SPATIAL DISTRIBUTION OF PETROPHYSICAL PROPERTIES ON THE BASIS OF LABORATORY RESULTS, WELL LOGGING AND SEISMIC DATA

Jadwiga A. Jarzyna[1], Paulina I. Krakowska[1], Edyta Puskarczyk[1], Kamila Wawrzyniak-Guz[1], Jakub Bielecki[2], Wojciech M. Kwiatek[3], Michał Gruszczyk[4]

1. Introduction

The Miocene formation in the Polish Carpathian Foredeep is still the subject of prospecting works due to many gas fields discovered there in the long period from the 19th century up to now [1]. The Sarmatian sandy-shaly thin-bedded formation in gas fields from this region was selected for tests of proposed methodology as rocks being potential hydrocarbon and water reservoirs.

Mutual relationships between rock properties determined using methods based on different physical phenomena and measured in various scale (micro- in laboratory, mezzo- and macro- *in situ*) were the basis for petrophysical three-dimensional analysis. Rock models – important for proper petrophysical parameters determination – were the result of modeling of mineral composition, volume and type of media filling pore space (combining data from various sources and of different scale). Input parameters for simulations were obtained from laboratory measurements on rock plugs and comprehensive interpretation of well logging. The X-ray computed microtomography (μCT) is a new non-destructive technique for visualization of three dimensional rock structures basing on variations in X-rays absorption. Prototype μCT equipment (IFJ PAN) provided structural data of fine spatial resolution (about 4 μm). Basing on μCT data simulations of the fluid dynamics in the void space of porous media was carried out. The Lattice Boltzmann method was used in order to predict the hydraulic permeability of the media. Mercury porosimetry provided us with data on the volume of porous space and its geometry (distribution of predominating pore diameters and specific surface of porous space). Nuclear Magnetic Resonance laboratory spectroscopy delivered information on total porosity with division into clay bound water, capillary water and movable water or hydrocarbons. Mineralogical investigations (roentgen analysis) and results of well logging interpretation were the basis for construction of the mineral composition of rock formation. The spatial distribution of petrophysical properties was realised on the basis of combination of seismic attributes calculated in the vicinity of wells with attributes calculated in the same way as seismic ones for the acoustic full wavetrains. Reservoir and elastic properties

[1]AGH University of Science and Technology, Faculty of Geology Geophysics and Environment Protection, Department of Geophysics, al. Mickiewicza 30, 30-059 Krakow, Poland, [2]National Centre for Nuclear Research, Swierk, ul. A. Soltana 7, 05-400 Otwock, Poland; [3]H. Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN), ul. Radzikowskiego 152, 31-342 Krakow, Poland, [4]GEOFIZYKA Krakow, ul. Lukasiewicza 3, 31-429 Krakow, Poland

e-mail addresses: jarzyna@uci.agh.edu.pl; paulina.krakowska@gmail.com; puskarczyk@geol.agh.edu.pl; wawrzyniak@geol.agh.edu.pl; jakub.bielecki@ncbj.gov.pl; wojciech.kwiatek@ifj.edu.pl; michal.gruszczyk@gk.com.pl

were included in properties distribution calculations to gain information on the fluid flow ability of the rock.

2. Geological setting

3D seismic survey T-C-Z in the middle part of the Polish Carpathian Foredeep was selected as the study subject [1, 2]. Four wells (C2, C3, C5k and M1) are sited in the western part of the project. The goal of the seismic industry standard processing and interpretation was recognition of the Miocene siliciclastic formation as a potential gas reservoir. In the presented study the Sarmatian sandy-shaly thin-bedded formation in the depth between 900 and 3500 m was the subject of special core and well logging analyses and advanced processing of seismic data.

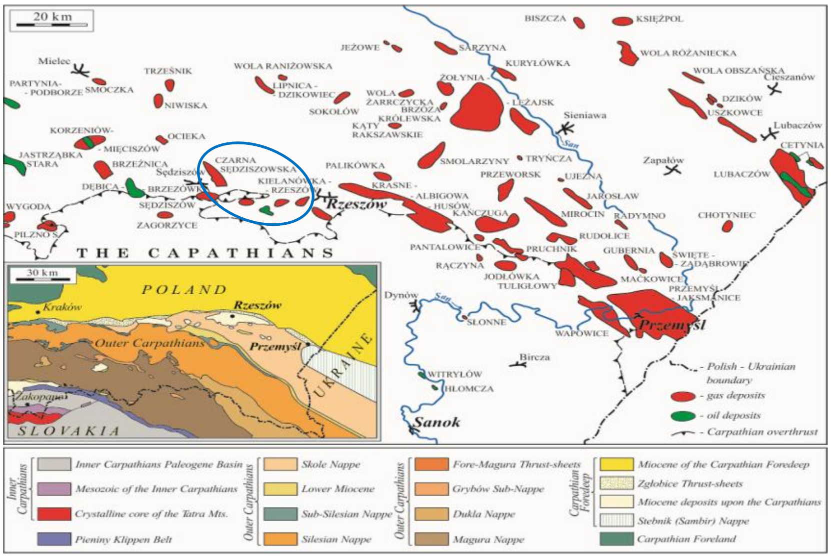


Figure 1. Location of the study (blue ellipse) area on the background of the Polish Carpathian Foredeep (after [1, 2])

3. Data set

Industry seismic data and well logging results were of good quality to be a proper basis for non-standard analyses. Seismic acquisition was done by GEOFIZYKA Krakow in 2006 and 2007 in the Vibroseis system for POGC Co., Warsaw, Poland [3]. Attributes were calculated both on the basis of the pre-stack (AVO) seismic data and on the final data after migration.

Well log data comprised the following results: natural gamma ray intensity, GR, neutron porosity, NPHI, acoustic transit interval time, DT, bulk density, RHOB, photoelectric absorption index, Pe, resistivity logs – ILD, ILM and HRAI, and caliper, CAL. Also, results of the comprehensive interpretation were included: total porosity, PHI, volumes of sandstone, VSAND, volume of shale, VSH, water saturation, SW and permeability K. Acoustic full waveforms were available in all wells.

A few dozen lab results of porosity and permeability were at our disposal, but in the C2, C3 and C5k wells only single data were dispersed in the Sarmatian depth section. In Well M1 25 samples were gathered in the Miocene interval (1065.5-1699.65 m). Standard lab measurements comprised: total porosity, specific density, bulk density, permeability, resistivity, radioactivity – volume of K, U, Th. Laboratory NMR results and mercury porosimetry outcomes and micro-CT images and other μ-CT digital data were also available. Roentgen mineralogical analyses were done only on samples from two wells: C5k and M1, but data from two wells S34 and S33k, sited closely to south-western part of the study area, were additionally included into analyses.

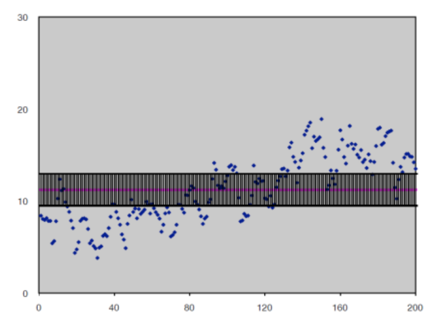
3. Relationships between rock properties

Mutual relationships between petrophysical properties from various sources are the basis for rock model construction [4]. Different values of the parameters obtained from different methods provide additional information due to the physical basis of selected measurements. Results obtained for rock samples in Well C5k are presented in Table I. There are distinct differences observed in porosity values. The large differences visible in permeability are explained on the basis of methods of calculation of the parameter.

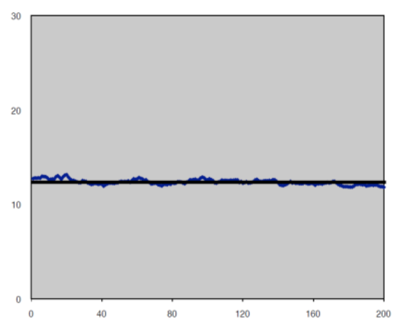
Table I. Results of laboratory measurements and well logging interpretation

	VSAND [%]	VSH [%]	PHI [%]	Por_{NMR} [%]	FFI [%]	$Por_{\mu CT}$ [%]	Por_{Hg} [%]	Ra [mm]	Ts [m^2/g]	K [mD]	$K_{\mu CT}$ [mD]
9023	35	61	3.78	18.06	10.11	14.76	8.85	0.1799	1.967	0.064	24
9025	33	63	4.23	12.82	6.73	11.27	0.03	0.1129	0.12	0.095	3.5
9026	38	56	6.10	13.09	7.03	1.76	4.55	0.1355	1.343	0.705	3.5
9087	56	34	10.4	19.48	16.41	20.33	8.61	0.2410	1.429	7.02	175
9088	45	50	5.86	13.10	4.90	12.41	4.23	0.0246	6.891	0.52	8.5
9090	50	40	10.1	19.26	14.77	20.79	6.01	0.0751	3.203	5.39	52

VSAND, VSH – volume of sandstone and shale, respectively; PHI – total porosity, Por NMR – total porosity from NMR, FFI – movable water from NMR, Por μ-CT-porosity from microtomography, Por Hg – porosity from mercury porosimetry, Ra – radius of pores, Ts – specific surface, K- permeability from well logging interpretation, K μ-CT – permeability from microtomography



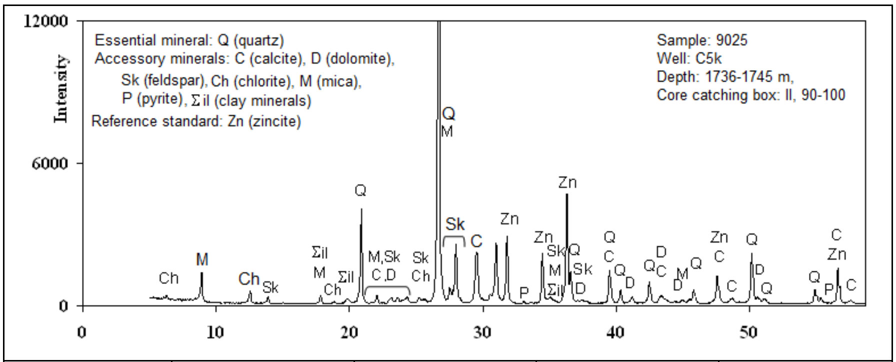
Sample – 9025
Por μ-CT (average) = 11.27%,
Stand. Dev. = 3.62%
VSAND =32% , VSH=64%



Sample – 9088
Por μ-CT (average) = 12.41%,
Stand. Dev. = 0.28%
VSAND=45% , VSH=40%

Figure 2. Porosity from μ-CT method; C5k well; left sample is heterogeneous, right one is homogeneous; vertical axis- porosity, horizontal axis – scan number

Two examples of porosity results from the microtomography method illustrate the influence of heterogeneity of the rock (Fig. 2). Total porosity, Por μ-CT, is similar in both samples. The increased volume of clay in Sample 9025 justifies changes in results.



Quartz	Calcite	Feldspar	Dolomite	Total Clay
49 %	17 %	9 %	11 %	14 %

Figure 3. Results of the roentgen analysis of Sample 9025, Well C5k

Results of the roentgen analysis were used for determination of element (mineral) content in the rock sample (Fig. 3). They were compared with data obtained from well logging interpretation. Dispersion of data observed in Figure 4 reflects the difficulties in depth matching of well logging and laboratory data and the influence of vertical resolution of well logs.

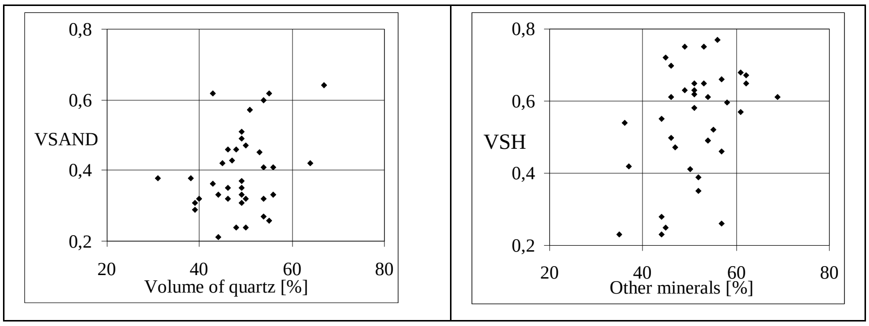


Figure 4. Comparison of mineralogical analysis results made on the basis of roentgen measurements and well logging interpretation

Histograms of sandstone volume in sandy-shaly rock formation and the volume of quartz from roentgen analysis are compared to illustrate unavoidable differences resulting from point rock samples in laboratory analyses and averaged values of parameters determined from well logging interpretation due to the defined radius of investigation and vertical resolution of log devices.

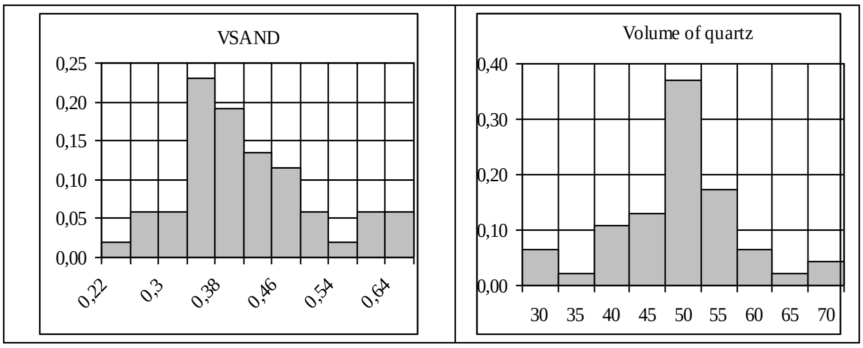


Figure 5. Histograms of volume of sandstone, VSAND and volume of quartz

3. Acoustic full waveforms and seismic attributes

Wide list of seismic attributes were calculated from seismic traces located in the vicinity of wells. Among other attributes, results of spectral decomposition for specific frequencies (sd10Hz, sd25Hz, sd40Hz, sd60Hz, and avgFr_sd60Hz) and integral (calculated from impedance section) were used [5]. Instantaneous attributes such as amplitude envelope, AE_P, instantaneous phase and instantaneous frequency, were calculated on the basis of acoustic full waveforms for the P-, S- and Stoneley-wave packets using seismic software. Selected plots of attributes vs. depth are presented to reveal mutual relationships between petrophysical properties of gas sandy-shaly reservoira (Figs. 6 and 7).

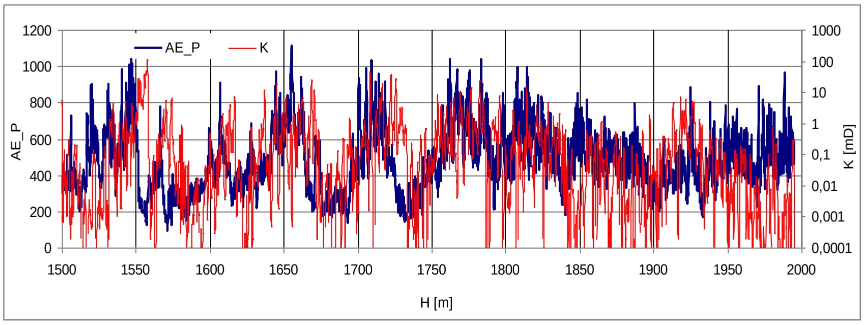


Fig. 6. Attribute of amplitude envelope of P-wave from acoustic full waveform, AE_P, and permeability from well logging, K, vs. depth; Well C2

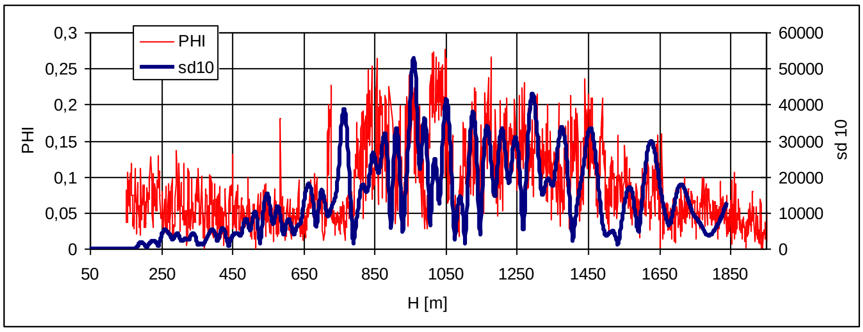


Fig. 7. Seismic attribute, sd10Hz, and total porosity, PHI, vs. depth; Well M1

4. Conclusions

A model of the reservoir rock should be constructed on the basis of all available data. Wide-ranging analysis of laboratory results is the source of information which cannot be obtained in other way. Improvement of mutual relationships between petrophysical parameters from measurements made on different scales (micro- in the laboratory, mezzo- in well logging *in situ*, and macro- in seismic *in situ*) is necessary to obtain the basis for rock model construction. Combining laboratory results and well logging results with seismic data is a way of upscaling data and of making the spatial distribution of petrophysical properties. Elastic properties as a basis of seismic method and acoustic method are the platform of data junction from various methods.

Acknowledgments

This research was done in the frame of the scientific project No. NN 307 294439 (2010-2013) financed by Ministry of Science and Higher Education, Poland. The authors thank the Polish Oil and Gas Company Co., Warsaw, Poland, for the data. Standard laboratory measurements were done in the Oil and Gas Institute, Krakow. Porosimetry results were obtained from AutoPore equipment at AGH UST. Microtomography results were obtained at the H. Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences, Krakow. Seismic survey and interpretation and measurements and interpretation of well logging were done by GEOFIZYKA Krakow.

References

[1] Karnkowski P.: Oil and Gas Deposits in Poland. Geosynoptics Society “GEOS”, Cracow, Poland, 1999, pp.197

[2] Oszczypko N., 2006 - Development of the Polish sector of the Carpathian Foredeep. Prz. Geol., 54: 396–403 (in Polish, abstract in English)

[3] Syrek-Moryc, C.: 3D seismic survey Trzciana-Cierpisz-Zaczernie as a cause of renaissance of exploratory works in Miocene deposits and its mesopalaeozoic substratum in the middle part of the Carpathian Foredeep. Proceedings of the Geopetrol 2008 Conference, Zakopane, September, 2008, pp. 87-95 (in Polish, abstract in English)

[4] Jarzyna J.A., Krakowska P.I., Puskarczyk E., Wawrzyniak-Guz K., Semyrka R., Bielecki J., Kwiatek W.M., 2012 - Reservoir rocks – digital models and petrophysical analysis of clastic rocks. Proceedings of the Geopetrol 2012 Conference, Zakopane, 2012 (in Polish, abstract in English)

[5] Wawrzyniak-Guz K., Gruszczyk M., 2012 - Attributes of acoustic full waveforms and seismic attributes for determination of petrophysical properties of sandy-shaly formations. Proceedings of the Geopetrol 2012 Conference, Zakopane, 2012 (in Polish, abstract in English)