3D STRUCTURAL MODEL OF TERTIARY SEDIMENTS IN NW PART OF THRACE BASIN

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ABSTRACT. The region in the most south-eastern part of Bulgaria (northwest flank of Thrace basin) is characterized with relatively poor geological, geophysical and drilling knowledge. The available and accessible field geological, geophysical and drilling information extremely irregularly describing the geology in that part of Bulgaria, as well as the information from the Thrace basin in Turkey became useful for building the 3D structural model of the Tertiary sequences in that region. The Thrace basin is characterized with very complex tectonic and lithological environment of sedimentation. This fact predetermined careful selecting the processes and steps in building the 3D model. Both the data from hypothetical faults and folds, which is mapped out at surface geological mapping, and the data from the same faults, which is interpreted on the sections of deep geophysical researches are used in order to build the tectonic model. In the next stage of creating the digital 3D model, by using the information obtained from research conducted on Bulgarian and Turkish area, lithological interpretation and correlation of lateral and vertical relations of the main stratigraphic boundaries and lithological formations in the region is done. After that interpretation, the data are applied and implemented to the already created tectonic model, thus the complete 3D geological model is formed. As a result of the 3D structural modelling of the NW part of the Thrace basin, the complex spatial and structural-tectonic relationships between the main stratigraphic boundaries and lithological formations and bodies can be traced, hydrocarbon potential prospects (structures, bodies, etc.) can be identified, and their area, thickness or volume can be calculated.

Keywords: 3D geological model, tectonic model, litho-structural interpretation, NW flank of Thrace basin

3Д СТРУКТУРЕН МОДЕЛ НА ТЕРЦИЕРНИТЕ НАСЛАГИ В СЕВЕРОЗАПАДНАТА ЧАСТ НА ТРАКИЙСКИЯ БАСЕЙН

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РЕЗЮМЕ. Районът в най-югоизточната част на България (северозападен борд на Тракийския басейн) се характеризира със сравнително слаба геолого-геофизична и сондажна изученост. Наличната общодостъпна полева геоложка, геофизична и сондажна информация, крайно неравномерно отразяваща геологията на тази част на България, а така също и информацията от продължението на Тракийския басейн в Турция, послужи за изграждане на 3Д структурен модел на терциерните наслаги в района. Тракийският басейн се характеризира със сложна тектонска и литофациална обстановка на седиментация, което предопределя внимателното подбиране на процесите и стъпките при изграждане на 3Д модела. За изграждане на тектонския модел са използвани данните от предполагаемите структурно-тектонски нарушения, набелязани при повърхностните геоложки наблюдения и последващото им привързване с данните от дълбочинните геофизични изследвания. В следващия етап на изграждане на цифровия 3Д модел, основавайки се на информацията, получена от изследвания на българска и турска територия, е направена литоложка интерпретация и проследяване на латералните и вертикалните взаимоотношения на основните стратиграфски граници и литоложки формации в изучавания район. След литоложката интерпретация данните са добавени и привързани към създадения вече тектонски модел, като по този начин е оформен цялостния 3Д геоложки модел. В резултат на създадения 3Д структурен модел на северозападната част на Тракийския басейн е възможно проследяване сложните пространствени и структурно-тектонски взаимоотношения на основните стратиграфски граници и литоложки формации и тела, набелязване на перспективни в нефтогазоносно отношение обекти (структури, тела и пр.), изчисляване на тяхната площ, дебелина или обем.

Ключови думи: 3Д геоложки модел, тектонски модел, литолого-структурна интерпретация, северозападен борд на Тракийския басейн

Introduction

Identification and characterization of litho-stratigraphic units, subsequently distinguishing of potential reservoirs and seals in tertiary sequences in the most south-eastern part of Bulgarian territory (northwest flank of Thrace basin) is in the basis of the evaluation of the hydrocarbon potential of that region. In order to trace the complex vertical and lateral spatial and structural-tectonic relationships of these sedimentary rock sequences, it is necessary to illustrate and present them in three-dimensional space by means of digital geological model. Past research for the purpose of regional and ore geology and some separate wells drilled in different parts of the region present extremely irregular geological features of that part of Bulgaria. Oil, gas and gas-condensate fields and accumulations found in the Thrace basin in Turkey, as well as the increased interest of exploration companies in its Bulgarian section, are preconditions for the creation of 3D structural model for clearer presentation of the geological features of this region. A 3D structural model would allow and help to identify oil and gas prospects and objects as well.

Principal geological (tectonic and litho-stratigraphic) features of the region

The limited number and arsenal of research predetermine the existence of different concepts about tectonic belonging of the area under investigation to one or another tectonic unit (Fig.1). In earlier publication (Занева-Добранова, Мерачева, 2014) the issue is dealt with more details, where the area is called northwest flank of Thrace basin. Some authors (Boyanov and Goranov, 2001) call it South Sakar depression, others (Йовчев и др., 1971) consider it as element of Madjarovo foreland depression.

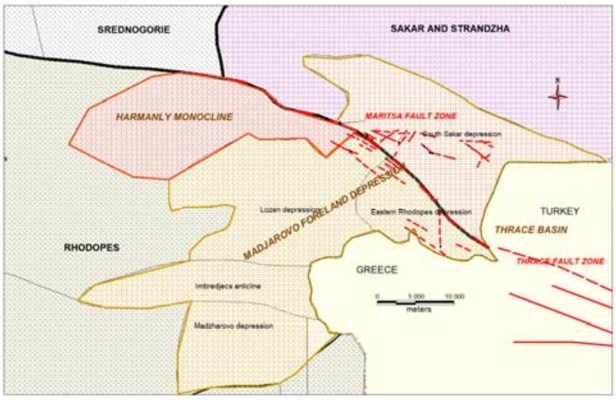

Fig. 1. Tectonic structure of the region of investigation (according to Yovchev, 1971 with author's additions)

The probable reason for the lack of accurate division of the tectonic units in this part of the country, is the fact that there is no single opinion about the faults. The most significant fault is the Maritza fault zone, a structural element still widely disputable according to dozens of authors, not traced on any geological map as a continuous line. Outlined tectonic structures are normal faults with east-west to NNW-SSE and NW-SE direction. It is considered (Мерачева и др., 2017) that these faults are an extension of the southeastward spreading North Osmancik fault zone in Thrace basin, where in the north part of it the faults with NW-SE direction prevail. Numerous studies in the Turkish part of the basin give grounds to most of the Turkish researchers (Turgut, Eseller. 2002.) to come to the conclusion, that in structural terms the Thrace basin is composed of great number of folds and faults oriented to greater or lesser extent parallel to the boundaries of the basin, which is observed on Bulgarian territory as well. The main right strike-slip fault zone in the north part of the basin is Terzili and it is located to the south of North Osmancik fault zone. On the other hand, close to our border with Greece lies the root system of Maritza fault zone, which could be a Bulgarian extension of the Turkish Terzili fault zone. Such a concept is also considered by Bulgarian researchers (Иванов и др., 2001; Герджиков и Георгиев, 2006), who, in a broad sense, assign all subequatorial or spreading NW-SE strik-slip faults located to the north of the Rhodope Mountains to the Maritza fault system. These faults control the distribution of thicknesses, relationships, and spreading of lithostratigraphic units with Tertiary Age. The thickness of the sediments with Tertiary age increases from north to south and from north-west to south-east. The largest drilled thickness of the Tertiary sequence is in R-1 Svilengrad well, where the value of 1136 m is registered.

Tertiary sequence in the region of research consists of sedimentary rocks with Paleogene and Neogene Age (Fig.2). It overlies discordantly above different level pre-Paleogene fundament and is partly or fully covered by eluvial, proluvial and alluvial-talus sediment of Quaternary (Кожухаров и др., 1995).

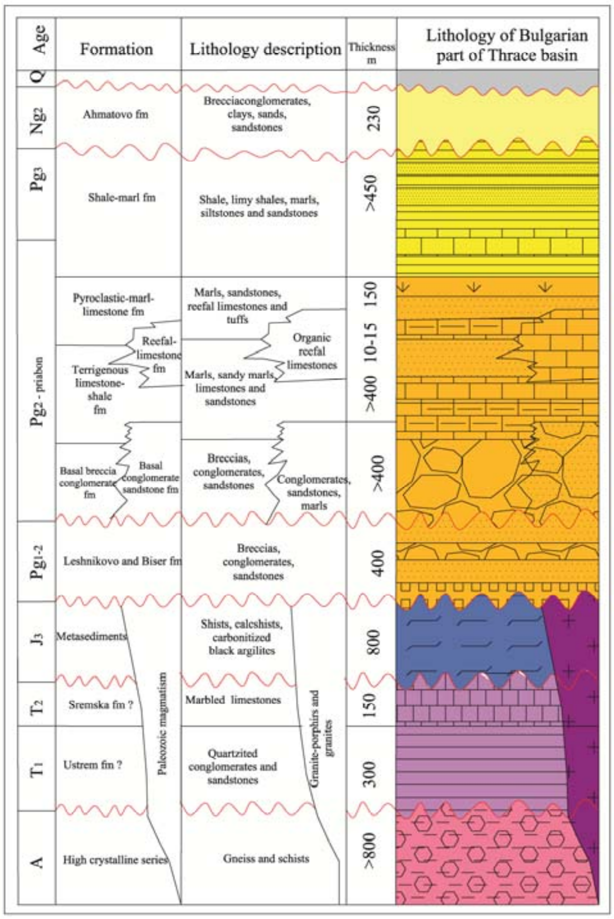

Fig. 2. Litho-stratigraphic characteristic of the region of investigation

At the base of the Tertiary section, according to data from the seismic surveys, north of R-1 Svilengrad well, a zone with unclear configuration and characteristic sand-conglomerate facies is observed. These rocks, by lithological features, could be assigned to Biser and Leshnikovo formations with Paleocene-Eocene (?) age. In earlier publications (Палакарчева, Стефанова, 2013), they were assumed as analogues of the Hamitabat formation in the Turkish part.

Above them or directly on the fundament overlay with transgression the clastic-carbonate rocks of the formations with Priabonian age. By litho-stratigraphic features the rocks are assigned to breccia-conglomerate, conglomerate-sandstone, terrigenous-limestone-shale and pyroclastic-marl formations and these are in complex spatial relationships. In some places a smooth lithofacies replacement of the rocks from one formation to the neighbouring is observed, and in other sectors of the area the lithological units pass through each other by gradual transition. In the south-east their probable correlates are the sediments of Koyunbaba and Ceylan formations. The rocks in the section are followed by the Oligocene deposits of the shale-marl formation, which could be correlated with the formations of the Muhacir group on Turkish territory - Mezardere, Osmancik, Danismen. The Paleogene deposits are transgressively and discontinuously covered by continental Neogene sedimentary rocks included within the scope of the Ahmatovo formation.

Model building methods

For visual presentation and characterization of the complex subsurface geological environment and relationships of rocks, a suitable geological computer program is used. The result of the applied processes of geological interpretation, geostatistical prediction for volumetric representation of the heterogeneity in the subsurface, and graphical visualisation, is the geological model. These processes, in which a geological characteristic of a given object is actually performed, can be described by a section or map of some surface, or by a block or a grid of cells. However, we should take into account the fact that the geological subsurface is not a set of surfaces or sections or blocks. Neither is it a continuum except in the broadest sense of the term. This is because every geological unit is an irregular volume with distinguishing characteristics. The boundaries between units create discontinuities that are further complicated by faulting, erosion and lack of sedimentation. Within this heterogeneous complexity we are concerned with variables that are continuously variable within the volume of a unit, but discontinuous across boundaries (Houlding, 1994). The spatial distribution of a geological characteristic frequently influences the spatial variation of a variable. In order to adequately represent such a complex geological environment, it is necessary to consider this set of discrete, irregular, discontinuous volumes that control the spatial variation of variables. Within this 3D context, using the necessary computer tools for geological characterisation, 3D geological modelling was performed in the following order:

1. Management of spatial information;
2. Geological interpretation of the available data, as a complex of points and lines;
3. Creation of structural framework containing the main surfaces – faults, horizons, unconformities, geological bodies;
4. Building of three-dimensional grid, based on the structural framework to support volumetric representation of heterogeneity in the subsurface by geostatistical prediction of data;
5. Enhanced graphical visualization.

Management of spatial information

The first step, before building the model, is a continuous process in which the relevant information from performed in the region research is collected, reviewed, analysed and implemented in the software program. The quality, representativeness and scale of the data used is important for the creation of the present model, as the area is characterised by poor knowledge. This fact determines the complexity of the next steps in the model creation and affects the spatial variation of the variables in creating the three-dimensional grid. The vast majority of the information - drilling, logging, seismic and geological data is imported into the geological software for use in the next stages.

Geological interpretation

During the geological interpretation, faults on each seismic section are picked and correlated, as well as the main seismic horizons and litho-stratigraphic boundaries (Fig.3).

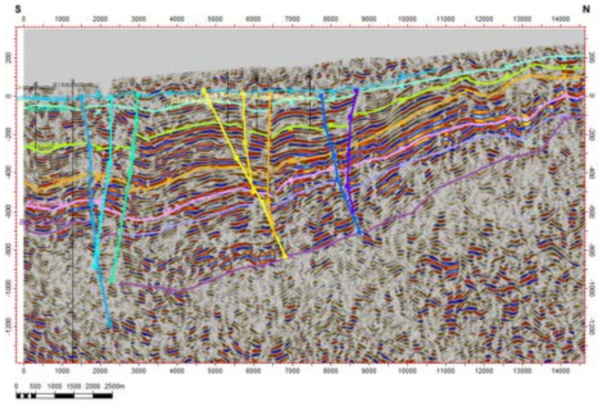

Fig. 3. Geological interpretation of faults and seismic horizons

The stratigraphic interpretation was performed using the data from the investigated wells in the studied area. In the process of interpretation, the geological intuition and experience of the authors, which are indispensable for the limited information on a large part of the geology in the area, are important. After determining the location of the wells in the three-dimensional space in the computer program, information from all available drilling studies is imported and used. The digitised in advance logging data help to perform a litho-stratigraphic interpretation and characteristic of subsurface 3D space. The data from the defined boundaries of the lithostratigraphic units in the wells became useful for basis during the geological interpretation and correlation of the seismic horizons. The geological information about the locations and geometry of mapped on the surface faults and formations from past geological and structural mappings in the research area are correctly performed in the software. They are then compared to seismic data.

Subsequent process at this stage is an interactive interpretation of faults and seismic horizons, which allows the correlation and control of the process in the three-dimensional space. Initially, on the seismic sections on which wells are projected, the main seismic horizons and stratigraphic boundaries are picked from the data on the welltops of the formations. In the same sections, the main tectonic breaks are identified, each in a different colour for easier visual recognition. Then, using the interactive drawing tools, all boundaries are interpreted and correlated in space when each seismic section is intersected with another. In this way, each of the interpreted components is oriented in the 3D space, while controlling the interpretation by simultaneous visualisation of the process both in the 2D window - the seismic section and in the 3D window - the three-dimensional viewpoint. In the process of interpretation of each of the elements on the sections it is possible to observe and model their direction, orientation and shape in real time in 3D space.

Structural framework creation

In the next stage, the data from the interpreted boundaries on the 2D sections is extended into 3D space and their subsequent conversion into 3D spatial images is done. What was created at the previous interpretation stage became useful as input data when creating the 3D image. Using the appropriate software tools, a structural framework has been created, combining, extending and correlating the interpreted data and creating surfaces (faults and main horizons) in the three-dimensional space (fig.4). At this stage, it is possible to reflect and represent any elements that arise from complex geological environment such as pinch-out, lithological replacement, faulting, folding, and so on.

There are three main steps that have been undertaken in creating the structural framework:

1) Structural framework geometry definition on X, Y and Z coordinates – on X and Y the model covers a large part of the study area, and Z coordinates of the model defines the bottom surface of the sediments with Tertiary Age.
2) Tectonic modelling – a grid of interpreted faults has been created, while the relationships between the connected faults are presented. In this case, the presence of listric and truncated faults, which in the places of their intersection require increased attention when connecting them.
3) Horizon modelling (main geological boundaries) – grid of points and subsequent surfaces creation, where geological features are considered – pinch-out, unconformity, erosion and so on.

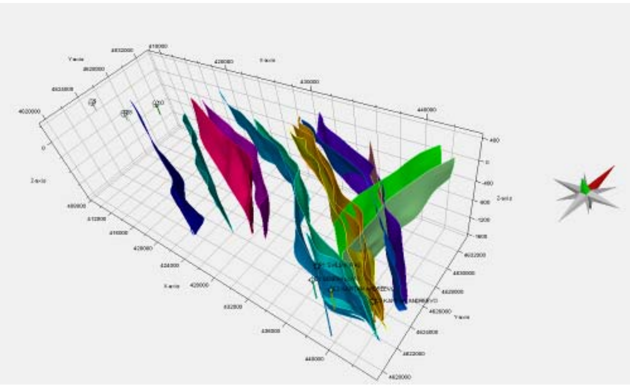

Fig. 4. Tectonic model of the region of investigation

Three-dimensional grid building

The structural maps and fault surfaces created in the previous stage are made up of points that are irregularly distributed in space. This means that the distances between the data points are randomly spaced and always create empty spaces ("holes") between them. Gridding fills in the holes by extrapolating or interpolating Z values in those locations where no data exists. Thus, gridding produces a regularly spaced array of Z values from irregularly spaced XYZ input data. There are several methods of creating a three-dimensional grid, each of which is based on the calculation of the points' values by a specific algorithm, resulting in different results in each interpretation. To create the current structural model, a method is used, that best describes the results of the geology of the area, namely the Minimum Curvature method. The preference of the method is based on the fact that it is used in the absence of data for much of the space. In addition, this method is efficient and fast enough. The interpolation process, in this case, is smooth, with minimal bending when using data values. Thus, the final stage of creating the 3D structural model is accomplished in the following steps:

1) A grid of pillars is built from the fault surfaces, the combination of which forms each fault surfaces by means of Pillar gridding process. The basic idea is to use the faults from the tectonic model as the basis for generating a 3D grid of corner points for each fault. Tectonic modelling processes are closely related to the process of creating a grid of pillars. This allows a return to the process of tectonic modelling and editing of the work on it in order to improve the 3D grid of pillars forming the fault surfaces. Of particular importance is the correct definition of the top, middle and bottom corner points of each pillar in the fault surfaces in terms of cell type, size, and orientation. Based on this Pillar gridding, it is possible to define the relationships between the surfaces representing the stratigraphic boundaries and the lithological formations. It is essential for building the three-dimensional grid to connect the intersecting fragments as early as the tectonic model. In the present case, the presence of listric and truncated faults predetermines the complexity of the realisation of this step as well as the need for adequate quality control of this process. The result from Pillar gridding is a set of pillars, both along the faults but also in between faults.
2) At the final stage of model creation, the surfaces have been created from the interpreted stratigraphic boundaries and litho-stratigraphic units, and subsequently those are implemented in the tectonic model. At the same time, the amplitude, the offset angle, the azimuth, and the impact zone in meters for each fault that has influenced the distribution of the geological units in the model are assigned and defined. For the region of investigation, the model is complicated by the presence of a syn-tectonic/syn-rift sedimentation zone, where the thickness of the lithological unit on both sides of the faults should be predefined. At this stage the relationships between the formations, such as unconformity, pinch-out, etc., have been defined, thanks to which the geological model fully represents the real paleo environmental conditions of sedimentation.

Graphical visualization

After building the geological model, it is possible to easily visualise each part of it (Fig. 5). This is done by reorienting the view plane or profile, changing the direction, changing the scale, or concentrating on a particular location of the model of particular interest. If necessary, using powerful workstations and appropriate visualization and viewing tools, it is possible to visualise the model from a certain angle, as well as access a particular object and use the information contained therein. This makes the model sufficiently informative for subsequent activities in 3D space.

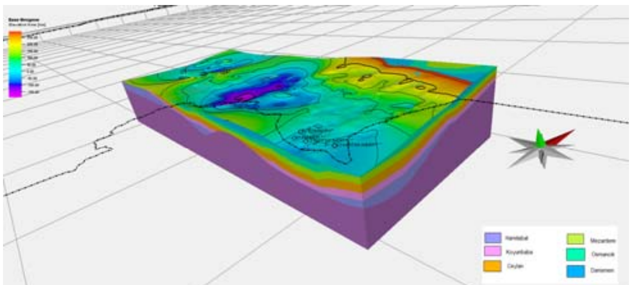

Fig. 5. 3D structural model of the region of investigation

Results of the 3D model

As a result of the performed modelling and geological analyses in the process of building of the 3D structural model, geology, tectonic structure and litho-structural features in the studied area were clarified and specified. The questions raised in the interpretation and analysis of the input data concerning the direction of spreading, the dip, the type and relationship of the faults found a response in the created tectonic model. The presence of normal faults on the north of our border with Greece, as well as the predominant direction of east-west, SSE-NNW to SE-NW, have been confirmed. The tectonic model became useful for correlation of the relationships between two main branches of the North Osmanchik normal fault, their extension to the west and their listric character (Fig. 6).

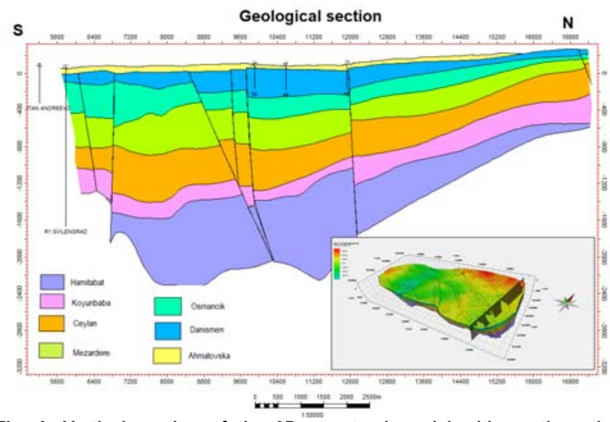

Fig. 6. Vertical section of the 3D structural model with south-north direction

The boundaries of the spreading of the main litho-stratigraphic units with Tertiary Age, getting shallower on the north and northwest to the edges of the sedimentary basin, the unconformable relationships with the overlaying formation could be clearly observed. The 3D structural model allowed northwest tracking (Fig.7) in the three-dimensional space previously identified area, located to the north of the main fault, characterised by syn-tectonic processes of sedimentation during the Upper Eocene Age. The area south of the main fault zone, which has as thick sedimentary complex as the one found north of the fault is extremely interesting.

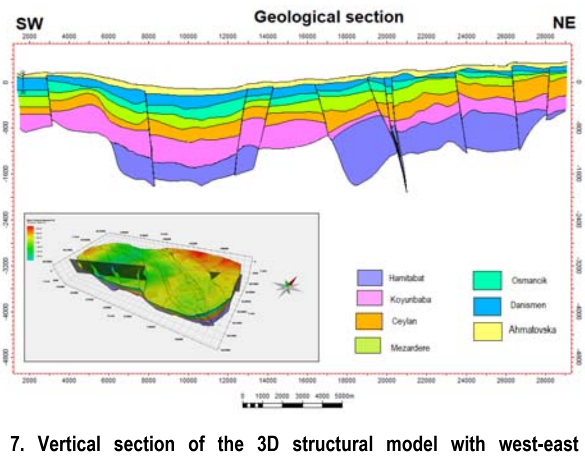

Fig. 7. Vertical section of the 3D structural model with west-east direction.

Conclusions

Based on the created 3D structural model of the north-western part of the Thrace basin opportunities are revealed for:

- Correlation, observation and specifying the direction, dip, azimuth and type of the faults, as well as their impact on the general geological architecture;
- Correlation of the complex spatial and structural-tectonic relationships of the main stratigraphic boundaries and lithological units in the sequence with Tertiary Age;
- Identification of oil and gas potential prospects (structure, non-structure bodies etc.), calculation of their geometry and volume;
- Identification and observation of the spreading and relationships between litho-stratigraphic units with specific petrophysical properties;
- Prediction of migration paths for fluids with different phase state.

The created 3D structural model can be useful for subsequent analytical and research works related to:

- Stratigraphic modelling of geological bodies of varied genesis – riffs, channel-levee systems etc. (Geobody modelling);
- Facies modelling and paleo environmental modelling;
- Petroleum system modelling;
- Petrophysical modelling;
- Geomechanical modelling;
- Reservoir modelling and simulation.

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