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Correction of the seismic attribute sweetness by using porosity-thickness map, Lower Pontian LP reservoir, Sava Depression

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Abstract

The seismic attribute of sweetness is often used to define the quality of the hydrocarbon reservoir due to the ability to identify sandstone bodies, which have a stronger reflection compared to the surrounding marls. The quality of deposits can also be described by porosity-thickness maps. Coarser material in the center of the channel has higher values of porosity, but also greater thicknesses. By multiplying these two variables, depositional channels would be emphasised. The LP reservoir of the A field, located in the Sava Depression, has been analysed. The Lower Pontian LP reservoir is composed of sandstones, deposited by a regional transport of turbidite currents. The structure of the reservoir is an anticline with two maxima separated with the structural saddle. The LP reservoir was analysed with a seismic attribute of sweetness and with a porosity-thickness map. The m aps showed many similarities, but there were certain differences, especially in the central part of the southern maximum. According to the well data this part show lack of LP reservoir, and the seismic is of poor quality. Correlation of the mapped parameters is confirmed by correlation coefficients (medium correlation, for the whole analysed area and strong correlation only for the northern part with thicker sandstones). In the central part of the southern maximum, the correlation between the attributes of sweetness and the porosity-thickness map was not established. The seismic attribute correction is made by the ratio function of the sweetness attribute and the porosity-thickness values for the entire area and for the northern part. Corrected maps of seismic attribute are only slightly different than the original ones.

Key words: seismic attribute sweetness, porosity-thickness map, sandstones, Sava Depression, Croatia.

1. Introduction

Seismic interpretation is an important element, both in exploration and in the development of hydrocarbon reservoirs. Seismic attributes have become an indispensable tool in the description of the underground, and the attribute of sweetness is often used to define the quality of the deposit itself. Therefore, it is very useful in identifying isolated sand bodies due to their stronger reflection compared to surrounding marls. However, in the environment with sandstones and marls intercalations, it will not yield such good results (**Hart, 2008**). **Radovich & Oliveros (1998)** pointed out that the seismic attribute of sweetness, apart from the sandy bodies, also indicates their saturation with hydrocarbons due to high amplitude and low frequency. However, there are some examples of sweetness attribute interpretation where it has been proven that the same attribute values have sandstones saturated with oil and water.

The quality of the reservoir can also be described by the porosity-thickness map, starting from the fact that each of the mentioned variables is a direct result of the deposition itself. Suppose that in the centre of the channel, due to the stronger current, coarser material will be found, unlike the edges of the channel, where the current strength decreases and a fine grained detritus begin to deposit. Accordingly, coarser material in the centre of the channel will have higher values of porosity and thickness. Multiplication of these two proportional parameters will emphasize the quality of the reservoir and define the position of depositional channels in the analysed area. Of course, the precondition for such a method of interpretation is a large number of input data, required for quality geostatistical analysis and distribution.

Since both parameters (seismic attribute sweetness and porosity-thickness map) describe the quality of the reservoir, they can be correlated. Their correlation was made for the Lower Pontian LP reservoir of the A field in the Sava Depression. Numerous similarities are found in the output maps, but there are some differences. The highest differences are in areas where the sand body is very thin or even not present, which match with a very poor seismic. The similarities in the output maps are mathematically represented by the coefficient of correlation. Also, the ratio equations of the sweetness attribute and porosity-thickness values at well locations are also shown, for the entire field area and for

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the area of the best map matching (northern part of the field). The same functions were used for the correction of the seismic attribute, since the porosity-thickness map more precisely describes the reservoir.

2. Geological settings of the Sava Depression

According to **Ćorić et al. (2009)** the oldest Miocene deposits in the Sava Depression are of the Badenian age, which discordantly lay on the Palaeozoic-Mesozoic basement. Extensional tectonic got stronger during Badenian and the main depositional depressions have been opening. Mechanisms that deposited siliciclastic material of local origin in the shallow sea were alluvial fans (**Tišljar, 1993; Malvić, 1998, 2006**).

The end of Badenian and the beginning of the Sarmatianis are characterized by the deposition of calcareous marls and clayey limestones. The area had become calmer due to weakening of the extension tectonic. During that time clayey marls and sandstones were deposited (**Vrbanac, 1996; Rögl, 1996, 1998**). The Lower Pannonian deposits are represented by rhythmic changes of clayey limestone, silty marl, marl and sandstone, which were filling brackish shallow area (**Rögl & Steininger, 1984; Vrbanac, 1996; Rögl, 1996; 1998; Magyar & Geary, 1999; Magyar et al., 1999; Muller et al., 1999**).

On the Lower Pannonian, Upper Pannonian is followed. In the Sava Depression, sandstones of that time have significant amount of hydrocarbons. Lithologically, they are presented with marls, silts and sandstones. Sedimentation at the time of the Upper Pannonian indicates the beginning of a significant change in the depositional environment when the turbid currents mechanism began to dominate (**Vrbanac, 1996; Rögl, 1996, 1998**). The material transport was regional with a source in the Eastern Alps (**Šimon, 1980; Malvić et al., 2005**).

The Lower Pontian sandstones were deposited through turbid currents, and the material transport direction was also regional. In calm periods, when the turbid currents were not active, marl, as a sediment typical for the deep water environment, was deposited.

During Upper Pontian, the sedimentation mechanisms become local. The depositional area continued to fill with material. The Upper Pontian deposits are clayey marls, marly clays and clays and the appearance of lignite (**Rögl & Steininger, 1984; Vrbanac, 1996; Rögl, 1996, 1998**).

During Pliocene and the part of Pleistocene, the remaining shallow parts were filled with marly clays, marls and sporadically sandy marls. Coarse grained material followed (gravel, sand) and clay with the appearance of lignite. The final inversion of the structure and sedimentation of sediments characteristic of glacial and interglacial periods is typical for Quaternary (**Velić & Saftić, 1991, Velić & Durn, 1993, Velić et al., 1999, Bačani et al., 1999**). The youngest sediments are represented by loess, clay, humus, gravel and sand. Chronostratigraphic units, as well as transport and depositional mechanisms in Sava Depression are given in **Figure 1**.

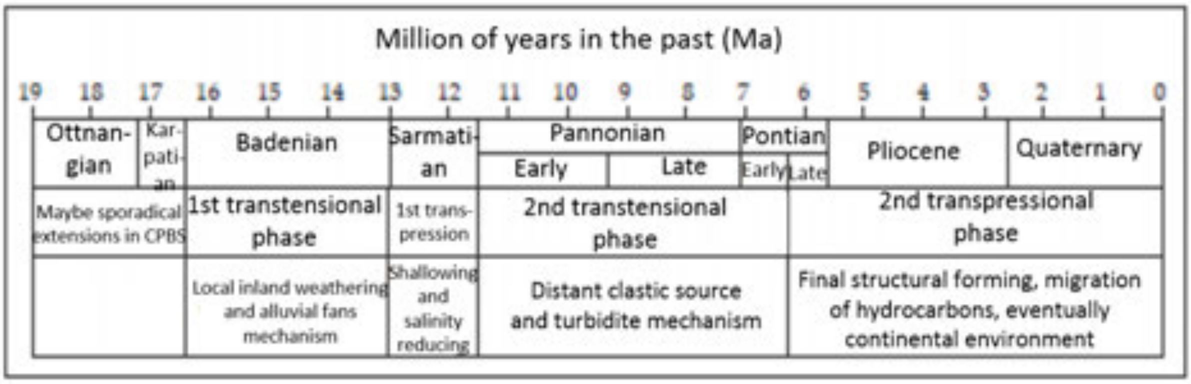

Figure 1: Chronostratigraphic units and transport and depositional mechanisms (**Malvić and Velić, 2011**)

Neogene sediments can be divided into three depositional megacycle (**Velić et al., 2002**). The first is represented by the sin-rift extension, with the high influence of tectonics on sedimentation, when pull-apart structures were formed. The Badenian is marked by the first transtension, and the Sarmatian by the first transpression phase (**Figure 1**). Sediments of the second megacycle were deposited at the time of re-extension of the basin (**Horvath & Tari, 1999**) during Pannonian and the Pontian (**Figure 1**) (**Velić et al., 2002**). The deposits of the third megacycle belong to the second transpression (**Figure 1**), with the structure inversion. Normal faults, which were active during the extensional phase, reactivate and change the character. In the uplifted parts numerous transitional structures were formed.

2.1. Geological settings of the analysed area

Field A is located about 50 km east of Zagreb in the area of the Sava Depression. It fits into the development of the Sava Depression. Based on the deep wells data, a normal sequence of chronostratigraphic units (Sarmatian, Lower Pannonian, Upper Pannonian, Lover Pontian, Upper Pontian, Pliocene and Quaternary) was established.

Sarmatian sediments were proven only in four wells of the A field. They were represented with calcareous and sandy marls, marly sandstones and conglomerate sandstones. Lower Pannonian deposits are more or less calcareous marls. Lithologically, Upper Pannonian is represented by grey sandy and low calcareous marls intercalated with fine-grained quartz-mica sandstones. Upper Pannonian and Lower Pontian sandstones are the main hydrocarbon reservoirs of the A field. The Lower Pontian sediments consist of clayey and sandy marls and fine to medium-grained sandstones. Analysed LP reservoir is located within these deposits. Clayey and marly sediments and sandy intervals of small horizontal distribution are characteristic for Upper Pontian deposits. Lithologically Pliocene consists of sandy clay and clayey sandstones. There is vertical and horizontal interlayering of clay, sand and gravel. Sandstones occur in the form of limited lenses and are sometimes filled with gas. The Quaternary is represented by humus, sandy clay, fine-grained sand and gravels of different granulations. The lithostratigraphic column of the field A is shown on **Figure 2**.

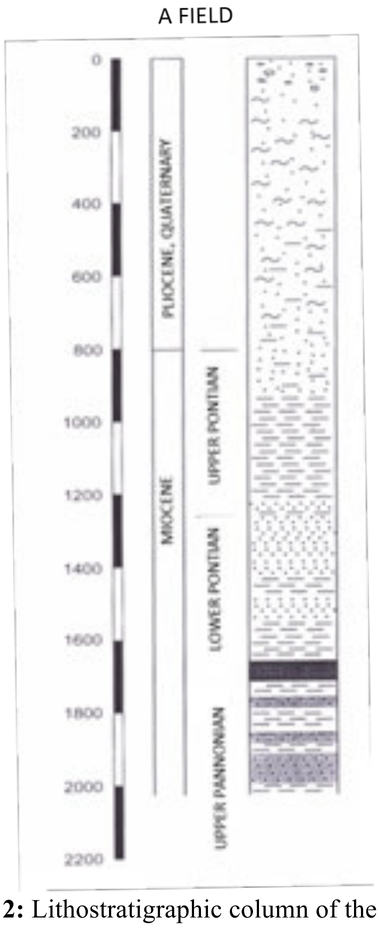

Figure 2: Lithostratigraphic column of the A field

The field structure is an anticline with two maxima, north and south, with a structural saddle between them (**Figure 3**). The main direction of the structure is northwest-southeast. In the area of the north and south maximum, the LP reservoir is gas prone. From the shallower and deeper sand intervals, it is divided by continuous marls with an average thickness of 10 to 15 m. There are good reservoir properties in the northern part of the reservoir and in the edge of the south maximum. The basic physical parameters of the reservoirs were determined based on the quantitative interpretation of the well logging and the results of core analysis.

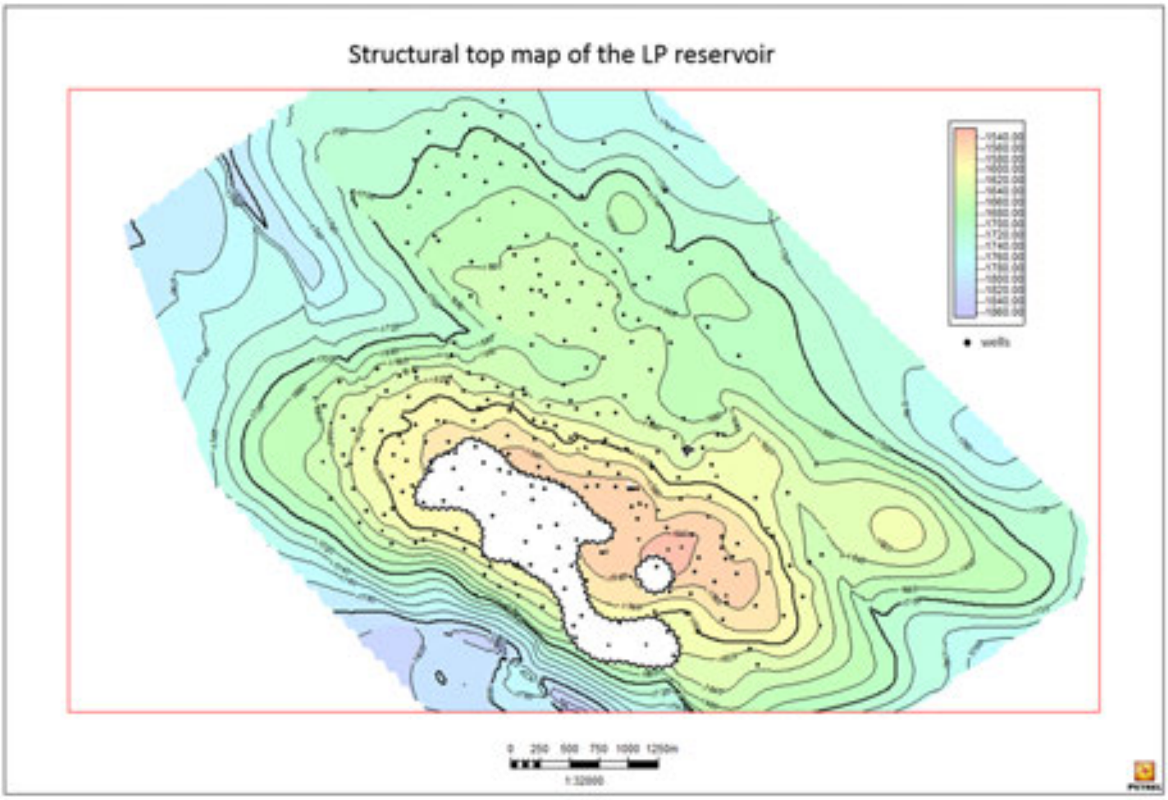

Figure 3: Structural top map of the LP reservoir

3. Correlation between seismic attribute sweetness and porosity-thickness map of the LP reservoir

The seismic attribute sweetness is interpreted in a 16 ms interval (8 ms above and 8 ms below) of the interpreted horizon (**Figure 4**). The problem is the central part of the field with poor seismic. The well data show very thin or even lack of the LP reservoir in the central part. So, it is possible that the interval of +/- 8 ms is actually affected by the sand bodies above or below the reservoir itself. Therefore, in some parts, attribute show higher values than expected. Of course, the seismic interpretation of the analysed horizon is also questionable in this area. However, regardless of the seismic quality, the map can generally point to depositional channels of the regional NW-SE direction.

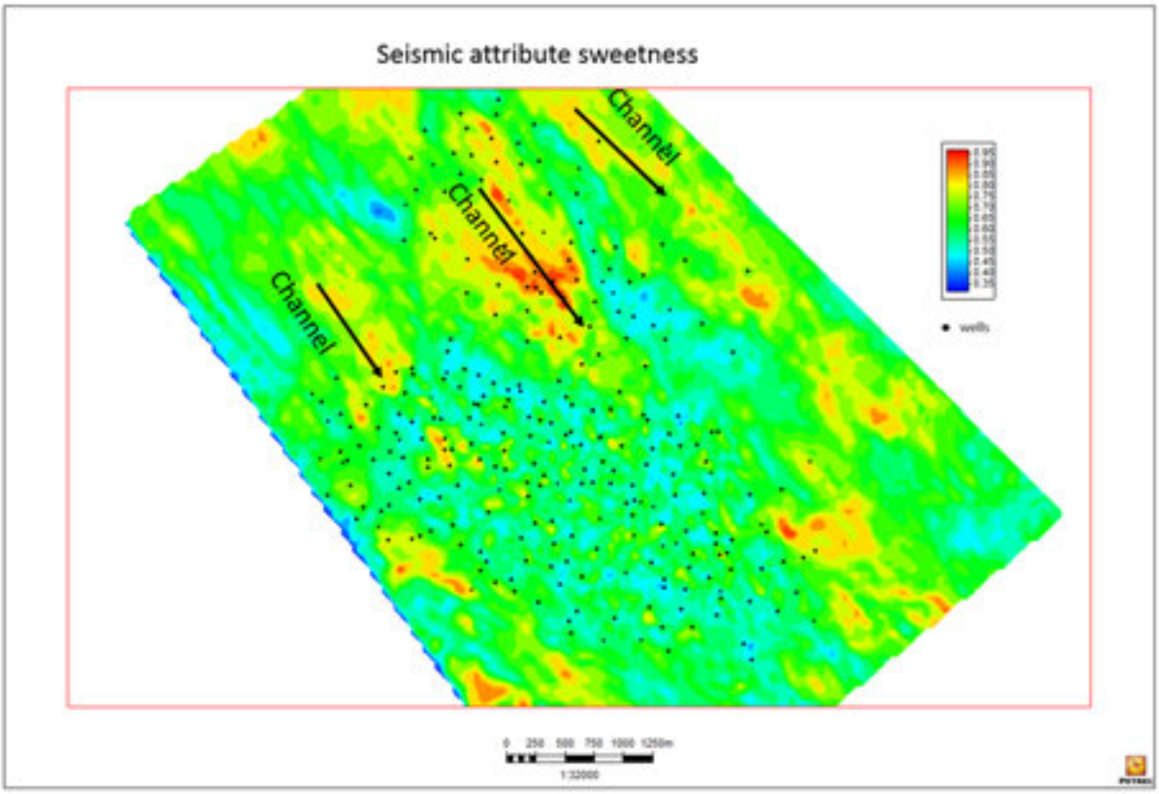

Figure 4: Seismicattributesweetnessinthe interval of 8 ms above and below the interpreted LP horizon

Due to the huge amount of data, detail variogram analyses were made for the porosity distribution. Porosity was distributed by the Ordinary Kriging method. Thickness represent the total thickness of the zone from the top to the bottom of the reservoir. Considering the assumption that higher values of porosity and thickness have sandstones in the central part of the channel, two variables (porosity and thickness) are multiplied to emphasize sand bodies, i.e. depositional channels distribution. Average map of distributed porosity multiplied with total thickness is shown in **Figure 5**. Visually, there is great similarity with the seismic attribute sweetness map. However, there are some differences. The southern sedimentation channel is visible only on the seismic attribute. It is not visible on the porosity-thickness map due to the lack of well data. Furthermore, porosity-thickness map clearly show lack of the LP reservoir in the central part of the south maximum, where the seismic attribute shows certain values, but the sedimentation bodies are not visible. Therefore, in the case of a sufficient number of well data, it can be assumed that porosity-thickness map more precisely describes the distribution of depositional channels.

Compared multiplied porosity-thickness and sweetness values were normalized. Correlation has been proved mathematically, with a medium correlation for the whole area and strong correlation in the northern part, where sandstones have higher thicknesses (**Figure 6**). However, there is no correlation between the seismic attribute and the porosity-thickness map in the central part of the southern maximum (**Figure 6**).

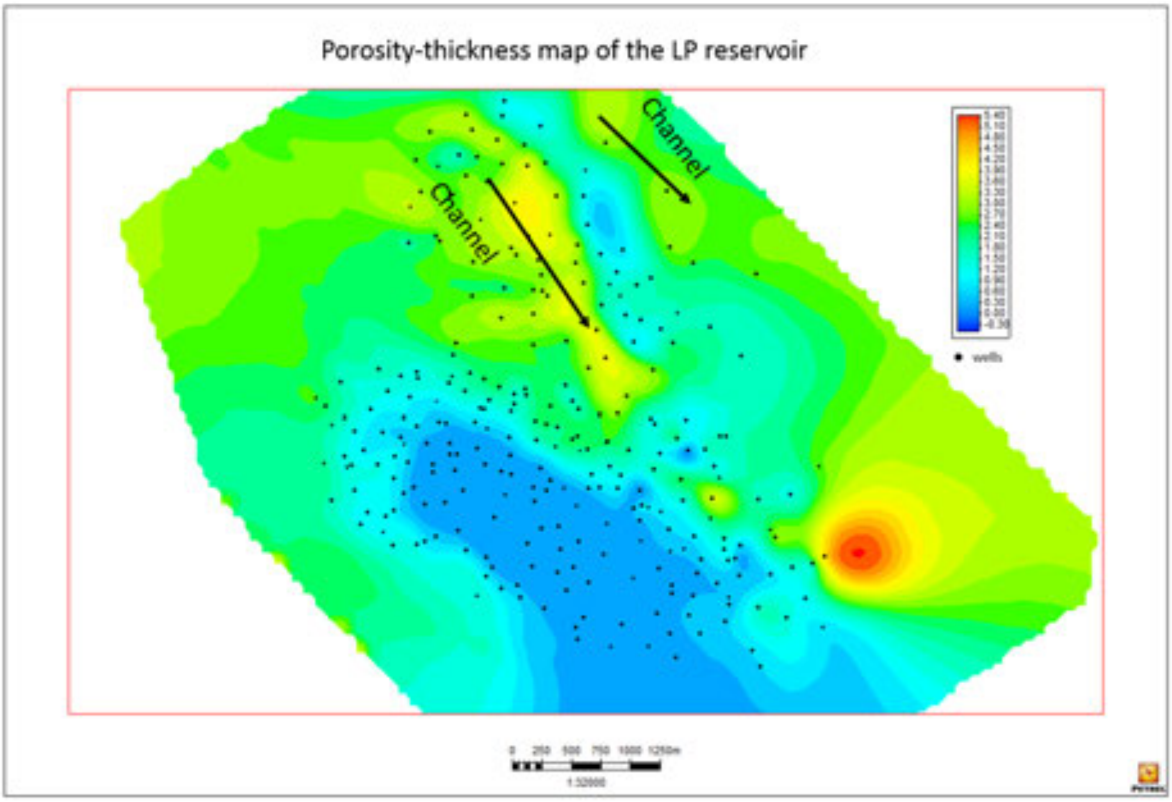

Figure 5: Porosity-thickness map of the LP reservoir

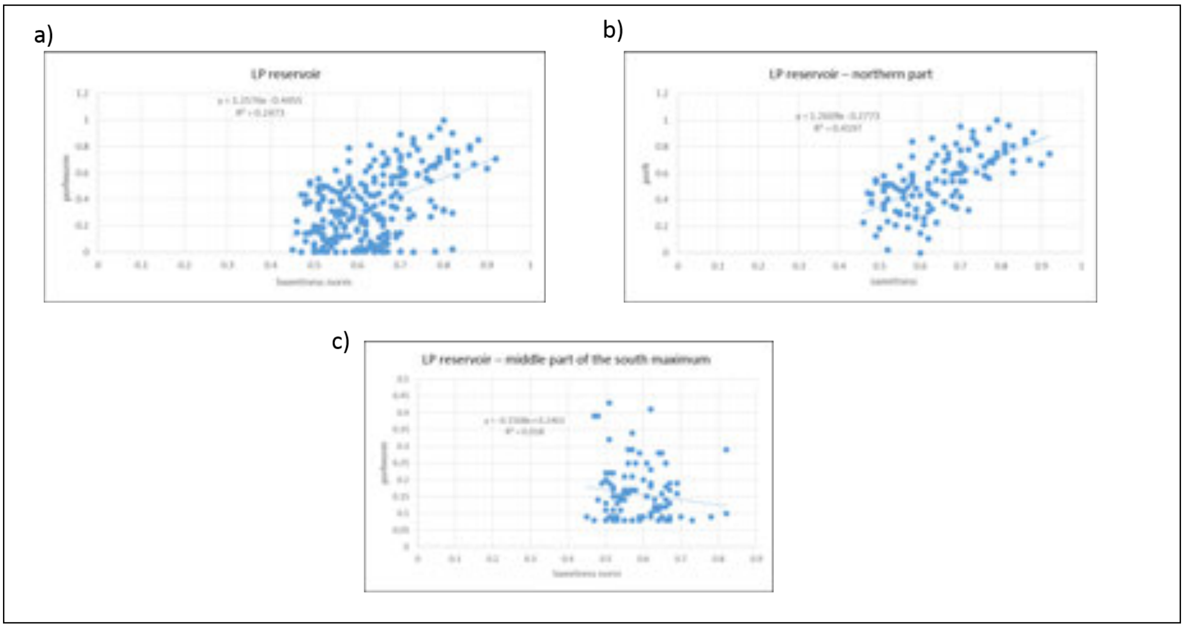

Figure6: Correlations of sweetness attribute and porosity-thickness normalized values for a) whole analysed area, b) northern part and c) central part of the south maximum

4. Correction of the seismic attribute sweetness

Considering that the porosity-thickness map of the LP reservoir is more representative in distribution of sand bodies, since it was made exclusively on the well data, the seismic attribute was corrected by the function of sweetness and porosity-thickness ratio for:

a) The entire field area, including all well data, with a medium correlation

$$y=1.2576x-0.4455 \quad (1)$$

b) Northern part of the field with a strong correlation

$$y= 1.2609x-0.2773 \quad (2)$$

Figures 7 and 8 show the comparison of the seismic attribute corrected by function for the entire area and function for the northern part. In both cases no significant change of attributes is noticed, especially for the central part of the south maximum, where correction is most needed. Only a minor change can be observed in the north and central channel, with slightly lower attribute values (less orange on the map).

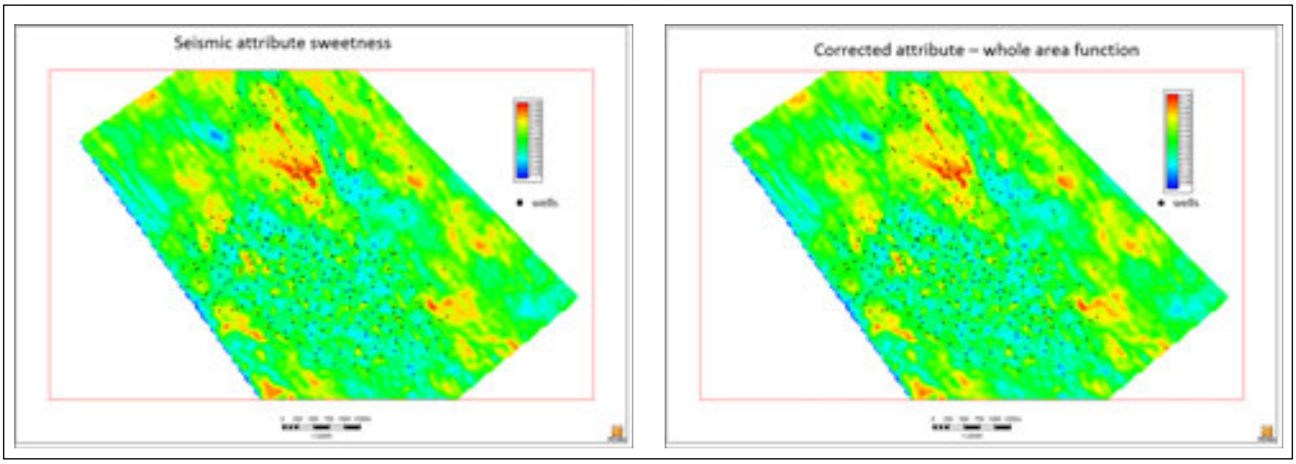

Figure7: Comparison of the seismic attribute of sweetness and corrected attribute by function for the whole area

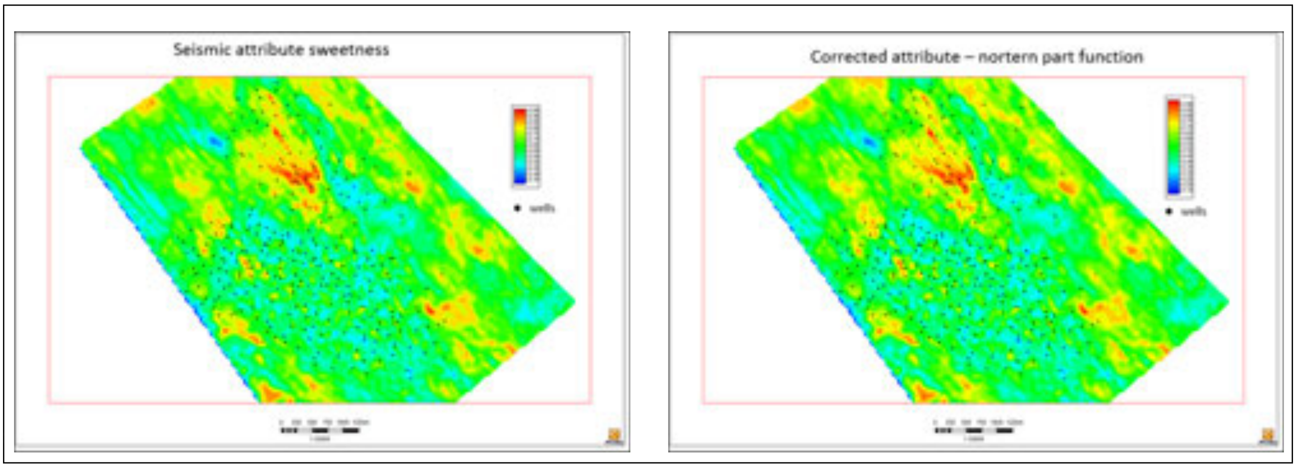

Figure8: Comparison of the seismic attribute of sweetness and corrected attribute by function for the northern part

5. Conclusion

The analysed LP reservoir of the A field is located in the Sava Depression. Sedimentologically it fits in the development of Sava Depression. The LP reservoir is Lower Pontian age. It is composed of material from the regional detritus transport through turbid currents from the Eastern Alps. The reservoir structure is an anticline with two maxima with structural saddle between them. The reservoir is composed of quartz-mica sandstones, which pinch-out in the central part of the southern maximum. It is separated from the shallower and deeper reservoirs by continuous marl, deposited in calm periods, when turbid currents were not active.

The LP reservoir was analysed by seismic attribute of sweetness and by porosity-thickness map in order to confirm depositional channels locations. Similarities in the sweetness and porosity-thickness maps were established. Interdependence of the mapped parameters is confirmed by the correlation coefficients; a) medium correlation, if all wells of the analysed area are involved, and b) strong correlation only for the northern part, with sandstones of greater thicknesses. Data used for correlation are normalized values of variables in well locations. In the central part of the southern maximum the correlation between the attributes of sweetness and the porosity-thickness map was not established. Visually, that part show the most significant differences in the maps. The porosity-thickness map clearly show lack of the LP reservoir, while the map of the seismic attribute show areas with even high values. Such high attribute values are dispersed, and sandy bodies are not visible.

The correction of the seismic attribute was performed by the ratio function of the seismic attribute and the porosity-thickness maps for the whole area, with the medium correlation and by the function for the northern part, where strong correlation of the parameters was established. The result is a corrected map of seismic attributes, which is only slightly different than the original.

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Extended abstract in Croatian

Korekcija seizmičkog atributa sweetness pomoću umnoška karata šupljikavosti i debljine, donjopontsko ležište LP, Savska depresija

Interpretacija seizmike važan je element, kako u istraživanju, tako i u razradi ležišta ugljikovodika. Seizmički atributi su postali neizostavni alat u opisu podzemlja, a atribut sweetness često se koristi za definiranje kvalitete samog ležišta. Stoga je vrlo koristan prilikom identifikacije izoliranih pješčanih tijela, zbog njihove jače refleksije u odnosu na okolne lapore.

Jednako tako, kvalitetu ležišta mogu opisati i karte umnoška šupljikavosti i debljine, polazeći od činjenice da je svaka od spomenutih varijabli direktna posljedica samog taloženja. Naime, pretpostavimo li da će se u središtu kanala, zbog jače struje taložiti krupniji materijal, za razliku od rubova kanala, gdje se jačina struje smanjuje te se počinje taložiti i sitniji detritus. Krupniji materijal u središtu kanala će sukladno tome imati veće vrijednosti šupljikavosti, ali i veće debljine. Umnožak tih dvaju proporcionalnih parametara dodatno će naglasiti kvalitetu ležišta te definirati položaj taložnih kanala u prostoru. Naravno, preduvjet za ovakvu metodu interpretacije je veliki broj ulaznih podataka potrebnih za kvalitetnu geostatističku analizu i prostornu distribuciju.

Analizirano ležište LP polja A nalazi se u području Savske depresije. Sedimentološki se potpuno uklapa u sliku razvoja Savske depresije. Ležište LP je donjopontske starosti. Sastavljeno je od materijala regionalnog donosa turbiditnim strujama iz područja Istočnih Alpi. Struktura ležišta je antiklinala s dva nadsvođenja između kojih se nalazi sedlo. Kolektorske stijene su kvarc-tinjčasti pješčenjaci, koji u središnjem dijelu strukture južnog nadsvođenja isklinjuju. Od plićih i dubljih ležišta dijele ga kontinuirani lapori, taloženi u dubljevodnim mirnim uvjetima, kada turbiditne struje nisu bile aktivne.

Ležište LP analizirano je seizmičkim atributom sweetness te kartom umnoška šupljikavosti i debljine, kako bi se utvrdilo rasprostiranje taložnih kanala. Budući da oba parametra (seizmički atribut sweetness i karta umnoška debljine ležišta i šupljikavosti) opisuju kvalitetu ležišta, oni se mogu međusobno uspoređivati. Utvrđene su sličnosti u kartama sweetness atributa i umnoška šupljikavosti i debljine. Međusobna ovisnost kartiranih parametara potvrđena je koeficijentima korelacije i to srednjom korelacijom, ukoliko se uključe sve bušotine analiziranog područja i snažnom korelacijom samo za sjeverni dio, gdje su pješčana tijela većih debljina. Podaci korišteni za korelaciju su normalizirane vrijednosti varijabli na lokacijama bušotina. U središnjem dijelu južnog nadsvođenja nije utvrđena korelacija atributa *sweetness* i umnoška šupljikavosti i debljine. Upravo taj dio i vizualno ima najveće razlike u kartama. Na karti umnoška

šupljikavosti i debljine jasno se uočava nedostatak ležišta, dok se na karti seizmičkog atributa uočavaju područja s čak visokim vrijednostima. Takve visoke vrijednosti atributa su raspršene, a pješčana tijela nisu vidljiva.

Korekcija seizmičkog atributa napravljena je pomoću funkcije odnosa atributa i umnoška šupljikavosti i debljine za cijelo područje, sa srednjom korelacijom i po funkciji za sjeverni dio, gdje je utvrđena snažna korelacija parametara. Rezultat su korigirane karte seizmičkog atributa koje se tek neznatno razlikuju od originala.

Ključne riječi: seizmički atribut *sweetness*, karta umnoška šupljikavosti i debljine, pješčenjaci, Savska depresija, Hrvatska.

Authors contribution

Kristina Novak Zelenika (PhD, reservoir modelling expert) provided part of theoretical background, provided distribution maps and conclusions. **Saša Smoljanović** (reservoir geology senior expert) provided parts of theoretical background.