Introduction

In order to define the structural-tectonic relations of the Ježevo oil field and establish new hydrocarbon reserves, we have used Petrel software to create a three-dimensional seismic interpretation. So far, the explorations have been based exclusively on 2D seismic data; however, the specific feature of this particular research is that we have been used both the borehole data and 3D seismic data. In the Ježevo field, the carriers of the economically significant acumulations of hydrocarbons are the collectors of the thin Gama sandstone series. Based on the well logs and the data from the cores, the lithology log plot have been made and both the top and bottom of the Gama sandstone series have been identified. E-log marker Rs7 (Sarmatian/Pannonian), Rs5 (Lower/Upper Pannonian), Z' (Pannonian/Pontian), Rφ (Lower/Upper Pontian), and the structural-tectonic interpretation of the 3D seismic data have also been made. For reliable settings of lithological limits on the seismic section, the one-dimensional modeling (synthetic seismogram) has been used. We have created a new model that is based on 3D seismic interpretation and contains the tectonic complex limiting the reservoir. In order to achieve a more accurate interpretation of seismic horizons and fault complex, we have used seismic trace and horizon attributes, as well as continuity/discontinuity attributes. With the help of the above mentioned, the information about the lithologic diversity in the sedimentary bodies and the lateral changes of the reservoir characteristics have been gathered. The attribute of continuity/discontinuity has improved the resolution of the fault and express provision of the layers that have the same characteristics, so it can be considered as a control of the seismic interpretation.

The basic information of the Ježevo oil field

The exploatation field Ježevo is located around 30 km east of Zagreb (Figure 1). In 1961 began the detailed 2D seismic researches, based on which was created the first exploration borehole Je-A. The borehole was drilled at the top of the north-west anticlinal structure, which was important for the development of economically quantities of hydrocarbons.

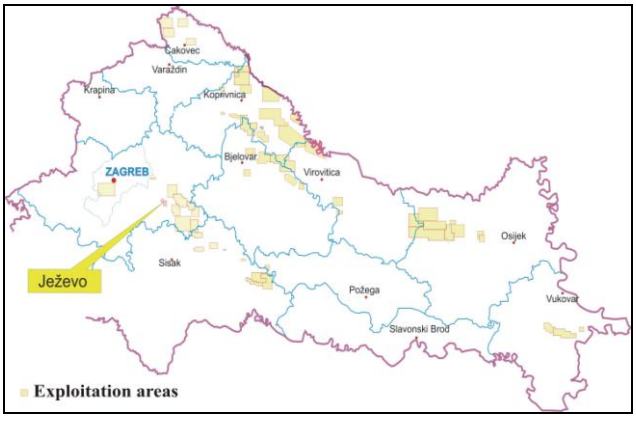

***Figure 1**: Location of the Ježevo field.*

The oil field Ježevo geotectonically belongs to the deeper west part of the Sava Depression, and the carriers of the economically significant accumulations of the hydrocarbons are the collectors of the Gama sand serie (Iva sandstones), which belongs to the layers of the Upper Pannonian (Linić et al., 1977). Iva sandstones make the elongated sediment body whose direction is northwest-southeast. Upper šarampovska marl represents the top of the Iva sandstones. The complex is lithologically homogenous, represented by thick layer of marl, up to 30 m thick, that makes the impermeable barrier at the vertical hydrocarbon migrations.The

lithological mixture of the Gama serie is composed of sandstone layers interspersed with marl, that is, sand marls and marl sandstones of poor collector features.

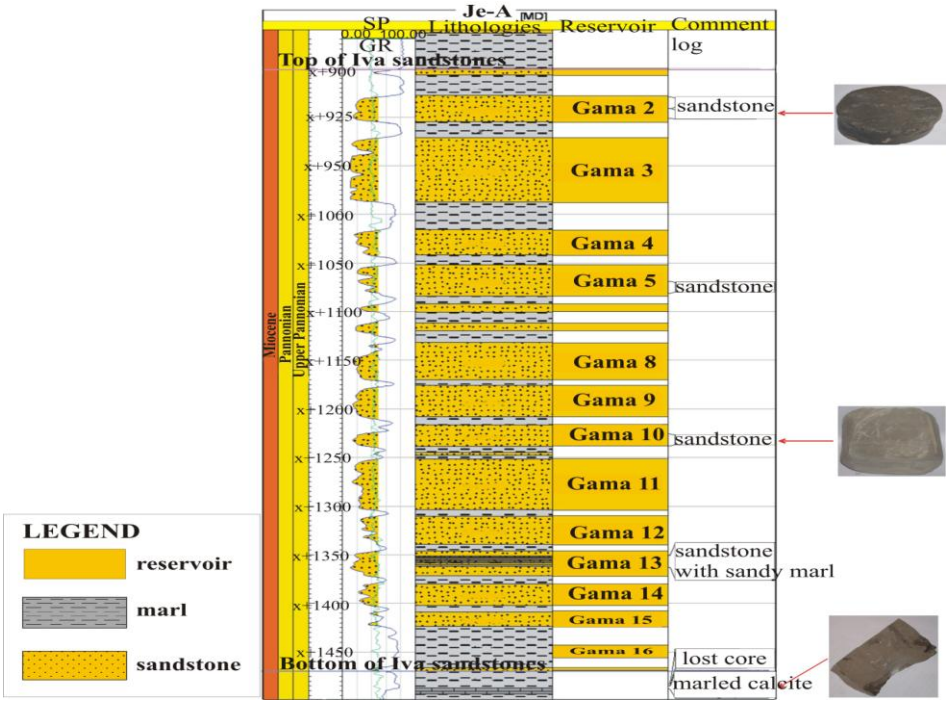

***Figure 2**: Lithology log plot on Je-A.*

17 sand layers within the series that can be tracked on the whole structure have been extracted with the help of the well log correlation (Figure 2). The marls separating the sand layers , represent the isolating rocks within the same serie. By using the well log data and examining the single layers, it has been established that the depth of the oil-water contact for the single layers is different. Based upon that fact, the sand layers have been extracted as single hydrodinamic units, that is reservoires. Economically accumulations have been established in layers, that is in the Gama 4, Gama 5, Gama 9, Gama 11, Gama 13, Gama 14 reservoires (Majer et al. 2006).

Seismic characterisation of the lithologic boundaries

For the purpose of connecting borehole and seismic data more accurately, we have created a synthetic seismogram at the Je-C* borehole. With the help of this seismogram, the horizon depths values have been located on the seismic section. In the calculation, the Ricker zero-phase wavelet has been used. It has the frequency of 27 Hz. Since the top of the reservoir is defined as the contact area of marl and sandstone, the acoustic impedance occurred at the top, which is the geological border. The negative value of the amplitude is the result of the acoustic impedance decrease at the contact of marl and gas saturated sandstone.

According to one-dimensional modeling, the top of the Gama serie matches the negative value of the amplitude, and is located at the level of the two-way traveltime around x+1500 ms. The basic reflex, by which the seismic response of the bottom of the reservoir is defined, is the positive amplitude value, and it is located at the level of the two-way traveltime around x+1650 ms. Due to weak reflectivity crossing from the sandstones to bottom marls, as well as the changes in the thickness of the sand layers in the deposits and saturation, there has been interference of different signs. The E-log marker Rs7 is defined as a strong positive amplitude value in the two-way traveltime, around x+1750 ms. E-log marker Rs5 matches the negative

amplitude, and is located at the level of the two-way traveltime around x+1700 ms. The surface Z' is defined as a negative amplitude value at the level of the two-way traveltime, around x+1400 ms, and Rφ matches the positive amplitude, at TWT around x+1250 ms.

Structural-tectonic interpretation

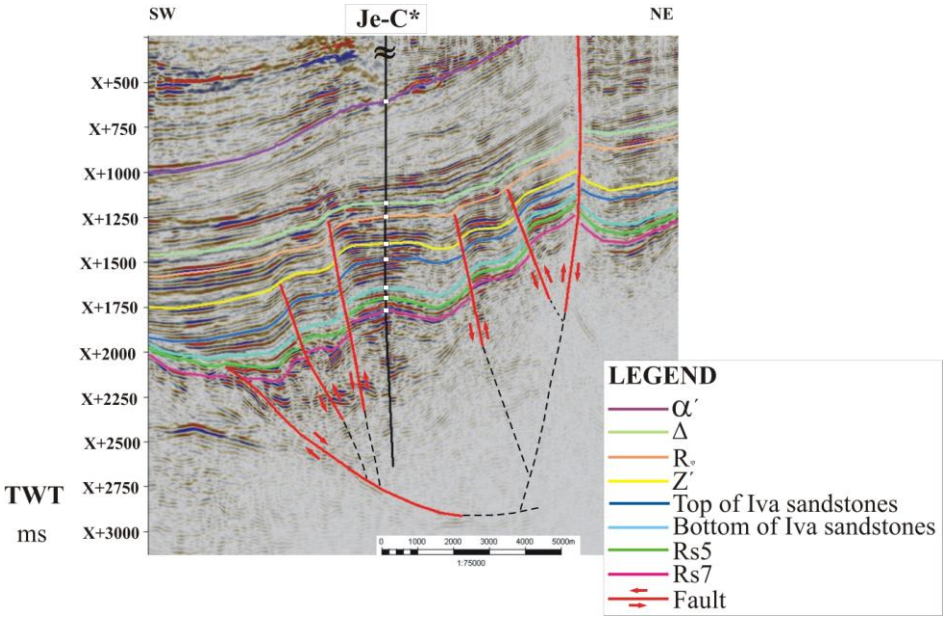

***Figure 3**: Seismic horizons interpretation and the flower structure sheme.*

Ježevo structure has been represented by the brachyanticline which are separated by the mild saddle (Barišić, 1977.). The north-western anticline has the Dinaric direction, and the other anticline is situated at the south-eastern part of the field and its direction is nearer to the east-west direction, than the Dinaric one. Other important tectonic characteristics are the faults, mostly reversed and spreading in the NW-SE direction, and they are clearly visible and interpreted on both crossline and inline seismic sections (Figure 3). West wing layers of the anticline are mildly sinking into the deeper part of the Sava Depression, while on the east side they are brought into a higher position because of the series of longitudinal faults. In the compression area, the local deformities of the reversed faults' roof wings create positive flower structures.

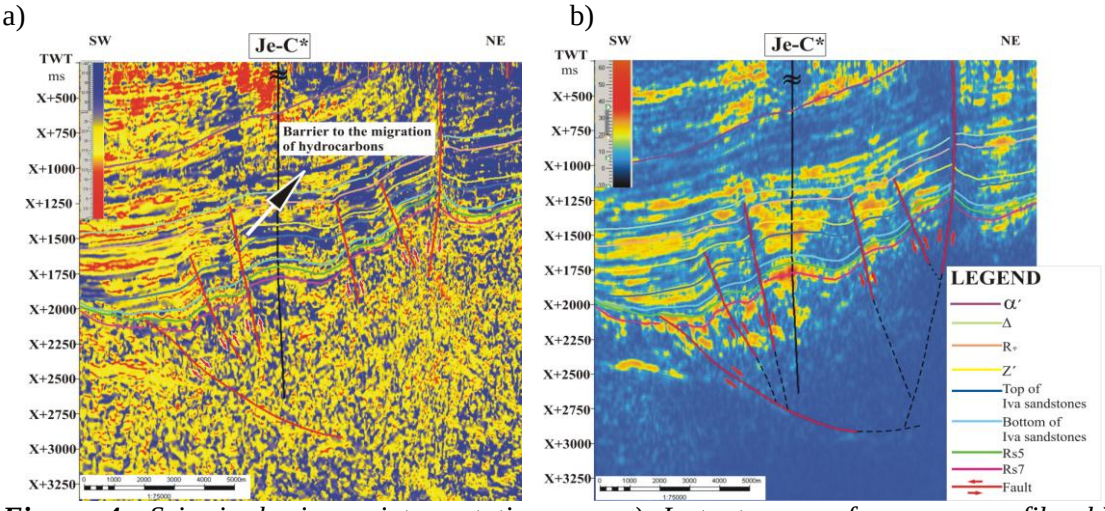

***Figure 4**: Seismic horizons interpretation on: a) Instantaneous frequency profile, b) Instantaneous amplitude profile.*

During the interpretation, the seismic attributes have been made and analised. The seismic trace attribute; instantaneous amplitude, instantaneous frequency and the instantaneous phase, horizon attributes: RMS amplitudes, average instantaneous frequency and the average instantaneous phase, as well as continuity/discontinuity attributes.
The instantaneous frequency of the crossline seismic section points to the reverse fault on the SW part of the field, which represents the probable barrier to the migration of hydrocarbons (Figure 4a). Low frequency areas outside the field, represent better collector characteristics water-saturated, while the upper parts of the structure, contain increased marled component, which causes the increase of the frequency. The first three Gama series have been marled and there is no production in any of the boreholes in these reservoir. In the display of instantaneous amplitude, in the zone of E-log marker Rs7, it is possible to extract clayely carbonates in the package of layers (Figure 4b). Clayely carbonates are characterised by high acoustic impedance and they can often contain bitumen, while in some places they contain gas which could be the reason for high instantaneous amplitude value. Areas outside the reservoir show increased amplitude values and decreased frequency values, which would match the hydrocarbons saturation.However, these are Okoli sandstones, which are water-saturated in the Ježevo field.

Conclusion

With the 3D seismic interpretation, we have defined the structural-tectonic complex of the Ježevo oil field, as well as the whole research area. The seismic attributes analysis helped define improved collector characteristics, so that, new hydrocarbon reserves could be developed in the future. With the seismic attributes analysis it has been established that the wells Je-B, Je-C, Je-D, Je-E and Je-IS are located in the area of decreased amplitude values, which means this area's reservoir potential is poor. Increased frequency values in the Ježevo field, are the consequence of the large amount of marled component in the shallow parts of the Gama series, however it is possible to extract two lower frequency values zones at the NW part of the field around the well Je-I and on SE, around the well Je-A*.

References

Barišić M. [1985] A review of structural relationships of the oil field Ježevo and the area of Duga Greda-Posavski Bregi (Sava Depression). *Nafta*, **1-2/36**, 5-16 (In Croatian).

Linić, P., Krznarić, B. [1977] Report on oil and gas reserves of the field Ježevo. Expert Document Fund, Ina-Naftaplin, Zagreb (In Croatian).

Majer, Đ., Đureković, M. [2006] Report on hydrocarbon reserves of the exploitation field Ježevo. Expert Document Fund, Ina-Naftaplin, Zagreb (In Croatian).