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Physical and chemical properties of flysch sediments in the Ždánice oil deposit (Outer Western Carpathians, Czech Republic)

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Abstract: A petrophysical investigation was carried out on the hydrocarbon deposit, which occurs in East Moravia near the village Ždánice at the depth of 1 km. The objective of investigations was to find out whether there is a significant difference in the radioactivity of the rock and in other studied parameters between rocks above the deposit and rocks from a distance of 2–3 km. Shallow boreholes were drilled above the deposit and in its vicinity to get rock samples (claystones and siltstones — CLS and sandstones — SNS). Petrophysical parameters — densities, porosity, magnetic susceptibility, radioactivity, and contents of carbon and sulphur were determined and statistically evaluated. Statistical tests of difference between petrophysical parameters of rocks over the oil deposit and outside the oil deposit show a low indicative power of separate petrophysical parameters, while their comprehensive application may enhance their petroleum indicative value.

Key words: radioactivity, densities, magnetic susceptibility, oil deposit, prospective indicators, flysh sedimentary rocks, contents of sulphur.

Introduction

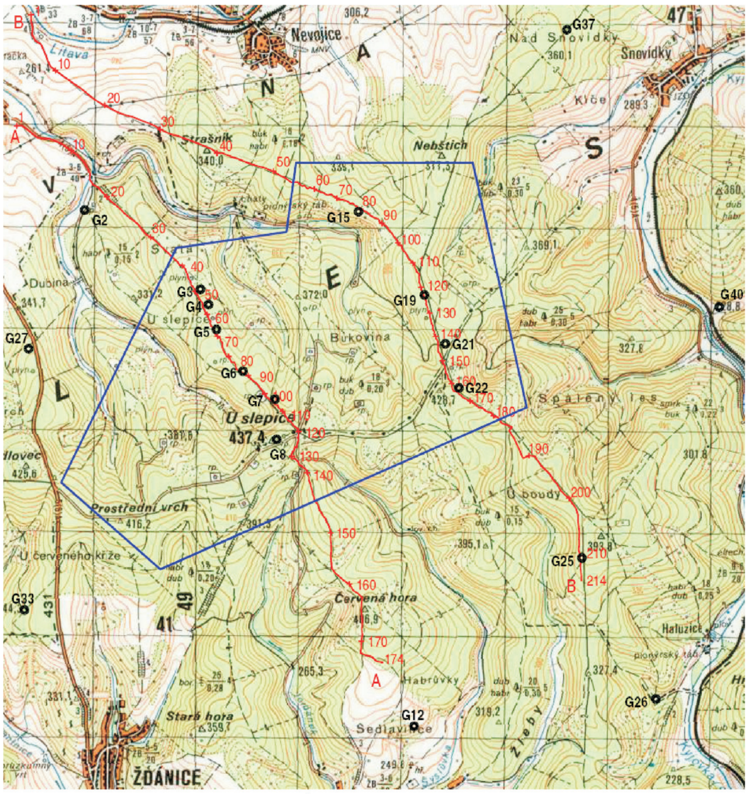
In East Moravia between the villages Nevojice and Ždánice a hydrocarbon deposit occurs at the depth of approximately 1000 m (Krejčí 1993). The deposit is located in the surface part of Upper Proterozoic granitoids, with overlying flysch sediments and overlying Miocene sediments buried by Carpathian flysch thrust sheets. Above the deposit and in its vicinity, shallow boreholes (5 of them 20 m deep and 13 ones 12 m deep) were drilled to search for indicators of a buried hydrocarbon deposit in near-surface portions of the flysch sediments (Fig. 1). A total of 444 borehole samples were collected for determination of the contents of natural radioactive elements and specific activity of ^{137}Cs and 300 samples for determination of densities and porosity and magnetic susceptibility. Two hundred selected samples were taken for determination of mineral and organic carbon and content of sulphur.

The objective of the investigations was to find out whether there is a significant difference in the studied parameters between the boreholes above the deposit and the boreholes situated at the distance of 2–3 km. Research conducted in other countries found various changes in sediments over hydrocarbon deposits, including radioactivity, for example Shideler & Hinze (1971) or Saunders et al. (1993), which prompted the assumption that similar petrophysical changes in overlying beds might be present at the Ždánice deposit, though the deposit proper occurs at a depth of approximately 1 km under the surface.

Geology of the deposit and its vicinity

The Ždánice oil-gas bearing deposit can be found on the NW border of the pre-Devonian elevation in the Ždánický les Highlands. The reservoir rocks of natural hydrocarbons are tectonically deformed and weathered granitoids (granodiorites, diorites, rarely granites) of Brunovistulicum and Lower Miocene sediments (sandstones and conglomerates) of the Carpathian Foredeep. The seal of the deposit was formed during Late Miocene by the tectonically emplaced Ždánice thrust sheet, which attains the thickness of 750 to 870 m over the hydrocarbon field (Krejčí 1993). From the orographic viewpoint the area of interest is part of the Ždánický les (Forest) unit whose highest landmark, elevation 438 m "U slepice", is situated in the middle of the area.

The Ždánice Nappe, which is the subject of our study, belongs to the Outer Flysch Belt of the Western Carpathians. During the orogenetic movements after the Lower Miocene the nappe shifted far to the south-eastern margin of the European Platform. Its rock structure is made up of Paleogene



G 33 Borehole No. 33 A 30 Geophysical profile A Oil deposite

Fig. 1. Location of boreholes in the area between Nevojice and Ždánice.

to Lower Miocene sediments of the Ždánice Unit and Quaternary cover. The Ždánice Unit contains the Němčice, Menilite and Ždánice-Hustopeče Formations.

The Němčice Formation (Paleocene to Lower Oligocene) is composed of prevalent green-grey, brown-grey and grey, and scarce red claystones to clays, alternating in irregular interbeds and schliers, with thin intercalation of sandstones, and sporadic occurrences of conglomerates.

The Menilite Formation (Oligocene) is made up of dark brown bituminous shales with cherts, overlying brown Dynow Marls and Šitbořice Member with characteristic rhythmically alternating green-grey and grey claystones with fine-grained sandstones.

The Ždánice-Hustopeče Formation (Upper Oligocene to Aquitanian) is the most extended strata within the study area. It is characterized by alternating intercalations, layers and bodies of light grey, as a rule little consolidated sandstones, siltstones and grey lime claystones. There are also scarce beds of conglomerates. A strong facial variability is typical of the strata.

The study area is part of the Ždánice synclinorium where fold structural elements strike in the south-eastern–south-western direction. Dipping beds, only observed in the Ždánice-Hustopeče Formation, are prevalently medium. The Menilite and Němčice Formations crop out in the core of the anticline in the east, and the Menilite Formation in the south-west of the area, presumably in the overthrust line. The sediments of the Ždánice Unit were folded during neo-Alpine orogeny. According to the study of magnetic anisotropy (Hrouda & Stráník 1985) the deposits of the Ždánice Unit underwent at least two foldings: in the Late Oligocene and after the Early Miocene. During the post-Early Miocene orogeny the sedimentary fill of the Ždánice basin was folded and detached from the home area and thrust in the form of a shear nappe over the Lower Miocene cover of the Ždánice elevation crystalline unit. The fold structures are disturbed with south-western–south-eastern transverse faults. Natural water springs, in places with structural foamstones affiliated with faults, testify to their recent activity.

Measuring methods and evaluation

Mineralogical density (Dm), which is an important material parameter, was measured together with **porosity** (Por) giving the volume of pore space and **bulk density** (Do) by the ‘triple weighting’ method. Samples were dried up at a temperature of 100 ºC up to constant mass, weighted and then in vacuum saturated with kerosene, which is a suitable liquid as it does not penetrate the crystalline structure of clayey minerals and easily fills all open pores. The fully saturated samples were weighted again in kerosene and in air. Standard deviation of one determination is $\pm 0.001\ g \cdot cm^{-3}$ for Dm, $\pm 0.003\ g \cdot cm^{-3}$ for Do, and ±0.02 % for porosity.

Magnetic susceptibility is a dimensionless parameter expressed in SI units. Although it is a tensor, for observation of material changes its mean value (SUSC) is used. Measurements were made on the kappabridge KLY-4 with sensitivity of 10^{-8} SI in the laboratory of company AGICO in Brno. As a rule, the rock is composed of diamagnetic minerals as quartz, pure felspars, calcite, and paramagnetic minerals such as felspars with admixtures (SUSC in the order of 10^{-6} to 10^{-5}), mica, chlorides (SUSC in the order of 10^{-4} to 10^{-3}), amphiboles, pyroxenes and ilmenite (SUSC in the order of 10^{-3}). Magnetic susceptibility is significantly affected by ferrimagnetic minerals, mainly magnetite and maghemite (SUSC in the order of 10^{-1} to SI units) and monoclinic pyrrhotine (SUSC in the order of 10^{-1}), in sediments also greigite. The antiferromagnetic minerals hematite, hexagonal pyrrhotine, etc. are major carriers of remanent magnetization (NMR). However, their SUSC does not exceed the value of 10^{-2}.

Contents of **natural radioactive elements** Th, U and K in the measured samples were determined by gamma spectrometry in the laboratory of Exploranium CZ, Ltd. Along with natural radioactive elements, **specific activities of ^{137}Cs** were automatically determined from the measured spectra. The samples crushed to grains under 3 mm were closed in plastic cases, and when equilibrium between radium and radon was gained, they were placed in the shielded NaI(Tl) detector 4″ in diameter and 4″ in height, with energy resolution of 7.9 % (662 keV). Spectra measured with a multichannel spectrometer PCAP (Nucleus USA) were evaluated by comparison with spectra of the IAEA standards from Vienna and IIZ standards from Prague. The measuring time was 20 minutes, sample mass ranged around 400 g. As U content evaluated on the basis of low-power gamma radiation of ^{234}Th and ^{235}U isotope is not very accurate, the content of ^{226}Ra was determined and recalculated to the content of Ura. If radioactive equilibrium is retained in the decay chain, then the values of U and Ura should be equal. However, differences frequently occur in Quaternary sediments and altered rocks. Standard deviation of one determination is ±0.3 ppm for Th, ±0.5 ppm for U, ±0.1 ppm for Ura, ±0.04 % for K, and ±4 $Bq \cdot kg^{-1}$ for ^{137}Cs.

Contents of C and S were measured in the Testing Laboratory of the Czech Geological Survey, branch Brno, on the apparatus METALYT CS 100/1000S (ELTRA, Germany). The procedure consists of determination of CO_2 generated in combustion at 1250 °C (total C, TC), and determination of mineral C (TIC) by sample decomposition by acid. The content of organic carbon (TOC) is given by the difference TC-TIC or is found by direct analysis of the decarbonated sample. The content of S is measured analogically to TC according to SO_2 generated in combustion at 1250 °C.

A theoretical substantiation of observed differences in contents of radioactive elements in sediments above the hydrocarbon deposit and outside it was published by Saunders et al. (1993). They assume that by the action of organic acids and CO_2, clay and other minerals are decomposed, and consequently U and K are released and removed. As a result, sediments affected by hydrocarbons are poorer in these radioactive elements than sediments not affected. It is also presumed that Th remains immobile. The following **derived radioactive parameters** were identified as suitable indicators of radioelement changes:

Kd = [Ka – (Kmo/Thmo)·Tha]/Ka
Ud = [Ua – (Umo/Thmo)·Tha]/Ua
Drad = Ud – Kd

Ka, Ua, Tha are contents of radioactive elements in individual samples of the investigated sedimentary unit with hydrocarbons occurrence (or altered by their products), Kmo, Umo and Thmo are mean contents of these elements in the same unit outside the deposit accompanying alterations. The authors are of the opinion that negative values of Kd and Ud and positive values of Drad indicate hydrocarbons. Their findings, however, relate to arid climates, and the theoretical model may not be generally valid and the distribution of radioactive elements can be more complicated (see Gnojek 1976; Borovec 1985; Fiala 1989; etc.).

Statistical data processing

Methodology

The measured and derived values of studied variables representing a random selection were, according to the geological character of the samples, grouped into two working sets: **Claystones and siltstones (CLS)** and **Sandstones (SNS)**.

Both these lithological types differ in a number of physical and chemical properties, and if they were evaluated together, the results might not be objective.

Both sets were statistically processed with the objective of finding out whether the values of the studied variables measured above the deposit (samples designated by code A) and outside the deposit (samples designated by code O) come from one or two sets, or whether they can be used to separate the deposit from its surroundings or not. As some tests of good fit are based on the assumption of normal distribution, normality of distribution of the values of individual variables was tested at first. For this purpose the Kolmogorov-Smirnov normality test was applied based on the maximal difference between selective cummulative distribution (its values are given by relative frequency in the sampling), and assumed cummulative distribution. As a variant the Shapiro-Wilks normality test W was applied. It was preferred to other tests for its high efficiency (StatSoft, Inc. 1999). Probability p-p graphs were constructed for visual control of data distribution normality.

The mean values of sets were compared by means of the commonly used t-test for independent groups of data (normal distribution of values and only slightly different variation coefficients are required). In case of other than normal distribution of values non-parametric tests were applied — the Kolmogorov-Smirnov test for comparison of means in two independent selections expressing agreement in the form of distribution curve and the Mann-Whitney U test which can also be used for work with sets of a different extent of observation (Koshin et al. 1992), which is this case. The level of significance α in all statistical evaluations was set at 0.05 (i.e. 95 %).

Evaluation

Claystones and siltstones (CLS)

The numbers of observations are not equal in all studied variables within individual sets. However, the ratio of samples collected above the deposit and outside it is approximately constant — 3:1. The Kolmogorov-Smirnov and Shapiro-Wilks W tests showed that the condition of normality is satisfied by a large number of variables (see Table 1), mainly in the Kolmogorov-Smirnov test.

In the case of equal sets the below given results of t-test can be considered reliable. Roughly a half of the variables, however, exhibit normal distribution values in one subset only (Figs. 2, 3).

According to the results of good fit tests the mean values of sets from above the deposit and outside it do not exhibit substantial statistic differences. According to the t-test variables K and Drad are an exception, in the Kolmogorov-Smirnov test (see Table 2) and the Mann-Whitney test variables Th, K, and ^{137}Cs. These variables could be statistically used as indicators of the deposit. In the case of ^{137}Cs we must not forget that its distribution was affected by the

Table 1: Variables in subsets of claystones (CLS) with normal asymptotic data distribution.

Test	Code	Variables
Kolgomorov-Smirnov	O	Do, **Por**, SUSC, **TIC**, TOC, **Th**, U, Ura, **K**, ^{137}Cs, **Ud**, **Kd**, **Drad**, Ura/U
	A	Dm, **Por**, **TIC**, **Th**, **K**, **Ud**, **Kd**, **Drad**
Shapiro-Wilks W test	O	Do, SUSC, **TIC**, **K**, **Ud**, Kd, Drad
	A	Dm, **TIC**, **K**, **Ud**

Notes: Marked values in the list of variables satisfy the distribution normality condition in both sets (O and A). Sets O relate to the area outside the deposit, sets A to the area above the deposit. (Highlighted variables with statistically significantly different mean values.)

Chernobyl accident. Nevertheless, it is remarkable that its specific activities in the two areas significantly differ.

Even though the mean values of the sets of values from above the deposit and outside it are statistically different, it is obvious that in practice differentiation of the manifestation of the deposit from its geological surroundings is not easy. Bar charts constructed for any of the suitable variables (e.g. Th in Fig. 4) show that the sets nearly overlap in their range of values. On the other hand, it is highly probable that in the Ždánice deposit the contents of Th and also K are lower above the deposit.

As for sulphur, the two subsets substantially differ. The distribution of values, however, is distinctly asymmetric (L-distribution) in both of them, but extreme values above the deposit are much higher (up to 0.53 %), while in the vicinity of the deposit they do not go beyond the limit of sensitivity of the analytical method 0.20 % (Fig. 5).

There are almost no low contents of potassium under 1.65 % in the vicinity of the deposit, while above the deposit there are approximately 30 % of such values (Fig. 6).

Drad values over 0.330 are rare outside the deposit (Fig. 7).

The susceptibility of claystones above the deposit also attains relatively high values over 200×10^{-6} (SI), reflecting the presence of a ferromagnetic mineral (see below).

Sandstones (SNS)

The numbers of observations in the subsets of sandstones are again very different, while the number of samples from above the deposit is roughly two to three times larger than the number of samples from the vicinity of the deposit. Similarly to the previous set, the normality condition is satisfied by more variables in the Kolmogorov-Smirnov test than in the Shapiro-Wilks W test. They are listed in Table 3.

All three tests of good fit give roughly the same results. According to the t-test, the mean values of variables Dm, S, K and ^{137}Cs are statistically substantially different. The normality condition is not satisfied by any variable in either subset. Strictly in terms of statistics, results of the t-test are referential only. According to the Kolmogorov-Smirnov test (Table 4), Dm, U and ^{137}Cs display statistically significantly different mean values, in the Mann-Whitney test differences were found in Dm, S, U, K and ^{137}Cs. In terms of statistics, these first four variables could be used to identify the deposit. As in the previous set CLS, their application is made difficult by an analogical range of U, K and ^{137}Cs values in both subsets.

Sulphur exhibits values analogical to the CLS set. Above the deposit, increased values up to 0.37 % occur, while no contents over 0.02 % were observed outside the deposit (Fig. 5).

Although data distribution in K is nearly identical in both statistical populations, outside the deposit right-hand asymmetry is apparent and indicates decrease in potassium over the deposit (Fig. 6).

In the subset of mineralogical density (Dm) values over 2.735 $g\cdot cm^{-3}$ are rare and it is obvious that the mineral-

Table 2: Results of good agreement test for claystones (CLS).

Kolmogorov-Smirnov test of agreement of mean values
Groups according to variable Code
Highlighted-tests are significant at level p < 0.5

Variable	MN Difference	MP Difference	Level p	Mean A	Mean O	SD A	SD O	No A	No O
Do ($g\cdot cm^{-3}$)	–0.071	0.210	p > 0.10	2.160	2.134	0.174	0.135	113	36
Dm ($g\cdot cm^{-3}$)	–0.095	0.247	p < 0.10	2.730	2.720	0.019	0.046	113	36
Por (%)	–0.182	0.088	p > 0.10	20.853	21.509	6.409	5.252	113	36
SUSC (10^{-6} SI)	–0.166	0.142	p > 0.10	160.243	130.424	234.048	19.020	113	36
TIC (%)	–0.124	0.313	p > 0.10	3.693	3.444	0.721	0.574	62	20
TOC (%)	–0.160	0.016	p > 0.10	0.186	0.224	0.222	0.211	62	20
S (%)	–0.124	0.177	p > 0.10	0.078	0.052	0.128	0.057	62	20
Th (ppm)	**–0.234**	**0.031**	**p < 0.05**	**9.293**	**9.668**	**1.382**	**1.348**	**164**	**50**
U (ppm)	–0.137	0.030	p > 0.10	3.196	3.512	1.410	1.361	164	50
Ura (ppm)	–0.185	0.165	p > 0.10	3.126	3.260	0.637	0.960	164	50
K (%)	**–0.296**	**0.008**	**p < 0.005**	**1.838**	**1.962**	**0.245**	**0.206**	**164**	**50**
^{137}Cs ($Bq\cdot kg^{-1}$)	**–0.220**	**0.000**	**p < 0.05**	**2.207**	**3.342**	**1.551**	**1.887**	**164**	**50**
Ud	–0.159	0.213	p < 0.10	–0.027	–0.064	0.189	0.290	164	50
Kd	–0.183	0.062	p > 0.10	–0.037	–0.001	0.169	0.115	164	50
Drad	–0.026	0.188	p > 0.10	0.009	–0.064	0.218	0.260	164	50
Ura/U	–0.066	0.191	p > 0.10	1.245	1.012	1.342	0.383	164	50

Legend: **MN** = maximal negative, **MP** = maximal positive, **SD** = standard deviation, **No** = number of valid observations.

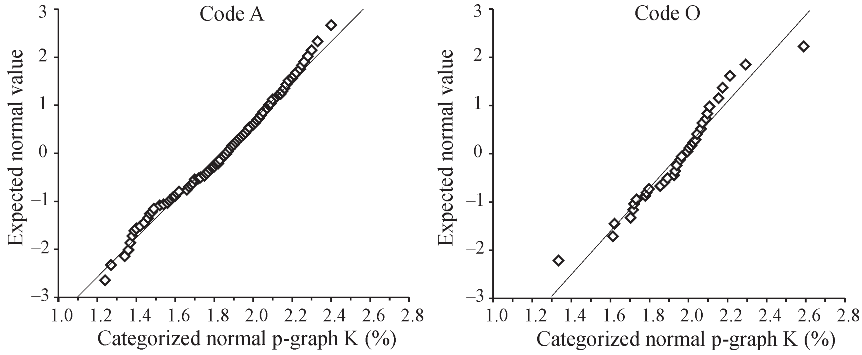


Fig. 2. Example of a variable with normal distribution of values in subsets.

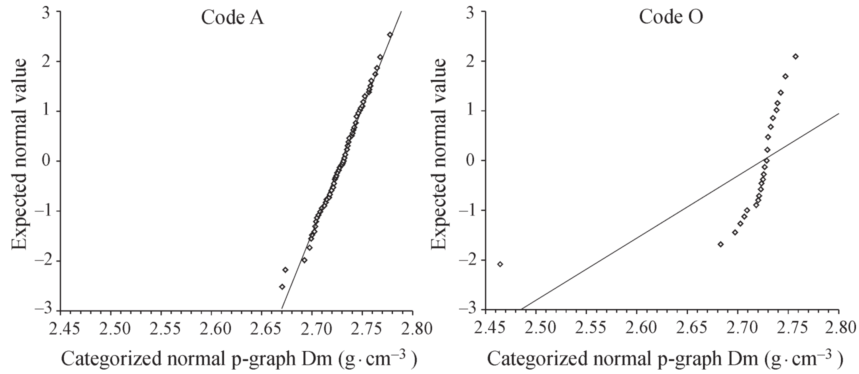


Fig. 3. Example of a variable with different distribution of values in subsets.

sets (CLS, SNS) into two main sets. However, they contain a mixture of samples of both types.

In conclusion it can be said that differentiation of the area above the oil deposit from its vicinity is not easy or even impossible in a majority of the evaluated parameters. To a certain extent this can be due to the different numbers of observations in sets and their small number (samples from outside the deposit), which significantly affects the shape of the distribution curve (Žáček & Křivánek 1991). Another cause may be the sampling itself (large distance between sampled objects, approx. 1 km from the deposit) and in the studied variables. The content of sulphur seems to be a good identification parameter, which in both sets (CLS and SNS) exhibits higher values in samples collected above the deposit only (Fig. 5). In claystones and siltstones these samples represent 18 % and in sandstones nearly 27 % of values. Regardless of statistics, content of sulphur can be regarded as a good indicator of a potential oil deposit. Analogically, magnetic susceptibility maxima and minima of K content in claystones and siltstones or maxima of mineralogical density or the ratio Ura/U in sandstones can be indicators of oil. However, these indication samples represent only a low percentage of the whole set, and therefore should be combined in the search for oil.

ogical density of sandstones above this value is a significant indicator of the area above the deposit (Fig. 8).

As far as uranium itself is concerned, the bar chart (Fig. 9) shows an obvious left-hand asymmetry of the distribution of values measured above the deposit. This fact also indicates that the difference in the content of uranium above the deposit and in the vicinity of the Ždánice deposit is much more significant in sandstones than in claystones, which is presumably due to the better migration abilities of uranium in porous environments.

An attempt was made to identify the defined bodies (above the deposit, outside the deposit) by means of hierarchical clustering. The Ward method was applied where the block distance (Manhattan) was used as the rate of distance. This attempt resulted in separation of the two initial data

Table 3: Variables in subsets of sandstones (SNS) with normal asymptotic data distribution.

Test	Code	Variables
Kolgomorov-Smirnov	O	Do, Por, **SUSC**, **Th**, U, **K**, ^{137}Cs, **Ud**, Kd, **Drad**, Ura/U
	A	Dm, **SUSC**, **Th**, **K**, **Ud**, **Drad**
Shapiro-Wilks W test	O	**Th**, K, ^{137}Cs, **Ud**, Drad
	A	**Th**, **Ud**

Notes: see Table 1.

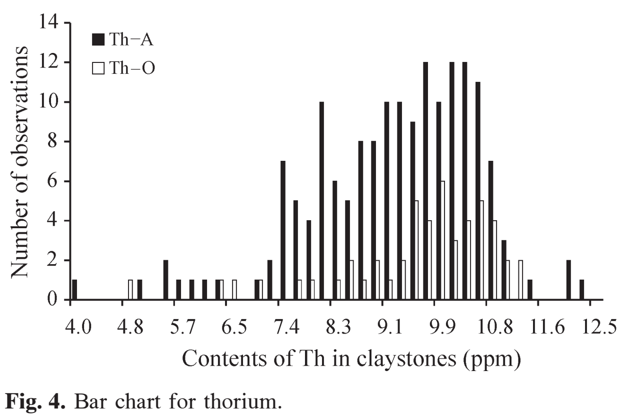


Fig. 4. Bar chart for thorium.

Discussion

Statistical evaluation proved that the sets of measured values exhibit normal distribution in rare cases only. In smaller portions of sets data distribution is right-hand asymmetric. For this reason the Kolmogorov-Smirnov and the Shapiro-Wilks W tests were chosen for testing of agreement. According to these tests the distribution of radioactive elements can be evaluated as follows.

Contents of thorium in claystones outside the deposit are substantially higher than above the deposit, contents of Th in sandstones are equal in both areas. It is apparent that claystones above the deposit are presumably slightly

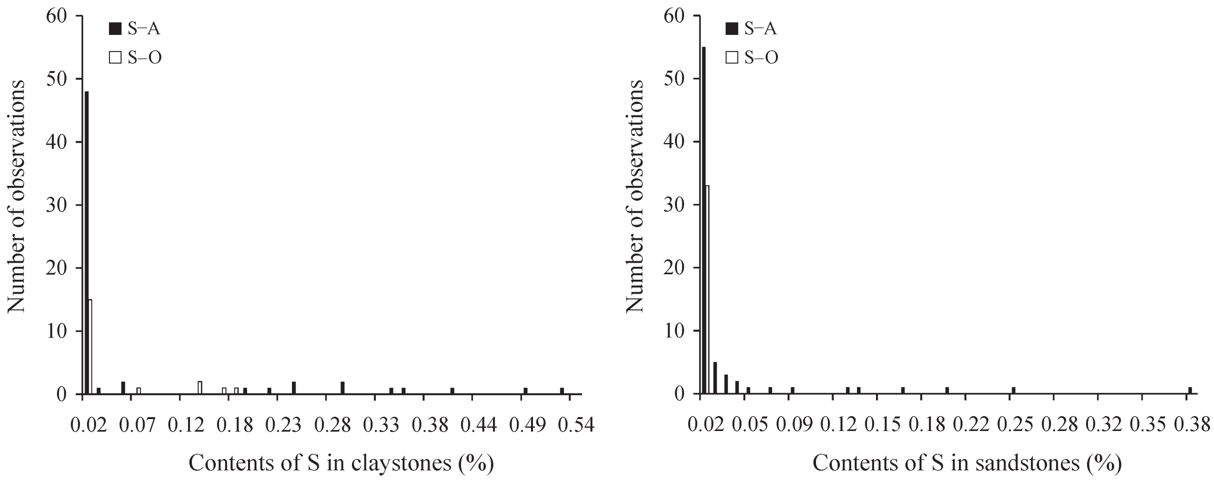


Fig. 5. Bar charts for sulphur.

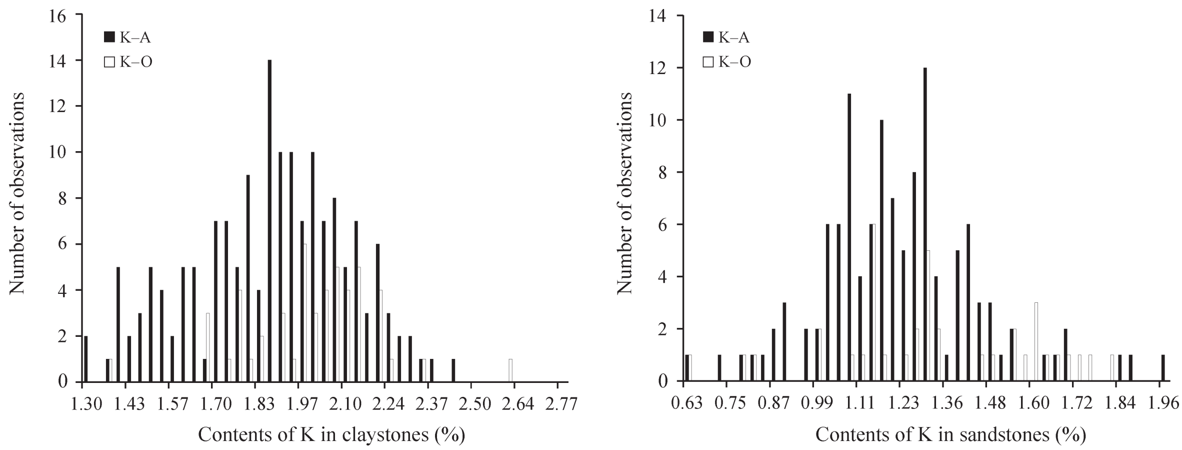


Fig. 6. Bar charts for potassium.

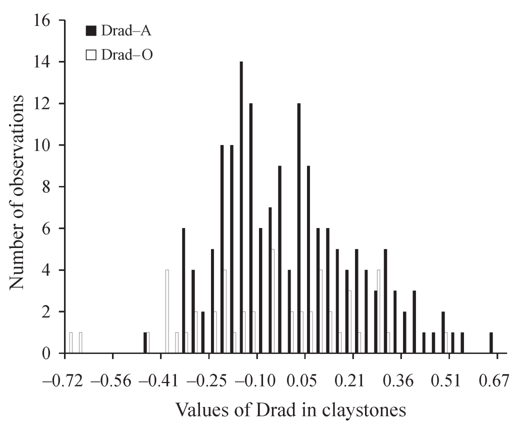


Fig. 7. Bar chart for Drad.

depleted in Th, and it can be assumed that its small, but noticeable migration occurred. This is in contrast with the assumption of Saunders et al. (1993) of geochemical stability of Th.

The Kolmogorov-Smirnov test shows the same distribution of uranium in claystones, but the bar chart (Fig. 9) indicates a certain depletion in the deposit area as compared with the area outside the deposit. The difference is significant in sandstones poorer in uranium above the deposit. Contrary to thorium, uranium exhibits undoubtable mobility in sandstones. In radium (Ura) no difference was found. There is no significant disequilibrium between uranium and radium (slightly more radium then uranium) in the area above the deposit.

The distribution of potassium in compared areas is different in claystones (Fig. 6), in sandstones the difference is statistically negligible. In contrast to thorium the content of potassium is substantially higher outside the deposit, and it seems that the sediments from the deposit area are depleted in potassium.

To summarize, the area above the deposit is generally poorer in potassium and uranium, which confirms the findings of Saunders et al. (1993). Moreover, it is likely that the content of thorium is also not stable. Despite the large distance from the deposit, existence of phenomena causing changes in contents of radioactive elements was confirmed.

No significant differences were found in coefficients of Ud, Kd and Drad. Nevertheless, it can be said that the very low values of Kd, in claystones under –0.28 and in sand-

Table 4: Results of good agreement test for sandstones (SNS).

	Kolmogorov-Smirnov test of agreement of mean values Groups according to variable Code Highlighted-tests are significant at level p <0.5								
Variable	**MN Difference**	**MP Difference**	**Level p**	**Mean A**	**Mean O**	**SD A**	**SD O**	**No A**	**No O**
Do (g·cm^{-3})	–0.027	0.175	p > 0.10	2.471	2.422	0.162	0.207	112	35
Dm (g·cm^{-3})	**–0.029**	**0.316**	**p < 0.01**	**2.724**	**2.707**	**0.017**	**0.039**	**112**	**35**
Por (%)	–0.175	0.096	p > 0.10	9.301	10.541	5.737	7.280	112	35
SUSC (10^{-6} SI)	–0.072	0.247	p < 0.10	78.098	70.847	23.587	16.215	111	35
TIC (%)	–0.110	0.114	p > 0.10	4.389	4.319	0.845	0.876	75	33
TOC (%)	–0.051	0.035	p > 0.10	0.104	0.125	0.139	0.190	75	33
S (%)	0.000	0.267	p < 0.10	0.042	0.020	0.061	0.000	75	33
Th (ppm)	–0.070	0.075	p > 0.10	5.058	5.050	1.093	1.011	121	38
U (ppm)	**–0.259**	**0.030**	**p < 0.05**	**2.208**	**2.532**	**1.023**	**0.948**	**121**	**38**
Ura (ppm)	–0.187	0.083	p > 0.10	2.202	2.426	0.507	1.088	121	38
K (%)	–0.253	0.046	p < 0.10	1.236	1.328	0.222	0.279	121	38
^{137}Cs (Bq·kg^{-1})	**–0.280**	**0.000**	**p < 0.025**	**1.931**	**3.108**	**1.456**	**1.568**	**121**	**38**
Ud	–0.167	0.070	p > 0.10	–0.128	–0.103	0.273	0.335	123	38
Kd	–0.201	0.070	p > 0.10	–0.081	–0.049	0.271	0.356	123	38
Drad	–0.125	0.240	p < 0.10	–0.048	–0.054	0.300	0.500	123	38
Ura/U	–0.086	0.212	p > 0.10	1.182	1.002	0.558	0.308	123	38

Legend: see Table 2.

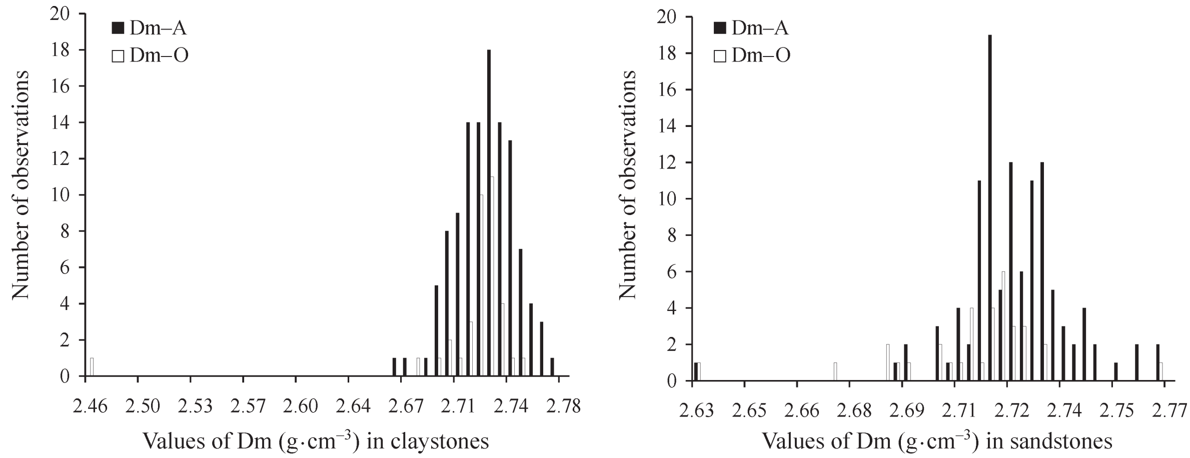


Fig. 8. Bar charts for mineralogical density.

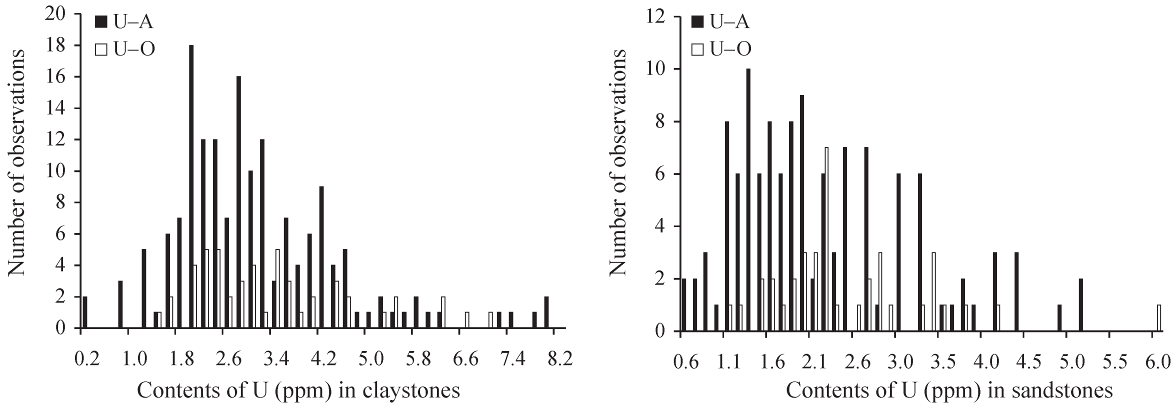


Fig. 9. Bar charts for uranium.

stones under –0.3, mainly occur above the deposit (Fig. 10). Drad values in claystones (bar chart in Fig. 7) exhibit a slight increase over the deposit (see Table 2) in accordance with the assumption of Saunders et al. (1993).

The contents of sulphur in claystones and sandstones can be regarded as suitable prospective indicators of an oil deposits. Extreme values, substantially different from medians, increase in sandstones (25 % of samples above the

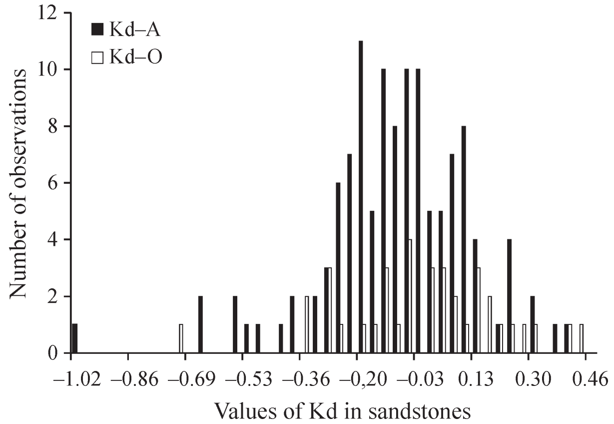


Fig. 10. Bar chart for Kd.

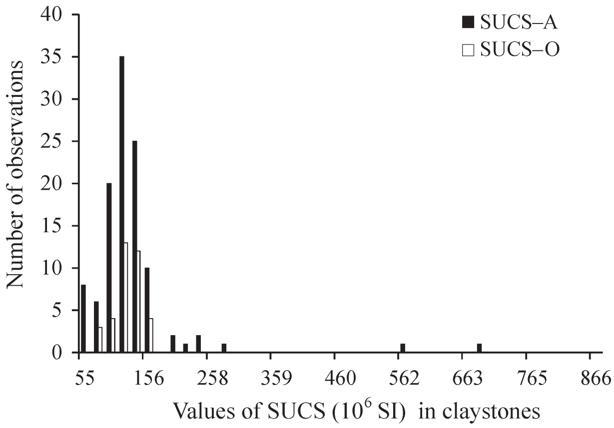


Fig. 11. Bar chart for magnetic susceptibility.

deposit) up to 0.25 %, while outside the deposit they are below the limit of detection. In claystones 18 % of samples are above 0.20 %, while outside the deposit there is no such sample (Fig. 5).

Our results — higher contents of sulphur in rocks above the Ždánice oil deposit support the theory of Saunders et al. (1993) who suppose the reaction of ascendent hydrocarbonates with sulphates in subterranean waters producing hydrogen sulphide and carbon dioxide. This causes secondary carbonate mineralization. Sulphate reducing bacteria can also take part in these processes. Ascendant diffusion and penetration of small bubbles of light hydrocarbonates with proportions of colloidal particles through the system of microcracks and intergranual spaces filled with subterranean water enable distribution of sulphur ionts above the oil deposit. High concentrations of carbon dioxide generate carbonic acid reacting with clay minerals starting secondary carbonate mineralization and silicification in intergranual spaces. This mineralization could have caused the higher mineralogical densities found above the Ždánice oil deposit.

Magnetic susceptibility can also be an indicator. Its values go up significantly in some beds of claystones (Fig. 11). A ferrimagnetic mineral is the carrier, not magnetite. On the curves of SUSC dependence on temperature in the range of 0 down to –192 °C no Verwey transition (corresponding with multidomain magnetite) can be observed.

Conclusions

Evaluation of the results of petrophysical investigations on the hydrocarbon deposit near the village of Ždánice based on statistical tests of differences between petrophysical parameters of rocks over the oil deposit and outside it shows a low indicative power of separate petrophysical parameters, although their comprehensive application may enhance their petroleum indicative value (Tables 2 and 4).

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