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APPLICATION OF GEOPHYSICAL METHODS IN THE EXTRAPOLATION OF SEDIMENTOLOGICAL DATA ON UNMASTERED AREAS OF DEPOSITS (ON THE EXAMPLE OF PENNSYLVANIAN CARBONATE RESERVOIR, AKANSKOYE OILFIELD, EAST OF RUSSIAN PLATFORM)

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A b s t r a c t

A feature of the oil-bearing carbonate deposits of the lower Pennsylvanian in the east of the Russian platform is their rapid vertical and horizontal change. It is often difficult to make correlations between sections, especially in the absence of core data when using only geophysical data. In addition, not all facies are reliably identified and traceable from log data and not all have high reservoir properties. Authors made an attempt to trace the promising facies both to adjacent wells and, in general, to the entire field area using core study results and translation of these results using log and seismic data. The data showed pinching of rocks with high reservoir characteristics in the direction of the selected profile (from south to north within the field). Coastal shallow water facies, represented by Grainstones and Packstones, with high reservoir properties in the south of the field, are replaced by lagoon facies and facies of subaerial exposures, represented by Wakestones and Mudstones with low reservoir characteristics, in the north of the field. The authors suggest that this approach can be applicable for rocks both in this region and for areas with a similar structure.

Keywords:
Pinch-out;
Well data;
Seismic data;
Limestone;
Facies;
Reservoir rocks.

1. Introduction

During the new field development, the choice of future exploration drilling locations is complicated by the lack of sufficient information. Promising reservoir rocks location based only on geophysical data is difficult, especially in high facies variability of deposits. However, such studies still take place [1, 2]. These objects include carbonate reservoir rocks of the Bashkirian stage in the east of the Russian platform. The high degree of lithological heterogeneity of Bashkirian sediments, both vertically (along the section) and horizontally often does not allow to reliably trace potential reservoir rocks even at a distance of 5-10 km within the same field [3]. Using seismic data, well logging data and detailed core material studies authors proposed an approach of the extrapolation of available data to new unexplored areas. Such studies are known in geological exploration and have shown good results [4-7]. The purpose of the chosen approach was to identify potentially promising for development areas as well as to explain the reasons for pinch-out or the appearance of reservoir intervals with high reservoir properties. The Akanskoye oil field, located in the Nurlatsky district, southeastern part of Tatarstan, east of the European part of Russia, was chosen as a model object (fig.1A-B). Southern part of the field is in the actively developed and is well characterized by geophysical data as well as core material, while the northern part of the license area is much less investigated, and the available information is limited only by geophysical data.

The authors set several tasks:

1. Is it possible to extrapolate the reservoir distribution identified from the core data using geophysical surveys in poorly explored fields?

2. What is the demand for core material studies to predict new or underdeveloped areas?

3. How applicable and efficient are geological models on polyfacial and complex sections of carbonate reservoir rocks?

2. Geological setting

The study focusses on the Akanskoye field oil-bearing limestones of the Bashkirian stage, tectonically located on the eastern side of the Melekesskaya depression, within the Volga-Ural

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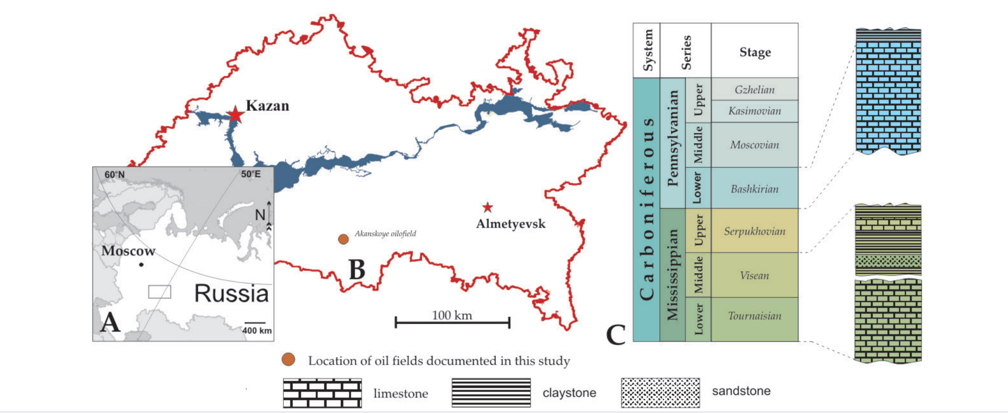

Fig.1. Regional location of the research object and brief stratigraphy. (A) European part of Russia - Volga-Ural region. (B) Map of the Tatarstan Republic and the location of the Akanskoye field. (C) Stratigraphy and lithology of the Tournaisian, Visean and Bashkirian stages

anteclise in the east of the Russian platform. Paleozoic sedimentary cover (up to 1900 m thick) lies on the metamorphosed Archean-Proterozoic crystalline basement rocks. Paleozoic deposits are represented mainly by terrigenous Middle and Upper Devonian deposits, mainly carbonate Carboniferous deposits and mainly carbonate-evaporite Permian rocks. Study area experienced a tectonic stabilization with minor vertical tectonic movements in the post-Permian stage [8]. Since the Neogene the territory has acquired a stable tectonic uplift, which is accompanied by the appearance of erosional incisions (100-150 m) composed of Neogene-Quaternary alluvial deposits [9, 10].

Most of the Devonian clastic reservoirs currently being developed are at a late stage of development and are largely depleted. For that reason, carbonate oil reservoirs are acquiring more economic importance. The most significant commercial oil deposits in carbonate reservoirs are mainly confined to Carboniferous deposits and are actively developed in the lower Mississippian and lower Pennsylvanian (fig.1C). The source rocks are Upper Devonian black-shale formations [11, 12] that and occur mainly in the Frasnian stage [13] and represented by thin-layered high-carbonaceous-siliceous rocks [11, 14].

Data on the structural features of Carboniferous carbonate reservoirs in the east of the Russian platform in the international literature are rather scarce [3, 10, 15]. The study area was a vast shallow-water carbonate platform in the earlier Pennsylvanian time [16]. The high variability of facies along the section is most often explained by global glacioeustatic fluctuations recorded in synchronous sections around the world [17-20]. Most of the studied facies are represented by normal marine sediments; however, traces of subaerial exposures are observed in some sections, which is caused by periodic drainage of certain parts of the study area [3]. The most common lithotypes are grainstones and packstones, while mudstones and carbonate breccias are less common [3, 10]. The most promising intervals are associated with shallow-water grainstones and leached packstones.

3. Methods

Macroscopic study of the core.

The studied core material was taken from several wells of the Akanskoye field and has a high core recovery (90-100%). This allowed making a detailed description of the sections and makes a high-quality selection of samples for research. The description was carried out from the bottom up the section, since this approach allows finding the rocks types change regularities and tracing the dynamics of the sedimentation changing conditions of the Bashkirian paleosea. A special attention was paid to the nature of the lithotypes relationship, lithological and paleontological composition, structural and textural features of rocks. The samples were taken with a step of 30 to 70 cm, depending on the nature of lithotype change and fluid saturation.

Optical microscopic studies.

Optical microscopic analysis of petrographic thin sections was carried out using an «AxioImager A2» polarizing microscope. Thin sections analysis included determination of the mineral composition, identification of microtexture and structure of rocks, fossils, determination of the certain facies conditions of carbonate sediments accumulation. The international structural classification of Dunham [21] was chosen as the carbonate rocks classification. For more information on the methodology of facies identifying and sections constructing, as well as tracing the identified facies over the area see the paper of Kolchugin et al [3].

The used geophysical data was: welllogs for wells 2013, 692 and 924: GR, Neutron, RhoB. Seismic data are represented by a cube (67 inlines 301 crosslines). All geophysical interpretation was performed using the Petrel 2018 software.

4. Data presentation.

The average thickness of the Bashkirian deposits within the Akan field is 37 meters. The section is composed of limestones. Thus, the predominant lithotypes are peloid and foraminiferal packstones, ooid and bioclastic grainstones (fig.2). Wackestones and mudstones are found much less frequently (fig.2).

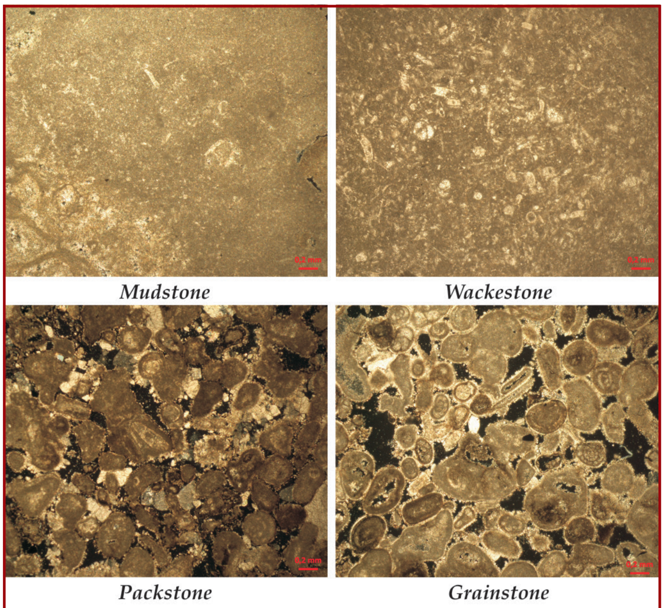

Fig.2. Thin sections of the main limestone types composing the Akanskoye field, well. 2013

The distribution of limestone types combined into the corresponding facies [3] is shown on the example of typical section of the deposit (fig.3). In addition, the section has identified intervals characterized by high petrophysical properties, uniform and intense oil saturation and are the most promising for development. The analysis of the rocks intervals with high petrophysical characteristics shows that they are confined to the grainstones and packstones in the upper and middle parts of the section. The average porosity and permeability for the upper section part are 15.2% and 213 mD respectively, in the middle part 11.4% and 146 mD. It should be noted that packstones pores are secondary and are formed as a result of secondary leaching under conditions of drilling diagenesis of rocks. The grainstones pore space is mostly inherited and is represented by intergranular pores formed during sedimentation. In general, the pore space is represented by intergranular pores [22].

Integration of geological and seismic data are the widely used approach in oilfield exploration. Authors have done investigations on the several oilfields in Tatarstan [23-25].

The top of the Bashkirian stage (C_{2b}) is marked by high neutron and density and low gamma-ray log readings. The Serpukhov Stage (C_{1s}) is marked by a sharp decrease in the neutron and density logs (fig.3).

According to logging data the Bashkirian stage can be divided into 2 parts: upper (high porous) and lower (low porous). The boundary between high-porous and low-porous interlayers was marked as the P boundary (fig.3). Structural map of the Bashkirian stage top with the location of 2013, 692 and 924 wells and Profile 1 is shown in figure 4.

Bashkirian stage top is a positive reflection according to the seismic to well tie. This boundary is marked as C_{2b} on fig. 5. The P boundary has negative reflection. The C1s boundary marking the boundary between Bashkirian and Serpukhovian stages is positive reflection. The 2013 well (which was investigated with core samples) is located outside the seismic cube, however, the data from this well (as well as 692 and 924) was used in the interpretation of seismic Profile 1 (fig.5).

According to the maps were built, P reflection wedges out northward (fig.6). This shows that the upper highly porous part of the Bashkirian stage is pinched out in a northerly direction.

The authors carried out the extraction of the initial seismic amplitudes values along the horizon P (fig.7). As can be seen on the resulting map, there is a significant change in the amplitudes of the seismic wave reflection, but in general, the amplitude is negative. A change in the amplitude values can

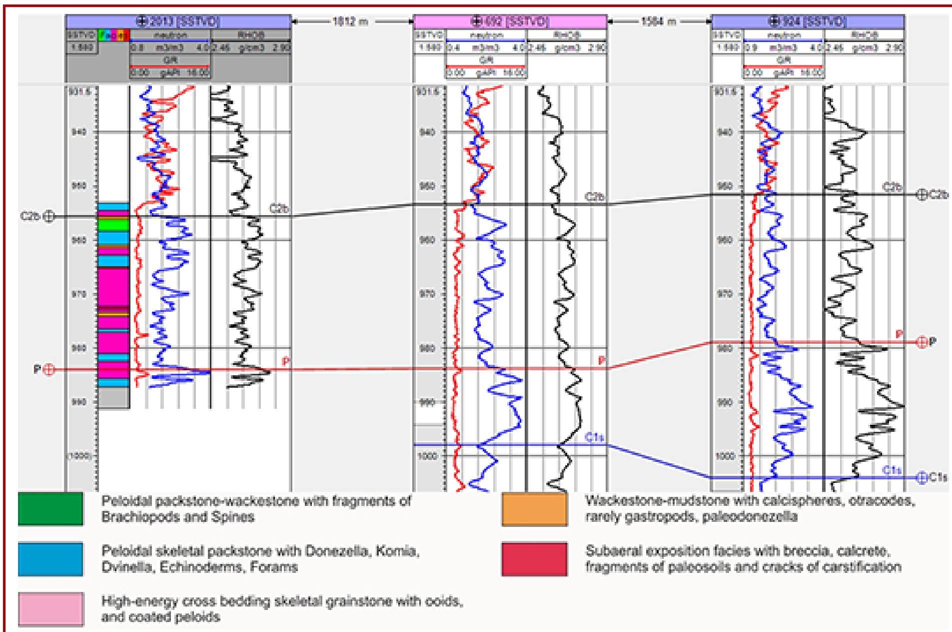

Fig.3. Stratigraphic boundaries location according to well logging data of 2013, 692 and 924 wells

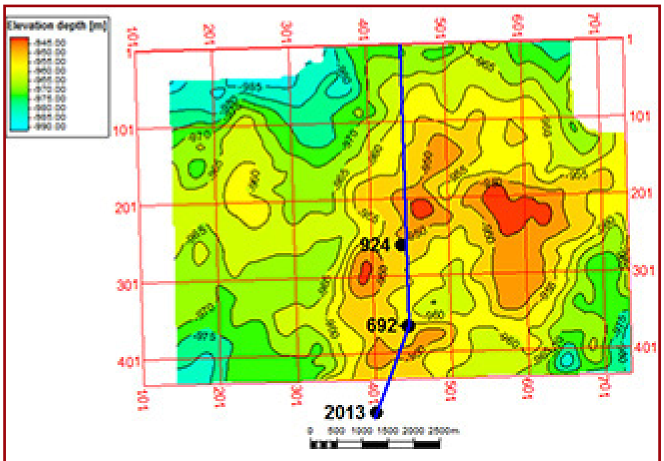

Fig.4. Structural map of the Bashkirian stage top with the location of 2013, 692 and 924 wells and Profile 1 (blue line)

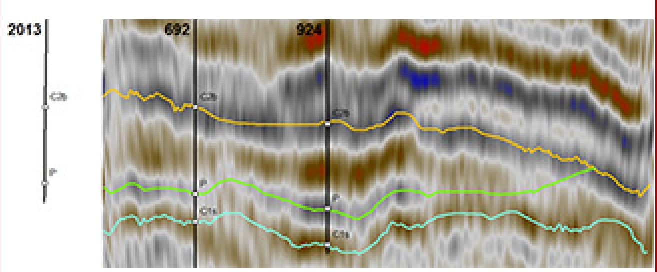

Fig.5. Seismic profile 1 (location is shown on the fig.4). Yellow line shows reflection from the C_{2b}, green line shows the reflection from P, blue line shows reflection from C_{1s}

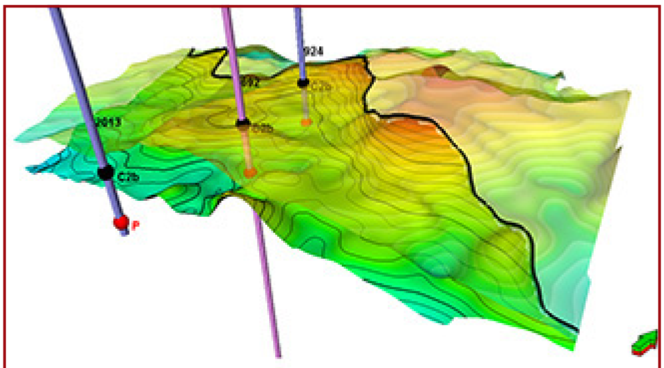

Fig.6. Structural maps of C_{2b} (transparent) and P

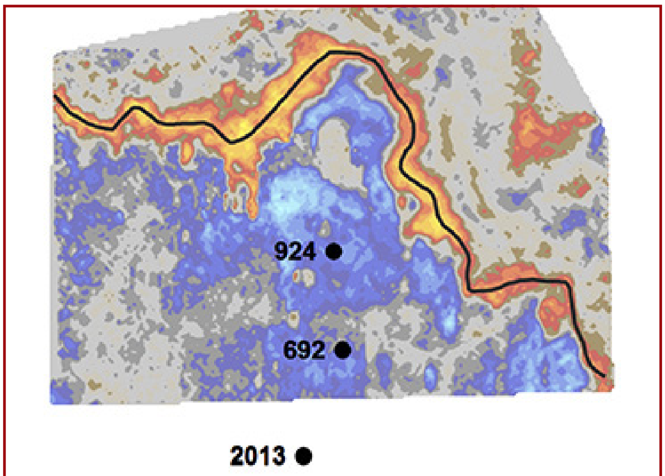

Fig.7. Slice of the seismic data cube along reflection P. The pinch line (black line) is highlighted in the slice

be associated with a change in the thickness of the formation and with a change in its facies composition.

5. Discussion.

Authors interpret the data and find the possible reasons for the pinching out of potentially promising highly porous reservoir rocks. The wedging out can be caused by two reasons: 1) a change in the limestone facies (wedging out of potentially promising packstones and grainstones); 2) the peculiarities of the limestones diagenetic history and the accompanying secondary mineralization. At the very beginning, it should be noted that both possible reasons are extremely difficult to confirm or deny due to the lack of core in the northern part of the studied field. However, both options should be analyzed in more detail.

The Bashkirian paleobasin in the studied area was a vast epicontinental sea with extremely insignificant depth differences. Periodic glacioeustatic fluctuations of the sea basin drained some areas, which led to partial erosion of carbonate deposits. It should be noted that the Bashkirian age was a time of active fluctuations in the sea level due to global glaciation processes [19, 20]. Probably, glacioeustatic fluctuations played a key role in changing of the sea level, periodic drainage and flooding of vast areas of a shallow-water paleobasin. However, in the sections studied within the field (not only within the studied profile), traces of erosion of rocks are captured only in presence of thin brecciated limestones, while traces of the subaerial conditions impact on rocks of have not been revealed. This may indicate that the study area was in relatively deeper water conditions than, for example, sections located eastward (100-150 km to the east). Traces of erosion of synchronous deposits and the impact of meteoric diagenesis are quite intense in the eastern sections [3]. It should be noted that diagenesis predetermine the future appearance of the rocks and the porosity inheriting for the initially porous rocks more often than any other factors of the Bashkirian stage rocks of the region. Thus, under meteoric diagenesis, grainstones often completely lose their porous space and become dense impermeable rocks as a result of pores filling with early diagenetic calcite. Packstones, on the other hand, are often characterized by intense recrystallization, where a significant portion of the original micrite is recrystallized into sparite. Under such diagenetic conditions, both types of limestones acquire a dense structure (no more than 3% porosity and 10 mD permeability) and does not have any significant reservoir properties.

Another feature of the Bashkirian limestones is the secondary processes: formation of secondary cement of calcite, dolomite, sulfate minerals (gypsum and anhydrite), less often chalcedony. As a rule, secondary cements fill the pores, cavities, and fractures, reducing the reservoir characteristics, locally forming denser rocks areas. However, such processes are more often occurs in the lower part of the section, namely, the water-oil transition zones [10]. Such areas have little effect on the overall section productivity, especially considering that the upper part of the section is the most productive.

Thus, according to the authors, the most justified reason for the wedging out of reservoirs is the local facies variability of rocks caused by the transition of shallower facies (composed of grainstones and packstones) into facies of more submerged settings (represented by wackestones and mixed types of packstone-wackestone) with initially low reservoir characteristics. This is confirmed by the absence of a relationship between the reservoir wedging out in the study area and the structural uplifts, that is, the limestones petrophysical properties variability does not depend on their position within the structures (crest, flank of reservoir) and the position of the water-oil contact.

The use of geophysical methods at the selected object, coupled with elements of field modeling, has shown its effectiveness. Indeed, it is extremely difficult to predict the potentially promising rocks distribution over the area without a reference point, which is the core material of one of the studied wells, especially in conditions of high facies variability. So, having the detailed core description of the section and high-quality geophysical data (well logs and seismic) it is possible with a high degree of confidence to extrapolate the core study data to adjacent wells, adjacent structures and even areas. However, it should be noticed that the more core material the researchers have, the more correct the sedimentological model of the field will be.

Conclusions

Thus, the materials obtained during the study of the Akanskoye deposit and their geological interpretation led to the following conclusions:

- Based on the data obtained, it was revealed that the change in reservoir characteristics of the most promising upper part of the Bashkirian sediments from south to the north, is due to facies variability: pinching out of highly porous limestones by denser low porous limestones.
- To predict the facies variability of sediments, including predicting the potential reservoir rocks distribution, application of exclusively geophysical methods is not enough. However, the combined use of geophysical data and detailed sedimentological studies has shown its effectiveness.
- Construction of geological models of deposits for polyfacies sections implies a large volume of sedimentological studies, as well as detailed work with well logging data, to identify facies from core on well logs and trace them over the study area. The use of seismic data along given profiles can greatly facilitate the task of extrapolating the available data over an area.

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Использование геофизических методов в экстраполяции седиментологических данных на неосвоенных участках месторождений (на примере пенсельванских карбонатных резервуаров, Аканское месторождение, восток Русской платформы)

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Реферат

Особенностью нефтеносных карбонатных отложений нижнего пенсильванского яруса востока Русской платформы является их резкое изменение по вертикали и горизонтали. Часто возникают сложности с проведением корреляции между разрезами, особенно исключительно по геофизическим данным при отсутствии данных керна. Кроме того, не все фации можно надежно идентифицировать и проследить по каротажным кривым, и не все фации обладают высокими коллекторскими свойствами. Авторы предприняли попытку проследить перспективные фации как в соседних скважинах, так и в целом по всей площади месторождения, комбинируя результаты исследования керна с использованием каротажных и сейсмических данных. Результаты свидетельствуют о выклинивании пород с высокими коллекторскими характеристиками в направлении выбранного профиля (с юга на север в пределах месторождения). Прибрежные мелководные фации, представленные грейнстоунами и пакстоунами, с высокими коллекторскими свойствами на юге месторождения, заменяются фациями лагун и субаэральных обнажений, представленных вейкстоунами и аргиллитами, с плохими коллекторскими свойствами на севере месторождения. Авторы предполагают, что такой подход может быть применим для отложений как в этом районе, так и для участков с аналогичным геологическим строением.

Ключевые слова: выклинивание; каротажные данные; сейсмические данные; известняк; фации; коллектор.

Yataqların mənimsənilməmiş ərazilərində sedimentoloji məlumatların ekstrapolyasiyası zamanı geofiziki metodların istifadəsi (Rusiya platformasının şərqində Penselvan karbonat rezervuarları, Akan yatağı timsalında)

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Xülasə

Rusiya platformasının şərqində aşağı Pensilvaniya mərhələsinin neftli karbonat çöküntülərinin özəlliklərindən biri onların kəskin şaquli və üfüqi dəyişməsidir. Çox vaxt, xüsusən də kern məlumatları olmadıqda, kəsiklər arasında geofiziki məlumatların korrelyasiyasının aparılmasında çətinliklər yaranır. Bundan əlavə, bütün fasiyaları karotaj əyrilərinə əsasən etibarlı şəkildə identifikasiya etmək və izləmək mümkün olmur və bütün fasiyalar yüksək kollektor xassələrinə malik deyildir. Müəlliflər kern analizinin nəticələrini karotaj və seysmik məlumatların istifadəsilə birləşdirərək, həm yanaşı (qonşu) quyularında, həm də bütövlükdə yatağın bütün sahələrində perspektivli fasiyaları izləməyə çalışmışlar. Nəticələr seçilmiş profil istiqamətində (yatağın daxilində cənubdan şimala doğru) yüksək kollaktor xassələrinə malik süxurların pazlanmasını göstərir. Yatağın cənubunda yüksək kollektor xassələrinə malik qreynstoun və pakstoun sahilyanı dayaz su fasiyaları yatağın şimalındakı pis kollektor xassələrinə malik veykstoun və arqillit kimi təqdim olunan laqon və subaeral fasiyaları ilə əvəz olunur. Müəlliflər hesab edirlər ki, bu yanaşma həm bu ərazidəki çöküntülər, həm də oxşar geoloji quruluşa malik ərazilər üçün tətbiq oluna bilər.

Açar sözlər: pazlama; karotaj məlumatları; seysmik məlumatlar; əhəngdaşı; fasiya; kollektor.