MGPB

The Mining-Geology-Petroleum Engineering Bulletin
UDC: 550.832.4
DOI: 10.17794/rgn.2015.1.1

preliminary communication

Overview and Reinstatement of Some Geophysical Interpretations in the Eastern Sava Depression

***Tihana Ružić**
INA - Industrija nafte, d.d., Sektor za geologiju i inženjering, Šubićeva 29, 10000 Zagreb

Abstract
The eastern part of Sava Depression is bounded on the south with the Sava River and on the north with Psunj Mountain, Požeška and Dilj Hills. In this part thicker Neogene-Quaternary sediments than in the western part were found, and there is almost never reached thermal maturity sufficient to catagenesis. Therefore, after the first seismic survey and exploratory drilling, a new additional research never continued. The overview and assessment of the reconstruction of the part of geophysical measurements was prepared in the eastern part of the Sava Depression. In some previous interpretations rocks between the Upper Pannonian and Upper Pontian are described as result of deltaic systems, with the clinoforms. Regional deposition at the time of the Early Pannonian indicates the beginning of significant changes in the environment in Croatian part of the Pannonian Basin System (CPBS), with a distinct domination of turbidites. Clinoforms are possible results of especially psammitic detritus deposited toward the margins of the depression, and partly in the direction material transport. In the Early Pontian regionally depositional environments started to be local. In the Quaternary can be expected the existence of the delta or alluvial fans.

Keywords
Sava Depression, Pannonian Basin System, 2D seismic profiles, Upper Miocene, turbidites

1. Introduction

The article presents the overview of a small part of the previous research and results in the eastern part of the Sava Depression and has made rating reinterpreted data and models. In the study area has not been determined oil or gas fields, but in several wells oil and gas occurrences are found. For example, **Žgaljić (2003)** stated evidence of oil on the surface in locality Paklena and in the village Baćindol. Potential reservoirs are situated in the Pannonian and Pontian sandstones (Ivanić Grad, Kloštar Ivanić and Široko Polje Formations) and in the Middle Miocene sediments of Prkos and Prečec Formations.

In some previous interpretations rocks between the Upper Pannonian and Upper Pontian are described as result of deltaic systems. However, regional deposition model in the Early Pannonian indicates that turbidites start to predominate in the Croatian part of the Pannonian Basin System (CPBS), what lasted to the end of Late Pontian.

*Corresponding author: Tihana Ružić
tihana.ruzic@ina.hr

2. Geography

The eastern part of Sava Depression is bounded on the north with Psunj Mountain and Požeška and Dilj Hills, and in the south with the Sava River. The area that covers approximately 325 km^2 is covered with very rare network of 2D seismic profiles (25 profiles) where the distance between them is over 5 km (**Figure 1**).

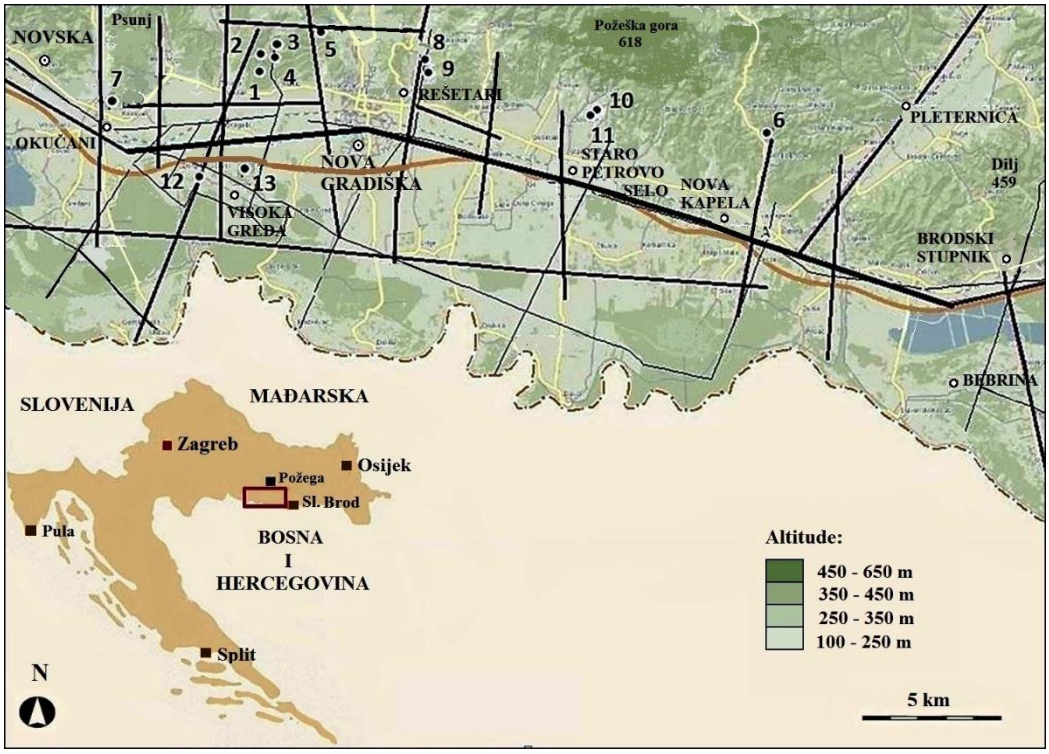

Figure 1. Location map of analysed area with a network of 2D seismic profiles and exploration wells

3. Review of previous researches in analysed area

Profiles are recorded in the period from 1978 to 1990. In the period from 1955 to 1962 13 exploration wells are drilled. The 3 of them reached basement rocks (informal unit "Temeljno gorje"), 3 have reached Middle Miocene sediments (Prečec Formation), and 7 are finished in the Lower Pontian sediments (Kloštar Ivanić Formation). In 2 were found in oils and gas shows, in 1 of oil, and in 3 of gas (**Table 1**, **Figure 1**).

Table 1. The wells located in the analysed area

Well	Year of drilling	Final depth (m)	Hydrocarbons how(s)
1	1955	1101	Gas
2	1955/56	1710	Gas
3	1956	2360	Negative
4	1956/57	1478	Gas
5	1958	1581	Gas
6	1957	1156	Oil
7	1962	1694	Negative
8	1921/23	1500	Negative
9	1956	1896	Negative
10	1956	905	Oil
11	1956	796	Oil
12	1958	1394	Negative
13	1959	1725	Negative

4. Neogene and quaternary deposition through megacycles in analysed area and lithostratigraphy

The Neogene and Quaternary sedimentary complex in the studied area can be subdivided into three major megacycles (**Velić at al., 2002**; **Velić, 2007**). The oldest (1st) megacycle represents the Prečec Formation. The sedimentary complex is extremely heterogeneous, comprising breccias, conglomerates, sandstones, siltstones, shales, marls, igneous rocks and limestones. The Prkos, Ivanić-Grad, Kloštar Ivanić and Široko Polje Formations belongs to 2nd megacycle and are represented mostly by a monotonic marl/sandstone sequence. The 3rd megacycle is represented by the Lonja Formation, composed mostly of unlithified sediments, i.e. sands, gravels, loess and some lignite.

4.1. Litostratigraphic review of the exploration area

Based on lithological units, conditioned by tectonic movements, sedimentary development is spatially divided into three parts (Figure 2):

1. South-western part with the wells 7, 12 and 13 includes the complete lithostratigraphic development, ending into basement rocks;
2. The north-eastern part includes the wells 10, 11 and 6. In this area are missing Lonja, Široko Polje and Kloštar-Ivanić Formations. Ivanić Grad and Prkos Formations are drilled;
3. The northern and central parts include the wells1, 2, 4, 5 and 9. In this part sequence of upper part of Široko Polje Formation are missing. Ivanić Grad Formation is not drilled.

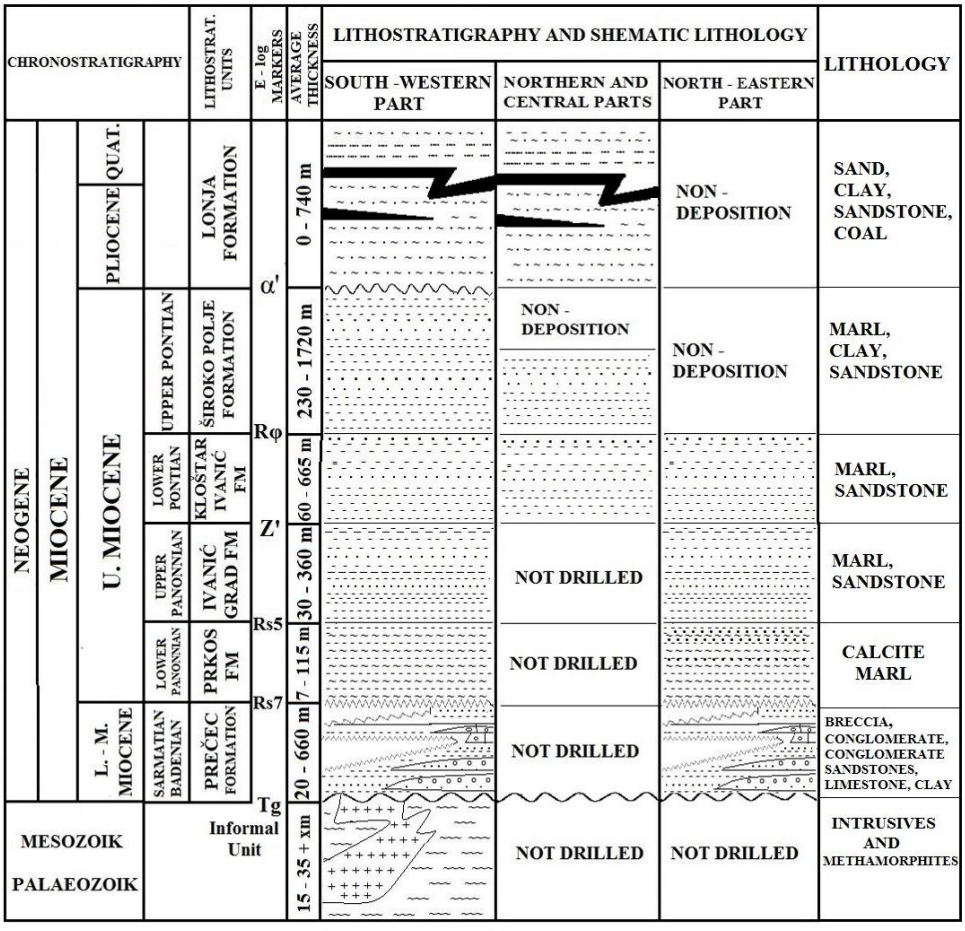

Figure 2. Formal lithostratigraphic and chronostratigraphic units, E-log markers and average thickness (thicknesses are not in scale) in the analysed area (schematic representation of units between south – western, northern and central parts and north-eastern part)

4.2. Description of lithostratigraphic formations

Lithological units are described in detail by formations. **Prečec Formation** represents the first Neogene-Quaternary megacycles in Sava Depression, including Badenian and Sarmatian (**Figure 2**), and locally possible deposits of Lower Miocene. The sedimentary series comprises breccias, conglomerates, sandstones, clay and limestones. Sediments of this formation are proven only in the south-west (wells 7, 12 and 13) and north-east (wells 6, 10 and 11) of the analysed area.

On the Sarmatian deposits overlapping sediments of the Early Pannonian or **Prkos Formation**, bounded by e-log markers Rs7 and Rs5 (**Figure 2**). In the southwestern part of the area are deposited calcite-rich marls (wells 7, 12 and 13).Sedimentation in the northeastern part (wells 10 and 11) differentiate from the one in the southwestern part, because in NE thin sandstone layers with oil shows appear.

Sedimentation in the Late Pannonian (**Ivanić Grad Formation**) indicates the beginning of significant changes in sedimentary environments, with the dominant transport of turbidity currents. Formation is bounded by e-log markers Rs5 and Z' (**Figure 2**).In the south-western part of depression (7, 12 and 13 wells) marl and sandstone accumulated.At the north-eastern part of the depression (10 and 11 wells) marl with high percentage of clay is described. Sandy component is very fine-grained and inserted, like lamina, in marls.

Sediments of **Kloštar Ivanić Formation** are bounded by markers Z' and Rφ (**Figure 2**). They are composed of fine-grained sandstone and marl. On the all analysed area fine-grained sandstones and marls are proven, but in the north and central part deposits of this formation are thicker.

Široko Polje Formation (Late Pontian) can be observed on the south-western, northern and central part of the area, and the north-eastern part is not deposited. It is bounded by markers Rφ and ά (**Figure 2**).On the south-western part, small occurrences of gas are registered. Sandstones and clays alternated with marl. In the northern and central part of the area upper part of formation is not deposited. On the north – eastern part formation are missing.

E-log marker ά separates deposits of the **Lonja Formation** and base (**Figure 2**). Lonja Formation includes weakly consolidated or unconsolidated sediments of Pliocene, Pleistocene and Holocene, like clays, sands and low carbonised coals. In the south-western part sediments are composed of sands and clay with rare layers of coals and sandstones deposited in freshwater conditions. In the northern and central part sediments become thinner.

5. Reinterpretation of some previous geophysical results in analysed area, problems and uncertainties

Seismic profile AA 'is connected with the profile B-B'. They do not continue directly, but its direction is on the southeast of area (Figure 3). Near the profile in Figure 2 are wells 12 and 13 distant about a kilometre (precisely well 12 about 1700 m, and 13 approximately 1000 m) (**Figure 3**, **Figure 4**).

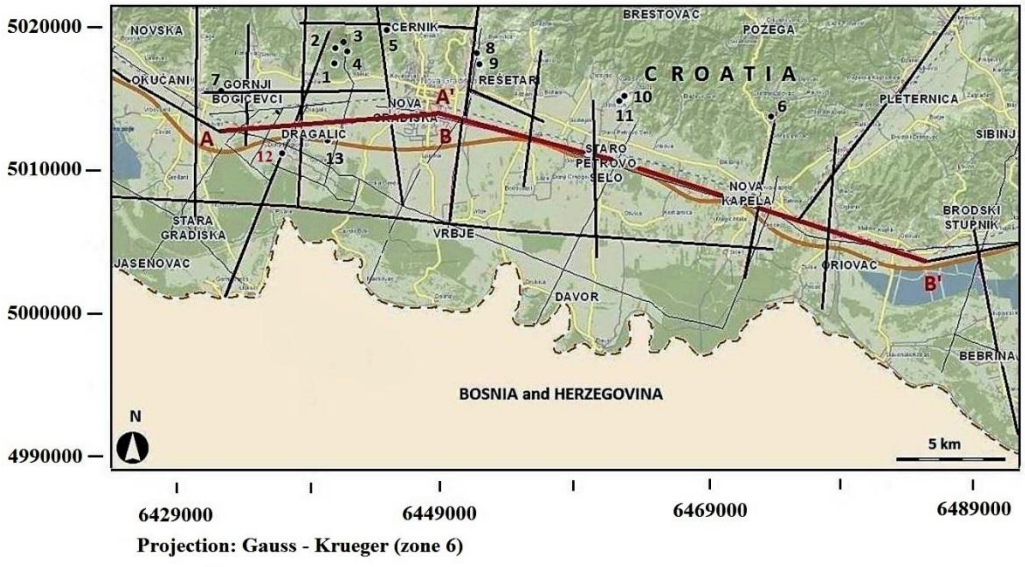

Figure 3: Location map of analysed area with profile A-A'-B-B' and Well 12 (red)

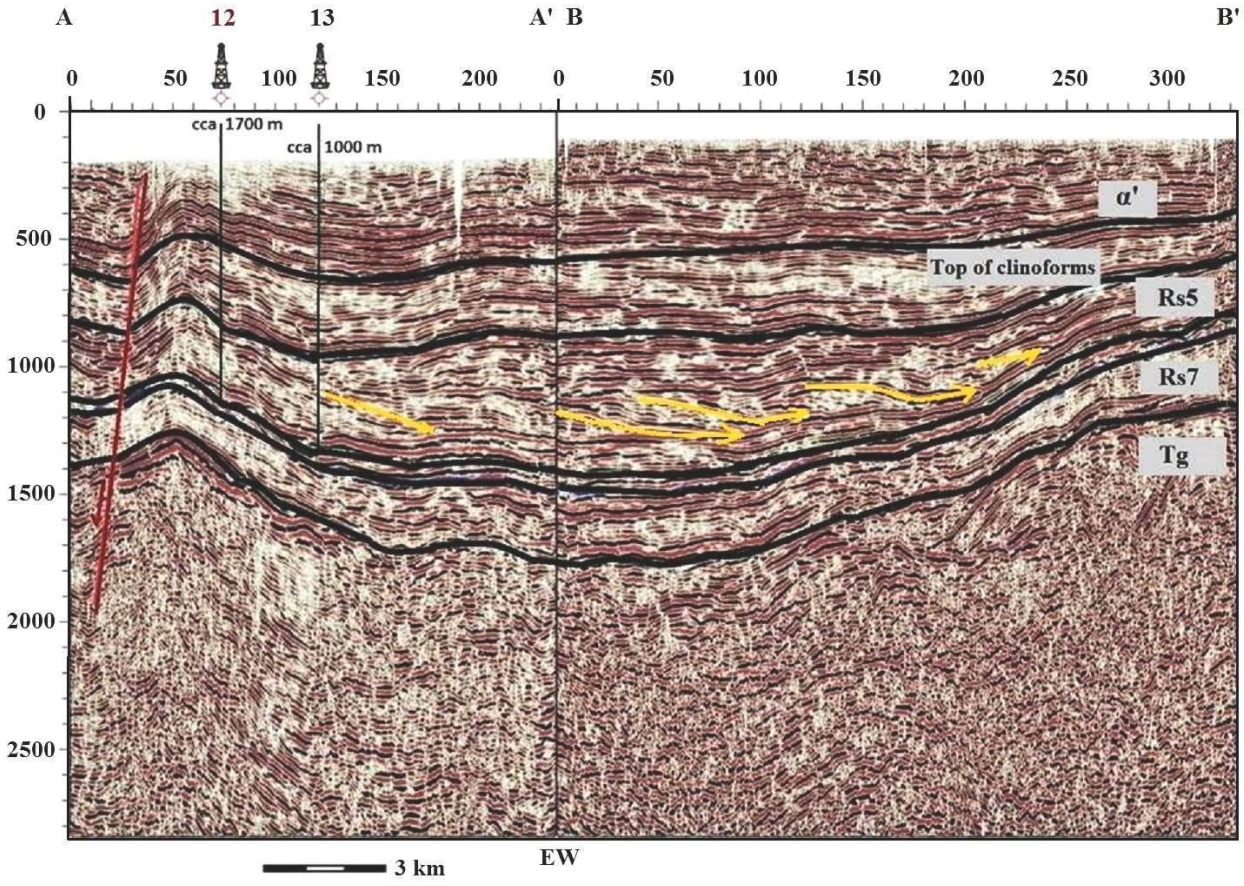

Figure 4: Interpreted 2D seismic profiles A-A' – B-B' (Top of previously interpreted clinoforms)

Both wells were drilled in the south-western part of the area, without hydrocarbon shows and reached basement rocks. Some previous interpretations (*Final Report, SE Sava 2D, 2011*) described top of clinoforms where is visible downlap. And downlap is described as progradation, with the deposition of clinoforms (arrows on **Figure 4**). Moreover, facies and overall well-log interpretations had been described as channel and delta environments (**Figures 4 and 5**).

However, e.g., **Rögl & Steininger (1984)** emphasized that sedimentation during the Late Pannonian marks the significant change in sedimentary environments, when started domination of turbidity currents. Such sedimentation occurred from cyclic turbidities in brackish to (later) freshwater environments. The morphology of the sand body follows the direction of sedimentary currents (e.g., **Vrbanac et al., 2010**), generally north-northwest / south-southeast. The main source of sediments was in the Eastern Alps, from where the multiple turbidity currents, along with regional tectonic ramps, transmitted to the place of deposition (e.g., **Malvić et al., 2005**; **Malvić, 2012**).

Upper Pontian sediments are represented with alteration of sandstones and marls. In periods when turbidity flows were not active because there was no gravitational instability and a sufficient amount of accumulated material, marls are deposited, as the sediments typical for calm conditions deep-environment.

Slow changes of sedimentary mechanisms become local again (deltas), in the Late Pontian, leading to the filling of the sedimentary basin (e.g., **Novak-Zelenika, 2012**).

In the Late Pontian deposits, it is possible to interpret delta environments from the EK diagrams of well 12 (**Figure 5**). Within the Široko Polje Formation (top to bottom) alterations of sandstones and marls are visible in the geological column. In the same column, sandstones are visible at a depth range of 800-1000 meters and marls are visible below sandstones as well.

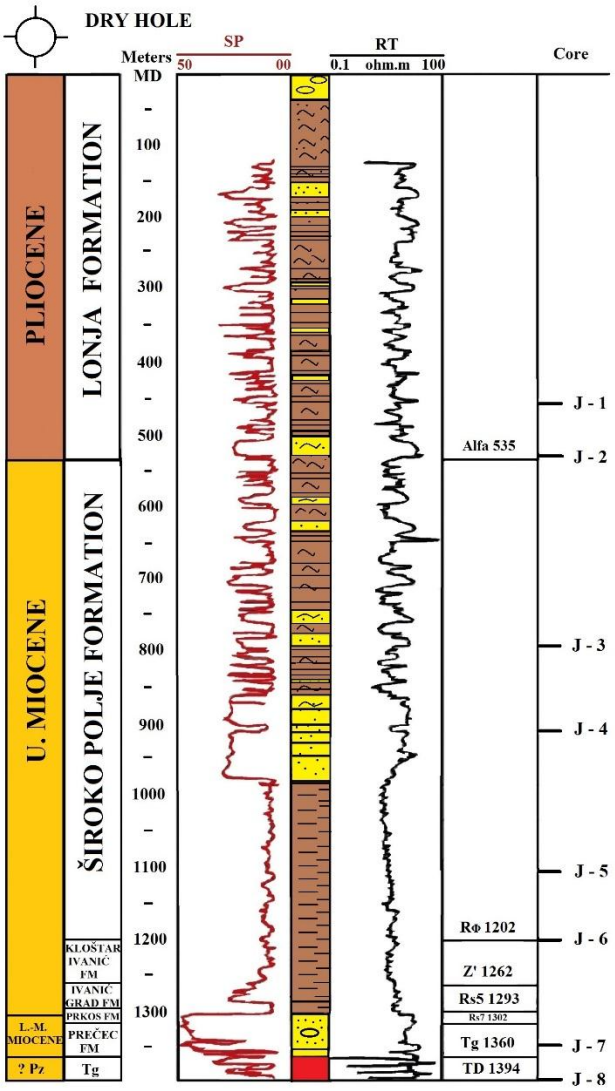

Figure 5: Geologic column Well 12 (*Final Report, SE Sava 2D, 2011*)

Progradation (visible on the **Figure 4)** could be interpreted as depositional model of turbidity flows in brackish and freshwater environments. Slow changes of sedimentary mechanisms toward local started in the Late Pontian (delta or alluvial fan), and in this way fills to depositional area, e.g., this is described in the western part of the depression (e.g. **Novak-Zelenika 2012**; **Novak-Zelenika et al., 2013**).Clinoforms represents deposition of pelitic and especially psammitic detritus at the edge of the depression, and partly (which is more seismically difficult to follow) in the direction of material transport. Furthermore, in the wells where well log curve is interpreted, lithostratigraphic and chronostratigraphic boundaries showed were unusual high thickness of Široko Polje Formation comparing to the relative formations thickness ratio in the rest of the Croatian part of Pannonian Basin System (CPBS). On north – eastern part of analyzed area Široko Polje Formation also missing. Lithotypes and thickness of individual sedimentary events in previous interpretation (Završni izvještaj, JI Sava 2D, 2011), should be definitely re-analyzed. Consequently, the lower part of Široko Polje Formation could easily be upper part of Kloštar-Ivanić Formation.

Furthermore, it should be mentioned that the source rocks in Sava depression generally belong to Prkos and Prečec Formations. Here they are drilled in wells 7, 12 and 13, in NW part. In the earlier studies (*Final Report, SE Sava 2D, 2011*), organic-geochemical analysis of surface rock samples are done. Samples contain considerable amount of organic substance which is thermally immature. Source rock has no generative possibilities. Assuming continuous increase of thermal maturity with depth, in this area the entry into "oil window " can be expected at a depth of more than 2500m.

6. Conclusion

In the south-eastern part of Sava Depression thinner Neogene-Quaternary sediments than in the western part were found, where almost never reached thermal maturity, necessary for catagenesis is.

This overview is given for the part of geophysical and well measurements in the eastern Sava Depression. In previous interpretations it was determined that clinoforms are not visible on the seismic profiles, as well as the fluvial channels and deltas. However, based on the seismic interpretations connected with existing knowledge of the regional geological evolution and structures in the CPBS it could not be confirmed possibility of deltas existence in Pannonian and Pontian. It especially cannot be stated as unique geological feature on such relatively small area inside the CPBS, as it is the eastern Sava Depression. Here the Upper Miocene sediments were also dominantly deposited from turbidity currents. Delta and alluvial fans can expect locally in the Late Pontian, Pliocene and Quaternary, what can be indicated, e.g., at the e-log, like in well 12 (**Figure 5**).

On north – eastern part of analysed area Široko Polje Formation missing. On northern and central parts also upper part of this formation are missing. For this small area it is almost impossible. Lithotypes and thickness of individual sedimentary events in previous interpretation (*Završni izvještaj, JI Sava 2D, 2011*), should be definitely re-analyzed. Wrong interpretation had been previously done.

7. References

MALVIĆ, T., VELIĆ, J. & PEH, Z. (2005): Qualitative-Quantitative Analyses of the Influence of Depth and Lithological Composition on Lower Pontian Sandstone Porosity in the Central Part of Bjelovar Sag (Croatia). Geologia Croatica, 58, 1, 73-85.

MALVIĆ, T. (2012): Review of Miocene shallow marine and lacustrine depositional environments in Northern Croatia. Geological quarterly, 3; 493-504.

NOVAK-ZELENIKA, K. (2012): Deterministic and stochastic geological models of Upper Miocene sandstone reservoirs at the Kloštar oil and gas field, Doctoral Thesis, Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb,Zagreb,190 p.

NOVAK-ZELENIKA, K., VELIĆ, J. & MALVIĆ, T. (2013): Local sediment sources and paleoflow directions in Upper Miocene turbidites of the Pannonian Basin System (Croatian part), based on mapping of reservoir properties. Geological Quarterly, 57 (2013), 1; 17-30.

RÖGL, F. & STEININGER, F. (1984): Neogene Paratethys, Mediterranean and Indo-pacific seaways; in: Fossils and climate, ed. Brenchey, P.J., Geological Journal, special issue 11, 171-200.

VELIĆ, J., WEISSER, M., SAFTIĆ, B., VRBANAC, B. & IVKOVIĆ, Ž. (2002): Petroleum geological characteristics and exploration level of the three Neogene depositional megacycles in the Croatian part of the Pannonian basin. Nafta 53, 6-7, 239-249.

VELIĆ, J. (2007): Geology of oil and gas reservoirs Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Zagreb, 342 p. (in Croatian)

VRBANAC, B.; VELIĆ, J.; MALVIĆ, T. (2010): Sedimentation of deep-water turbidites in main and marginal basins in the SW part of the Pannonian Basin, Geologica Carpathica. 61, 1, 55-69

ŽGALJIĆ, J. (2003): Five centuries of Croatian oil, Glosa d.o.o., Rijeka, 174 p.

Završni izvještaj (Final report), JI Sava 2D, (2011): Stručni fond INA-e, 69 str.