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Features of forecasting abnormally high reservoir pressures when drilling wells in areas of south-western Turkmenistan

Características del pronóstico de presiones de yacimiento anormalmente altas al perforar pozos en áreas del suroeste de Turkmenistán

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ABSTRACT

Introduction: The study is essential because predicting areas with high formation pressures in geophysical research is complex. It requires new technologies to accurately locate them and minimize unforeseen emergencies. The purpose of this study is to analyse and identify the peculiarities of predicting anomalously high formation pressures during well drilling in the territory of south-western Turkmenistan in order to provide more effective and reliable pressure management during drilling and operation. **Materials and Methods:** Methods such as analysis and prediction were used in this study. **Results and Discussion:** The paper presents valuable research data highlighting the changes in reservoir pressure gradients in the unique stratigraphic section of reservoirs in the oil and gas fields of the Pribalkan and Gogerendag-Ekerem zones. The analysis of the studies reveals the dynamism with which the properties of reservoir rock change with increasing depth of occurrence. Special attention is paid to the processes associated with the formation of anomalously high formation pressures, which is an important aspect for understanding complex geological processes. **Conclusions:** The study provides a detailed classification of formation pressures, considering the anomaly coefficient, enhancing our understanding of this phenomenon. Predicting formation pressures for specific horizons relies on analyzing deep well drilling results.

Keywords: Miocene, Enhanced Oil Recovery, Adjacent Territories, Drilling Fluid, Hydrodynamics.

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INTRODUCTION

The relevance of this study lies in the need to test the impact of the anomaly coefficient on key field development parameters. These parameters include reservoir pressure, hydrostatic pressure, porosity, and permeability of reservoir rocks, and fluid velocity in the reservoir. This indicator continues to be studied because it allows the energy state of the reservoir to be taken into account when making decisions on drilling operations. In addition, the anomaly coefficient plays an important role in improving well productivity and flow rates through the application of reservoir pressure maintenance (RPM), methods of intensification (MI) and enhanced oil recovery (EOR) techniques. However, it should be noted that there may be some inaccuracies in the use of the anomaly coefficient, which may lead to errors and leave some questions open in terms of geological and hydrogeological aspects. Despite this, the scientific community has proposed a number of hypotheses that are based on studies of the occurrence of anomalously high formation pressures (AHFP) and anomalously low formation pressures (ALFP). These hypotheses reveal the reasons why the introduction of a process parameter to compare formation pressure with hydrostatic (normal) pressure is an important step.

The research of M.A. Ashirmamedov [(1)] is aimed at identifying new prospects of oil and gas bearing capacity in the West Turkmen Depression and adjacent territories. This is based on the analysis of modern and historical geological conditions, peculiarities of oil and gas bearing formations, formation of fields and regularities of their spatial distribution. This work is aimed at accelerating the professional decision-making process to significantly expand the raw material base of the oil and gas industry. In this paper, a comprehensive study of oil and gas geology was carried out, which revealed the peculiarities of fold formation in Pliocene sediments: the impact of vertical and horizontal forces, shear along Mesozoic basement faults and crypto denudation. The multi-cyclic nature of oil and gas generation in the geological history determined the multistory of the oil and gas bearing complex of Meso-Cenozoic sediments. In the work carried out by T. Huszar et al. [(2)], studies were carried out to identify signs of temporary anomalously high contour pressures. Through detailed analyses, these features were identified and used to predict and quantify elevated reservoir pressures. As a result of the study, an algorithm was developed that can guide decisions on the selection of optimal well control procedures and steps, including yes, no, and maybe options.

A.R. Deryaev [(3)] presented recommendations on complex implementation of separate exploitation of several horizons at gas fields of Turkmenistan. And the author also developed a new well design for exploratory directional well by the method of simultaneous separate exploitation of 9 productive formations, which additionally led to the expansion of the productive part of the field, as well as the drilling of new several production wells. As a result of which, the saving of capital investments was achieved in order to drill the field and well development, as well as the reduction of operating costs [(4)]. Among the key strategic objectives for the company is to stabilize the volume of profitable oil production at the fields and to increase the interval between repairs of well equipment. Furthermore, important aspects are the search, selection, and introduction of new effective types of well equipment, as well as the use of new technologies to ensure well performance, including the use of chemical reagents. In this paper, a proposal to introduce equipment for simultaneous separate exploitation of reservoirs through one well was considered.

In the collection of JSC [(5)] describes the methods of laboratory analyses carried out in our own laboratory equipped in accordance with international standards. The collection presents schemes and tables of observations, conclusions on the economic significance of the tests, analysis of geological exploration in the Caspian Sea with prospects of oil and gas bearing capacity of the Ustyurt depression at depths up to 7000 m. Specific recommendations for

exploration and development of hydrocarbon fields are offered. The issues of three-dimensional seismic survey for the identification of tectonic disturbances are considered. Associated waters of Caspian oil and gas fields and their potential are discussed. The optimal technologies of treatment of bottomhole zones of wells are presented.
During his research, B.S. Aghayev [(6)] studied various methods and technologies used to assess anomalous values of formation pressure and to predict anomalous zones during the drilling of oil and gas wells. The results of the study show that the systems developed on the basis of such methods allow predicting anomalies in formation pressure without interrupting the drilling process and in real time. This research proposed a new prediction method that falls into this category of approaches. The basic principles of prediction, a description of the operating algorithm and a conceptual architectural model have been provided to develop an operating system that utilizes the proposed method. The presented works are of key importance in this topic, however, a more detailed study of the problem of predicting anomalously high reservoir pressures in the fields of south-western Turkmenistan has not been explored.
Accurate prediction of high-pressure zones in well drilling is crucial, particularly in southwest Turkmenistan's complex geological landscape. This study assesses the effectiveness of existing models for predicting high reservoir pressures in this region. Traditional models use offset well data and seismic interpretations, alongside empirical correlations based on depth and temperature. However, the scarcity of relevant offset well data and the region's intricate tectonic history limit the effectiveness of these generic models. As a result, there's significant uncertainty in pressure predictions, leading to well control incidents and varying estimates for prospects. Although there's a lack of comprehensive case studies in southwest Turkmenistan, the existing data suggests a need for improvement. Potential enhancements include integrating more seismic data to improve subsurface fluid system characterization and applying advanced basin modelling.
Based on the above, the aim of the research is to conduct a comprehensive analysis and detailed study of the influence of the anomaly coefficient of the formation pressure on the field development processes. This work is aimed at a deep understanding of the importance of this indicator in the context of oil and gas field development.

MATERIALS AND METHOD

In the course of the study, two methods were used, namely analytical and forecasting methods. The analytical method was the basis for analysing and understanding the complex influences of factors affecting the manifestation of abnormally high reservoir pressure. Available geological, geophysical and engineering data were analysed using this method. The predictive method was an important tool for predicting the future behaviour of anomalously high reservoir pressure. Using the collected data and analytical analyses, the researchers developed models and algorithms that allowed them to predict areas of possible AHFP based on current conditions and parameters. This method helped provide more accurate decision-making tools for drilling wells and planning production operations. Prediction also helped in better risk management and prevention of field contingencies.
A comprehensive analysis of the reservoir conditions and geological features of this region was carried out for the study. The initial approach was to collect all available geological data on the region of south-western Turkmenistan, including data on rock structure, formation parameters, geological history of rock formation and alteration. Based on the collected data, three-dimensional geological models were developed to represent the structure and composition of the rocks, as well as their geometry in different strata. These models provided a better understanding of the complexity of the geological environment. Reservoir parameters such as porosity, permeability, fluid saturation and other rock properties that

affect the behaviour of fluids in the reservoir were evaluated. Using geological models and reservoir parameters, numerical models were developed to simulate the distribution of reservoir pressures under different conditions. This included analysing the mechanisms for the formation of anomalous pressures. The developed models were compared with data obtained in practice during well drilling in the region. This allowed the accuracy and reliability of the prediction models to be assessed. The obtained results were carefully analysed and interpreted to identify the features and patterns of anomalously high formation pressures in south-western Turkmenistan. This included identification of possible factors contributing to the formation of such pressures. On the basis of analysing the results of the study, conclusions were drawn about the mechanisms of formation of anomalously high formation pressures and their impact on well drilling. Recommendations for more effective prediction and management of such pressures in the future were also proposed.

Based on the identified dependencies, mathematical models for predicting abnormally high formation pressures were developed. These models took into account various parameters and factors such as well depths, geological characteristics of reservoirs, and drilling parameters. The developed models were subjected to a validation process by comparing their predictions with real reservoir pressure data. This made it possible to assess the accuracy and reliability of the models. The models were tested on different data and, if necessary, parameters were corrected to achieve the best forecasting results. The developed and optimized models were implemented to predict anomalously high reservoir pressures in real time based on current drilling data and geological parameters. This study on the prediction of anomalously high reservoir pressures may have significant practical implications for efficient and safe operations in the oil and gas industry and related fields.

RESULTS

Over the last decades, a number of theories have emerged to explain the occurrence of anomalously high formation pressures, although there is still no dominant cause. According to the initial hypothesis proposed by W.K. Illing, anomalous reservoir pressure (AHFP) is formed in the process of gravitational compaction of clayey sediments accompanied by fluid flow from these clayey layers. According to this concept, the extent of AHFP depends on the rate of sediment accumulation and the length of time over which sediment burial has occurred. It also supports the view that the rapid accumulation of clayey sediments may have contributed to the formation of anomalous pressures within the rock layers. This is because water, gas, or oil that has not had time to flow out of the clay structure carries some of the load that would otherwise act on these layers. I.M. Murayev and A.P. Krylov [7] proposed possible conditions for the occurrence of AHFP in a shielded but not yet fully compacted layer. When the deposit is shielded by fractures, clay layers and other factors that lead to the cessation of fluid migration, and the load from the subsequent deposits formed after shielding is completely transferred to the fluid components. When, with shielding of the deposit, fluid migration is reduced to such an extent that the pressure from the loading of subsequent layers outpaces the pressure reduction caused by fluid migration from the deposit. And when the reservoir is not shielded and the porosity of the reservoir is high and migration from the reservoir is limited, the fluid takes up some external load.

In addition, each field may have unique features that cause formation pressure anomalies. In most cases, the polygenicity of anomalously high formation pressures is confirmed, as different causes and generation mechanisms can act simultaneously in the same reservoir. At the same time, it is necessary to take into account a variety of factors (geological, geophysical, geochemical) that affect the pressure in the reservoir. There are several ways in which formation pressure anomalies can be generated, including rock underconsolidation, thermal expansion of water, clay diagenesis, evaporite deposition, osmotic phenomena, tectonic and permafrost effects, and carbonate compaction. More recent studies by other scientists also confirm the role of these factors in the formation of anomalously high formation pressures [7].

The universal mechanisms of generation of anomalously high formation pressures at the regional level are fluid migration into the reservoir and compaction under the weight of rocks, hydrocarbon generation, vertical-migration processes, tectonic and neotectonic compressions, as well as the thermal factor. Fluid systems such as elision, geodynamic and infiltration systems are particularly important influencing conditions for reservoir pressure formation in fields. In particular, in geodynamic systems there are deformation-tensioned zones where anomalously high formation pressures are formed under the influence of high-frequency and deformation wave fields. Analyses of field deposits show that the relationship between anomalously high formation pressures and filtration-capacitance properties of rocks can be the cause of the formation of these pressures [2]. For example, low values of porosity and permeability of sandy silty rocks indicate the important role of fracture-pore reservoirs and secondary pore-type reservoirs in the formation of formation pressure anomalies [8]. Thus, the formation of anomalously high formation pressures can be associated with a variety of genetic features, including tectonic, hydrogeological and gravity factors, as well as features of fluid systems and rock properties.

The formation and maintenance of anomalously high formation pressures are also caused by rapid clay dehydration during intensive sedimentation, peculiarities of sediment lithology, the impact of tectonic processes and geothermal regime. The main reason for the formation of anomalous formation pressures are pore pressures in thick clay layers. However, there is the importance of the influence of deep gases, vapour-gas and gas-liquid mixtures, which can lead to the formation of anomalous pressures due to geodynamic pulsating fluid pushing under the saline and clay blankets of the upper sediments. From the point of view of genesis, there are two main conditions for the formation of AHFP and ALFP: the presence of impermeable cover at the reservoir, preventing the transmission of hydrostatic water pressure, and the inflow of gas phase from deep faults of underlying strata. It is also noted that the deterioration of filtration-capacitance properties of reservoir rocks can contribute to the formation of anomalous pressures, as the outflow of geofluids from the reservoirs is impeded [2].

The main reasons for the formation of anomalous reservoir pressures are: reservoir rock properties, pressure changes in the reservoir, tectonic movements, sedimentation rate, piezometric fluid level and sedimentation conditions. It is emphasized that the activity of tectonic and neotectonic processes associated with changes in reservoir pressure due to deformation and fluid yield plays a key role in the formation of anomalous pressures [9]. Basic theories of formation of anomalous formation pressures provide a general understanding of many factors contributing to the formation pressures exceeding hydrostatic pressures. Such areas with anomalous pressures are usually characterized by the presence of confined spaces with virtually impermeable boundaries, which underlines their significance from a geological point of view. In order to ensure an optimal drilling process, a thorough understanding of the patterns that determine changes in formation pressure with increasing well depth and changing nature of the geological section is required [10]. When it comes to drilling exploration wells in new areas, reliable methods for predicting reservoir pressures are needed to successfully cope with this task. The abnormally high pressures can be affected by multiple processes, including mineral conversions, rates of hydrocarbon production, aquathermal pressurisation, lateral fluid transfer, and topographic loading. These factors can lead to abnormal high pressures by influencing the physical characteristics of the underground, such as porosity, permeability, and fluid behaviour. Mineral transformations can cause alterations in the characteristics of rocks, which can impact the movement and pressure of fluids. The rates at which hydrocarbons are produced can affect the pressure within the pores of rocks, as a result of the production and movement of hydrocarbons. Aquathermal pressuring is the phenomenon when the pore pressure in the subsurface increases due to the thermal expansion of water. Fluids can generate pressure differences by lateral transmission, while pressure fluctuations can occur locally due to the weight of rock on topography. The precise geological and hydrogeological conditions of the subsurface determine the relative contributions of these elements. In a place where there are substantial hydrocarbon reserves, the rates at which hydrocarbons are produced may have a stronger effect on the occurrence of abnormally high pressures. On the other hand, in a region characterised by intricate faulting and movement of fluids, the sideways movement of fluids may have a more substantial impact.

Thermobaric conditions in the deep subsurface have a significant impact, including mud volcanism processes that have been observed in areas of south-western Turkmenistan. Many mud volcanoes in this region vent from deep strata. After sinking to a considerable depth, these strata activate gas generation processes, which leads to an increase in formation pressures to levels close to mountain (geostatic) pressures. Significant intensification of tectonic events in the Pliocene and, especially, in the post-Pliocene opened the door for excessive energy from deep layers, which acquired a unique manifestation in the form of mud volcanism. At the same time, existing methods for determining and predicting reservoir pressures have their limitations. Based on the first theory and using geophysical data reflecting the consolidation characteristics of clays, these methods show limited reliability. On the other hand, methods based on the (neo)tectonic theory have not yet been developed [(11)]. In the context of anomalously high reservoir fluid pressures in rock formations, it should be emphasized that for a long time there was no clear distinction between the concepts of "anomalously high", "elevated" and "normal" pressures.

The indicators of formation pressure during drilling and well research in the regions of South-West Turkmenistan, allow classifying them according to the anomaly coefficient as follows [(12)]:

1. Anomalously low formation pressure at KA<0.8.
2. Low (KA=0.8-1).
3. Normal (KA=1-1.3).
4. Elevated (KA=1.3-1.5).
5. Abnormally high (KA=1.5-2).
6. Ultra-high formation pressure (KA>2).

In the analysis of abnormally high formation pressures, three main types are distinguished: the first one is in thick and stable reservoir formations, second - in lenticular thin reservoirs, and third - due to pore pressures in clays.

Anomalously high formation pressures in clay rocks can cause the rocks to protrude inside the wellbore and collapse. In the case of thin lenticular reservoirs, this can be manifested by sudden ejections of clay mud during drilling [(2)]. When designing well construction, the prediction of formation pressures is carried out by analysing and generalizing the available material on the actually measured values of formation pressures in neighbouring wells or in neighbouring areas. Measurements are made by three methods of direct measurement using the method of inducing flow from the reservoir such as testers of formation on drill pipes (TFDP), during reservoir development in the production string (DPR), and by means of packerless measurement according to the Nebitgazylmytaslama methodology (SBI).

In the areas of the Pribalkan district, formation pressures exceed the conventional hydrostatic pressure and are at elevated and anomalously high levels. In Apsheron deposits, initial formation pressures exceed hydrostatic pressure by 1.1-1.15 times. In the Goturdepe and Barsagelmez areas, they represent the beginning of the productive section. The Lower

Apsheron, Akchagyl and Upper Red-Coloured deposits are separated from each other by clay packs varying in thickness from 20 to 100 m. They have gas-oil contacts (GOC) and water-oil contacts (WOC) at similar depths, and the initial reservoir pressures in these fields are also close to each other. At East Goturdepe, they exceed hydrostatic values by a factor of 1.2-1.22 and at Barsagelmez by a factor of 1.25-1.27. Continuing the analysis, it is important to note that on the relatively elevated West Goturdepe, the exceedance reaches 1.33. In the following sediments, mainly represented by the watered section of red-coloured strata, there are only isolated cases of tectonically shielded or closed small oil deposits. The lowest measured pressures in this part of the section are 1.2-1.3 times the hydrostatic pressure. Nevertheless, currently productive horizons of the Apsheron, Akchagyl and Upper Red-Coloured deposits are drained by long-term exploitation and have current reservoir pressures not exceeding hydrostatic pressures. Formation pressure gradients are 0.04-0.05 kg/cm^2 per 1 m depth, indicating the presence of anomalously low formation pressures in this context [13].

In the lower part of the reddish-coloured strata, there is a significant increase in formation pressures, exceeding hydrostatic pressure by 1.4-1.7 times. In their basement in some areas, this index even reaches the value of 1.95 and higher. This phenomenon can be explained by the increased clay content of the section, where permeable strata here are lenticularly embedded in thick clay strata [14]. The analysis of formation pressure values in the territory of South-Western Turkmenistan reveals a wide range of its changes depending on the geological conditions and features of the sections. Classification by the anomaly coefficient allows structuring the obtained data and a better understanding of different reservoir pressure regimes. Formation pressures are a fundamental element in the study of subsurface resources and complex mining and geological conditions, influencing the formation and implementation of all key technical and technological decisions related to well construction. It is the most important parameter on which engineers and geologists conducting exploration and production operations in geological sections are oriented (Figure 1).

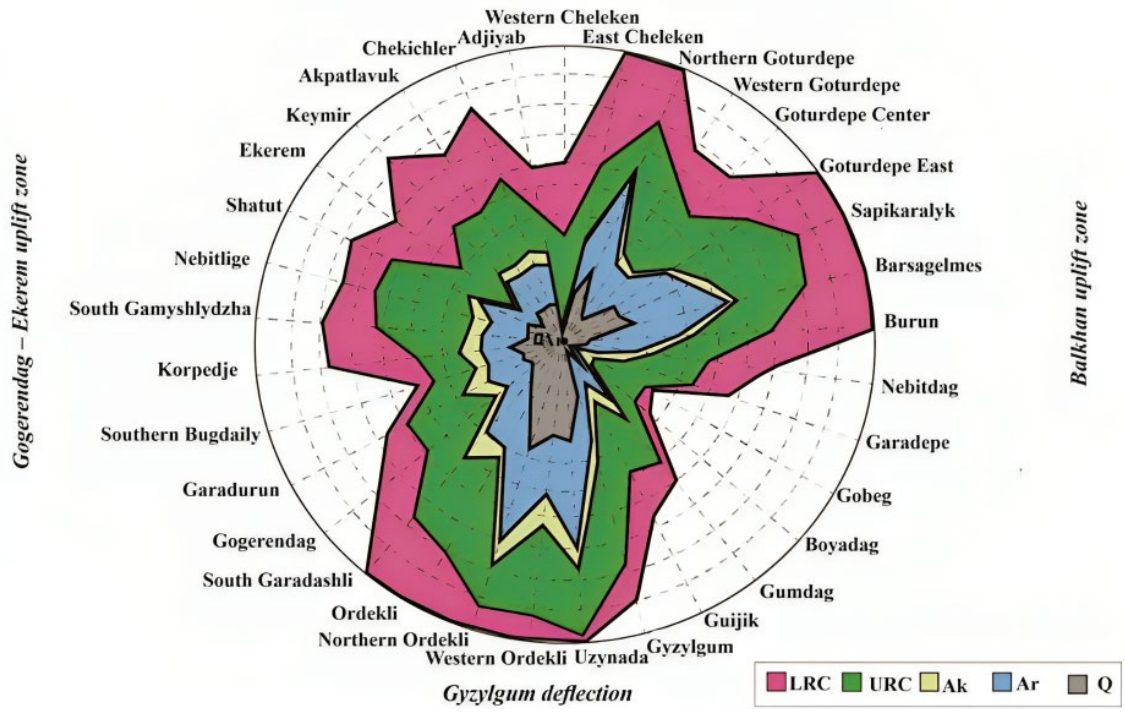

Figure 1. Stratigraphy of the areas of the West Turkmen depression
Note: Q – Quaternary deposits; Ap – Apsheronian stage; Ak – Akchagyl stage; VK – upper red flower; NK – lower red flower
Source: compiled by the author based on [15].

In the areas of Boyadag, Gumdag, Monjukly, Garadepe, Syrtlanly, Goturdepe, Eastern Cheleken and Cheleken (Aligul), an exposure of Pont-Miocene sediments underlying the red-coloured strata is observed. These deposits mainly consist of clayey rocks with rare sandstone layers. Due to the high clay content of these deposits, increased reservoir pressure is characteristic. For example, in the Eastern Cheleken and Cheleken (Aligul) areas, the excess of reservoir pressure over hydrostatic pressure is 1.9-2.16 times, and in Goturdepe – 2-2.22 times. To ensure drilling safety under these conditions, high-density clay solutions (2-2.3 g/cm^3) were used to avoid manifestations and collapses of the well walls (Figure 2).

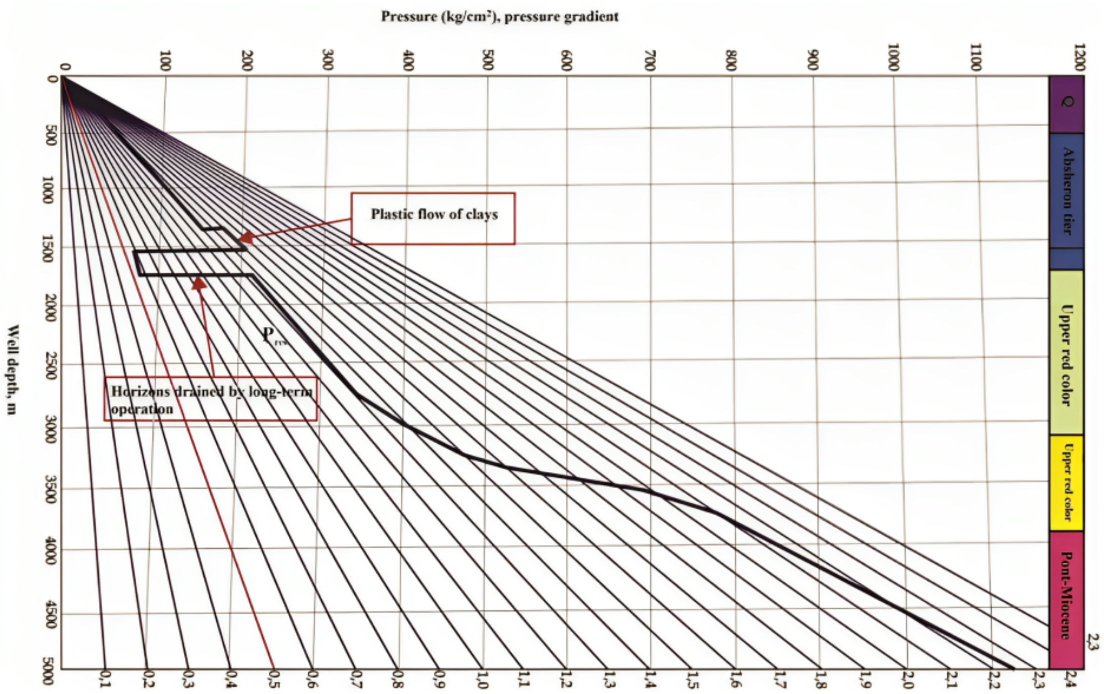

Figure 2. Change in reservoir pressure with depth in the Balkhan uplift zone (using the example of Goturdepe)

Source: compiled by the author based on [16].

Below the Miocene sediments in the Pribalkhan area are Lower Cretaceous sediments. They occur in the Garadepe, Cheleken (Aligul) and East Cheleken areas, represented by alternating sands, sandstones, and clays. Anomaly coefficients in these sediments range from 1.9-2.08 in the Cheleken (Aligul) and East Cheleken areas. The Garadep well No. 23, drilled to the Neocomian Lower Cretaceous sediments, showed a different pattern of reservoir pressure variations. The Pontic Miocene sediments in this well are characterized by lower formation pressures, and drilling in this part of the complex was carried out using drilling muds with a density of 1.45-1.58 g/cm^3. The Upper Cretaceous is characterized by slightly higher formation pressures, and the density of clay mud was increased to 2.2 g/cm^3 for drilling in this part of the complex. In the Lower Cretaceous sediments, formation pressure values decrease and clay mud density decreases to 1.65 g/cm^3.

In the Gogerendag-Ekeremsky area, the distribution of formation pressures shows the following patterns: in the upper part of the section, including the Apsheron and Akchagyl stages, there is a steady increase in formation pressure values and their gradients up to 0.125 kg/cm^2 per 1 m depth. Absolute values of formation pressures in the Upper Red increase moderately to 0.14 kg/cm^2 per 1 m depth. Ekizak is present in some parts of this part of the section. Formation pressure gradients in the Gogerendag, Keymir sections remain stable or decrease to a minimum in the middle (0.125 kg/cm^2 per 1 m depth), then increase again. In the roof and footwall of the upper part of the redbed, the pressure gradients are equal. In the lower part of the reddish-coloured sediments, the clay content increases, which leads to

a sharp increase in formation pressures with depth, especially in the Goturdepi Formation, where the absolute values of formation pressures reach the mountain pressure. Pressure gradients in the lower reddish-coloured sediments are 0.17-0.222 kg/cm² per 1 m depth. For example, drilling mud with a density of 2.25-2.3 g/cm³ was used when drilling wells in the areas of Ekerem (wells No. 2M, 3M), South Gamyshlydzha, Akpatlavuk, Chekichler due to the presence of formations with abnormally high formation pressures [17].
The study was carried out in Korpedje, Shatut, Nebitlidje, Akpatlavuk and other locations where formation pressure gradients in Ponto-Miocene sediments were closely analysed. An important result of this study is the finding of stability of reservoir pressure gradients in the Ponto-Miocene sediments, which remain at the same level as the Lower Red-Coloured sediments. This indicates some relationship between these strata and the presence of common factors affecting formation pressure in these geological formations (Figure 3).

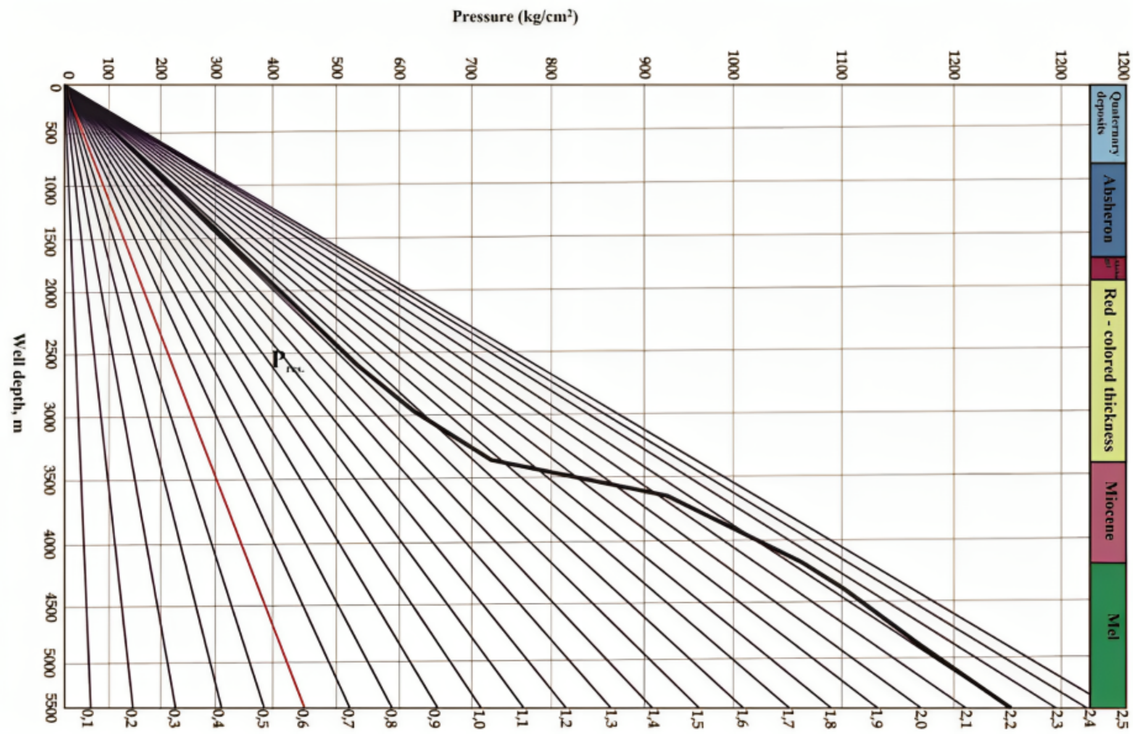

Figure 3. Changes in reservoir pressure and depth in the Gogerendag-Ekerem uplift zone
Source: compiled by the author based on [18].

Separately, it is worth highlighting the results of a study in the Akpatlavuk area in well N40, where reservoir pressure in the Lower Cretaceous deposits was not measured due to technical difficulties. However, despite this, the use of drilling fluid with increased density in the range of 2.28-2.3 g/cm³ hints at the presence of formations with abnormally high pressures in this area. This aspect highlights the importance of additional research and more detailed analysis of reservoir pressures in this area to obtain more accurate data and a better understanding of the processes occurring in underground geological structures.

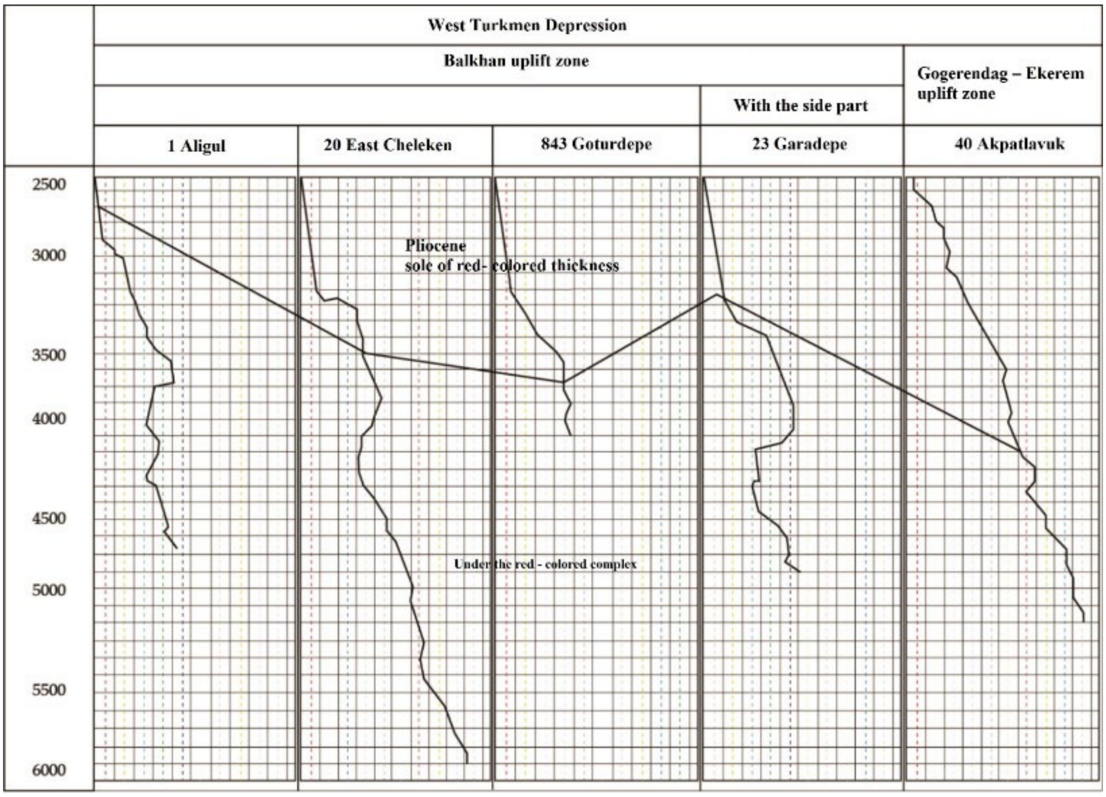

Figure 4. Changes in pore pressure in Pliocene sediments and underlying sediments of the West Turkmen depression
Source: compiled by the author based on [19].

The study highlights the complexity of the interaction of different geological formations and their influence on reservoir pressure. It is noted that pressure gradients in formations may be subject to changes depending on the lithological composition, the content of clay components and other geological parameters. This provides significant information for developing drilling and production strategies for these fields. Also, in order to optimise safety and efficiency in high-pressure drilling operations, the implementation of several solutions is crucial. These strategies involve the utilisation of improved methods to estimate formation pressure, the use of drilling fluids that can withstand high temperatures and pressures, and the implementation of secure cementing technologies to provide proper isolation between different zones. Furthermore, precise forecasting of Equivalent Circulating Density (ECD) is essential for effectively controlling wellbore pressures. Pressured Mud Cap Drilling techniques offer advantages when dealing with high-pressure fractured reservoirs. To minimise hazards, it is crucial to prioritise safety standards, conduct regular equipment maintenance, and provide comprehensive staff training on well control methods. Additionally, it is crucial to monitor and detect early indicators of high-pressure formations, such as alterations in the characteristics of drilling mud and the presence of different types of gases, in order to ensure operational safety and achieve desired outcomes.

DISCUSSION

Taking into account the results of the conducted research, it can be said that the results of the study significantly improve the safety and efficiency of drilling and well operation processes, contributing to the optimization of work in the fields and the development of practical geophysical science and engineering. It is also additionally worth analysing other data of some scientists who also studied the features. prediction of anomalous formation pressures. In their studies, scientists have paid attention to various aspects of the problem under consideration.

In the study conducted by M.R. Amjad et al. [20], the problem of overpressure caused by unbalanced compaction in structural subdivisions of the Murree formation was considered. The analysis showed that most wells with overpressured intervals exhibited elevated porosity values, indicating deviation from normal compaction patterns. Pressure prediction confirmed that the main cause of overpressure in the Murree Formation is the imbalance of compaction processes caused by intense sediment accumulation. This means that the sediments accumulated too fast for them to compact properly. Deformation mechanisms and the presence of a variety of structural geometries also played a role in the formation of the anomalous pressures. The results of the study show that overpressurisation in the Murree Formation is a complex problem caused by multiple factors. To reduce the risk of gas releases, well cave-ins and well damage, it is necessary to consider all these factors when planning and developing oil and gas wells in the Murree Formation. It is worth noting that data can vary depending on the location being explored. It is for this reason that a very different cause of the anomalously high pressures in south-west Turkmenistan can be determined, which was shown in this study.

In their study, W. Huzhen et al. [21] studied aspects of solving problems of predicting the distribution of reservoir pressure and productivity after hydraulic fracturing in horizontal wells in stressed reservoirs. In their study, they used methods including dynamic permeability and dynamic threshold pressure gradient. In addition, they developed a numerical model to simulate two-phase water-in-oil flow using the finite element method. Analysis of the calculation results revealed the following patterns: the effect of reservoir pressure on well productivity is mainly seen during the first year of operation, with the effect enhanced by volumetric fracturing. The effect of stress sensitivity mainly affects the middle and late stages of production. It is important to point out that as sensitivity increases, there is a loss of reservoir permeability, concentrated generally in the low-pressure region close to the artificial fracture, resulting in a zone of high flow resistance and, as a result, a reduction in development efficiency in the farther reaches of the well. It should be emphasized that for additional reservoir pressure estimation it is worthwhile to apply direct investigation methods like TFDP, DPR and SBI, which were used in the research work carried out.

The study by A. Elyasi et al. [22] represents an important contribution to the development and analysis of strategies for predicting pore pressure and three fracture gradients for the Koppeh-Dagh sedimentary basin. In the study, the researchers utilized a wealth of petrophysical data as well as downhole pressure and well drilling events in the field. Three different strategies for determining the pressure gradient in the fractures were analysed, and their results were compared in detail with actual data and drilling events. This approach allowed the scientists not only the flexibility and comprehensiveness of the study, but also allowed them to evaluate the effectiveness of each strategy under real-world conditions. The most extensive and accurate results were demonstrated when applying a strategy based on the Ben Eaton model to predict the pressure gradient in fractures. This model arguably provided more reliable and consistent results with reality, emphasizing its important role in the field of pressure and gradient prediction. It is important to note that in order to perform this analysis and final prediction, it is important to always have up-to-date data, which may not always be possible due to the hazardous terrain, which was not considered in the study.

Y. Jiao [23] published a study that analyses different methods of pore pressure prediction for multiple mechanisms of formation pressure generation. In the paper, the authors proceed from the fundamental principle of the improved Fillippone method using a high-precision 3D seismic velocity field from geological model inversion. The basic concept of the study is to construct a 3D pore pressure model for the target block. To do this, pressure slices are extracted both along the horizon and across the target well. In addition, the scientists analyse

other pressure transmission mechanisms, possibly related to reservoir connectivity. These data are integrated into a mathematical model for pore pressure prediction, ultimately leading to significantly improved prediction accuracy. The significance of this method is demonstrated by its successful application in predicting pore pressure prior to drilling in a typical high temperature and high pressure (HTHP) block in the South China Sea. The obtained results demonstrate high accuracy of forecasts exceeding 95%. The method is good enough for future forecasting. By combining the data of the scientists and this paper, more accurate predictions can be obtained for the anomalous pressures of Turkmenistan.
C. Fan et al. (24) conducted a study to unravel the mechanisms of overpressure formation and to predict pore pressure. This study provides important clues to understanding reservoir dynamics and cautions against potential risks in the drilling process. During the study, the researchers delved into vertical effective stress analysis and conducted geological assessments to unravel the mechanisms of overpressure formation. Simultaneously, pore pressure was successfully predicted using a method proposed by Bowers. Proving to be very fruitful, this study not only helped to unravel the mysteries of reservoir pressure, but also provided practical predictions for drilling operations. The results of this study provide valuable guidance to industry and the research community on how to effectively predict and manage pressure in a variety of zones, including both non-diapiric and diapiric zones, in the Ingehai Basin. It is important to point out that this methodology will not be suitable for all zones investigated; however, the study provides a platform for further refinement of forecasting techniques and an in-depth understanding of geological processes, which in turn contributes to the safety and efficiency of field operations. This conducted study utilizes universal reservoir pressure prediction methods, which are more versatile and will be able to suit different well drilling depths. It is also additionally important to control the amount of drilling mud, because it also has a direct effect on the reservoir pressure level (25; 26).
It should be noted that inaccurate high reservoir pressure predictions can have significant implications across economic, environmental, and safety domains. Economically, such inaccuracies can lead to unexpected drilling challenges, increasing costs due to the need for more equipment, materials, and extended operational time to manage high-pressure formations (27-30). This also causes production delays, impacting project timelines and potentially leading to financial losses from reduced productivity, along with a misallocation of resources as operational plans and budgets need adjustment. Environmentally, these inaccuracies can contribute to well control incidents like blowouts and mud volcanoes, causing oil spills and contamination of natural habitats, and may also hinder efficient resource extraction, affecting environmental sustainability (31; 32). From a safety perspective, unforeseen high pressures pose risks to workers, potentially leading to accidents and injuries. Additionally, these situations create complex and hazardous well control challenges, compromising the safety of personnel and the integrity of the wellbore (33; 34). It would be beneficial to integrate geophysics, petrology, and fluid dynamics enhances the prediction of high reservoir pressures in well drilling. By combining geophysical well logs with petrological data, a deeper understanding of subsurface pressure regimes is achieved, improving pore pressure prediction accuracy (27; 35). Utilizing principles of fluid dynamics and reservoir engineering, such as pressured mud cap drilling, helps manage high-pressure environments more effectively, optimizing drilling operations and safety. Additionally, merging geophysical and petrophysical data with fluid dynamics can aid in early detection of high-pressure formations, improving risk management (33; 36; 37). This interdisciplinary approach, encompassing basin modelling, well-logging, and reservoir data analysis, provides a comprehensive view of subsurface pressures, leading to better predictions through the synthesis of various data types and methods (38).
In this topic, further research is possible to expand the knowledge of predicting anomalous formation pressures and to better understand the factors that influence this phenomenon.

One direction for future research could be to study in more detail the geological structures and fractures that play a role in the formation of AHFP zones. This would allow for more accurate models and predictions based on specific geological parameters of the field. In addition, the following studies can focus on analysing the influence of different parameters on reservoir pressure dynamics. The study of geothermal conditions, rock properties, characteristics of hydrodynamic processes and interaction with the environment will allow creating more complete models of anomalous pressure formation. Another interesting research direction is related to the application of modern technologies such as computer modelling and machine learning. These techniques can help to analyse large amounts of data and identify complex relationships between parameters, which can help to better predict anomalous reservoir pressures. In addition, future research can delve deeper into analysing contingency cases and field emergencies associated with abnormal pressures. Analysing such cases will help to identify the characteristics and causes of such situations, which in turn will enable the development of more effective measures to prevent and manage them.

CONCLUSIONS

In summary, examination of the upper layers of the reddish-coloured sediments suggests a constantly changing nature of the rocks as one moves deeper into the earth. At greater depths, there is a decrease in both the number of sandy-silty sediments and their thickness. Simultaneously, clay formations become dominant in the lower part of this section and occupy an important position. Especially high clay content is preserved in Miocene and Lower Cretaceous layers. An interesting observation can be made in the areas of the Gogerendag-Ekerem area, where active tectonic processes influence the structure of the section, both in the Pliocene period and in the Lower Cretaceous. These dynamics explain why there are no obvious channels for the release of accumulated gases and liquids.

The findings from the analysis and the combined knowledge of reservoir pressures in the Southwest Turkmenistan region play an essential role in predicting reservoir pressures when drilling new wells. To ensure successful drilling, it is important to continuously monitor drilling fluid parameters and correlate formation pressures throughout the process. Additionally, the importance of validating reservoir pressure predictions using direct survey methods such as TFDP, DPR and SBI should be emphasized. This provides accurate and reliable data to help improve the efficiency and reliability of drilling and well operation processes.

Further research could include the following areas: a deeper and more detailed study of the geological structure of the region and rock properties could help to better understand the mechanisms of anomalously high formation pressures; the use of numerical models and simulations could more accurately predict the behaviour of formation pressures under different drilling and operating conditions; the use of various geophysical techniques such as seismic surveys, gravimetry, magnetometry could provide additional information on the formation pressure behaviour of the wells; and the use of various geophysical methods such as seismic surveys, gravimetry, and magnetometry could provide additional information on the behaviour of formation pressures under different drilling and operating conditions.

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