

# NATURAL RESERVOIR SYSTEMS IN THE TERTIARY SECTION OF THE EAST RHODOPE DEPRESSION AND PERSPECTIVES FOR STORAGE OF NATURAL GAS AND CARBON DIOXIDE

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**Abstract:** The East Rhodope Depression situated in South Bulgaria is a Paleogene imposed structure. It is mostly filled with Tertiary sedimentary, sedimentary-volcanogenic and volcanic rocks. The tectonic low-order elements distinguished in it are specific volcano-tectonic, block and block-fold structures. The subjects of our study are the aquifer layers (reservoir systems) situated in these structures investigated from the point of view of the possibilities, if other favorable conditions for storage of natural gas and carbon dioxide (CO<sub>2</sub>) exist. Special studies carried out by the authors in the limits of the perspective structures are concentrated mostly on the: lithological-physical segmentation of the Tertiary section; defining of permeable and hard-permeable formations and their studying (structure, lithology, reservoir and sealing parameters, spatial behavior); defining of natural reservoirs and studying their spatial relationships; prognosis of possible types of local structures and natural traps. Because of the restricted volume and the absence of specialized information for a number of important geological preconditions and parameters, prognostic assessments are made with the use of indirect data, based on the contemporary ideas about the geological evolution of the examined region. Such are the structural-tectonic, the seismotectonic and the hydrogeological (hydrochemical, hydrodynamic) and the thermo-baric conditions. The prognoses concerning the perspectives for storage of natural gas and CO<sub>2</sub> are connected to the sunken areas within the Dzhebel and Krumovgrad depressions.

**Keywords:** East Rhodope Depression, natural reservoir systems, CO<sub>2</sub> sequestration; Underground gas storage (UGS)

## 1. Introduction

The perspectives for storage of natural gas and carbon dioxide (CO<sub>2</sub>) in aquifer layers suppose the presence of appropriate natural reservoirs and traps. They should correspond to definite requirements (criteria) that are regulated in the contemporary theory and practice in accordance with the natural conditions of the studied sites.

The territory of South Bulgaria is characterized by a lot of specific features that determine essential differences in the approaches for assessment of the possibilities for storage of natural gas and CO<sub>2</sub> in aquifer layers compared to those, proposed by the authors for a part of the territory of North Bulgaria. These special features are mainly connected to the geological conditions, the degree of studying, from the point of view of the examined problem and the type of the geological exploration works carried out for the present moment.

In North Bulgaria a study subject are the local structures, registered by seismic data and developed by boreholes. In South Bulgaria objects of studying are the reservoir systems, situated in larger-scale graben structures (depressions) in the limits of the imposed Tertiary depressions. The presence of local structures (natural traps of a structural or other type) in them could be registered after carrying out of additional (basically seismic and well-log) exploration works with the purpose of registering these structures.

The subject of more detailed examination in the studied graben structures are the reservoir systems. More general considerations are represented for the other geological preconditions (structural-tectonic, seismotectonic, hydrogeological), because of the absence or the insufficient information with a view to the thoroughness of the prognostic assessments for storage of natural gas and CO<sub>2</sub>.

## 2. Brief information for the geology of the region

The East Rhodope Depression situated in South Bulgaria is a typical Paleogene superimposed structure. It is mostly filled with sedimentary,

sedimentary-volcanogenic and volcanic rocks of Paleogene and partially Neogene age (Fig.1). They cover the Pre-Paleogene basement, which has a complicated structure resulting from a multiphase tectonic evolution. It consists of Precambrian metamorphic and Mesozoic metamorphic, mag-

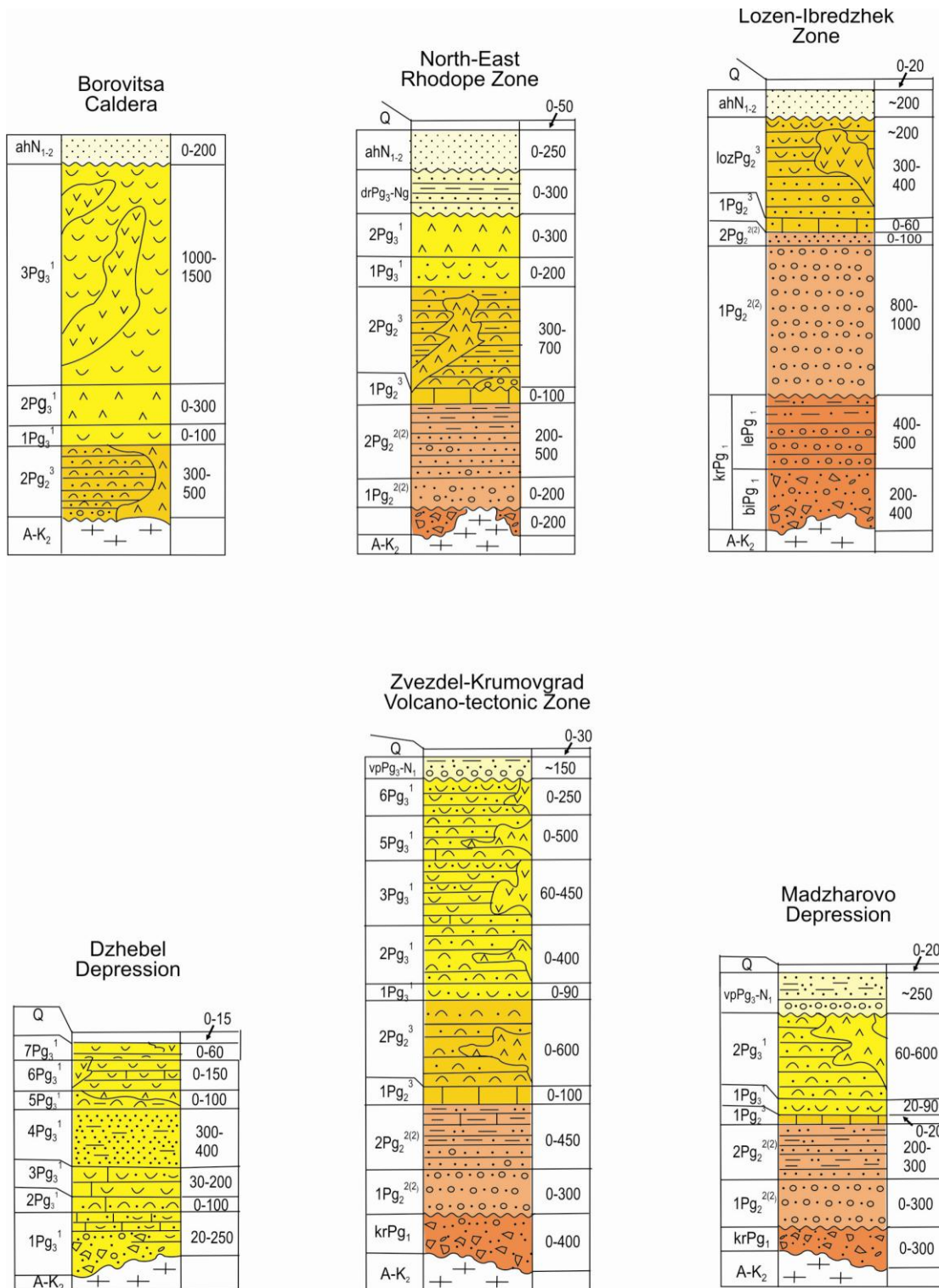


Fig.1. Summarized lithologic-stratigraphic columns in block structures from the East Rhodope Depression (Boyanov and Goranov 1994).

matic and sedimentary rocks. The low-order tectonic elements distinguished in the East Rhodope Depression are specific volcano-tectonic, block and block-fold structures (Borovitsa Caldera, North-East Rhodope Zone, Lozen-Ibredzhek Zone, Dzhebel Depression, Dobromiritsi-Chorbadzhiysko Zone, Zvezdel-Krumovgrad Volcano-tectonic Structure, Madzharovo Depression, Bryagovo Depression) (Boyanov and Goranov, 2001) (Fig.2).

coarse clastic and carbonate-terrigenous sediments. It is supposed that they are with unsustained area and vertical distribution and are cracked in some places by dykes. In the Dobromiritsi-Chorbadzhiysko Zone and the Bryagovo Depression the sections are thoroughly built by reservoir rocks. Polymetal deposits of variable scale are registered in the peripheral parts of Borovitsa and Zvezdel-Krumovgrad depressions, as well as in the central

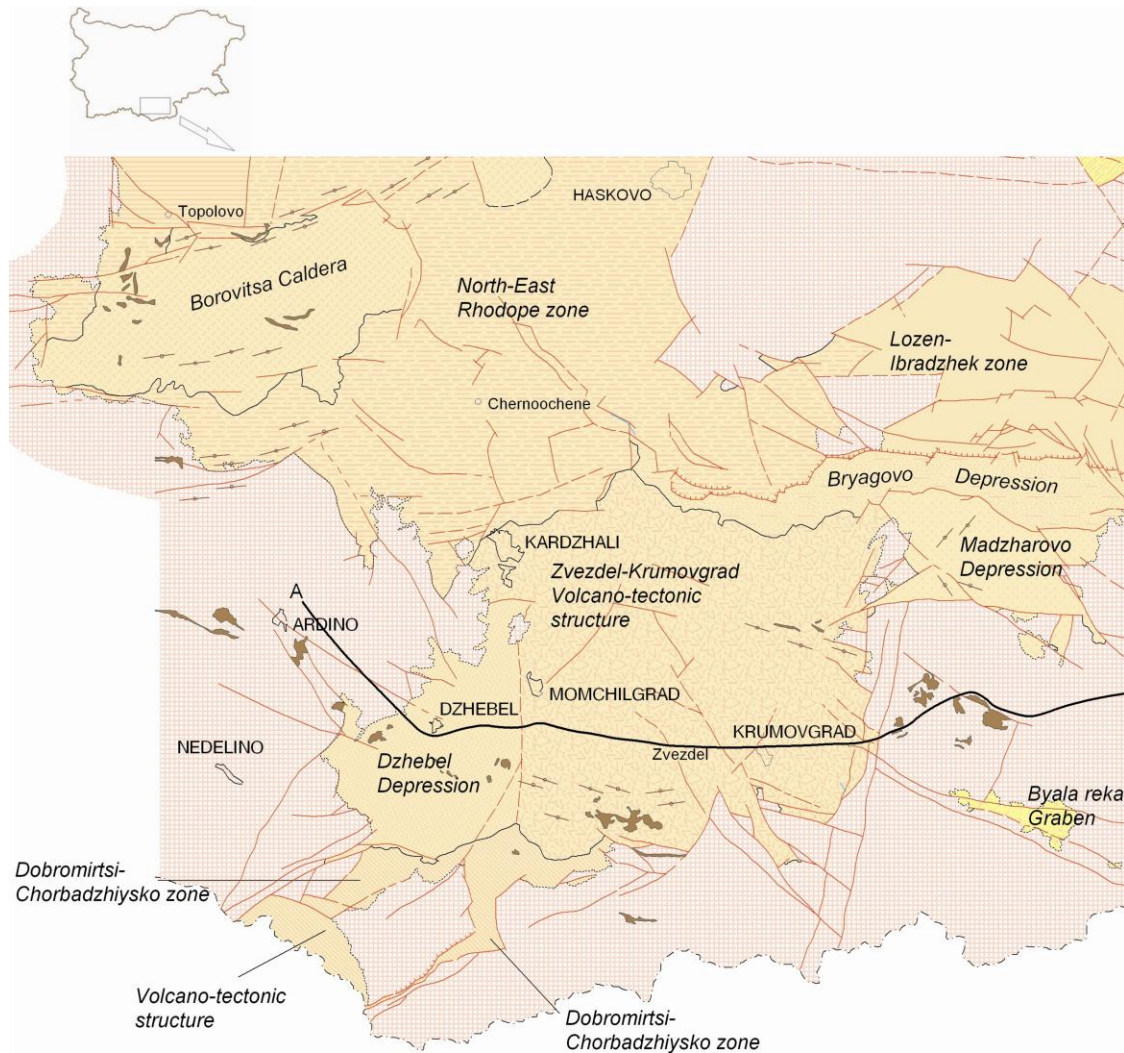


Fig.2. Tectonic map of the East Rhodope Depression (Boyanov and Goranov 2001).

The indicated structures of variable order are too different by their inner structure, dimensions and geological development. Despite of that, they possess some common characteristics. They are depression structures of second and third order. Their structure is complicated and they are built of Tertiary sedimentary, sedimentary-volcanogenic and volcanic rocks. All of them are with graben-like complicated periphery. Reservoir rocks of Paleogene and Eocene age occur in the sections according to data from the outcrops. They consist of

parts of Madzharovo and Lozen tectonomagmatic structures.

According to data from the regional seismic section Ivaylovgrad-Ardino in the south-eastern part of the East Rhodope Depression, two depression areas are distinguished. In them the Paleogene sediments are with significant depth (more than 1000 m). They are situated in the region of Dzhebel Depression and the eastern part of the Zvedel-Krumovgrad Zone (Krumovgrad depression). The



Dzhebel Depression is situated in the south-western part of the East Rhodope Depression. Its western slope is slant and its eastern slope is strongly faulted and terraced (Fig.3). The Tertiary section in it consists of Oligocene sediments that in the western and northern part develop on the surface. Two deeper areas are distinguished on the regional seismic section in the central part of the depression. The section's thickness in them reaches up to 1150 m. The Krumovgrad Depres-

preconditions: lithologic, structural-tectonic, seismotectonic, lithological-physical (petrophysical), hydrogeological and termobaric. They could not be completely applied for South Bulgaria and partially for the Tertiary structures in the East Rhodope Depression. This is due to the specific geological conditions and the poorly studying of this territory. From the point of view of the examined problem the assessment criteria characterize structures of a higher grade – graben depressions.

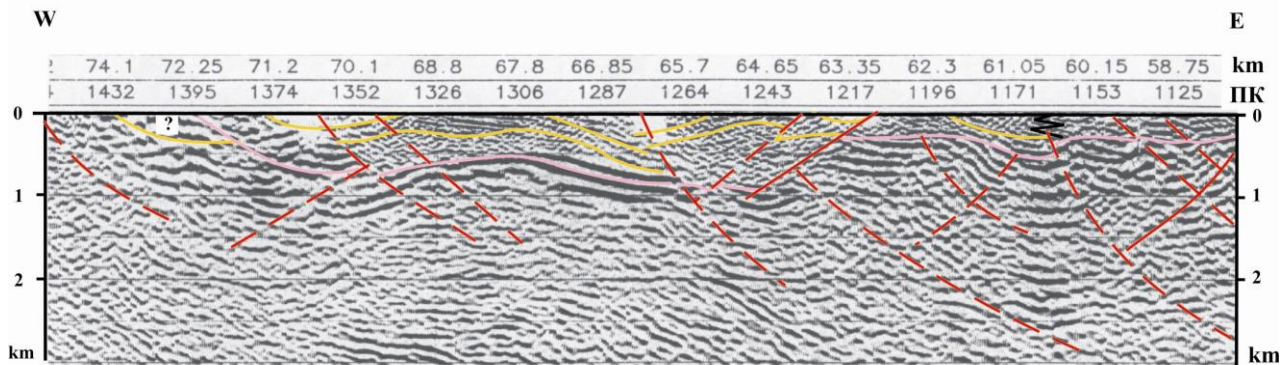


Fig.3. Regional seismic section (Dzhebel Depression) (interpreted by A. Goranov and A. Velev)

sion is situated in the southern part of the East Rhodope Depression. It is a complicated depression structure with shallower western part, where the thickness of the Paleogene deposits reaches up to 1400 m (Fig.4). Its eastern part is faulted and the section's thickness reaches up to 2300 m. Probably the regional seismic section doesn't cross the deepest parts of the depression.

Data from the interpretation of the regional seismic studies gives a definite notion about the spatial behavior of the defined reservoir systems and the structural-tectonic environment. In this sense the specialized studies carried out by the authors in the limits of the possible perspective graben structures (depressions) are concentrated mostly on the: lithological- physical segmentation of the Tertiary

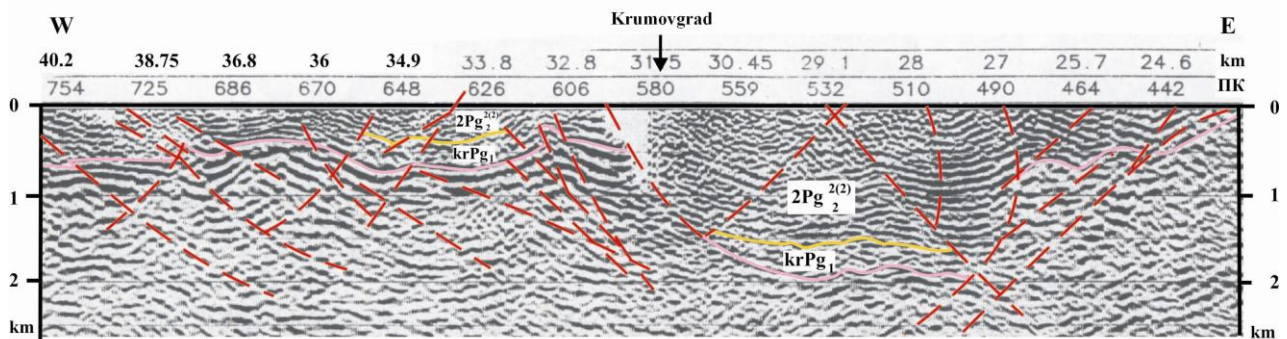


Fig.4. Regional seismic section (Krumovgrad Depression) (interpreted by A. Goranov and A. Velev)

### 3. Methodical approaches

The methodical approaches worked out by the authors in previous studies for identifying of perspective aquifer structures for storage of natural gas and CO<sub>2</sub> (Balinov et al., 2007, 2008 a,b) are applicable for North Bulgaria. They are based on the main requirements for suitability of the geological sites and are connected to the concrete geological

section; defining of permeable and hard-permeable formations and their studying: structure, lithology, reservoir and sealing parameters, spatial behavior; defining of natural reservoirs and studying their spatial relationships; prognosis of possible types of local structures and natural traps. Because of the restricted volume and the absence of specialized information for a number of important geological

preconditions and parameters, prognostic assessments are made with the use of indirect data, based on the contemporary ideas about the geological evolution of the examined region. Such are the structural-tectonic, the seismotectonic and the hydrogeological (hydrochemical, hydrodynamic) and the thermobaric conditions.

The subjects of our study are only a part of the vary-order graben structures that could be assessed in advance as possible prospective structures according to selected criteria parameters. On the basis of the full complex of parameters, a comparative assessment is made of the perspective graben structures and the reservoir systems containing in them.

#### **4. Natural reservoir systems**

The permeable and hard-permeable formations, distinguished in the Tertiary section of the East Rhodope Depression, are with unsustained area and vertical distribution. Late volcanic dykes are often inserted in them. In some cases they are situated in the periphery of the structures, because the central parts are filled with volcanic rocks. In other cases hard-permeable rocks are missing in the section or the formations develop on the surface. Because of this most of the structures are not interesting with a view to storing of natural gas and CO<sub>2</sub>. In this relation, special attention should be paid to the mentioned areas in Dzhebel and Krumovgrad Depression. The interest for them is connected to the presence of reservoir and sealing volcanogenic or sedimentary rocks. On the basis of the carried out litological-physical segmentation of the sedimentary section, two perspective natural reservoirs are distinguished.

##### ***4.1. Natural reservoir, connected to the Oligocene Terrigenous – carbonate – pyroclastic reservoir formations in the Dzhebel Depression***

The Oligocene Terrigenous-carbonate-pyroclastic Reservoir Formation (1Pg<sub>3</sub><sup>1</sup>) and the hard-permeable rocks that restrict it from below and above belonging to the Pre-Paleogene basement and the Oligocene Volcanogenic Reservoir Formation (2Pg<sub>3</sub><sup>1</sup> и 3Pg<sub>3</sub><sup>1</sup>) take part in building of the natural reservoir (Fig.1).

*4.1.1. The Oligocene Terrigenous-carbonate-pyroclastic Reservoir Formation* is built by the eponymous formation from the Complex of the first acid volcanism (Lower Oligocene). Its struc-

ture is complicated. It consists of clastic and carbonate (reef limestones) rocks, interbedded by acid tuffs and epiclasts. Their spatial behavior could not be followed. In outcrops the thickness of the formation varies from 20 to 250 m. According to data from the regional seismic section the basal conglomerate's thickness is bigger – from 300 to 500 m. The depth of the top of the reservoir formation is variable and reaches up to 800-900 m. The reef and the coarse clastic sediments, situated in the basis of the section are expected to possess the best petrophysical parameters.

*4.1.2. The Oligocene Volcanogenic Sealing Formation (cover)* consists of rocks from the Complex of the second middle-acid volcanism (Terrigenous-carbonate-epiclastic Formation) and the Complex of the second acid volcanism (Carbonate-pyroclastic-lava Formation and the Terrigenous-carbonate-pyroclastic Formation). The Permeable Sandstone Formation (Dzhebel sandstones) or the hard-permeable deposits of the Complex of third middle-acid volcanism (Lower Oligocene) are situated above the sealing formation. The information for them, according to data from outcrops, doesn't allow conclusions for its spatial behavior to be made. The thickness probably varies in the limits from 200-300 to 800-900 m. The sealing formation is with variable properties. The sediment rocks in it are mainly permeable, but it is supposed that in the sunken areas their presence is insignificant.

*4.1.3. Pre-Paleogenic hard-permeable rocks (underlayer)* consist of variable metamorphic rocks (Precambrian) and Mesozoic low-crystalline and magmatic rocks.

##### ***4.2. Natural reservoir, connected to the Upper Cretaceous –Middle Eocene Terrigenous-Reservoir Formation in the Krumovgrad Depression***

The Upper Cretaceous – Middle Eocene Terrigenous Reservoir Formation (krK<sub>2</sub>-Pg<sub>1</sub>, 1Pg<sub>2</sub><sup>2(2)</sup> and 2Pg<sub>2</sub><sup>2(2)</sup> – lower part) and the hard-permeable rocks that restrict it from below and above belonging to the Pre-Paleogene basement and the Eocene-Oligocene Terrigenous-carbonate-volcanogenic Sealing Formation (2Pg<sub>2</sub><sup>2(2)</sup>.- top, 1Pg<sub>2</sub><sup>3</sup>, 2Pg<sub>2</sub><sup>3</sup>, 1Pg<sub>3</sub><sup>1</sup>, 2Pg<sub>3</sub><sup>1</sup>, 3Pg<sub>3</sub><sup>1</sup>, 5Pg<sub>3</sub><sup>1</sup>, 6Pg<sub>3</sub><sup>1</sup>) take part in building of the natural reservoir (Fig.1).

*4.2.1. The Upper Cretaceous – Lower Eocene Terrigenous Reservoir Formation* is built of the rocks

of the Krumovgrad Group, the Breccia-conglomerate Formation from the Complex of the varicolored (red) breccia-conglomerate, sandstones and sandy clay and the lower part of the Sandy-coal-bearing Formation (Maastricht – Middle Eocene). The scanty information doesn't allow the spatial behavior of the reservoir formation to be traced. According to data from the outcrops, its thickness varies from 200-300 m (in the western part of the depression) to 400 m (in the eastern part). The thickness near its top is variable and in its eastern part (according to data from the regional seismic section) reaches up to 1900 m and it reduces in western direction to 800-900 m. The quantity data for the reservoir parameters of the permeable rocks are missing. Having in mind their lithologic variation, it is supposed that they possess variable capacity and filtration properties.

*4.2.2. The Eocene-Oligocene Terrigenous-carbonate-volcanogenic Sealing Formation (cover)* includes the upper part of the Sandy-coal-bearing Formation, the clayey-carbonate (the Marl-limestone Formations) and the volcanogenic (the Complexes from first to third middle-acid and acid volcanism) rocks (middle Eocene-Lower Oligocene). The scanty information doesn't allow their relations to be traced. Obviously, the hard-permeable rocks consecutively situated in the section build the sealing formation with a significant thickness that reaches up to 1900 m. It is covered by the hard-permeable Coal-bearing-terrigenous Formation (Valchepol Molasse). Quantity data for sealing parameters of the formation are missing. Having in mind the lithologic characteristic of rocks, it could be supposed that they possess from high to low sealing properties.

*4.2.3. Pre-Paleogenic hard-permeable rocks (underlayer)* consist of variable metamorphic rocks of the Rhodope Higher Group (Precambrian) and Mesozoic low-crystalline and magmatic rocks.

## **5. Structural-tectonic, hydrogeological and seismotectonic conditions**

The structural-tectonic characteristics of the Tertiary section suppose the presence mainly of lithologic (stratigraphic) and the combined type of natural traps. An important factor for their forming is the block structure of the basement, determined by the multiple breaks that comprise the Tertiary section as well.

The Tertiary section of the East Rhodope Depression is poorly studied in hydrogeological relation.

The direct hydrogeological information from the well data is received only for separate thermo-aquifer and ore zone or fields in the peripheral parts of the graben structures (Antonov and Danchev, 1980). The hydrogeological space in the Paleogene section and in the basement of the depression in the most tectonic units is cut by water-main, fault dislocations and permeable contacts of cutting volcanic bodies. They are open towards the surface. Geostructural and lithofacial preconditions for presence of aquifer bodies and horizons protected from water-exchange with the surface occur only in Ddzhebel and Krumovgrad Depression.

During the regional geothermal separation of South Bulgaria, well-outlined anomalies of the heat flow are distinguished. Their nature is accepted to be endogenous. In the Central Rhodope active geothermal zone the distribution of temperatures to the depth of 5 km is of the rate of 140-180 °C. The studied region is to the east of this zone and the temperatures are lower than 130 °C (Dobrev et al., 2004).

The summarized analysis of the seismic activity in South Bulgaria indicates that more intensive seismic shows in the studied region are registered only in the Kardzhali Zone. It is situated in north-northwestern direction, outside the perspective areas.

## **6. Conclusion**

The applied methodical approaches are in accordance with the specific geological conditions and the poorly studied East Rhodope Depression, from the point of view of the examined problem. In this connection the subject of our study are part of the graben structures of variable order with accent put on the studying of the reservoir systems and the conditions for forming of suitable natural traps. In this relation, two natural reservoirs, situated in the Tertiary section of the sunken areas of Dzhebel and Krumovgrad Depressions, are assessed as possible perspective zones. The reservoir formations are mostly built of clastic deposits and their thickness is significant. Sealing rocks are mainly the volcanogenic ones. Natural traps of stratigraphic and combined type are bounded to the perspective reservoir systems. It is supposed that there are favorable hydrodynamic and thermobaric conditions of the aquifer horizons and good hermeticity of the potential storages. The perspective areas are situated in a zone of low seismic activity.

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