Variogram Database Updated in 2009 for Petrophysical Values in the Sava and Drava Depressions (SW Part of the Pannonian Basin, Croatia)

Tomislav Malvić[1*, 2], Josipa Velić[1], Marko Cvetković[1***]**

[1]Faculty of Mining, Geology and Petroleum Engineering, Pierottijeva 6, 10000 Zagreb, Croatia (*Assist. Prof. ; **Full Prof. ; ***Assistant). E-mails: josipa.velic@rgn.hr , marko.cvetkovic@rgn.hr
[2]INA-Inustry of Oil Plc., Šubićeva 29, 10000 Zagreb, Croatia (Advisor). E-mail: tomislav.malvic@ina.hr

Abstract

There is large set of hydrocarbon fields and reservoirs that had been geostatistically analysed in the Croatian part of Pannonian Basin, i.e. in the Sava or Drava Depressions. Analyses had been done by programs Variowin 2.21™ (freeware), Landmark™ application RC^2, Surfer 8.0™, 3DField™, RC^2 and Petrel™. In the **western part of the Sava Depression** are analysed four fields. In the Voloder and Okoli Fields permeability and porosity in sandstone reservoirs of Lower Pontian age had been modelled by vertical 1D variograms. In the Ivanić-Grad Field porosity had been analysed in sandstones of Upper Pannonian age and interpolated by Ordinary Kriging. In the Kloštar Field target were Lower Pontian sandstones. In the **western part of the Drava Depression** geostatistical analyses are performed at Molve, Kalinovac and Stari Gradac-Barcs Nyugat Fields in reservoirs of Devonian, Triassic and Neogene ages. There are selected the best variogram model for each lithofacies in entire structural zone, followed by representative porosity map. The clastics of Badenian age in the Stari Gradac-Barcs Nyugat Field had been specially detailed analysed with stochastical geostatistical methods and maps. In the **eastern part of the Drava Depression** in the Beničanci Field experimental variograms in 2D had been calculated for porosity in breccias reservoir of Badenian age and interpolated by Ordinary Kriging. But, only 1D vertical experimental variograms are calculated in the Ladislavci-Kučanci Field for porosities and permeabilities values in Badenian reservoir. In **the Bjelovar Subdepression** are calculated comprehensive set of only 1D experimental variograms for porosity and permeability core data (without maps). The valid results are obtained in Badenian and Lower Pontian sediments.

Keywords: geostatistics, porosity, permeability, Devonian, Triassic, Neogene, Pannonian Basin, Croatia.

1. INTRODUCTION

There are several hydrocarbon fields and reservoirs of different ages that had been geostatistically analyzed in the Croatian part of Pannonian Basin. All of such fields are located in the Sava or Drava Depressions or in the Bjelovar Subdepression as the southern branch of the Drava Depression (**Figure 1.1**). The most often in all cases, the porosity had been selected as analyzed variable, but also rarely permeability had been analysed in vertical direction.

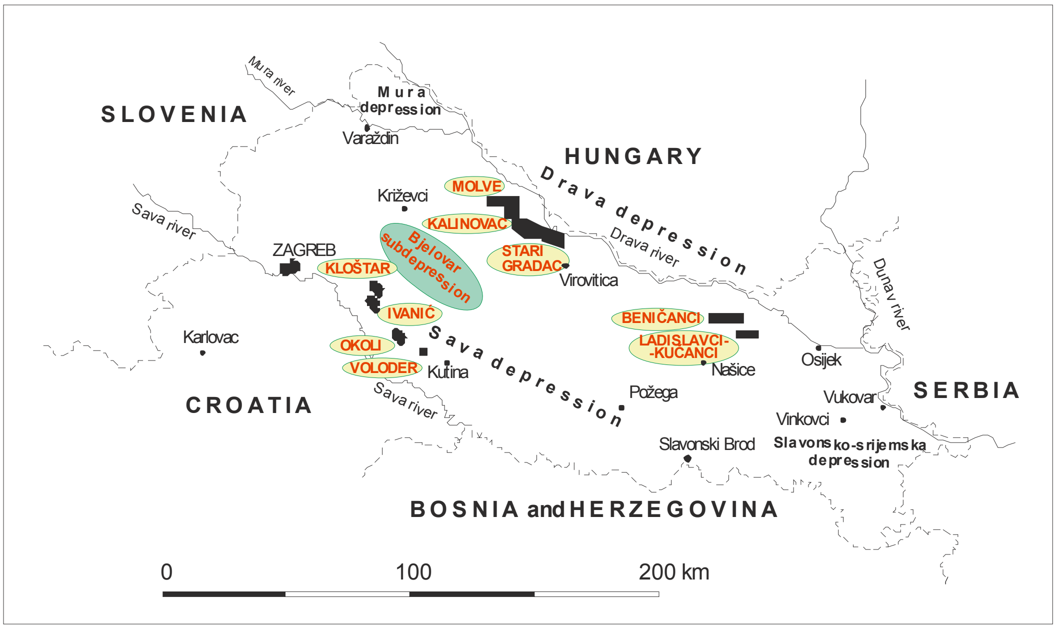


Fig. 1.1. Geostatistical analyzed areas in the Croatian part of the Pannonian Basin System

Experimental variograms were calculated by freeware program Variowin 2.21^{TM} (PANNATIER, 1996) or in licensed Landmark^{TM} application RC^2.
The porosity and thickness maps are interpolated with licensed programs Surfer 8.0^{TM} or 3DField^{TM}.
All analyses are done using both chronostratigraphic and lithostratigraphic criteria. In chronostratigraphic way there are mostly used unit of system rang (Devonian, Triassic, Neogene) and lower. In lithostratigraphy are used units in rang of lithostratigraphic member. The valid chronostratigraphic and lithostratigraphic nomenclature from Badenian to Lower Pontian for the Sava and Drava Depression in the Croatian part of Pannonian Basin is given at **Figure 1.2**.

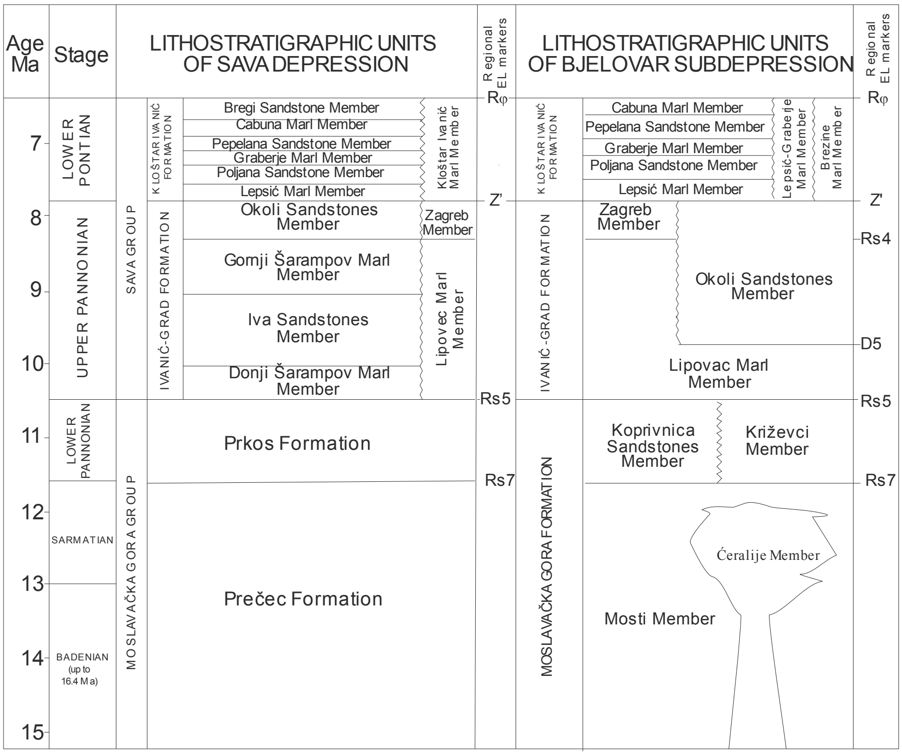


Fig. 1.2. Chronostratigraphic and lithostratigraphic nomenclature for the Sava and Drava Depressions in the Croatian part of the Pannonian Basin System

2. The Sava Depression

In the western part of the Sava Depression porosity had been analyzed by variograms in the fields Voloder and Okoli (HERNITZ et al., 2001), Ivanić-Grad (MALVIĆ, 2008) and Kloštar (BALIĆ et al., 2008). The data are mostly collected in sandstones of Pannonian and Pontian ages, deposited in environment of deeper brackish and fresh-water lake by mechanism of turbidite currents (VRBANAC et al., 2010; SAFTIĆ et al., 2003; VELIĆ et al., 2002).

2.1. Voloder and Okoli Fields

In **the Voloder** and **the Okoli Fields** permeability and porosity in sandstone reservoirs of **Lower Pontian age** had been analyzed. These are 1D variograms calculated in vertical direction in the selected wells from core data (**Figures 2.1** and **2.2**).

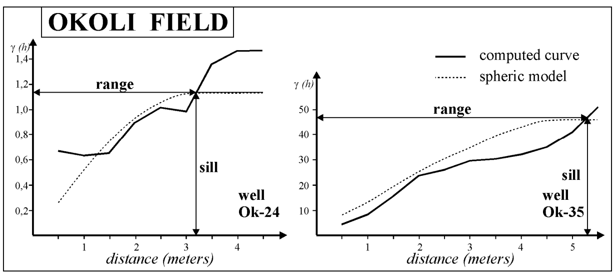


Fig. 2.1: Porosity semivariograms, sandstones, Okoli Field

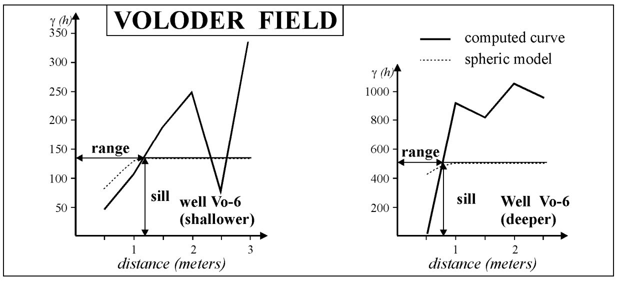


Fig. 2.2. Permeability semivariograms, sandstones, Voloder Field

2.2. Ivanić-Grad Field

In the **Ivanić-Grad Field t**he cores from 5 wells and 6 depth intervals are analyzed regarding porosity measured in sandstones of **Upper Pannonian** age. The original dataset can be considered as rarely extensive porosity set available for Croatian hydrocarbon reservoirs, and it was possible calculate very reliable semivariogram surface, semivariograms and interpolated Ordinary Kriging maps (**Figures 2.3-2.5**).

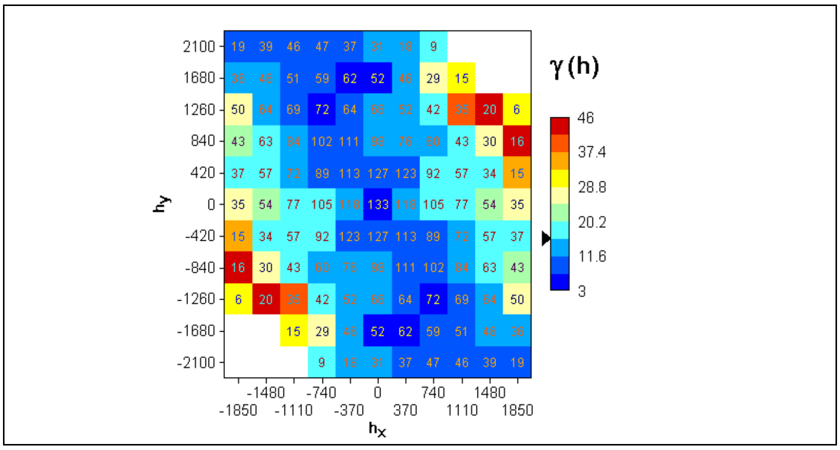


Fig. 2.3: Semivariogram surface map, porosity, Ivanić-Grad Field

Semivariogram surface map (**Figure 2.3**) showed that primary (**Figure 2.4**) semivariogram axis has NW-SE direction (135°-315°) and secondary (**Figure 2.5**) one is characterized by NE-SW direction (45°-225°). The experimental semivariograms at both axes were calculated using 15 lags, lag length of 400 meters, and angle tolerance of 45°.

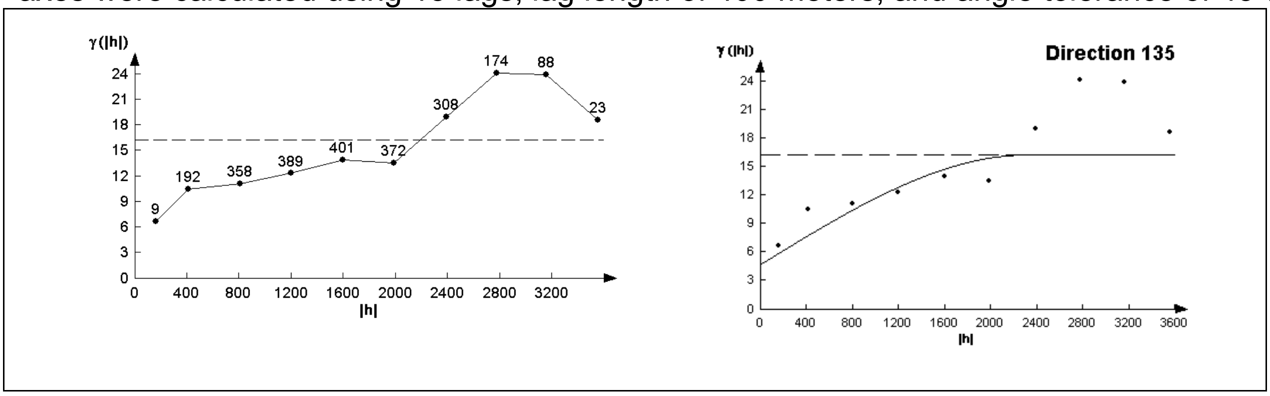


Fig. 2.4: Porosity semivariograms, primary axis, Ivanić-Grad Field

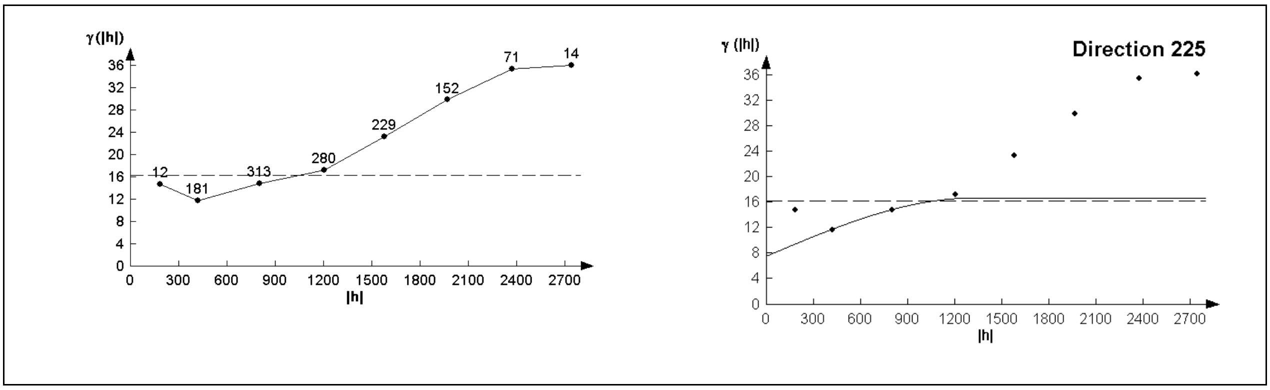


Fig. 2.5: Porosity semivariograms, secondary axis, Ivanić-Grad Field

Finally, relevant porosity map, valid for sandstone reservoir of Upper Pannonian age, is given at **Figure 2.6**. Porosity scale is given in colour at the left side of figure, and well locations (hard-data) are presented with red coloured crosses. Coordinates are given in Gauss-Krüger system.

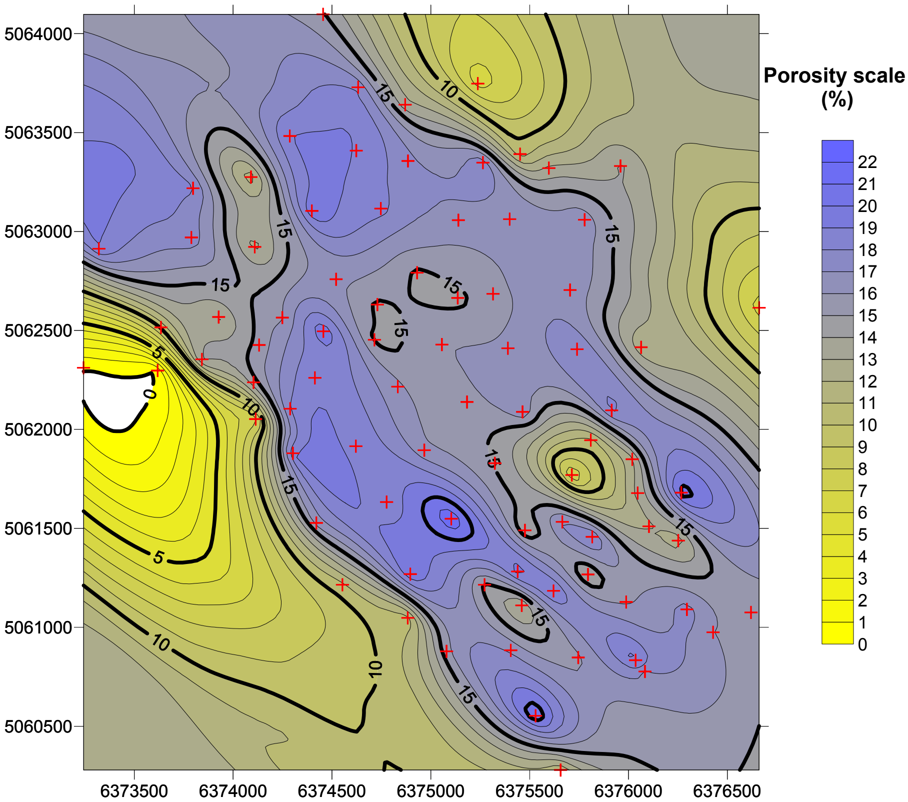


Fig. 2.6: The Ordinary Kriging porosity map of input values

2.3. Kloštar Field

The quality of porosity interpolation was evaluated based on two criteria. The first, graphical one, included the geological description of isoporosity line shapes, and also takes into consideration all available maps interpolated unofficially earlier by hand. The second, numerical criterion represented the estimation of interpretation quality with regards to the amount of mean square error (MSE).

There is tested several semivariogram models for the same porosity dataset and one of them is shown on **Figure 2.7**. Very similar model (range is a little lower) is used for kriging map presented on **Figure 2.8**. The lowest MSE was accompanied by kriging (366.93), and the highest by the nearest neighbourhood method (389.00). The final decision was made using both criteria.

Moreover, the two methods described as exact interpolators (kriging and inverse distance weighting) are selected as the most appropriate for porosity mapping in the analysed reservoirs. In addition, their comparison is followed by point-error data analyses, improving the "classical" MSE calculation. The point-error (or residual) maps reveal the areas where estimation can be described as more at risk of being moderately subdued by method error. These areas are the south-western margin of the field and one of the wells located in the north-west.

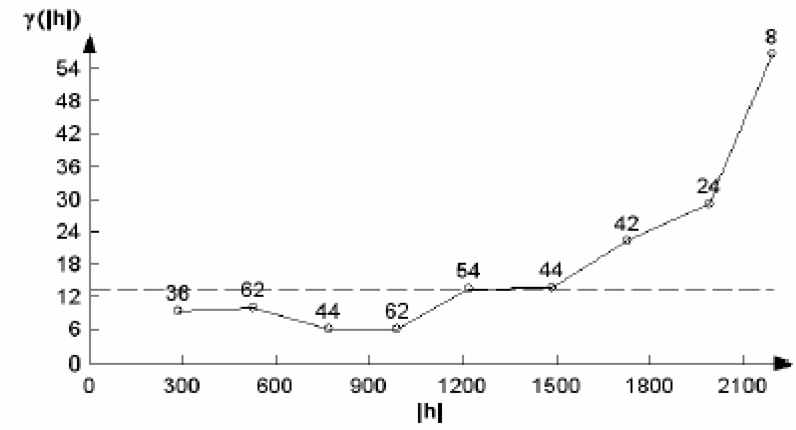


Fig. 2.7: Experimental omnidirectional semivariogram (approximated by exponential model) with parameters: range 1200 m, class width 250 m, no. of classes 15, nugget 0.7, sill 13.26)

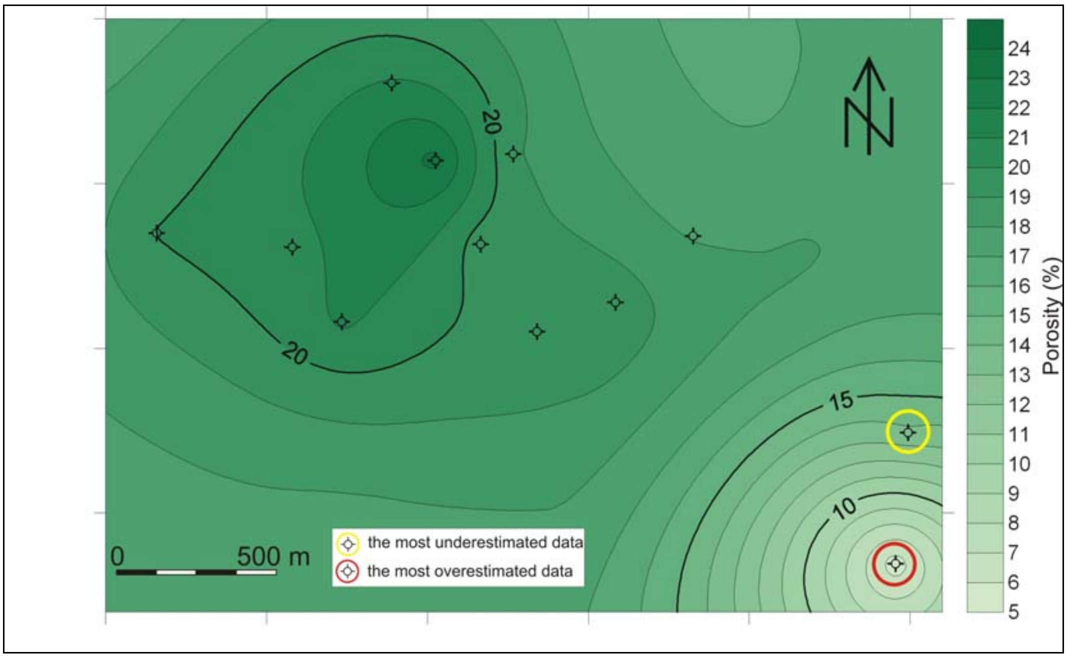
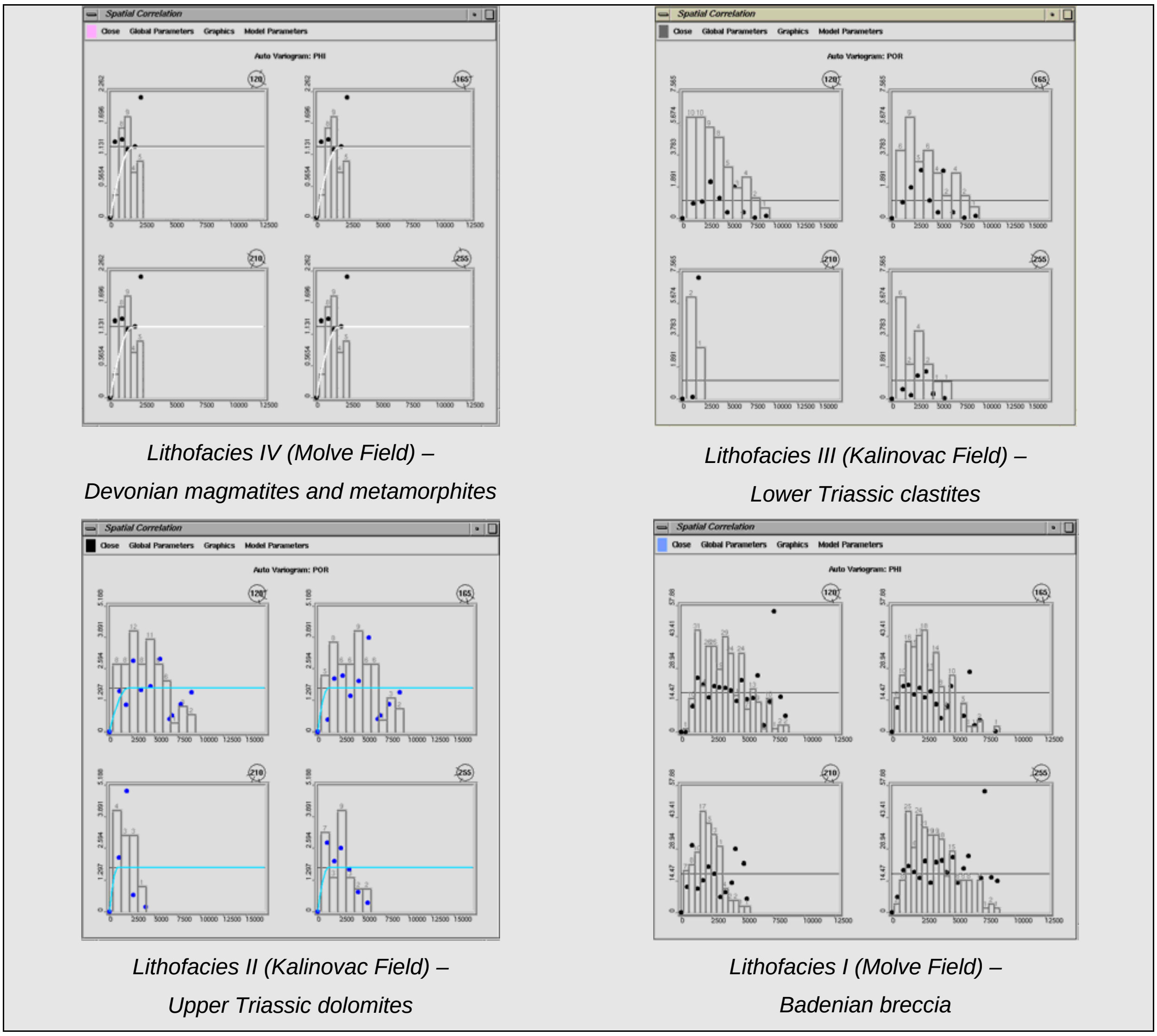


Fig. 2.8: Porosity map interpolated by kriging (isotropic variogram model, range 1100 m)

3. The Drava Depression

In **the western part of the Drava Depression** geostatistical analyzes are performed at the three gas-condensate fields **Molve, Kalinovac and Stari Gradac-Barcs Nyugat** (MALVIĆ & VELIĆ, 2010; MALVIĆ & ĐUREKOVIĆ, 2003; SMOLJANOVIĆ & MALVIĆ, 2004; MALVIĆ, 2005 etc.) for reservoirs of **Devonian, Triassic and Neogene systems**. The analyzed Neogene sediments (VELIĆ et al., 2002) are of Badenian age and represents the second large clastic complex regarding reservoir and source rocks potential (e.g. SAFTIĆ et al., 2003). All three mentioned fields are connected in larger structural zone.

3.1. Molve, Kalinovac, Stari Gradac-Barcs Nyugat Fields



Lithofacies IV (Molve Field) – Devonian magmatites and metamorphites

Lithofacies III (Kalinovac Field) – Lower Triassic clastites

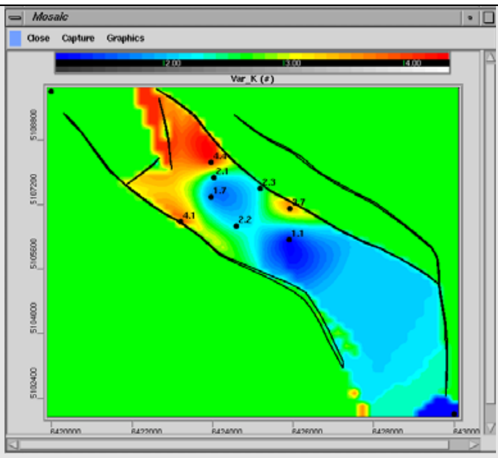
Lithofacies II (Kalinovac Field) – Upper Triassic dolomites

Lithofacies I (Molve Field) – Badenian breccia

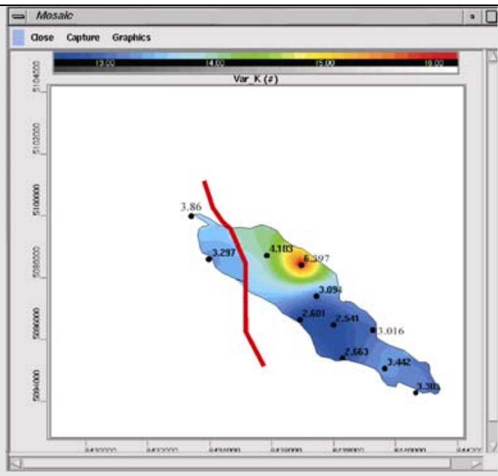
Fig. 3.1: Representative porosity variograms for field's lithofacies, western Drava Depression

That is anticlinorium, with mutual spill points, sharing the same reservoir lithofacies numbered as IV (Devonian), III (Lower Triassic), II (Upper Triassic) and I (Badenian).

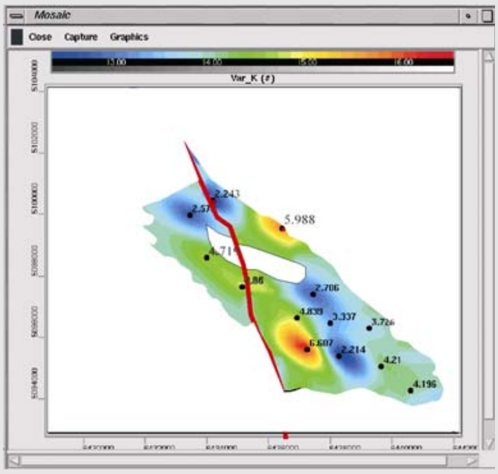
Horizontal experimental and theoretical variograms are calculated for all four lithofacies at all three fields. There is selected the best one model (**Figure 3.1**) lithofacies by lithofacies, valid for each field in this anticlinorium.
Consequently, for the each variogram model was able to interpolate porosity map in the selected lithofacies for any of three observed fields. But, to reach the most accuracy, the porosity map is done for the same field and relevant lithofacies where lithofacies' representative variogram had been selected (**Figure 3.2**).



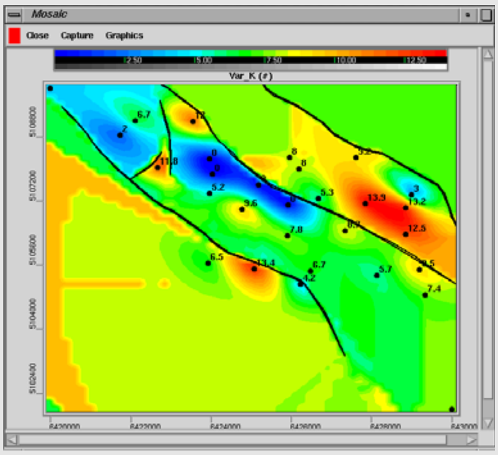
Lithofacies IV (Molve Field) –
Devonian magmatites and metamorphites



Lithofacies III (Kalinovac Field) –
Lower Triassic clastites



Lithofacies II (Kalinovac Field) –
Upper Triassic dolomites



Lithofacies I (Molve Field) –
Badenian breccia

Fig. 3.2: Representative porosity maps for field's lithofacies, western Drava Depression

3.2. Stari Gradac-Barcs Nyugat Field – extended analysis

The Stari Gradac-Barcs Nyugat Field had been also specially detailed analysed with different geostatistical methods (deterministically and stochastically), especially **clastics** of **Badenian age** (MALVIĆ, 2006; MALVIĆ & BASTAIĆ, 2008). Available porosity dataset is relatively limited (15 inputs), but enough for geostatistical application in horizontal plane (2D).

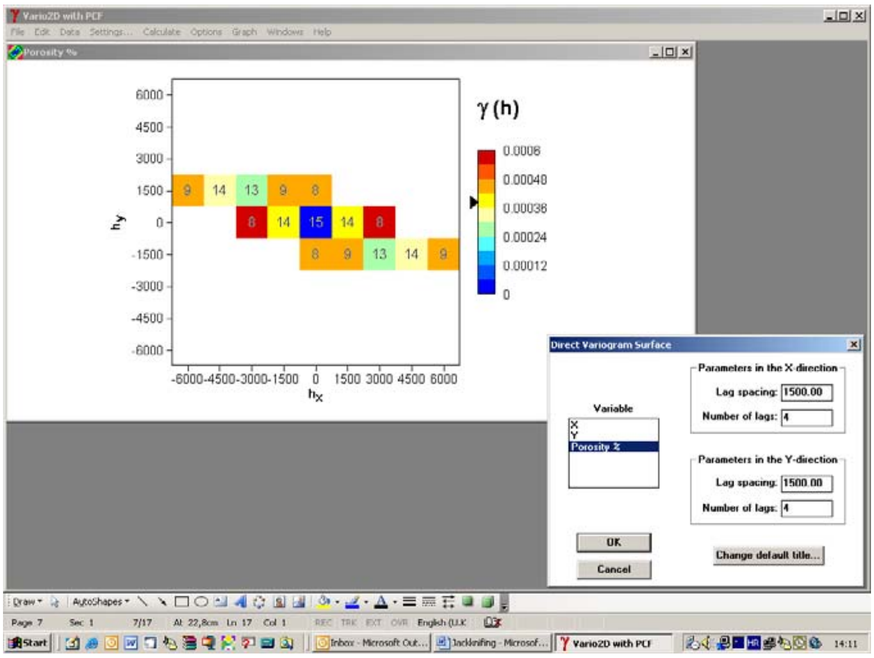


Fig. 3.3: Semivariogram surface maps, porosity, Badenian, Stari Gradac-Barcs Nyugat Field

Normal score transformation did not perform, but it is accepted that porosity is characterised by the normal distribution. Semivariogram analysis was performed in two directions, following the main field structural axes: 120°-300° as principal and 30°-210° as subordinate axis. Equivalence of structural and variogram axes were confirmed by the variogram surface map **Figure 3.3**.

Unfortunately, secondary axis could not be modelled using the *first sill crossing* approach, because range would be unrealistically low, due to small number of inputs. It is why variogram is modelled as omnidirectional (**Figure 3.4**).

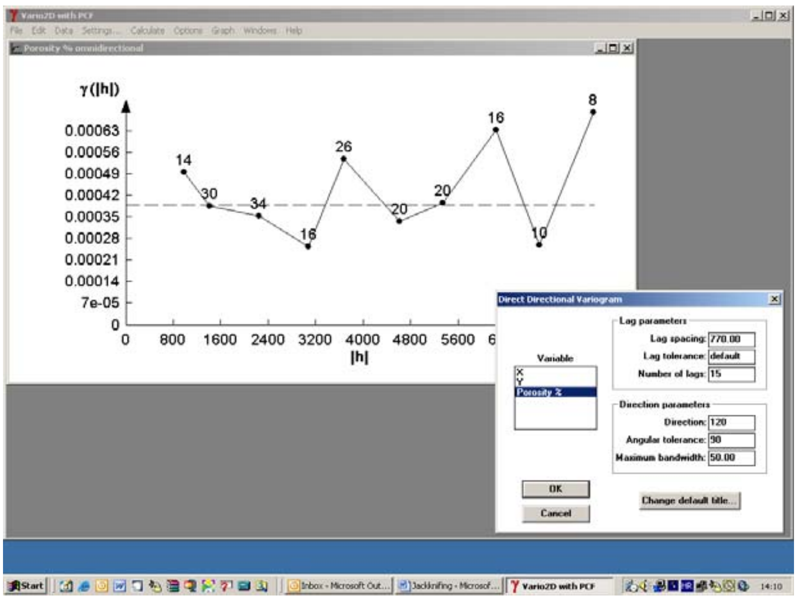


Fig. 3.4: Omnidirectional experimental semivariogram, Badenian, Stari Gradac-Barcs Nyugat Field

Experimental model had been approximated by theoretical one, shown on **Figure 3.5**. Finally, porosity map was interpolated using kriging algorithm in 3DField program what is presented at the **Figure 3.6**.

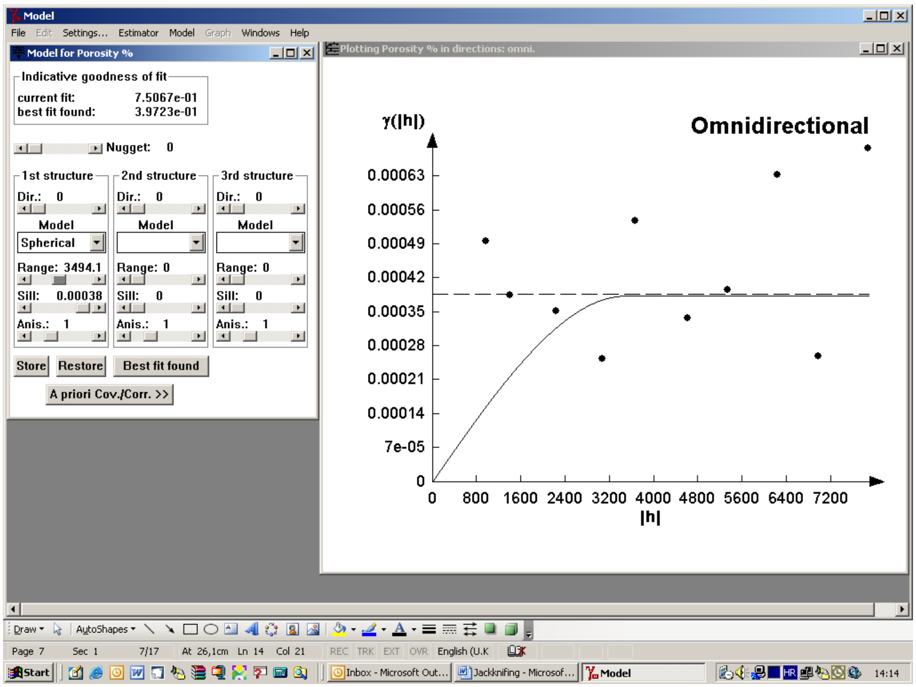


Fig. 3.5: Spherical theoretical model, Badenian, Stari Gradac-Barcs Nyugat Field

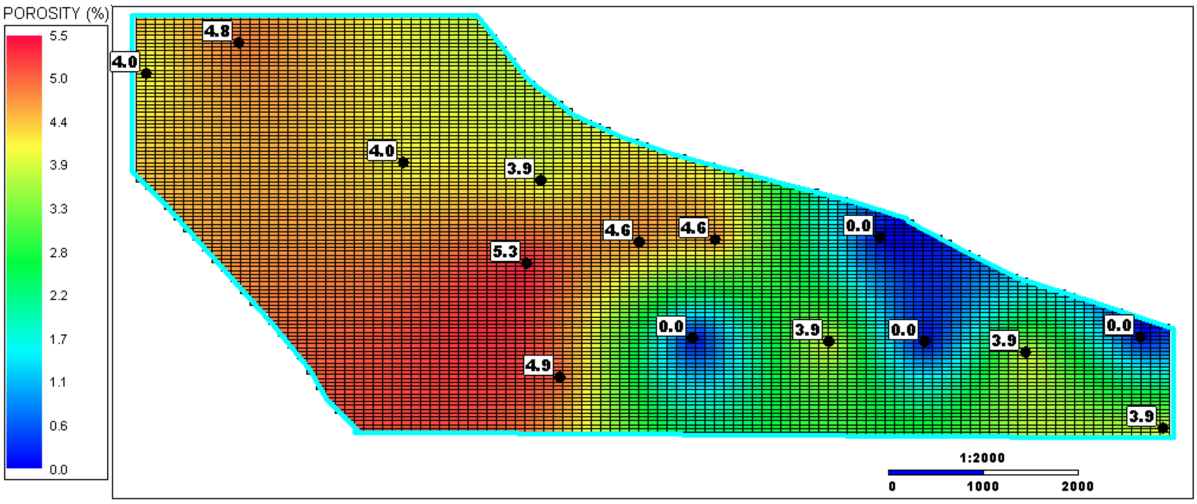


Fig. 3.6: Porosity map, Badenian, Stari Gradac-Barcs Nyugat Field

3.3. Beničanci Field

In the **eastern part of the Drava Depression** experimental horizontal variograms in 2D had been calculated for **breccias** reservoir of the **Beničanci Field** of **Badenian age** (e.g. MALVIĆ & ĐUREKOVIĆ, 2003; MALVIĆ & PRSKALO, 2007). Representative semivariograms and porosity map interpolated by Ordinary Kriging are presented on **Figures 3.7** and **3.8**.

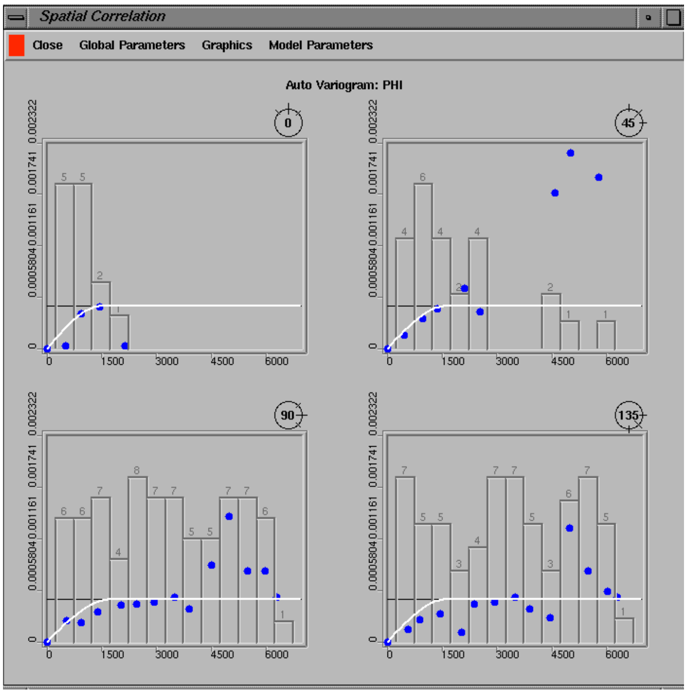


Fig. 3.7: Porosity semivariograms, Badenian, Benicanci Field

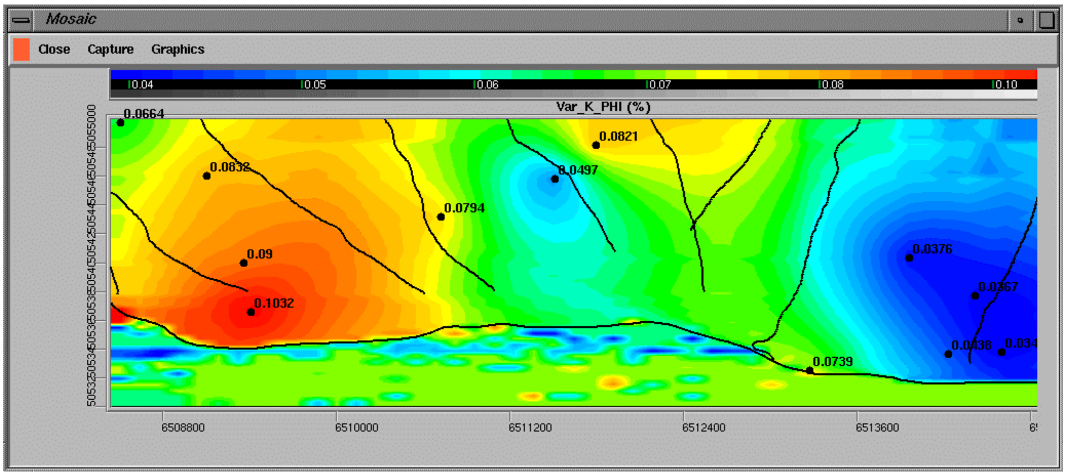


Fig. 3.8: Ordinary Kriging porosity map, Badenian, Benicanci Field

3.4. Ladislavci-Kučanci Field

The experimental variograms in **1D**, i.e. **in vertical direction** of selected wells (HERNITZ et al., 2001) are made for reservoir of **Badenian age** in the Ladislavci-Kučanci Field. These one-dimensional semivariograms are calculated for porosity as well as permeability data taken from cores (**Figure 3.9**).

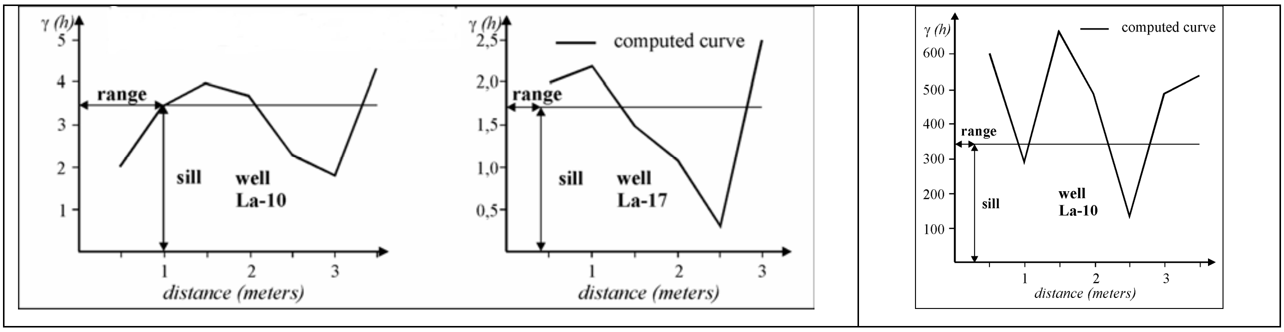


Fig. 3.9: Porosity (left) and permeability (right) semivariograms, Badenian, Ladislavci-Kučanci Field

4. The Bjelovar Subdepression (southern branch of the Drava Depression)

There is calculated a set of **1D experimental variograms** in numerous wells for porosity core data (MALVIĆ, 2003). These cores are taken from Badenian breccia (Mosti Members) and Lower Pontian sediments (Poljana and Pepelana Sandstones).

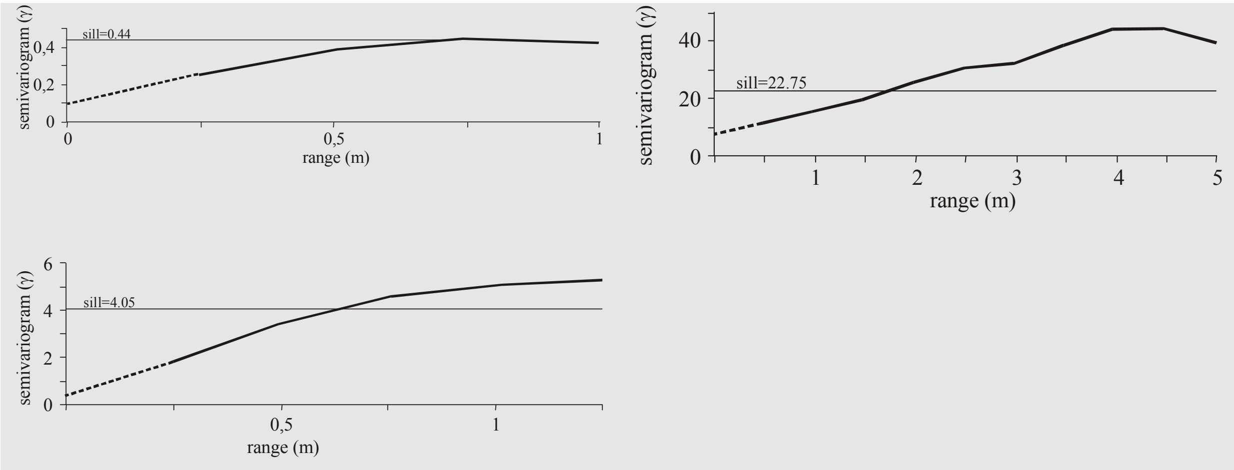


Fig. 4.1: Experimental porosity semivariograms, Badenian breccia, Bjelovar Subdepression (1. row: Dež-1, Pav-4 wells; 2. row: VC-1)

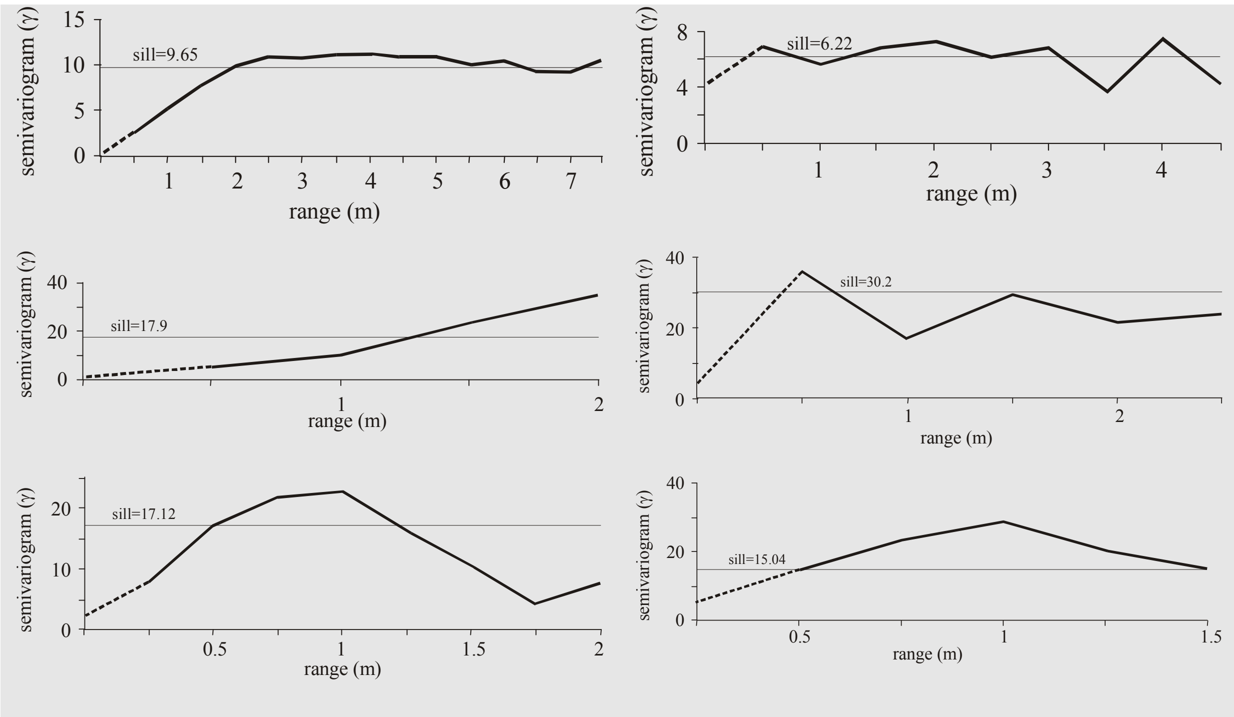


Fig. 4.2: Experimental porosity semivariograms, Lower Pontian sandstones, Bjelovar Subdepression (1. row: Pav-1 and Pav-2/I. interval wells; 2. row: Pav-2/II. and Rov-1; 3- row: VC-1/I., VC-1/II.)

Experimental variograms had been calculated by computer program made in Visual Basic 5.0 and 6.0™ as part of MALVIĆ doctoral thesis in 2003 and later published in MALVIĆ (2003). All experimental semivariograms and sills are given at **Figure 4.1- 4.3**.

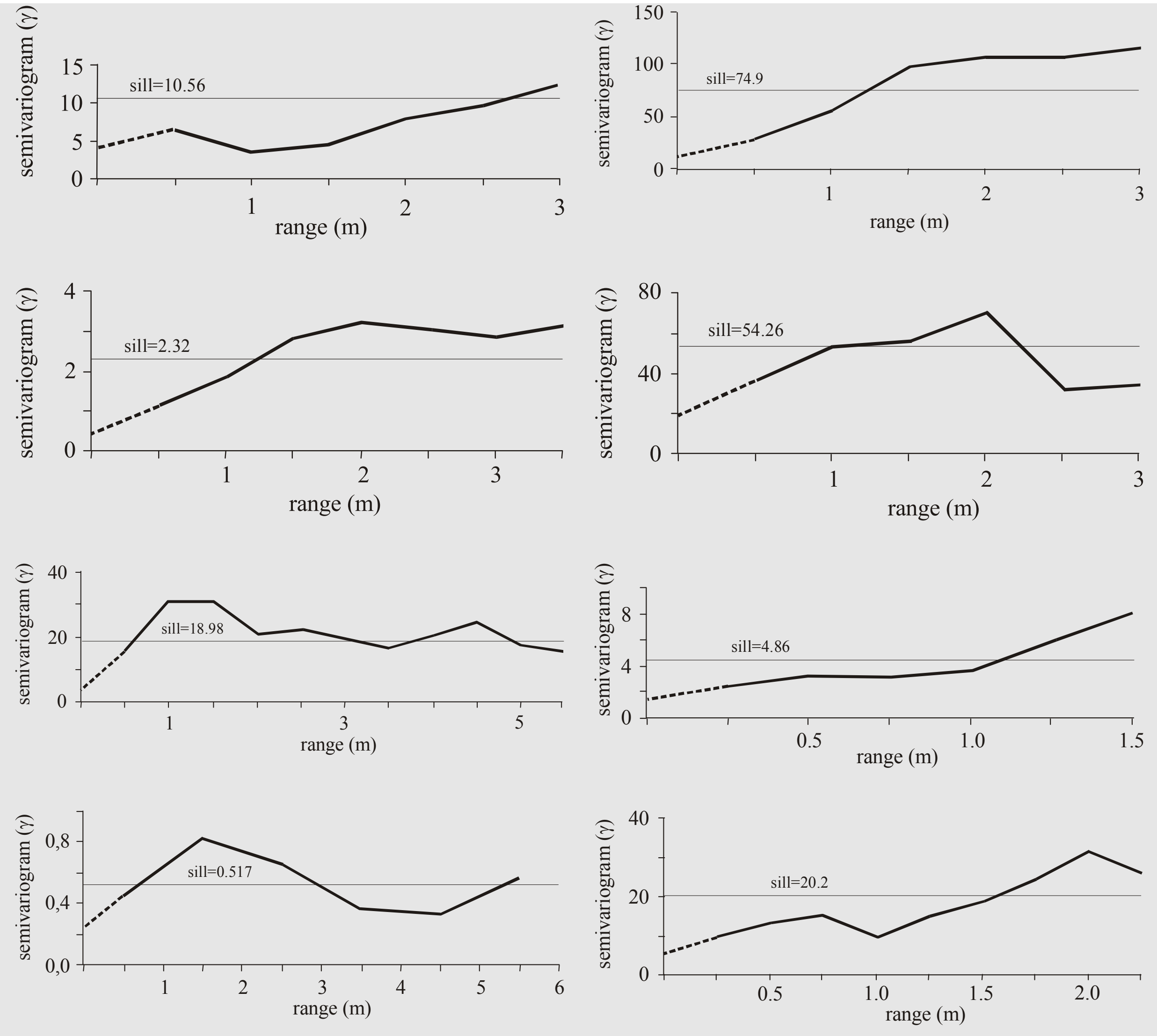


Fig. 4.3: Experimental porosity semivariograms, Lower Pontian sandstones, Bjelovar Subdepression

(1. row: Pav-1, Rov-1; 2. row: Ša-5/**I**., Ša-5/**II**.; 3. row: Ša-35, VC-1/**I**.; 4. row: VC-1/**II**., VC-1/**III**.)

5. Results and Conclusions

Geostatistical methods of interpolation are the most appropriate for porosity values measured in all Neogene sediments in the Croatian part of Pannonian Basin. Sometimes variogram ranges also can outline the behaviour of permeability in well cores in vertical direction. The number of inputs need to be enough large for application of geostatistical methods, what includes at least 10 values.

The first experimental work is done at the Voloder and Okoli Fields. The first extensive variogram analyses are calculated in the Bjelovar Subdepression, but only for core

porosity values collected in vertical direction. The maps are not interpolated, just variogram parameters (range, sill, nugget) had been sediments of Neogene (Badenian and Pontian) and Triassic ages. It was continued by numerous of variogram analysis and geostatistical interpolation in the Sava and Drava Depressions, mostly in sandstones of Pontian and Pannonian ages.
Variogram is accepted as valuable tool for determination of spatial dependence in horizontal or vertical direction, especially of rocks of Neogene age. The kriging is definitely confirmed as the best interpolation approach for reservoirs of Neogene age in the Sava and Drava Depressions.

6. REFERENCES

Balić, D., J. Velić & T. Malvić, 2008, Selection of the most appropriate method for sandstone reservoirs in Kloštar oil and gas field: Geologia Croatica, 61, 1, 27-35.
Hernitz, Z., N. Bokor & T. Malvić, 2001, Geostatistical Modelling of Petrophysical Data of Oil Fields in the Northern Croatia: EAGE, Extended abstract book, 63rd Conference and Technical Exhibition.
Malvić, T., 2003, One-dimensional variogram and statistical analysis in reservoir units of the Bjelovar sag, Croatia: Nafta, 54, 7-8; 267-274.
Malvić, T. & M. Đureković, 2003, Application of the Methods: Inverse Distance Weighting, Ordinary Kriging and Collocated Cokriging in the Porosity Evaluation and Results Comparison in the Beničanci and Stari Gradac Field: Nafta, 54, 9, 331-340.
Malvić, T., 2005, Results of geostatistical porosity mapping in Western Drava Depression fields (Molve, Kalinovac, Stari Gradac): Nafta, 56, 12, 465-476.
Malvić, T., 2006, Middle Miocene Depositional Model in the Drava Depression Described by Geostatistical Porosity and Thickness Maps (Case study: Stari Gradac-Barcs Nyugat Field): Rudarsko-geološko-naftni zbornik, 18, 63-70.
Malvić, T. & S. Prskalo, 2007, Some benefits of the neural approach in porosity prediction (Case study from Beničanci field): Nafta, 58, 9; 455-467.
Malvić, T., 2008, Production of a porosity Map by Kriging in Sandstone Reservoirs, Case study from the Sava Depression. Cartography and Geoinformation, journal of Croatian Cartographic Society, 7, 9, 12-19.
Malvić, T. & B. Bastaić, 2008, Reducing variogram uncertainties using the ' jack-knifing' method, a case study of the Stari Gradac – Barcs-Nyugat field. Bulletin of Hungarian Geological Society (Foltani Kozlony): 138, 2; 165-174.
Malvić, T. & J. Velić, 2010, Relation between Effective Thickness, Gas Production and Porosity in Heterogeneous Reservoirs: and Example from the Molve Field, Croatian Pannonian Basin. Petroleum geoscience: 16, 1; 41-51.
Pannatier, Y., 1996, VARIOWIN – Software for Spatial Data Analysis in 2D: New York, Springer Verlag, 91 p.
Saftić, B., J. Velić, O. Sztano, G. Juhas & Ž. Ivković, 2003, Tertiary subsurface facies, source rocks and hydrocarbon reservoirs in the SW part of the Pannonian Basin (northern Croatia and south-western Hungary). Geologia Croatica, 56, 1; 101-122.
Smoljanović, S. & T. Malvić, 2004, Improvements in reservoir characterization applying geostatistical modelling (estimation & stochastic simulations vs. standard interpolation methods), Case study from Croatia: Proceedings of World Petroleum Congress, 1st Youth Forum / Committee (Ed.). Beijing, China, Chinese National Committee for WPC, Published by Petroleum Industry Press & Beijing Kehai Electronic Press, 1054-1061.

Velić, J., M. Weisser, B. Saftić, B. Vrbanac & Ž. Ivković, 2002, Naftnogeološke značajke i istraženost triju neogenskih megaciklusa u hrvatskom dijelu Panonskog bazena. Nafta: 53, 6-7; 239-249.

Vrbanac, B., J. Velić & T. Malvić, 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.