Comparing core analyses and well logs using a Hungarian gas field as example

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PRELIMINARY COMMUNICATION

The purpose of this study was to build small-scale genetic models of a reservoir by comparing the small and medium scale information derived from core analyses and well logs. The examined gas field is situated in the eastern part of the Pannonian Basin System. For the numerical solution several one (univariate) and multivariable (multivariate) statistical methods were used to describeone and multidimensional similarities. Finally a multivariable identifying model summarizes the information gained in different scales. The analyses showed that there was a correlation between the rock physical properties and the shapes of well logs. The porosity and the permeability did not depend on the individual log shapes but the most typical log shapes of the rock body which resulted from the electro-facies. The oscillation of the pore throat size distribution caused small changes on the log. This model can be regarded as a tool for classifying new information according to the genetic hierarchy identified.

Key words: geomathematics, core analysis, well log

1. INTRODUCTION

Comparison of core analyses and well logs is not an easy problem. To solve this, an indirect method was used on selected Hungarian gas field where small-scale genetic model was built by comparing core analyses and well logs derived information. The examined field belongs to the MOL Hungarian Oil and Gas Public Limited Company, so the need for confidentiality was respected in methods and results presenting through paper.

The field is situated in the eastern part of the Pannonian Basin System, i.e. in the northern part of the Makó-Hódmezővásárhely Trench (Figure 1.1). This field consists of several individual deep water fan-type rock bodies1 which belong to the Szolnok Formation. The developing of this formation is connected to period of the Lake Pannon existence.

The Lake Pannon was the remnant of the Paratethys, which earlier separated from the Tethys Sea gradually from the Oligocene. The Pannon Basin System was formed because of the tensions caused by subduction. In the Early and Middle Miocene it had been connected with the Paleo Mediterranean Sea and the Indo-Pacific Ocean.[5] In the Sarmatian stage these connections did not exist anymore and disintegration of Paratethys resulted in creation of several larger brackish lakes. One of them was the Lake Pannon. In such environment the salinity fluctuated extremely[3], and eventually regionally

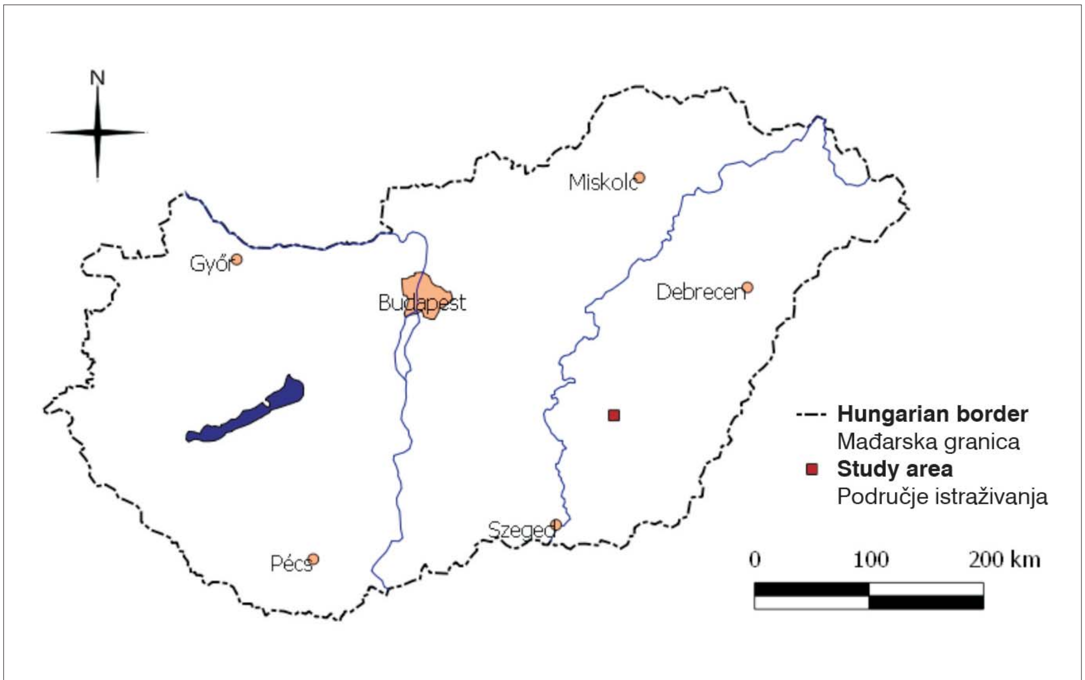

Fig. 1.1 Location map of the analysed field area
Sl. 1.1. Položajna karta istraživanog područja polja

decreased when it became brackish with 8-15‰ salinity.[7]

At the same time the uplifting of the Alps and Carpathians produced a great amount of sediment.[5] According to the mineralogy of the sandstones in the Pannonian Basin System, the sources of the sediment were mainly the metamorphites of the Western Carpathians and partly the volcanic rocks of Inner Carpathians.[6]

The sedimentary environments can be classified by the morphology of the lake.[4] According to seismic sections there were three depositional paleoenvironments active in the Lake Pannon, also highly influenced by paleomorphology. Those were: (a) basin, (b) slope and (c) shelf. The basin was located in the inner parts of the lake where the slow, lacustric pelagic sedimentation was disturbed only occasionally by turbidites. On the slope coarse grain sediment were eroded far away, and mostly claystones and siltstones were remained and lithified. The shelf and the coastal parts had been filled by lagoonal, swampy and marshy, shallow marine, littoral and river sediments.[4]

The analysed sediments lithostratigraphically belong to the Upper Miocene aged Szolnok Formation. It was formed 12-8 million years ago. It contains sediments deposited in turbidity systems which fill in the deepest parts of the basin or pelitic sediments from the calm period. Its distal part mainly consists of siltstones and claystones, and its proximal part made of fine sands, that can be separated to channel and lobe facies. The maximal thickness of the formation is 1000 m. The Szolnok Formation is bordered by the Endrőd and Algyő Formations. The Endrőd Formation is on the base, it consists of hemi-pelagic marlstones. The Algyő Formation was formed on the slope, and its principal rock types are clayey marlstones and siltstones and occasionally gravitational sandstones.[2]

2. APPLIED MEASUREMENTS AND METHODS

There are 37 boreholes with well logs and core measurements are available from 20 wells (Figure 2.1). Data included porosity, horizontal and vertical permeability and pore structure, which is measured by mercury porosimetry.

In the dataset there are three main rock types: sandstones, siltstones and claystones. The reservoir series consists of 17 rock bodies which are the informally

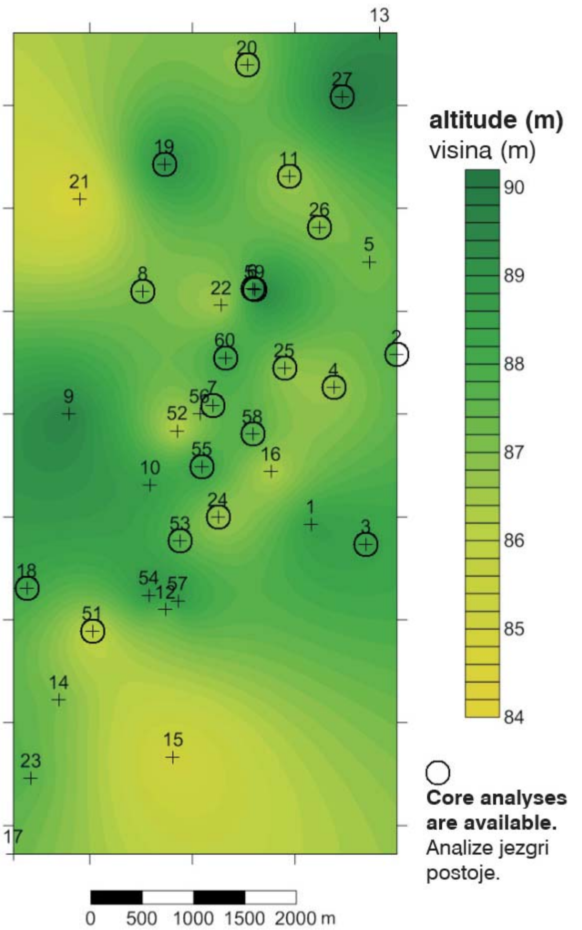

Fig. 2.1. Map of the well locations
Sl. 2.1. Karta lokacija bušotina

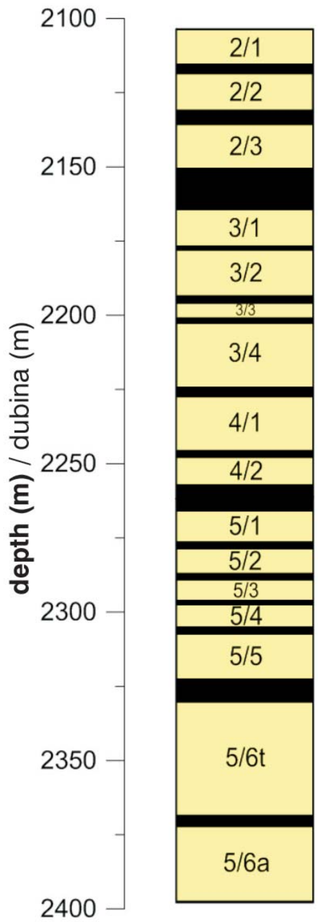

Fig. 2.2. Average depth of the rock bodies
Sl. 2.2. Srednja dubina intervala stijenskih uzoraka

named, following from top to bottom, as: 2/1, 2/2, 2/3, 3/1, 3/2, 3/3, 3/4, 4/1, 4/2, 5/1, 5/2, 5/3, 5/4, 5/5, 5/6t and 5/6a (Figure 2.2). The main rock type of the rock bodies is fine sandstone. The rock bodies are separated from each other by clayey marlstone layers.

At first porosity and permeability was analysed for each rock type and rock body in the dataset. The mean, confidence interval of mean, median, standard deviation, distribution, outliers and extremes were calculated and compared to other rock bodies. Because of the asymmetric distribution of permeability, its natural logarithm was examined.

To analyse the pore size distribution, using mercury porosimetry, nine pore size intervals with quasi-equal frequency on a logarithmic scale were determined.

The analyses had been done in sandstones because of the small number of samples taken in other lithologies (lithologic units). The following features were analysed by correlation, factor and cluster analysis for each rock type: porosity, horizontal and vertical permeability, mean, standard deviation and mode of pore size distribution as well as the frequency of the nine pore size intervals. Eventually, the obtained the clusters were put back to the rock column and interpreted.

Using the shape of the well logs, a genetic model was built and searched for connections between the electro facies and core analyses.

3. RESULTS

Porosity, permeability and pore throat size distribution were analysed for each rock type and rock body by statistical methods. In clay, due to low number of samples, only the porosity and pore throat size distribution are presented. Both variables are asymmetrically distributed (Figures 3.1 and 3.2).

The distribution of the permeability of siltstones is asymmetric (Figure 3.3). The porosity is also asymmetric and has two modes (Figure 3.4), which come from two different rock body groups.

The pore throat size distribution of siltstones is also bimodal but cannot be explained with the distribution of the rock bodies (Figure 3.6).

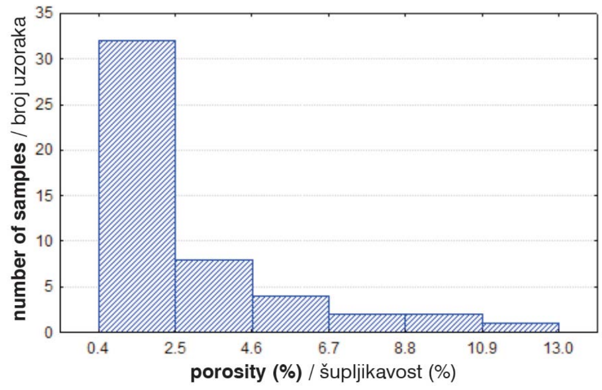

Fig. 3.1. Distribution of porosity of clays
Sl. 3.1. Razdioba šupljikavosti glina

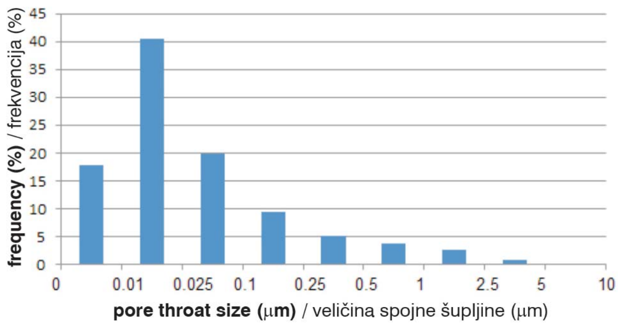

Fig. 3.2. Pore throat size distribution of clays
Sl. 3.2. Razdioba raspodjele "spojnih" šupljina glina

The sands have also bimodal porosity and permeability (Figures 3.7 and 3.9). The modes are caused by different groups of rock bodies. Those groups have the same members in case of porosity and permeability. Consequently, rock bodies 3/2, 5/2 and 5/3 have similarly large

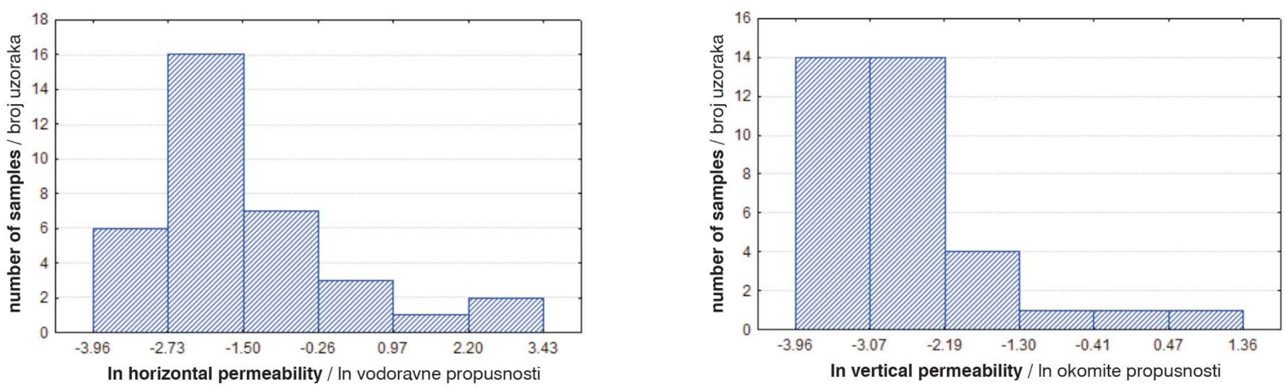

Fig. 3.3 Distribution of horizontal and vertical permeability of siltstones
Sl. 3.3. Razdioba vodoravne i okomite propusnosti siltova

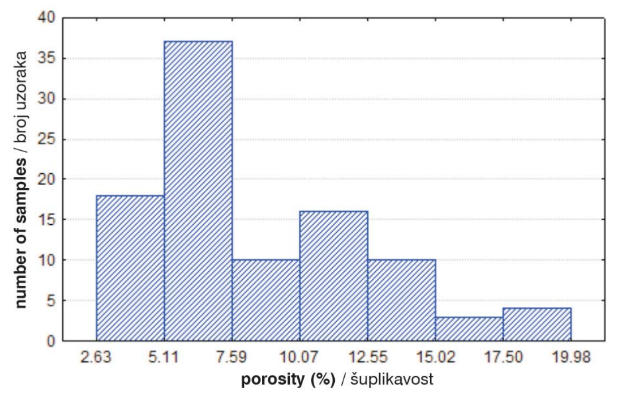

Fig. 3.4 Distribution of porosity of siltstones
Sl. 3.4. Razdioba šupljikavosti siltova

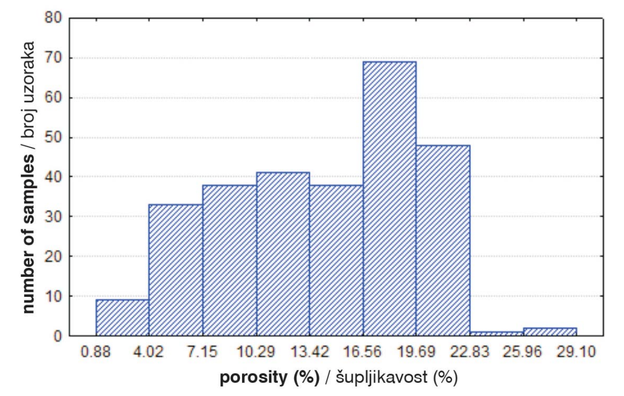

Fig. 3.7 Distribution of porosity of sands
Sl. 3.7. Razdioba šupljikavosti pijesaka

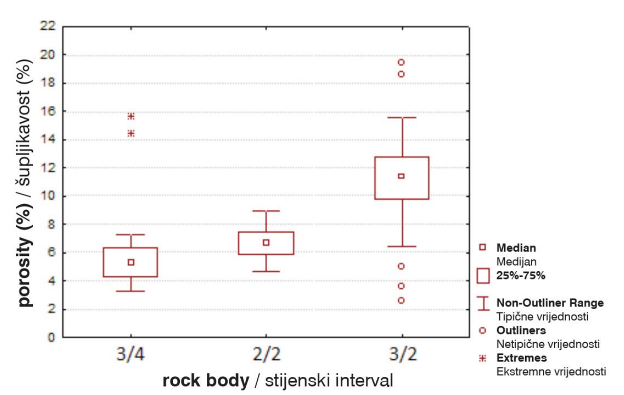

Fig. 3.5. Distribution of porosity of siltstones for three particular rock body
Sl. 3.5. Razdioba šupljikavosti siltova tri pojedinačna stijenska uzorka

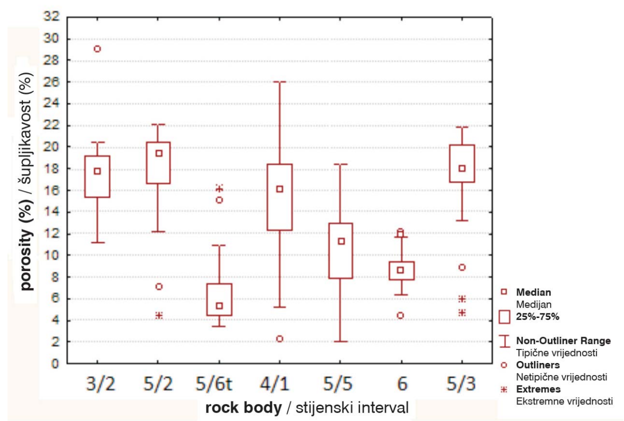

Fig. 3.8 Distribution of porosity of sands for each rock body
Sl. 3.8. Razdioba šupljikavosti pijesaka za svaku analiziranu skupinu uzoraka stijena

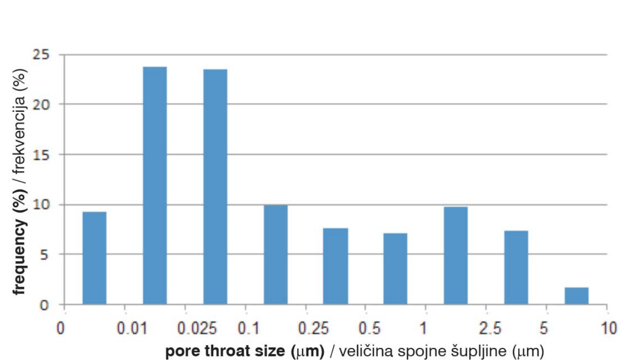

Fig. 3.6 Pore throat size distribution of siltstones
Sl. 3.6. Razdioba raspodjele dimenzija šupljina siltova

porosity and permeability. The other rock bodies are characterised by significant larger uncertainties, what is visible in large percentile interval around median values (Figures 3.8 and 3.10).

The pore throat size distribution of the sandstones has two modes (Figure 3.11). The distribution of two rock bodies look similar to this but the other two have only one mode (Figure 3.12).

Spearman correlation was made using the depth, porosity, permeability, frequency of pore throat size intervals, mean, standard deviation and mode of pore throat size. The following types of connection were observed (Table 3.1):

- positive connection between porosity, permeability, pore throat mean, standard deviation and mode;
- positive connection between these and large pore throat sizes;
- negative connection between these and small pore throat sizes;
- negative connection between large and small pore throat sizes;
- positive connection between neighbouring pore throat sizes;

The depth and the medium pore throats have no significant connections.

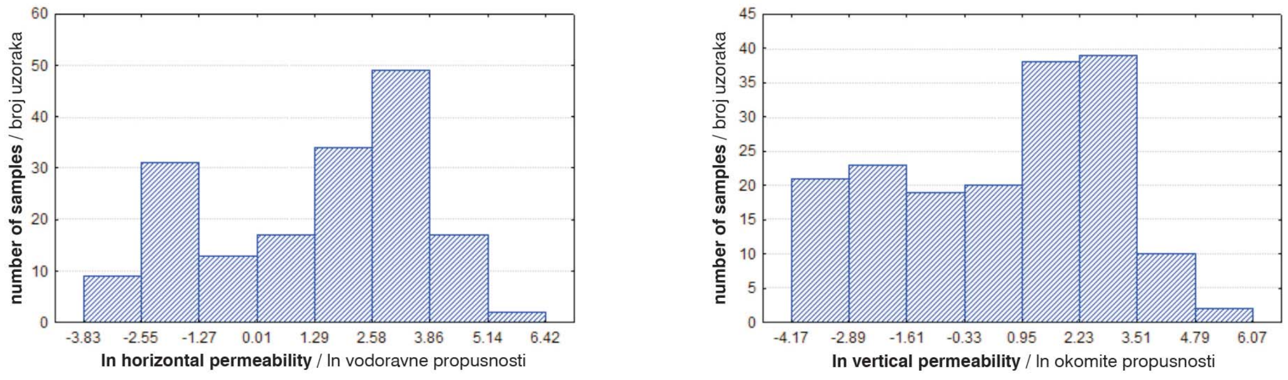

Fig. 3.9. Distribution of horizontal and vertical permeability of sands
Sl. 3.9. Razdioba vodoravne i okomite propusnosti pijesaka

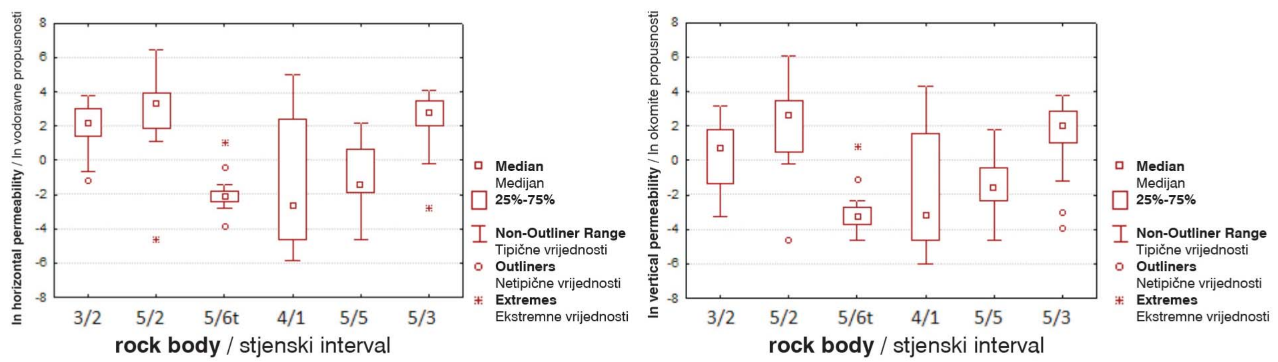

Fig. 3.10. Distribution of horizontal and vertical permeability of sands for each rock body.
Sl. 3.10. Razdioba vodoravne i okomite propusnosti pijesaka za svaku analiziranu skupinu uzoraka stijena

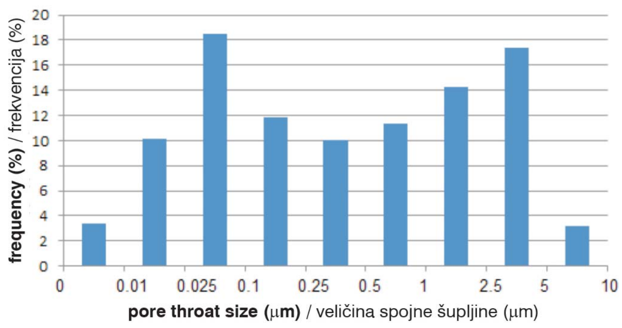

Fig. 3.11. Pore throat size distribution of sands
Sl. 3.11. Razdioba raspodjele veličine "spojnih" šupljina u pijescima

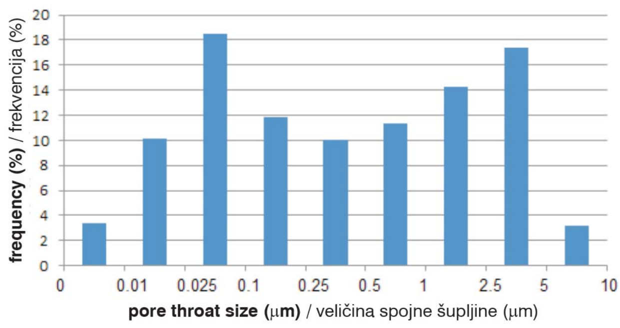

Fig. 3.12 Pore throat size distribution of sands for each rock body
Sl. 3.12. Razdioba raspodjele dimenzija ulaza šupljina za svaku stijenu

The same connections can be observed at factor analysis (Table 3.2). The first factor consists of the porosity, permeability, pore throat mean, standard deviation, mode, small and large pore throats. The second one contains the medium and small pore throats.

Table 3.1. Spearman correlation of depth, porosity, natural logarithm of horizontal and vertical permeability, pore throat size intervals, mean, standard deviation and mode of pore throats in case of sands. Shaded are significant connections.

	depth	porosity	ln hor. perm.	ln ver. perm.	p. th. 0-0.01 μm	p. th. 0.01-0.025 μm	p. th. 0.025-0.1 μm	p. th. 0.1-0.25 μm	p. th. 0.25-0.5 μm	p. th. 0.5-1 μm	p. th. 1-2.5 μm	p. th. 2.5-5 μm	p. th. 5-10 μm	pore throat mean	pore throat st. dev.	pore throat mode
depth	1	-0.25	-0.21	-0.16	0.15	0.19	0.24	0.11	0.1	0.03	-0.07	-0.13	0.08	-0.11	0.02	-0.16
porosity		1	0.81	0.79	-0.71	-0.82	-0.8	-0.25	0	0.36	0.68	0.8	0.71	0.81	0.76	0.77
ln hor. perm.			1	0.93	-0.7	-0.71	-0.71	-0.42	-0.14	0.21	0.6	0.8	0.73	0.8	0.78	0.75
ln ver. perm.				1	-0.62	-0.65	-0.66	-0.32	-0.08	0.24	0.61	0.73	0.69	0.72	0.73	0.69
p. th. 0-0.01 μm					1	0.74	0.65	0.2	0	-0.4	-0.7	-0.75	-0.58	-0.71	-0.64	-0.68
p. th. 0.01-0.025 μm						1	0.83	0.28	0.05	-0.36	-0.69	-0.84	-0.7	-0.85	-0.75	-0.79
p. th. 0.025-0.1 μm							1	0.37	0.02	-0.39	-0.67	-0.85	-0.76	-0.88	-0.8	-0.87
p. th. 0.1-0.25 μm								1	0.34	0.21	-0.29	-0.46	-0.4	-0.42	-0.38	-0.37
p. th. 0.25-0.5 μm									1	0.61	0.04	-0.19	-0.12	-0.16	-0.11	-0.12
p. th. 0.5-1 μm										1	0.38	0.18	0.22	0.26	0.24	0.3
p. th. 1-2.5 μm											1	0.64	0.66	0.65	0.65	0.64
p. th. 2.5-5 μm												1	0.82	0.95	0.89	0.89
p. th. 5-10 μm													1	0.9	0.97	0.84
pore throat mean														1	0.95	0.95
pore throat st. dev.															1	0.89
pore throat mode																1

Table 3.2. Factor analysis of sands. Shaded are factor determining variables. Legend: expl. var. Is abbr. for explained variance; prp. totl. Is abbr. for percentage of the total variance explained.

	factor 1	factor 2
depth	0.146	-0.033
porosity	-0.885	0.073
ln hor. perm.	-0.818	-0.248
ln ver. perm.	-0.778	-0.161
p. th. 0-0.01 μm	0.668	-0.567
p. th. 0.01-0.025 μm	0.796	-0.56
p. th. 0.025-0.1 μm	0.758	-0.129
p. th. 0.1-0.25 μm	0.385	0.424
p. th. 0.25-0.5 μm	0.216	0.558
p. th. 0.5-1 μm	-0.01	0.595
p. th. 1-2.5 μm	-0.69	-0.017
p. th. 2.5-5 μm	-0.861	-0.289
p. th. 5-10 μm	-0.73	-0.286
pore throat mean	-0.949	-0.222
pore throat st. dev.	-0.93	-0.179
pore throat mode	-0.876	-0.237
expl. var.	8.218	1.893
prp. totl.	0.514	0.118

The cluster analysis resulted in 4 clusters and two separated samples (Figure 3.13). The elements of A and B clusters are mixed, and they are located together in several boreholes and rock bodies. Both clusters have high porosity and permeability. C and D are represented in only one rock body each. C has medium porosity and permeability and D has the lowest (Figures 3.14 and 3.15).

A genetic model was built from the shape of the well logs for each rock body and borehole. The most frequent shapes were the bell, cylindrical, funnel and saw teeth. Since the analysed field consists of deep water fan-type rock bodies, the bell form was explained as sediments from the main turbidity channel, the cylindrical form as anastomosing channel, the funnel as lobe. The saw teeth-like log means the alternation of very fine grained turbidites and pelagic sediments.

The log shapes were analysed for each rock bodies. For example, on Figure 3.16 there is an anastomosing channel system and a lobe. The Table 3.3 summarizes the most characteristic facies for each rock body. The sedimentation was the most intensive in the middle part.

4. DISCUSSION

By comparing the different analyses, further information is obtained.

In case of siltstones the bimodal distribution of the pore throat sizes can be explained from the well logs, especially in thicker intervals, where is compensated the

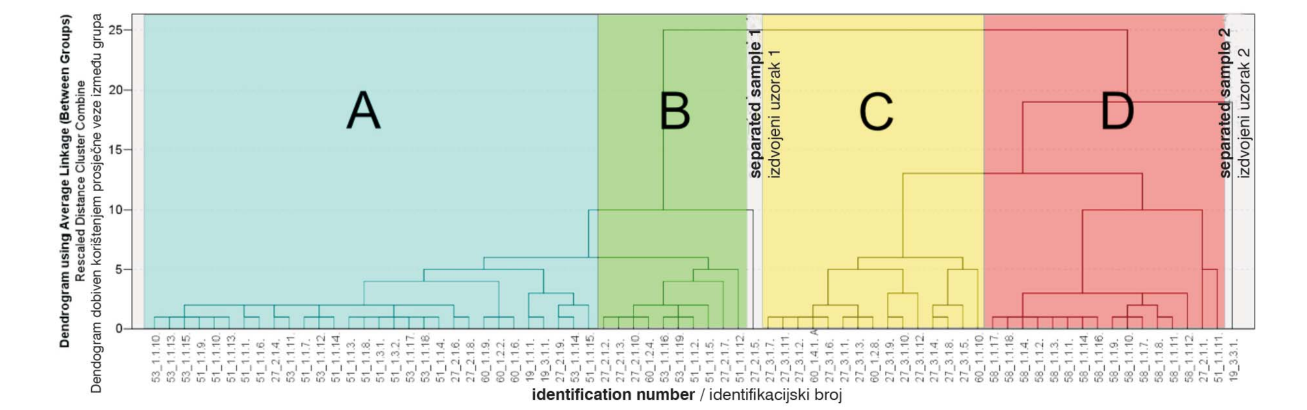

Fig. 3.13. Clusters of sand samples
Sl. 3.13. Klasteri uzoraka pijesaka

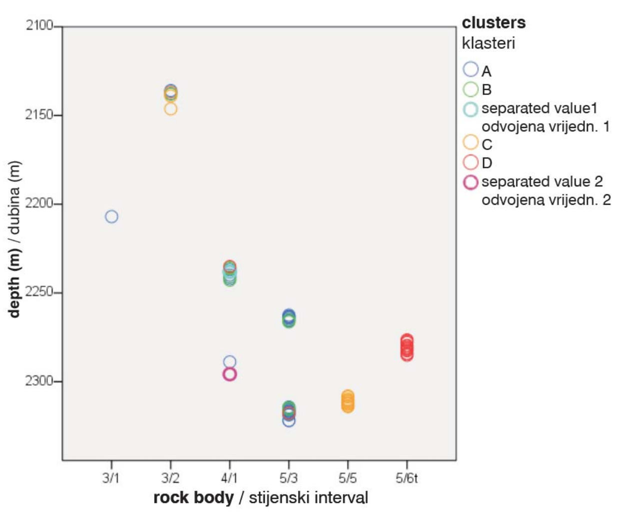

Fig. 3.14. Position of clusters in the rock column
Sl. 3.14. Položaj klastera obzirom na dubinu i uzorak

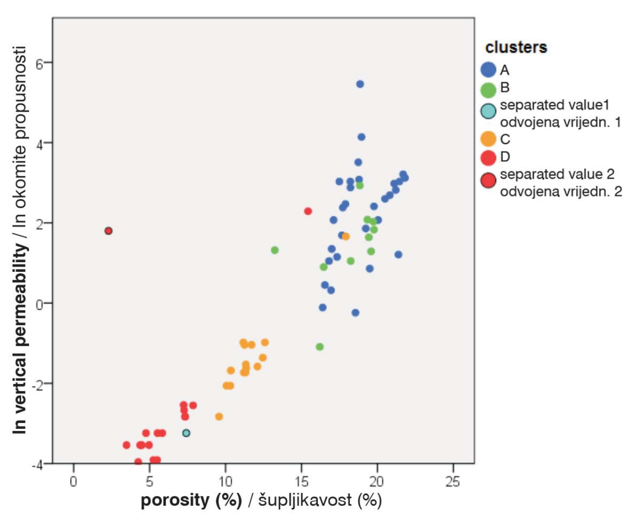

Fig. 3.15. Porosity and permeability of clusters
Sl. 3.15. Šupljikavost i propusnost pojedinačnih klastera

physical necessities for developed clear log curve. Of course, smaller pore throats mean to finer and larger pore throats coarser sediment (Figure 4.1).

In case of sandstones individual samples are bimodal, what is caused by the mixing of different grain sized sediment and intercalations (Photo 4.1).

Cluster A and B are very similar considering their porosity, permeability and position in the rock column. The only difference is in pore throat sizes, i.e. in cluster A larger pore throats are more frequent than in B (Figure 4.2). According to the logs, A has higher sand content than B, i.e. they are coarser grained sandstones (Figure 4.3).

Comparison of clusters and well log shapes was difficult due to fact that there are no core analyses from rock bodies with funnel- or saw teeth-shaped logs, so only channel environments are represented.

In the first factor there is a negative connection between the largest and the smallest pore throats (see Table 3.1).

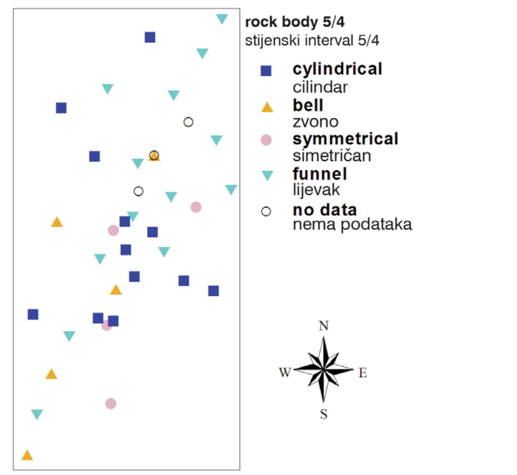

Fig. 3.16. Shapes of well logs in rock body 5/4
Sl. 3.16. Oblici karotažnih dijagrama u stijenskom intervalu 5/4

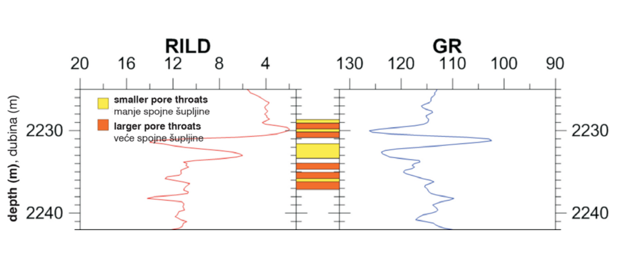

Fig. 4.1. Smaller and larger pore throats in rock body 3/2
Sl. 4.1. Manji i veći promjeri "spojnih" šupljina u stijenskom intervalu 3/2

Photo 4.1 Claystones laminas in sand in 5/3 rock body[1]
Foto 4.1. Lamine glinjaka u pješčenjaku iz stijenskog intervala 5/3[1]

Table 3.3. Dominating environments and mechanisms interpreted from electro-facies of rock bodies

rock body	Interpretation based on electro-facies
2/1	distal turbidites
2/2	distal turbidites
2/3	distal turbidites
3/1	channels and distal turbidites
3/2	anastomosing channels
3/3	lobe
3/4	channels
4/1	anastomosing channels
4/2	distal turbidites and lobe
5/1	anastomosing channels
5/2	anastomosing channels
5/3	lobe
5/4	channels and lobe
5/5	channels
5/6t	distal turbidites
5/6a	distal turbidites

Such connection can be observed in case of A, B and C clusters (Figure 4.4). Moreover, the second factor contains the smallest and medium pore throats, and negative connection between these two groups is recognised in case of cluster D (Figure 4.4), where the medium pore throats are the largest ones.

While analysing the porosity and permeability of sandstones, 3 rock bodies (3/2, 5/2 and 5/3) seemed to be very

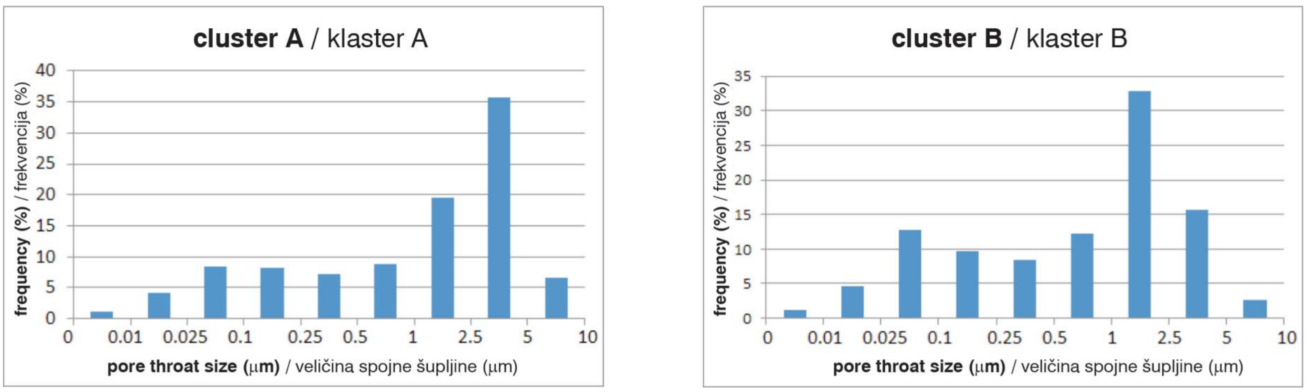

Fig. 4.2. Pore throat size distribution of cluster A and B
Sl. 4.2. Raspodjela veličina "spojnih" šupljina klastera A i B

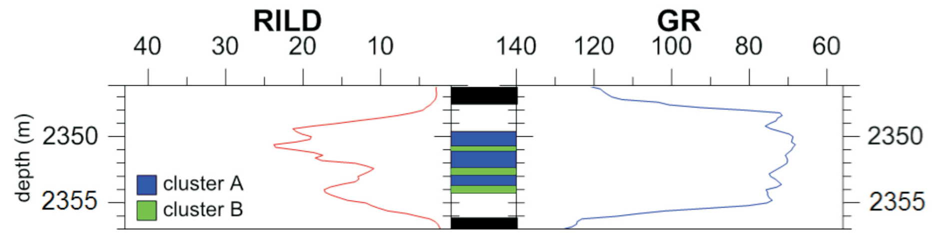

Fig. 4.3 Position of cluster A and B in the rock body 5/3
Sl. 4.3. Položaj klastera A i B u stijenskom intervalu 5/3

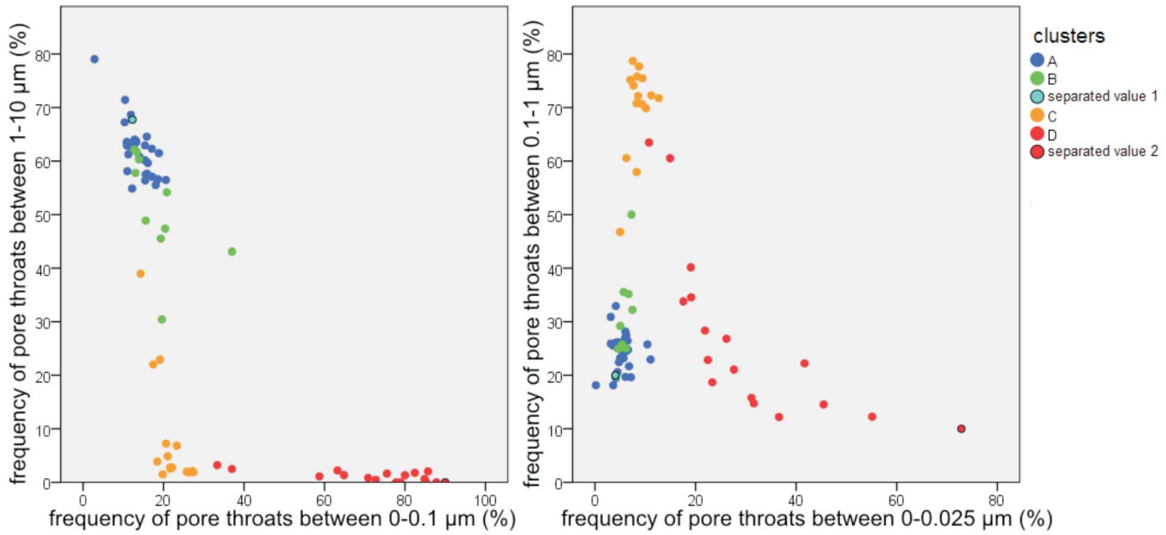

Fig. 4.4. Characteristic connections in case of factor 1 and factor 2
Sl. 4.4. Karakteristične veze u slučaju faktora 1 i 2

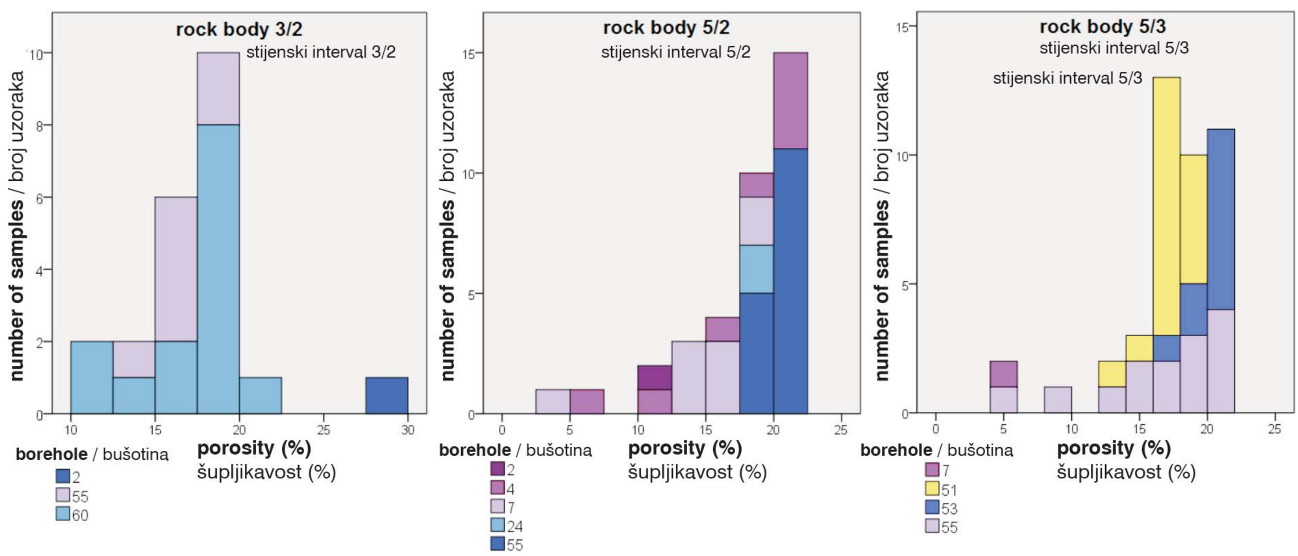

Fig. 4.5. Porosity of sandstones in 3/2, 5/2 and 5/3 rock bodies for each borehole. Colours mean log shapes: blue - cylindrical, purple - funnel, yellow - bell.
Sl. 4.5. Šupljikavost pješčenjaka u stijenskim intervalima 3/2, 5/2 i 5/3 po bušotinama. Boje označuju oblik: dijagrama: plava - cilindar, ljubičasta - lijevak, žuta - zvono.

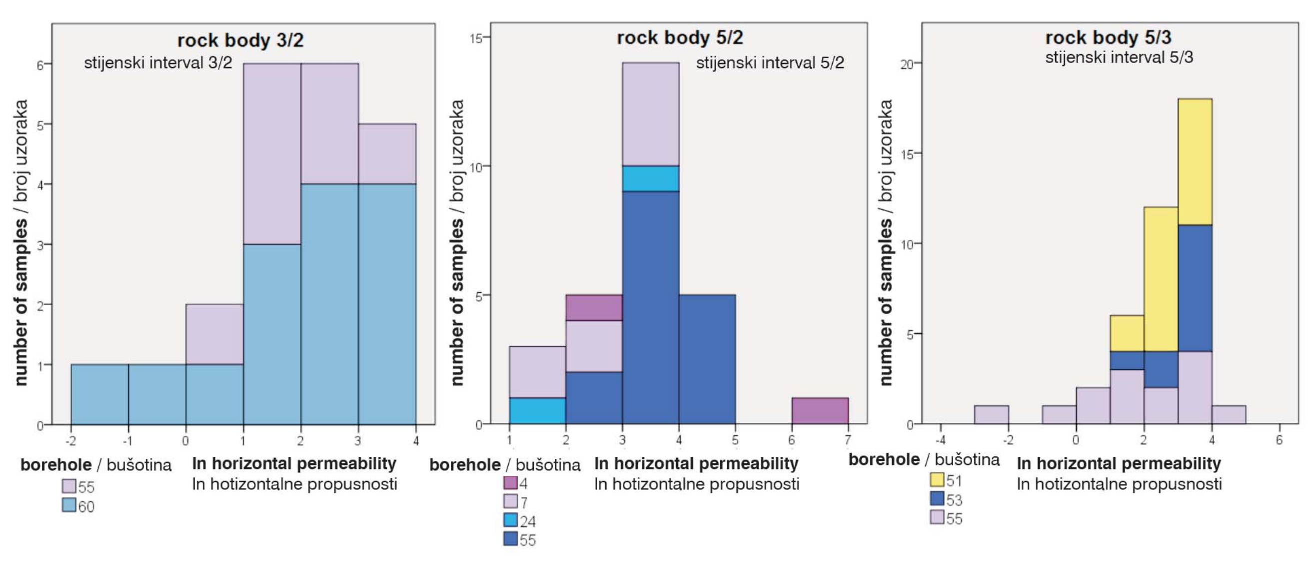

Fig. 4.6. Natural logarithm of horizontal permeability of sandstones in 3/2, 5/2 and 5/3 rock bodies for each borehole. Colours mean log shapes: blue - cylindrical, purple - funnel, yellow - bell.

Sl. 4.6. Prirodni logaritam vodoravne propusnosti pješčenjaka u stijenskim intervalima 3/2, 5/2 i 5/3 po pojedinačnim bušotinama. Boje označuju oblik dijagrama: plava - cilindar, ljubičasta - lijevak, žuta - zvono.

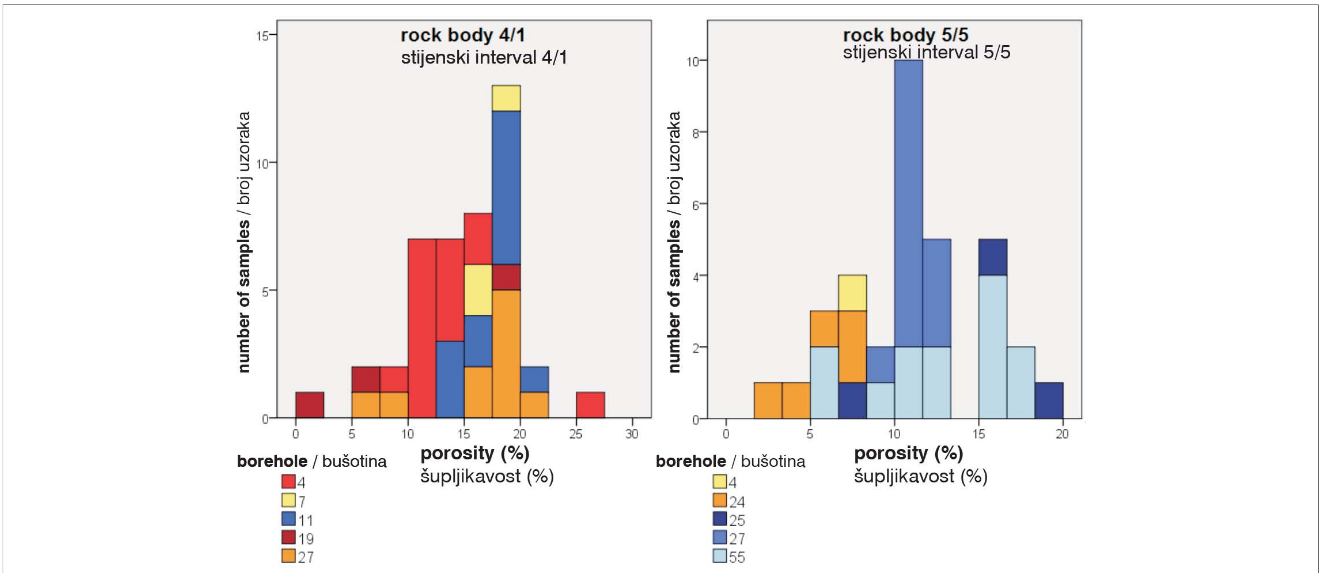

Fig. 4.7. Porosity of sandstones in 4/1 and 5/5 rock bodies for each borehole. Colours mean log shapes: blue - cylindrical, yellow and orange - bell, red - symmetrical.

Sl. 4.7. Šupljikavost pješčenjaka u stijenskim intervalima 4/1 i 5/5 po pojedinačnim bušotinama. Boje označuju oblik dijagrama: plava - cilindar, ljubičasta i narančasta - zvono, crvena - simetričan.

similar (see Figure 3.8 and 3.10). Considering their shapes in well logs, they are mainly cylindrical and funnel (Figure 4.5 and 4.6), and have permanently large sand content, and high porosity and permeability with small standard deviation.

Two other rock bodies are also similar; the most frequent log shape is the bell and cylindrical in these rock bodies (Figure 4.7 and 4.8). Bell shape on well log means decreasing grain size so the interval boxes are wide (see Figure 3.8 and 3.10).

5. CONCLUSIONS

1. There are only a few claystones and siltstones samples because the rock bodies mostly consist of sandstones. More data is necessary to interpret those rock types.
2. The porosity and permeability of analysed sandstones have bimodal character. The bimodality is caused by grouping rock bodies with similar electro-facies, i.e. deposited into different paleoenvironments onto basin bottom by turbiditic currents.

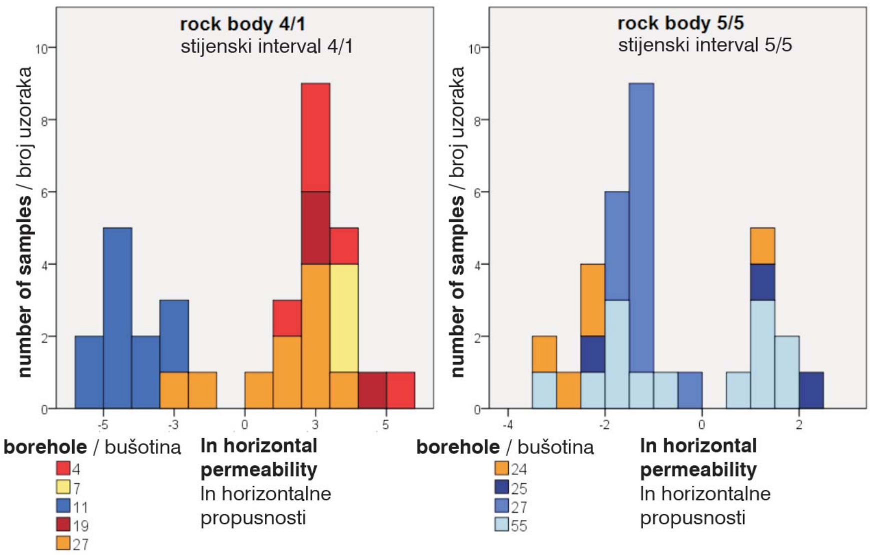

Fig. 4.8. Natural logarithm of horizontal permeability of sandstones in 4/1 and 5/5 rock bodies for each borehole. Colours mean log shapes: blue - cylindrical, yellow and orange - bell, red - symmetrical.

Sl. 4.8. Prirodni logaritam vodoravne propusnosti pješčenjaka u stijenskim intervalima 4/1 i 5/5 po pojedinačnim bušotinama. Boje označuju oblik dijagrama: plava - cilindar, ljubičasta i narančasta- zvono, crvena - simetričan.

3. The rock physical properties do not depend on the individual log shapes but can be concluded from the most typical log shapes (i.e. electro-facies) that characterised rock body.
4. The rock bodies dominantly with bell and saw teeth shaped well logs have smaller porosity and permeability than the mainly cylindrical and funnel shaped rock bodies. It is result of lower transporting energy and consequently finer carried detritus eventually deposited into distal lobes or anastomosing channels.
5. The small changes on well logs usually mean changes in pore throat size distribution but not in general lithology.
6. There are 4 clusters of sandstones but they are valid only in case of channels because the other depositional areas were not enough numerous sampled and existing electro-facies could not be used as "typical" for statistical and depositional analyses.

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6. REFERENCES

1. GEIGER, J., KORMOS, L. & POLLNER, L. (2004): Az Endrőd-II mező Pl1-2, Pl1-3, Pl1-4 és Pl1-5 kőzettestében levő telepek rezervoár geológiai reambulációja [*Reservoir geological reambulation of Pl1-2, Pl1-3, Pl1-4 and Pl1-5 rock bodies in Endrőd-II Field*] - MOL Open-File Report, Szeged.
2. JUHÁSZ, GY. (1998): A magyarországi neogén mélymedencék pannóniai képződményeinek litosztratigráfiája. [*Lithostratigraphy of the Pannonian formations of Neogene basins in Hungary*] - In: Bérczi, I. & Jámbor, Á. (edit.) (1998): Magyarország geológiai képződményeinek rétegtana. [*Stratigraphy of geological formations in Hungary*] - MOL Rt. and MÁFI, Budapest, 517.
3. JUHÁSZ, GY., POGÁCSÁS, GY., MAGYAR I. & VAKARCS G. (2006): Integrált-sztratigráfiai és fejlődéstörténeti vizsgálatok az Alföld pannóniai s.l. rétegsorában [*Integrated stratigraphy and sedimentary evolution of the Late Neogene sediments of the Hungarian Plain, Pannonian Basin*] - Bulletin of Hungarian Geological Society (Földtani Közlöny) 136, 1, 51-86.
4. MAGYAR, I. (2010): A Pannon-medence ősföldrajza és környezeti viszonyai a késő miocénben. [*Paleogeography and environmental situation of the Pannonian Basin in the late Miocene*] - GeoLitera Publisher, Szeged, 140.
5. MÜLLER, P. (1998): A pannóniai képződmények rétegtana. [*Stratigraphy of Pannonian formations*] - In: Bérczi, I. & Jámbor, Á. (edit.) (1998): Magyarország geológiai képződményeinek rétegtana. [*Stratigraphy of geological formations in Hungary*] - MOL Rt. and MÁFI, Budapest, 517.
6. UHRIN, A. (2011): A Pannon-tó só- és vízháztartásának számítása. [*Calculation of salinity and water balance in the Lake Pannon*] - Bulletin of Hungarian Geological Society (Földtani Közlöny) 141, 4, 383-392.
7. THAMÓNÉ BOZSÓ, E., JUHÁSZ, GY. & Ó. KOVÁCS, L. (2006): Az alföldi pannóniai s. l. képződmények ásványi összetétele I. A pannóniai s. l. homokkövek jellemzői és eredete. [*Mineralogical composition of Pannonian s.l. formations in Hungarian Plain I. Characterisation and origin of Pannonian s.l. sandstones.*] - Bulletin of Hungarian Geological Society (Földtani Közlöny) 136, 2, 407-430.

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