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Structural and Stratigraphical Relations in the Eastern Part of the Drava depression - Wider Area of the field Beničanci

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Abstract
This article closely defines the stratigraphic and structural relations within the eastern part of the Drava depression. These relations are explained in detail for the more important fields located in the area of exploration such as Beničanci, Klokočevci, Števkovica and others. A geological column has been synthesized for the Beničanci area together with correlation profiles to better display the lithology of the Lower and Middle Miocene. Furthermore, structural maps of key bed H and EL-markers G, Z', Rρ, α have been developed and interpreted and the stratigraphic-structural relations of the investigation area have been laid down.

Keywords
structural and stratigraphic relations, geological column, marker beds, mapping, Drava depression, Croatia

1. Introduction

The evolution of the southwestern part of the Pannonian Basin System is of great importance for the entire petroleum geology system in Croatia. The factors that allowed the formation of that system are tectonic movements, especially lowering, the relatively high geothermal gradient, the accumulation of large amounts of organic matter in certain stages of sedimentation (mostly in Badenian, Sarmatian and Pannonian) as well as the existence of sedimentary environments which resulted in the occurrence of rocks with good reservoir properties (**Velić, 2007**). The migration paths have been defined as short whilst lateral and vertical movement of fluids dependent on free energy levels and pressure (**Hernitz et al., 1995**). Source rocks are widespread and possess a high generative potential (**Velić, 2007**). They belong to the Middle and Upper Miocene. The main reservoir rocks are clastics of Miocene age and in some places migmatites. Generally speaking, the sedimentary infill can be in the stratigraphic range from the Lower Badenian (in some places perhaps Ottnanghian) to Holocene, and the whole series is divided into several lithostratigraphic units (**Figure 1**).

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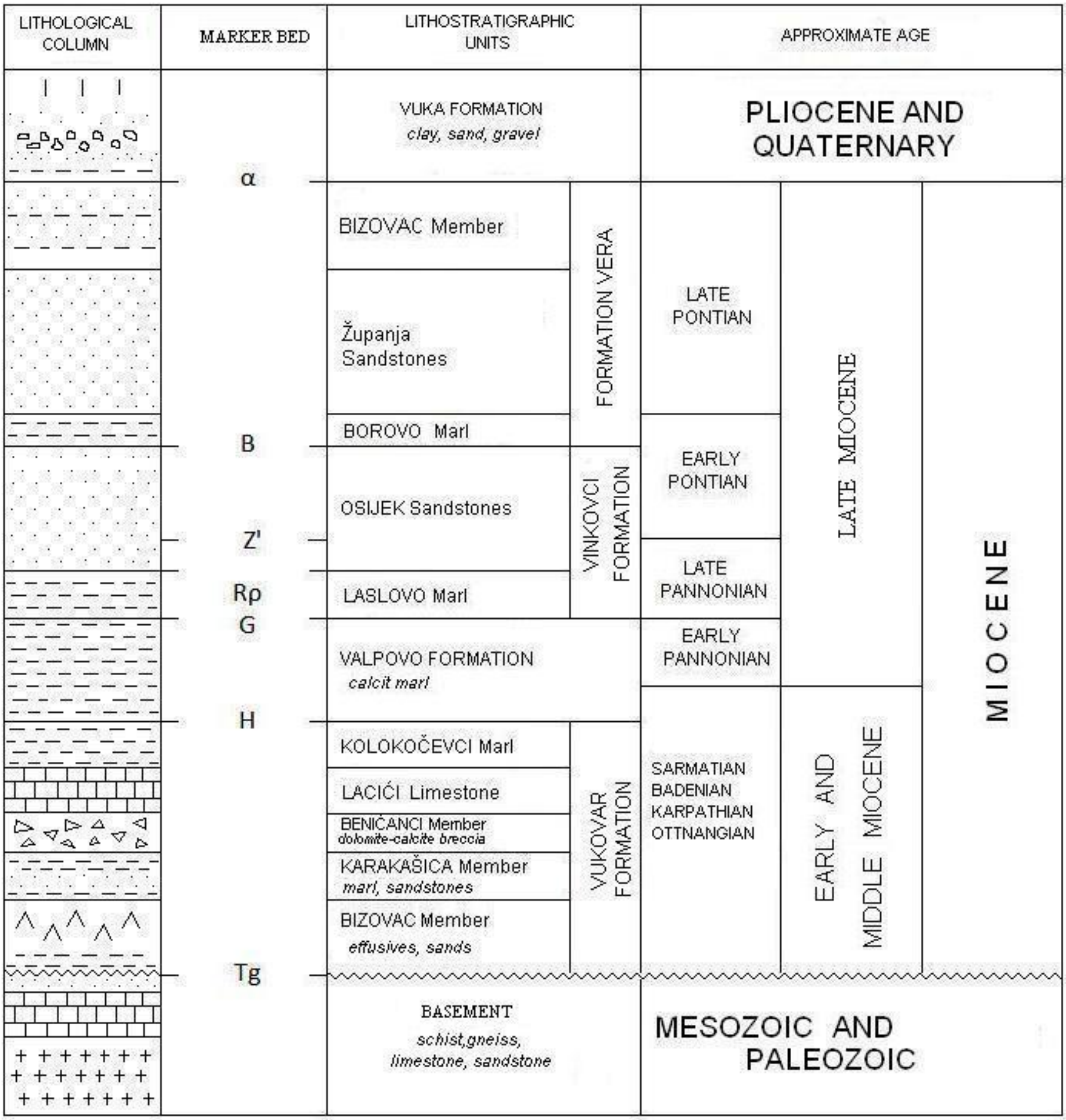

Figure 1: Preview of litostratigraphic units in the eastern part of the Pannonian Basin System (modified after **Hernitz, 1983**)

2. Methods

In order to present the stratigraphic-structural relations clearly, structure maps of the EL-markers have been made. Structural maps are subsurface maps which show structural relations represented on a selected surface layer. When creating structural maps, the source of input data is most important and the reliability of the same map depends upon it. Input data consists primarily of well data obtained by geophysical measurements and data obtained by seismic measurements that contribute to the accuracy of the original interpretation of the data.

Five structural maps have been developed: the structural map of key bed H (presumed border of Sarmatian and the upper Pannonian), the structural map of EL-marker G (presumed border of younger and older Pannonian), the structural map of EL-marker Z' (presumed border of Pannonian and Pontian), the structural map of EL-marker Rρ (Early Pontian), and the structural map of EL-marker α (presumed border of the older Pontian and

Pliocene). All maps were developed using the program Golden Software Surfer. The structural map of EL-border Tg was not made due to the lack of data.
Values on the maps are derived from the interpolation and extrapolation of well data. Interpolation is the process of drawing the appropriate lines of the same values on the map, to which appropriate values are allocated within the well workspace. These values are based on existing point data (well, seismic and other). Extrapolation is the process of drawing the appropriate lines of the same values on the map, to which appropriate values are allocated from outside the well workspace up to the edge of the map. Some of the mapping methods are: Inverse Distance Weighting, Nearest Neighbourhood, Moving Average and Kriging (**Balić et al., 2008**). The mapping method used in the preparation of structural maps in this paper is Inverse Distance Weighting. The mentioned method is based on the assumption that the nearest measured surrounding values have the greatest influence on the variable value being estimated. The number of values included in the estimate ($z_1 ... z_n$) are determined by the radius of the circle drawn around the location of the estimated variable. The values are estimated by a simple mathematical expression (**Eq. 1**) where z_{IU} describes the estimated value, $z_1 ... z_n$ of the real values on the sites 1, ..., n, $d_1 ... d_n$ the location distances from 1 to n from the evaluation site z_{IU} and p exponent distance, which is most often 2. The result of the method often depends a lot on the value of the exponent distance. Mostly it is 2 for the purpose of simpler results.

$$z_{IU} = \frac{\frac{z_1}{d_1^P} + \frac{z_2}{d_2^P} + \cdots + \frac{z_n}{d_n^P}}{\frac{1}{d_1^P} + \frac{1}{d_2^P} + \cdots + \frac{1}{d_n^P}} \qquad \textbf{(Eq. 1)}$$

3. Geographical position of the investigation area

The investigated area covers the following exploitation fields: Beničanci, Bokšić, Klokočevci, Crnac, Števkovica, Obod-Lacić and the Obod oil field. The above mentioned fields are located in the eastern part of Croatia (**Figure 2**). According to the administrative and territorial division, they belong to the Osijek – Baranja and Virovitica – Podravina County. From a morphological perspective, the fields are located on mainly flat terrain at an average of 92 meters above sea level.

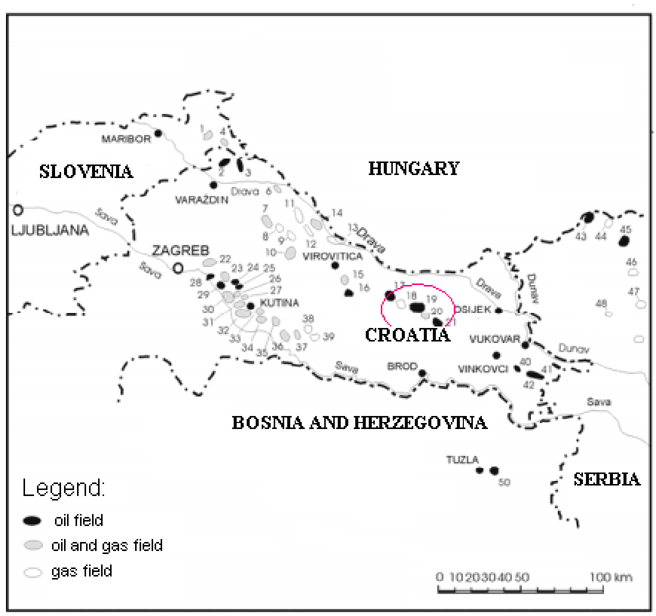

Figure 2**:** Approximate location of the investigation area (**Velić, 2007**)

4. Research history of the Beničanci area

The investigation of the Drava Depression began in the late 60's and early 70's of the 20th century (**Takšić 1970**, **1973**). A significant contribution to the understanding of tectonic movements and their petroleum geological significance of the Sava – Danube area was made by **Kranjec** (**1972**); normal faulting used to be the main point of interest, but the attention shifted to the consideration of reverse faulting. **Cvijanović** (**1969/70**) researched the seismicity of the Slavonia region and came to the conclusion that the registered earthquakes are linked to the routes of the main faults.

The exploitation of the investigated fields began in the 70's of the 20th century. Production of oil and gas from the Beničanci field began in 1972. **Knapp and Koščec** (**1974)** published terrestrial and aerial gravimetric measurements in the area Beničanci. By analysing the data, they determined the contours of structures that match the actual contours determined by drilling. 1972 was also the year of the beginning of the exploitation of hydrocarbons in the Bokšić – Klokočevci field. The Obod field was put into production in 1975. **Malez** and **Takšić** (**1977**) provided a general overview of the geological structure of the eastern part of Slavonia. **Radić** and **Hrnčić** (**1979**) indicated that hydrocarbon deposits are formed in structural type traps in the area of the eastern part of the Drava depression in the Bizovac, Obod, Beničanci and Bokšić fields. Exploitation in the field Števkovica began in 1979 and in the field Crnac in 1981. **Hernitz (1983)** describes structural and tectonic relationships in the subsurface of the eastern part of Slavonia in his doctoral thesis. In recent years, numerous research and studies of the area Beničanci were conducted. As an example, **Vulama** (**1994**) examines the potential of source rocks in the eastern part of the Drava depression based on geophysical measurements in wells. In the same area, **Hernitz et al.** (**1995**) describe the source rock as dense, very solid marls/marl containing organic matter in the range of 0.6% to 6.0%. Also, **Malvić** and **Prskalo** (**2007**), estimate the porosity of the zone Beničanci using neural networks, emphasizing the linking of seismic attributes to the petrophysical properties of the rocks.

5. Geological settings of Beničanci, Klokočevci, Crnac and Števkovica Fields with an emphasis on trap and reservoir relations

5.1. Stratigraphic and structural relationship of the investigation areas

The geochemical characteristics of the source rocks in the basin should be noted, i.e. their maturity, generation, migration and the preservation of hydrocarbons. Through geological history, heat flow had a great influence on the maturity of the source rocks which is very high even today (>80 mW/m^2) (**Hurter & Haenel, 2002**). By reviewing the structural and stratigraphic relations, as well as the Petroleum system elements, correlated profiles were developed in order to identify boundaries between certain formations. **Figure 4** shows the correlation profile (Profile A-B) traversing the Števkovica oil field, with a Southwest-Northeast orientation. The profile length is approximately 4300 m. The route of the profile is shown in **Figure 3,** and it passes through wells Štv-17, Štv-30, Štv-10, Štv-1, Štv-13 and Štv-9. The correlation profile (Profile C-D) with West to East orientation is shown in **Figure 6.** It intersects the entire investigation area and also the following exploitation fields: Števkovica, Crnac, Kućanci, Beničanci, Obod and Lacić where their location is shown approximately. The total length of the profile is approximately 27000 m. The route of the profile can be seen in **Figure 5**, which does not show all the wells within these fields, rather the wells in the vicinity of the route of the profile.

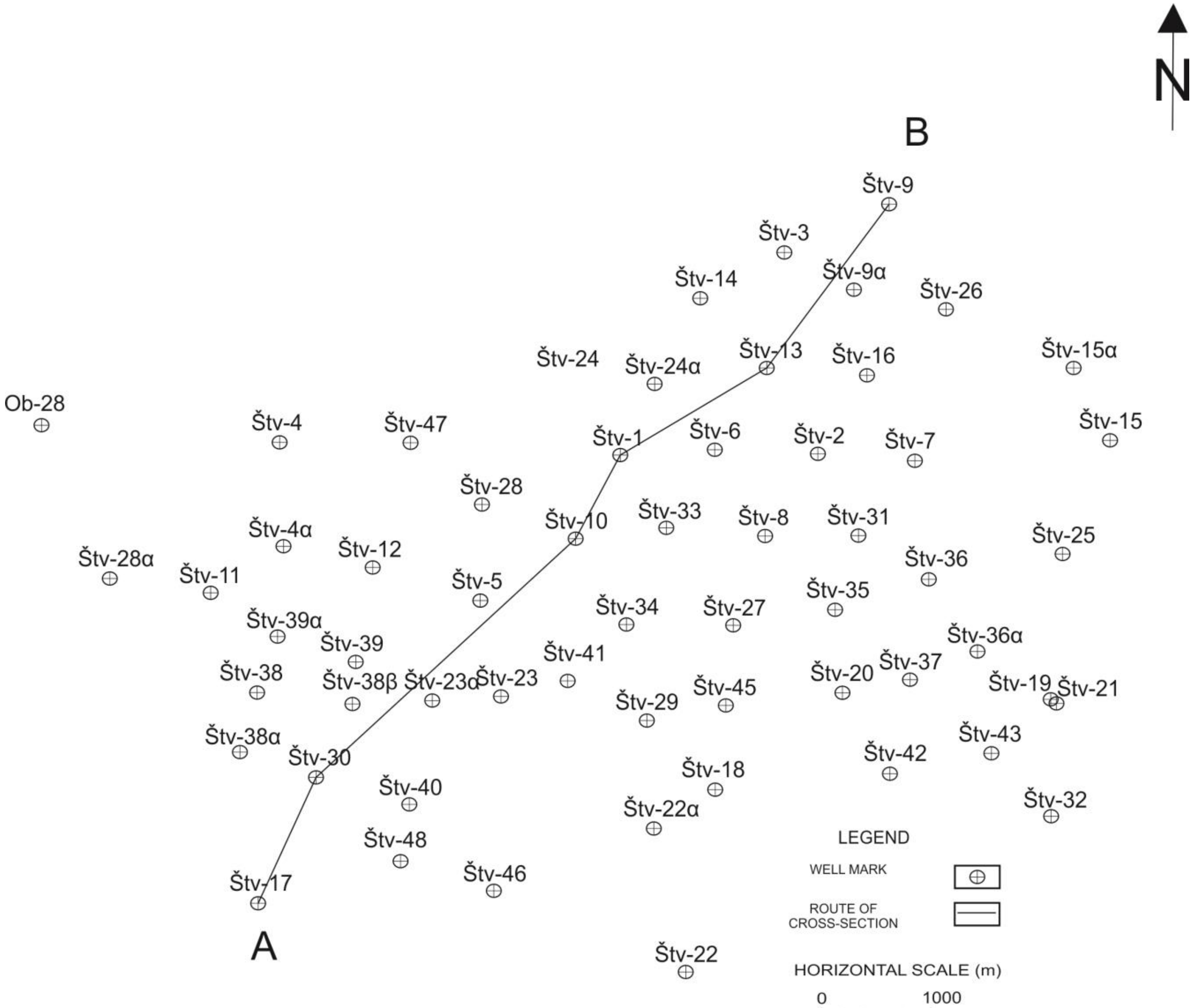

***Figure 3*:** The route of the cross-section of Števkovica Oil Field (**Slavinić, 2014**)

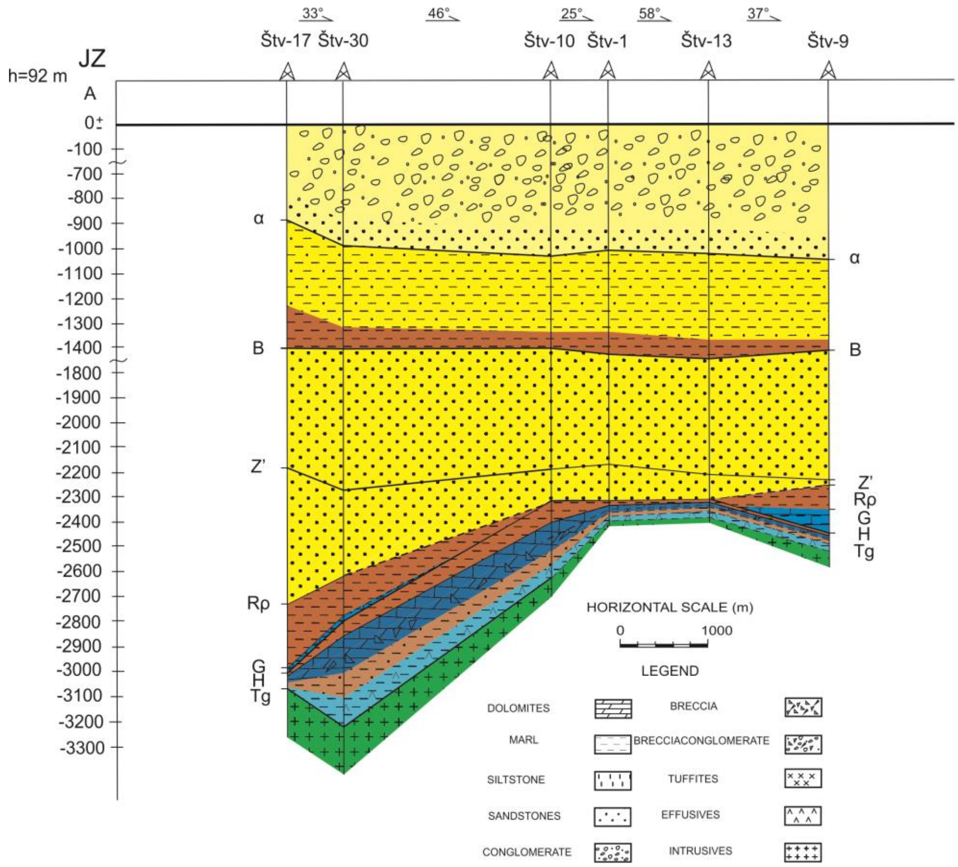

***Figure 4*:** Cross-section of Števkovica Oil Field (**Slavinić, 2014**)

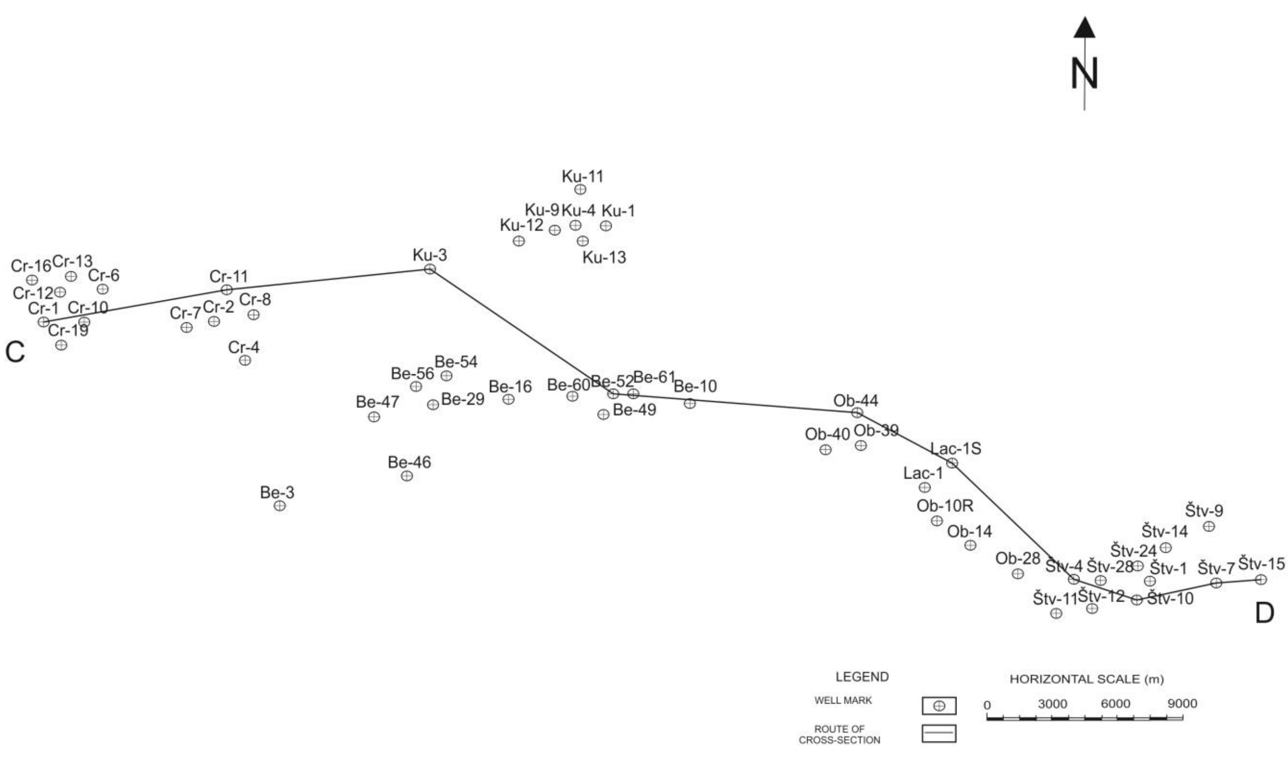

Figure 5: The route of the longitudinal section of the investigation area (**Slavinić, 2014**)

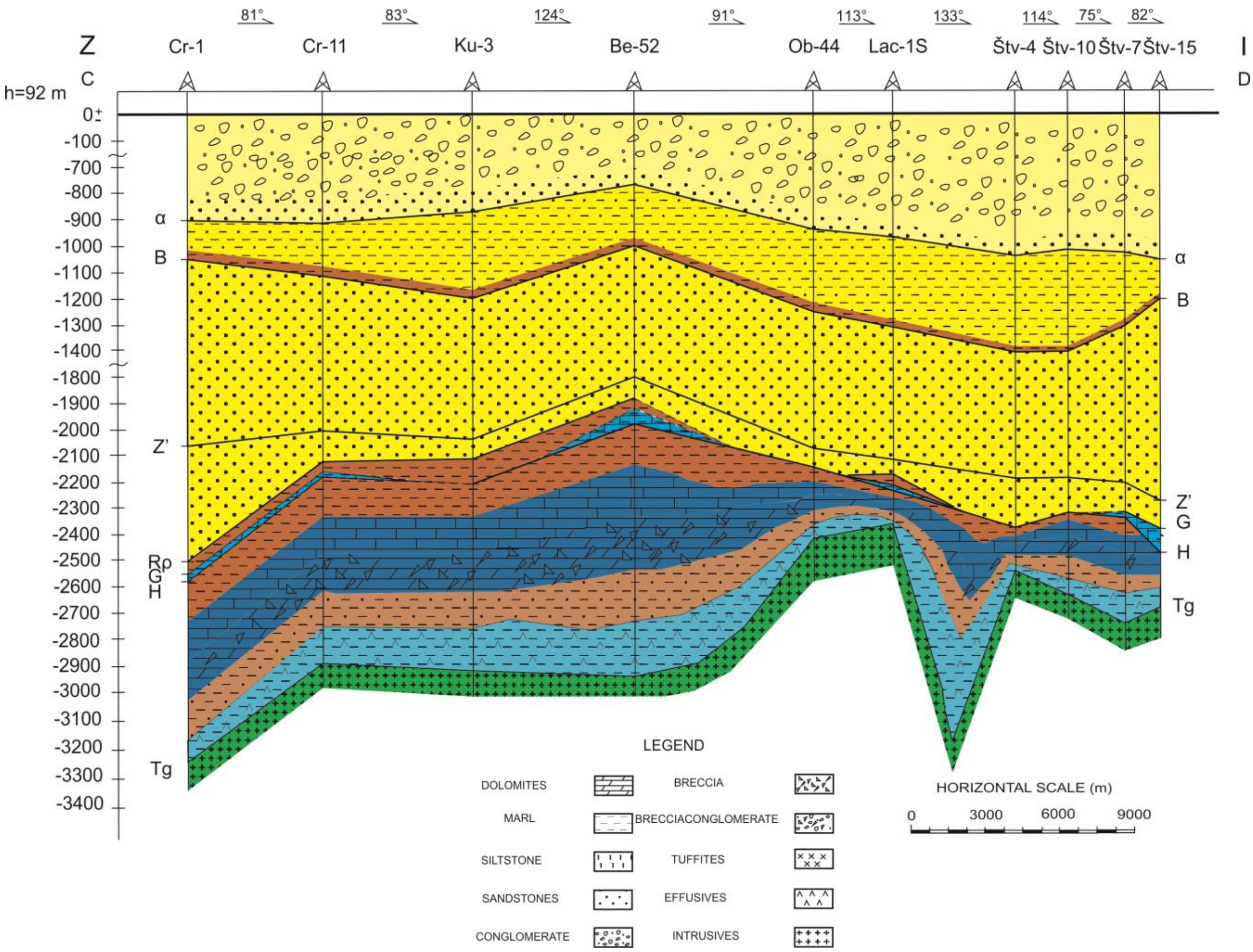

Figure 6: Longitudinal profile of the investigation area (**Slavinić, 2014**)

Geological history of the investigation areas is associated with strong tectonics, a variating depositional environment and the accumulation of large amounts of organic matter. A decisive role in the recognition and correlation of established units in the investigation area was played by EL-markers, key bed and conditional EL-border Tg, i.e. their successful spatial tracking. By comparing the geological columns on the eastern part of the Drava depression, the following regional EL-markers have been singled out: α, B, Z', R $_{\rho}$, G, H and EL-border PT (Tg) (**Šimon, 1973**). The basement rocks of the investigation area consist of igneous and metamorphic rocks, Paleozoic phyllite, quartzite, tuffs, intrusive rocks and clastic rocks (**Alajbeg et al., 1996**). Their age is often only roughly estimated due to many orogeneses, which have eroded and destroyed the primary assemblages of the rocks (**Malvić & Cvetković, 2013**). Palaeozoic and Mesozoic sediments are separated from Neogene sediments by a regional discontinuity.

5.2. Lithological characteristics

The lithological characteristics of the investigation area are represented by the standard geological column for which one of the wells on the Klokočevci structure has been selected for the representation (**Figure 7**). The geological column was developed based on the data from the cores and the results of the biostratigraphic analysis of the well. The total depth is 3554 meters to which the Vukovar, Vinkovci and Valpovo Formations have been drilled. The deepest parts of the well contain basalts and andesites. Coarse breccia overlaps them at the depth of about 3000 meters. This is followed by a 1000 meters thick interval of marl and calcitic marl within which we can find a scud of breccia conglomerate with a sandy matrix. After 2050 meters, sandstones and siltstones are deposited with thin layers of shale.

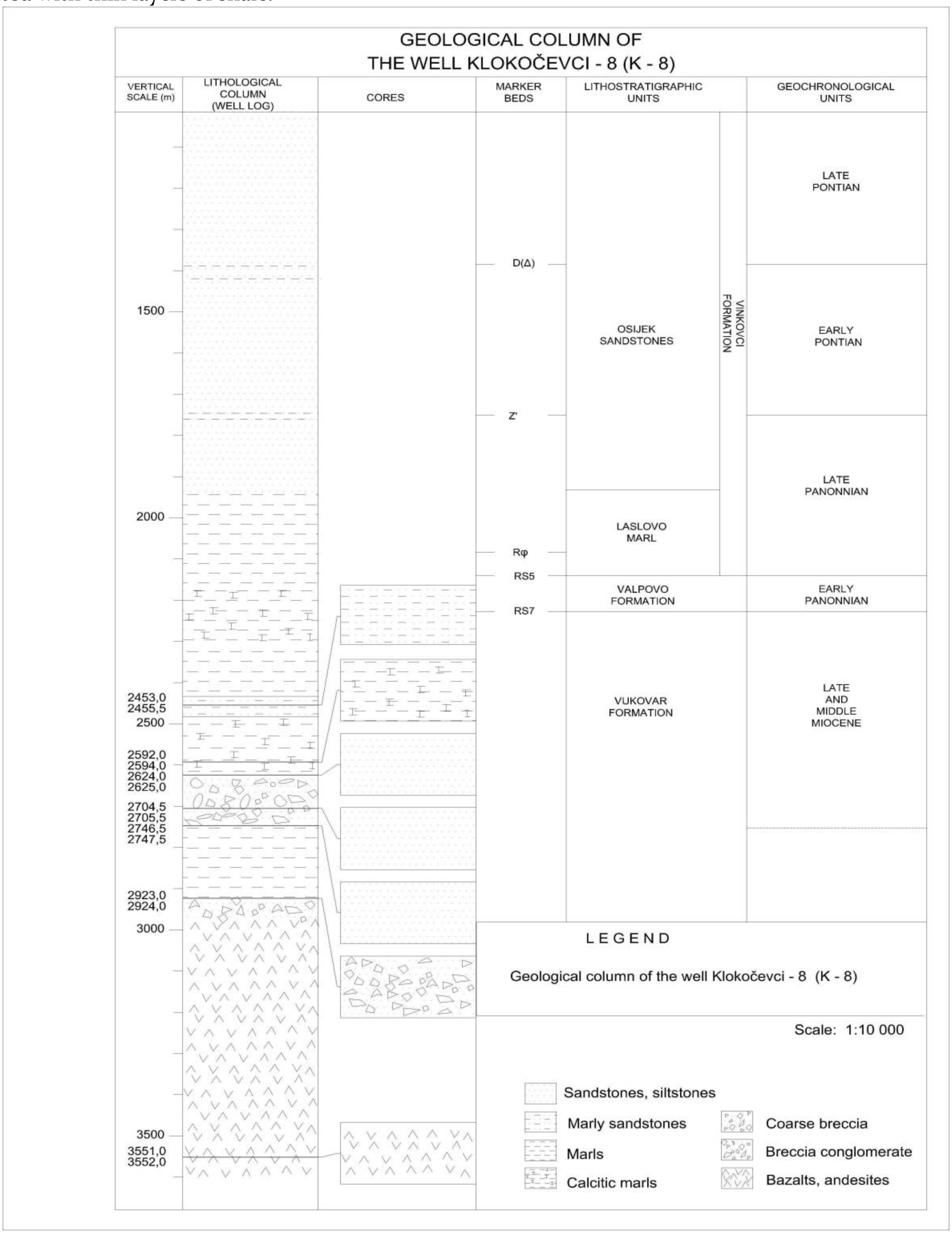

***Figure 7*:** Geological column of well Klokočevci-8 from the exploatation field Bokšić-Klokočevci (**Drmić, 2014**)

5.3. Structural characteristics of the investigation area

In the area of the Pannonian Basin System, the extension began in Ottnanghian (**Malvić, 2003)** and was accompanied by local marine transgressions, volcanic activity, paralic deposition conditions and faults with displacement along the strike.

The first transtensional phase began in the Badenian period when tectonic activity was most active and formed the majority of the structures. Lower Badenian sediments of the Vukovar Formation are mainly effusive rocks, sandstone and marl while Middle Badenian sediments are coarse breccia and breccia conglomerate, which form reservoir rock of the investigation area. After repeated cycles of transgression and regression in Badenian, a regression phase started in Sarmatian, which is typical for the central part of the Paratethys (**Rögl & Steininger, 1984**). The post-extension phase is marked by thermal lowering and thus extensive tectonics shifted to compression, i.e. to the first transpressional phase (**Malvić & Velić, 2011**). Thus, reverse NW-SW faulting occurred within the Števkovica field (**Gaćeša, 1982**). Sea levels dropped, reducing the level of salinity and the environment therefore become paralic. The second transtensional phase began in the early Pannonian (**Malvić & Velić, 2011**) and the reoccurrence of stretching faults. After the Pannonian period, the marl deposition continued with an increased amount of organic matter belonging to the Valpovo formation (**Malvić & Velić, 2011**).

As aforementioned (chapter 2), structure maps of each EL-marker and key bed have been made. In **Figure 8**, which is referring to the period of Early Pannonian, it can be seen that the isolines are less dense, indicating a decrease in tectonic activity and marl deposition within the mentioned formation. The Valpovo formation is separated from the Vukovar formation by key bed H (**Figure 4** and **Figure 6**). In the Early and Late Pannonian, sediments are up to 2 km thick because of large quantities of clastic material which was brought from the area of the Eastern Alps and which is characteristic for the Vinkovci formation and its members (**Hernitz et al., 1995**). These sediments are considered to be good collector rocks (**Hernitz, 1983**). The Vera formation, which corresponds to the period of Early Pontian, is characterized by a monotonous alteration of marl and sandstone. The marl formation is caused by periodic hemipelagic sedimentation in the lake environment (**Malvić & Velić, 2011**). The Vera formation is separated from the Vinkovci formation by marker bed B. In the period of the Early Pontian, Pliocene and Quaternary the second transpressional phase started when the preformed negative flower structures and faulted anticlines were uplifted and when the migration of hydrocarbons to the collector rocks occurred (**Malvić & Velić, 2011**). The Vuka formation, which belongs to the Pliocene, Pleistocene and Holocene period, covers the whole investigation area. According to the structural map of EL-marker α (**Figure 12**), the filling of the deeper parts of the environment and the reduction of the aquatic environment can be observed, and finally the terestric phase. In the deeper areas, the formation is composed of clay, sand and silt, and in the shallower areas of sand and conglomerate.

5.3.1. Structural map of key bed H (border between Sarmatian and Early Pannonian)

On the structural map of key bed H (**Figure 8**) the depth values range from -1800 up to -2950 meters. The increment is 50 meters. The crosses on the map represent the wells. The shallowest area on the map is located in its central part, the area of the Beničanci field and represents a big anticline. There are several smaller synclines East and South of this anticline. In the center of the map the distance between isolines gets smaller; about -2100 meters and about -2250 meters at the eastern part of the mapped area. This mapped area could be interpreted as a possible fault zone.

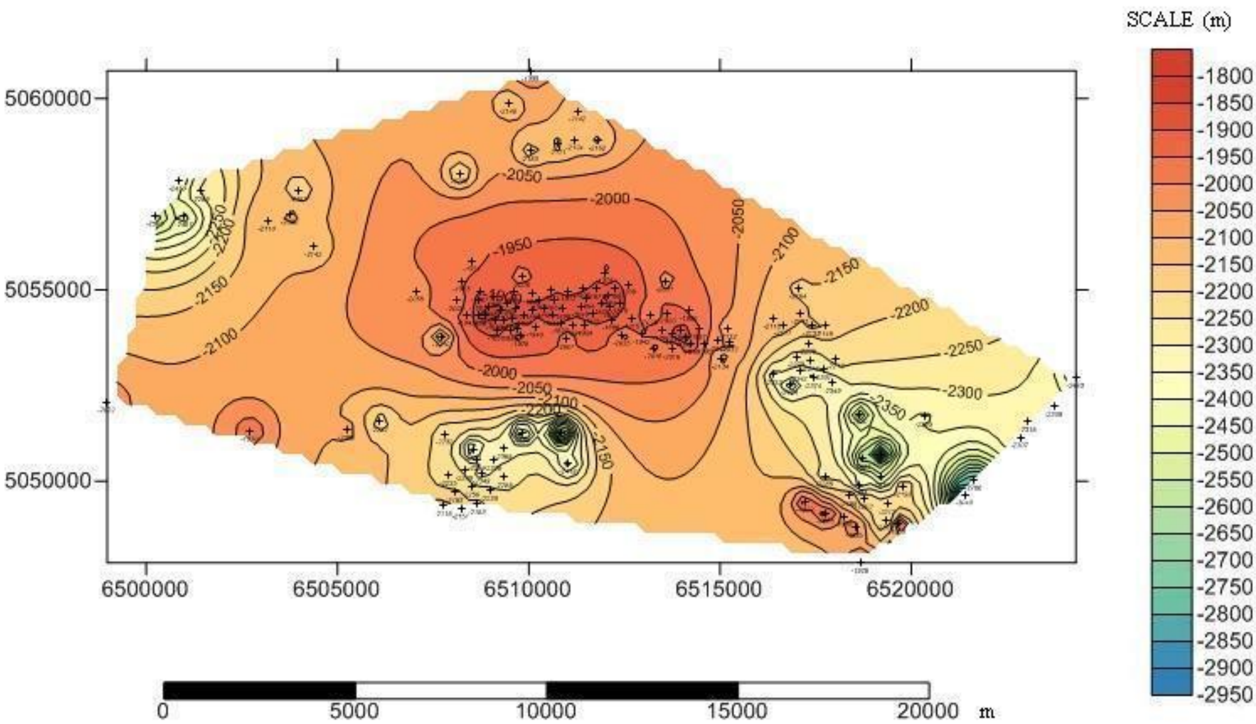

***Figure 8*:** Structural map of key bed H (the border between Sarmatian and Early Pannonian)

5.3.2. Structural map of EL-marker G (border between Early and Late Pannonian)

EL-marker G is located within the Late Pannonian and it separates the Valpovo and the Vinkovci formation. The structural map of EL-marker G is represented in **Figure 9**. The increment of 50 meters was used, as in the previous map. Depths of the EL-marker G reach up to -2950 meters. The areas marked blue are the locations of the deepest parts of the structure in the southern and southeastern part of the mapped area. The areas marked orange red are areas of small depth in the central part of the mapped area (the Beničanci Field).

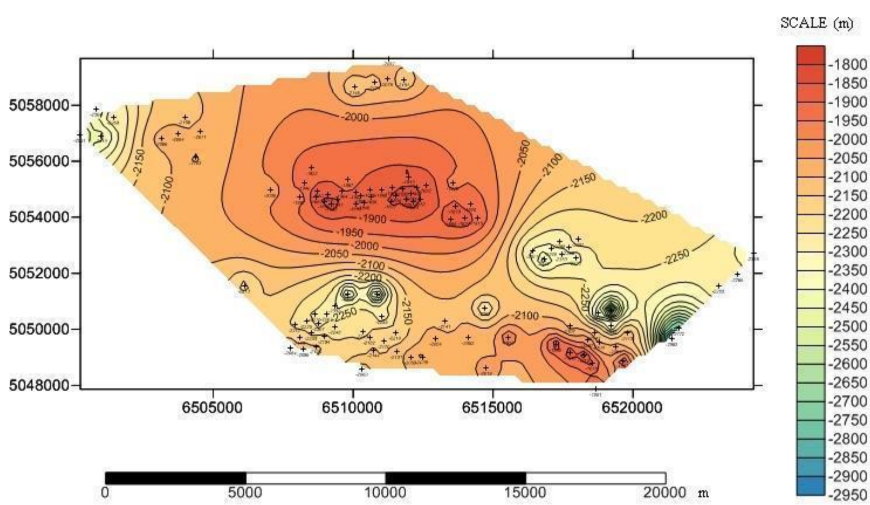

***Figure 9*:** Structural map of EL-marker G (the border between Early and Late Pannonian)

When comparing the structural maps of EL-marker G and key bed H, there are no visible larger structural changes. It can be emphasized that the isolines on the structural map of EL-marker G are not as dense as on the previous map, and that can be correlated with the less intense tectonic activity and marl deposition within the Valpovo formation.

5.3.3. Structural map of EL-marker Z' (border between Late Pannonian and Early Pontian)

EL-marker bed Z' is located in the Vinkovci Formation (**Figure 10**). In general, the depths of EL-marker Z' range between -1700 and -2000 meters in the whole area. Towards the South and the Southwest, there is a decrease in the depths in which is EL-marker Z' located. In this part of the mapped area, the area of the field Obod, where there are several anticlines, the crests of which are located at depths of less than -900 meters.

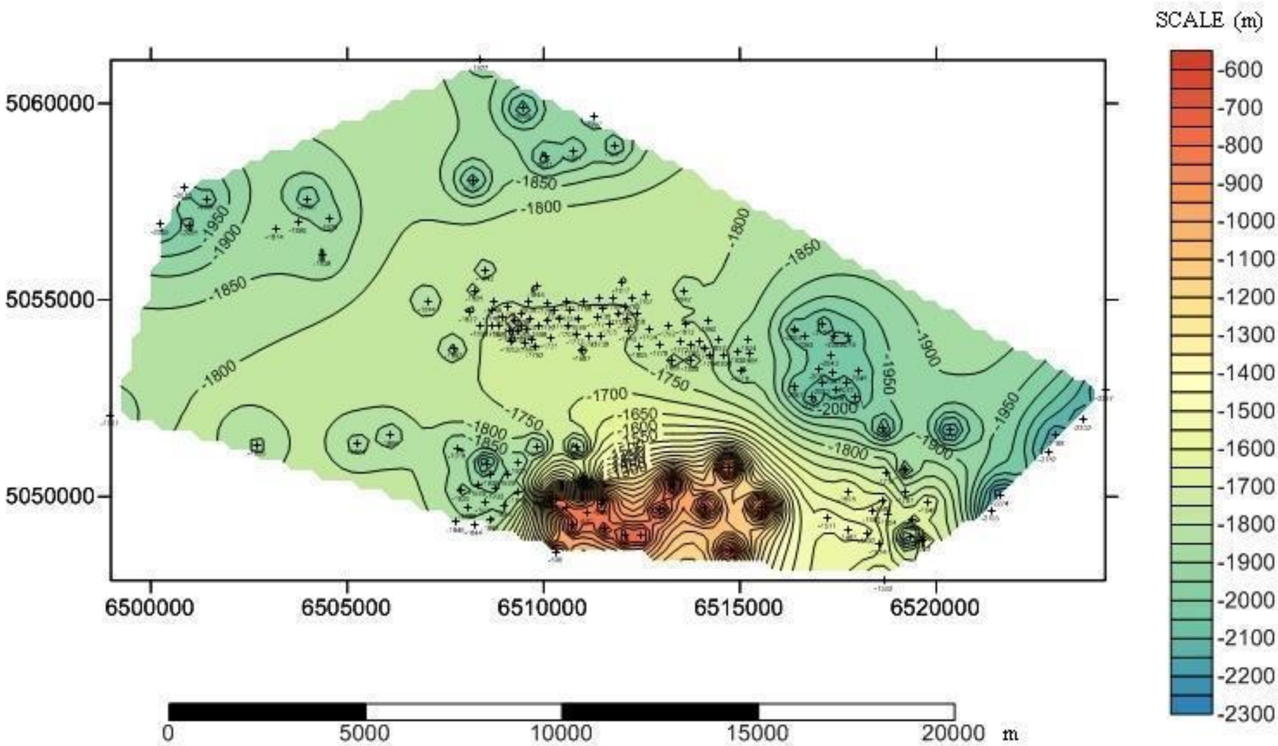

***Figure 10*:** Structural map of EL-marker Z' (the border between Late Pannonian and Early Pontian)

5.3.4. Structural map of EL-marker Rρ (Early Pontian)

EL-marker bed Rρ is located in the Vinkovci formation. The same equidistance was used for the structural map of EL-marker Rρ (**Figure 11**) as in the previous maps. The represented depths range from -1700 meters up to -2750 meters. The deepest parts of the area are located in the southeastern part of the mapped area where there are the three anticlines, the crests of which are located at depths of over -2100 meters. Towards the North, there is a decrease in the depths in which EL-marker Rρ is located. Two shallowest anticlines are located within the isoline of -2000 meters. One is located in the central part of the mapped area in the area of the field Klokočevci and the other in the southern part of the mapped area in the area of the field Števkovica.

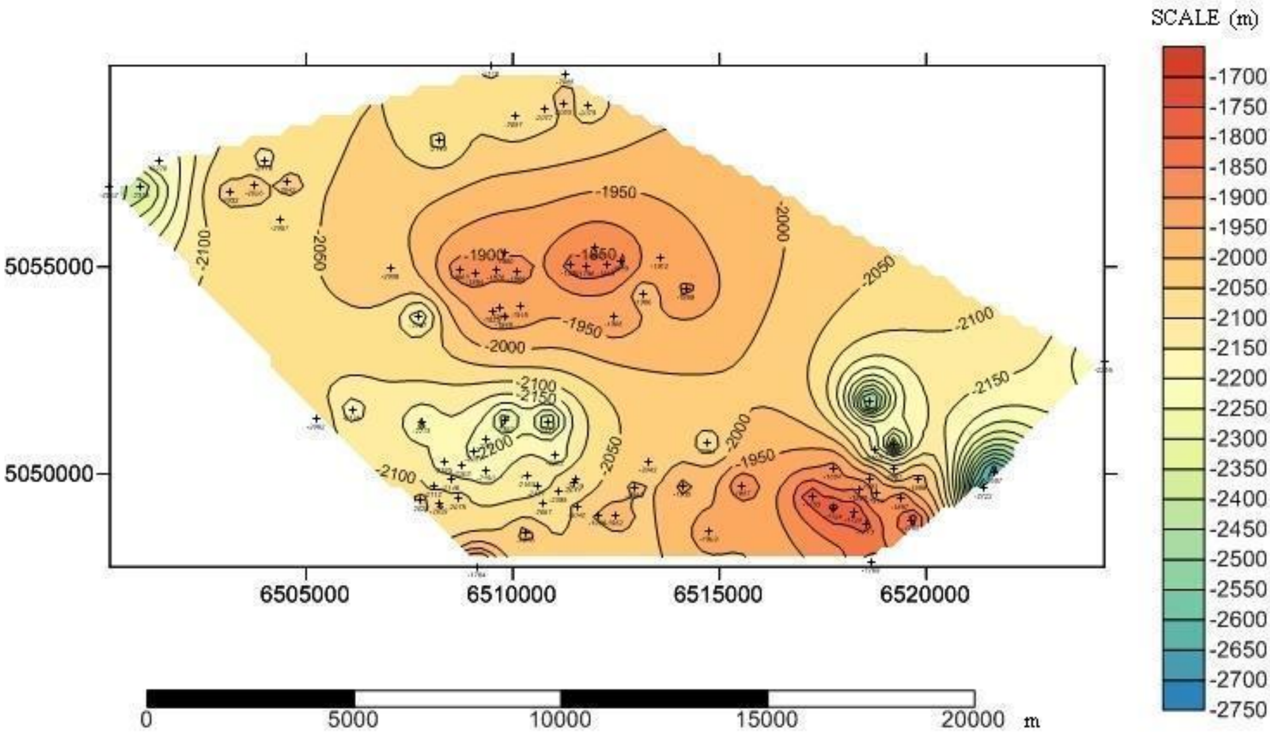

***Figure 11*:** Structural map of EL-marker Rρ (Early Pontian)

5.3.5. The structural map of EL-marker α (Base of Pliocene)

A structural map of the EL-marker α (**Figure 12**) was also developed. The increment of this map is 100 meters and that makes the difference between this map and the other structural maps. The reason for this is the fact that the structural map of EL-marker α with an equidistance of 50 m does not sufficiently reflect structural details and their changes because isolines are too dense in some parts. The minimum depths of EL-marker α in the mapped area are 200 meters. The anticline, the crest of which is located at a depth of approximately -200 meters, is located in the northwestern part of the map. The greatest depths reach up to -1900 meters. The depths of EL-marker α decrease by going from North to South.

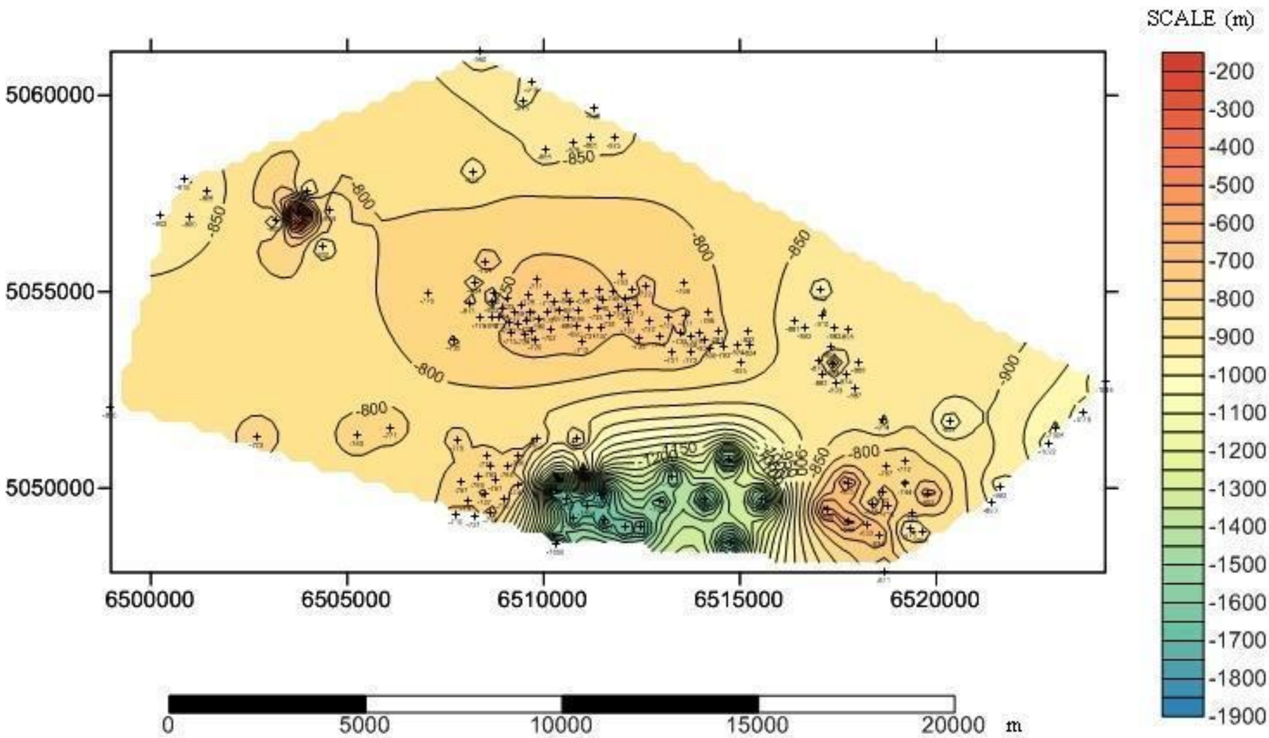

***Figure 12*:** Structural map of EL-marker α (the border of older Pontian and Pliocene)

6. Conclusion

The structural maps present areas of minimum and maximum depth (anticlines and synclines) of the investigation area and their development throughout geological time. The structural maps that have been created confirm the development phases of the Pannonian basin system. Hydrocarbon reservoirs of the mapped areas belong to the structural and stratigraphical type. The source rocks date back to the Miocene period and are located within the Vukovar and Valpovo formation, precisely between EL-marker G and key bed H and the conditional EL-border Tg, at depths greater than -2000 m. The reservoir rocks vary from field to field. In the Števkovica field, these are marly limestones that were originally source rocks while in other fields, these rocks are still merely source rocks (**Vulama, 1994**).

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8. Sažetak (abstract in Croatian)

Ovaj članak pobliže definira strukturno – stratigrafske odnose unutar istočnog dijela Dravske depresije. Ti odnosi detaljnije su objašnjeni za važnija polja u istraživanom području kao što su Beničanci, Klokočevci, Števkovica i ostala. Izrađen je tipski geološki stup zone Beničanci zajedno s korelacijskim profilima radi zornijeg prikaza litologije donjeg i srednjeg miocena. Nadalje, izrađene su i interpretirane strukturne karte po EK-markerima G, Z', R_ρ, α i EK-reperu H te su utvrđeni i stratigrafsko – strukturni odnosi istraživanog područja.

Ključne riječi

Strukturno - stratigrafskio odnosi, geološki stup, EK-markeri, EK-reper, kartiranje, Dravska depresija, Hrvatska.