Rudarsko-geološko-naftni zbornik	Vol. 18	str. 63-70	Zagreb, 2006.

UDC 551.3.051:519.28
UDK 551.3.051:519.28

Original scientific paper
Originalni znanstveni rad

Language/Jezik:*English/Engleski*

MIDDLE MIOCENE DEPOSITIONAL MODEL IN THE DRAVA DEPRESSION DESCRIBED BY GEOSTATISTICAL POROSITY AND THICKNESS MAPS (CASE STUDY: STARI GRADAC-BARCS NYUGAT FIELD)

TOMISLAV MALVIĆ[1]

[1]*INA-Industry of Oil Plc., Reservoir Engineering and Field Development Department, Šubićeva 29, Zagreb, Croatia;*
e-mail: tomislav.malvic@ina.hr

Key words: depositional model, Middle Miocene, geostatistics, porosity, thickness, Stari Gradac-Barcs Nyugat

Abstract

Neogene depositional environments in the Drava depression can be classified in two groups. One group is of local alluvial fans, which were active during the period of Middle Miocene (Badenian) extension through the entire Pannonian Basin. The second group is represented by continuous Pannonian and Pontian sedimentation starting with lacustrine environment of partly deep water and partly prodelta (turbidity) fans and terminating at the delta plain sedimentation.

The coarse-grained sediments of alluvial fans have the great hydrocarbon potential, because they often comprise reservoir rocks. Reservoir deposits are mostly overlain (as result of fan migration) by pelitic seal deposits and sometimes including organic rich source facies. That Badenian sequences are often characterised by complete petroleum systems, what is confirmed by large number of oil and gas discoveries in such sediments in the Drava and other Croatian depressions.

Alluvial environments are characterised by frequent changes of petrophysical properties, due to local character of depositional mechanism and material sources. In the presented paper, Stari Gradac-Barcs Nyugat field is selected as a case study for demonstrating the above mentioned heterogenic features of the Badenian sequences. Structural solutions are compared by maps of parameters related to depositional environment, i.e. porosity and thickness maps. Geostatistics were used for spatial extension of input dataset. The spatial variability of porosity values, i.e. reservoir quality, is interpreted by transition among different sub-environments (facies) in the alluvial fan system.

Ključne riječi: taložni model, srednji miocen, geostatistika, poroznost, debljina, Stari Gradac-Barcs Nyugat

Sažetak

Neogenski taložni okoliši u Dravskoj depresiji mogu se podijeliti u dvije skupine. Prva skupina obuhvaća lokalne okoliše aluvijalnih lepezi, koje su bile aktivne u razdoblju srednjomiocenske (badenske) ekstenzije u cijelom Panonskome bazenu. Druga skupina predstavljena je kontinuiranom panonskom i pontskom sedimentacijom u lakustričkom okolišu, koja je započela djelomično s dubokovodnom, a dijelom taloženjem u prodeltnim lepezama (turbiditni facijesi). Taj ciklus završio je sedimentima karakterističnim za deltne ravnice.

Krupnozrnati sedimenti aluvijalnih lepezi karakterizirani su velikim naftnoplinskim potencijalom, jer vrlo često obuhvaćaju ležišne stijene. Ti sedimenti uglavnom su prekriveni (a kao rezultat migracije aluvijalnog okoliša u vremenu i prostoru) pelitskim izolatorskim stijenama koje ponegdje sadrže i matične facijese bogate organskom tvari. Zato takve badenske sekvence često obuhvaćaju cjelovite naftnoplinske sustave, što je potvrđeno otkrićem velikog broja naftnih i plinskih ležišta u tim sedimentima, kako unutar Dravske tako i u drugim depresijama u hrvatskom dijelu Panonskog bazena.

Aluvijalni okoliši su karakterizirani čestim promjenama petrofizikalnih svojstava, a zahvaljujući lokalnom karakteru takvoga taložnog okoliša i izvora materijala. U prikazanom radu odabrano je polje Stari Gradac-Barcs Nyugat kao ogledni primjer, na kojemu je prikazana ranije spomenuta heterogenost badenskih sekvenci. Strukturna rješenja su uspoređena s karatama onih parametara čije vrijednost ovisi o taložnom okolišu, tj. s kartama poroznosti i debljina. Geostatistika je upotrijebljena za prostornu analizu ulaznog skupa mjerenja. Prostorna varijabilnost vrijednosti poroznosti, tj. kvaliteta ležišta, je objašnjenja prijelazom između različitih podokoliša (facijesa) unutar sustava aluvijalne lepeze.

INTRODUCTION

Sediments of Middle Miocene in the Croatian part of the Pannonian Basin are common reservoir and source rocks. These are the earliest sediments deposited during Neogene transgression covering the entire Pannonian region. These sequences embracing mostly the Badenian, Sarmatian and Lower Pannonian (s.l.) ages are mainly clastic rocks. Badenian age started by coarse-grained alluvial sediments and Lower Pannonian finished by lacustric marls. This stratigraphic interval encompasses reservoir, seal and source rocks.

Generally, Miocene extension starting at Ottnangian age, have created marine environments in Hrvatsko zagorje and Mura depression, and fresh water fluvial and lacustric areas far away to the east (**Rögl, 1996, 1998**). In Badenian, marine environments (**Vrbanac, 1996; Rögl, 1996, 1998**) extended to the entire northern Croatia. Irregular palaeorelief of Palaeozoic and Mesozoic basement caused significant depth differences. Large parts of present-day mountains in northern Croatia, like Medvednica, Kalnik, Moslavačka gora, Psunj and Papuk Mts., remained more or less isolated islands above the sea-level. Submarine basement played important geomorphological role on the bottom of the sea.

All these uplifted areas were source regions of different detritus. Palaeozoic rocks and basement gave siliciclastic and Mesozoic carbonate detritus. Lithoral algae reefs were abundant, but in shallow marine environments such reefs (mostly *Coralinacea* and *Briozoa* origin) were eroded by sea currents and represented important source of carbonate clasts.

Sedimentation in Lower and Middle Badenian was mostly characterised by coarse-grained sediments. They were deposited in the proximal part of alluvial fan (**Malvić, 1998**). Absence of carbonate clasts indicated the absence of reef organisms. Coarse and medium-grained sandstone was deposited in the middle part of alluvial fan. Sometimes their green colour, due to mica and chlorite minerals, is the indication of weak reductive environment in sea with normal salinity (**Odin and Matter, 1981; Tišljar, 1993**). Medium and fine-grained sandstones were deposited in the distal part of alluvial fan and this sequence characterise a fan migration in time and space as well as the transition toward brackish, shallow and stagnant environment of Upper Badenian. Badenian top is represented with marlstones and marly limestones deposited in such stagnant and shallow (mostly up to 100 m deep) sea. Such conditions were continued in Sarmatian age, accompanied by further reduction of salinity and depositional area, and by domination of lithoral psamitic and pelitic clastics. Reefs slowly disappear. In Lower Pannonian period the sea environment was replaced by lacustric, characterised mostly by carbonate sedimentation. Some parts in Croatian depressions were uplifted above sea-level. In other parts lacustric-plain carbonate sedimentation represented by clayey limestones and marls was dominant.

The above described Badenian-Lower Pannonian sequence was mapped at many hydrocarbon fields in the Drava and Sava depression. It comprises (Lower-) Middle Badenian reservoir rocks connected by cataclized basement rocks along unconformities. Upper Badenian, Sarmatian and Lower Pannonian included seal rocks, while source rocks are proven in Upper Badenian and Lower Pannonian deposits.

The very frequent field structures are regarded to be major extensional faults and basement buried hills. These features had strong influence on the sedimentation of Middle Miocene sequences and distribution of different lithologies. That is why Middle Miocene facies, described by structural maps, palinspastic reconstructions and geological sections, can be additionally explained using some other maps describing parameters being characteristics for the different depositional environments. They are porosity and thickness maps.

The Stari Gradac-Barcs Nyugat is selected as the case study for demonstrating such analysis. This field was the target of several porosity mapping studies (**Malvić and Smoljanović, 2004; Smoljanović and Malvić, 2004, 2005**) as well as detailed stratigraphic and structural analyses. The Stari Gradac-Barcs Nyugat input dataset was relatively small but still enough reliable by 15 well to perform Kriging interpolation (**Malvić and Đureković, 2003**).

Kriging was selected as interpolation method that theoretically provides the least estimation risk in the range of variogram model. Stochastic simulations were used as tools for describing the small-scale heterogeneity of cell values away from control points (wells). The same variograms were applied in Kriging as well as in conditional simulation, and results were not very different.

GEOLOGICAL SETTING OF THE STARI GRADAC - BARCS NYUGAT FIELD

The Stari Gradac-Barcs Nyugat gas-condensate field is located on the Croatian-Hungarian border (**Figure 1**), along the Drava river, approximately 150 km east from Zagreb. Hydrocarbon reservoirs were discovered in 1980 and total of 15 wells were drilled until 2003. The field structure is situated in the northwestern part of the Drava depression. This is anticline formed above Mesozoic buried hills. Reservoir lithology comprises four lithofacies, but presents unique hydrodynamic unit with single gas/water contact. These reservoir lithofacies are informal lithostratigraphic units named as follows: Clastites (Badenian age), Dolomites (Lower Triassic age), Quartzites (Lower Triassic age) and Metavolcanites (Carboniferous to Permian ages).

Figure 1 Location map

Slika 1. Položajna karta

The size of the field, contoured by gas-water contact in the Clastites lithofacies, is 18.9 km^2. Structural map, given on **Figure 2**, shows two fault systems by strikes NW-SE and NNE-SSW. All faults being perpendicular to the structure (strike NNE-SSW) are mostly completely permeable for fluid flow. It is assumed, that the fault being in the centre of structure with extremely curved fault line (its strike changed from the NNE-SSW to the NW-SE) played the major role in this system. This fault had been probably activated in the Middle Miocene as the normal one. Later in the postextensional phase its character of displacement was changed to reverse fault.

Two major faults with direction NW-SE define field margins (the SW fault margin is shown on **Figure 2**). These faults existed before Neogene age, and reactivated in Badenian as strike-slip extensional faults, defining and uplifting field' structure.

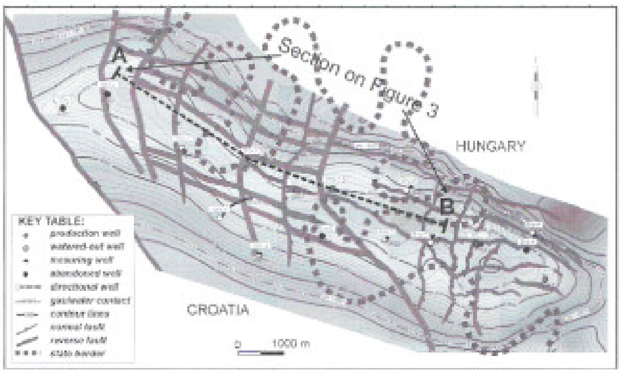

Figure 2 Structural map showing the top of Clastites lithofacies (from: **Gaćeša et al., 2001**)

Slika 2. Strukturna karta po krovini litofacijesa Klastita (iz: ***Gaćeša et al., 2001****)*

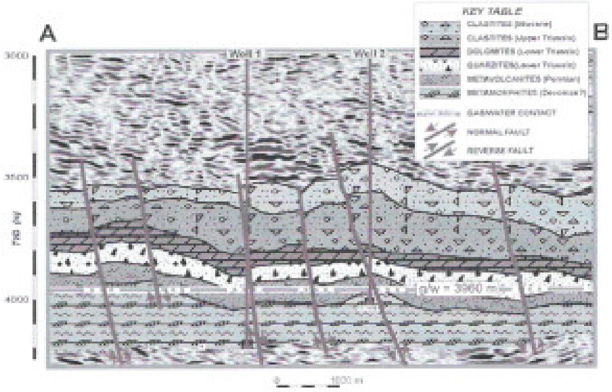

Figure 3 NW-SE cross section along the field (from: **Gaćeša et al., 2001**)

Slika 3. *Geološki profil kroz polje Stari Gradac-Barcs Nyugat pružanja SZ-JI (iz:* ***Gaćeša et al., 2001****)*

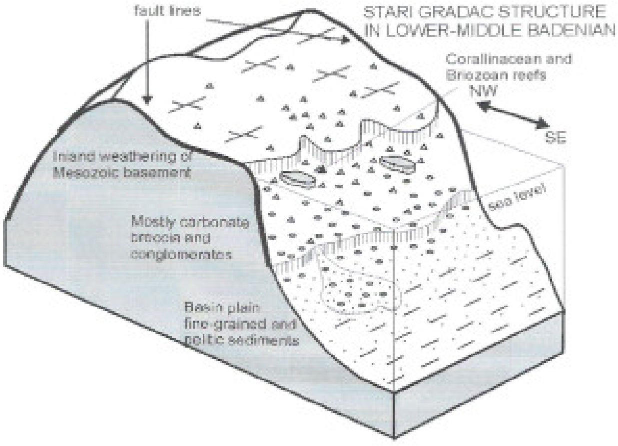

Figure 4 Depositional environment in Lower-Middle Badenian (schematic) in the area of Stari Gradac-Barcs Nyugat

Slika 4. Taložni okoliš u donjem i srednjem badenu u području Stari Gradac-Barcs Nyugat (shematski)

DEPOSITIONAL ENVIRONMENT

The relation between the Badenian clastites and Mesozoic basement is shown on **Figure 3**. The major Badenian anticlines are hereditary structures defined by Mesozoic buried hills.

Badenian coarse-grained lithology is characterised by small scale heterogeneity of thickness and porosity (within the range of several hundreds of meters). Badenian depositional environment was interpreted as typical alluvial fan series like several fields in the Croatian part of Pannonian basin. For example, it could be very well compared with alluvial mechanism described at Ladislavci, Beničanci and Obod fields in the eastern part of the Drava depression (**Tišljar, 1993**) or at the Galovac-Pavljani field in the central part of the Bjelovar subdepression (**Malvić, 1998**). Schematic alluvial fan mechanism in the period from Lower to Middle Badenian for the Stari Gradac-Barcs Nyugat field is on **Figure 4**.

Badenian sediments are represented mainly by coarse-grained clastics. The Mesozoic basement can be correlated by similar rocks observed in the outcrops of Papuk Mt. (more to the SW). It is almost impossible to distinguished Upper Triassic breccia, redeposited in Badenian, from the lithologically very similar sediments, which were weathered and deposited in Middle Miocene. These sediments are hydrodynamically connected to each other. Upper Triassic sequences include more poorly sorted breccia and conglomerates, while Badenian interval is characterised by domination of coarse-grained sandstones and greywacke.

KRIGED MAPS

Porosity and thickness are important reservoir parameters. Both of them characterised depositional mechanism and area, and sometimes these two variables can be multiplied in new reservoir attribute, useful in reservoir characterisation (product of porosity and thickness). Geostatistics offers strong tools for interpolation and extrapolation, spatial distribution analysis and uncertainty estimation for reservoir parameters (e.g. **Journel and Huijbregts, 1978; Hohn, 1988; Isaaks and Srivastava, 1989; Kelkar and Perez, 2002**) with the methods of different Kriging including Co-Kriging and stochastic simulations. Stari Gradac-Barcs Nyugat dataset is relatively limited, but enough reliable for geostatistical application (**Malvić and Smoljanović, 2004; Smoljanović and Malvić, 2004, 2005**).

It is important to mentioned that the normal score transformation was not performed. Such function can be defined for any continuous cumulative distribution function. It could be done where the cumulative frequency distribution of random variable is decidedly not normal. Many geostatistical techniques ask (as desirable) the data to be transformed to a Gaussian or normal distribution. But, due to only 15 inputs such transformation could be almost meaningless, and axiomatic rule that porosity is characterised by the normal distribution is accepted.

Variogram analysis

Variogram analysis is the most common tool used for spatial data analysis. Result of such analysis represents obligatory input for any geostatistical estimation methods - interpolation and simulation. Variogram analysis was performed in four directions, and two of them included the main field structural axes:

- Principal axis with strike 120°-300° and
- Subordinate axis with strike 30°-210° .

Equivalence of structural and variogram axes were confirmed by the variogram surface map (**Figure 5**) performed in Variowin™ program (**Pannatier, 1996**). Such map was made for Quartzites lithofacies, based on the same number of data as Clastites lithofacies dataset.

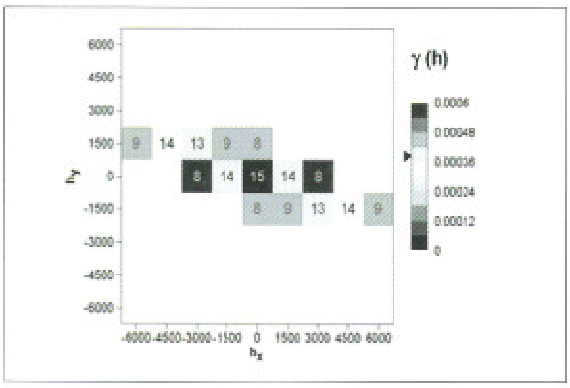

Figure 5 Variogram surface maps

Slika 5. Karta variogramske površine

Experimental variograms were modelled independently for each reservoir lithofacies. The ranges of influence obtained for Clastites lithofacies are 3500 meters for principal and 1200 meters for secondary axis (**Figure 6**). 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. The secondary range was assumed mostly from experience and analogy with variograms obtained on adjacent fields in the Drava depression. Experimental curves were approximated with spherical theoretical model (Equation 1; from **Hohn, 1988**).

$$\gamma(h) = C \left[\left(\frac{3h}{2a} \right) - \left(\frac{h^3}{2a^3} \right) \right] \qquad h \leq a \qquad \text{(Eq. 1)}$$

$$\gamma(h) = C \qquad h > a$$

Where are:

γ(h) - semivariogram

C - sill

a - range

h - variogram distance

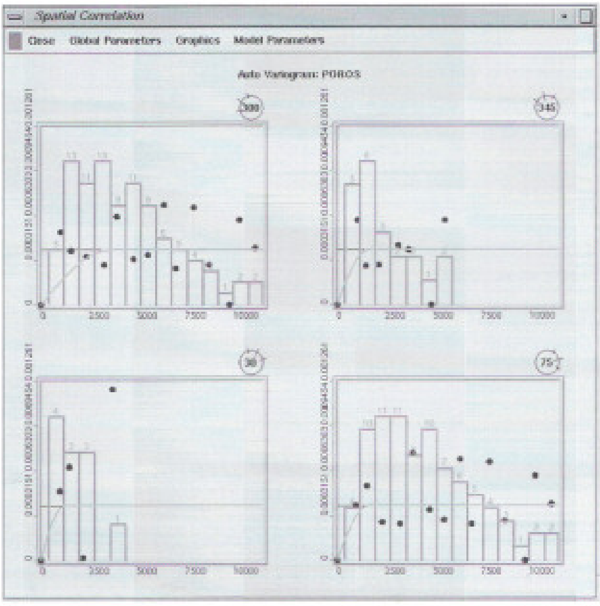

Figure 6 Variogram analysis in Clastites lithofacies

Slika 6. Variogramska analiza u litofacijesu Klastita

Kriging interpolation

For the interpolation of porosity and total (gross) thickness values were derived for 15 wells. Porosities lower than 3 % were set to 0. Such a manner four wells of the eastern part of the reservoir became non-productive.

Porosity and thickness data were interpolated by Kriging. In addition, cross-validation test was used as kind of numerical rating (MSE or Mean Square Error) of estimation error (**Davi, 1987**). Previously comparison of cross-validation results between Inverse Distance Weighting and Kriging methods at the Stari Gradac-Barcs Nyugat has shown the geostatistical approach to be more accurate linear interpolation tool than other traditional methods (**Malvić and Đureković, 2003**) for Clastites lithofacies (Kriging MSE=3.914 vs. IDW MSE=5.279).

The quality of geostatistical approach in griding of petrophysical parameters was also checked in the study of stochastic simulation of OGIP (Original Gas In Place) in the Stari Gradac-Barcs Nyugat field (**Smoljanović and Malvić, 2004, 2005**). The difference between the minimum and maximum estimation of OGIP did not exceed 12 % (**Figure 7**).

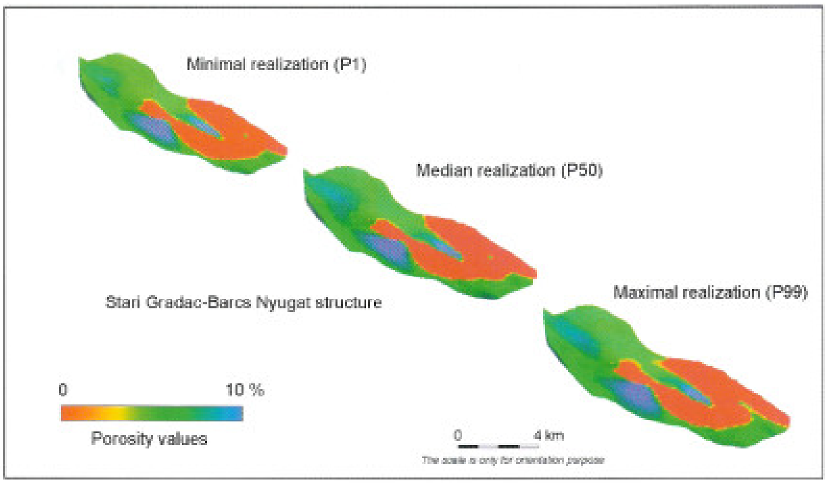

Figure 7 Minimal, median and maximal OGIP realizations at the Stari Gradac-Barcs Nyugat field (from **Smoljanović and Malvić, 2004**)

Slika 7. Minimalna, medijan i maksimalna realizacija OGIP-a na polju Stari Gradac-Barcs Nyugat (iz: ***Smoljanović and Malvić, 2004****)*

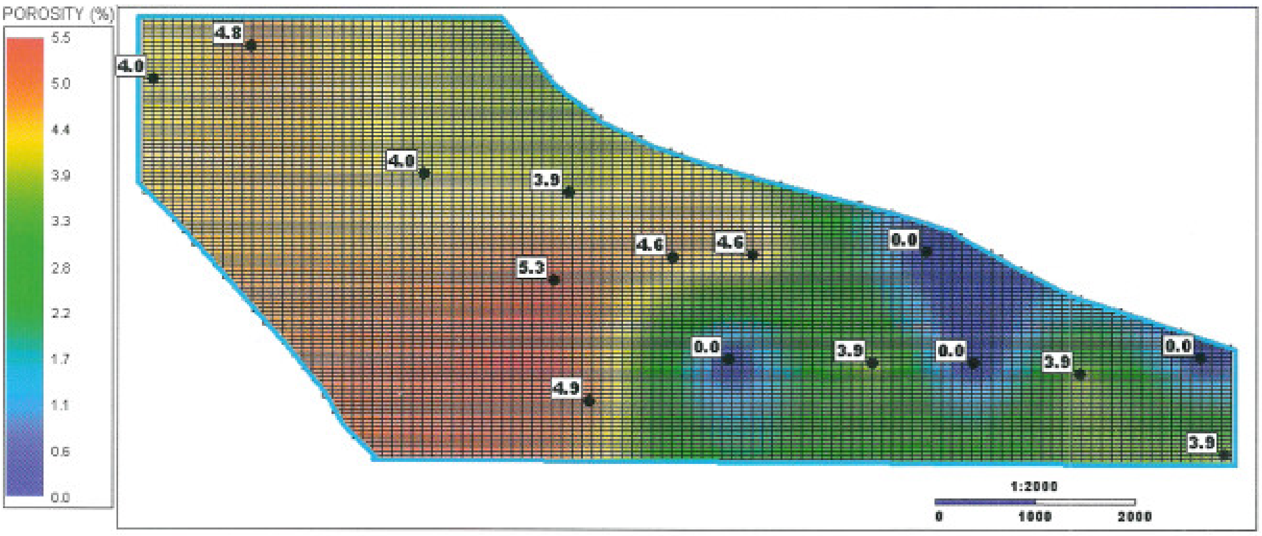

Figure 8 Porosity map of Clastites

Slika 8. Karta poroznosti Klastita

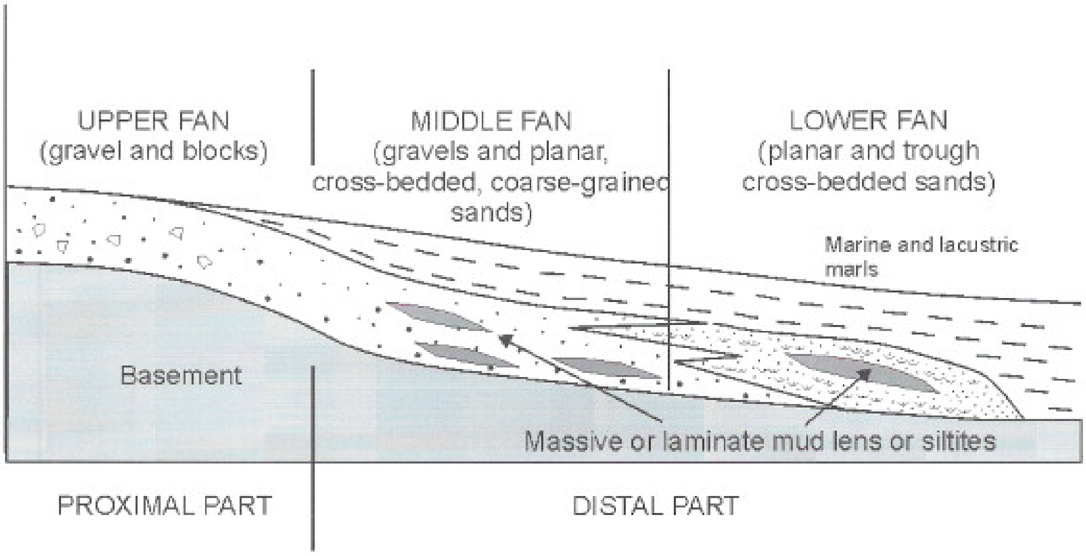

Figure 9 Schematic facies distribution in alluvial fan (from: **Tišljar, 1999**)

*Slika 9. Shematski prikaz distribucije facijesa u aluvijalnoj lepezi (iz: **Tišljar, 1999**)*

Porosity and thickness values are very often axiomatically connected. This connection strongly depends on the type and size of depositional environment. Taking these facts into consideration, it is worth comparing porosity and structural maps (**Figures 2** and **8**). Four anticline tops can be observed on structural map, two of them in the NW and two of them in the SE parts of the field. If similar palaeostructure had existed in Badenian and depositional and faulting mechanism had been the same on the entire Stari Gradac-Barcs Nyugat structure, porosity distribution would had been very similar on present-day geological maps. But, obviously this is not true. There are several reasons that could result in differences between porosity and structural maps. In Badenian sequences, the major influence on porosity distribution has well's locations regarding its position in alluvial fan (more precise – upper, middle or lower part of the fan). Schematic distribution of alluvial fan facies is shown on **Figure 9**.

Comparison of porosity and total thickness map (also known as gross thickness or gross pay map) for Stari Gradac-Barcs Nyugat can be done comparing maps on **Figures 8** and **10**. The colour scale is the same – the maximum is red and the minimum marked by blue. Comparing porosity and thickness maps indicated on opposite location of related maximums and minimums. Thus the porosity maximum corresponds to minimal thickness on the NW edge. Another porosity maximum located in the central part can be compared by approx. average thickness. Finally, porosity minimum is mapped on the same area as maximum total (gross) thickness, i.e. on the SE edge of the field.

Based on the regional studies it can be assumed that Badenian sediments were not eroded at all or such process played only a minor role.

Generally, porosity values measured in wells are strongly depends on the wells palaeostructural position regarding field structure or depositional facies. Depositional mechanism of wider area of the Stari Gradac-Barcs Nyugat is shown on **Figure 4**. It can be reasonable assumed that in Badenian period, NW from the Stari Gradac-Barcs Nyugat structure, existed the uplifted Mesozoic basement. This uplifted area was, in the beginning of the extension, weathered and cataclized by activity of strike-slip faults, which are shown on **Figures 2** and **4**. These faults also defined area of the Stari Gradac-Barcs Nyugat structure. The Mesozoic basement was weathered and cataclized and coarse-grained sediments (mostly carbonate detritus) were deposited at NW part of the field structure. Toward to the SE, sedimentation was changed to fine-grained carbonate clastics and deeper basin-plain pelitic sediments. This plain area consumed larger thickness of sediments through Badenian. Such reconstruction explains why the thickness map on **Figure 10** contains larger values on the SW part, and contemporaneously, why porosity map includes even four wells where the average porosity in the Badenian interval is smaller than the cut-off (i.e. it is replaced by 0).

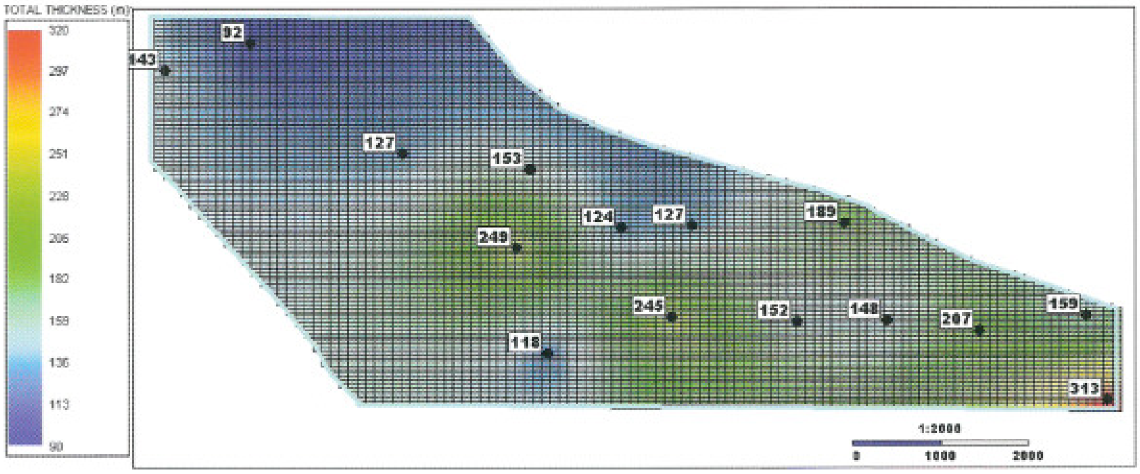

Figure 10 Total thickness map

Slika 10. *Karte ukupne debljine*

DISCUSSION

Reservoir space is always characterised with uncertainties. There is permanent problem how to express such hidden geological features. Geostatistics was chosen as the tool for handling uncertainties. Variogram analysis expressed the spatial continuity of porosity values. Kriged maps of porosity and thickness described spatial distribution of these geological variables. On the basis of comparison these maps, the qualitative differences could be interpreted by the lateral changes of the Badenian depositional environments.

In Badenian, the proximal part of alluvial fan was active only on the NW part of the Stari Gradac-Barcs Nyugat structure.

This area is built up by coarse-grained sandstones and gravel deposits, which have significant primary porosity. Uplifted Mesozoic basement located close to the NW margin of the structure can be regarded as local source of depositional material. As response for the activity of the main faults (strike NW-SE) bordering the structure the depositional site was opened (**Figure 2**).

The region of smaller porosities and larger thicknesses are connected by the distal part of alluvial fan, which existed on the SW part of the structure. This part is characterised by fine-grained planar and trough cross-bedded sands or basin-plain marls. The porosity is low and rarely can reach value about cut-off (here 3 %). In Badenian this area was tectonically subdued along the main fault of the NNE-SSW striking fault system (central perpendicular fault line at **Figure 2**), and later, in the post-extensional phase, it was uplifted (changing of fault character) along the same fault line. This postextensional uplifting of the entire structure was also active along the main faults of structure (faults of NW-SE strike that bordered the structure).

Received:09.09.2006.
Accepted:30.10.2006.

REFERENCES

Davi, B. (1987): Uses and Abuses of Cross Validation in Geostatistics. Mathematical Geology, 19 (3), 241-248.

Hohn, M.E. (1988): Geostatistics and Petroleum Geology. Van Nostrand Reinhold, 264 p., New York.

Isaaks, E. and Srivastava, R. (1989): An Introduction to Applied Geostatistics. Oxford University Press, 561 p., New York.

Journel, A.G. and Huijbregts, C.J. (1978): Mining Geostatistics. Academic Press, 600 p., Orlando.

Kelkar, M. and Perez, G. (2002): Applied Geostatistics for Reservoir Characterization. Society of Petroleum Engineers, 264 p., Richardson.

Malvić, T. (1998): Strukturni i tektonski odnosi, te značajke ugljikovodika šire okolice naftnoga polja Galovac-Pavljani. Master thesis, Faculty of Mining, Geology and Petroleum Engineering, 111 p., Zagreb.

Malvić, T. and Đureković, M. (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, Zagreb.

Malvić, T. and Smoljanović, S. (2004): Geostatistical Estimation and Simulation Approaches for More Detailed OGIP Calculations (Stari Gradac - Barcs Nyugat Field). In: Steiner, I. (editor): IOR Methods for Economical Oil Recovery from Small Size and/or Marginal Oil Fields, Petroleum Summer School, Faculty of Mining, Geology and Petroleum Engineering, 119-128, Zagreb.

Odin, S.G. and Matter, A. (1981): De glauconiarum origine. Sedimentology, 28/5, p. 611-641, Blackwell Scientific Publications, Oxford.

Pannatier, Y. (1996): VARIOWIN: Software for Spatial Data Analysis in 2D. Springer-Verlag, 91 p., New York.

Rögl, F. (1996): Stratigraphic correlation of the Paratethys Oligocene and Miocene.– Mitteilungen Ges. Geol. Bergbaustud. Österreich, 41, 65–73, Wien.

Rögl, F. (1998): Palaeographic consideration for Mediterranean and Paratethys seaways (Oligocene to Miocene).–Ann. Naturhist. Mus. Wien, 99A, 279–310, Wien.

Smoljanović, S. and Malvić, T. (2004): Improvements in reservoir characterization applying geostatistical modelling (estimation & stochastic simulations vs. standard interpolation methods), Case study from Croatia. In: Forum Committee (ed.): Proceedings of World Petroleum Congress, 1st Youth Forum, Chinese National Committee for WPC, Published by Petroleum Industry Press & Beijing Kehai Electronic Press, 1054-1061.

Smoljanović, S. and Malvić, T. (2005): Improvements in reservoir characterization applying geostatistical modelling (estimation & stochastic simulations vs. standard interpolation methods), Case study from Croatia. Nafta, 56, 2; 57-63, Zagreb.

Tišljar, J. (1993): Sedimentary bodies and depositional models for the Miocene oil-producing areas of Ladislavci, Beničanci and Obod. Nafta, 44, 10, 531-542, Zagreb.

Vrbanac, B. (1996): Paleostrukturne i sedimentološke analize gornjopanonskih naslaga formacije Ivanić grad u Savskoj depresiji [*Palaeostructural and sedimentological analysis of the Upper Pannonian deposits of the Ivanić Grad Formation in the Sava depression* – in Croatian]. Unpublished PhD Thesis, University of Zagreb, 303 p., Zagreb.

Papers from the archive of INA-Naftaplin

Gaćeša, S., Futivić, I., Gyorgy, F. and Horvath, Z. (2001): Barcs Nyugat - Stari Gradac field study. INA-Naftaplin & MOL KTD, company archive, INA-Naftaplin, Zagreb.

Tišljar, J. (1999): Seminar iz sedimentologije. Internal script, INA-Industry of Oil Plc., E&P of Oil and Gas, organised in May, 1999 in Zagreb, company archive, Zagreb.

Acknowledgment

The presented research is done through activity of Reservoir Engineering & Field Development Department (INA-Exploration and Production of Oil and Gas). Thanks all colleagues who participated in some parts of research and application of geostatistics, and for the material given from professional documentation of Reservoir Engineering and Field Development department.

I wish to thank author of VARIOWIN 2.2., Mr. YVAN PANNATIER, for using one of the most popular freeware software for variogram analysis. Variowin copyright © 1993, 1994, 1995 belongs to Yvan Pannatier.

The maps are made using 3DField, contouring surface plotting and 3D data program that run under MsWindows. Author is Mr. VLADIMIR GALOUCHKO. The program was licensed by author and used for interpolation.

Author

The author is employed in INA-Industry of Oil Plc., Exploration and Production of Oil and Gas, Reservoir Engineering and Field Development Department, Zagreb as expert. He obtained BSc. and MSc in Geology and PhD. in Geosciences at the University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering.