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On Systemic Uncertainties and Geological Risks in the Process of Geological Exploration Works

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Abstract: The article is devoted to the study of systemic uncertainties and geological risks in the process of geological exploration. An analysis is provided of the risks arising during the prospecting, exploration, and development of complex-structured deposits in the Eastern Ustyurt region. It is shown that complicating factors are formed due to the interrelation between risk and uncertainty. Their consideration in the process of comprehensive project planning is recommended. Based on the analysis of uncertainties and risks, a map of the success rate of geological exploration in the Eastern Ustyurt region has been developed.

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1 INTRODUCTION

In recent decades, there has been an increase in the discovery of fields with complex geological structures in the Eastern Ustyurt oil and gas-bearing region. This, in turn, is accompanied by the simultaneous manifestation of various risks, including geological ones. Therefore, research is needed on the systematization and classification of uncertainties and risks, as well as on the development of methods for accounting and managing risks during the design and operation of deposits. The currently explored and developed fields in the mentioned region represent a multifunctional complex characterized by numerous types of uncertainties and geological risks.

Study and Detailed Classification of Existing Uncertainties and Risks in the Exploration and Production of Oil, Gas, and Gas-Condensate Fields Worldwide. Research focused on the study and detailed classification of existing uncertainties and risks in the exploration and production of oil, gas, and gas-condensate fields worldwide has been conducted by many prominent foreign and domestic scientists, field developers, and petroleum geologists. Among them are the works of Andreev A.F., Ananyev V.V., Bekov B.Kh., Vasiliev Yu.N., Vishnyakov Ya.D., Galkin S.V., Gasumov E.R., Glukhov T.V., Dolinsky I.G., Evstafiev I.L., Ermasov N.B., Zabrodin Yu.N., Zubareva V.D., Kalist L.V., Kachalov R.M., Kerimov V.Yu., Kulikov E.E., Kostylev A.O., Miloserdov L.V., Nazarov V.I., Nazarova U.S., Peter R. Rose, Polyakov A.A., Sarkisov A.S., Sunnatov M.S., Safonov V.S., Semerikova A.E., Radaev N.N., Rumyantsev A.V., Tasmukhanova A.E., Tyatyushkin S., Shapkin A.S., Shevelev V.V., and others.

However, the previously obtained geological and geophysical data on deposits and geological formations of the Ustyurt oil and gas-bearing region require substantial refinement and more detailed study. Such data will make it possible to establish a more reliable understanding of the structure of the stratigraphic section, the processes of reservoir formation, and the regularities of hydrocarbon accumulation in natural traps.

2 MATERIALS AND METHODS

According to the findings of numerous researchers, in the prospective areas of the Ustyurt region, the Upper Jurassic productive sequence is represented by sediments of deltaic, lagoonal, and littoral facies (Nazarov, Sunnatov, Abdurakhmanov, Valiev, Bekov, 2023). These deposits were formed in a dynamically transforming sedimentary environment. As a result, the productive sequence acquired a complex internal structure. The Upper Jurassic sequence is characterized by frequent alternation of sandstone–siltstone layers and clay seals. This, in turn, led to significant facies variations and irregular distribution of reservoirs both laterally and vertically. The reservoirs are marked by poor correlation between sandstone bodies, which mainly consist of thin interbeds and lenticular layers. Their thickness varies from several tens of centimeters to several meters.

For many such bodies, a limited area of distribution is typical, which complicates the identification of productive intervals and the construction of detailed geological and hydrodynamic models. However, this increases uncertainty when predicting effective thicknesses, reservoir filtration-capacity properties (FCP), and the oil and gas saturation of formations.

Based on the structural features of the Upper Jurassic deposits, it can be assumed that similar structural-facies conditions are present in the Middle and Lower Jurassic sequences. Consequently, during the process of exploration and development, there is a high probability that productive reservoir layers may remain unpenetrated within the drilling intervals. Such situations often lead to negative well testing results and to the underestimation of the potential of certain structural traps.

The classification of risks and uncertainties in geological exploration (GE) involves their categorization according to different attributes: geological (related to the quality and quantity of reserves), technological, financial, legal, environmental, informational, and managerial (personnel) risks. Risks may also be systematized by project stages — from exploration to production — and by the probability of their occurrence.

To reduce geological risks and improve the reliability of predictive calculations, a comprehensive application of modern methods should be implemented, including 3D seismic surveying, petrophysical modeling, detailed stratigraphic correlation, and hydrodynamic simulation. The efficiency of exploration and the success rate of drilling directly depend on effective risk management at all stages of geological exploration.

Quite often, due to the lack of sufficient statistical data, decisions are made under conditions of high uncertainty. The degree of risk reflects the level of potential damage, which depends on the magnitude of uncertainty.

Risk identification represents the systematic detection and classification of events that may have a negative impact on the project. The classification of risks provides for their qualitative description according to various characteristics — geological, technological, economic, and others. Risk assessment means the quantitative or qualitative determination of their magnitude.

2.1 Geological risks and 3D modeling

A project is accompanied by risks at all its stages — from the regional stage to industrial operation. The design process includes three main phases: the prospecting stage (justification for pilot-industrial testing, PIT), the exploration stage (reserve estimation), and the development stage (production stage — refinement of geological and geophysical information).

The first stage focuses on determining whether commercial reserves are present or absent. The emergence of uncertainties at this stage leads to peak values of technological and economic risks. In such cases, it is recommended to preliminarily model three possible scenarios — optimistic, base, and pessimistic. Geological uncertainties tend to give rise to technical and technological risks.

The second stage — the exploration phase — is related to solving the tasks of delineating field boundaries, evaluating recoverable reserves, and transferring sites to pilot-industrial testing (PIT). The final stage — the development phase — aims to ensure maximum extraction of drainable reserves under a rational operating regime, minimizing unrealized profit.

Indicators of success rate and probability of geological success depend on the coefficient of prospecting/exploration efficiency, which is determined by the formula:

(1)

Where: N_{field} – the number of actually discovered fields; $N_{structure}$ – the number of actually drilled structures.

The overall efficiency of geological exploration works (GEW) depends on the degree of current regional study followed by the level of subsequent exploration maturity. Initially, this efficiency increases, but later it tends to decline (Kerimov, 2017).

3 RESULTS AND DISCUSSION

Based on the assessment of geological success determined by formula (1), a map of the success rate of geological exploration in the Eastern Ustyurt region was compiled (Fig. 1). According to this map, five tectonic blocks were identified, within which industrial gas-condensate accumulations have been discovered. These accumulations are currently under industrial development and comprehensive preparation for production. According to the map data, the most thoroughly studied areas include the Berdakh–Takhtakair uplift and the Shakhpakhty step, where the success coefficients are 0.329 and 0.50, respectively.

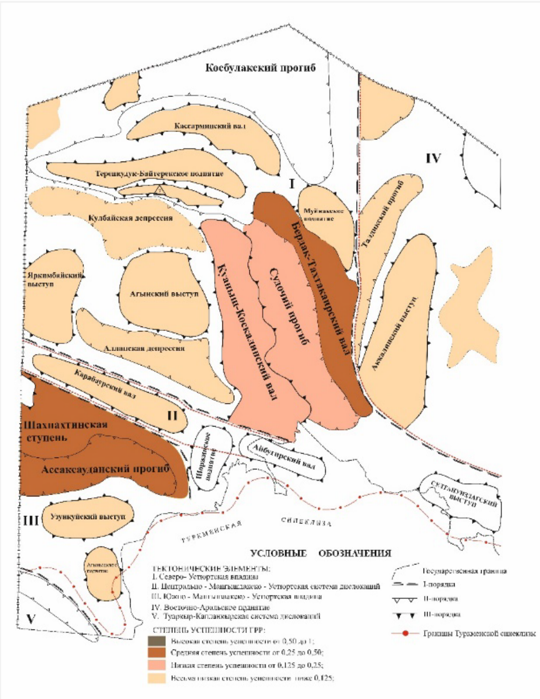

Figure 1: Map of exploration and prospecting success based on the tectonic zoning of the Eastern Ustyurt region.

Meanwhile, in the study by I.L. Evstafiev and I.G. Dolinsky (Evstafyev, Dolinsky, 2018), a formula was proposed for the assessment of geological risks based on the consideration of potential geological success. This indicator determines the likelihood of discovering a field or obtaining an industrial inflow of hydrocarbons and is calculated using the following formula:

$$K_{geo\ risk} = 1 - K_{success} \quad (2)$$

Where $K_{geo\ risk}$ is the coefficient of geological risk.

However, from a geological standpoint, formulas (1) and (2) alone cannot fully identify the conditions of hydrocarbon generation and accumulation, nor can they explain the internal structure of reservoirs (traps and collectors). In this regard, Peter R. Rose proposed the following formula, which takes into account the five key geological model factors when evaluating prepared traps at the hydrocarbon prospecting stage:

(3)

Where P_{gen} – probability of hydrocarbon generation; P_{mig} – probability of the presence of hydrocarbon migration pathways; P_{res} – probability of a hydrocarbon reservoir; P_{trap} – probability of a hydrocarbon trap; P_{seal} – probability of hydrocarbon preservation.

It should be noted that the essence of formula (3), described by Peter R. Rose, lies in the author's clear explanation that the absence of any one factor implies the following: based on exploration and prospecting results, no new deposits will be discovered in that area. From a geological standpoint, a geological object may prove to be dry due to the absence of truly mature source rocks, since in the regions under consideration, the basement may be structurally elevated. This conclusion was formulated in the work of S. Tyatyushkin, who considered the absence of mature oil- and gas-generating source rocks to be an objective reason for negative geological exploration results. The mere presence of a hydrocarbon accumulation does not guarantee its industrial significance based on productivity testing. This is especially relevant for wells drilled in non-traditional, facies-variable areas with very sparse drilling grids and in zones poorly covered by seismic profiling.

It should also be noted that the large-scale application of Peter R. Rose's formula (3) is limited to traditional types of deposits (Rose, 2011). Traditional types refer to geological objects that are lithologically and stratigraphically uniform, not belonging to complex structural categories: the depth of hydrocarbon-bearing layers does not exceed 3000 meters, and the productive horizon is characterized by under-saturated fluid conditions (Semerikova, Rumyantseva, 2024).

In this regard, the authors of the present study propose using a multifactor model instead of a five-factor one. In this model, the sixth and seventh factors are introduced — the coefficient of lithological uniformity and the coefficient of lithological connectivity, respectively.

The proposed formula is analytically expressed as follows:

(4)

Where P_{gen} – probability of hydrocarbon generation; P_{mig} – probability of the presence of hydrocarbon migration pathways; P_{res} – probability of the presence of a hydrocarbon reservoir; P_{trap} – probability of a hydrocarbon trap; P_{seal} – probability of hydrocarbon preservation; P_{unif} – probability of a lithologically uniform reservoir within local hydrocarbon-bearing zones; P_{conn} – probability of lithological connectivity within reservoirs in local hydrocarbon-bearing zones.

The geologist V.Yu. Kerimov (2017), based on empirical data in the field of petroleum geology and geochemistry (Kerimov, 2017), classifies geological success into the following categories:

- Very low success rates (geological risk probability ranging from 0.875 to 0.99): only 1 to 3 factors are no higher than neutral, with one or two being doubtful or neutral. In this case, the new prospective hydrocarbon accumulation zone (HAZ) with assumed productivity in the petroleum basin is located more than 50 km away from a previously successful geological exploration area.
- Low success rates (geological exploration success coefficient from 0.125 to 0.25, corresponding to geological risk probability between 0.75 and 0.875): two or three factors range from encouraging to favorable, and one or two — from encouraging to neutral. The object is situated within a new prospective HAZ with assumed productivity in the petroleum basin or within a hydrocarbon accumulation zone with proven productivity, located 20 to 50 km away from a previously successful geological exploration area.
- Moderate success rates (geological exploration success coefficient from 0.25 to 0.50, with geological risk probability from 0.50 to 0.75): all factors are encouraging. The object is located within a HAZ with proven productivity, situated more than 10 km from a successful geological exploration area.
- High success rates (geological exploration success coefficient from 0.50 to 0.99, with geological risk probability from 0.01 to 0.50): all geological factors of the object are situated within a hydrocarbon accumulation zone with proven productivity, less than 10 km away from a previously successful geological exploration area.

At present, a wide range of systematic approaches to the classification of uncertainties and risks in the field of oil and gas exploration and production has been developed (Kholismatov, Tursunova, Zokirov, Hayitov, 2022; Khayitov, Umirzokov, Rakhmatov, Gafurov, Abdurakhmonova, 2024). It has been established that geological risks and uncertainties are among the most potentially dangerous types of known risks. Considering this, the authors of this paper have developed a correlation scheme for the categories "Uncertainty – Complication Factor – Risk – Loss" (Table 1). It has been determined that, unlike previous models, this scheme introduces an additional link — the complication factor — between uncertainty and risk.

This is because investment in individual or group projects, especially in long-term, complex, and capital-intensive projects such as international oil and gas projects, is inherently tied to specific risks.

Consequently, an investment project may ultimately prove unsuccessful — that is, fail to achieve its goals, show low efficiency, or perform below the expected results. Therefore, during the industrial application of the scheme (see Table 1), when analyzing individual or group investment projects related to exploration or field development at the pre-financing stage, it is essential to consider the complication factors that either prevent the occurrence of hazardous risk events or minimize the potential risks associated with the project's implementation.Based on this scheme, and using the examples of the Sharkiy Berdak, Shimoliy Berdak, and Surgil fields, three main directions of complication factors have been identified from geological and technological uncertainties. These factors significantly influence the outcomes of exploration and field development design, leading to deviations from project indicators or to revenue losses and economic damages depending on the scale of the investment project (Gafurovich, 2020).

Table 1 presents the correlation scheme "Uncertainty — Complication — Risk — Loss." In this scheme, complication factors are highlighted between uncertainty and risk. Based on geological, technological, and economic uncertainties from the Sharkiy Berdak, Shimoliy Berdak, and Surgil fields, a total of 37 criteria (19 + 10 + 8) have been identified that have a significant impact on project design results and actual performance indicators.

Table 1: The "Uncertainty–Risk" process is a sequence of interrelated actions in the field of hydrocarbon exploration.

№	Indicator Name	Description
1	Uncertainty	Insufficient information about the studied geological objects to make a specific technical-technological or techno-economic decision, or very limited information on the degree of reliability of risk assessment, or a complete absence of such information
2	Complicating Factors	A partially disturbing or deviating instrument for any process within a certain time interval, particularly during the exploration and production of oil, gas, and gas condensate
3	Risks	Events with adverse consequences associated with complex geological structures that may arise during activities aimed at reducing and controlling the efficiency of the hydrocarbon production system, as well as in cases of losses compared with the forecasted indicators.
4	Losses	Damage or financial loss resulting from the occurrence of a risk event under conditions of complex uncertainty

According to A.E. Tasmukhanova (Tasmukhanova, 2006), a prerequisite for assessing geological risk is the preliminary identification of the circumstances leading to geological uncertainties, which determine the reliability of data for calculating geological and recoverable reserves. Based on this standpoint, the authors of the present article have developed a schematic representation of geological, technological, and economic uncertainties using the examples of the Sharkiy Berdak and Shimoliy Berdak gas condensate fields. Many researchers have also expressed their viewpoints on the nature of uncertainty and risk.

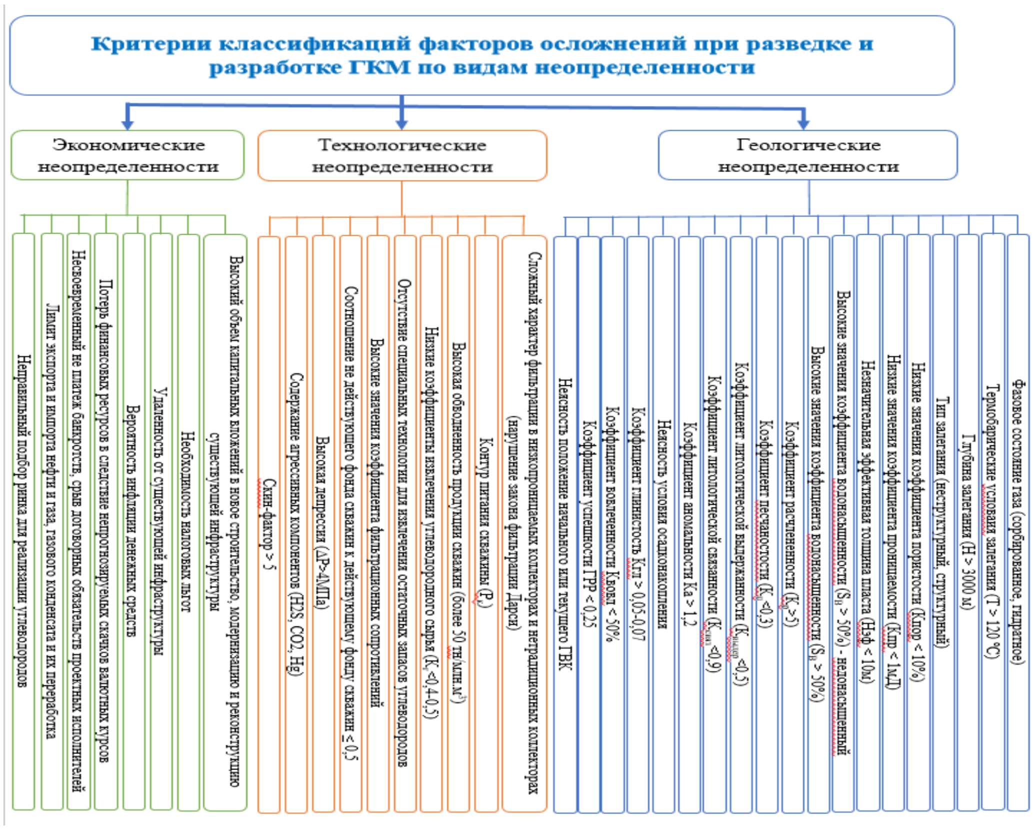

Figure 2: Scheme of criteria for classifying complication factors using the examples of the identical fields Sharkiy Berdak, Shimoliy Berdak, and Surgil.

As noted by Yu.N. Vasiliev, the consequences of geological uncertainties also include technological and economic risks (Nazarov, Sunnatov, Abdurakhmanov, Valiev, Bekov, 2023). A similar statement can be found in the work of T.V. Glukhov, where uncertainty is defined as the source of risk (Glukhov, 2022).

In the study by A.E. Semerikova (2024), based on the experience of Russian oil and gas producing companies, it is emphasized that greater attention should be paid to financial risks and to modern concepts of strategic risks. Semerikova proposed a risk classification by categories: financial, operational, strategic, legal, and environmental (Semerikova, Rumyantseva, 2024).

A.E. Tasmukhanova developed a methodology according to which the assessment of geological risks should be carried out taking into account the systematic evaluation of geological uncertainties, viewed as sequential functions of alternative geological models and as a step-by-step implementation of model calculations, following her proposed scheme (Tasmukhanova, 2006).

In the work of A.O. Kostylev, for assessing the risk of an innovative project, a modified Monte Carlo method—the Latin Hypercube Sampling (LHS) technique—was proposed. This method allows for the simultaneous and comprehensive consideration of multiple uncertainty factors and enables a more accurate determination of the investment project's implementation risk (Kostylev, Skopina, 2015). Ignoring uncertainties and risks during the design phase of an investment project leads to an increase in financial losses and a decrease in reputation among major oil and gas companies.

Quantitative risk assessment methods are the most applicable in the analysis of investment projects, as they allow for the calculation of project performance indicators under various scenarios and development options (Rose, 2011).

According to the research results of V.S. Safonov (Safonov, 1996), optimal risk management in geotechnological systems leads to a reduction in risk levels, a more accurate assessment of feasibility and necessity of implementation options, and a balanced distribution of risk probabilities among various economic scenarios.

It has been established that geological risk associated with the recovery of production after drilling and well development in a gas-bearing area can be managed through the application of well placement technologies in zones near existing production wells, by determining their current operational characteristics and zones of influence. Under the established operating conditions of the field, the location of a new well should be determined at a distance of two drainage radii from the nearest producing well (Orinbaev, Akramov, Khayitov, Mallaev, Gadoev, 2024).

Risks of not obtaining gas inflow from newly drilled wells can be managed by reassigning wells from the target horizon to an alternative formation. In fields with small reserves, the placement of exploration, appraisal, and production wells is carried out using a "creeping" method—from the crest toward the periphery—along a radius determined by the algorithm for calculating the conditional radius of the previous well's drainage contour (R_k), with the new well location set at a distance of two conditional drainage radii.

This approach makes it possible to reduce geological risks during the assessment of oil, gas, and gas condensate reserves (especially in exploratory drilling) and to minimize the risk of non-productive wells in appraisal and production drilling based on geological models. Furthermore, it allows for the integration of geological exploration objectives with those of pilot-industrial operations, ensuring a more coherent development process.

Finally, the risks of achieving and maintaining the design productivity of wells should be managed by establishing rational technological operating modes, preventing exceedances of design parameters, using electronic metering devices for well production, and monitoring real-time productivity dynamics of the wells.

4 MAIN CONCLUSIONS

1. A linking element — the "complication factor" — has been introduced between uncertainty and risk.
2. The classification criteria for complication factors have been developed based on geological, technological, and economic uncertainties.
3. A scheme of sequential actions has been developed for the stages "exploration – appraisal – development."
4. The "Uncertainty–Risk" process has been defined as a sequence of interrelated actions in the field of hydrocarbon exploration and production.
5. A multifactor model has been proposed for calculating the success coefficient of geological exploration and development (GER) activities.

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