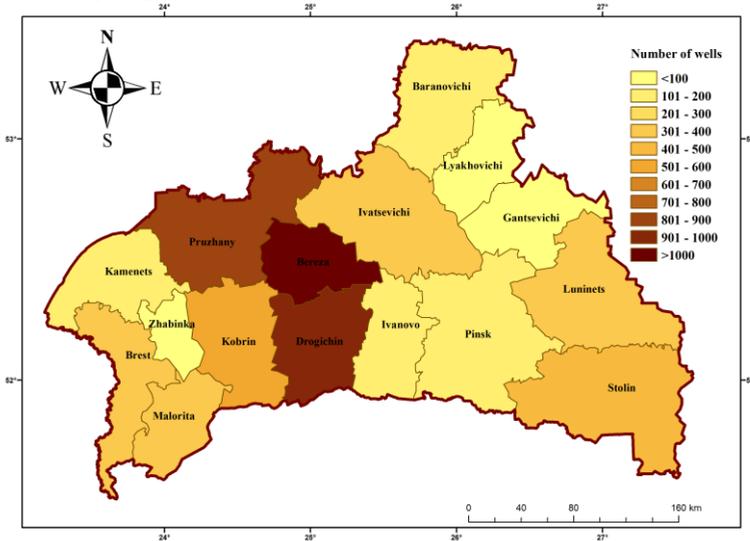
Fig. 1. Information on the number of boreholes in the context of the administrative districts of the Brest region

The methodology for constructing structural geological maps of the Cenozoic deposits of the Brest region included several successive stages (Fig. 2) they were implemented using the desktop software ArcGIS 10.5. We will dwell on them in more detail below.


1. • Pretreatment of the input data
2. • Construction of grid surfaces
3. • Assessment of the quality of the realized surfaces. Post-processing
4. • Performing operations with implemented grid surfaces
5. • Visualizing the grid as maps of different types
6. • Maps composition

Fig. 2. The method of creating a set of structural geological maps of the Cenozoic deposits of the Brest region

Pretreatment of the input data. In order to eliminate errors that may be present in the initial data at the initial stage, preliminary processing was carried out which included the search for "outliers" in the initial data (points that are strongly out of sequence and do not fit into the model for any reason). Many methods are proposed (as a rule, these are various graphical tools, as well as statistical methods; most of the methods for finding data with outliers are based on distance measures, clustering, and spatial methods) to detect outliers in data in the scientific literature [27, 28].

Kriging method was used to detect anomalies in the existing dataset. We used values obtained as a result of interpolation errors using the ordinary kriging method to identify outliers. Subsequently, the interpolation results were added to the original attribute table using the Extract tool. After that, in the field calculator, the obtained indicators were subtracted from the original data, thus the error indicators were found between the interpolated value and the value at the starting point.

The advantages of using this method, in contrast to other common methods of finding errors in data (for example, the use of tools for geostatistical analysis of ArcGIS), allows, on the one hand, to detect data with errors (Fig. 3) and perform their quick removal and on the other hand, to preserve data with natural anomalies (for example, areas of manifestation of karst processes). Such areas are displayed as errors when using other methods.
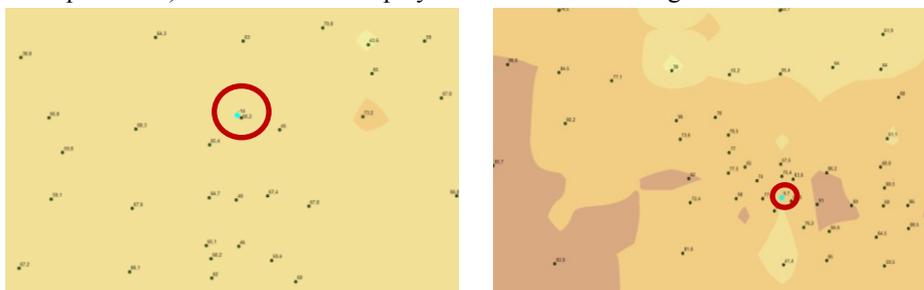
Fig. 3. Data errors identified using the kriging tool

Construction of grid surfaces. Currently, when creating interpolation models, as a rule, two main forms of surface representation are used: grid and tin [29, 30]. The grid method was chosen for the construction of structural geological maps presented in this work and it is the most common type of model of structural surfaces. In addition, grids are easy to transform and perform mathematical operations.

Creation of grid models of the top and bottom of beds of the Cenozoic sediments of the Brest region included several sub-stages [31]:

1. *The choice of the option for constructing a geological model* (the construction was carried out according to the principle "from the general to the particular", i.e. the construction from the larger stratigraphic units, in this case the "system", to the smaller ones – the "horizon".

2. *Preparation of input data*. This stage included work on the unification of stratigraphic units represented in the original database to the system level as well as sampling of layers from the unified database where stratigraphic units were used as a criterion. Three layers were formed according to the results of the sampling and they correspond to three periods of the Cenozoic era.

3. *Choice of interpolation method*. The application of several interpolation methods proposed in ArcMap was considered: IDW, Natural Neighbor, Kriging, Topo to Raster (Figure 4) to construct grid models of the top and bottom of beds presented in this paper. In general, all types of interpolation presented in this set of tools show correct results and it is due to a rather dense network of wells. But given the fact that in this case we are talking about creating terrain models, the Topo to Raster tool was chosen which allows to create hydrologically correct digital elevation models (DEM).

4. *Creation of interpolation grid-models of the top and bottom of beds*. Based on the layers obtained during the sampling (Paleogene system, Neogene system, Quaternary system) as well as the selected interpolation method (Topo to Raster), the surfaces of the top and bottom of beds were constructed.

Assessment of the quality of the realized surfaces. Post-processing. The correctness of the constructed grid models was checked within this stage. At the first stage, for the subsequent identification of modeling errors, the created grid models (having the same raster resolution)

were reclassified according to the roof / bottom values (for example, the roof of the Neogene system / the bottom of the Quaternary system). The reclassified surfaces were then subtracted using the Map Algebra tool (Spatial Analyst toolbox). The "processing extent" was set (as for a larger raster layer) when subtracting raster surfaces. This is due to the fact that the deposits of some stratigraphic units do not cover the entire territory of the Brest region. After subtraction of rasters, cells in places where deposits of one of the stratigraphic subdivisions are absent automatically are assigned the value "no data", instead of which, after processing by the isNull function, the necessary indicators from another raster can be substituted.

Two variants of surfaces were formed as a result of raster processing:

1. Surfaces with no construction errors, i.e. the model is correct and no further processing is required.

2. There are build errors. The surface is not modeled correctly. An adjustment operation is required.

The adjustment (averaging) of surfaces with errors can be implemented using two options that allow to get equally correct results.

1. Using the Cell Statistics tool which calculates statistics based on cell values from multiple rasters.
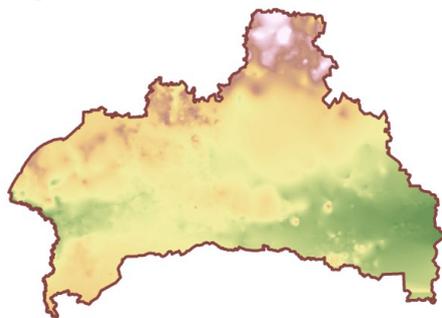
2. Using the Con (Conditional) tool with specifying the necessary conditions. For example, if the values of the roof raster cells differ from the values of the bottom raster cells, the mean of the cells of both rasters will be written as the value in the resulting raster.
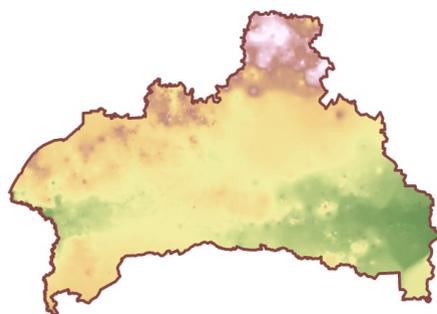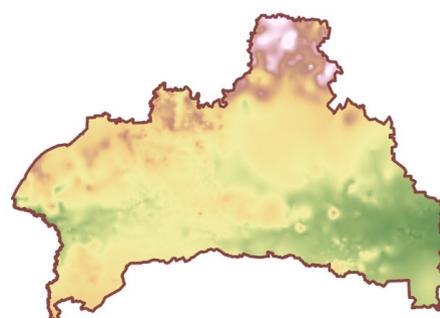
a) an example of using the inverse distance weighted method
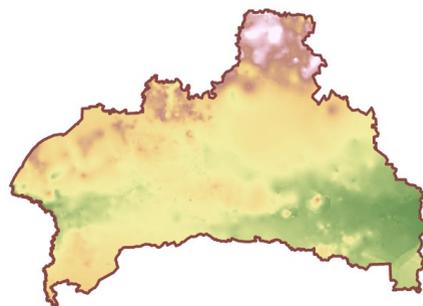
b) an example of using the kriging method

c) an example of using the natural neighborhood method

d) an example of using the topo to raster method

Fig. 4. An example of using different interpolation methods when building a map of the top of Quaternary deposits

Performing operations with implemented grid surfaces. At this stage, based on the obtained grid surfaces using the Map Algebra tool (Spatial Analyst module), the vertical and true thickness for each Cenozoic horizon was calculated. The vertical thickness represents the vertical distance between the top and the bottom of the bed and was

calculated as the difference between the structural maps of the horizons, the thickness between which is calculated. True thickness is the shortest distance between the bottom and the top of the bed and was calculated by multiplying the vertical power by sine of the angle of incidence of solids.

Visualization of the grid as maps of various types. At this stage, based on the obtained grid surfaces, they were visualized in the form of maps of various types. In this study, 3 types of maps were implemented:

1. Contour maps. These maps are maps in contours with a certain step. Isolines can be smoothed and the space between the lines can be filled with a color palette.

2. Raster maps. Map data is a raster with smooth transitions from minimum to maximum values.

3. Shaded relief. They are a surface with a light source fixed at some point.

Maps composition. The final stage in compiling a set of maps was the development of a layout of composition. For its compilation, taking into account the type of maps being implemented, all the elements were placed, a general view was formed, taking into account the main recommendations for map compilation. The development of design techniques for the design and symbolization of maps was carried out using a method for displaying a cartographic image. Class intervals, colors, line types and other graphic elements were selected.

Results and Discussion

Thus, using the above technique, a set of structural-geological maps of the horizons of the Cenozoic deposits of the Brest region was compiled based on the interpretation of data on the geological structure of the Cenozoic deposits. In general, the following map compositions were formed for each of the Cenozoic units (table).

Table. Sets of cards made for Cenozoic sediments of the Brest region

Paleogene system	- hypsometric maps of the roof and bottom of the Paleogene system - hypsometry maps of the roof and bottom of the Kiev suite - hypsometry maps of the roof and bottom of the Kharkiv suite - map of sediment thickness of the Paleogene system - map of the thickness of the Kiev formation - map of the thickness of the Kharkiv Formation deposits - maps of overburden thickness - maps of sediment thickness combined with maps of overburden thickness - maps of the thickness of sediments combined with maps of the roof of the horizons
Neogene system	- hypsometric maps of the roof and bottom of the Neogene system - hypsometric maps of the roof and bottom of the Brinevsky horizon - hypsometry maps of the roof and bottom of the Antopol horizon - map of sediment thickness of the Neogene system - map of the thickness of sediments of the Brinevsky horizon - map of the thickness of sediments of the Antopol horizon - maps of overburden thickness - maps of sediment thickness combined with maps of overburden thickness - maps of the thickness of sediments combined with maps of the roof of the horizons
Quaternary system	- hypsometry maps of the roof and bottom of the Quaternary system - hypsometric maps of the top and bottom of the Pleistocene - maps of hypsometry of the roof and bottom of the Holocene - map of the thickness of sediments of the Quaternary system - map of thickness of Pleistocene sediments - map of Holocene sediment thickness - maps of overburden thickness - maps of sediment thickness combined with maps of overburden thickness - maps of the thickness of sediments combined with maps of the roof of the horizons

The analysis of the implemented cartographic materials made it possible to detail the features of the geological structure of the Cenozoic sediments in the territory of the Brest region.
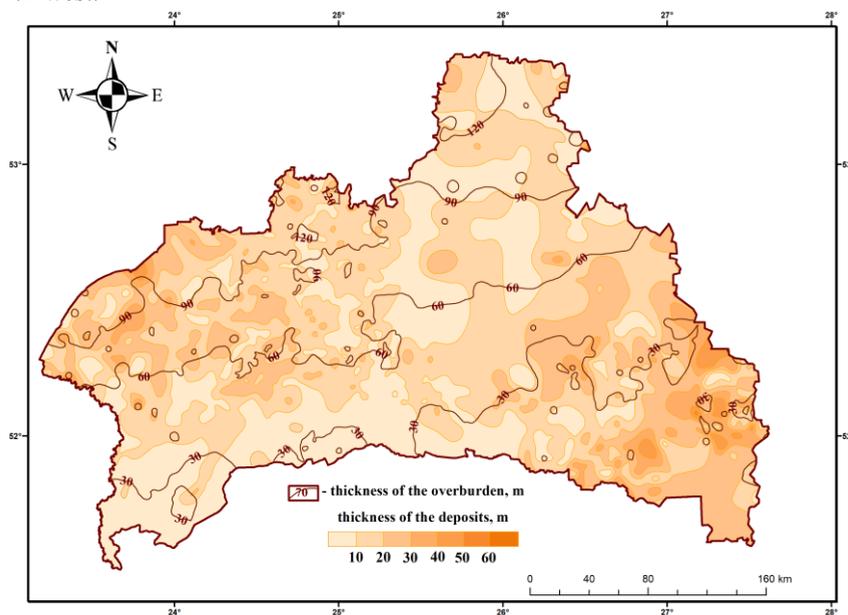
Paleogene sediments occupy significant areas within the study area and lie on Cretaceous formations underlying the Neogene and in some cases directly Quaternary. In lithological terms, sediments of the upper part of the Middle Eocene, Upper Eocene and Oligocene are distinguished here.

Analysis of the hypsometry of the bottom of the described formations shows that they occupy the highest position in the southwestern parts of the region (about 140 m) and the lowest in the northern (about 50 m) (Fig. 5). Their depth on average is 60–70 m, in the south of the region – 25–30 m.
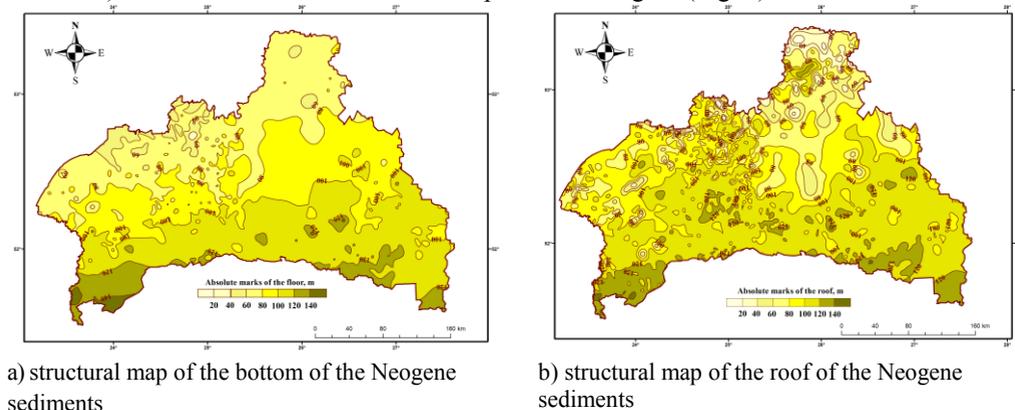

a) structural map of the bottom of the Paleogene sediments

b) structural map of the roof of the Paleogene sediments
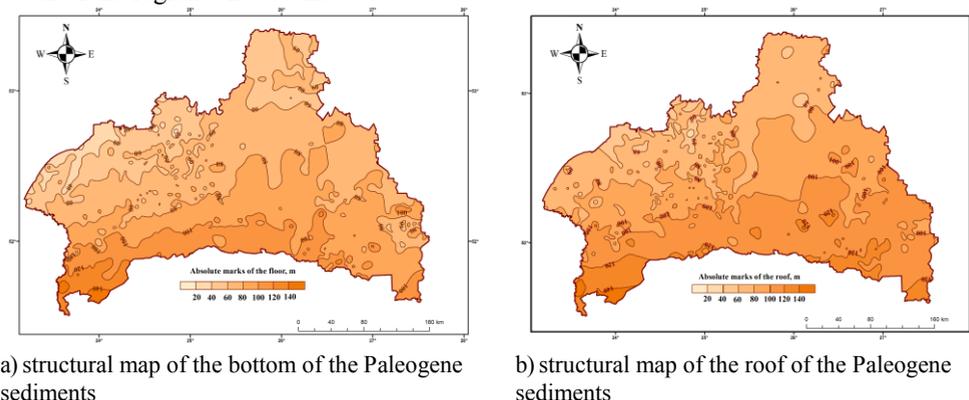
Fig. 5. Structural maps made for the Paleogene sediments of the Brest region

Fig. 6 gives an idea of the thickness of the Paleogene sediments. The average thickness of the Paleogene sediments is 20–30 m. The absolute marks of the roof vary within 20–150 m. The overburden thickness varies from 20–30 m in the south of the region to 120–130 m in the north-west.
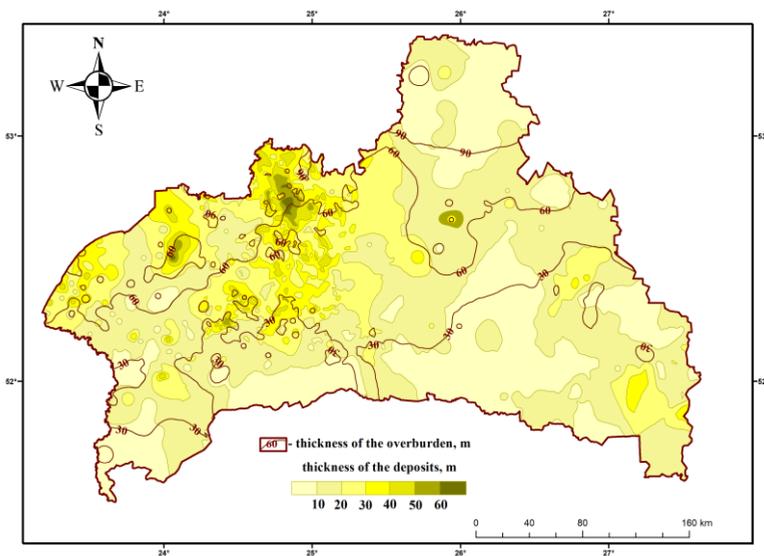

Fig. 6. Thickness of Paleogene sediments of the Brest region

Neogene sediments within the Brest region also occupy significant areas, directly underlying the Quaternary. According to the data of spore-pollen analysis, sediments of the Lower, Middle, and Upper Miocene and deposits of the Lower and Upper Pliocene were distinguished in the Neogene strata. The absolute marks of the bottom of the studied sediments vary in the interval of 10–150 m (Fig. 7). Average depth of occurrence is 90 m. The average thickness of the Neogene sediments is 15–20 m. The maximum values (60 m and more) are recorded in the north-western parts of the region (Fig. 8).

a) structural map of the bottom of the Neogene sediments

b) structural map of the roof of the Neogene sediments
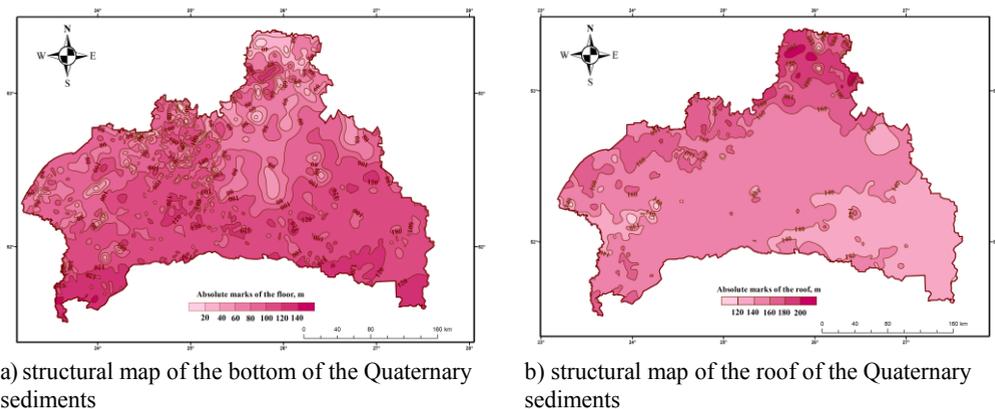
**Fig. 7.** Structural maps made for the Neogene sediments of the Brest region

Fig. 8. Thickness of the Neogene sediments of the Brest region

Analysis of the hypsometry of the bottom of the described formations shows that the highest elevations are characteristic of the southern districts of the region (120 m and more), the lowest are in the northern parts, where they are about 40 m (Fig. 9). The average depth of their occurrence ranges from 80 to 110 m.

Quaternary sediments are characterized by uneven power distribution. The average thickness of the Quaternary strata is 80 m. The maximum values are recorded in the northern parts of the region, the minimum - in the southwest and southeast (Fig. 10).

a) structural map of the bottom of the Quaternary sediments

b) structural map of the roof of the Quaternary sediments

Fig. 9. Structural maps made for the Quaternary sediments of the Brest region
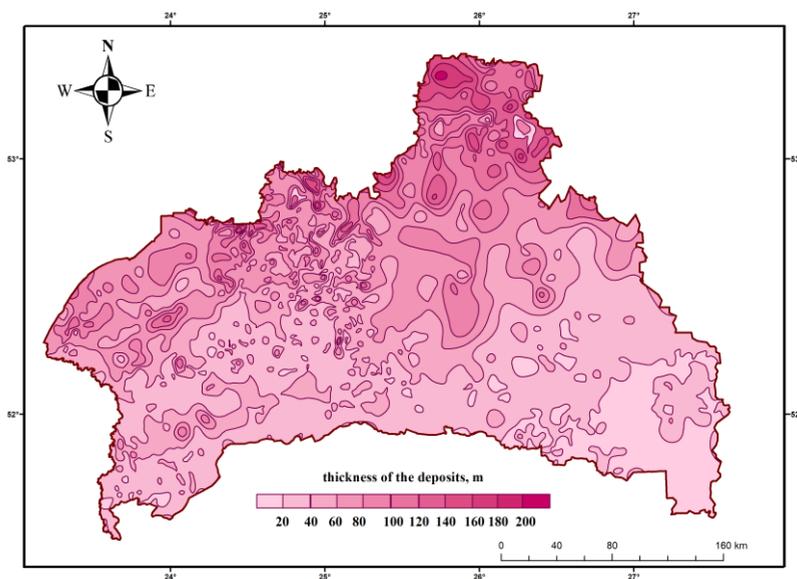
Fig. 10. The thickness of the Quaternary sediments of the Brest region

Conclusions

Thus, in the course of the study:

1. The analysis of the existing theoretical and methodological approaches in the field of structural geological mapping showed that currently in the scientific literature there are many approaches to the creation of structural-geological maps (both traditional and based on the use of GIS technologies). However, in most of the existing methods, insufficient attention is paid to the issue of preliminary processing of spatial data.

2. The selection of the information necessary for the construction of horizontal structural geological maps of the Brest region presented in the original Microsoft Access database (containing data obtained from the results of geological drilling of the territory) has been performed. The selected information based on the existing gridding is introduced into the GIS.

3. Taking into account the peculiarities of the available data set as well as the methodological approaches presented in the scientific literature, a method is proposed for

creating a set of structural geological maps based on drilling knowledge using GIS technologies (for example, mapping the horizons of Cenozoic deposits in the Brest region).

4. The approaches presented in the scientific literature in the field of preliminary processing of large geological data are considered. For the existing dataset, the best error search results were achieved using kriging which preserves areas of natural anomalies.

5. The construction of grid models of the top and bottom of the layers was implemented using various interpolation methods presented in the Spatial Analyst toolbox. In general, all the presented methods allow creating sufficiently high-quality models. However, given the fact that in this study interpolation is used to create terrain models, the Topo to Raster method was chosen.

6. To improve the quality of the created cartographic materials, the analysis of the constructed grid surfaces was carried out which makes it possible to identify errors that arise at the modeling stage.

7. The calculation of the thickness of the sediments for each stratigraphic horizon in the course of performing mathematical operations with the constructed surfaces.

8. Based on the realized grid surfaces, a set of maps was made for each period of the Cenozoic era, including the following compositions: hypsometry of the top and bottom of the horizons, the thickness of sediments, the thickness of overburden, combined maps of the thickness of sediments and overburden as well as the thickness of sediments and the top of the horizons. The completed cartographic materials made it possible to detail the features of the geological structure of the Cenozoic stratigraphic units in the Brest region.

In general, in the course of the implemented study, a number of new cartographic materials were obtained on the structural features of the stratigraphic horizons of the Cenozoic in the Brest region as well as information was updated and more accurate results were obtained on the structure of Cenozoic deposits within the territory of the Podlyassko-Brest depression. The use of geoinformation technologies in the course of creating makes it possible to quickly and timely update them, in case of receiving new information about the structure of this territory.

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