Computer Program for 1D Numerical Variogram Calculation of Well Data, Freeware in Visual Basic

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Abstract

Large majority of variogram modelling and geostatistical estimations are performed in 2D, rarely in 3D, and just occasionally in 1D. However, very often there is set of measurements oriented along borehole, very often set in vertical direction. Such sets of well measurements can be considered as 1D datasets. Large number of such datasets had been collected in oil and gas wells from northern and north-eastern part of the Bjelovar subdepression (Croatian part of the Pannonian Basin) and analyzed in 2002 and 2003. Porosity values had been selected as analytical target, and processed with own-made computer code written in Visual Basic for 1D variogram analysis. The emphasis was given on numerical variogram values, sill and range. The most reliable results were obtained in sandstones of Lower Pontian age analysed in 4 wells and 6 intervals in older lithostratigraphic member Poljana Sandstones and 5 wells and 8 depth intervals in younger Pepelana Sandstones. Porosities varied approximately between 15 and 30% and ranges from 0.27 to 1.73 m. Range was specifically calculated as relative value expressing interval between two lags where the sill had been first time crossed. Analysis assumed that input data are divided in intervals (cells) of the same size and characterised with mean values. The interval size in testing phase was 50 cm but any value could be set. Eventually, if range is multiplied with number of lag before crossing sill and interval's size, exact range can be calculated in relevant units (cm, m). The computer code had been improved in 2010. Data can be easily loaded and saved as simple ASCII files and later transformed in other programs. Numerical values of experimental, exponential and spherical variograms are also given on the screen. Graphical plot can be simple drawn importing ASCII results in Excel™ worksheet.

Keywords: 1D variogram, porosity, lithostratigraphy, sandstone members, Lower Pontian, Pannonian Basin, freeware.

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1. INTRODUCTION

Input data were porosity values gained from laboratory measurements of cores in vertical direction. These data are measured in INA-Naftaplin laboratory and documented in well files. Ages of cores were Palaeozoic, Mesozoic and Neogene. All analyses were oriented along core lengths. Reservoir dimensions are much larger in the horizontal plane (ratio is approximately 15:1), but number of data is much lower and it is why it was not possible to perform reliable calculations. Porosity shows different properties regarding to chosen direction and distance from datum point what means it is regionalized variable.

Spatial (or semivariogram) analysis requires that input point data be arranged according to equal distances. In practice, cores are distinguished according to length, numbers and positions of data. It is why such group of values was necessary to equalize, because it was not possible to give same "weight" in calculation of data, which had mutual distance 0.5 and 1.5 meter. Cores are divided in the same lengths intervals and for each interval mean value of existing data is calculated. In the intervals without laboratory data mean value is evaluated based on porosity curve that connect margin values in neighboring intervals.

Interval size of 0.5 m is demonstrated as the most favorable based on testing results. Most cores were analyzed with 1-2 laboratory measurements in each 0.5 m. Also, reservoirs mostly have a thickness of ten or more meters and larger interval does not give enough resolution for scanning all changes in reservoirs. Contrary, smaller interval would cause most input data to be deduced from porosity curves, and not from laboratory measurements.

In some wells cored intervals were short, comprising less than 10 laboratory measurements. In such case, the interval size for (geo) statistical analysis is set to 0.25 m. Such approximation increased the number of wells available for 1D semivariogram analysis.

The technique of data selection and calculation needed to be accompanied with purpose why such calculation program is useful in analysis of geological data in hydrocarbon exploration and production. In this case, data are collected in relative rarely explored subdepression, very often covered by one well in area of several dozen square kilometers or so. It means that any lateral (2D) correlation of well data is meaningless or, in the best case, based on analogy. It put the emphasis on vertical data collected in one well or borehole. Here are selected petrophysical data, more precisely porosities measured in sandstone reservoirs as the dataset with lower variance than permeability from the same intervals. It had been supposed that spatial dependency determined in cored reservoir's parts can be extrapolated in uncored parts, transferring the same descriptive statistical values. The most often tool for spatial dependency calculation is semivariogram, and here is presented such technique applied for one dimensional data.

2. Meaning and Calculation of 1D Variograms

Minimal interval numbers for one core in semivariogram analysis is set on 10 (due to 5 and more data pairs in each interval). That value is reached by testing of computer program 1D Semivariogram analysis made in Visual Basic^{TM} 6.0. The next values are calculated: *semivariogram* $\gamma(h)$*, mean value, spherical and exponential models* and *mean square errors* between experimental and theoretical models.

2.1. Porosity Modeling with 1D Semivariograms

Porosity modeling in 1D had been performed with data located in exploration or production wells for hydrocarbon in the Bjelovar Subdepression (**Figure 1**). This subdepression is southern branch of the Drava Depression, located at the southwestern part of Pannonian Basin System (in Croatia and Hungary). These well locations had been divided in two groups. The first group encompasses wells inside borders of hydrocarbon fields. The second group includes wells from exploration prospects in the subdepression (1 or 2 wells on each prospect).

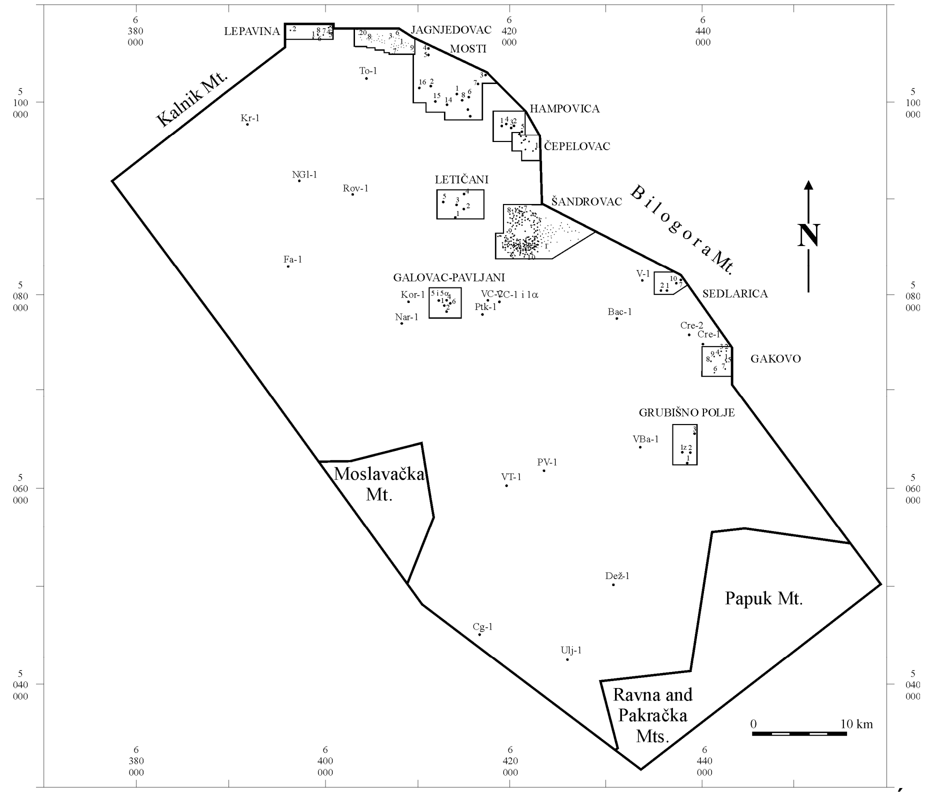


Fig. 1. Location of fields and exploration wells in the Bjelovar Subdepression (MALVIĆ, 2003)

2.1.1. Kloštar-Ivanić Formation, Poljana Sandstone Members

In sediments of Poljana sandstones cores from 5 wells and 6 depth intervals are analyzed (MALVIĆ, 2003). In the well **Pav-1** on depth 913-929 m (interval 0.5 m), well **Pav-2** on depth 977-986 and 1071-1075.5 m (interval 0.5 m), well **Rov-1** on 1311-1317 m (interval 0.5 m) and well VC-1 on 1747-1751 and 1843.5-1846.25 m (interval 0.25 m). Calculated ranges and experimental semivariogram are given in **Table 1** and **Figure 2**.

Table 1: Mean porosities and ranges from 5 wells and 6 core intervals, Poljana Sandstone Member

Well	*ϕ (%)*	*range (m)*	*Well*	*ϕ (%)*	*range (m)*
Pav-1	27.17	1.72	**Rov-1**	21.43	0.42
Pav-2 (1)	25.23	0.45	**VC-1 (1)**	12.58	0.49
Pav-2 (2)	20.44	1.29	**VC-1 (2)**	16.39	0.27

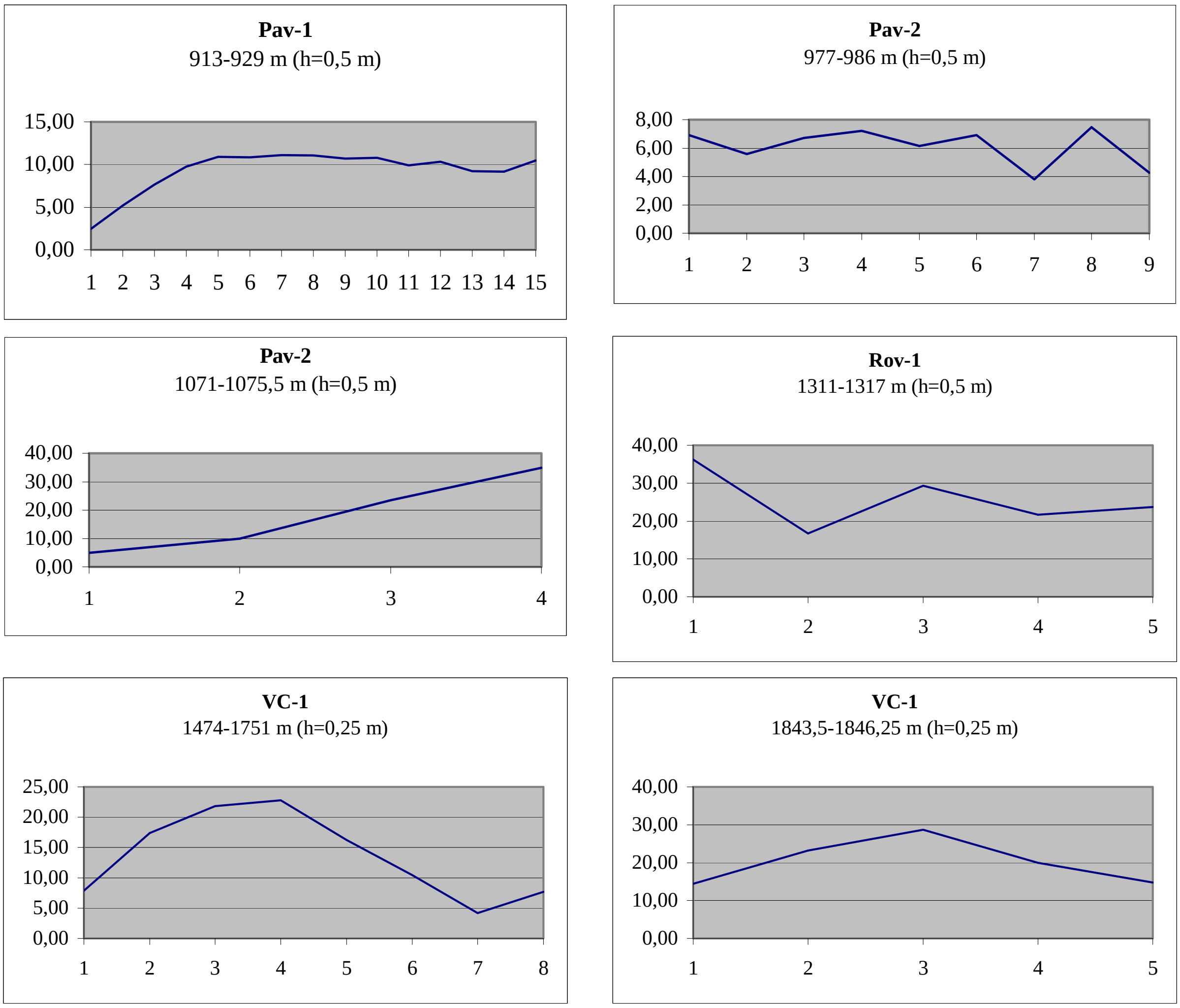


Fig. 2. Semivariogram porosity curves calculated with 1D Variogram Program and drawn in Excel for data from Poljana Sandstone Member (Axis X – 1=0.25/0.50 m, 2=0.50/1.00 m etc.).

Lithologically Poljana Sandstones Member includes significant beds of siltites and marls. It is notable at shape and ranges of semivariogram curves too (**Figures 2**). In permeable parts of member porosity varied between approx. 15 and 30 %. Such favorable permeable intervals are especially found in northern and northeastern part of the subdepression.

In parts of Poljana sandstones with significant part of marlstone porosity was less then 10 %, and accompanied permeability about $1x10^{-3}$ μm^2 and less. Such impermeable zones are mostly drilled in older parts of member. Entire member is characterized with poor reservoir properties on the east and southeast.

Statistically and by semivariogram 6 intervals of Poljana sandstones in 4 wells are analyzed (**Table 1**). High analytical values are gained in the parts of the sag with good reservoir properties. Mean porosity is 20.44-27.17 %, except of Velika Ciglena were marls dominate. Range values are very wide, from 0.32 to 1.41 m, depending on content of siltites and marls in reservoirs.

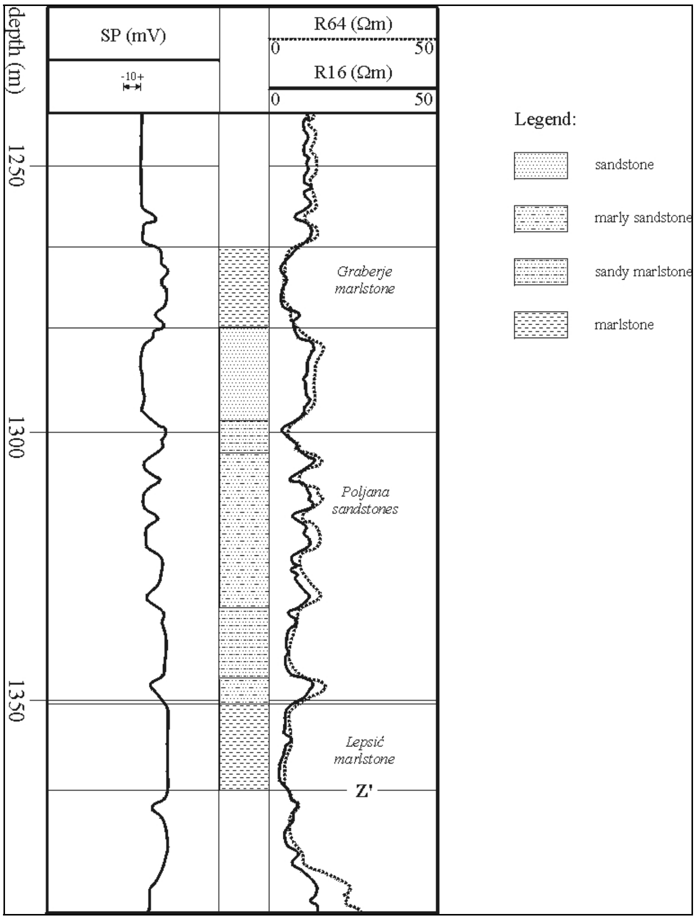


Fig. 3. Conventional electro-log of typical lithology of the Poljana Sandstone Member (northern part of subdepression)

2.1.2. Kloštar-Ivanić Formation, Pepelana Sandstone Members

In Pepelana Sandstones Member cores from 5 wells and 8 depth intervals are analyzed (MALVIĆ, 2003). In the well Pav-1 on the depth 850-856 m (interval 0.5 m), well Rov-1 on 1047-1053 m (interval 0.5 m), well Ša-5 on 680.3-686.3 and 810.6-816.6 m (intervals 0.5 m), well Ša-35 on 797.7-813.7 m (interval 0.5 m), well VC-1 on 1479.25-1482.50 (interval 0.25 m), 1536-1542 (interval 0.5 m) and 1579-1583.5 m (interval 0.25 m).

Number of porosity data had been smaller than in Poljana Sandstone Member. Also, lithological changes from sandstone to siltite and marls are smaller than in previously described member.

In permeable intervals relatively high values of porosity and permeability are documented. Porosity is often more than 15 %, on the Šandrovac field more than 30 % (**Table 2**), and horizontal permeability is 0.31-5.33x10^{-3} μm^2.

Table 2: Mean porosities and ranges from 5 wells and 8 core intervals, Pepelana Sandstone Member

Well	ϕ (%)	range (m)	**Well**	ϕ (%)	range (m)
Pav-1	25.03	2.67	**Ša-35**	23.15	0.69
Rov-1	22.54	1.23	**VC-1 (1)**	14.63	1.14
Ša-5 (1)	31.15	1.25	**VC-1 (2)**	15.02	0.60
Ša-5 (2)	21.75	1.08	**VC-1 (3)**	19.91	1.56

Generally, Pepelana Sandstones Member have better reservoir properties than Poljana Sandstones Member. Although oil and gas pools in this member are discovered only on the Šandrovac field, this is one of the largest hydrocarbon reservoirs in the subdepression as well as one of the largest in the Drava depression.

Reservoirs in the Pepelana Sandstone Members are divided in four so called reservoir “series” named as C, D, E and F. Each of them comprises one or more particular reservoirs intercalated by marls. E “series” is the most productive and consists of four pools named E, E’, E’’, E’’’.

First two reservoirs (E and E’) are especially good developed as the large channel sandstones, very good outlined on the SP logs (**Figure 4**). It is very easy to recognize characteristic cylindrical and bell shapes of SP curve, of sand bodies deposited in different sedimentation environments of turbiditic currents in Early Pontian.

Experimental semivariograms had been presented at **Figure 5**, and generally they are characterized by a little bit larger ranges than semivariograms from the Poljana Sandstones Member.

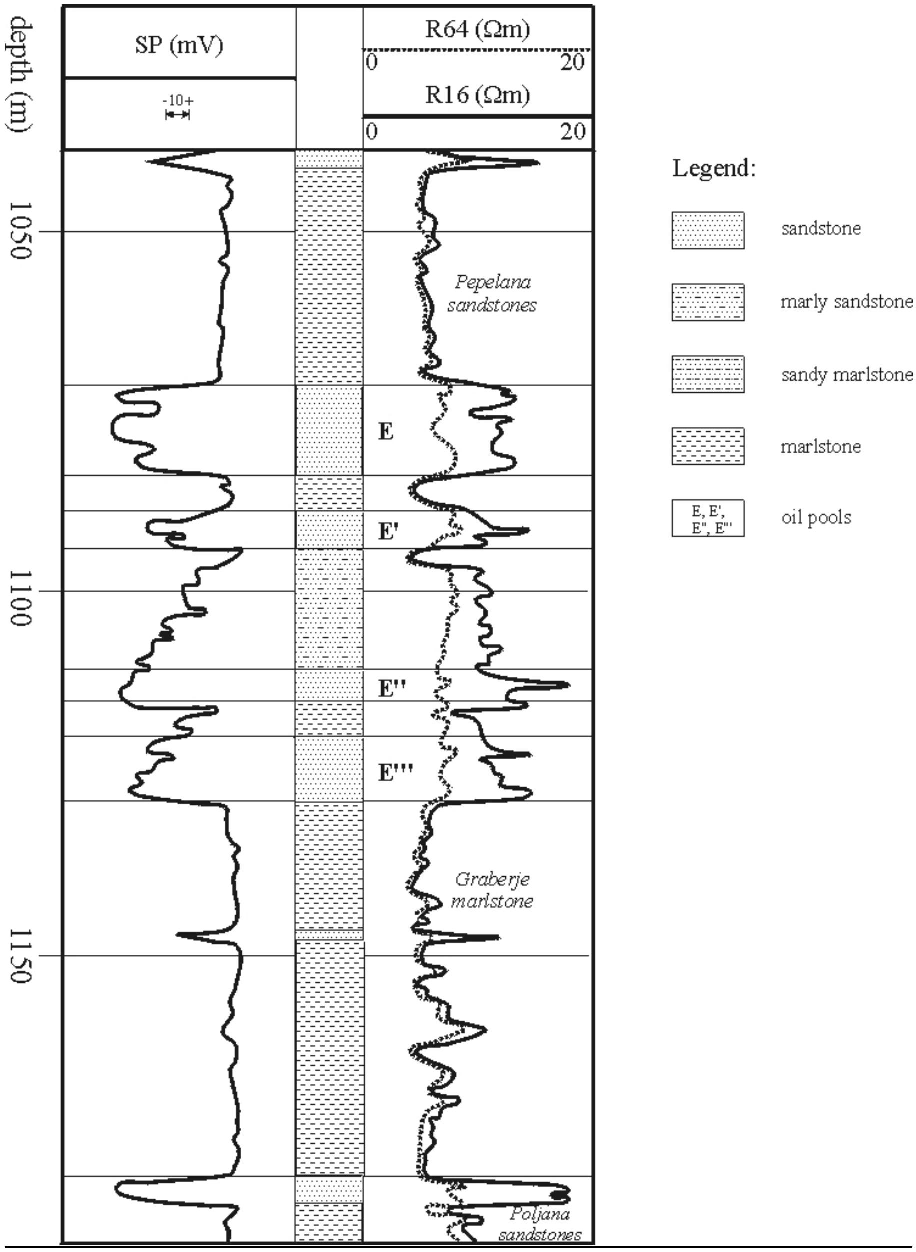


Fig. 4. Conventional electro-log of oil reservoirs in the Šandrovac Field of the Pepelana Sandstone Member (northern part of subdepression)

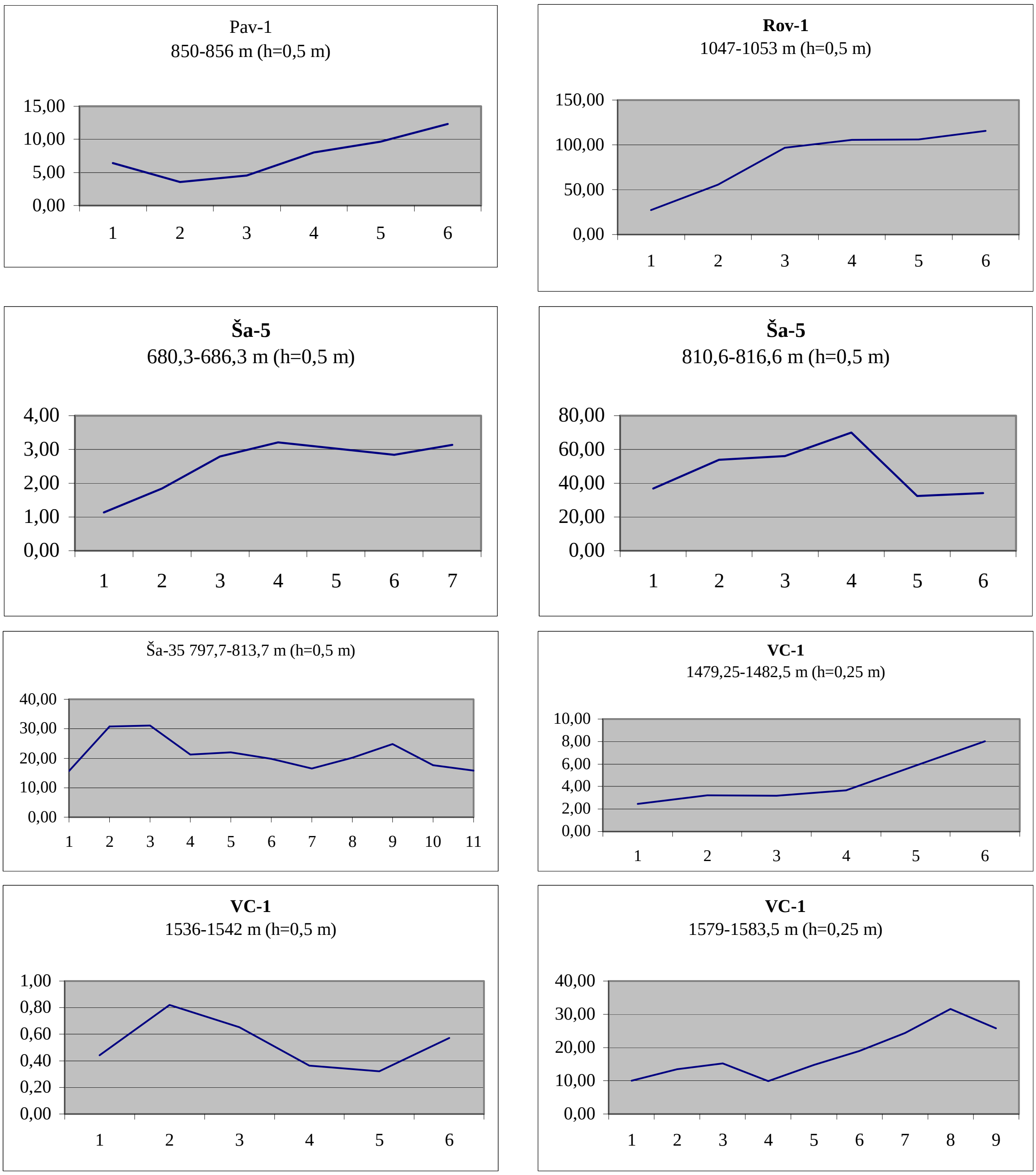
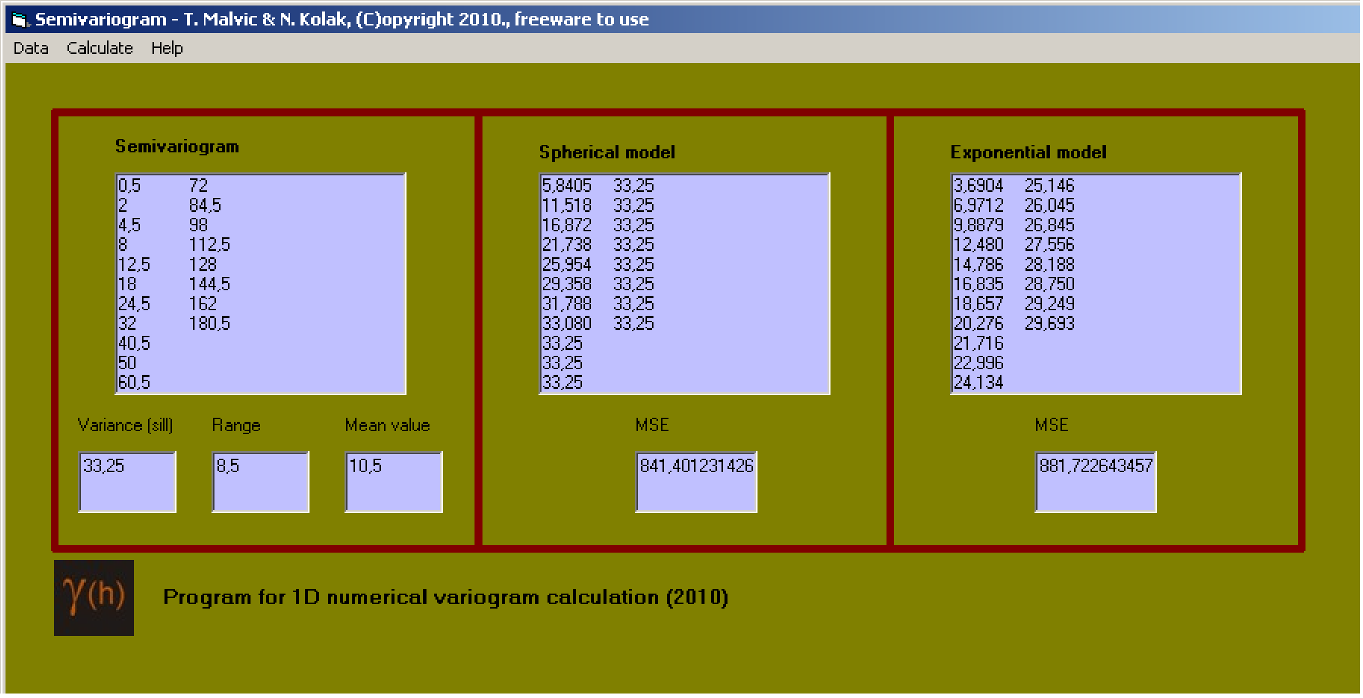


Fig. 5. Semivariogram porosity curves calculated with 1D Variogram Program and drawn in Excel for data from Pepelana Sandstone Member (Axis X – 1=0.25/0.50 m, 2=0.50/1.00 m etc.).

2.2. The Program “1D Semivariogram Calculation”

The program mask in presented at the **Figure 6**. There is also given numerical results for one imaginary (testing) dataset represented with 20 numerical values as follows: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20.



Semivariogram

```
0,5     72
2       84,5
4,5     98
8       112,5
12,5    128
18      144,5
24,5    162
32      180,5
40,5
50
60,5
```

Variance (sill): 33,25

Range: 8,5

Mean value: 10,5

Spherical model

```
5,8405  33,25
11,518  33,25
16,872  33,25
21,738  33,25
25,954  33,25
29,358  33,25
31,788  33,25
33,080  33,25
33,25
33,25
33,25
```

MSE: 841,401231426

Exponential model

```
3,6904  25,146
6,9712  26,045
9,8879  26,845
12,480  27,556
14,786  28,188
16,835  28,750
18,657  29,249
20,276  29,693
21,716
22,996
24,134
```

MSE: 881,722643457

Fig. 6. The program visual mask with three main result boxes as following (a) Semivariogram results, (b) Spherical model, (c) Exponential model

The main goal of program is numerical calculation of semivariogram values in 1 direction, i.e. along the measurements collected along well or borehole. This experimental numerical model can be approximated, in this program, with two the most often theoretical, approximation models – spherical and exponential. The selection of the better approximation can be done using MSE (“Mean Square Error”) result, where are compared experimental and theoretical models.

Moreover, the experimental semivariogram part (**Figure 6**) included the values of variance, range and mean values for analyzed dataset.

The program does not include graphical output, but it is possible to export numerical results in three, separate ASCII files (semivariogram, spherical and exponential ASCII files). These data can be easily imported in Excel^{TM} package and visualized in 2D graphs.

2.2.1. Help File of the Program “1D Semivariogram Calculation”

The program is equipped with short, but effective help file (**Figure 7**). It includes the very basic theory about variogram and variogram parameters (as range, nugget, sill etc.). This help file was not written with intention to be comprehensive geostatistical manual, but of course calculation of semivariograms is based on all mathematical rules of variogram calculation. But the reader for the most of different geostatistical methods and techniques (deterministical as well as stochastical) can look at reference list and find there list of very first geostatistical papers and books (KRIGE, 1951, MATHERON, 1962, 1963, 1965) and some of the most famous books from that field (CRESSIE, 1991, DUBRULE, 1998, HOHN, 1988, ISAAKS & SRIVASTAVA, 1989, JENSEN et al., 2000, JOURNEL & HUIJBREGTS, 1978, KELKAR & PEREZ, 2002). The Croatian reader can found two very first books from geostatistics in Croatian (ANDRIČEVIĆ et al., 2007, MALVIĆ, 2008) as well as one doctoral thesis (MALVIĆ, 2003).

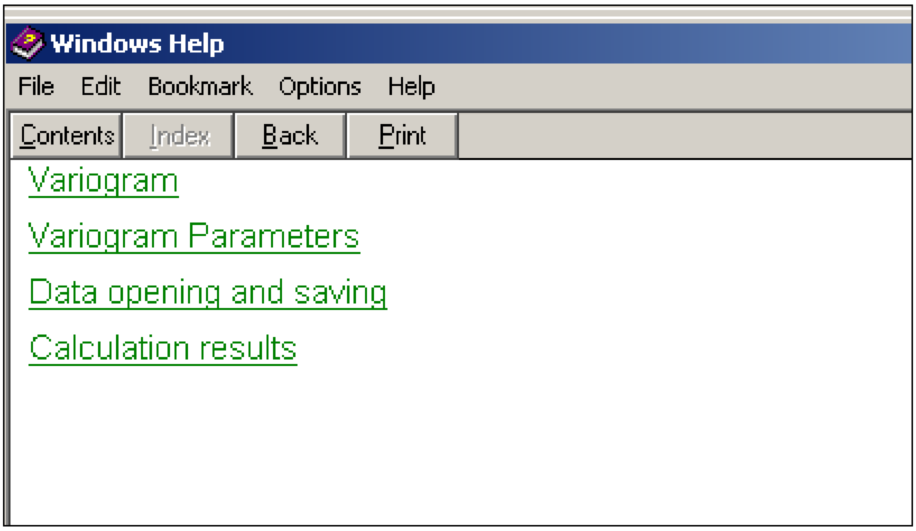


Fig. 7. The visual mask of the program help file with four help topics as follows: (a) Variogram, (b) Variogram Parameters, (c) Data opening and saving, (d) Calculation results

The all operations related to data opening and saving of numerical models are explained also in relevant help topic. Eventually, results of semivariogram calculations using this program are also presented through this help file, but due to importance of this topic it is also explained in separate subchapter.

2.2.2. Calculation Results

Results of semivariogram calculations comprise the three main boxes. In each of them are listed results of experimental variogram as well as theoretical spherical and experimental models for each semivariogram interval (i.e. class, including lag).

Results are expressed as numerical array. If the intention is plot these numbers they could be easily copied and pasted in Excel worksheet and plot through diagrams. Moreover, each of three main boxes is accompanied with additional outputs for validation of resulting variograms.

Experimental variogram also includes the data about variance, range and mean of inputs. Range is specifically expressed as number of interval/class where the sill is first time crossed (e.g. 4.5 means that range is observed after class four).

Mean Square Error (MSE) is given together with theoretical variogram numbers and exactly shows differences between theoretical and experimental model values calculated for each lag.

2.3. Review of the Most Important Results

Petrophysical parameters and analyses are shown with regard to particular lithostratigraphic units. Main problem in core classification and selecting of input data was high lithological difference in described members. Sometimes it was reason for high difference in close sample values, even in the same core. Of course, such cases were characterized by high variance and low applicability. The analyzed units were two sandstone members from Kloštar-Ivanić Formation. Those were lithostratigraphic members Poljana Sandstones and Pepelana Sandstones.

Poljana Sandstone Member contained a number of data and (geo) statistically are analyzed very reliable. Results were in wide interval. Range had values between 0.21 and 1.41 m for porosity values up to 30 %. Such values are completely in according with lithological properties of the member, i.e. vertical and horizontal changeability determined even in the same reservoir. This lithostratigraphy unit has the highest lithological changeability compared to all other analyzed members. It is one of the main reasons for relatively low hydrocarbon reserves found in this unit.

The youngest Pepelana Sandstones contained a more abundant dataset. The highest mean porosity is also up to 30 %, but general ranges were the higher (0.55-1.73 m). These results, together with stratigraphic review, indicated the most constant lithological composition among all described units. Oil and gas potentials of the Pepelana sandstones are proven by great discoveries of C, D, E, and F series on the Šandrovac field. Lithology of Pepelana Sandstones is very different in other parts of the sag, but variability is lesser then in Poljana Sandstones.

Both lithostratigraphic members had been analyzed by previous version of presented “1D Semivariogram Calculation” program (MALVIĆ, 2003). From geological point of view it confirmed 1D semivariogram analyzes as useful and meaningful tool for introspection of core or log data collected in only 1 well in vertical direction. Very often, in such cases, interesting (reservoir) lithologies had been analyzed only in some parts of reservoirs, and there is question how far such data can be extrapolated in another, uncored or unlogged, reservoir parts. Calculation of 1D semivariograms and accompanied ranges can answer on such question.

Also, presented program can be also applied for any type of vertical (1D) data. The only condition is that collected data are in meaningful geological, physical or any other engineering connection. It is simple presented at **Figure 6** where analyzed hypothetical numerical dataset is in sequential order (1-20), but with interpretable results.

3. Appendix (Part of Program Code)

In this appendix is given the most important part of the program code written in Visual Basic 6.0^{TM}. This part of code included lines where are experimental semivariogram is calculated via iterative procedure for each semivariogram class.

Anybody interested in entire freeware computer code can download it from the web site of the Geomathematical section of the Croatian Geological Society (http://www.geologija.hr/geomat.php) or send e-mail to authors of paper.

```
' ******************************************************************
' CALCULATION OF EXPERIMENTAL SEMIVARIOGRAM
' ******************************************************************

Dim korak, brparova, trenpod, h As Integer
Dim s
' korak – searching radius, brparova – number of data pairs for particular step
' trenpod – current active data, h – semivariogram value for particular class (step), s – current sum of all semivariogram values
korak = 1: brparova = 0: h = 1
Do While korak < brpod

    s = 0

    trenpod = korak + 1

    Do While trenpod <= brpod
       ' ----------------------------------------------------------------------------------------------------
       ' SEMIVARIOGRAM CALCULATION for pair with next-observed data interval
       ' ----------------------------------------------------------------------------------------------------

       If (trenpod + korak) <= brpod Then

         s = ((vrijednost(trenpod) - vrijednost(trenpod + korak)) ^ 2) + s

         brparova = brparova + 1

       End If

       ' ---------------------------------------------------------------------------------------------------
       ' SEMIVARIOGRAM CALCULATION for pair previous-observed data interval
       ' ---------------------------------------------------------------------------------------------------

       If (trenpod - korak) > 0 Then

         s = ((vrijednost(trenpod) - vrijednost(trenpod - korak)) ^ 2) + s

         brparova = brparova + 1

       End If

       trenpod = trenpod + 1

    Loop
```

```
    ' -----------------------------------------------------------------------------------------------------
    ' CALCULATION AND STORING OF SEMIVARIOGRAM VALUE GAMMA (h)
    ' -----------------------------------------------------------------------------------------------------

    gamma(h) = s / (2 * brparova)
    ' ----------------------------------------------------------
    ' writing of SEMIVARIOGRAM for current step
    ' -----------------------------------------------------------

    LB_Podaci.AddItem Left(gamma(h), 6)


    ' calculation of RANGE from 2nd step

    If (gamma(h) > var And h > 1 And TB_Doseg = 0) Then
    TB_Doseg = h - 0.5

    doseg = TB_Doseg

    End If
    ' opening of semivariogram for the next step ready for writing

    h = h + 1

    brparova = 0

    korak = korak + 1

Loop
```

Explanation of variable names (named in Croatian):

korak = *step*
brparova = *number of data pairs*
trenpod = *current data*
s = *local variable*
vrijednost() = *value ()*
gamma (h) = *semivariogram (h)*
h = *interval (variogram class) currently calculated*

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