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Use of Probabilistic and Statistical Methods for the Analysis of Deep Deposits of the Upper Pechora Deep

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Использование вероятностно-статистических методов для анализа глубокопогруженных отложений Верхнепечорской впадины

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Upper Pechora depression, deep sediments, probabilistic-statistical methods, oil, gas, concentration, organic carbon, tectonic characteristics, subsidence rate, occurrence depth, sapropelic organic matter, mixed organic matter, humic organic matter, statistical differences.

The Upper Pechora depression is one of the northern depressions of the Cis-Ural foredeep. The structure of the upper horizons of the sedimentary cover is well studied, but deep deposits remain uneven and insufficiently studied. Therefore, it is of interest to model the formation of oil and gas potential at great depths using various methods. In this article, this problem was solved by using probabilistic-statistical methods. The concentrations of organic carbon (C_{org}), the rate of subsidence, and the depth of the layers were used for the analysis. As a result, fundamental differences were established in the tectonic conditions for the formation of the C_{org} concentration for the studied types of organic matter. Comparison of the average C_{org} values showed the presence of statistical differences between the types of organic matter in the deep sediments of the Upper Pechora depression. Correlation analysis determined that both positive and negative relationships with varying degrees of closeness were observed between the studied indicators. With the help of linear discriminant analysis, it was determined that sapropelic and humic organic substances were separated quite clearly, and mixed organic matter practically did not stand out according to the given characteristics. The performed stepwise regression analysis for each of the considered parameters, carried out for these types of organic matter separately, confirmed the cardinal difference in the processes of accumulation of organic matter of the sapropel and humus types. Thus, the performed statistical analysis showed the regulatory role of tectonic factors in the formation of organic matter concentrations.

Ключевые слова:
Верхнепечорская впадина, глубокопогруженные отложения, вероятностно-статистические методы, нефть, газ, концентрация, органический углерод, тектонические характеристики, скорость погружения, глубина залегания, сапропелевое органическое вещество, смешанное органическое вещество, гумусовое органическое вещество, статистические различия.

Верхнепечорская впадина – одна из северных впадин Предуральского краевого прогиба. Строение верхних горизонтов осадочного чехла хорошо изучено, но глубокопогруженные отложения остаются неравномерно и недостаточно исследованными. Поэтому представляет интерес моделирование формирования нефтегазоносности больших глубин с помощью различных методов. В данной статье эта задача решена путем применения вероятностно-статистических методов. Для анализа использованы концентрации органического углерода ($C_{орг}$), скорости погружения и глубины залегания слоев. В результате установлены принципиальные различия в тектонических условиях формирования концентрации $C_{орг}$ для изучаемых типов органического вещества. Сравнение средних значений $C_{орг}$ показало наличие статистических различий между типами органических веществ в глубокопогруженных отложениях Верхнепечорской впадины. Корреляционный анализ определил, что между изучаемыми показателями наблюдаются как положительные, так и отрицательные связи с различной степенью тесноты. С помощью линейного дискриминантного анализа определено, что сапропелевое и гумусовое органические вещества разделены достаточно четко, а смешанное – по заданным характеристикам практически не выделяется. Выполненный пошаговый регрессионный анализ по каждому из рассматриваемых параметров, проведенный для этих типов органических веществ по отдельности, подтвердил кардинальное различие в процессах накопления органических веществ сапропелевого и гумусового типов. Таким образом, выполненный статистический анализ показал регулирующую роль тектонических факторов в процессах формирования концентраций органических веществ.

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Introduction

The Upper Pechora Depression is one of the northern depressions of the Cis-Ural foredeep, a sedimentary basin of tectonic nature between the Ural fold and the adjacent Timan-Pechora plate. The structure of the upper horizons of the sedimentary cover has been well studied – hydrocarbon fields have been developed since the 1960s, but deep sediments (deeper than 4 km, older than the Early-Middle Visean age) remain under-researched. Currently, 46 deep wells have been drilled within the Upper Pechora Depression, most of them are confined to the Vuktyl tectonic plate in the east of the territory. Therefore, it is of interest to model the formation of oil and gas content at great depths using various modelling techniques.

Research Technique

Tectonic characteristics such as subsidence and sedimentation rates largely determine oil and gas formation processes. Sustained and intense subsidence over a large area is not only necessary for sedimentary basin formation, but also an important criterion for zones of highest hydrocarbon concentration.

A.I. Dyakonov (2009) showed that oil generation and oil fields formation in the conditions of the main zone of oil formation at sapropel and mixed types of organic matter (OM) are connected with the zones of increased rates of deflection – more than 40–50 m/million years. Gas generation with gas fields formation dominates when the corresponding thermobaric conditions are reached for the humus and mixed types of organic matter accumulated at much lower subsidence rates – 20–40 m/million years. These features are conditioned by the degree of medium recovery, relative content of biomass, OM, bitumoids, conditions of their preservation, and geochemical facies in the sediment [1, 2].

As a result of 1D-basin modelling using the Petromod and Genex software packages of wells that penetrated the deep lying sediments, the subsidence rates of the Upper Pechora Basin section strata were calculated. The methodology of basin modelling is considered in many works [3–18], it is always carried out on the basis of an extensive database of geological, geophysical and geochemical studies [18–20]. Examples of change graph of subsidence rates by wells of different parts of the Upper Pechora Basin are shown in Fig. 1.

According to A.I. Dyakonov (2009), the concentration of OM in sediments increases with increasing of fossilization rates, and then, reaching a certain optimum, decreases again, due to the regulating role of sedimentation rate in the balance of organic and mineral components of sediments [1].

The patterns of change in OM concentrations depending on subsidence rates have not been described in detail.

Therefore, probabilistic-statistical methods were applied to analyse the dependence of organic carbon concentrations (C_{org}) and the tectonic characteristics chosen by the authors of this paper – subsidence rates (V_s) and layers depth (H_s). The methods of mathematical statistics and probability theory were used to construct statistical models, which received full coverage in numerous Russian and foreign papers [21–48].

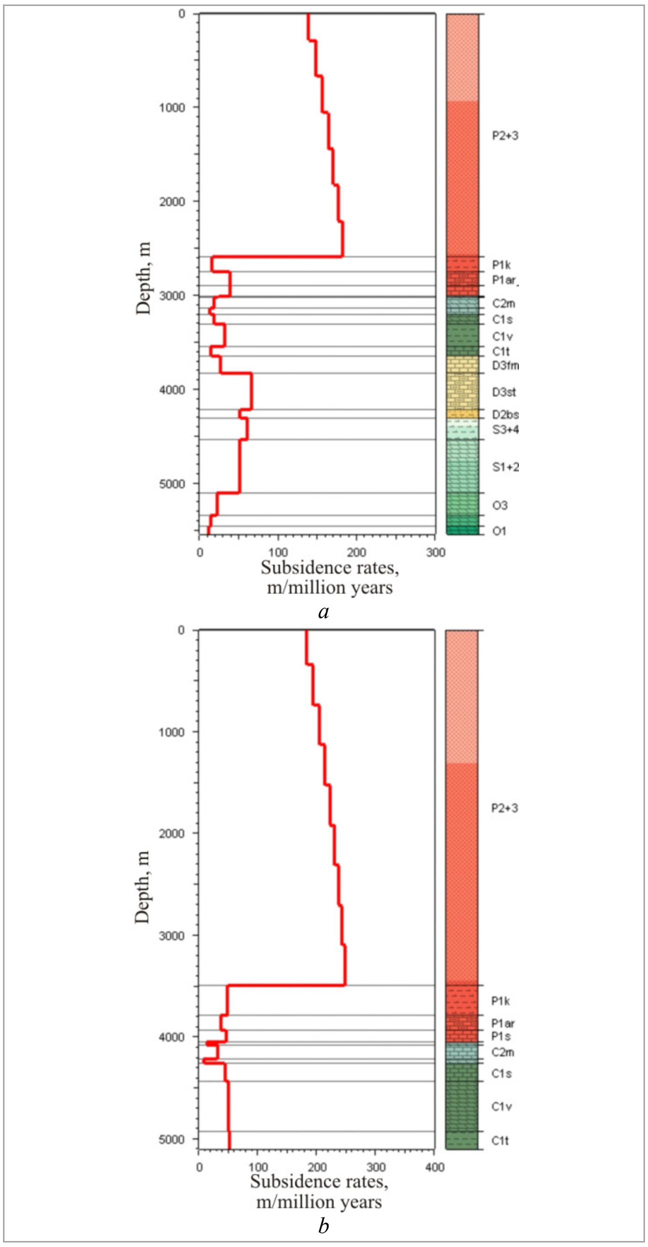

Fig. 1. Sedimentation rate according to 1D modeling data from wells of the Upper Pechora Depression: *a* – W. Vuktylskaya-1; *b* – E. Vuktylskaya-1

Results and Discussions

The initial data were the results of 1D-modelling of 10 wells in the Upper Pechora Depression, with pyrolytic studies of deep sediments conducted by the Timan-Pechora Research Centre.

The first statistical tool is to test the hypothesis of differences or lack thereof between the mean values of the considered characteristics of OM concentrations and the selected tectonic characteristics using the Student's *t*-criterion.

Statistical calculation data of mean values (*t*-criterion and achieved significance level *p*) of organic carbon concentration (C_{org}), subsidence rates (V_s) and

Table 1

Comparison of mean C_{org}, V_s and H_s values

Indicators, UoM.	Mean values $\left(\frac{x \pm \sigma}{\min - \max}\right)$			Criteria $\frac{t}{p}$
	OM type, number of observations			
	sapropel, 27	mixed, 40	humus, 93	
C_{org}, %	0.248 ± 0.291 0.101–1.19	0.472 ± 0.518 0.031–2.24		–2.043974 0.045012
	0.248 ± 0.291 0.101–1.19		1.047 ± 1.3 0–5.97	–3.159772 0.002006
		0.472 ± 0.518 0.031–2.24	1.047 ± 1.3 0–5.97	2.696356 0.007931
V_s, m/mln yr	53.19 ± 18.96 12.0–72.0	50.93 ± 40.53 9.0–170.0		0.270019 0.788001
	53.19 ± 18.96 12.0–72		61.96 ± 42.28 15.0–175.0	–1.045539 0.297911
		50.93 ± 40.53 9.0–170.0	61.96 ± 42.28 15.0–175.0	1.396911 0.164802
H_s, m	5160.43 ± 779.37 4385.5–6987.5	4751.96 ± 956.47 3047.0–6040.0		1.842893 0.069905
	5160.43 ± 779.37 4385.5–6987.5		4625.69 ± 674.72 2946.5–5800.0	3.498782 0.000660
		4751.96 ± 956.47 3047.0–6040.0	4625.69 ± 674.72 2946.5–5800.0	–0.867879 0.387048

Table 2

Correlation matrix

Example	C_{org}	H_s	V_s	C_{org}	H_s	V_s	C_{org}	H_s	V_s
	Sapropel OM			Mixed OM			Humus OM		
C_{org}	1.00	-0.44*	0.40*	1.00	-0.31*	-0.10	1.00	-0.12	-0.25*
H_s		1.00	-0.26*		1.00	-0.03		1.00	0.26*
V_s			1.00			1.00			1.00

N o t e : * – statistically significant correlations.

depth of occurence (H_s) for the studied sediments are given in Table 1.

Comparison of mean values showed that there are statistical differences in the mean values of C_{org} between all types of OM, mean values of V_s are not statistically different, mean values of H_s are statistically different between sapropel and humus OM.

To understand the process of C_{org} concentration formation depending on V_s and H_s, correlation fields between the studied values were constructed and analysed. The analysis showed that correlations and strength of correlations within the considered OM types differ significantly, which is clearly seen from the data given in Table 2.

The analysis of r values shows that both positive and negative correlation with different degrees of strength are observed between C_{org}, V_s and H_s, as well as between the indicators themselves. Furthermore, subfields are observed within the correlation fields for all types of OM.

Linear discriminant analysis (LDA) was used to establish the following linear discriminant functions:

$$Z_1 = -0.767004\ C_{org} - 0.01266\ V_s + 0.00062\ H_s - 1.62656$$
at $R = 0.393$, $\chi^2 = 28.63$, $p = 0.000072$;

$$Z_2 = 0.42529\ C_{org} + 0.01121\ V_s + 0.00110\ H_s - 6.19442$$
at $R = 0.126$, $\chi^2 = 2.5$, $p = 0.285886$.

The linear discriminant function Z_1 is statistically significant, while Z_2 is not. The values of Z_1 and Z_2 were calculated using these functions. The correlation of Z_1 and Z_2 values depending on the types of OM is shown in Fig. 2.

It is obvious that according to the Z_1 and Z_2 values the studied sample to a certain extent (64 %) is divided into the considered types of OM, as sapropel and humus OM are divided rather strongly, and mixed OM is practically not distinguished according to the given characteristics.

Then, using stepwise regression analysis, the influence of V_s and H_s values on C_{org} was assessed differently depending on the type of OM. Construction of multidimensional models, which allowed estimating the influence of V_s and H_s values on C_{org}, was made according to the following scheme: the first regression equation is built according to three minimum C_{org} values ($n = 3$), the next model at $n = 4$, and so on up to $n = 27$. The models calculated in this way for sapropel OM are given in Table 3.

Table 3

Models for analysing the formation of C_{org} values from V_s and H_s

Model construction interval on C_{org}, %	Absolute term	Coefficients		R	Significance level p
		at H_s	at V_s		
0.0101–0.019	-0.055	-0.000105	0.000012	1.000	
0.0101–0.045	0.105	0.000074	-0.000015	0.449	<0.89330
0.0101–0.046	0.123	-0.000050	-0.000016	0.566	<0.67959
0.0101–0.054	-0.046	-0.000509	0.000016	0.362	<0.80953
0.0101–0.056	0.070	0.000134	-0.000007	0.332	<0.79112
0.0101–0.065	0.051	0.000208	-0.000004	0.249	<0.85248
0.0101–0.087	0.084	0.000392	-0.000010	0.535	<0.36318
0.0101–0.104	0.122	0.000021	-0.000013	0.364	<0.60769
0.0101–0.104	0.146	0.000053	-0.000017	0.427	<0.44689
0.0101–0.112	0.122	0.000257	-0.000013	0.343	<0.56870
0.0101–0.113	0.145	0.000322	-0.000017	0.451	<0.32161
0.0101–0.125	0.166	0.000327	-0.000020	0.480	<0.23664
0.0101–0.164	0.206	-0.000011	-0.000024	0.423	<0.30660
0.0101–0.166	0.238	0.000104	-0.000030	0.505	<0.14753
0.0101–0.196	0.258	0.000362	-0.000035	0.555	<0.07600
0.0101–0.205	0.289	0.000444	-0.000041	0.606	<0.03252
0.0101–0.241	0.315	0.000451	-0.000044	0.572	<0.04223
0.0101–0.263	0.226	0.000900	-0.000030	0.432	<0.17282
0.0101–0.394	0.310	0.000866	-0.000043	0.425	<0.16710
0.0101–0.410	0.378	0.001102	-0.000056	0.474	<0.08939
0.0101–0.414	0.433	0.001303	-0.000067	0.509	<0.04997
0.0101–0.549	0.530	0.001202	-0.000081	0.494	<0.05323
0.0101–0.554	0.562	0.001847	-0.000092	0.531	<0.02611
0.0101–0.994	0.644	0.003161	-0.000115	0.532	<0.02198
0.0101–1.190	0.698	0.004666	-0.000135	0.530	<0.01910

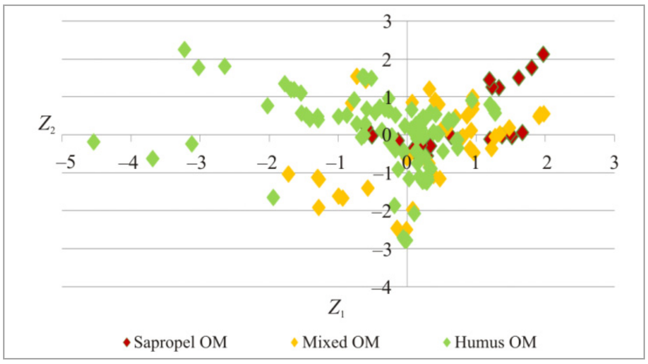

Fig. 2. Ratio between Z_1 and Z_2 for the selected classes of OM

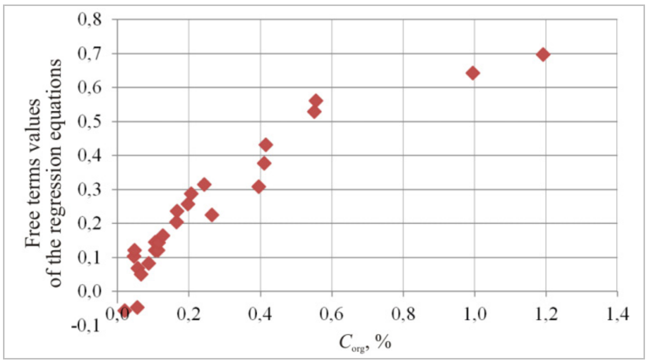

Fig. 3. Variation of free terms values of regression equations depending on C_{org}

Thus, 25 regression equations were constructed for sapropel OM. The free terms values of the regression equations of the studied sequence vary from -0.055 to 0.698. with the mean value of 0.245. The change in the free terms values of the regression equations depending on the C_{org} values is shown in Fig. 3.

It is seen that with increasing C_{org} values the free terms values of the regression equations increase along a rather complex trajectory, within which two areas can be distinguished. The first one is at C_{org} < 0.4 %. Here we observe an increase in the free terms values of the regression equations. At C_{org} > 0.4 %, the free terms values of the regression equations change insignificantly.

Variation of coefficients at H_s depending on C_{org} values is shown in Fig. 4. *a*. The H_s value was used in the construction of all 25 models. The values of coefficients at H_s varied from -0.0009 to 0.00002 along a rather complex trajectory, within which three areas can be distinguished. The first area at C_{org} < 0.4 % – here we observe a decrease in the values of coefficients at H_s in the regression equations. At C_{org} > 0.4 % the values of coefficients at H_s change insignificantly.

The dependence analysis of the coefficients at V_s on C_{org} values (Fig. 4. *b*) shows that when C_{org} values increase, the values of the coefficients at V_s change along the trajectory within which two areas can be distinguished. The boundary of these areas can be drawn by the C_{org} value = 0.2 %. At C_{org} < 0.2 %, there is a slight variation of the parameter values in the interval – 0.0005-0.0004, and then at C_{org} > 0.2 % – a constant increase up to 0.0047.

The values variation of the multiple correlation coefficients R as a function of C_{org} values is shown in Fig. 5.

The graph shows that within its limits there are three areas where the changes of R depend on C_{org} have their own types. On the first area at C_{org} < 0.2 % there are chaotic changes of R values from 0.249 to 1.0. At C_{org} values > 0.2 %, R values are in the range of 0.425–0.572.

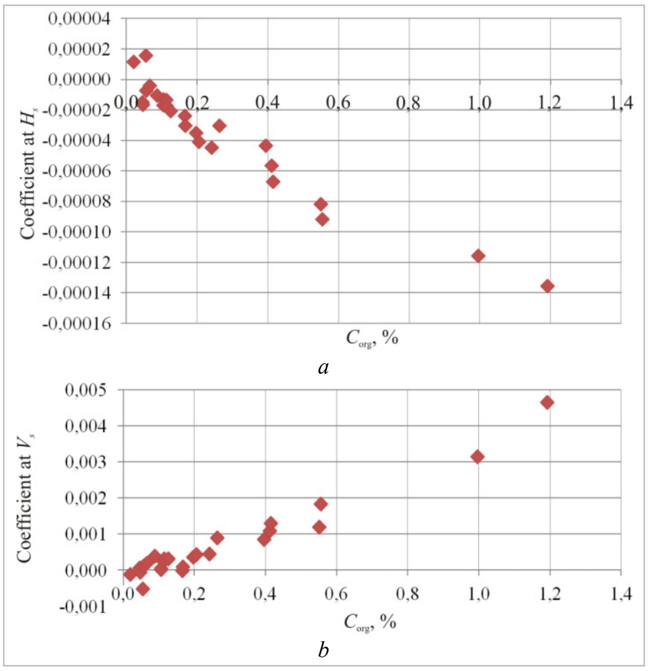

Fig. 4. Variation of coefficient values:
a – at H_s depending on C_{org}; *b* – at V_s depending on C_{org}

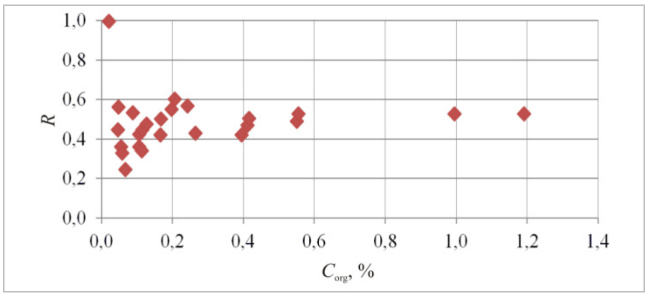

Fig. 5. Variation of multiple correlation coefficients *R* depending on C_{org}

The performed analysis shows that H_s and V_s values affect differently the formation of C_{org} values. At the same time, this analysis at the statistical level determined that the values formation is controlled to a greater extent by the H_s value. It was also found that for this type of OM the C_{org} values are not controlled by the age of the studied rocks.

A similar complex analysis was performed for mixed and humus OM. 38 regression equations describing the dependence of H_s, V_s and C_{org} were constructed for mixed OM, for the humus – 91.

The joint analysis of the free terms changes of the regression equations for all types of OM determined that they are quite similar for sapropel and mixed OM and differ significantly for humus OM. The change analysis of coefficients values in the regression equations at H_s depending on C_{org} shows that they change differentially for the studied OM types.

The change analysis in the values of coefficients at V_s showed that they have opposite signs for sapropel and humus OM. For mixed OM, the coefficients at V_s are located between them and are characterised by a much smaller range of values.

The change analysis in the values of the multiple correlation coefficients *R* depending on the C_{org} values for different types of OM has revealed that with increasing C_{org} values the range of *R* changes significantly decreases for all types of OM, which is clearly seen from the data shown in Fig. 5 for sapropel type of OM.

Conclusion

The performed probabilistic-statistical analysis of C_{org} concentration formation for different types of OM showed that this process is mainly determined by tectonic conditions, which can be used to assess the petroleum source rock characteristics of the studied deep sediments of the Upper Pechora Depression.

References

1. D'iakonov A.I., Ovcharova T.A., Shelemei S.V. Otsenka gazoneftianogo potentsiala avtokhtonov i allokhtonov Predural'skogo kraevogo progiba na evoliutsionno-geneticheskoi osnove [Evaluation of the gas-oil potential of autochthons and allochthons of the Cis-Ural marginal foredeep on an evolutionary-genetic basis]. Ukhta: Ukhtinskii gosudarstvennyi tekhnicheskii universitet, 2008, 76 p.
2. Kuznetsova E.A. Vliianie skorosti osadkonakopleniia na neftegazonosnost' otlozhenii iugo-vostochnykh raionov Timano-Pechorskoi neftegazonosnoi provintsii [Influence of sedimentation rate on the oil and gas potential of sediments in the southeastern regions of the Timan-Pechora oil and gas province]. *Novye napravleniia neftegazovoi geologii i geokhimii. Razvitie geologorazvedochnykh rabot*, 2019, pp. 293-298.
3. Allen A.Ph., Allen J.R. Basin analysis: principles and application to petroleum play assessment. 3 ed. Wiley-Blackwell, 2013, 619 p.
4. Al-Hajeri M.M., Al Saeed M., Derks J. et al. Basin and petroleum system modeling. *Oilfield Rewiew*, 2009, vol. 21, iss. 2, pp. 14-29. DOI: 10.1007/978-3-319-49347-3_11
5. Roeder D., Goffey G.P. Craig, J. et al. Fold-thrust belts at peak oil. *Hydrocarbons in contact belts*. London: Geological Society, 2010, vol. 348, pp. 7-31. DOI: 10.1144/SP348.2
6. Hantschel T., Kauerauf A. Fundamentals of basin and petroleum systems modeling. Berlin: Springer-Verlag, 2009, 476 p. DOI: 10.1007/978-3-540-72318-9
7. Roure F., Swennen R., Schneider F. et al. Incidence and importance of tectonics and natural fluid migration on reservoir evolution in foreland fold-and-thrust belts. *Oil and Gas Science and Technology Revue de l'IFP*, 2005, vol. 60, no. 1, pp. 67-106. DOI: 10.2516/ogst: 2005006
8. Neumaier M., Littke R., Hantschel T. et al. Integrated charge and seal assessment in the Monagas fold and thrust belt of Venezuela. *AAPG Bulletin*, 2014, vol. 98, no. 7, pp. 1325-1350. DOI: 10.1306/01131412157
9. Maerten L., Maerten F. Chronologic modeling of faulted and fractured reservoirs using geomechanically based restoration. *Technique and industry applications: AAPG Bulletin*, 2006, vol. 90, no. 8, pp. 1201-1226. DOI: 10.1306 /02240605116
10. Magoon L.B., Dow W.G. The Petroleum system: from source to trap. Tulsa, Oklahoma: AAPG, 1994, 655 p. DOI: 10.1306/M60585
11. Nemcok M., Schamel S., Gayer R. Thrustbelts. Structural architecture. *Thermal Regimes and Petroleum Systems*, 2009, 527 p. DOI: 10.2113/gscanmin.44.6.1563
12. PetroMod petroleum system modeling. *Schlumberger Information Solutions*, 2011, no. 10, 256 p.
13. Schneider F. Basin modeling in complex area: examples from Eastern Venezuelan and Canadian Foothills. *Oil and Gas Science and Technology*, 2003, vol. 58, no. 2, pp. 313-324. DOI: 10.2516/ogst:2003019
14. Belokon' A.V. Modelirovanie tektonicheskoi i temperaturnoi istorii raiona bureniia Timano-Pechorskoi glubokoi opornoi skvazhiny [Modeling of the tectonic and temperature history of the drilling area of the Timano-Pechora deep reference well]. *Vestnik Permskogo gosudarstvennogo tekhnicheskogo universiteta*, 2000, no. 3, pp. 71-76.
15. Galkin V.I., Kozlova I.A. Vliianie istoriko-geneticheskikh faktorov na neftegazonosnost' [Influence of historical and genetic factors on oil and gas potential]. *Vestnik Permskogo universiteta. Geologiia*, 2000, iss. 4, pp. 8-18.
16. Galushkin Iu.I. Modelirovanie osadochnykh basseinov i otsenka ikh neftegazonosnosti [Modeling of sedimentary basins and assessment of their oil and gas potential]. Moscow: Nauchnyi mir, 2007, 456 p.
17. Pestereva S.A., Popov S.G., Belokon' A.V. Istoriko-geneticheskoe modelirovanie evoliutsii osadochnogo chekhla v raionakh razvitiia glubokopogruzhennykh otlozhenii Timano-Pechorskogo neftegazonosnogo basseina [Historical and genetic modeling of the evolution of the sedimentary cover in the areas of development of deep deposits of the Timan-Pechora oil and gas basin]. *Vestnik Permskogo universiteta. Geologiia*, 2011, iss. 2, pp. 8-19.

18. Kuznetsova E.A. Description and prospects of oil and gas potential of the Middle Devonian - Lower Frasnian complex of the south-east of the Timan-Pechora province. *IOP Conf. Ser.: Earth Environ. Sci.*, 1021, 012036. DOI: 10.1088/1755-1315/1021/1/012036
19. Kochneva O.E. Karaseva T.V., Kuznetsova E.A. Perspektivy neftegazonosnosti glubokopogruzhennykh otlozhenii Verkhnepechorskoi vpadiny po dannym basseinovogo modelirovaniia [Prospects of oil-and-gas content of the deep-shipped deposits of the Verkhnepechorsky hollow by data basin modeling]. *Neftianoe khoziaistvo*, 2015, no. 3, pp. 14-16.
20. Kuznetsova E.A., Karaseva T.V. Osobennosti geologicheskogo stroeniia i formirovaniia neftegazonosnosti v raione Vuktyl'skogo nadviga [Features of geological structure and formation of oil & gas deposits in the Vuktyl thrust fault region.]. *Nedropol'zovanie*, 2017, vol. 16, no. 4, pp. 313-320. DOI: 10.15593/2224-9923/2017.4.2
21. Amanat U. Chaudry. Oil well testinghanbook. *Advanced TWPSON Petroleum Systems Inc.* Houston, 2004. – 525 p.
22. Friedman J. Regularized discriminant analysis. J*ournal of the American Statistical Association*, 1989, vol. 84, P. 165-175. DOI: 10.2307/2289860
23. Ahlbrandt T.S., Charpentier R.R., Klett T.R., Schmoker J.W., Schenk C.J., Ulmishek G.F. Global resource estimates from total petroleum systems. *AAPG Memoir*, 2005, no. 86, pp. 1-334. DOI: 10.1306/M861061
24. Horne R.N. Modern well test analysis: A computer Aided Approach. 2nd ed. Palo Alto: PetrowayInc, 2006, 257 p.
25. Tan Pang-Ning, Steinbach Michael, Kumar Vipin. Introduction to data mining. – Boston: Pearson Addison Wesley, 2005, 769 p.
26. Johnson N.L., Leone F.C. Statistics and experimental design. New York - London - Sydney - Toronto, 1977, 606 p.
27. Koshkin K.A., Melkishev O.A. Use of derivatives to assess preservation of hydrocarbon deposits. *IOP Conf. Series: Journal of Physics: Conference Series*, 2018, vol. 1015, 032092 p. DOI: 10.1088/1742-6596/1015/3/032092
28. Montgomery D.C., Peck E.A., Introduction to liner regression analysis. New York: John Wiley & Sons, 1982, 504 p.
29. Bouchaala F., Ali M.Y., Matsushima J. et al. Scattering and intrinsic attenuation as a potential tool for studying of a fractured reservoir. *Journal of Petroleum Science and Engineering*, 2019, vol. 174, pp. 533-543. DOI: 10.1016/j.petrol.2018.11.058
30. Tiab D. Modern core analysis. Vol. 1. Theory, core laboratories. Houston, Texas, 1993, 200 p.
31. Watson G.S. Statistic on spheres. New York: John Wiley and Sons, Inc., 1983, 238 p.
32. Yarus J.M. Stochastic modeling and geostatistics. *AAPG*. Tulsa, Oklahoma, 1994, 231 p.
33. Vistelius A.V. Osnovy matematicheskoi geologii [Fundamentals of mathematical geology]. Leningrad: Nedra, 1980, 389 p.
34. Davydenko A.Iu. Veroiatnostno-statisticheskie metody v geologo-geofizicheskikh prilozheniiakh [Probabilistic-statistical methods in geological and geophysical applications]. Irkutsk, 2007, 29 p.
35. Devis Dzh. Statistika i analiz geologicheskikh dannykh [Statistics and analysis of geological data]. Moscow: Mir, 1977, 353 p.
36. Devis Dzh.S. Statisticheskii analiz dannykh v geologii [Statistical data analysis in geology]. Moscow: Nedra, 1990, Book 1, 319 p.
37. Devis Dzh.S. Statisticheskii analiz dannykh v geologii [Statistical data analysis in geology]. Moscow: Nedra, 1990, Book 2, 426 p.
38. Dement'ev L.F. Matematicheskie metody i EVM v neftegazovoi geologii [Mathematical methods and computers in oil and gas geology]. Moscow: Nedra, 1987, 264 p.
39. Dement'ev L.F., Zhdanov M.A., Kirsanov A.N. Primenenie matematicheskoi statistiki v neftepromyslovoi geologii [Application of mathematical statistics in oilfield geology]. Moscow, 1977, 255 p.
40. Dreiper N., Smit G. Prikladnoi regressionnyi analiz [Applied Regression Analysis]. Moscow: Vil'iams, 2007.
41. Krivoshchekov S.N., Galkin V.I., Volkova A.S. Razrabotka veroiatnostno-statisticheskoi metodiki prognoza neftegazonosnosti struktur [Development of a probabilistic-statistical methodology for predicting the oil and gas potential of structures]. *Neftepromyslovoe delo*. Moscow: VNIIOENG, 2010, no. 7, pp. 28-31.
42. Mikhalevich I.M. Primenenie matematicheskikh metodov pri analize geologicheskoi informatsii (s ispol'zovaniem komp'iuternykh tekhnologii) [Application of mathematical methods in the analysis of geological information (using computer technology)]. Irkutsk, 2006, 115 p.
43. Mikhalevich I.M. Primenenie matematicheskikh metodov pri analize geologicheskoi informatsii (s ispol'zovaniem komp'iuternykh tekhnologii: Statistica) [Application of mathematical methods in the analysis of geological information (using computer technology: Statistica)]. Irkutsk: Irkutskii gosudarstvennyi universitet, 2006, 115 p.
44. Pomorskii Iu.L. Metody statisticheskogo analiza eksperimental'nykh dannykh [Methods of statistical analysis of experimental data]. Leningrad, 1960, 174 p.
45. Porotov G.S. Matematicheskie metody modelirovaniia v geologii [Mathematical modeling methods in geology]. Saint Petersburg: Sankt-Peterburgskii gosudarstvennyi gornyi institut (tekhnicheskii uniersitet), 2006, 223 p.
46. Putilov I.S. Razrabotka tekhnologii kompleksnogo izucheniia geologicheskogo stroeniia i razmeshcheniia mestorozhdenii nefti i gaza [Development of technologies for a comprehensive study of the geological structure and location of oil and gas fields]. Perm': Permskii natsional'nyi issledovatel'skii politekhnicheskii universitet, 2014, 285 с.
47. Chini R.F. Staticheskie metody v geologii [Static methods in geology]. Moscow: Mir, 1986, 189 p.
48. Sharapov I.P. Primenenie matematicheskoi statistiki v geologii. Statisticheskii analiz geologicheskikh dannykh [Application of mathematical statistics in geology. Statistical analysis of geological data]. Moscow: Nedra, 1971.

Библиографический список

1. Дьяконов А.И., Овчарова Т.А., Шелемей С.В. Оценка газонефтяного потенциала автохтонов и аллохтонов Предуральского краевого прогиба на эволюционно-генетической основе. – Ухта: УГТУ, 2008. – 76 с.
2. Кузнецова Е.А. Влияние скорости осадконакопления на нефтегазоносность отложений юго-восточных районов Тимано-Печорской нефтегазоносной провинции // Новые направления нефтегазовой геологии и геохимии. Развитие геологоразведочных работ. – 2019. – С. 293–298.
3. Allen A.Ph., Allen J.R. Basin analysis: principles and application to petroleum play assessment. – 3 ed. – Wiley-Blackwell, 2013. – 619 p.
4. Basin and petroleum system modeling / M.M. Al-Hajeri, M. Al Saeed, J. Derks [et al.] // Oilfield Rewiew. – 2009. – Vol. 21, iss. 2. – P. 14–29. DOI: 10.1007/978-3-319-49347-3_11
5. Fold-thrust belts at peak oil / D. Roeder, G.P. Goffey, J. Craig [et al.] // Hydrocarbons in contact belts. – London: Geological Society, 2010. – Vol. 348. – P. 7–31. DOI: 10.1144/SP348.2
6. Hantschel T., Kauerauf A. Fundamentals of basin and petroleum systems modeling. – Berlin: Springer-Verlag, 2009. – 476 p. DOI: 10.1007/978-3-540-72318-9
7. Incidence and importance of tectonics and natural fluid migration on reservoir evolution in foreland fold-and-thrust belts / F. Roure, R. Swennen, F. Schneider [et al.] // Oil and Gas Science and Technology Revue de l'IFP. – 2005. – Vol. 60, № 1. – P. 67–106. DOI: 10.2516/ogst: 2005006
8. Integrated charge and seal assessment in the Monagas fold and thrust belt of Venezuela / M. Neumaier, R. Littke, T. Hantschel [et al.] // AAPG Bulletin. – 2014. – Vol. 98, № 7. – P. 1325–1350. DOI: 10.1306/01131412157
9. Maerten L., Maerten F. Chronologic modeling of faulted and fractured reservoirs using geomechanically based restoration // Technique and industry applications: AAPG Bulletin. – 2006. – Vol. 90, № 8. – P. 1201–1226. DOI: 10.1306 /02240605116
10. Magoon L.B., Dow W.G. The Petroleum system: from source to trap. – Tulsa, Oklahoma: AAPG, 1994. – 655 p. DOI: 10.1306/M60585
11. Nemcok M., Schamel S., Gayer R. Thrustbelts. Structural architecture // Thermal Regimes and Petroleum Systems. – 2009. – 527 p. DOI: 10.2113/gscanmin.44.6.1563
12. PetroMod petroleum system modeling // Schlumberger Information Solutions. – 2011. – № 10. – 256 p.
13. Schneider F. Basin modeling in complex area: examples from Eastern Venezuelan and Canadian Foothills // Oil and Gas Science and Technology. – 2003. – Vol. 58, № 2. – P. 313–324. DOI: 10.2516/ogst:2003019
14. Белоконь А.В. Моделирование тектонической и температурной истории района бурения Тимано-Печорской глубокой опорной скважины // Вестник Пермского государственного технического университета. – 2000. – № 3. – С. 71–76.
15. Галкин В.И., Козлова И.А. Влияние историко-генетических факторов на нефтегазоносность // Вестник Пермского университета. Геология. – 2000. – Вып. 4. – С. 8–18.
16. Галушкин Ю.И. Моделирование осадочных бассейнов и оценка их нефтегазоносности. – М.: Научный мир, 2007. – 456 с.
17. Пестерева С.А., Попов С.Г., Белоконь А.В. Историко-генетическое моделирование эволюции осадочного чехла в районах развития глубокопогруженных отложений Тимано-Печорского нефтегазоносного бассейна // Вестник Пермского университета. Геология. – 2011. – Вып. 2. – С. 8–19.
18. Kuznetsova E.A. Description and prospects of oil and gas potential of the Middle Devonian – Lower Frasnian complex of the south-east of the Timan-Pechora province // IOP Conf. Ser.: Earth Environ. Sci. – 1021 – 012036. DOI:10.1088/1755-1315/1021/1/012036
19. Кочнева О.Е. Карасева Т.В., Кузнецова Е.А. Перспективы нефтегазоносности глубокопогруженных отложений Верхнепечорской впадины по данным бассейнового моделирования // Нефтяное хозяйство. – 2015. – № 3. – С. 14–16.

20. Кузнецова Е.А., Карасева Т.В. Особенности геологического строения и формирования нефтегазоносности в районе Вуктыльского надвига // Недропользование. – 2017. – Т. 16, № 4. – С. 313–320. DOI: 10.15593/2224-9923/2017.4.2
21. Amanat U.Chaudry. Oil well testinghanbook // Advanced TWPSON Petroleum Systems Inc. – Houston, 2004. – 525 p.
22. Friedman J. Regularized discriminant analysis // Journal of the American Statistical Association. – 1989. – Vol. 84. – P. 165–175. DOI: 10.2307/2289860
23. Global resource estimates from total petroleum systems / T.S. Ahlbrandt, R.R. Charpentier, T.R. Klett, J.W. Schmoker, C.J. Schenk, G.F. Ulmishek // AAPG Memoir. – 2005. – № 86. – P. 1–334. DOI: 10.1306/M861061
24. Horne R.N. Modern well test analysis: A computer Aided Approach. – 2nd ed. – Palo Alto: PetrowayInc, 2006. – 257 p.
25. Introduction to data mining / Pang-Ning Tan, Michael Steinbach, Vipin Kumar. – Boston: Pearson Addison Wesley, 2005. – 769 p.
26. Johnson N.L., Leone F.C. Statistics and experimental design. – New York – London – Sydney – Toronto, 1977. – 606 p.
27. Koshkin K.A., Melkishev O.A. Use of derivatives to assess preservation of hydrocarbon deposits // IOP Conf. Series: Journal of Physics: Conference Series. – 2018. – Vol. 1015. – P. 032092. DOI:10.1088/1742-6596/1015/3/032092
28. Montgomery D.C., Peck E.A., Introduction to liner regression analysis. – New York: John Wiley & Sons, 1982. – 504 p.
29. Scattering and intrinsic attenuation as a potential tool for studying of a fractured reservoir / F. Bouchaala, M.Y. Ali, J. Matsushima [et al.] // Journal of Petroleum Science and Engineering. – 2019. – Vol. 174. – P. 533–543. DOI: 10.1016/j.petrol.2018.11.058
30. Tiab D. Modern core analysis. Vol. 1. Theory, core laboratories. – Houston, Texas, 1993. – 200 p.
31. Watson G.S. Statistic on spheres. – New York: John Wiley and Sons, Inc., 1983. – 238 p.
32. Yarus J.M. Stochastic modeling and geostatistics // AAPG. – Tulsa, Oklahoma, 1994. – 231 p.
33. Вистелиус А.В. Основы математической геологии. – Л.: Недра, 1980. – 389 с.
34. Давыденко А.Ю. Вероятностно-статистические методы в геолого-геофизических приложениях. – Иркутск, 2007. – 29 с.
35. Девис Дж. Статистика и анализ геологических данных. – М.: Мир, 1977. – 353 с.
36. Девис Дж.С. Статистический анализ данных в геологии. – М.: Недра, 1990. – Кн. 1. – 319 с.
37. Девис Дж.С. Статистический анализ данных в геологии. – М.: Недра, 1990. – Кн. 2. – 426 с.
38. Дементьев Л.Ф. Математические методы и ЭВМ в нефтегазовой геологии. – М.: Недра, 1987. – 264 с.
39. Дементьев Л.Ф., Жданов М.А., Кирсанов А.Н. Применение математической статистики в нефтепромысловой геологии. – М., 1977. – 255 с.
40. Дрейпер Н., Смит Г. Прикладной регрессионный анализ. – М.: Изд. дом «Вильямс», 2007.
41. Кривощеков С.Н., Галкин В.И., Волкова А.С. Разработка вероятностно-статистической методики прогноза нефтегазоносности структур // Нефтепромысловое дело. – М.: ВНИИОЭНГ, 2010. – № 7. – С. 28–31.
42. Михалевич И.М. Применение математических методов при анализе геологической информации (с использованием компьютерных технологий). – Иркутск, 2006. – 115 с.
43. Михалевич И.М. Применение математических методов при анализе геологической информации (с использованием компьютерных технологий: Statistica). – Иркутск: ИГУ, 2006. – 115 с.
44. Поморский Ю.Л. Методы статистического анализа экспериментальных данных: монография. – Л., 1960. – 174 с.
45. Поротов Г.С. Математические методы моделирования в геологии. – СПб.: Изд-во Санкт-Петербур. гос. горн. ин-та (техн. ун-та), 2006. – 223 с.
46. Путилов И.С. Разработка технологий комплексного изучения геологического строения и размещения месторождений нефти и газа. – Пермь: Изд-во Перм. нац. исслед. политехн. ун-та, 2014. – 285 с.
47. Чини Р.Ф. Статические методы в геологии: пер. с англ. – М.: Мир, 1986. – 189 с.
48. Шарапов И.П. Применение математической статистики в геологии. Статистический анализ геологических данных. – М.: Недра, 1971.

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