ISSN 2712-8008
Volume / Том 24 №3 2024
Journal Homepage: http://vestnik.pstu.ru/geo/

Perm Journal of Petroleum and Mining Engineering

UDC 622+553.982.2.276.6
Article / Статья

Development of Geological and Statistical Models for Forecasting the Confirmability of Structures in the Territory of the South of Perm Krai

Evgeniy S. Kolesnikov

NEFTGASISSLEDOVANIE LLC (20 Komsomolskiy av., Perm, 614045, Russian Federation)

Разработка геолого-статистических моделей для прогноза подтверждаемости структур на территории юга Пермского края

Е.С. Колесников

ООО «НЕФТЬГАЗИССЛЕДОВАНИЕ» (Российская Федерация, 614045, г. Пермь, Комсомольский пр., 20)

Received / Получена: 12.01.2024. Accepted / Принята: 26.07.2024. Published / Опубликована: 30.08.2024

Keywords:
geological and morphological characteristics, amplitude of the structure, geological exploration, confirmability of structures by deep drilling, risk assessment, reflecting horizon, geological and statistical approach.

Today, 3D seismic surveys carried out in the south of Perm Krai are increasingly focused on identifying and preparing for deep drilling local geological structures, the amplitude of which is often comparable to the accuracy of structural constructions. Based on this, there is a need to develop a new geological and statistical approach that allows assessing the risks associated with the problem of unconfirmability of prepared objects by deep drilling. Minimizing such risks would reduce the number of negative results of exploration and appraisal drilling, which would directly affect the efficiency of the oil and gas producing enterprise in the field of geological exploration for oil and gas.
This article proposes one of the options for developing a geological-statistical approach to assessing the accuracy of the structural constructions of the studied area, which allows drawing conclusions about the degree of exploration of the territory under consideration. Based on the results obtained, conclusions were drawn about the correspondence of the structural plans of the reflecting horizons of the southern part of the Perm region with each other. A comparison of the obtained boundary values of discrepancies with the errors of structural constructions estimated from the results of 3D CDP seismic surveys in the south of Perm Krai.
This geological and statistical approach can be used to clarify the risks associated with the problem of unconfirmation of the geological and morphological characteristics of structures.

Ключевые слова:
геолого-морфологические характеристики, амплитуда структуры, геолого-разведочные работы, подтверждаемость структур глубоким бурением, оценка рисков, отражающий горизонт, геолого-статистический подход.

На сегодняшний день сейсморазведочные работы 3D, проводимые на территории юга Пермского края, все больше ориентированы на выявление и подготовку к глубокому бурению локальных геологических структур, амплитуда которых часто сопоставима с точностью структурных построений. Исходя из этого, возникает необходимость разработки нового геолого-статистического подхода, позволяющего оценить риски, связанные с проблемой неподтверждаемости подготовленных объектов глубоким бурением. Минимизация таких рисков позволила бы снизить количество отрицательных результатов поисково-оценочного бурения, что напрямую повлияло бы на эффективность деятельности нефтегазодобывающего предприятия в области геолого-разведочных работ на нефть и газ.
Предлагается один из вариантов разработки геолого-статистического подхода к оценке точности структурных построений изучаемой выборки, позволяющий сделать выводы о степени изученности рассматриваемой территории. На основе полученных результатов сделаны выводы о соответствии структурных планов отражающих горизонтов южной части Пермского края между собой; также приводится сопоставление полученных граничных значений невязок с погрешностями структурных построений, оцененными по результатам выполнения сейсморазведочных работ МОГТ 3D в южной части Пермского края.
Данный геолого-статистический подход может применяться для уточнения рисков, связанных с проблемой неподтверждаемости геолого-морфологических характеристик структур.

© **Evgeniy S. Kolesnikov** (SPIN-code: 5862-2836) – 2nd category specialist of the Block for Implementation And Support Of Digital Solutions For Intelligent Fields (tel.: +007 (912) 580 50 60, e-mail: zhenya.kolesnikov.1997@mail.ru).

© **Колесников Евгений Сергеевич** – (SPIN-код: 5862-2836) – специалист 2-й категории блока внедрения и поддержки цифровых решений для интеллектуальных месторождений (тел.: +007 (912) 580 50 60, e-mail: zhenya.kolesnikov.1997@mail.ru).

Please cite this article in English as:
Kolesnikov E.S. Development of geological and statistical models for forecasting the confirmability of structures in the territory of the south of Perm Krai. *Perm Journal of Petroleum and Mining Engineering*, 2024, vol.24, no.3, pp.102-111. DOI: 10.15593/2712-8008/2024.3.1

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
Колесников, Е.С. Разработка геолого-статистических моделей для прогноза подтверждаемости структур на территории юга Пермского края / Е.С. Колесников// Недропользование. – 2024. – Т.24, №3. – С.102–111. DOI: 10.15593/2712-8008/2024.3.1

Introduction

One of the ways to assess the accuracy of structural interpretations of reflecting horizons is considered in the paper, based on the analysis of the amplitude discrepancies between structures confirmed by drilling and structures prepared for deep drilling.

Minimizing the risks associated with the problem of prepared object unconfirmability by deep drilling would reduce the number of negative exploration and appraisal drilling, which would directly affect the efficiency of the oil and gas producing enterprise in the field of oil and gas geological exploration [1].

The studied sample comprised structures prepared for deep drilling by various methods (structural drilling, seismic exploration by the 2D and 3D common depth point (CDP) method). The sample size is sufficient to conduct a full-fledged regression analysis by reflecting horizons III (19 structures), II^P (99 structures), II^E (97 structures), I^P (43 structures), I^E (21 structures) [2–8].

To analyze the discrepancy nature between the amplitudes of structures according to drilling data (A_D) and the amplitudes of structures prepared for deep drilling according to passport data (A_P), and to assess the accuracy of structural constructions according to reflecting horizons III, II^P, II^E, I^P, I^E, a stepwise multiple regression was performed using Statistica software for groups with different numbers of structures *N*, already drilled at the time of the study in the southern region of the Perm Krai [9–24].

Independent variables in this study, in addition to the amplitude of the structure prepared for deep drilling, according to the data sheet (A_P) were such geological and morphological characteristics as the length (*D*) and width of the structure (*S*), the width ratio of the structure to its length (*S/D*), the area of the structure along the corresponding reflecting horizon (S_{RH}), the intensity of the structure (I), the angle of consistency of the structure and the axis (or boundary) of the nearest tectonic element (γ), the distance from the structure to the center (L^1_C) and the nearest edge (L^1_E) of the first-order tectonic element, the distance from the center of the first-order tectonic element (D^1_C, calculated as the ratio of L^1_C to the sum of L^1_C and L^1_E), as well as the distance from the structure to the center (L^2_C) and the nearest edge (L^2_E) of a second-order tectonic element [25–42].

During the stepwise increase of *N*, the influence of statistically significant parameters on A_D was analyzed [43–52].

Bold font is used in tables to highlight statistically significant parameters, for which the *p*-criterion value, that characterizes the probability of a first-order errors type, is less than or equal to 0.05.

Justification of the boundary values of the $|A_D – A_P|$ parameter for reflecting horizon III

Table 1 presents the results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, \gamma, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$ with the $|A_D – A_P|$ parameter in ascending order for reflecting horizon III.

As can be seen from the data in the table, regression was performed for *N* ranging from 9 to 19 structures inclusive, based on the reflecting horizon III.

The results of this regression study for reflecting horizon III allowed combining the obtained geo-statistical models, similar in the influence nature of significant parameters. Thus, for the reflecting horizon III, one class of structures was identified.

Statistically significant parameters controlling the model in the range of *N* from 9 to 19 are A_P and, fragmentarily S_{RH}, I, D^1_C.

The coefficient of multiple correlation (R^2) in this interval varies from 0.523 to 1.000, gradually decreasing. The value of the *p*-criterion in the interval of the formed geo-statistical model fluctuates around 0.000–0.004.

Correlation field $B = f(|A_D – A_P|)$ based on the results of regression analysis for reflecting horizon III is shown in Fig. 1, *a*.

When analyzing the data in Table 1 and Fig. 1, *a*, we see that there is no fundamental restructuring of the geo-statistical model in the considered interval $|A_D – A_P|$ from 4 to 14 m, which suggests the existence of a boundary value of the $|A_D – A_P|$ parameter outside the considered range.

Justification of the boundary values of the $|A_D – A_P|$ parameter for the reflecting horizon II^P

Table 2 presents the results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, \gamma, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$ with the $|A_D – A_P|$ parameter in ascending order based on the reflecting horizon II^P.

Multiple correlation coefficient (R^2) in this interval varies from 0.401 to 0.614, gradually decreasing. The *p*-criterion of the geo-statistical model formed in this interval fluctuates around 0.000.

Table 1

Results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, \gamma, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$ with the $|A_D – A_P|$ parameter in ascending order by reflecting horizon III

No	A_P, m	A_D, m	$\lvert A_D – A_P\rvert$, m	*B*, fr. of units	Coefficients for parameters, fractions of units.												R^2, fr. of units	*p-cr.*, fr. of units	*SE*, m
					A_P	S_{RH}	*I*	*D*	*S*	*S/D*	γ	L^1_C	L^1_E	D^1_C	L^2_C	L^2_E			
1	6	6	0																
2	14	14	0																
3	21	21	0																
4	6	7	1																
5	7	8	1																
6	9	7	2																
7	12	14	2																
8	9	6	3																
9	7	3	4	-2.155	1.818	-3.076	-0.784		-0.616		0.050		-0.065		0.549	-0.463	1.000		0.000
10	7	3	4	0.782	**1.566**	**-2.972**	**-0.953**					0.149	0.063		0.030		0.993	0.002	0.797
11	9	13	4	-0.577	**1.243**		**-0.416**				0.030					0.095	0.960	0.000	1.437
12	25	20	5	-0.577	**1.243**		**-0.416**				0.030					0.095	0.960	0.000	1.437
13	9	3	6	2.553	**0.828**					-8.087					0.220		0.842	0.001	2.843
14	21	14	7	5.095	**0.701**					-7.260						0.237	0.810	0.001	3.014
15	17	9	8	5.174	**0.687**					-9.374					0.137		0.752	0.001	3.286
16	13	3	10	3.518	**0.728**					-8.259					0.136		0.638	0.001	3.703
17	14	3	11	5.007	**0.651**					-5.087							0.623	0.001	3.821
18	19	6	13	6.913	**0.543**									-9.016			0.529	0.004	4.236
19	22	8	14	7.944	**0.505**									**-10.203**			0.523	0.003	4.130

Table 2

Results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, \gamma, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$ with the $|A_D - A_P|$ parameter in ascending order by the reflecting horizon II^P

No	A_P, m	A_D, m	$\|A_D - A_P\|$, m	*B*, fr. of units	Coefficients for parameters, fractions of units.												R^2, fr. of units	*p-cr.*, fr. of units	*SE*, m
					A_P	S_{RH}	*I*	*D*	*S*	*S/D*	γ	L^1_C	L^1_E	D^1_C	L^2_C	L^2_E			
1	6	6	0																
2	12	12	0																
3	12	12	0																
4	14	14	0																
5	16	16	0																
6	18	18	0																
7	20	20	0																
8	20	20	0	0.000	1.000												1.000		0.000
9	8	7	1	**-2.016**	**1.047**		0.035	0.290			**0.014**					0.027	1.000	0.000	0.126
10	13	12	1	0.959	**1.018**					-1.857	0.010				-0.059	0.078	0.998	0.000	0.297
11	13	12	1	**-3.789**	**1.042**					1.154	0.007	0.050	0.040				0.998	0.000	0.328
12	14	13	1	**-3.306**	**0.936**	0.525	0.076				0.010	**0.055**	**0.038**		-0.017		0.999	0.000	0.219
13	15	14	1	**-3.380**	**0.938**	**0.536**	**0.080**				**0.010**	**0.054**	**0.037**		-0.012		0.999	0.000	0.199
14	20	19	1	**-3.838**	**1.064**					1.121	**0.013**	**0.047**	0.030		-0.012		0.997	0.000	0.327
15	20	19	1	**-3.035**	**0.995**				0.586			**0.050**	**0.048**				0.992	0.000	0.451
16	21	20	1	**-7.770**	**1.077**	-0.553	-0.044	2.505	-2.861	**8.078**	**0.015**	0.035	0.004		-0.032		0.998	0.000	0.325
17	17	18	1	-7.383	**1.117**	-0.432	-0.049			1.878	0.009	0.008	0.107	5.404			0.996	0.000	0.416
18	9	7	2	**-3.592**	**1.083**	-0.704	-0.019		**1.605**			0.042	0.028				0.989	0.000	0.609
19	9	7	2	**-4.211**	**1.166**	-0.586	-0.049		0.684	2.140	0.007	0.025					0.990	0.000	0.634
20	12	10	2	**-4.476**	**1.167**	-0.680	-0.046		1.044	2.486		0.026				-0.023	0.989	0.000	0.621
21	12	10	2	**-4.621**	**1.211**	-0.437	-0.061			**3.206**	0.008	0.025			-0.036		0.985	0.000	0.716
22	13	11	2	**-3.250**	**1.066**					1.573		0.022					0.973	0.000	0.830
23	15	13	2	**-5.023**	**1.213**	-0.472	-0.059			**3.399**	0.008	0.030			-0.030		0.980	0.000	0.786
24	18	16	2	-1.584	**1.061**												0.949	0.000	1.033
25	27	25	2	-1.452	**1.048**												0.945	0.000	1.056
26	14	16	2	-0.925	**1.008**												0.953	0.000	1.080
27	24	26	2	-0.808	**1.057**			-0.377									0.955	0.000	1.163
28	34	36	2	-0.579	**1.085**									-1.641	-0.036		0.973	0.000	1.144
29	13	10	3	-0.545	**1.091**									-1.790	-0.045		0.972	0.000	1.167
30	14	11	3	-0.652	**1.094**									-1.914	-0.039		0.968	0.000	1.218
31	15	12	3	-1.350	**1.093**							-0.035					0.964	0.000	1.254
32	18	14	4	-0.810	**1.067**					2.288		-0.051	-0.049			-0.036	0.953	0.000	1.494
33	20	16	4	-1.661	**1.049**					1.734		-0.035					0.939	0.000	1.609
34	7	11	4	-0.026	**1.033**							-0.051					0.929	0.000	1.683
35	10	5	5	-2.032	**1.053**					2.165		-0.039					0.929	0.000	1.743
36	10	5	5	-2.736	**1.064**					2.868		-0.037					0.930	0.000	1.761
37	11	6	5	-1.838	**1.070**					3.169		-0.057	-0.041				0.934	0.000	1.757
38	13	8	5	-1.202	**1.083**				1.102			-0.074			-0.040		0.929	0.000	1.808
39	11	11	5	-0.896	**1.076**				0.961			-0.074			-0.041		0.927	0.000	1.818
40	19	14	5	-1.202	**1.083**				1.102			-0.074			-0.040		0.929	0.000	1.808
41	22	17	5	-0.896	**1.076**				0.961			-0.074			-0.041		0.927	0.000	1.818
42	25	20	5	-0.802	**1.057**				0.790			-0.080					0.915	0.000	1.902
43	11	16	5	-2.412	**1.039**					3.366		-0.047					0.892	0.000	2.118
44	11	16	5	-1.876	**1.019**					3.371		-0.050					0.869	0.000	2.306
45	23	28	5	-4.665	**1.013**					**5.819**							0.855	0.000	2.476
46	31	36	5	-5.479	**1.060**					**6.115**							0.874	0.000	2.554
47	11	5	6	-5.757	**1.074**					**6.036**							0.869	0.000	2.628
48	18	12	6	-3.539	**1.074**			-0.692		4.369							0.860	0.000	2.723
49	22	16	6	-5.097	**1.046**					**5.273**							0.841	0.000	2.840
50	25	19	6	-4.271	**1.040**				-1.495	**6.935**							0.831	0.000	2.932
51	12	18	6	-4.178	**1.012**				-1.226	**6.863**							0.821	0.000	2.997
52	20	26	6	-2.751	**1.006**					**5.660**				-2.614		-0.063	0.817	0.000	3.110
53	10	3	7	-3.015	**1.030**					**4.816**		-0.054					0.815	0.000	3.148
54	12	5	7	-2.545	**1.037**					4.268		-0.067					0.813	0.000	3.187
55	14	7	7	-3.454	**1.047**					4.686		-0.053					0.802	0.000	3.287
56	15	8	7	-3.357	**1.044**					**4.940**				-2.917			0.792	0.000	3.361
57	24	17	7	-1.848	**1.015**					3.723				-3.628			0.777	0.000	3.447
58	10	17	7	-2.921	**1.006**								0.084				0.735	0.000	3.695
59	15	22	7	-2.502	**1.003**								0.071				0.712	0.000	3.855
60	17	24	7	-2.497	**0.951**		0.064						0.076				0.710	0.000	3.925
61	17	24	7	-2.693	**0.961**		0.056						0.093				0.700	0.000	4.013
62	19	26	7	-3.050	**1.019**		0.053						**0.111**				0.690	0.000	4.088
63	32	39	7	-3.764	**1.072**								0.109				0.723	0.000	4.157
64	10	2	8	-5.178	**1.089**					2.765			0.072				0.723	0.000	4.258
65	17	9	8	-5.041	**1.077**					2.893			0.079			-0.088	0.719	0.000	4.312
66	19	11	8	-5.390	**1.068**					3.476			0.084			-0.094	0.712	0.000	4.335
67	27	19	8	-2.519	**1.075**	-0.630							0.088			-0.090	0.704	0.000	4.369
68	18	26	8	-2.760	**1.084**	-0.720							0.106			-0.073	0.699	0.000	4.435
69	18	26	8	-3.030	**1.086**	-0.657							**0.121**			-0.074	0.691	0.000	4.513
70	20	28	8	-2.686	**1.104**	-0.778							0.104			-0.079	0.684	0.000	4.615
71	26	34	8	-2.233	**1.120**			-1.125					0.115			-0.077	0.695	0.000	4.664
72	17	8	9	-2.676	**1.116**			-1.043					0.113				0.679	0.000	4.747
73	20	11	9	-2.848	**1.105**			-1.000					**0.123**				0.669	0.000	4.798
74	20	11	9	-2.463	**1.102**			-1.240					**0.126**				0.663	0.000	4.813
75	11	20	9	-4.086	**1.052**								**0.137**				0.629	0.000	4.990
76	19	28	9	-3.818	**1.062**								**0.137**			-0.091	0.625	0.000	5.096
77	23	32	9	-4.219	**1.077**								**0.152**			-0.098	0.635	0.000	5.121
78	30	39	9	-4.846	**1.109**								**0.162**			-0.093	0.659	0.000	5.149
79	13	24	11	-4.024	**1.094**								**0.141**			-0.108	0.633	0.000	5.338
80	18	29	11	-5.906	**1.082**			0.922					**0.141**				0.620	0.000	5.468
81	20	8	12	-6.123	**1.067**			1.095					**0.140**				0.602	0.000	5.592
82	28	16	12	-17.864	**0.968**			**5.275**	-6.474	**18.962**			0.094		0.255	-0.338	0.596	0.000	5.711
83	3	15	12	-19.643	**1.004**	-1.388		**6.932**	-5.826	**19.450**			0.081		0.213	-0.288	0.614	0.000	5.659
84	33	45	12	-5.803	**1.006**				2.077				0.097		0.228	-0.321	0.601	0.000	5.918
85	15	2	13	-6.160	**1.011**				2.409				0.091		0.212	-0.308	0.590	0.000	6.060
86	15	2	13	-17.444	**1.035**			4.044	-4.331	**18.805**					**0.292**	-0.428	0.609	0.000	6.002
87	19	6	13	-15.593	**1.018**	-1.784		4.171		**13.268**					0.273	-0.416	0.597	0.000	6.100
88	22	8	14	-16.188	**1.002**	-1.654		4.131		**14.209**					**0.290**	-0.450	0.591	0.000	6.135
89	28	14	14	-13.042	**0.961**			1.522		**10.600**			0.097		**0.306**	-0.454	0.578	0.000	6.197
90	38	24	14	-10.807	**0.865**			1.422		**10.403**			0.123		0.229	-0.391	0.531	0.000	6.510
91	10	24	14	-12.594	**0.927**			1.748		**10.494**			0.099		**0.294**	-0.450	0.550	0.000	6.390
92	24	9	15	-10.451	**0.841**			1.392		**10.563**			0.107		0.238	-0.373	0.504	0.000	6.675
93	28	13	15	-10.598	**0.820**			1.428		**10.852**			0.111		0.258	-0.406	0.497	0.000	6.687
94	31	16	15	-10.380	**0.803**			1.326		**11.252**			0.109		0.267	-0.425	0.492	0.000	6.687
95	7	22	15	-9.714	**0.776**			1.279		**11.335**			0.101		0.288	-0.455	0.474	0.000	6.773
96	16	32	16	-7.464	**0.769**				2.767	6.829			0.097		**0.315**	-0.462	0.473	0.000	6.850
97	27	10	17	-5.447	**0.780**					**8.268**			0.085		**0.333**	-0.480	0.443	0.000	6.984
98	23	3	20	-5.467	**0.761**					**8.133**			0.115		0.306	-0.460	0.421	0.000	7.162
99	30	10	20	-5.139	**0.723**					**7.727**			0.123		**0.337**	-0.477	0.401	0.000	7.262

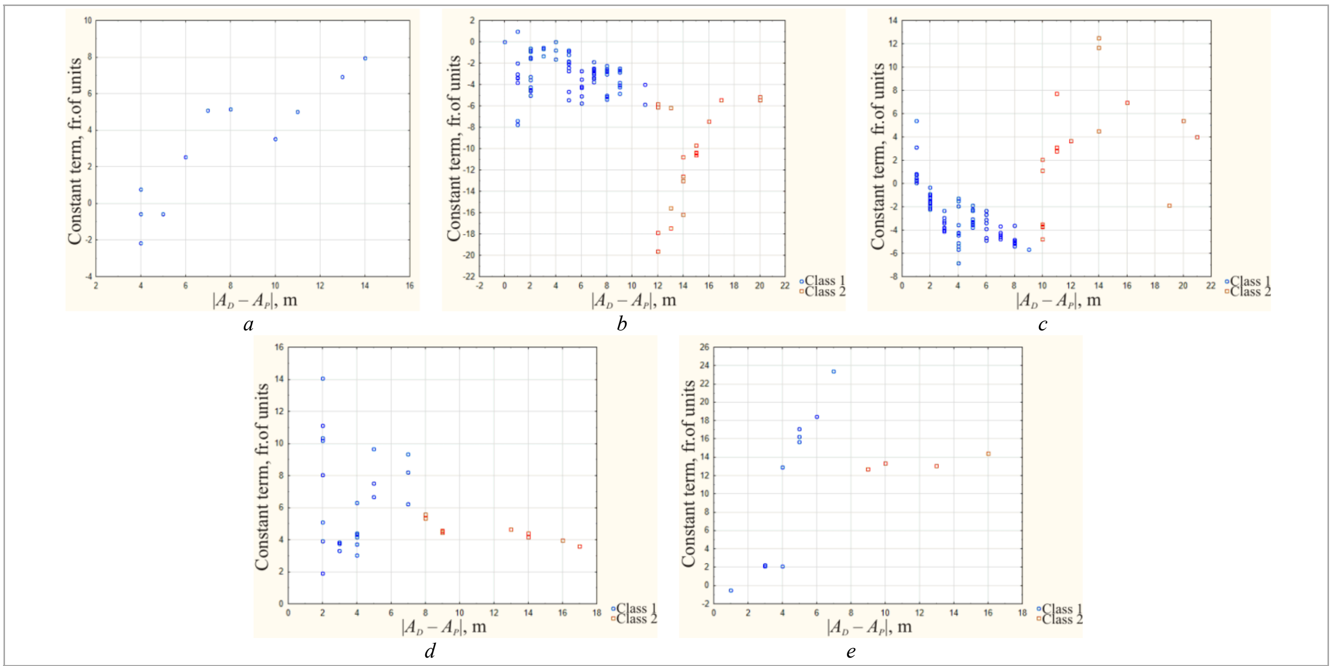

Fig. 1. Correlation field $B = f(|A_D - A_P|)$ according to the results of regression analysis by reflecting horizon: *a* – III; *b* – II^P; *c* – II^E; *d* – I^P, *e* – I^E

As can be seen from Table 2, the regression was performed for *N* from 8 to 99 structures inclusive along the II^P reflecting horizon.

The results of this regression analysis for reflecting horizon II^P allowed combining the obtained geo-statistical models, similar in the nature of the influence of significant parameters. Thus, two classes of structures were identified for the reflecting horizon II^P.

Class "1" corresponds to the first stable geo-statistical model, observed for *N* from 8 to 80.

Statistically significant parameters that control the model in this interval, are A_P and fragmentary, *S, D, S/D*, S_{RH}, I, γ, L^1_C, L^1_E.

Multiple correlation coefficient (R^2) in this interval varies from 0.620 to 1.000, gradually decreasing. The *p*-criterion in this interval of the formed geo-statistical model fluctuates around 0.000.

The reconstruction of the geo-statistical model from the first to the second occurs at *N* equal to 81.

Class "2" corresponds to the second stable geo-statistical model, observed at *N* from 81 to 99.

Statistically significant parameters that control the model in this interval are A_P, *S/D*, L^2_E and, fragmentarily, *S, D*, L^1_E, L^2_C.

The correlation field $B = f(|A_D - A_P|)$ based on the results of the regression analysis for the reflecting horizon II^P is presented in figure 1, *b*.

Having analyzed Table 2 and Fig. 1, *b*, we can conclude that the boundary value of the $|A_D - A_P|$ parameter is in the range from 11 to 12 m (11.5 m is taken as the average value).

Justification of the boundary values of the $|A_D - A_P|$ parameter for the reflecting horizon II^E

Table 3 presents the results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, γ, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$ with the $|A_D - A_P|$ parameter in ascending order for the reflecting horizon II^E.

As can be seen from Table 3, the regression was performed for *N* from 8 to 97 structures inclusive for the reflecting horizon II^E.

The results of this regression study for reflecting horizon II^E allowed combining the obtained geo-statistical models, similar in the nature of the influence of significant parameters. Thus, for the reflecting horizon II^E two classes of structures were identified.

Class "1" corresponds to the first stable geo-statistical model, observed at *N* from 11 to 80.

Statistically significant parameters that control the model in this interval are A_P and, in part, *S, S/D*, γ, L^1_E, D^1_C.

The multiple correlation coefficient (R^2) in this interval varies between 0.667 and 1.000, gradually decreasing. The value of the *p*-criterion in this interval of the formed geo-statistical model fluctuates around 0.000.

The reconstruction of the geo-statistical model from the first to the second occurs at *N* equal to 81.

Class "2" corresponds to the second stable geological-statistical model, observed at *N* from 81 to 97.

Statistically significant parameters that control the model in this interval are A_P, S_{RH} and, fragmentarily, L^1_E, D^1_C.

The coefficient of multiple correlation (R^2) in this interval varies from 0.408 to 0.673, gradually decreasing. The *p*-criterion in this interval of the formed geo-statistical model fluctuates around 0.000.

Correlation field $B = f(|A_D - A_P|)$ based on the results of the regression analysis for reflecting horizon II^E is shown in Fig. 1, *c*.

Having analyzed the data in Table 3 and Fig. 1, *c*, we can conclude that the boundary value of the $|A_D - A_P|$ parameter is in the range from 9 to 10 m (9.5 m is taken as the average value).

Justification of the boundary values of the $|A_D - A_P|$ parameter for the reflecting horizon I^P

Table 4 presents the results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, γ, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$ with the $|A_D - A_P|$ parameter in ascending order for the reflecting horizon I^P.

As can be seen from Table 4, the regression was performed for *N* from 10 to 43 structures inclusive for the reflecting horizon I^P.

The results of this regression study for reflecting horizon I^P allowed combining the obtained geo-statistical models, similar in the nature of the significant parameters influence. Thus, for the reflecting horizon I^P two classes of structures were identified.

Table 3

Results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, \gamma, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$ with the $|A_D - A_P|$ parameter in ascending order by the reflecting horizon II^E

No	A_P, m	A_D, m	$\|A_D - A_P\|$, m	*B*, fr. of units	Coefficients for parameters, fractions of units.												R^2, fr. of units	*p-cr.*, fr. of units	*SE*, m
					A_P	S_{RH}	*I*	*D*	*S*	*S/D*	γ	L^1_C	L^1_E	D^1_C	L^2_C	L^2_E			
1	7	7	0																
2	11	11	0																
3	12	12	0																
4	15	15	0																
5	18	18	0																
6	26	26	0																
7	6	5	1																
8	9	8	1																
9	10	9	1																
10	8	9	1																
11	9	10	1	5.417	1.069	0.716	-0.117		-3.372		-0.017	0.019	0.011	-6.155	0.006	0.098	1.000		0.000
12	11	10	1	**3.096**	**0.969**					-4.067	-0.024		**0.059**	-2.455	0.075	0.029	0.999	0.000	0.317
13	11	10	1	0.463	**1.037**					-3.233	-0.007		**0.053**				0.993	0.000	0.577
14	12	11	1	0.291	**1.037**					-3.139	-0.007		**0.057**				0.991	0.000	0.594
15	11	12	1	0.217	**1.032**					-2.966	-0.010		**0.067**				0.989	0.000	0.619
16	13	12	1	0.061	**1.032**					-2.916	-0.008		**0.068**				0.987	0.000	0.643
17	14	13	1	0.058	**1.032**					-2.881	-0.008		**0.067**				0.987	0.000	0.616
18	15	14	1	0.850	**1.029**					-3.610	-0.014	-0.014	**0.076**				0.988	0.000	0.609
19	25	26	1	0.747	**1.010**					-2.999	-0.018	-0.015	**0.069**		0.050	-0.067	0.994	0.000	0.565
20	9	7	2	-0.903	**1.050**					-1.844			**0.056**				0.984	0.000	0.758
21	8	10	2	-1.007	**1.018**								0.032				0.971	0.000	0.978
22	12	10	2	-0.336	**1.013**					-2.360			0.049		0.037		0.973	0.000	0.980
23	12	10	2	-1.298	**1.019**								0.042				0.965	0.000	1.025
24	15	13	2	-1.215	**1.011**								0.038				0.960	0.000	1.076
25	17	19	2	-1.450	**1.022**								**0.048**				0.958	0.000	1.109
26	17	19	2	-1.621	**1.029**								**0.055**				0.958	0.000	1.119
27	17	19	2	-1.734	**1.041**								**0.057**				0.956	0.000	1.160
28	26	28	2	-1.939	**1.057**								**0.058**				0.965	0.000	1.150
29	27	29	2	-2.102	**1.072**								**0.058**				0.971	0.000	1.144
30	33	35	2	-2.207	**1.084**								**0.056**				0.979	0.000	1.129
31	9	6	3	-2.327	**1.099**								0.045				0.975	0.000	1.242
32	3	6	3	-3.973	**1.093**					**2.889**	0.020	0.021					0.972	0.000	1.351
33	10	7	3	-4.124	**1.097**					**3.055**	0.017	0.021					0.968	0.000	1.434
34	11	8	3	-2.944	**1.080**					**3.074**							0.962	0.000	1.495
35	13	10	3	-3.225	**1.071**					2.678			0.032				0.961	0.000	1.526
36	7	10	3	-3.361	**1.058**					**3.144**			0.039				0.959	0.000	1.551
37	14	11	3	-3.410	**1.055**					2.863			0.049				0.956	0.000	1.579
38	15	12	3	-3.749	**1.052**					**3.508**			0.056			-0.054	0.954	0.000	1.616
39	18	15	3	-3.833	**1.046**					**4.090**			0.041			-0.045	0.949	0.000	1.687
40	10	6	4	-6.817	**1.156**		-0.186	1.910	-5.269	**12.408**			0.044				0.951	0.000	1.702
41	12	8	4	-4.227	**1.087**		-0.099			**4.707**			0.057			-0.052	0.945	0.000	1.759
42	14	10	4	-4.446	**1.087**		-0.102			**5.097**			0.059			-0.065	0.943	0.000	1.763
43	16	12	4	-5.686	**1.011**	0.619				**5.129**			**0.070**			-0.070	0.942	0.000	1.755
44	17	13	4	-5.409	**0.999**	0.638				**4.274**			**0.079**			-0.050	0.933	0.000	1.857
45	10	14	4	-5.117	**0.986**	0.681				**4.273**			**0.076**			-0.059	0.921	0.000	2.001
46	10	14	4	-1.271	**0.981**	1.215		-1.205					**0.075**				0.899	0.000	2.208
47	19	15	4	-1.508	**0.966**	1.252		-1.111					**0.084**				0.895	0.000	2.219
48	13	17	4	**-4.277**	**0.962**	0.698				3.310			**0.086**			-0.067	0.896	0.000	2.218
49	13	17	4	**-3.531**	**0.908**	0.993	0.101						**0.107**			-0.054	0.884	0.000	2.323
50	15	19	4	-1.917	**1.000**								**0.101**			-0.060	0.876	0.000	2.348
51	8	3	5	**-3.411**	**1.014**					2.551			**0.090**			-0.068	0.879	0.000	2.371
52	12	7	5	**-2.196**	**1.022**								**0.078**				0.856	0.000	2.529
53	13	8	5	**-2.332**	**1.023**								**0.081**				0.850	0.000	2.570
54	14	9	5	**-3.484**	**1.025**					2.495			0.059				0.846	0.000	2.613
55	17	12	5	**-3.530**	**1.016**					2.530			0.064				0.840	0.000	2.642
56	11	16	5	**-3.378**	**1.008**					2.770			0.059				0.825	0.000	2.738
57	12	17	5	-1.909	**1.000**								0.077				0.805	0.000	2.845
58	14	19	5	**-3.034**	**1.004**					2.664			0.057				0.801	0.000	2.900
59	16	21	5	**-3.252**	**0.998**					2.297			0.046		0.070		0.799	0.000	2.951
60	26	31	5	**-3.799**	**1.027**					2.784			0.047		0.065		0.817	0.000	2.975
61	13	7	6	**-3.884**	**1.026**					2.510			0.051		0.071		0.809	0.000	3.032
62	22	16	6	**-2.643**	**1.001**								0.079		0.069		0.794	0.000	3.101
63	11	17	6	**-3.106**	**0.974**	0.412							0.080		0.082		0.780	0.000	3.207
64	15	21	6	**-4.660**	**0.976**	1.596			-3.590	6.222			0.060		0.091		0.784	0.000	3.243
65	18	24	6	-2.312	**1.008**					3.352	-0.020				0.059		0.764	0.000	3.364
66	19	25	6	-4.886	**1.015**	1.445			-3.230	**7.691**					0.084		0.775	0.000	3.357
67	20	26	6	-3.395	**1.028**	0.364				**4.939**	-0.020						0.771	0.000	3.410
68	10	3	7	-3.674	**1.038**	0.418				**4.864**	-0.021						0.767	0.000	3.473
69	13	6	7	-4.216	**1.045**				2.196				0.056				0.749	0.000	3.586
70	14	7	7	-4.376	**1.044**				2.222				0.059				0.740	0.000	3.649
71	15	8	7	-4.601	**1.038**				2.332				0.066				0.731	0.000	3.697
72	17	10	7	-4.480	**1.029**				2.344				0.059				0.718	0.000	3.768
73	21	14	7	-4.784	**1.007**				**2.654**				0.072				0.712	0.000	3.778
74	11	3	8	-5.065	**1.016**				**2.746**				0.069				0.707	0.000	3.843
75	8	8	8	-4.936	**1.012**				**2.672**				0.071				0.709	0.000	3.821
76	20	12	8	-3.618	**0.981**				2.286		-0.019		0.069				0.695	0.000	3.911
77	22	14	8	-4.841	**0.969**				**2.830**				0.082				0.684	0.000	3.926
78	13	21	8	-5.147	**0.960**				**3.107**				0.095				0.678	0.000	3.971
79	14	22	8	-5.401	**0.955**				**3.309**				**0.106**				0.672	0.000	4.017
80	10	1	9	-5.680	**0.972**				**3.327**				**0.101**				0.667	0.000	4.108
81	13	3	10	-3.725	**0.978**	1.753		-1.464	0.669				**0.133**				0.673	0.000	4.156
82	17	7	10	-3.520	**0.970**	2.056		-1.532	-0.065				**0.145**				0.661	0.000	4.224
83	10	20	10	-3.642	**0.950**	**1.986**		-1.406					**0.164**				0.643	0.000	4.302
84	12	22	10	-4.781	**0.941**	**1.221**							**0.162**				0.607	0.000	4.496
85	20	30	10	2.069	**0.955**	**1.366**								-7.540			0.631	0.000	4.473
86	29	39	10	1.087	**1.025**	**1.318**								-7.199			0.653	0.000	4.610
87	15	4	11	2.800	**1.029**	**2.169**		-1.768						-6.492		-0.082	0.651	0.000	4.697
88	17	6	11	7.722	**1.033**	**2.893**		-3.371		-5.098				-7.266			0.630	0.000	4.837
89	23	12	11	3.091	**0.996**	**1.869**		-1.232				0.097		-11.782		-0.081	0.623	0.000	4.881
90	21	9	12	3.645	**0.974**	**2.083**		-1.505				0.093		-11.799		-0.094	0.613	0.000	4.927
91	31	17	14	4.520	**0.918**	0.802					-0.021	0.088		-11.670		-0.158	0.572	0.000	5.159
92	36	22	14	**12.517**	**0.867**	**2.400**		-3.327		-5.644	-0.021			-8.366		-0.100	0.560	0.000	5.259
93	16	30	14	**11.655**	**0.873**	**2.435**		-3.360		-5.258				-8.176		-0.115	0.541	0.000	5.443
94	27	11	16	**6.972**	**0.804**	1.493		-1.373				0.089		-11.704		-0.141	0.510	0.000	5.592
95	26	7	19	-1.890	**0.735**	**1.016**							**0.186**			-0.143	0.456	0.000	5.821
96	25	5	20	5.364	**0.726**	**3.006**		-3.860		-5.283			**0.187**			-0.122	0.451	0.000	5.917
97	31	10	21	3.995	**0.692**	**2.927**		-2.558	-3.180				**0.175**			-0.154	0.408	0.000	6.120

Table 4

Results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, \gamma, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$ with the $|A_D - A_P|$ parameter in ascending order by the reflecting horizon I^P

No	A_P, m	A_D, m	$\|A_D - A_P\|$, m	*B*, fr. of units	Coefficients for parameters, fractions of units.												R^2, fr. of units	*p-cr.*, fr. of units	*SE*, m
					A_P	S_{RH}	*I*	*D*	*S*	*S/D*	γ	L^1_C	L^1_E	D^1_C	L^2_C	L^2_E			
1	7	7	0																
2	7	7	0																
3	9	9	0																
4	3	2	1																
5	3	4	1																
6	6	5	1																
7	6	7	1																
8	7	8	1																
9	9	8	1																
10	2	4	2	8.029	0.554		-0.210	-0.029	-1.919		-0.034	-0.043	-0.015		-0.022	-0.080	1.000		0.000
11	6	4	2	**14.061**						-10.577		-0.030			-0.205	-0.175	0.935	0.001	0.729
12	6	4	2	**10.198**				0.861		-6.770		-0.021			-0.201		0.900	0.001	0.862
13	7	5	2	10.352			-0.282	1.500	-3.265	-1.207	-0.035	-0.025			-0.073		0.943	0.008	0.774
14	6	8	2	**11.119**			**-0.400**	1.305	-3.667	-0.332	-0.048	-0.028					0.938	0.001	0.713
15	11	9	2	1.904	**0.727**						-0.017					0.090	0.774	0.001	1.173
16	10	12	2	**5.089**	**0.592**					-5.559			0.033				0.782	0.000	1.348
17	15	13	2	**3.930**	**0.695**					-4.647			0.034				0.836	0.000	1.329
18	7	4	3	3.329	**0.693**					-4.146			0.044				0.785	0.000	1.507
19	8	5	3	**3.757**	**0.668**					-4.837			0.047				0.777	0.000	1.496
20	8	5	3	**3.765**	**0.645**					-4.975			0.055				0.755	0.000	1.532
21	9	6	3	**3.831**	**0.615**					-5.113			0.064				0.742	0.000	1.526
22	7	3	4	**4.306**	**0.614**					-5.906			0.056				0.721	0.000	1.599
23	7	3	4	**4.149**	**0.608**					-5.996			0.063				0.688	0.000	1.696
24	7	3	4	**3.707**	**0.626**		-0.054			-5.122			**0.081**				0.746	0.000	1.574
25	8	4	4	**4.406**	**0.584**					-6.471			**0.070**				0.694	0.000	1.660
26	4	8	4	3.018	**0.644**		-0.121	1.154	-3.786		-0.001		**0.102**		-0.089	0.154	0.768	0.000	1.624
27	7	11	4	**6.310**	**0.683**		-0.134		-2.875	-2.830			0.087		-0.122	0.208	0.679	0.001	1.912
28	12	7	5	**6.686**	**0.606**	**-1.024**	-0.112			-5.146			0.086		-0.108	0.196	0.648	0.002	1.955
29	3	8	5	**7.534**	**0.544**		-0.134		-3.364	-3.145			**0.108**		-0.118	0.166	0.615	0.002	2.009
30	15	20	5	**9.653**	**0.786**		-0.173		-4.282					-4.340	-0.116	0.248	0.685	0.000	2.343
31	10	3	7	**8.186**	**0.560**		-0.106	1.444	-4.950					-5.434	0.031		0.641	0.000	2.492
32	2	9	7	**9.341**	0.466		-0.113	1.630	-5.249					-6.044	0.029		0.623	0.000	2.517
33	11	18	7	6.240	0.463					-10.323	0.026		0.124		0.062		0.525	0.001	3.094
34	1	9	8	**5.325**				**2.577**			0.020			-5.811			0.415	0.001	3.266
35	6	14	8	**5.594**				**2.577**			0.020			-5.811			0.415	0.001	3.266
36	10	1	9	**4.558**				**2.828**			0.022			-5.399			0.407	0.001	3.422
37	14	5	9	**4.430**				**2.824**			0.023			-5.331			0.405	0.001	3.387
38	15	6	9	**4.529**				**2.817**			0.022			-5.468			0.404	0.000	3.344
39	22	9	13	**4.651**				**2.777**			0.022			-5.568			0.407	0.000	3.298
40	3	3	14	**4.419**				**2.831**			0.023			-5.459			0.418	0.000	3.262
41	3	17	14	**4.154**				**2.510**			**0.039**			-4.380			0.352	0.003	3.689
42	8	24	16	3.943				**2.420**			**0.047**			-3.460			0.245	0.013	4.523
43	18	1	17	3.614				**2.362**			**0.051**			-3.182			0.240	0.013	4.574

Class “1” corresponds to the first stable geo-statistical model, observed for *N* from 10 to 33.

Statistically significant parameters that control the model in this interval are A_P and, fragmentarily, S, S/D, S_{RH}, I, γ, L^1_E, D^1_C, L^2_C.

Multiple correlation coefficient (R^2) in this interval varies from 0.525 to 1.000, gradually decreasing. The value of the *p*-criterion in this interval of the formed geo-statistical model fluctuates around 0.000–0.008.

The reconstruction of the geo-statistical model from the first to the second occurs at *N* equal to 34.

Class “2” corresponds to the second stable geo-statistical model, observed at *N* from 34 to 43.

Statistically significant parameters controlling the model in this interval are *D* and fragmentarily γ, D^1_C. The coefficient of multiple correlation (R^2) in this interval varies from 0.240 to 0.418, gradually decreasing. The value of the *p*-criterion in this interval of the formed geol-statistical model fluctuates around 0.000–0.013.

Correlation field $B = f(|A_D - A_P|)$ based on the results of regression analysis for reflecting horizon I^P is shown in Fig. 1, *d*.

Having analyzed the data in Table 4 and Fig. 1, *d*, we can conclude that the boundary value of the $|A_D - A_P|$ parameter is in the range from 7 to 8 m (7.5 m is taken as the average value).

Justification of the boundary values of the parameter $|A_D - A_P|$ for the reflecting horizon I^E

Table 5 presents the results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, \gamma, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$ with the $|A_D - A_P|$ parameter in ascending order for the reflecting horizon I^E.

As can be seen from Table 5, the regression was performed for *N* from 8 to 21 structures inclusive for the reflecting horizon I^E.

The results of this regression study for reflecting horizon I^E allowed combining the obtained geo-statistical models, similar in the nature of significant parameters influence. Thus, for the reflecting horizon I^E two classes of structures were identified.

Class "1" corresponds to the first stable geo-statistical model, observed at *N* from 8 to 17.

Statistically significant parameters that control the model in this interval are A_P and fragmentary A_P, S, D, S/D, S_{RH}, I, γ, L^1_C, D^1_C, L^2_C. The multiple correlation coefficient (R^2) in this interval varies from 0.799 up to 1,000, gradually decreasing.

The value of the *p*-criterion in this interval of the formed geo-statistical model fluctuates around 0.000–0.002.

The geo-statistical model is reconstructed from the first to the second at *N* equal to 18.

Table 5

Results of the regression study $A_D = f(A_P, S, D, S/D, S_{RH}, I, \gamma, L^1_C, L^1_E, D^1_C, L^2_C, L^2_E)$
with the $|A_D - A_P|$ parameter in ascending order by the reflecting horizon I^E

No	A_P, m	A_D, m	$\|A_D - A_P\|$, m	*B*, fr. of units	Coefficients for parameters, fractions of units.												R^2, fr. of units	*p-cr.*, fr. of units	*SE*, m
					A_P	S_{RH}	*I*	*D*	*S*	*S/D*	γ	L^1_C	L^1_E	D^1_C	L^2_C	L^2_E			
1	4	4	0																
2	6	6	0																
3	8	8	0																
4	9	9	0																
5	2	3	1																
6	2	3	1																
7	4	5	1																
8	11	10	1	**-0.491**	**0.880**	**0.272**	-0.025		**0.763**			**0.116**		-4.496			1.000	0.001	0.005
9	11	8	3	**2.112**	**0.733**											-0.087	0.956	0.000	0.637
10	12	9	3	**2.246**	**0.717**										-0.098		0.958	0.000	0.615
11	5	9	4	**2.103**	**0.517**								0.084				0.799	0.002	1.307
12	13	17	4	**12.920**	0.458	**8.689**	0.294	-8.126		-9.656	-0.042					-0.100	0.988	0.001	0.699
13	7	2	5	**15.681**	**0.535**		-0.494					-0.147			-0.315		0.850	0.002	1.903
14	9	4	5	**16.212**	**0.525**		-0.523					-0.150			-0.329		0.856	0.001	1.804
15	13	8	5	**17.072**	**0.455**		-0.538					-0.144			-0.367		0.836	0.001	1.830
16	13	7	6	**18.466**	0.343		-0.475					-0.158			-0.409		0.818	0.000	1.836
17	14	7	7	**23.396**		0.452	-0.333					-0.227			-0.578	0.144	0.818	0.001	1.837
18	4	13	9	**12.720**			-0.238					-0.890		35.457			0.511	0.016	2.883
19	20	10	10	**13.357**								-0.197					0.350	0.008	3.058
20	17	4	13	**13.030**								-0.184					0.373	0.004	2.988
21	18	2	16	**14.384**			-0.266				0.037			-10.189			0.328	0.073	3.344

Table 6

Comparison of structural constructions the error for reflecting horizons III, II^P, II^E, I^P, I^E
based on the results of 3D CDP seismic exploration with boundary $|A_D - A_P|$ parameter values

Reflecting horizon	Limit value $\|A_D - A_P\|$, m	Accuracy of structural constructions based on the results of 3D CDP seismic exploration works, m Average value (min/max)		The difference between the average value of structural accuracy and the boundary value $\|A_D - A_P\|$, m	
		Southern part of Perm Krai	Northern part of Perm Krai	Southern part of Perm Krai	Northern part of Perm Krai
III	> 14	18.9 (10/32.5)	28.9 (21.2/41)	< 4.9	< 14.9
II^P	11.5	12.4 (6.4/16.8)	23.2 (12.9/33.9)	0.9	11.7
II^E	9.5	12.1 (8/17.4)	24.2 (13.2/34.2)	2.6	14.7
I^P	7.5	10.1 (6/16.5)	22.3 (9.1/35)	2.6	14.8
I^E	8	9.8 (7/15.1)	15.9 (15.9/15.9)	1.8	7.9

Class "2" corresponds to the second stable geo-statistical model, observed at *N* from 18 to 21.

Statistically significant parameters that control the model in this interval are L^1_C and, fragmentarily, D^1_C.

The coefficient of multiple correlation (R^2) in this interval varies from 0.328 to 0.511, gradually decreasing. The value of the *p*-criterion in this interval of the formed geo-statistical model fluctuates around 0.004–0.073.

Correlation field $B = f(|A_D - A_P|)$ based on the results of regression analysis for reflecting horizon I^E is shown in Fig. 1, *e*.

Having analyzed Table 5 and Fig. 1, *e*, we can conclude that the boundary value of the $|A_D - A_P|$ parameter is in the range from 7 to 9 m (8 m is taken as the average).

Justification for the correspondence of structural maps of reflecting horizons

To justify the correspondence of structural maps of reflecting horizons III, II^P, II^E, I^P, I^E summary correlation fields were constructed between each other $k(A_P) = f(|A_D - A_P|)$ where $k(A_P)$ is the coefficient value at A_P (Fig. 2).

To justify the correspondence of structural maps of reflecting horizons, the equations of trend lines and variation ranges in the coefficient value at A_P were analyzed for each reflecting horizon:

– the trend line equation for reflecting horizon III is $k(A_P) = 1.7352–0.0997*(|A_D - A_P|)$, with a range of variation in $k(A_P)$ from 0.505 to 1.818;

– the trend line equation for reflecting horizon II^P is $k(A_P) = 1.1194–0.0129*(|A_D - A_P|)$, with a range of variation in $k(A_P)$ from 0.723 to 1.213;

– the trend line equation for reflecting horizon II^E is $k(A_P) = 1.0822–0.0136*(|A_D - A_P|)$, with a range of variation in $k(A_P)$ from 0.692 to 1.156;

– the trend line equation for reflecting horizon I^P is $k(A_P) = 0.7272–0.0271*(|A_D - A_P|)$, with a range of variation in $k(A_P)$ from 0.463 to 0.786;

– the trend line equation for reflecting horizon I^E is $k(A_P) = 0.9934–0.1049*(|A_D - A_P|)$, with a range of variation in $k(A_P)$ from 0.343 to 0.880;

Thus, for the reflecting horizons II^P and II^E, the trend lines $k(A_P)$ are practically parallel to each other, and $k(A_P)$ takes values in the general range from 0.692 to 1.213, whereas for the reflecting horizons I^P and I^E, a clearly non-zero angle is observed between the trend lines $k(A_P)$, but $k(A_P)$ also takes values in the general range from 0.343 to 0.880 (it is necessary to take into account the unequal size of samples for different reflecting horizons).

Based on the provided data, it can be concluded that the structural plans for the pairs of reflecting horizons II^P – II^E and I^P – I^E correspond to each other, while their plans do not correspond to the structural plan for reflecting horizon III. This confirms the geological structure concept of the southern part of the Perm Krai.

Comparison of the obtained boundary values with the results of calculating the accuracy of structural constructions performed within the framework of the 3D CDP seismic exploration reports

To compare the previously obtained boundary values of $|A_D - A_P|$ parameter with the accuracy of the structural constructions reflecting horizons III, II^P, II^E, I^P, I^E based on the results of 3D CDP seismic surveys in the southern part of the Perm Krai, 27 reports on seismic exploration works were analyzed from 2007 to 2019 to assess the accuracy of structural constructions for reflecting horizons [53, 54].

In all the studied reports, the structural constructions accuracy was assessed according to the requirements set out in the document "Guidelines for the Evaluation of the Quality of Structural Constructions and the Reliability of Identified Objects Based on CDP Seismic Reflection Method, 1984" [55].

As can be seen from Table 6, the structural constructions, as well as the previously calculated boundary values of the $|A_D - A_P|$ parameter, have a minimum error at the overlying horizons and a maximum error at the underlying horizons.

For comparison, Table 6 shows the error values of structural constructions for the northern part of the Perm Krai (according to data from nine reports on the results of 3D seismic exploration works carried out at the same time).

The southern part of the Perm Krai is characterized by little difference between the average value of structural constructions accuracy calculated by the results of 3D seismic exploration work and the boundary value $|A_D - A_P|$ (for reflecting horizon III – no more than 4.9 m, for II^P – 0.9 m, for II^E – 2.6 m, for I^P – 2.6 m, for I^E – 1.8 m), while for the northern part of the Perm Krai it is characterized by a large one (for reflecting horizon III – no more than 14.9 m, for II^P – 11.7 m, for II^E – 14.7 m, for I^P – 14.8 m, for I^E – 7.9 m).

The small difference between the average value of the structural constructions accuracy calculated by the results of 3D CDP seismic surveys for the southern part of the Perm Krai and the boundary value $|A_D - A_P|$ obtained in this study allows us to conclude that the southern part of the Perm Krai is more thoroughly studied compared to its northern part. It also confirms the applicability of the geo-statistical methods used, which support the conformity of structural plans of the main reflecting horizons, mainly for the southern part of the Perm Krai.

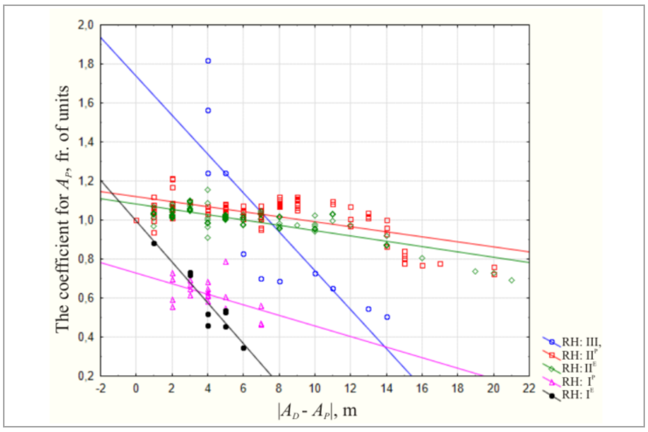

Fig. 2.Combined Correlation Field $k(A_P) = f(|A_D - A_P|)$ according to the results of regression analysis

Conclusion

This study examined one of the options for developing a geo-statistical approach to assessing the accuracy of structural constructions of the studied sample based on the analysis of structure amplitudes dependencies according to prospecting and appraisal drilling data on various geo-morphological parameters. For each model, the nature and degree of significant parameters influence on the confirmability of the amplitude by drilling were determined and described.

This approach allowed us to draw conclusions about the degree of territory study under consideration. Based on the results obtained, it was concluded that the structural plans of reflecting horizons in the southern part of the Perm Krai correspond to each other. Thus, in the southern part of the Perm Krai can be observed a correspondence of structural plans separately for pairs of reflecting horizons IIP – IIE and IP – IE and a mismatch of their plans with the structural plan of reflecting horizon III, which confirms the geological structure concept of the studied territory.

The obtained boundary values of discrepancies were compared with the errors of structural constructions assessed by the results of 3D CDP seismic exploration in the Perm Krai. Based on this, conclusions were drawn that the southern part of the Perm Krai is more thoroughly studied compared to its northern part

This geo-statistical approach can be used to clarify the risks associated with the problem of geo-morphological characteristics unconfirmability of structures by deep drilling.

References

1. Nechaeva N.Iu., Makalovskii V.V., Iakovlev Iu.A., Raspopov A.V., Chetyrkin A.I., Kylosova N.I. Geologo-ekonomicheskaia otsenka neftegazovykh ob"ektov (na primere Permskogo kraia) [Geological and economic assessment of oil and gas facilities (using the example of the Perm Krai)]. Perm': Presstaim, 2006, 146 p.
2. Vinnikovskii S.A., Sharonov L.V. Zakonomernosti razmeshcheniia i uslovii formirovaniia zalezhei nefti i gaza Volgo-Ural'skoi oblasti - Tom II. Permskaia oblast' i Udmurtskaia ASSR [Patterns of placement and conditions of formation of oil and gas deposits in the Volga-Ural region - Volume II. Perm region and Udmurt Autonomous Soviet Socialist Republic]. Moscow: Nedra, 1977, 272 p.
3. Voevodkin V.L., Galkin V.I., Krivoshchekov S.N. Issledovanie vliianiia kriteriev neftegazonosnosti i izuchennosti territorii Permskogo kraia na raspredelenie mestorozhdenii uglevodorodov [Investigation of the influence of oil and gas content criteria and geological and geophysical knowledge on the distribution of hydrocarbon deposits in the Perm Region]. *Neftianoe khoziaistvo*, 2012, no. 6, pp. 30-34.
4. Vinnikovskii C.A. et al. Geologicheskoe stroenie Kamsko-Kinel'skoi vpadiny v sviazi s neftegazonosnost'iu i uglenosnost'iu Permskogo oblasti [Geological structure of the Kama-Kinel depression in connection with the oil and gas and coal content of the Perm region]. *Geologiia i neftegazonosnost' Kamsko-Kinel'skikh progibov*. Kazan': Kazanskii universitet, 1970.
5. Makalovskii V.V. Novye predstavleniia o geologicheskom stroenii i obosnovanie napravlenii neftepoiskovykh rabot v Permskom Priural'e [New ideas about the geological structure and justification of the directions of oil exploration work in the Perm Urals]. Ph. D. thesis. Perm', 1985, 187 p.
6. Nosov M.A., Galkin V.I., Krivoshchekov S.N., Melkishev O.A. Otlozheniia domanikovogo tipa - vozmozhnyi istochnik netraditsionnykh uglevodorodov dlia Permskogo kraia: obzor, perspektivy, rekomendatsii [Domanic type deposits – target object of prospecting works]. *Neftianoe khoziaistvo*, 2012, no. 10, pp. 90-91.
7. Shershnev K.S., Blaginykh L.L., Dulepov Iu.A. et al.Osobennosti geologicheskogo stroeniia i neftenosnost' Kamsko-Kinel'skikh progibov na territorii Permskoi oblasti [Features of the geological structure and oil-bearing capacity of the Kama-Kinel troughs in the Perm region]. *Geologiia i osvoenie resursov nefti v Kamsko-Kinel'skoi sisteme progibov.* Moscow: Nauka, 1991, pp. 79-84.
8. Provorov V.M. Istoriia geologicheskogo razvitiia territorii Permskoi oblasti [History of geological development of the territory of the Perm region]. *Obshchaia i regional'naia geologiia, geologiia morei i okeanov, geologicheskoe kartirovanie: obzor OOO Geoinformtsentr*. Moscow, 2003, 38 p.
9. Zhukov Iu.A. Analiz i utochnenie syr'evoi bazy nefti, gaza i kondensata Permskoi oblasti: otchet o NIR [Analysis and clarification of the raw material base of oil, gas and condensate in the Perm region: research report]. Perm': PermNIPIneft', 2000.
10. Varushkin S.V., Chukhlov A.S. Kompleksirovanie rezul'tatov geologo-geofizicheskikh issledovanii v tseliakh povysheniia effektivnosti geologorazvedochnykh rabot [Integration of results of geological and geophysical studies in order to improve the efficiency of geological exploration work]. *Geologiia v razvivaiushchemsia mire. Materialy 11 Mezhdunarodnoi nauchno-prakticheskoi konferentsii studentov, aspirantov i molodykh uchenykh.* Ed. A.B. Trapeznikova. Perm': Permskii gosudarstvennyi natsional'nyi issledovatel'skii universitet, 2018, vol. 1, pp. 213-217.
11. Galkin V.I., Suvorova A.S. Razrabotka statisticheskoi modeli prognoza podtverzhdaemosti amplitud struktur, podgotovlennykh po otlozheniiam srednego karbona na territorii Permskogo kraia [Development of a statistical model for predicting the confirmability of the amplitudes of structures prepared from the deposits of the middle carboniferous in the Perm region]. *Izvestiia Tomskogo politekhnicheskogo universiteta. Inzhiniring georesursov*, 2023, vol. 334, no. 8, pp. 129-136. DOI: 10.18799/24131830/2023/8/4065
12. Galkin S.V. Veroiatnostnyi prognoz geologicheskikh riskov pri poiskakh mestorozhdenii nefti i gaza [Probabilistic forecast of geological risks in oil and gas exploration]. Perm': Knizhnyi mir, 2009, 224 p.
13. Galkin S.V. Opyt i rezul'taty primeneniia veroiatnostno-statisticheskikh kriteriev pri otsenke perspektiv neftegazanosnosti antiklinal'nykh ob"ektov Permskoi oblasti [Experience and results of application of probabilistic-statistical criteria in assessment of oil and gas potential of anticlinal objects of Perm region]. *Geologiia, geofizika i razrabotka neftianykh mestorozhdenii*, 2002, no. 3, pp. 4-9.
14. Galkin V.I., Alekseev A.O., Solov'ev S.I. Razrabotka statisticheskoi modeli dlia otsenki stepeni perspektivnosti priobreteniia neftianogo uchastka (na primere territorii Permskogo kraia) [Development of the statistical model to assess the prospects of an oil site acquisition (the Perm region territory is taken as an example)]. *Geologiia, geofizika i razrabotka neftianykh i gazovykh mestorozhdenii*, 2016, no. 1, pp. 29-32.

15. Galkin V.I., Solov'ev S.I. Raionirovanie territorii Permskogo kraia po stepeni perspektivnosti priobreteniia neftianykh uchastkov nedr [Classification of Perm krai areas according to prospectivity for oil fields acquisition]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2015, no. 16, pp. 14-23. DOI: 10.15593/2224-9923/2015.16.2
16. Iakovlev Iu.A., Melkomukov V.V., Makalovskii V.V. O pereotsenke resursov i ranzhirovanii fonda vyiavlennykh i podgotovlennykh struktur Permskogo kraia [On the revaluation of resources and ranking of the fund of identified and prepared structures of the Perm Territory]. *Geologiia, geofizika i razrabotka neftianykh i gazovykh mestorozhdenii*, 2007, no. 9, pp. 4-6.
17. Galkin V.I., Rastegaev A.V., Galkin S.V., Voevodkin V.L. Opredelenie perspektivnykh napravlenii poiskov mestorozhdenii nefti i gaza v Permskom krae s pomoshch'iu veroiatnostno-statisticheskikh metodov [Determination of promising directions for oil and gas field exploration in the Perm region using probabilistic statistical methods]. *Nauka - proizvodstvu*, 2006, no. 1, pp. 1-5.
18. Galkin V.I., Shurubor O.A., Rastegaev A.V., Galkin S.V. Otsenka effektivnosti lokal'nogo prognoza neftegazonosnosti na territorii Permskoi oblasti [Efficiency estimation of local petroleum forecast in the Perm region]. *Vestnik Permskogo gosudarstvennogo tekhnicheskogo universiteta. Neft' i gaz*, 2000, vol. 2, no. 3, pp. 28-34.
19. Galkin V.I., Rastegaev A.V., Galkin S.V. Prognoznaia otsenka podtverzhdaemosti struktur, podgotovlennykh seismorazvedkoi [Predictive estimates of structures confirmability prepared with seismic]. *Vestnik Permskogo gosudarstvennogo tekhnicheskogo universiteta. Neft' i gaz*, 2000, vol. 2, no. 4, pp. 19-24.
20. Putilov I.S., Galkin V.I. Razrabotka metodiki veroiatnostno-statisticheskogo prognoza neftegazonosnosti lokalizovannykh struktur (na primere iuzhnoi chasti Permskogo kraia) [Developing the technology for probabilistic and statistical forecast of oil-and-gas-bearing capacity of the South Perm Region]. *Neftianoe khoziaistvo*, 2014, no. 4, pp. 26-29.
21. Rastegaev A.V. Nauchnoe obosnovanie metodov prognoza podtverzhdaemosti struktur, podgotovlennykh seismorazvedkoi k glubokomu neftepoiskovomu bureniiu [Scientific substantiation of methods for predicting the confirmability of structures prepared by seismic exploration for deep oil exploration drilling]. Ph. D. thesis. Perm', 2000.
22. Rastegaev A.V. Prognozirovanie podtverzhdaemosti struktur, podgotovlennykh seismorazvedkoi, na primere Bymsko-Kungurskoi vpadiny [Structures verifiability prediction, prepared with seismic on the example Bymsko-Kungurskaya structural low]. *Vestnik Permskogo gosudarstvennogo tekhnicheskogo universiteta. Neft' i gaz*, 2000, vol. 2, no. 3, pp. 3-7.
23. Sosnin N.E. Razrabotka statisticheskikh modelei dlia prognoza neftenosnosti (na primere terrigennykh devonskikh otlozhenii Severo-Tatarskogo svoda) [Development of statistical models for predicting oil-and-gas content (on the example of terrigenous Devonian sediments of North Tatar arch)]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2012, no. 5, pp. 16-25.
24. Shaikhutdinov A.N. Razrabotka veroiatnostnykh modelei dlia prognoza neftegazonosnosti verkhneiurskikh otlozhenii (na primere territorii deiatel'nosti TPP "Kogalymneftegaz") [Probabilistic models construction for prediction of oil and gas potential of Upper Jurassic deposits (exemplified by the BU Kogalymneftegaz activity area)]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2014, no. 11, pp. 11-28. DOI: 10.15593/2224-9923/2014.11.2
25. Galkin V.I., Karaseva T.V., Kozlova I.A., Nosov M.A., Krivoshchekov S.N. Differentsirovannaia veroiatnostnaia otsenka generatsionnykh protsessov v otlozheniiakh domanikovogo tipa Permskogo kraia [Differentiated probabilistic assessment of the generation processes in Domanic sediments of Perm region]. *Neftianoe khoziaistvo*, 2014, no. 12, pp. 103-105.
26. Galkin V.I., Kozlova I.A., Krivoshchekov S.N., Melkishev O.A. K obosnovaniiu postroeniia modelei zonal'nogo prognoza neftegazonosnosti dlia nizhne-srednevizeiskogo kompleksa Permskogo kraia [On the justification of the construction of models for oil and gas potential area forecast Visean deposits of Perm region]. *Neftianoe khoziaistvo*, 2015, no. 8, pp. 32-35.
27. Merson M.E., Voevodkin V.L., Galkin V.I., Rastegaev A.V., Kozlova I.A. K voprosu postroeniia geologo-matematicheskikh modelei sootnoshenii promyshlennykh zapasov i resursov dlia territorii Permskoi oblasti [On the issue of constructing geological and mathematical models of the relationship between industrial reserves and resources for the territory of the Perm region]. *Geologiia, geofizika i razrabotka neftianykh i gazovykh mestorozhdenii*, 2005, no. 9-10, pp. 15-18.
28. Koshkin K.A. Razrabotka veroiatnostno-statisticheskikh modelei dlia otsenki perspektiv neftegazonosnosti plastov Tl2-b i Bb Pozhvinskogo uchastka [Development of probabilistic and statistical models for evaluation of oil and gas potential of $Tl_{2\text{-}b}$ and Bb reservoirs of Pozhvinskiy sector]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2018, vol. 17, no. 1, pp. 4-16. DOI: 10.15593/2224-9923/2018.1.1
29. Krivoshchekov S.N. Razrabotka regional'no-zonal'nykh kriteriev prognoza neftegazonosnosti territorii Permskogo Prikam'ia veroiatnostno-statisticheskimi metodami [Establishment of regional and zonal criteria of Perm Region`s oil forecast probabilistic and statistical methods]. *Neftianoe khoziaistvo*, 2011, no. 10, pp. 10-14.
30. Krivoshchekov S.N., Galkin V.I., Kozlova I.A. Opredelenie perspektivnykh uchastkov geologorazvedochnykh rabot na neft' veroiatnostno-statisticheskimi metodami na primere territorii Permskogo kraia [Determination of potentially oil bearing areas by behavioristical method by the example of Perm region (krai)]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2012, no. 4, pp. 7-14.
31. Krivoshchekov S.N., Kochnev A.A., Sannikov I.V. Perspektivy neftegazonosnosti otlozhenii domanikovogo tipa na territorii Permskogo kraia [Oil and gas prospects of domanic sediments in Perm krai]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2013, no. 9, pp. 18-26. DOI: 10.15593/2224-9923/2013.9.2
32. Krivoshchekov S.N., Nosov M.A., Petrov A.N. Primenenie veroiatnostno-statisticheskikh metodov pri zonal'nom prognoze neftegazonosnosti vizeiskikh otlozhenii iugo-vostoka Permskogo kraia [Application of probabilistic-statistical methods in zonal forecast of oil and gas potential of Visean deposits in the south-east of Perm Krai]. *Nauchnye issledovaniia i innovatsii*, 2010, vol. 4, no. 1, pp.16-20.
33. Melkishev O.A. Vydelenie i ispol'zovanie antiklinal'nykh i sinklinal'nykh oblastei dlia zonal'nogo prognoza neftegazonosnosti (na primere otlozhenii vizeiskogo terrigennogo neftegazonosnogo kompleksa na iuge Permskogo kraia) [Identification and use of anticlinal and synclinal areas for petroleum potential zonal prediction (by the example of deposits of Visean terrigene oil and gas complex in the South of Perm territory)]. *Neftepromyslovoe delo*, 2015, no. 6, pp. 15-19.
34. Melkishev O.A. Issledovanie osobennostei raspredeleniia neftegazonosnosti na iuge Permskogo kraia (v predelakh Bashkirskogo svoda) [Study of the distribution features of oil and gas potential in the south of Perm Krai (within the Bashkir arch)]. *Problemy razrabotki mestorozhdenii uglevodorodnykh i rudnykh poleznykh iskopaemykh*, 2014, no. 1, pp. 48-51.
35. Melkishev O.A., Galkin V.I., Kozhevnikova E.E., Karaseva T.V. Zonal'nyi prognoz neftegazonosnosti devonskogo terrigennogo neftegazonosnogo kompleksa na iuge Permskogo kraia [Prediction of zonal hydrocarbon potentials Devonian clastic sediments on the south of Perm region]. *Neftianoe khoziaistvo*, 2014, no. 6, pp. 4-8.
36. Merson M.E., Galkin V.I., Rastegaev A.V. Ispol'zovanie geologo-matematicheskikh metodov dlia prognoza neftegazonosnosti lokal'nykh struktur [Use of geological and mathematical methods for forecasting oil and gas potential of local structures]. Perm': Permskii gosudarstvennyi tekhnicheskii universitet, 2006, 291 p.
37. Armstrong, M. Basic Linear Geostatistics. Springer, 1998, 155 p.
38. Horne R.N. Modern well test analysis: A computer Aided Approach. 2nd ed. Palo Alto: PetrowayInc, 2006, 257 p.
39. Houze O., Viturat D., Fjaere O.S. Dinamie data analysis. Paris: Kappa Engineering, 2008, 694 p.
40. Huber P.J. Robust statistics procedures. Philadelphia: SIAM, 1977, 56 p.
41. Huber P.J. Robust statistics. N.Y.: Wiley, 308 p.
42. Isaaks E.H., Srivastava R.M. An Introduction to Applied Geostatistics. Oxford University Press, 1989, 561 p.
43. Kaufman M.G. Statistical issues in the assessment of undiscovered oil and gas resources. MITCEEPR, 1992, 30 p.
44. Montgomery D.C., Peck E.A. Introduction to liner regression analysis. New York: John Wiley & Sons, 1982, 504 p.
45. Dem'ianov V.V., Savel'eva E.A. Geostatistika: teoriia i praktika [Geostatistics: Theory and Practice]. Ed. R.V. Arutiunian. Moscow: Nauka, 2010, 327 p.
46. Savel'ev A.A., Mukharamova S.S., Piliugin A.G., Chizhikova N.A. Geostatisticheskii analiz dannykh v ekologii i prirodopol'zovanii (s primeneniem paketa R) [Geostatistical analysis of data in ecology and nature management (using the R package)]. Kazan': Kazanskii universitet, 2012, 120 p.
47. Davydenko A.Iu. Veroiatnostno-statisticheskie metody v geologo-geofizicheskikh prilozheniiakh [Probabilistic-statistical methods in geological and geophysical applications]. Irkutsk, 2007, 29 p.
48. Devis Dzh.S. Statisticheskii analiz dannykh v geologii [Statistical analysis of data in geology]. Moscow: Nedra, 1990. book 1, 319 p.
49. Devis Dzh.S. Statisticheskii analiz dannykh v geologii [Statistical analysis of data in geology]. Moscow: Nedra, 1990, book 2, 426 p.
50. Dement'ev L.F. Matematicheskie metody i EVM v neftegazovoi geologii [Mathematical methods and computers in oil and gas geology]. Moscow: Nedra, 1983.
51. Dement'ev L.F. Sistemnye issledovaniia v neftegazopromyslovoi geologii [Systematic research in oil and gas field geology]. Moscow: Nedra, 1988, 204 p.
52. Dem'ianov V.V., Kanevskii M.F., Savel'eva E.A., Timonin V.A., Chernov S.Iu. Kriging i bazovye modeli geostatistiki [Kriging and Basic Geostatistical Models]. Moscow, VINITI, 1999, 13 p.
53. Galkin V.I., Rastegaev A.V. O neobkhodimosti ucheta geologo-tektonicheskikh uslovii pri podgotovke struktur k glubokomu bureniiu seismorazvedkoi [The need to integrate geologotectonic conditions in preparing stuktura for deep drilling with seismic]. *Vestnik Permskogo gosudarstvennogo tekhnicheskogo universiteta. Neft' i gaz*, 2000, vol. 2, no. 3, pp. 13-18.
54. Lunev V.G. Razrabotka i sovershenstvovanie metodov prognozirovaniia nefteperspektivnykh ob"ektov v vizeiskoi terrigennoi tolshche Permskogo Prikam'ia na osnove seismogeologicheskogo modelirovaniia i seismofatsial'nogo analiza [Development and improvement of methods for forecasting oil-promising objects in the Visean terrigenous strata of the Perm Kama region based on seismogeological modeling and seismic facies analysis]. Ph. D. thesis. Perm', 1986.
55. Instruktsiia po otsenke kachestva strukturnykh postroenii i nadezhnosti vyiavlennykh i podgotovlennykh ob"ektov po dannym seismorazvedki MOV-OGT (pri rabotakh na neft' i gaz) [Instructions for assessing the quality of structural constructions and the reliability of identified and prepared objects based on seismic exploration data (in oil and gas operations)]. Moscow: VNIIGeofizika, 1984.

Библиографический список

1. Геолого-экономическая оценка нефтегазовых объектов (на примере Пермского края) / Н.Ю. Нечаева, В.В. Макаловский, Ю.А. Яковлев, А.В. Распопов, А.И. Четыркин, Н.И. Кылосова. – Пермь: ООО «Издательский дом «Пресстайм», 2006 – 146 с.
2. Винниковский, С.А. Закономерности размещения и условий формирования залежей нефти и газа Волго-Уральской области. – Т.II. Пермская область и Удмуртская АССР / С.А. Винниковский, Л.В. Шаронов. – М.: Недра, 1977. – 272 с.
3. Воеводкин, В.Л. Исследование влияния критериев нефтегазоносности и изученности территории Пермского края на распределение месторождений углеводородов / В.Л. Воеводкин, В.И. Галкин, С.Н. Кривощеков // Нефтяное хозяйство. – 2012. – № 6. – С. 30–34.
4. Геологическое строение Камско-Кинельской впадины в связи с нефтегазоносностью и угленосностью Пермского области / С.А. Винниковский [и др.] // Геология и нефтегазоносность Камско-Кинельских прогибов. – Казань: Изд-во Казан. ун-та, 1970.
5. Макаловский, В.В. Новые представления о геологическом строении и обоснование направлений нефтепоисковых работ в Пермском Приуралье: дис. … канд. геол.-мин. Наук / В.В. Макаловский. – Пермь, 1985 – 187 с.
6. Отложения доманикового типа – возможный источник нетрадиционных углеводородов для Пермского края: обзор, перспективы, рекомендации / М.А. Носов, В.И. Галкин, С.Н. Кривощеков, О.А. Мелкишев // Нефтяное хозяйство. – 2012. – №10. – С. 90–91.
7. Особенности геологического строения и нефтеносность Камско-Кинельских прогибов на территории Пермской области / К.С. Шершнев, Л.Л. Благиных, Ю.А. Дулепов [и др.] // – Геология и освоение ресурсов нефти в Камско-Кинельской системе прогибов. – М.: Наука, 1991ю – С. 79–84.
8. Проворов, В.М. История геологического развития территории Пермской области / В.М. Проворов // Общая и региональная геология, геология морей и океанов, геол. Картирование: обзор ООО Геоинформцентр. – М., 2003. – 38 с.
9. Жуков, Ю.А. Анализ и уточнение сырьевой базы нефти, газа и конденсата Пермской области: отчет о НИР / Ю.А. Жуков. – Пермь: ПермНИПИнефть, 2000.
10. Варушкин, С.В. Комплексирование результатов геолого-геофизических исследований в целях повышения эффективности геологоразведочных работ / С.В. Варушкин, А.С. Чухлов // Геология в развивающемся мире: матер. 11-й Междунар. науч.-практ. конф. студентов, аспирантов и молодых ученых: в 3 кн. / отв. ред. А.Б. Трапезникова. – Пермь: ПГНИУ, 2018 – Т.1. – С. 213–217.
11. Галкин, В.И. Разработка статистической модели прогноза подтверждаемости амплитуд структур, подготовленных по отложениям среднего карбона на территории Пермского края / В.И. Галкин, А.С. Суворова // Известия Томского политехнического университета. Инжиниринг георесурсов. – 2023. – Т. 334, № 8. – С. 129–136. DOI: 10.18799/24131830/2023/8/4065

12. Галкин, С.В. Вероятностный прогноз геологических рисков при поисках месторождений нефти и газа / С.В. Галкин. – Пермь: Книжный мир, 2009. – 224 с.
13. Галкин, С.В. Опыт и результаты применения вероятностно-статистических критериев при оценке перспектив нефтегазаносности антиклинальных объектов Пермской области / С.В. Галкин // Геология, геофизика и разработка нефтяных месторождений. – 2002. – № 3. – С. 4–9.
14. Галкин, В.И. Разработка статистической модели для оценки степени перспективности приобретения нефтяного участка (на примере территории Пермского края) / В.И. Галкин, А.О. Алексеев, С.И. Соловьев // Геология, геофизика и разработка нефтяных и газовых месторождений. – 2016 – №1. – С. 29–32.
15. Галкин, В.И. Районирование территории Пермского края по степени перспективности приобретения нефтяных участков недр / В.И. Галкин, С.И. Соловьев // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2015 – №16. – С. 14–23. DOI: 10.15593/2224-9923/2015.16.2
16. Яковлев, Ю.А. О переоценке ресурсов и ранжировании фонда выявленных и подготовленных структур Пермского края / Ю.А. Яковлев, В.В. Мелкомуков, В.В. Макаловский // Геология, геофизика и разработка нефтяных и газовых месторождений. – 2007 – №9. – С. 4–6.
17. Определение перспективных направлений поисков месторождений нефти и газа в Пермском крае с помощью вероятностно-статистических методов / В.И. Галкин, А.В. Растегаев, С.В. Галкин, В.Л Воеводкин. // Наука - производству. – 2006. – № 1. – С. 1–5.
18. Оценка эффективности локального прогноза нефтегазоносности на территории Пермской области / В.И. Галкин, О.А. Шурубор, А.В. Растегаев, С.В. Галкин // Вестник Пермского государственного технического университета. Нефть и газ. – 2000. – Т. 2, № 3. – С. 28–34.
19. Галкин, В.И. Прогнозная оценка подтверждаемости структур, подготовленных сейсморазведкой / В.И. Галкин, А.В. Растегаев, С.В. Галкин // Вестник Пермского государственного технического университета. Нефть и газ. – 2000. – Т. 2. – № 4. – С. 19–24.
20. Путилов, И.С. Разработка методики вероятностно-статистического прогноза нефтегазоносности локализованных структур (напримере южной части Пермского края) / И.С. Путилов, В.И. Галкин // Нефтяное хозяйство. – 2014. – №4. – С. 26–29.
21. Растегаев, А.В. Научное обоснование методов прогноза подтверждаемости структур, подготовленных сейсморазведкой к глубокому нефтепоисковому бурению : дис. ... д-р. геол.-мин. наук / А.В. Растегаев. – Пермь, 2000.
22. Растегаев, А.В. Прогнозирование подтверждаемости структур, подготовленных сейсморазведкой, на примере Бымско-Кунгурской впадины / А.В. Растегаев // Вестник Пермского государственного технического университета. Нефть и газ. – 2000. – Т. 2, № 3. – С. 3–7.
23. Соснин, Н.Е. Разработка статистических моделей для прогноза нефтеносности (на примере терригенных девонских отложений Северо-Татарского свода) / Н.Е. Соснин // Вестник Пермского научно-исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2012. – № 5. – С. 16–25.
24. Шайхутдинов, А.Н. Разработка вероятностных моделей для прогноза нефтегазоносности верхнеюрских отложений (на примере территории деятельности ТПП «Когалымнефтегаз») / А.Н. Шайхутдинов // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2014. – № 11. – С. 11–28. DOI: 10.15593/2224-9923/2014.11.2
25. Дифференцированная вероятностная оценка генерационных процессов в отложениях доманикового типа Пермского края / В.И. Галкин, Т.В. Карасева, И.А. Козлова, М.А. Носов, С.Н. Кривощеков // Нефтяное хозяйство. – 2014. – № 12. – С. 103–105.
26. К обоснованию построения моделей зонального прогноза нефтегазоносности для нижне-средневизейского комплекса Пермского края / В.И. Галкин, И.А. Козлова, С.Н. Кривощеков, О.А. Мелкишев // Нефтяное хозяйство. – 2015. – № 8 – С. 32–35.
27. К вопросу построения геолого-математических моделей соотношений промышленных запасов и ресурсов для территории Пермской области / М.Э. Мерсон, В.Л. Воеводкин, В.И. Галкин, А.В. Растегаев, И.А. Козлова // Геология, геофизика и разработка нефтяных и газовых месторождений. – 2005. – № 9–10. – С. 15–18.
28. Кошкин, К.А. Разработка вероятностно-статистических моделей для оценки перспектив нефтегазоносности пластов Тл2-б и Бб Пожвинского участка / К.А. Кошкин // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2018. – Т. 17, № 1. – С. 4–16. DOI: 10.15593/2224-9923/2018.1.1
29. Кривощеков, С.Н. Разработка регионально-зональных критериев прогноза нефтегазоносности территории Пермского Прикамья вероятностно-статистическими методами / С.Н. Кривощеков // Нефтяное хозяйство. – 2011. – № 10. – С. 10–14.
30. Кривощеков, С.Н. Определение перспективных участков геологоразведочных работ на нефть вероятностно-статистическими методами на примере территории Пермского края / С.Н. Кривощеков, В.И. Галкин, И.А. Козлова // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2012. – №4. – С. 7–14.
31. Кривощѐков, С.Н. Перспективы нефтегазоносности отложений доманикового типа на территории Пермского края / С.Н. Кривощѐков, А.А. Кочнев, И.В. Санников // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2013. – № 9 – С. 18–26. DOI: 10.15593/2224-9923/2013.9.2
32. Кривощеков, С.Н. Применение вероятностно-статистических методов при зональном прогнозе нефтегазоносности визейских отложений юго-востока Пермского края / С.Н. Кривощеков, М.А. Носов, А.Н. Петров // Научные исследования и инновации. – 2010 – Т.4, №1. – С.16–20.
33. Мелкишев, О.А. Выделение и использование антиклинальных и синклинальных областей для зонального прогноза нефтегазоносности (на примере отложений визейского терригенного нефтегазоносного комплекса на юге Пермского края) / О.А. Мелкишев // Нефтепромысловое дело. – 2015 – № 6 – С. 15–19.
34. Мелкишев, О.А. Исследование особенностей распределения нефтегазоносности на юге Пермского края (в пределах Башкирского свода) / О.А. Мелкишев // Проблемы разработки месторождений углеводородных и рудных полезных ископаемых. – 2014. – № 1. – С. 48–51.
35. Зональный прогноз нефтегазоносности девонского терригенного нефтегазоносного комплекса на юге Пермского края / О.А. Мелкишев, В.И. Галкин, Е.Е. Кожевникова, Т.В. Карасева // Нефтяное хозяйство. –2014. – № 6. – С. 4–8.
36. Мерсон, М.Э. Использование геолого-математических методов для прогноза нефтегазоносности локальных структур: учебное пособие / М.Э. Мерсон, В.И. Галкин, А.В. Растегаев. – Пермь: Изд-во Пермского государственного технического университета, 2006. – 291 с.
37. Armstrong, M. Basic Linear Geostatistics / M. Armstrong. – Springer, 1998. – 155 p.
38. Horne, R.N. Modern well test analysis: A computer Aided Approach / R.N. Horne. – 2nd ed. – Palo Alto: PetrowayInc, 2006 – 257 p.
39. Houze, O. Dinamie data analysis / O. Houze, D. Viturat, O.S. Fjaere. – Paris: Kappa Engineering, 2008 – 694 p.
40. Huber, P.J. Robust statistics procedures / P.J. Huber. – Philadelphia: SIAM, 1977. – 56 p.
41. Huber, P.J. Robust statistics / P.J. Huber. – N.Y.: Wiley. – 308 p.
42. Isaaks, E.H. An Introduction to Applied Geostatistics / E.H. Isaaks, R.M. Srivastava. – Oxford University Press, 1989 – 561 p.
43. Kaufman, M.G. Statistical issues in the assessment of undiscovered oil and gas resources / M.G. Kaufman. – MITCEEPR, 1992 – 30 p.
44. Montgomery, D.C. Introduction to liner regression analysis / D.C. Montgomery, E.A. Peck. – New York: John Wiley & Sons, 1982. – 504 p.
45. Геостатистика: теория и практика / В. В. Демьянов, Е. А. Савельева; под ред. Р. В. Арутюняна; Ин-т проблем безопасного развития атомной энергетики РАН. – М.: Наука, 2010. – 327 с.
46. Геостатистический анализ данных в экологии и природопользовании (с применением пакета R) / А.А. Савельев, С.С. Мухарамова, А.Г. Пилюгин, Н.А. Чижикова. – Казань: Казанский университет, 2012. – 120 с.
47. Давыденко, А.Ю. Вероятностно-статистические методы в геолого-геофизических приложениях / А.Ю. Давыденко. – Иркутск, 2007. – 29 с.
48. Девис, Дж.С. Статистический анализ данных в геологии / Дж.С. Девис. – М.: Недра, 1990. – Кн. 1. – 319 с.
49. Девис, Дж.С. Статистический анализ данных в геологии / Дж.С. Девис. – М.: Недра, 1990. – Кн. 2– 426 с.
50. Дементьев, Л.Ф. Математические методы и ЭВМ в нефтегазовой геологии: учеб. пособие для вузов / Л.Ф. Дементьев. – М.: Недра, 1983.
51. Дементьев, Л.Ф. Системные исследования в нефтегазопромысловой геологии: учеб. пособие для вузов / Л.Ф. Дементьев. – М.: Недра, 1988. – 204 с.
52. Кригинг и базовые модели геостатистики / В.В. Демьянов, М.Ф. Каневский, Е.А. Савельева, В.А. Тимонин, С.Ю. Чернов. – М., ВИНИТИ, 1999. – 13 с.
53. Галкин, В.И. О необходимости учета геолого-тектонических условий при подготовке структур к глубокому бурению сейсморазведкой / В.И. Галкин, А.В. Растегаев // Вестник Пермского государственного технического университета. Нефть и газ. – 2000. – Т. 2, № 3. – С. 13–18.
54. Лунев, В.Г. Разработка и совершенствование методов прогнозирования нефтеперспективных объектов в визейской терригенной толще Пермского Прикамья на основе сейсмогеологического моделирования и сейсмофациального анализа: дис. … канд. геол.-мин. наук / Лунев Владимир Георгиевич. – Пермь, 1986.
55. Инструкция по оценке качества структурных построений и надежности выявленных и подготовленных объектов по данным сейсморазведки МОВ-ОГТ (при работах на нефть и газ) / ВНИИГеофизика. – М., 1984.

Funding. The study had no sponsorship.
Conflict of interest. The author declares no conflict of interest.
The author's contribution is 100 %.