ISSN 2712-8008
Volume / Том 21 №3 2021
Journal Homepage: http://vestnik.pstu.ru/geo/

Perm Journal of Petroleum and Mining Engineering

UDC 622.553
Article / Статья

Development of Statistical Models for Predicting Circulation Losses Based on Characteristics of Faults

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Разработка статистических моделей для прогноза поглощений по характеристикам разрывных нарушений

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Received / Получена: 30.01.2021. Accepted / Принята: 30.04.2021. Published / Опубликована: 01.07.2021

Keywords:
faults, losses, drilling operations, oil and gas reservoirs, distance to the fault, seismic exploration, tectonic structure, statistical analysis, loss probability, statistical criteria, Student's *t*-test, probabilistic-statistical model, loss forecast, Usinskoye field, Timan-Pechora oil and gas province.

A method for predicting losses over the area of the deposit to minimize the risks of accidents, gas, oil and water showings for the Permian-Carboniferous reservoir of the Usinskoye field was developed. In addition, the analysis of the influence of faults on the number of losses in wells during drilling was carried out.
By analyzing results of drilling more than 250 wells, it was revealed that the circulation loss is a major problem during drilling. This problem was found in 46 % of the drilled wells. The intensity of the studied losses was in a wide range: from insignificant losses to strong ones, with a complete loss of mud circulation. The faults identified both from well drilling data and from seismic data were characterized by a various number of wells with and without losses.
By using a combination of various statistical methods, individual and complex models for predicting losses in wells depending on the distance from the fault were obtained.
The multilevel probabilistic-statistical modeling made it possible to study the influence of faults on losses: initially, based on the data of all the wells, regardless of the methods for identifying faults - the first-level model; by the method of identifying faults (drilling/seismic exploration) - the second-level models; according to the data of individual faults - the models of the third level. At the fourth level, a complex model was built, which takes into account the calculation results obtained at the previous levels of statistical modeling.
The presence of direct and inverse dependences of the absorption probability from the shortest distance to the fault was found.
We used the linear discriminant analysis to verify the results of predicting the probability of absorptions.

Ключевые слова:
разрывные нарушения, поглощение, буровые работы, коллекторы нефти и газа, расстояние до разлома, сейсморазведка, тектоническое строение, статистический анализ, вероятность поглощения, статистические критерии, *t*-критерий Стьюдента, вероятностно-статистическая модель, прогноз поглощений, Усинское месторождение, Тимано-Печорская нефтегазоносная провинция.

Разработан способ прогнозирования поглощений по площади залежи для минимизации рисков аварий и газонефтеводопроявлений для пермокарбоновой залежи Усинского месторождения. Кроме того, осуществлен анализ влияния разрывных нарушений на количество поглощений в скважинах во время бурения.
По результатам проведенного анализа результатов бурения более 250 скважин выявлено, что значительной проблемой при бурении явилось поглощение бурового раствора. Данное осложнение обнаруживается в 46 % пробуренных скважинах. Интенсивность изучаемых поглощений находится в широком диапазоне: от незначительных поглощений до сильных, с полной потерей циркуляции бурового раствора. Разломы, выделенные как по данным бурения скважин, так и по данным сейсморазведки, характеризуются различным количеством скважин с поглощениями и без таковых.
При помощи совместного использования различных статистических методов получены индивидуальные и комплексные модели прогноза поглощений в скважинах в зависимости от расстояния от разлома.
С помощью многоуровневого вероятностно-статистического моделирования выполнено исследование влияния разломов на поглощения: первоначально по данным всех скважин, независимо от методов выделения разломов, – модели первого уровня; по способу выделения разломов (бурение/сейсморазведка) – модели второго уровня; по данным отдельных разломов – модели третьего уровня. На четвертом уровне строится комплексная модель, которая учитывает результаты расчетов, полученные на предыдущих уровнях статистического моделирования.
Установлено наличие прямых и обратных зависимостей вероятности поглощений от кратчайшего расстояния до разлома.
С использованием линейного дискриминантного анализа проведена проверка результатов прогноза вероятности поглощений.

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Please cite this article in English as:
Galkin V.I., Rezvukhina D.V. Development of Statistical Models for Predicting Circulation Losses Based on Characteristics of Faults. *Perm Journal of Petroleum and Mining Engineering*, 2021, vol.21, no.3, pp.102-108. DOI: 10.15593/2712-8008/2021.3.1

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
Галкин В.И., Резвухина Д.В. Разработка статистических моделей для прогноза поглощений по характеристикам разрывных нарушений // Недропользование. – 2021. – Т.21, №3. – С.102–108. DOI: 10.15593/2712-8008/2021.3.1

Introduction

Faults (fractures) are typical for major deposits of the Timan-Pechora oil and gas province, which significantly complicates their geological structure. Inhomogeneities of the geological structure and intensive fault tectonics cause a number of challenges during the search, exploration and development of oil and gas deposits. A loss of drilling fluid is one of such challenges, which makes well constructions longer and, in worse cases, it can cause oil, gas and water shows (OGWS).

Thus, to minimize emergency risks and OGWS, it is important to develop a method for predicting such phenomena over the area of deposits.

As a rule, regions with massive faults are characterized by a specific rock jointing [1–5], a complex stress-strain state of the rocks, various catagenetic transformations of the rock oil and gas reservoirs. These can largely complicate drilling operations [6–8]. Such processes cover not only the area of the fault plane itself, but also a large area around it. So, the analysis of losses and tectonic structure of deposits is an issue of major concern.

Despite the fact that the losses can be associated with technological parameters of drilling (disturbances of drilling modes, density and rheological properties of a drill mud, etc.), geological reasons (a very high level of cavernosity, rock jointing, extremely low rock pressures, sharp changes of reservoir porosity and permeability (RPP) etc.) lie in a physical reason initiating the loss processes themselves.

To avoid losses it is customary to regulate density and rheological properties of a drill mud, cleanout rate and pressure, adding special fillers (solid particles of different shapes and sizes) etc [9–12]. These methods complicate drilling operations [13], increase drilling costs and extend drilling time of wells. If a drilling project does not include these risks, it leads to severe accidents and sometimes to OGWS.

Generalizations and studies of losses during drilling are found in [14–22], which are oriented on data of Timan-Pechora oil and gas province [23, 24]. To predict them, one uses the geological structure analysis methods using the 3D geological model [25], analysis and use of data from the Geological and Mining Information System (GMIS) (also during drilling) [26], using the 3D data of the seismic exploration [27] or various methods of predicting losses based on neural networks and decision-trees [28, 29]. Also there are papers based on rock mechanics, numerical modeling and processes of losses and fracture performance [30–34].

Sediments of Timan-Pechora oil and gas province are characterized by massive tectonic disturbances.

A great amount of data has recently been collected about occurrence of faults and losses within the deposit. This research uses the data about configurations of faults to evaluate how they influence losses in wells of Usinskoe Deposit to determine an interval (a deposit) of Lower Permian-Carboniferous carbonate deposits.

During the Carboniferous-Lower Permian time, sedimentation within the region took place in the shallow marine shelf conditions with a dominating carbonate, less often clay-carbonate and sulfate-carbonate (for the Serpukhovian time) sedimentations.

The sediments are characterized by extremely unstable reservoir porosity and permeability properties, which is caused both by the facies variation and a great influence of secondary transformations. In addition, it is greatly influenced by the tectonics of the region, which stimulates karstification processes in carbonate sediments of the Permian-Carboniferous reservoir.

We studied well drilling results in the period between 2016 and 2020 (254 wells) of the Permian-Carboniferous reservoir. The well drilling was mostly in the central and northwestern part of the reservoir.

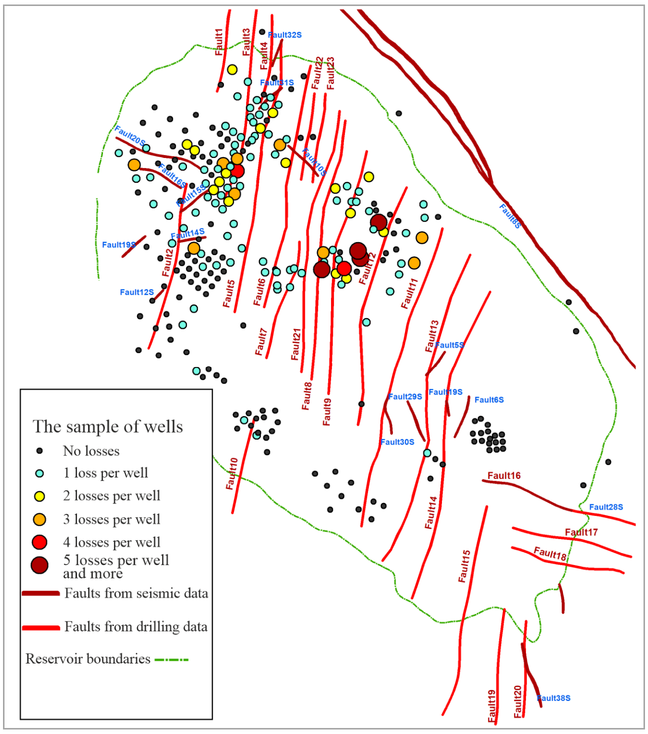

Fig. 1. The drilling pattern

Fig. 1. shows the location and number of losses during drilling.

At that period of time the loss of drilling mud was a great problem. It is found that 46 % of the drilled wells suffer from it. The intensity of losses varies in wide ranges, starting from several cubic meters per hour to disastrous losses with a complete loss of circulation. Meanwhile the disastrous losses were found in more than half of the cases.

If we speak about the stratigraphic confinement of the losses, then 50 % of them are related to the Middle Carboniferous sediments C_2 (55 % of them are disastrous losses), 23 % of them are related to the Upper Carboniferous deposits C_3 (62 % of them are disastrous losses), and 27 % are related to Lower Permian sediments P_1 (49 % of which are disastrous losses).

The faults can be confirmed based on well drilling data when a well passes the fault plane, based on stratigraphic studies in wells (by a sharp difference in absolute marks in the correlation of well sections), according to seismic data (identification of areas of faults based on attributive seismic data).

It is worth noting that faults identified both from well drilling data and from seismic data are characterized by various numbers of wells with and without losses, which is well illustrated by the information given in Table 1.

Here we can see that the number of wells with losses and without them for different faults varies much. As none of the well types dominates (with or without losses), then it is necessary to use multilevel models to describe and predict such phenomena.

The reason for this is that the multilevel probabilistic-statistical modeling enables a differentiated study of the process of influence of faults on losses: initially according to data from all wells, regardless of methods of finding losses - 1st level; according to data of methods of finding faults - 2nd level; according to data of individual faults - 3rd level. At the 4th level a model is built, which considers computation results obtained from previous levels of statistical modeling.

Thus, the multilevel 3D probabilistic-statistical modeling makes it possible to have a complex evaluation of phenomena and processes taking place during loss formations depending on faults.

Table 1

Data about faults (nearby wells)

Fault No.	No. of wells with losses	No. of wells without losses	Fault No.	No. of wells with losses	No. of wells without losses
Faults from drilling data					
1	1	1	12	26	9
2	12	27	13	1	0
3	40	8	14	0	3
4	0	1	15	0	0
5	13	10	16	0	11
6	7	3	17	0	0
7	3	3	18	0	0
8	12	0	19	0	0
9	19	2	20	0	0
10	2	13	21	1	0
11	7	11	22	0	1
Faults from seismic data					
6 S	0	8	16 S	4	2
8 S	0	3	19 S	0	2
10 S	3	0	20 S	9	16
14 S	0	1	31 S	0	1
15 S	6	1	–	–	–

Table 2

Characteristics of models, P (Lp) dependence on Lp

Indicator	Losses were found, arithmetic mean ± σ	Losses were not found, arithmetic mean ± σ	Regression equation - upper line, model application - lower line	Criteria t_p / p	Criteria χ^2 / p
Lp, m	263.4 ± 202.1 0.529 ± 0.054	484.7 ± 365.8 0.484 ± 0.099	P (Lp) = 0,601–0,000271 Lp 0–1600 m	-6.66845 $<10^{-6}$	45.46375 $<10^{-6}$

Table 3

Distribution of values of indicators in wells

Object class	Variability intervals - Lp, m							
	0–200	200–400	400–600	600–800	800–1000	1000–1200	1200–1400	1400–1600
Frequency of occurrence for wells with losses, fr.unit (n = 167)	0.463	0.288	0.197	0.047			0.005	
Frequency of occurrence for wells without losses, fr.unit (n = 136)	0.259	0.229	0.205	0.117	0.088	0.051	0.036	0.015

Table 4

Characteristics of models of P (Lp) dependence on Lp, according to loss identification method

Indicator	Method of finding losses	Mean value of indicators: upper line- mean values of Lp-indicators, lower line-the probability of occurring losses P (Lp)		Regression equation - upper line, model application - lower line	Criteria t / p
		of losses found	of losses not found		
Lp, m	Drilling	271.4 ± 211.3 0.533 ± 0.066	485.6 ± 389.1 0.488 ± 0.121	$P_{dr}(Lp)$ = 0,638–0,000312 Lp 0–1600 м	-5.49512 $<10^{-6}$
	Seismic exploration	213.5 ± 122.1 0.533 ± 0.066	481.9 ± 285.9 0.488 ± 0.121	$P_s(Lp)$ = 0,707–0,000597 Lp 0–1190 m	-4.23175 $<10^{-6}$

Developing Models for Faults According to Their Characteristics

At the first level, in order to assess the possibility of forming the probability of losses $P(Lp)$, fr.units, from the values of the shortest distance from the fault to the studied well, Lp, m, a predicting model was built using all available data about the studied deposit. This model makes it possible to evaluate the influence of Lp values on loss formations. The method of building such probabilistic models is described in [36, 37].

Let us consider a method of building individual probabilistic models by using Lp indicator as an example. To do this, we used Lp values of 303 cases, where 167 of them had losses and 136 had no losses. Mean values of Lp for wells with observed losses, and for wells where losses were not observed are given in Table 2.

Here you can see that the mean value of Lp belonging to the class of wells where losses are observed is significantly lower than for those where no losses are found. The quantitative comparison of mean values is made using Student's t-test [38–43] and the significance level (α = 0.05).

The value of criterion t_p of Lp value is given in Table 2. It was revealed that the mean values are statistically different. Then based on Lp values we studied densities of distributions for the two researched classes. In the first case we study data from Lp values about the wells with losses, i.e. class 1 (n_1 = 167), in the second case we study data for wells without losses, i.e. class 2 (n_2 = 136). According to the applied method we build block diagrams at the first stage of building the probabilistic model based on Lp data for class 1 and 2. The optimal values of the intervals for grouping Lp values are calculated using the Sturges formula. To study the ratios of the proportion of objects that fell into different intervals of variation of Lp, the interval analysis was performed [36].

It is necessary to build a model based on the totality of coverage of Lp values, which will be used to evaluate the presence of losses in wells. Frequency of occurrence of wells for the studied classes based on Lp indicator are given in Table 3.

According to the analysis of results given in Table 3, it is found that there is an increase of occurrence of wells with losses in the range 0–200 m. For wells without losses in the range of 400–600 m, the values of frequency of occurrence are quite close. The maximum number of wells both with and without losses is found to be in the range 0-800 m. It all provides evidence of an opportunity to predict the occurrence of losses depending on Lp.

For a more complete statistical analysis, a comparison was made of the distribution density of the values of the indicators determined by the types of the studied wells, using Pearson statistics (χ^2). The values of criterion χ^2 according to Lp indicator are also given in Table 2, which shows that a statistical difference between the classes is found.

Then in each interval, probabilities of belonging to the class of wells with losses P (Lp) are computed. After that interval probabilities of belonging to this class are compared with mean interval values of Lp. By using values of P (Lp)

and Lp we calculate the matching coefficient of correlation *r* and build the regression equation. The further correction of the built models is performed on condition that the mean value of probabilities for the 1st class should be more than 0.5, and for the 2nd class it should be less than 0.5.

The probabilistic model of predicting using *Lp* from both drilling and seismic data, along with areas of use are given in Table 2. The dependences between *P* (*Lp*) and *Lp* for the first level of statistical modeling are illustrated in Fig. 2.

Here it can be seen that with an increase in *Lp* values, the individual probability of the presence of losses in wells, regardless of what data are used to identify faults, naturally decreases from 0.601 to 0.167 according to the relation given in Table. 2. The mean value of *P* (*Lp*) for wells with losses is 0.529 ± 0.054, for the wells without losses it is 0.484 ± 0.099 (Table 2). Mean values and probability density of values *P* (*Lp*) depending on well types have statistical differences.

Thus, the statistical analysis performed at the first level of statistical modeling proved that *Lp* values influence the presence of losses in wells.

At the second level of statistical modeling we built dependences of *P* (*Lp*) on *Lp* in a differentiated way based on faults data obtained according to drilling data (*Pdr* (*Lp*)) and seismic exploration (*Ps* (*Lp*)). The number of wells used to analyze the drilling data was 247, 144 of which were found to have losses, and 103 wells had no losses. The number of wells used to analyze faults obtained after the seismic exploration was 56, while 23 of them had losses and 33 had no losses. The models built according to these data are given in Table 4.

The illustration of dependences between *P* (*Lp*) and *Lp* with the orientation on the method of finding faults is given in Fig. 3.

Here it can be seen that with an increase in *Lp* values, the probability of the presence of losses in wells, taking into account the method of identifying faults, decreases according to the relations given in Table. 4. It is notable that the rates of decreasing the absorption probability differ depending on methods of finding faults.

Thus, at the second level of the statistical modeling it is fixed that regardless of the methods for identifying faults, there is a decrease of *P* (*Lp*) values.

At the third level of the statistical modeling we build models individually for certain faults. The number of wells with losses and without them from drilling data and seismic data are given in Table 1 and show that their number for various faults differs much. It indicates that not for all faults it is possible to build individual models. Such models for certain faults for computations of the loss probability based on *Lp* values are possible to be built only for those models that have data about wells in both groups. To use all the available information on those faults, in which there is data for only one of the studied classes, group models were built. Regression equations describing the influence of *Lp* value on the loss probability presence are given in Table 5.

This indicates that for faults confirmed with the results of drilling, nine models are built, while there are only three models built from seismic data. The illustrations of the models built at the third level of the statistical modeling are given in Fig. 3.

The resulted models built from the well drilling data are characterized by two types (Fig. 3.). The first type of models is characterized by a decrease of dependence of *P* (*Lp*) on *Lp,* and it complies with the models built at the first and second levels of statistical modeling. The second type of models (marked with a red ellipse in Fig. 4) is characterized by an increase of values in dependences of *P* (*Lp*) on *Lp*, and it does not agree with the models built at the first and second levels of the statistical modeling.

Hence, the influence of *Lp* on the loss probability is different, which should be taken in account when predicting losses in certain wells. As an example let us give the patterns of changing values of *P* (*Lp*) for faults No. 2 and 3 (Fig. 5).

Fig. 5 shows that for fault No.2 at a distance from faults, *P* (*Lp*) increases from 0.4 to 0.65. This model gives better

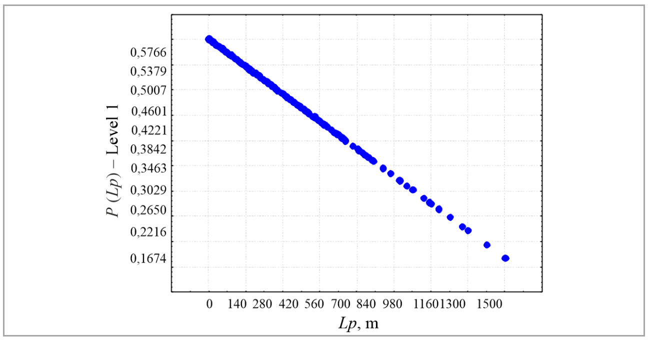

Fig. 2. Relation between *P* (*Lp*) and *Lp*

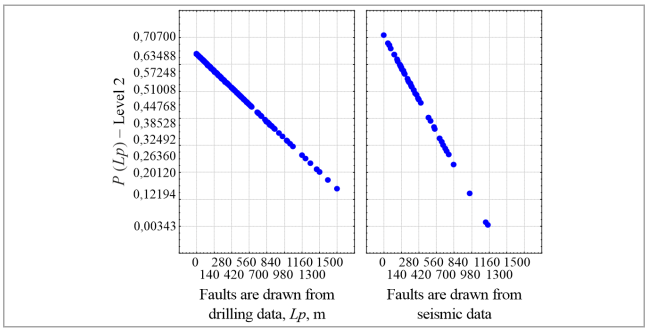

Fig. 3. The value of dependence of *P* (*Lp*) on *Lp* depending on methods of finding faults

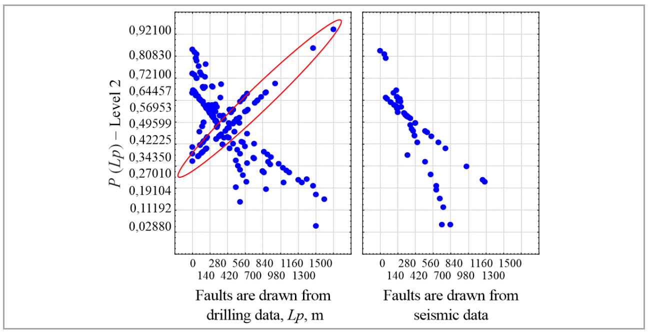

Fig. 4. Dependences between *P* (*Lp*) and *Lp* for the third level of statistical modeling

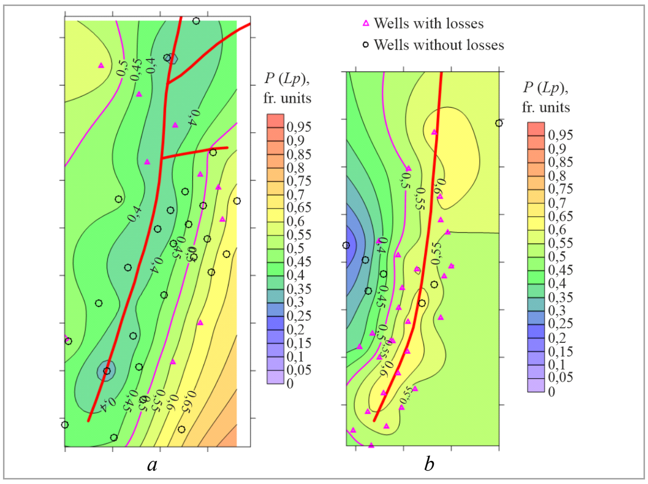

Fig. 5. Patterns of changing values of *P* (*Lp*) for faults No.2 (*a*) and No.3 (*b*)

results in the southern part rather than in the northern one. For fault No.3 there is a tendency to decreasing *P* (*Lp*) values at a distance from the fault. It all confirms the differentiated role of faults in occurrence of losses.

In order to justify *operability* of the developed models built at different levels, let us find block diagrams used to determine occurrences of wells for the studied classes according to *P* (*Lp*) indicator (Table 6).

Table 5

Characteristics of built models

Fault number	Mean values of indicators: the upper line shows mean values of Lp values, the lower line shows the probability of being related to losses P (Lp): losses were found	Losses were not found	The regression equation - the upper line, the model application area - the middle line, the range of probabilities - the lower line	Criteria $\frac{t}{p}$
Models built for several faults and individual faults				
2	551.5 ± 339.7 0.527 ± 0.127	428.5 ± 340.6 0.481 ± 0.128	$P_{dr}(Lp)$ = 0,321 + 0,000375 Lp 0–1600 m 0.321–0.921	1.04284 0.304
3	184.2 ± 128.9 0.549 ± 0.070	367.7 ± 280.6 0.449 ± 0.152	$P_{dr}(Lp)$ = 0,695–0,00041 Lp 10–840 m 0.193–0.646	-2.95009 0.005
5	262.3 ± 257.4 0.578 ± 0.144	367.7 ± 280.6 0.419 ± 0.116	$P_{dr}(Lp)$ = 0,726–0,000561 Lp 20–810 m 0.271–0.714	-2.93545 0.008
6	188.6 ± 82.7 0.550 ± 0.071	73.3 ± 63.5 0.449 ± 0.055	$P_{dr}(Lp)$ = 0,386 + 0,000870 Lp 0–330 m 0.386–0.673	2.13048 0.066
7	66.7 ± 73.4 0.800 ± 0.034	1390.0 ± 101.5 0.200 ± 0.044	$P_{dr}(Lp)$ = 0,831–0,000454 Lp 0–1500 m 0.150–0.831	-18.0455 0.00005
9	187.3 ± 131.1 0.599 ± 0.141	340.0 ± 282.8 0.399 ± 0.369	$P_{dr}(Lp)$ = 0.844–0.001307 Lp 20–540 m 0.138–0.817	-1.433876 0.168
10	215.0 ± 35.5 0.546 ± 0.028	340.0 ± 207.4 0.445 ± 0.168	$P_{dr}(Lp)$ = 0.721–0.0008 Lp 0–610 m 0.226–0.721	-0.824876 0.424
11	444.2 ± 39.1 0.543 ± 0.021	604.1 ± 397.8 0.457 ± 0.210	$P_{dr}(Lp)$ = 0.782–0.000538 Lp 140–1400 m 0.028–0.707	-1.047985 0.310
12	441.5 ± 128.9 0.549 ± 0.067	213.7 ± 280.6 0.449 ± 0.071	$P_{dr}(Lp)$ = 0,356 + 0,000439 Lp 0–620 m 0.356–0.628	3.79703 0.0006
Models built from seismic data				
15S	140.0 ± 68.1 0.649 ± 0.120	310.0 ± 0.00 0.349 ± 0.000	$Ps(Lp)$ = 0,897–0,001765 Lp 50–310 m 0.349–0.808	-2.310556 0.069
16S	195.0 ± 310.1 0.608 ± 0.008	440.0 ± 282.8 0.388 ± 0.256	$P_s(Lp)$ = 0,784–0,000898 Lp 190–640 m 0.209–0.613	-1.99668 0.117
20S	296.7 ± 142.1 0.531 ± 0.048	480.0 ± 371.5 0.468 ± 0.126	$P_s(Lp)$ = 0,632–0,00034 Lp 60–1190 m 0.227–0.612	-2.95009 0.005

Table 6

Distribution of P (Lp) values to statistical levels (frequency)

Class of objects	Variability interval of P (Lp)									
	0–0.1	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1.0
First level										
For wells with losses, n = 167			0.006	0.006	0.264	0.706	0.018			
For wells without losses, n = 136		0.014	0.058	0.148	0.309	0.413	0.058			
Second level										
For wells with losses, n = 167			0.005	0.005	0.191	0.487	0.307	0.005		
For wells without losses, n = 136	0.014	0.022	0.08	0.169	0.207	0.347	0.161			
Third level										
For wells with losses, n = 167			0.005	0.047	0.138	0.427	0.294	0.054	0.035	
For wells without losses, n = 136	0.022	0.051	0.147	0.192	0.236	0.236	0.08	0.029		0.007

Table 7

Characteristics of statistical models

Indicator	Loss: Found	Loss: Not found	Criteria $\frac{t}{p}$	Criteria $\frac{\chi^2}{p}$
First level				
P (Lp) – first level	0.529 ± 0.054	0.484 ± 0.099	6.66845 $<10^{-6}$	45.46375 $<10^{-6}$
Second level				
P (Lp) – second level	0.556 ± 0.067	0.472 ± 0.137	7.17418 $<10^{-6}$	47.77024 $<10^{-6}$
Third level				
P (Lp) – third level	0.571 ± 0.099	0.428 ± 0.158	9.495545 $<10^{-6}$	79.36611 $<10^{-6}$

Table 8

Characteristics of statistical model P_{comp}

Probability	Loss: found	Loss: not found	Criteria $\frac{t}{p}$	Criteria $\frac{\chi^2}{p}$
P_{comp}	0.639 ± 0.154	0.417 ± 0.249	10.49714 0.000000	89.39351 0.000000

The Table data indicate that for wells with losses there is an increase of presence of losses during an increase of P (Lp) for all three levels within the range 0.5-0.7. In the range of P (Lp) less than 0.2 for all the model variants, no wells with losses are available. Let us consider the quantitative difference in mean values and distribution densities of P (Lp) based on criteria t and χ^2, which are given in Table 7.

Here it can be seen that the mean values of P (Lp) for wells with losses increase from the first to the third levels from 0.529 to 0.571, for the wells with no losses, the mean values decrease from 0.484 to 0.428. Distribution densities differ most strongly when using models built on the 3rd level of the statistical modeling.

At the 4th level of statistical modeling, a complex criterion was calculated taking into account the built models at three levels, according to the following formula:

$$P_{comp} = \frac{\prod P_{lev}}{\prod P_{lev} + \prod (1 - P_{lev})},$$

where P_{lev} are probabilities obtained by the models of the first, second and third levels, and Π is their multiplication. We will quantitatively estimate the difference in the mean values and distribution densities of P_{comp} values according to the criteria t and χ^2, which are given in Table. 8. The dependence of P_{comp} on Lp is given in Fig. 6.

The data of Fig. 6 demonstrate that within the correlation field there are two subfields where the correlations between P_{comp} and Lp are characterized by various relations by type. The boundary can be conventionally drawn by value of $P_{comp} = 0.5$.

The contribution of models of each level for predicting losses can be carried out using the stepwise linear discriminant analysis (SLDA) [43], using the classification for group 1 when $P_{comp} > 0.5$ and for group 2 when $P_{comp} < 0.5$.

As a result of implementation of SLDA, we obtained the following linear discriminant function:

$$Z = -1{,}06764\mathrm{P}(Lp) - level1 -$$
$$- \ 2{,}27160\mathrm{P}(Lp) - level2 -$$
$$-6{,}17077\mathrm{P}(Lp) - level3 + 4.844$$

where $R = 0{,}494$, $\chi^2 = 84{,}057$, $p < 10^{-6}$.

Values χ^2 and p show that the resulted linear discriminant function is statistically valuable.

This formula was used to calculate values of Z and find probability data in relation to values of $P_{comp} > 0{,}5$–$P(Z)$. The dependence of $P(Z)$ on Z is given in Fig. 7.

One can follow that during changes of Z from negative to positive values, the probability of $P(Z)$ decreases with regularity. The mean value of Z when $P_{comp} > 0.5$ equals to 0.511, the mean value when $P_{comp} < 0.5$ is $+0.628$. The proportion of correctly classified cases was 76.23 %.

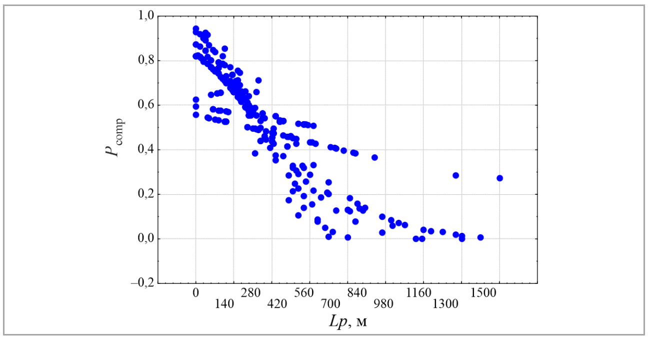

Fig. 6. Dependences of P_{comp} on Lp

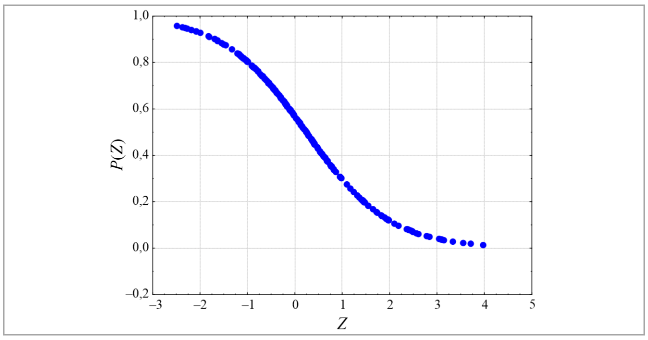

Fig. 7. Dependences of $P(Z)$ on Z

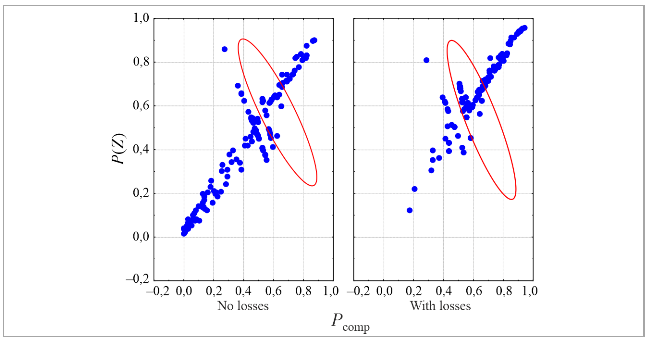

Fig. 8. Correlation field between P_{comp} and $P(Z)$

Conclusions

It has been shown that these criteria *work well* also for probabilities obtained according to different levels of statistical modeling. Consequently, if one develops models to predict losses, dividing data with regard to values of P_{comp} can have a positive effect during predictions. To compare data obtained using values of P_{comp} and $P(Z)$, a field of correlations is built between them, Fig. 8.

Here you can see that there are cases when dependences between $P(Z)$ and P_{comp} are inversely proportional (red ellipses in Fig. 8). It is possible that the formation of losses due to faults can be regularly predicted using the developed probabilistic-statistical models only in case of direct correlations between $P(Z)$ and P_{comp}.

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