Kriging with small number of data supported by jack-knifing, case study in the Sava Depression (Northern Croatia)

Tomislav Malvić, Josip Ivšinović, Josipa Velić and Rajna Rajić

Abstract: Presented is semivariogram and the Ordinary Kriging analyses of porosity data from the Sava Depression (Northern Croatia), as part of the Croatian part of the Pannonian Basin System. Data are taken from hydrocarbon reservoirs of the Lower Pontian (Upper Miocene) age, which belongs to the Kloštar-Ivanić Formation. Original datasets had been jack-knifed with purpose to “artificially” increased data and calculate the more reliable semivariograms. The results showed that such improvements can assist in the interpolation of more reliable maps. The both sets, made by original and jack-knifed data, need to be compared using geological recognition of non-allowed shapes (“bull-eyes”, “butterfly effects”) as well as cross-validation results. That comparison made possible to select the most appropriate porosity interpolation.

Keywords: Ordinary Kriging, variogram, jack-knifing, Upper Miocene, Northern Croatia, porosity

1. Introduction

The hydrocarbon reservoirs in the Sava Depression (Northern Croatia) are in the secondary or tertiary recovery phase. The most of the are supported by water injection. Here are analyzed two fields from mention depression with still significant production of hydrocarbons from selected reservoirs. Those are field “A”, reservoir “L” and the field “B”, reservoir “K”, hydrodynamic unit “K1”.

This analyses in the continuation and based of many previous works published for the volume of the Sava Depression as well as the entire Croatian part of the Pannonian Basin System (abbr. CPBS). The works [1] and [2] presented injection and separation of reservoir fluids in these fields. The costs of such processes are given in [2, 3]. Statistical and mapping represented continuation of previous regional works, especially in the Sava Depression. So, [4] presented using of descriptive statistics (porosity vs. depth) and tests (t, F-tests) and Pearson correlation for interpretation of influence of increasing of depth on decreasing of porosity in the Bjelovar Subdepression (the Kloštar-Ivanić Formation, Pepelana and Poljana Membe). [5] pointed out the Kriging as the most appropriate method for porosity interpolation in the Sava Depression. [6], for the data from the Stari Gradac-Barcs Nygat Field (the Drava Depression), for the first time in Croatian geology, applied the jack-knifing in the variogram modelling of the reservoir variables. In the same field, [7] for the first time applied stochastically improved probability of success calculation. [8] described the most often applied Kriging techniques – Simple, Ordinary and Indicator – and is given optimal Lagrange value in the Ordinary Kriging for the CPBS. [9] gave sequential Gaussian simulation (abbr. SGS) results for the Kloštar Field in the Sava Depression. [10] analyzed lithofacies from logs, porosity maps, and made indicator transformation and maps (the Kloštar Field, Sava Depression). In the same field, [11]
analyzed reservoir porosity, depth and thickness using 100 realizations of the SGS. [12] applied geostatistics for the most detail geological model of the Kloštar Field and typical depositional model of the Upper Miocene sandstone reservoirs in the Sava Depression. [13] described the four main application of geostatistics and recommended for the CPBS such interpolation for the datasets with 20 or more points. [14] recommended the Ordinary Kriging as the most appropriate technique for the sandstone reservoirs in the Sava Depression. [15] applied the sequential indicator simulations for porosity mapping (the CPBS), using reservoir thickness maps as the secondary source of information. [16] applied stochastically improved probability model of geological risk as new approach for clastic reservoirs in the CPBS. [17] used the Ordinary and Indicator Kriging as well as the SGS for CO2 sequestration in the oil reservoirs. Deterministical method for geological risk has been adapted for sequestration purpose. [18] mapped the Bjelovar Subdepression using the Ordinary Kriging and digitalized set of older maps. [19] analyzed data from the Šandrovac Field (the Drava Depression) comparing the Ordinary Kriging, Inverse Distance Weighting and Nearest Neighborhood. [20] used the Universal Kriging, for the first time in the Bjelovar Subdepression and proven as the best interpolation method in the CPBS if regional trend is visible. [21] described application of stochastic simulation for Lower Pontian reservoir in general (the CBPS). [22] presented the problem of selection appropriate mapping method for the dataset with small number of data (i.e., Nearest Neighborhood vs. Inverse Distance Weighting).

All these works have been analyzed before presented study. The problem of relatively small number of data is characteristic for almost each particular structure (field) in the Sava Depression. Such data cannot be additionally collected (most due to expenses), so the statistically available methods (jack-knifing) for increasing of “artificial” data are analyzed. For the fields “A” (reservoir “L”) and “B” (reservoir “K”,/HD “K1”) two variables are collected (porosity, injected water) and mapped with several methods (Nearest Neighborhood, Inverse Distance Weighting, Kriging). Both fields are located in the Sava Depression, about 90 km south-eastern from the capital Zagreb (Figure 1) and close to the highway A3 (5 km) and regional railroad (4 km).

The smaller location maps of analyzed fields has been presented at Figure 2 (the field “A” with blue and “B” with red borders). The both fields are on the hilly terrain. “A” is elongated structure with strike NW-SE and altitude 113-216 m, crossed by numerous landslides, and partially forested. Similarly, the altitude of field “B” is 120-231 m. The hills are steep, locally forested.

![Figure 1](image1.png)

**Figure 1.** Regional geological units of the 2nd order (depressions in the CPBS) and location of the fields „A“ and „B“ in the Sava Depression (from [23])
2. Geological history of the Sava Depression and analyzed structures

Here is given the short review of geological history for typical sandstone, Neogene hydrocarbon reservoir in the CPBS, and particularly Sava Depression, i.e. type that had been analyzed in this paper. The CPBS is located at the very south-western part of the PBS. Marginal location, regional position of the rock of the pre-Neogene basement and Neogene and Quaternary tectonics are reason for the present-day structures and their elongation northwest – southeast. The entire area is divided in the four depressions – Sava, Drava, Mura and Slavonia-Srijem (Figures 1 and 3).

Figure 2. Satellite maps of the fields „A“ and „B“ (taken from Google). The figure represents area boxed on Figure 1.
Figure 3. Regional geological units of the 1st order in the Pannonian Basin System (abbr. PBS)
(modified from MALVIĆ 2012b, ROYDEN, 1988)

Croatian depressions were situated always at the margins of the PBS. Consequently, those areas were covered by shallow marine environments of the Paratethys during Badenian and Sarmatian (16.4 – 11.5 Ma). It was reduced in the Pannonian Lake in the Lower Pannonian (11.5 – 9.3 Ma), and disintegrated during the Upper Pannonian (9.3 – 7.1 Ma) and Pontian (7.1 – 5.7 Ma) in several lakes. They were during Pliocene again connected in the smaller Slavonian Lake (PAVELIĆ & KOVAČIĆ, 2018) and eventually finished as continental facies (in Upper Romanian) that prevailing today (Holocene). The main stages of the geological evolution are shown on Figure 4.

Figure 4. Timescale of the main tectonical and depositional events during Neogene and Quaternary in the CPBS [25]

In the entire CPBS, from Badenian until Upper Pontian (Middle to Upper Miocene), firstly carbonate, later clastic environments dominated. During Lower Pontian (Figure 5) the clastic reservoirs, analyzed here, had been deposited in the Sava Depression. In was time when huge volumes of sand and silt were transported by turbidites. In the meantime, during “calm” periods, different carbonate-rich mud was deposited. Such alterations of clastic is typical for “high” and “low” energy environments in the CPBS and had been presented, e.g., in [26].
Consequently, more than 95% sandstone reservoirs in the CPBS are of turbidite origin, and Upper Pannonian or Lower Pontian age. Such sandstones include several lithofacies. In the central part those are “pure”, medium-grained sandstones, which gradually change into silty or clayey sandstones and siltstones on structural margins. Such heterogeneity was important for secondary migration as well as current recovery and production regime. The analyzed fields “A” and “B” are located in the western part of the Sava Depression, where currently water injection supports the production. The typical geological column has been drawn based on geological data from drilling and logging (Figure 6). The most of wells reached the rocks of the Kloštar-Ivanic Formation (Lower Pontian), because the reservoirs are discovered in that sediments. The formation is typical alteration of marlstones and sandstones, where analyzed reservoirs belong to the Pepelana Member. The marlstones are hard, grey to brown, and isolators for sandstone reservoirs (Figures 7 and 8).
<table>
<thead>
<tr>
<th>Age in Ma</th>
<th>Chronostratigraphy</th>
<th>Lithostratigraphy</th>
<th>Lithology</th>
<th>Reservoir unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5.6</td>
<td>NEogene</td>
<td>Pliocene</td>
<td>Lonja</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Romanian</td>
<td>Formation</td>
<td></td>
</tr>
<tr>
<td>5.6-6.3</td>
<td></td>
<td>Upper Pontian</td>
<td>Siroko</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polje Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.3-7.1</td>
<td>Miocene</td>
<td>Lower Pontian</td>
<td>Klostari</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ivanic Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6.** Typical geological column for the fields “A” and “B”. The formal and informal lithostratigraphic units are listed.
Figure 7. The composite log-lithological column in the field “A” (from archive of INA Plc. and re-drawn)
Figure 8. The composite log-lithological column in the field “A” (from archive of INA Plc. and re-drawn)
3. Results

Exploration drilling in the analyzed fields dated in the 1960's. Consequently, the subsurface mapping has been done for each particular reservoir. Such maps are regularly updated.

3.1. The field “A”, reservoir “L”

3.1.1. Reservoir type

According to classification [27] the reservoirs in the field “A” are of bedding type, capped by isolators, and margined with lithological and/or tectonical screens. The reservoir rocks are rhythmically interbedded with thin marls or sandy marls. The entire reservoir is single hydrodynamic units. Sandstones are enriched by mica minerals and dominant quartz detritus.

3.1.2. Granulometry, porosity, saturation and permeability of sandstones

Granulometry has been calculated from cores and CaCO₃ using calcimetry analysis (Table 1). Based on 619 data from cores taken in 10 wells porosity varied 22.3 – 24.7 %. Porosity estimated from logs showed slightly different values: 16.7 – 20.1 % in gas saturated and 15.6 – 23.9 % in oil saturated part. Saturation is also calculated dually – in 42 wells from cores, and in 36 from logs. The accepted values are 59.8 - 77.0 % for $S_g$ and 57.3 - 71.6 for $S_o$. The permeability has been calculated from data taken in 7 wells: $8 - 27 \times 10^{-3}$ µm².

Table 1. Granulometry of reservoir “L” (Md – mean grain diameter, So – coefficient of sorting, Sk – coefficient of asymmetry) (from archive of INA Plc.)

<table>
<thead>
<tr>
<th>Well</th>
<th>Md</th>
<th>So</th>
<th>Sk</th>
<th>Sand (%)</th>
<th>Coarse silt (%)</th>
<th>Clay (%)</th>
<th>CaCO₃ with gran. (%)</th>
<th>CaCO₃ (%)</th>
<th>No. of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.095</td>
<td>1.697</td>
<td>0.831</td>
<td>71.5</td>
<td>21</td>
<td>7.5</td>
<td>30.6</td>
<td>22.3</td>
<td>3</td>
</tr>
<tr>
<td>57</td>
<td>0.282</td>
<td>1.640</td>
<td>1.087</td>
<td>63</td>
<td>47</td>
<td></td>
<td>26.8</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>83</td>
<td>0.068</td>
<td>1.581</td>
<td>0.938</td>
<td>53</td>
<td>42</td>
<td>5</td>
<td>29</td>
<td>29</td>
<td>28</td>
</tr>
<tr>
<td>91</td>
<td>0.074</td>
<td>1.558</td>
<td>0.935</td>
<td>59</td>
<td>38</td>
<td>3</td>
<td>31.8</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>92</td>
<td>0.063</td>
<td>1.546</td>
<td>1.02</td>
<td>54</td>
<td>44</td>
<td>2</td>
<td>29</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td>145</td>
<td>0.081</td>
<td>2.31</td>
<td>0.683</td>
<td>59.5</td>
<td>37.5</td>
<td>3</td>
<td>26.5</td>
<td>26.5</td>
<td>6</td>
</tr>
<tr>
<td>153</td>
<td>0.066</td>
<td>2.135</td>
<td>0.786</td>
<td>50</td>
<td>47.7</td>
<td>2.3</td>
<td>26.5</td>
<td>23</td>
<td>11</td>
</tr>
</tbody>
</table>

3.1.3. Structural settings

The isopach map of reservoir “L” is given on Figure 9 with shown sections presented on Figures 10 and 11. It is clearly seen (Figure 10) that thickness of reservoirs in Kloštar-Ivanić Formation are mostly constant in central part (reservoir “N” about 150 m, “B” 20 m, “K” and “JL” 80 m, and “L” 45 m). However, analyzed “L” is example of thinning from 70 m (L-161) to only 20 m (L-153). Analyzing section SW-NE (Figure 11) thickness of the reservoir “L” is about 20 m (L-63, L-57, L-27) and gradually thicken to 39 m (L-131alfa).
Figure 9. Isopach map of the reservoir “L”, part where reservoir pressure is supported with water injection (from archive of INA Plc. and re-drawn)

Figure 10. Correlation section through wells L-161 – L-153 – L-27
3.1.4. Variogram analysis and Ordinary Kriging of porosity

Porosity data were available in 25 wells (Figure 12). In the past, porosity maps have not been properly interpolated for entire reservoir, i.e. often has been replaced with average for the single tectonic block.

The Kriging has been proven as the most appropriate method for interpolation of sandstone Upper Miocene reservoir variables in the CPBS (e.g., [5, 10, 12, 20]). Consequently, the experimental semivariogram for porosity had been calculated (Figure 13).
Unfortunately, the semivariogram is characterized with large oscillations and low number of data pairs per class. So, approximation had been possible done only with the simplest – linear model. The Ordinary Kriging map is shown on Figure 14.

The cross-validation (porosity expressed as parts of units, not as percentages, are used in this type of calculations) for the Kriged map is 0.000676. However, variogram model is obviously characterized with large uncertainties (estimation of nugget, number of data pairs). It is why that has been decided to apply jack-knifing statistical method with purpose to artificially increase number of data. Jack-knifing has been previously applied or described in the CPBS [6, 29]. Basically, this method has similar algorithm as cross-validation, where data or group of data has been “deleted” and estimation is done from the rest. Such re-sampling method is characterized with standard error (e.g., [30, 31, 32]) and can be used as one of the improvements in the basic Kriging techniques or data intended to interpolate using the Kriging (e.g., digital terrain model, DTM, data, like in [33]). In this study it had been applied for each variogram class (step), which was calculated several times. The final value was the approximation of each calculation set for the same class (lag). Consequently, the number of data pairs included in calculation of class has been much larger. The “jack-knifed” semivariogram for the same reservoir porosity is given on Figure 15. Oscillations are largely decreased in several points, and experimental semivariogram is approximated with exponential theoretical model, significantly decreasing the range.

Figure 13. Experimental semivariogram, reservoir “L”, porosity
Figure 14. Porosity map for reservoir “L” interpolated by the Ordinary Kriging

Figure 15. Experimental semivariogram, reservoir “L”, porosity, after jack-knifing

Using the new one semivariogram the new porosity map has been interpolated (Figure 16). Due to much smaller range, the new porosity map is characterized with numerous “bull-eyes” shapes.
Figure 16. Porosity map for reservoir “L” interpolated by the Ordinary Kriging with jack-knifed semivariogram

3.2. The field “B”, reservoir “K”, hydrodynamic unit “K1”

3.2.1. Reservoir type

According to [27] the reservoirs in the field “B” are of bedding type, capped by isolators, and margined with lithological and/or tectonical screens. In that brachiancline, with strike northwest – southeast, sandstones reservoirs are enriched by mica minerals and quartz and occasionally interbedded with marls and (shallower) sandy marls. The reservoir “K” is divided in several tectonic blocks, where each of them is mostly separated hydrodynamic unit (abbr. HD). It is why here is analyzed the largest one such unit – HD “K1”.

3.2.2. Granulometry, porosity, saturation and permeability of sandstones

Granulometry is shown in Table 2. Porosity is calculated for cores in 3 wells (27.2 – 31.5 %) and logs in 36 wells (18.2 – 22.3 % in gas saturated and 18.3 – 24.9 % in oil saturated part). Saturation has been determined using laboratory in 32 wells and from logs in 36 wells. $S_g$ is 69.3 – 79.5 % and $S_o$ 52.8 – 71.6 %. Permeability (in 3 wells) is $29.6 – 121.2 \times 10^{-3} \, \mu \text{m}^2$. 


Table 2. Granulometry of reservoir “K” (Md – mean grain diameter, So – coefficient of sorting, Sk – coefficient of asymmetry) (from archive of INA Plc.)

<table>
<thead>
<tr>
<th>Well</th>
<th>Md</th>
<th>So</th>
<th>Sk</th>
<th>Sand (%)</th>
<th>Coarse silt (%)</th>
<th>Clay (%)</th>
<th>CaCO₃ with gran. (%)</th>
<th>CaCO₃ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>0.071</td>
<td>1.560</td>
<td>1.239</td>
<td>56</td>
<td>44</td>
<td>0</td>
<td>30.1</td>
<td>14</td>
</tr>
<tr>
<td>31</td>
<td>0.101</td>
<td>1.430</td>
<td>0.980</td>
<td>76</td>
<td>24</td>
<td>0</td>
<td>28.4</td>
<td>4</td>
</tr>
<tr>
<td>33</td>
<td>0.099</td>
<td>1.660</td>
<td>1.100</td>
<td>75</td>
<td>25</td>
<td>0</td>
<td>35.4</td>
<td>1</td>
</tr>
<tr>
<td>45</td>
<td>0.094</td>
<td>1.496</td>
<td>1.445</td>
<td>85</td>
<td>15</td>
<td>0</td>
<td>28.8</td>
<td>1</td>
</tr>
<tr>
<td>55</td>
<td>0.094</td>
<td>1.461</td>
<td>1.172</td>
<td>77</td>
<td>23</td>
<td>0</td>
<td>27.6</td>
<td>41</td>
</tr>
<tr>
<td>57</td>
<td>0.037</td>
<td>1.564</td>
<td>1.251</td>
<td>28</td>
<td>72</td>
<td>0</td>
<td>20.4</td>
<td>2</td>
</tr>
<tr>
<td>59</td>
<td>0.095</td>
<td>1.460</td>
<td>1.150</td>
<td>79</td>
<td>21</td>
<td>0</td>
<td>27.0</td>
<td>15</td>
</tr>
<tr>
<td>68</td>
<td>0.098</td>
<td>1.530</td>
<td>1.300</td>
<td>53</td>
<td>21</td>
<td>0</td>
<td>28.7</td>
<td>1</td>
</tr>
<tr>
<td>120</td>
<td>0.065</td>
<td>1.167</td>
<td>1.044</td>
<td>72</td>
<td>47</td>
<td>0</td>
<td>31.2</td>
<td>18</td>
</tr>
</tbody>
</table>

3.2.3. Structural settings

HD unit “K1” is the largest tectonic block and HD in the reservoir “K”. The part where reservoir pressure is supported by water injection is given on Figure 17.

Figure 17. Isopach map of the HD unit “K1”, part where reservoir pressure is supported with water injection (from archive of INA Plc.)

This reservoir has been crossed with two sections. The first has strike approx. NW-SE (Figure 18), and the second NE-SW (Figure 19). The section on Figure 18 shows that the reservoirs have similar thickness in both wells (“N” about 120 m, “K” 100 m, “Z” 40 m). Some marls pinch out, what
could be reason for separation of hydrodynamic units. The next section (Figure 19) clearly shows partial structural inversion in the Kloštar-Ivanić Formation, i.e. transition from homocline (deeper) to fold (shallower).

![Figure 18. Correlation section through wells J-166 – J-174](image)

![Figure 19. Correlation section through wells J-167 – J-25alfa – J-166 – J-149](image)

3.2.4. Variogram analysis and Ordinary Kriging of porosity

Porosity data were available in 19 wells (Figure 20. The detailed porosity maps had not been interpolated up to now. It was why data were analyzed using semivariogram. The experimental one is shown on Figure 21.
Figure 20. Porosity data available for HD “K1” (from archive of INA Plc.)

Figure 21. Experimental semivariogram, reservoir/HD “K1”, porosity

Due to large uncertainties and small number of data pairs, semivariogram is approximated with the simple linear model. Unfortunately, such model did not allow to estimate nugget, and certain range. Such semivariogram is applied in the Ordinary Kriging and resulting map is shown on Figure 22. The cross-validation is 0.0013197.

Again, the new semivariogram had been calculated with “artificial” dataset obtained by jack-knifing. The new experimental model is given on Figure 23. This one could be approximated with the Gaussian theoretical model and the resulting Kriging map is shown on Figure 24. The
semivariogram sill is lower and range larger (based on goodness of fitting) than in previous variogram model based on original dataset (19 points). The new Kriged porosity map is shown on Figure 24 and accompanied cross-validation value is 0.0009704.

**Figure 22.** Porosity map for reservoir/HD “K1” interpolated by the Ordinary Kriging

**Figure 23.** Experimental semivariogram, reservoir/HD “K1”, porosity, after jack-knifing
4. Discussion and conclusion

Presented analysis is the first of such kind in the Sava Depression (Northern Croatia). It represented the continuation of previous geostatistical analyses done in that depression and entire CPBS. Here is pointed out the permanent problem of small datasets what could be the crucial for subsurface mapping of different geological variables. In numerous analyzes, the new hard data hardly can be obtained, mostly due to costs of drilling or seismic. Consequently, any statistical method that could increase reliability of existing datasets and their analytical results is more than welcome. The jack-knifing is one of such method. Previously, it was successfully applied in the (adjacent) Drava Depression, and here, for the first time, in the Sava Depression. That could be very appropriate for datasets of 15-30 points, where basic, descriptive statistics is more or less representative (variance and mean), and the Gaussian distribution can be assumed.

In both cases the original semivariogram results were very uncertain, with large oscillations, small number of data pairs per class and unknown nugget. Consequently, the linear model was only acceptable theoretical model to use. It was why much larger number of artificial data had been calculated using jack-knifing. As results, the new semivariograms could be approximated more reliable and with mathematically advanced theoretical models (exponential and Gaussian).

The hypothesis that new Kriged maps interpolated from “jack-knifed” semivariograms are more reliable was eventually check (a) visually (maps without the “bull-eyes” or “butterfly” effects are better) and (b) numerically using cross-validation. The results are given in Table 3 and pointed out that:

(1) When experimental semivariograms are described with large uncertainties it is recommended the calculated jack-knifed data and repeat the variogram modelling and the Kriging interpolation.
Any map from the set of “old” or “new” data/semivariograms need to be firstly visually checked. If the effects like “bull-eyeing” or “butterfly shapes” are numerous the map needs to be eliminated.

If both Kriged maps (based on original and jack-knifed datasets) are visually (geologically) acceptable the selection can be done based on cross-validation values.

For the small data sets (less than 15) it is also recommended to interpolate with Inverse Distance Weighting and compare both OK and IDW results.

Table 3. Comparison of cross-validation values for the Ordinary Kriging (abbr. OK) maps based on original and jack-knifed semivariograms (abbr. IDW is for Inverse Distance Weighting)

<table>
<thead>
<tr>
<th>Field/reservoir</th>
<th>OK (original semivariogram)</th>
<th>OK (jack-knifed semivariogram)</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>“A”/“L”</td>
<td>0.000676 (linear)</td>
<td>0.000420 (exponential)</td>
<td>OK with original semivariogram or IDW. The effect of “bull-eyes” eliminated the jack-knifed approach.</td>
</tr>
<tr>
<td>“B”/“K1”</td>
<td>0.001320 (linear)</td>
<td>0.000970 (Gaussian)</td>
<td>OK with jack-knifed semivariogram</td>
</tr>
</tbody>
</table>

Presented test of the jack-knifing had been done for the sandstone reservoir porosity. The selected fields (“A”, “B”) and reservoirs (“L”, “K1”) represents typical Upper Miocene sandstones in the Sava Depression, with portion of sandy detritus 50 – 72 % and porosity 14.5 – 23.9 % (“A”), i.e., 21.7 – 31.5 % (“B”). It is why those conclusions could be applied in any other such reservoirs of the same depression (the Kloštar-Ivanić Formation).

Author Contributions: Tomislav Malvić led the research and selected the fields for analyses. Josip Ivšinović made the jack-knifing analyses, interpolated maps and collected data. Josipa Velić organized the regional geology presentation and visualization. Rajna Rajić checked the mathematical consistency of applied equations and methods.

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