Sequential Indicator Simulations of sandstone reservoir thickness, Sava depression, Croatia (SW part of Pannonian basin)

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Abstract

Located 35 km east of the Croatian capitol Zagreb, in the Sava depression, the Kloštar oil field covers an area of some 30 km^2. Its hydrocarbon reservoirs were discovered in Palaeozoic igneous rocks and Miocene sediments. These reservoirs are subdivided into a number of operational units called 'reservoir series', among which the most important are fine- to medium-grained Early Pontian sandstones, called '1st sandstone series' that contain most of the oil reserves. Thickness of this reservoir was analysed using geostatistical simulation method called Sequential Indicator Simulations (abbr. SIS). The input dataset consisting of 19 hard data (wells) with average reservoir thicknesses ranging from 1 to 25m was used for making histogram in Excel™ and six thickness classes were defined with width of 4m. However, histogram analysis on such a small data set is not reliable and transformation had to be done using programs Surfer 8.0™ (licensed) and Grid Histogram™ (freeware). Original dataset had been interpolated by Inverse Distance Weighting method, obtaining grid with 7900 values, as base for new histogram calculation, confirming previously defined six cut-offs (5, 9, 13, 17, 21 and 25 m) and constructing cumulative density function (CDF). Omnidirectional indicator semivariograms were calculated for each cut-off and approximated (using Variowin 2.21™) with standardized theoretical models with sill=1 and nugget=0.6. It means that 3rd order stationarity is assumed, accepting only the intrinsic hypothesis as the minimum for dataset (mean is independent and semivariograms exist). SIS realizations were based on Simple Kriging techniques. Final model contained 630010 cells in each of 100 realizations created for thickness. Results show that variations in thickness are approximately isotropically dispersed. Thickness mostly varies between 10 and 25 meters. It indicates on approximately similar depositional condition in the largest part of the mapped reservoir, with larger thicknesses observed along "stripes" oriented NW-SE or NNW-SSE.

Keywords: Sequential Indicator Simulations, thickness, sandstone reservoirs, Sava Depression, Pannonian Basin.

1. INTRODUCTION

There are many 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 (**Figure 1**). The most often porosity had been selected as analyzed variable, and occasionally permeability or depth. Te most often geostatistically had been analyzed sandstone reservoirs of Upper Miocene age (e.g. in the Sava Depression in BALIĆ et al., 2008 or MALVIĆ, 2008).

The Kloštar field is located about 35 km east of Zagreb (**Figure 1**) and covers an area of around 30 km2 in the regional geological unit of the Sava depression (**Figure 1**). The hydrocarbon reservoirs are in lithostratigraphic units of Miocene age named the Prečec, Ivanić-Grad (Okoli Sandstones Member) and Kloštar Ivanić (Poljana Sandstones Member) formations. Minor oil reserves also occur in rocks of Palaeozoic age. Generally, there are twenty stratified and/or massive reservoirs proven, forming 5 units named (from the oldest): “Basement rocks”, “Miocene”, “Lower Pannonian”, “2nd sandstone series” and “1st sandstone series” (BALIĆ et al., 2008). The average effective thickness of particular reservoirs is 5 meters. The permeability varies between 2.4 and 179.9 x 10-15 m2 and porosity could reach up to 25%. There are a total of 196 wells, where 64 are classified as measuring wells, 59 are in production, 68 are abandoned and 5 wells are used for the injection of waste water (in 2008).

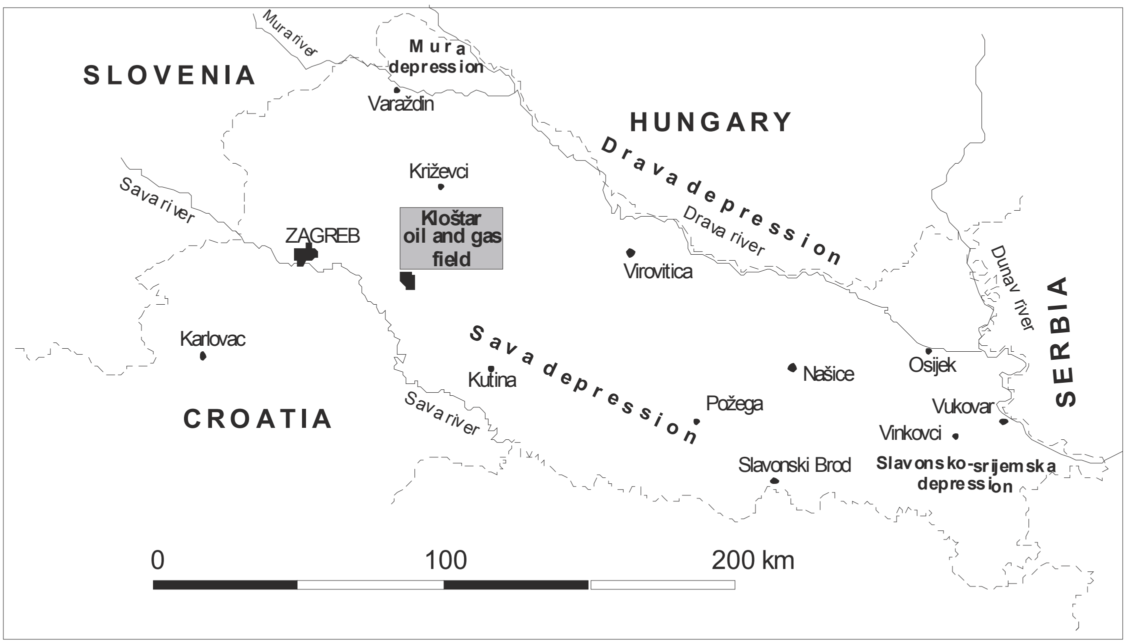


Fig. 1: Kloštar Field as analytical target

Many other regional studies have included investigation of the Kloštar field as part of explored area. Petrophysical properties of the sandstones as well as stratigraphic architecture in the western part of the Sava depression have been well defined by JÜTTNER et al. (2001), SAFTIĆ (1998) and SAFTIĆ et al. (2001). LADOVIĆ (1999) analyzed the bypassed oil in block 4 of the Kloštar field. VELIĆ & SAFTIĆ (2000)

published a general paper about hydrocarbons in Croatia, and finally CVETKOVIĆ (2007) applied neural networks for log analysis in the sandstone reservoirs in the Kloštar field.
The Kloštar structure was bordered by the principal northern fault zone of the depression. The vertical displacement, at the level of EL border "Tg" (basement top), is almost 1000 meters. This is why the geological setting of the field is very complex. Such a large displacement is also reflected in the fact that the reservoirs of the 1st sandstone series are dislocated in 17 blocks.
Here is again, as analytical target, selected sandstone reservoir in the Kloštar Field. This reservoir belongs to main sandstone sedimentary sequence that including several particular reservoir of Early Pontian age. This target comprises a lot of available data reading from previously published geostatistical analyses that included kriging interpolation or sequential Gaussian simulations. It is also typical sandstone hydrocarbon's reservoirs in the Sava Depression, which reflects typical roles of depositional mechanism, sequences and tectonics in the Upper Miocene. The 11 reservoirs of the 1st sandstone series belong to the Lower Pontian beds. The part of the 1st sandstone series that is saturated with hydrocarbons covers the north-eastern part of the field. The structure gently sinks toward the north-west. According to the classification of oil and gas reservoirs given by Brod, the hydrocarbon reservoirs of the 1st sandstone series represent a group of stratified beds delineated by tectonic and lithological barriers. The analyzed **reservoir "A"** represents the most important reservoir of the 1st sandstone series. This reservoir consists of fine- to medium-grained, weak sandstones, with a maximum thickness up to 10 meters.

2. HISTOGRAMS OF INPUT DATA

Histogram had been made by Excel^{TM} and Gridhisto^{TM} programs. Furthermore, experimental variograms were calculated by freeware program Variowin 2.21^{TM} (PANNATIER, 1996). Grid files had been created by Surfer 8.0^{TM} program.
The main input dataset included 19 hard data (wells) where average reservoir thicknesses had been measured in analyzed sandstone reservoir, here named as "A". It was base for making histogram in Excel^{TM}. There had been experimenting with width of histogram classes and eventually it was determined as 4m, making 6 classes for thickness range between 1-25m (**Figure 2**).

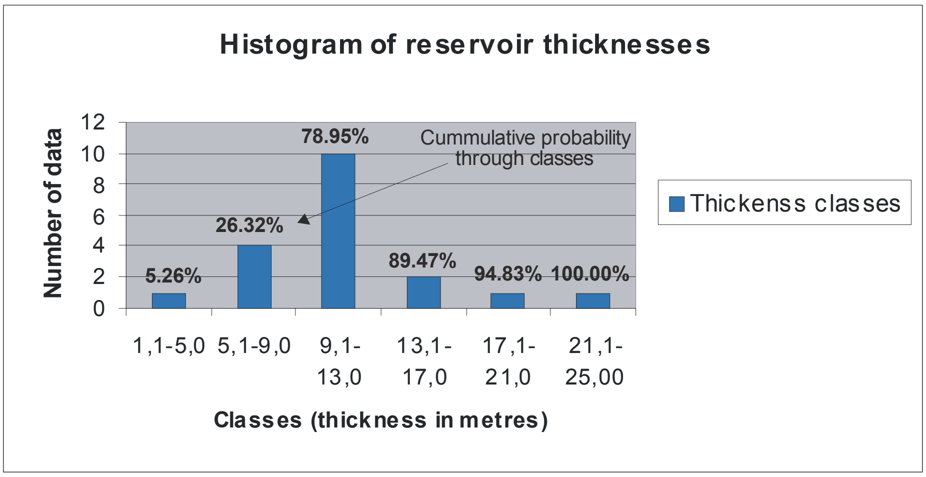


Fig. 2: Histogram of measured data (19 wells)

There could be observed that histogram classes follows approximately normal (Gaussian) distribution and each classes has calculated cumulative probability value (**Figure 2**). But, there is also fact that 19 data is relatively too small dataset for concluding about real distribution curve. There is several ways how to “increased” dataset with artificial data with similar properties as original dataset. Here is applied the procedure of interpolating entire new grid, based on 19 input values, using Inverse Distance Weighting method and obtaining much larger “artificial dataset” that had been used for conclusion about distribution. The new dataset included 7900 interpolated values and new histogram had been drawn by program Gird Histogram^{TM}. There is kept the same number and range of six classes (**Figure 3**) and additionally is constructed CDF. Particular class’s probabilities (PDF) are given on left vertical scale and cumulative (CDF) on right scale (**Figure 3**).

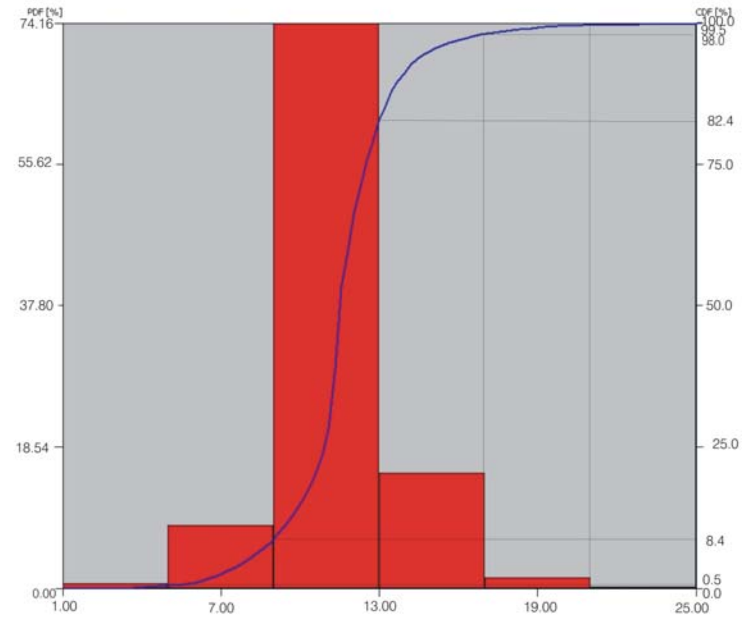


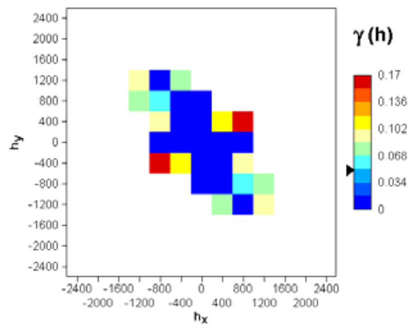
Fig. 3: Histogram of interpolated data (7900 points)

Such obtained thickness classes had been base for indicator transformation with six cut-offs as follows: (a) 1st cut-off 5m, (b) 2nd cut-off 9m, (c) 3rd cut-off 13m, (d) 4th cut-off 17m, (e) 5th cut-off 21m and (f) 6th cut-off 25m.

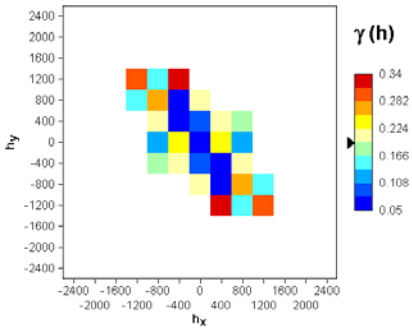
3. INDICATOR TRANSFORMATIONS AND SEMIVARIOGRAM ANALYSIS

The input dataset included thickness data collected in 19 wells from the reservoir ‘T’ of the Kloštar field and it had been transformed into indicator dataset, based on following cutoffs: 5, 9, 13, 17, 21 and 25 m. For each cutoff indicator semivariograms were calculated as omnidirectional and approximated with theoretical models using Variowin 2.21. Theoretical variogram models had to have same model function (spherical in this case), they had to be standardized (identical sill) and they had to have the same nagget (0,4). Lag spacing was set to 400 m, number of lags was 6.

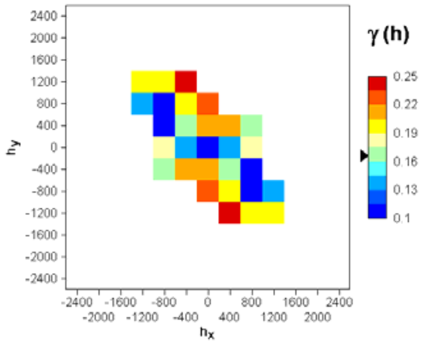
Semivariogram surfaces, semivariograms and their theoretical approximations for each cutoff are shown in following Figures (**Figure 4 and 5**).



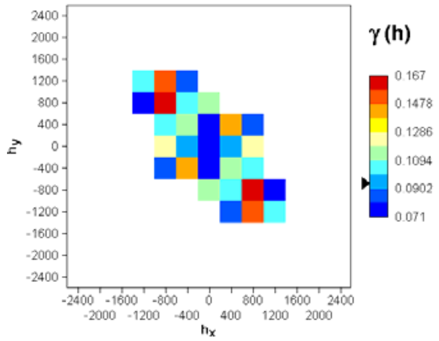
Semivariogram surface map for cutoff 5 m



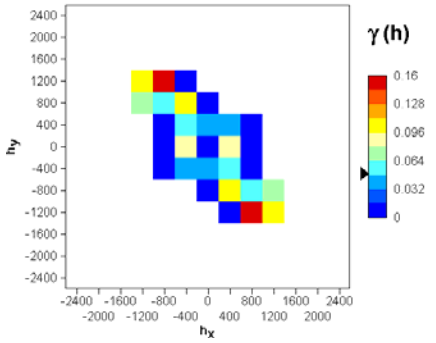
Semivariogram surface map for cutoff 9 m



Semivariogram surface map for cutoff 13 m

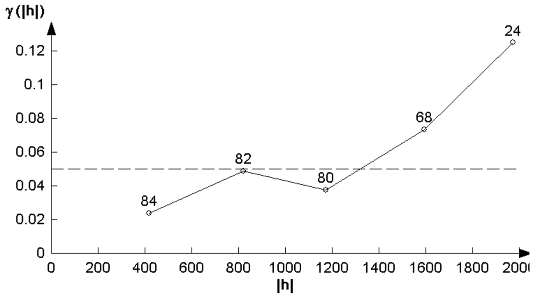


Semivariogram surface map for cutoff 17 m

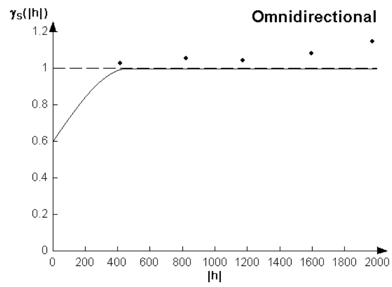


Semivariogram surface map for cutoff 21 m

Fig. 4: Semivariogram surface maps for each cutoff



Semivariogram for cutoff 5 m



and its approximation with theoretical curve

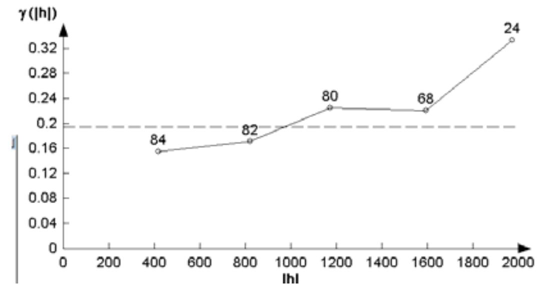
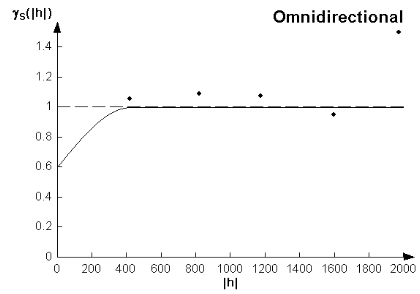
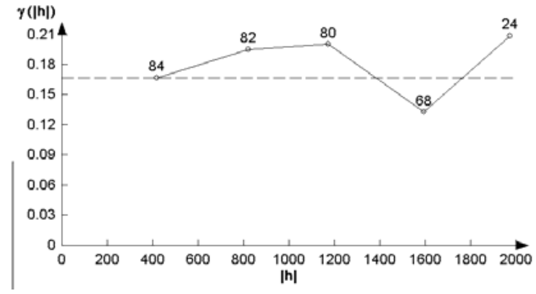
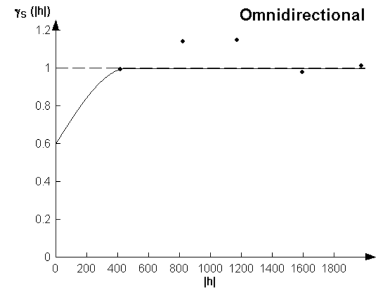
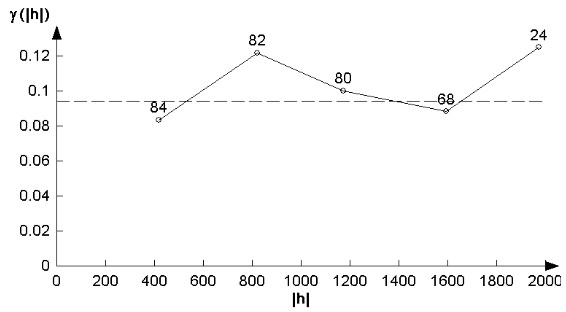
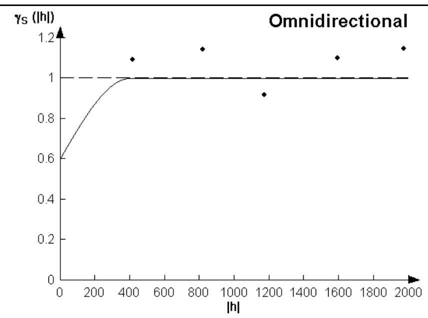
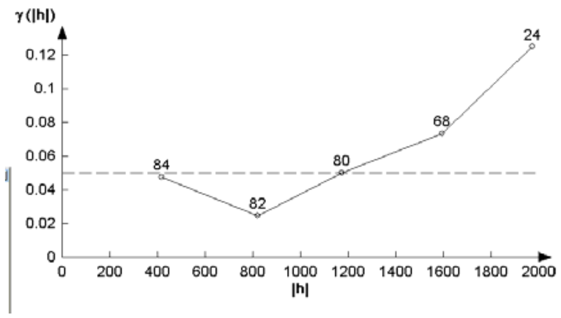
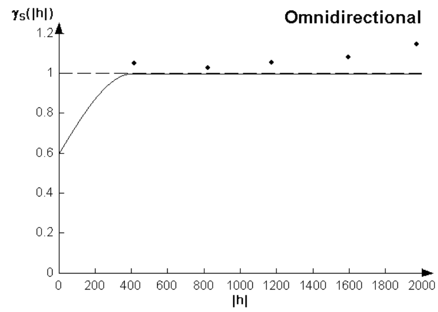
 Semivariogram for cutoff 9 m	 and its approximation with theoretical curve
 Semivariogram for cutoff 13 m	 and its approximation with theoretical curve
 Semivariogram for cutoff 17 m	 and its approximation with theoretical curve
 Semivariogram for cutoff 21 m	 and its approximation with theoretical curve

Fig. 5: Semivariograms for different cut-offs (left) and their approximations with theoretical curve (right)

4. SEQUENTIAL INDICATOR SIMULATIONS USING PROGRAM WINGSLIB

Indicator transformations data, theoretical semivariograms and cumulative probability distribution curve were input data for sequential indicator simulations. We also used categorical variable as variable type, Simple Kriging as Kriging type and Full IK as IK type to define parameters that were needed in simulations. In 'Grid definition' the number of cells in both directions was 251, so final model contains 630010 cells. There was 100 thickness realizations created and realizations number 1, 50 and 100 are shown in **Figure 6**.

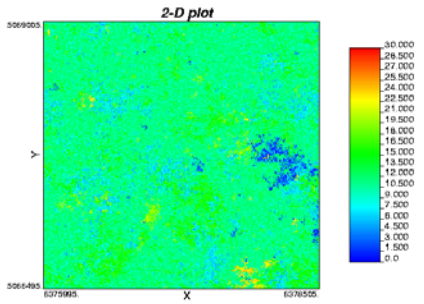
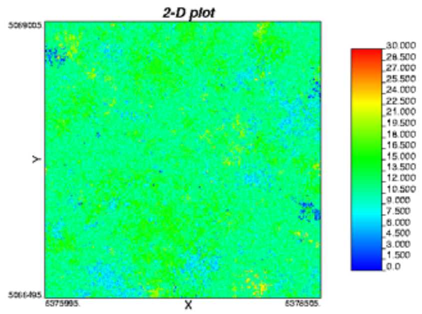
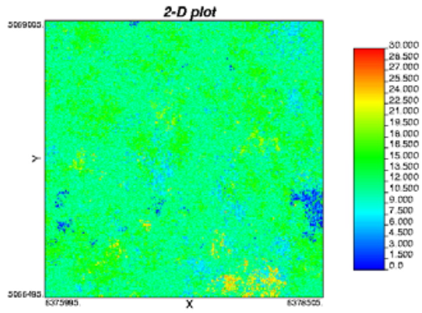
		
Thickness realization number 1	Thickness realization number 50	Thickness realization number 100

Fig. 6: Sequential indicator simulations realizations of thickness no. 1, 50 and 100

5. RESULTS AND CONCLUSIONS

- This is second time that geostatistical simulations are applied for data from sandstone reservoirs in the Kloštar Field. The first time it was used for SGS of porosity data from the same reservoir of Lower Pontian age.
- In this analytical target had been thickness that was transformed in indicator variables using the cut-offs of 5, 9, 13, 17 and 21 meters.
- All theoretical indicator variograms had been standardized with sill=1 and nugget=0.6. It means that 3rd order stationarity is assumed, because if we used variogram model it means that we accept only the intrinsic hypothesis as the minimum for dataset, which can be satisfy for sure (disregarding the nugget model). Intrinsic hypothesis assumes that the mean is independent and that semivariogram existing.
- Looking at the final results at **Figure 6** it is obvious that estimation with SIS gives much more uniform cell values and consequently differences between realizations is not so large.
- Original data range is 0-30m. SIS maps are mostly estimated with values around mean. That is because the variance of an indicator variable is: $\hat{F}(z_k)\cdot\left[1.0-\hat{F}(z_k)\right]$, where $\hat{F}(z_k)$ means the cumulative distribution function (CDF) of continuous random variable 'z' defined as $F(z_k)=\Pr ob\left[z_k \le z\right]$.

- Five cutoffs were used for defining indicator classes, because more cutoffs can be used to reduce the within-class noise (DEUTSCH & JOURNEL, 1998).

Acknowledgement

We thanks to Mr. Peter Zahuczki for make available as freeware Grid Histogram (Gridhisto) program. It creates histogram from a Surfer 7 grid file, using only the non blanked 'z' values of the grid. http://www.peter.zahuczki.hu (Grid Histogram copyright © 2007).
We also wish to thank author of VARIOWIN 2.21.., Mr. YVAN PANNATIER, for using one of the most popular freeware software for variogram analysis. Variowin copyright © 1993, 1994, 1995 belongs to Yvan Pannatier.
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