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Analysis of the reservoir properties of rocks of the Lower Kura depression (Azerbaijan)

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The article analyzes the features of Lower Kura Depression. A number of hydrocarbon deposits have been discovered in this oil and gas region. The Kalmas underground gas storage facility has the largest volume in Azerbaijan and is also located here. In the Lower Kura Depression, all Productive Series formations can be traced throughout the entire well section.

We considered the reservoir properties of the rocks. The analysis requires data obtained by using a complex of well logging methods (laterolog, spontaneous potential logging, induction logging, gamma logging, neutron logging, acoustic logging) and analyses of rock samples.

The relationship between petrophysical parameters (porosity, permeability, etc.) were evaluated graphically.

In the article, porosity distribution, permeability of sandy siltstone rocks and fractions greater than 0.1 of the Productive Series of the South-Eastern Gobustan and Baku Archipelago, which are part of the Low Kura Depression, are plotted and analysed. Plots of the porosity distribution of the Low Kura Depression by depth were also constructed.

Based on reservoir properties, the region is divided into 6 groups, and in each group intermediate values of the porosity and permeability coefficients are determined. In general, the porosity coefficient ranges within 5—25 % and permeability 1—250 mD. The reservoir properties of rocks vary over the area.

The capacitance-filtration properties of rocks were studied. Rocks with good and low reservoir characteristics were identified.

To study the variation in the determiningfactors, maps of the distribution of reservoir properties' indicators (fractions greater than 0.1 mm; porosity and permeability in sand-siltstone-containing rocks) were compiled by area and their causes were determined by comparison with other oil and gas fields. The reservoir properties of the rocks deteriorate with distance from the mouth of the Kura River (towards the right and left banks). This is due to an increase in the amount of clay in rocks. The change in porosity coefficient does not depend on depth. The content of sand-siltstone composition in the rocks along the section is 20—50 %.

Key words: reservoir, porosity, clayness, well, map, field.

Introduction. Tectonically, the Lower Kura Depression (LKD) (Azerbaijan) is the south-eastern end of the intermountain Kura trough, plunging into the waters of the Southern Caspian Sea [Akhmedov, Aghayeva, 2022; Seidov, Khalilova, 2023; Nasibovaa et al., 2023; Seidov et al., 2024]. The border of this area in the east and southeast is conventionally drawn along the coastline of the Caspian Sea (Fig. 1).

A characteristic feature of the area is its intensive subsidence and compensated sedimentation in the Neogene-Quaternary [Sid-

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diqui et al., 2020; Kerimova, 2023]. The thickness of the sedimentary complex in the LKD reaches 20 km, and in the most submerged zones about 6 km are Pliocene-Quaternary deposits.

Within the LKD, three anticlinal folds can be traced, represented by the following uplifts: 1) Pirsaat and Hamamdag, with most of the Hamamdag structure in the sea; 2) Kalamadin, Great Harami, Lesser Harami, Mishovdag, Kalmas, Khidirli, Bandovan; 3) Padar, Kurovdag, Garabagly, Babazanan, Durovdag, Khilli, Neftchala [Akhmedov, Aghayeva, 2023; Maharramov, 2023].

The Kyursangi anticlinal fold stands out, between the anticlinal folds Kalamadin—Bandovan and Kurovdag—Neftchala in the depression zone [Abasov et al., 2007; Kocharli, 2015; Seidov, Alibekova, 2022].

The LKD structures have a generally northwest-southeast strike. Most structures are highly complicated by tectonic disturbances and mud volcanoes [Geophysical ..., 1996; Aliev, 2003]. On the arches of more elevated structures (for example, Kalamadin, Harami, Babazanan, etc.) and on the northeastern side

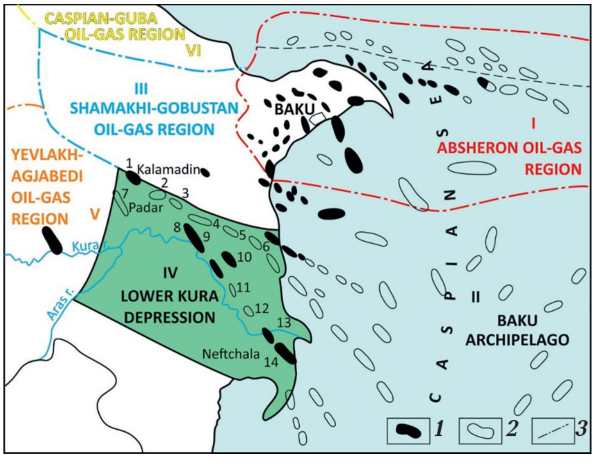


Fig. 1. Overview diagram of Azerbaijan oil and gas regions and defined structures: I — Absheron Oil-Gas Region; II — Baku Archipelago; III — Shamakhi-Gobustan Oil-Gas Region (OGR); IV — Lower Kura Depression; V — Yevlakh-Agjabedi Oil-Gas Region; VI — Caspian-Guba Oil-Gas Region; *1* — field; *2* — structures; *3* — OGR borders (1 — Kalamadin, 2 — Great Harami, 3 — Dashli, 4 — Mishovdag, 5 — Kalmas, 6 — Khidirli, 7 — Padar, 8 — Kurovdag, 9 — Garabagly, 10 — Kyursangi, 11 — Babazanan, 12 — Durovdag, 13 — Khilli, 14 — Neftchala).

of the LKD, the rocks of the productive series (PS) come to the surface, and in the adjacent synclines the roof of the PS sinks to a significant depth (3000 m or more). The maximum thickness of the PS is about 4000 m in the Pirsaat and Bandovan structures, where the underlying sediments are overlain by sediments of the Lower-Girmaki formation.

In the LKD, the PS is represented by polymict (quartz-feldspar-graywacke and feldspathic-quartz-graywacke) varieties with a predominance of rock fragments.

LKD rocks are characterized by high clay content and the development of authigenic montmorillonite, which is the main reason for their low permeability.

Lithologically, the PS rocks are represented by an uneven alternation of polymict sandy-silty and clayey rocks. In total, more than 20 predominantly sandy horizons are identified in the section. The PS section in the southeast direction becomes more clayey.

Industrial oil and gas content in the region is mainly associated with PS deposits.

Methods and results. The petrophysical properties of rocks were determined using the well data obtained by WL methods — lateral logging (LL), spontaneous potential (SP) logging, induction logging (IL), gamma ray (GR) logging, acoustic logging (AL) and neutron logging (NL) [Rusul, Ghamin, 2023]. Qualitative and quantitative interpretation was based on the measured well log curves. Porosity was determined using the LL, IL, AL and NL data, and conductivity was determined using the IL data.The coefficients of clayness and sandiness of rocks were estimated using SP logging and GR logging.

Laboratory analysis of rock samples was used to study some (volume-filtration and other) rock characteristics.

The reservoir properties of the sediments are quite well-studied for the upper section of the PS. According to the capacitance-filtration properties of the core and geophysical studies of wells of a number of LKD areas, there are 6 groups of rocks. They are shown in Fig. 2.

Area 1: rocks have no reservoir properties, which is obvious with permeability below 1 mD. This area includes Southern Kyursan-

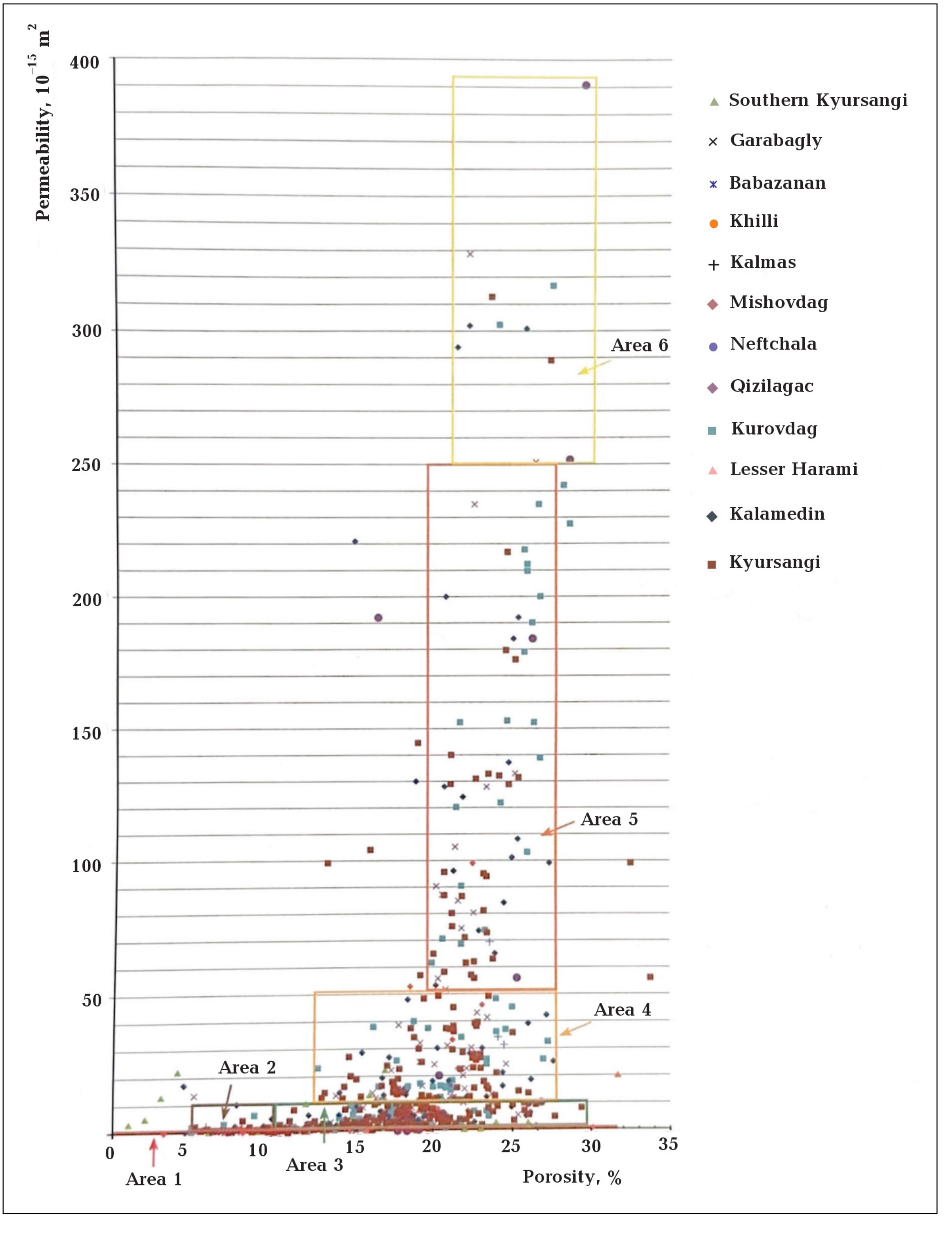


Fig. 2. Diagram of reservoir properties of deposits of the productive series of the Lower Kura Depression.

gi, Neftchala, Kurovdag, Kalamadin, Kalmas. Area 2: porosity is 5—10 %, permeability varies from 1 to 10 mD. These core samples (Southern Kyursangi, Neftchala, Kurovdag, Kalamadin, Mishovdag, Lesser Harami, Kalmas, Garabagly) can be said to have poor res-

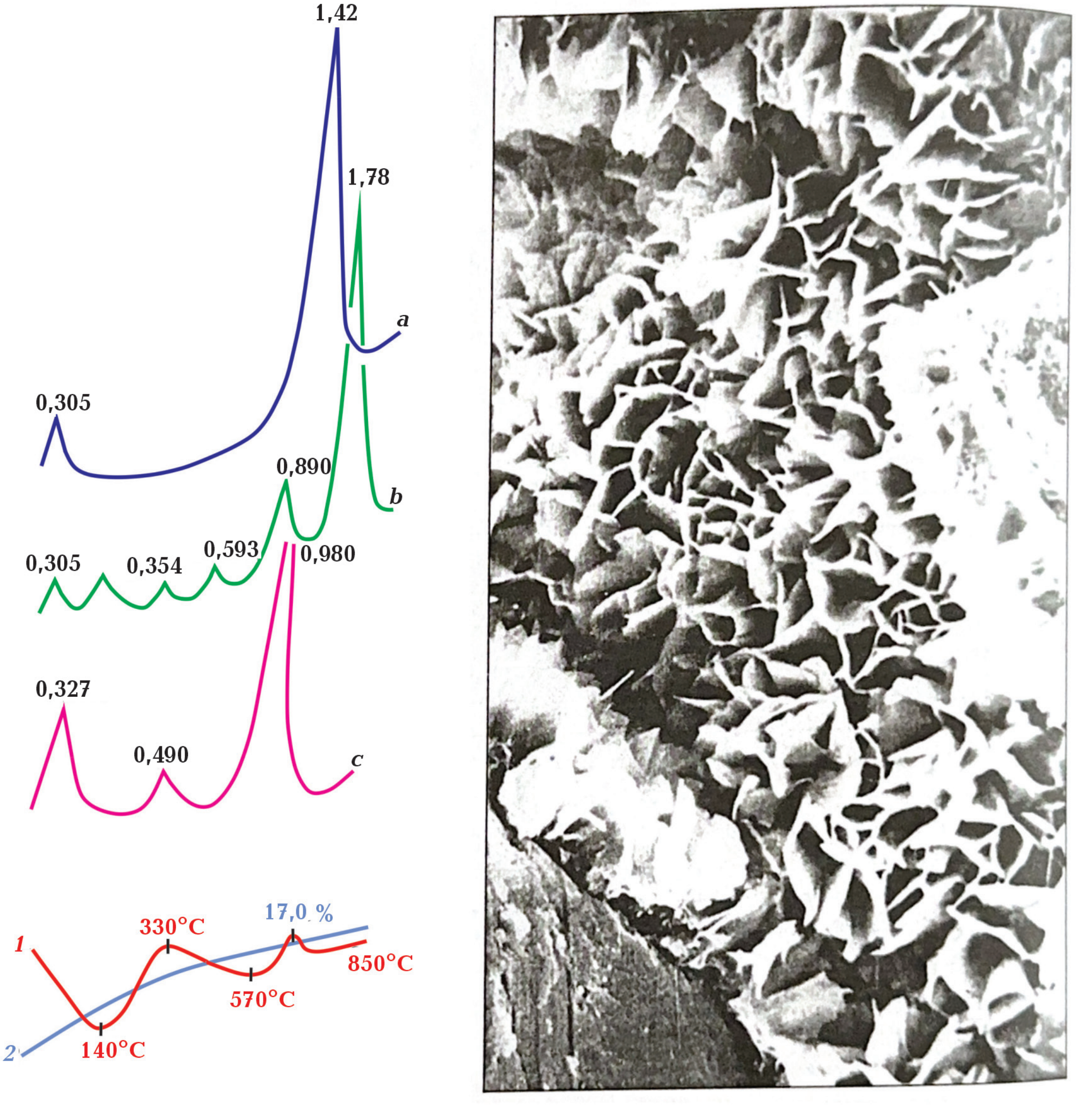


Fig. 3. X-ray diffraction patterns, thermograms and electron microphotography (×1240), characteristic of Lower Pliocene reservoirs of the Lower Kura Depression: *a* — X-ray diffraction pattern of an air-dry sample; *b* — saturated with glycerin; *c* — heated at 580°C; *1* — differential thermal analysis curve; *2* — weight loss curve.

ervoir properties. Area 3: moderately poor reservoir properties. These rocks have average and good porosity (>10 %) and poor permeability (1—10 mD). The absolute majority of the studied samples fall into this area. Area 4 (about a third of all samples): moderate reservoir properties, porosity >12 %, permeability 10—50 mD. Area 5: good reservoir properties, very good porosity exceeding 20 % and good permeability (50—250 mD). Area 6: very good reservoir properties, 20 % porosity, permeability over 250 mD. Good and very good indicators of reservoir properties were noted in several areas — Kurovdag, Kyursangi, Kalamadin, Mishovdag, Garabagly, Neftchala.

This analysis showed that reservoir properties, even within the same area, can range from very bad to very good.

First of all, this analysis used the results of studying the capacitance and filtration properties of all core samples without separation by stratigraphic age. As it is known, the reservoir properties of the rocks of individual formations of the productive series vary significantly, and are largely controlled by the granulometric composition. The distribution

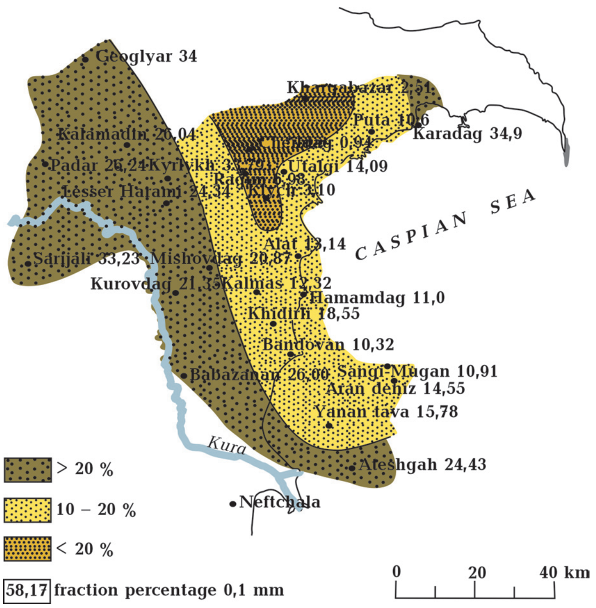


Fig. 4. The content of the fraction exceeding 0.1 mm in the rocks of the productive series of the Lower Kura Depression, South-Eastern Gobustan and the Baku Archipelago.

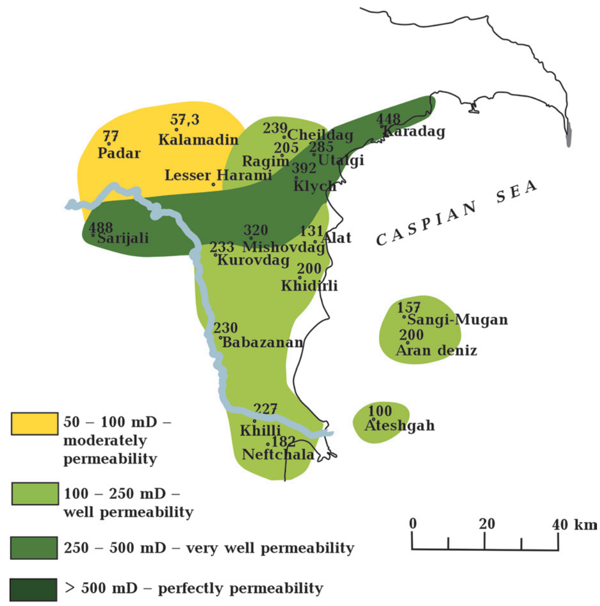


Fig. 6. Permeability of sandy-silty rocks of the productive series of the Lower Kura Depression, South-Eastern Gobustan and the Baku Archipelago.

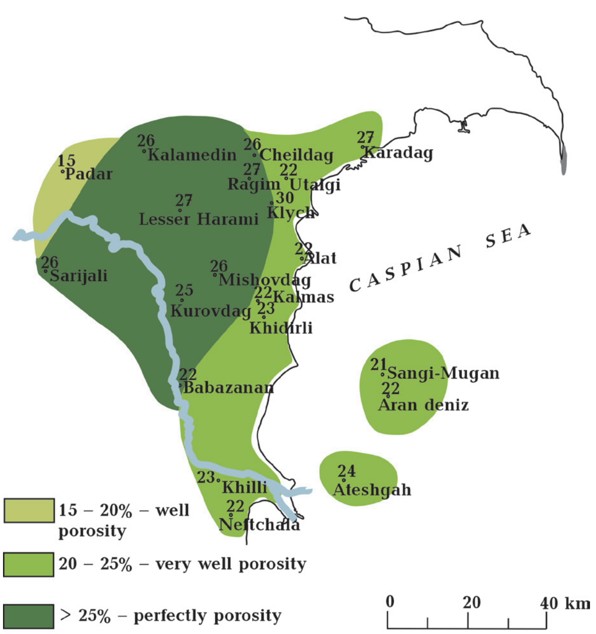


Fig. 5. Porosity of sandy-silty rocks of the productive series of the Lower Kura Depression, South-Eastern Gobustan and the Baku Archipelago.

of the contents of sand and clay fractions also showed a wide range (Fig. 3).

Most samples have all three fractions (sand, pelitic, aleurite) in approximately equal quantities (green square), which determines their moderately poor reservoir properties. A negative factor is the dominance of montmorillonite in the cement of these types.

Approximately equal numbers of samples are in fields with a high presence of sand (red square) or silt (blue square) fractions, which is reflected in their reservoir properties. According to Fig. 2, approximately 30 % of the samples have good and very good properties. Obviously, the proportion of sand fraction in such rocks is quite high.

Approximately the same number of studied samples have moderate reservoir properties, which corresponds to rocks with a high proportion of silt fraction.

Lastly, a small number of samples have a high proportion of clay and poor reservoir properties.

What, then, is the determining factor in such variations? Mapping the indicators of reservoir properties of deposits of the Surakhani formation PS and its analogues over the South Caspian Basin shows the best reservoir properties in the LKD along the Kurovdag-Garabagly-Babazanan anticline, which corresponds to the paleochannel of the Kura river in the Lower Pliocene (Fig. 4—6). Mov-

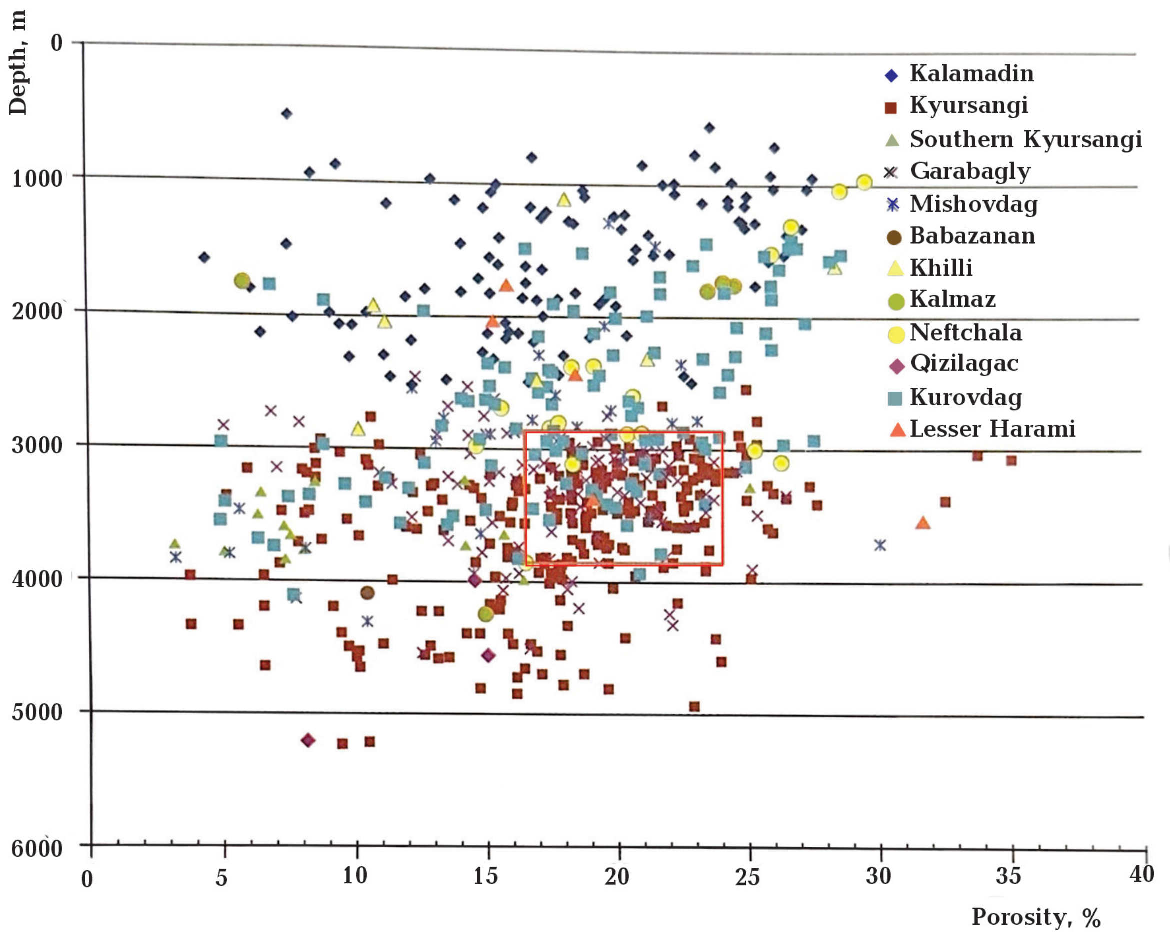


Fig. 7. The distribution of porosity of the Lower Kura Depression productive series sediments by depth.

ing away from the main river channel of the Paleo-Kura, the quality of the reservoirs deteriorates sharply, which is due to the change of sandy channel facies to floodplain deposits, naturally accompanied by a clay component in the rocks.

Noticeable variations in reservoir properties along the LKD are explained by frequent avulsions of the meandering Kura and changes in the location of its main channel.

If we compare the reservoir properties of the deposits of the Surakhani formation of the LKD and the Absheron Peninsula and the archipelago, their significant superiority in a number of areas of the LKD, located along the ancient riverbed of the Kura, is obvious. This fact is a good illustration of the conclusion about strong facial control over the reservoir properties of PS deposits.

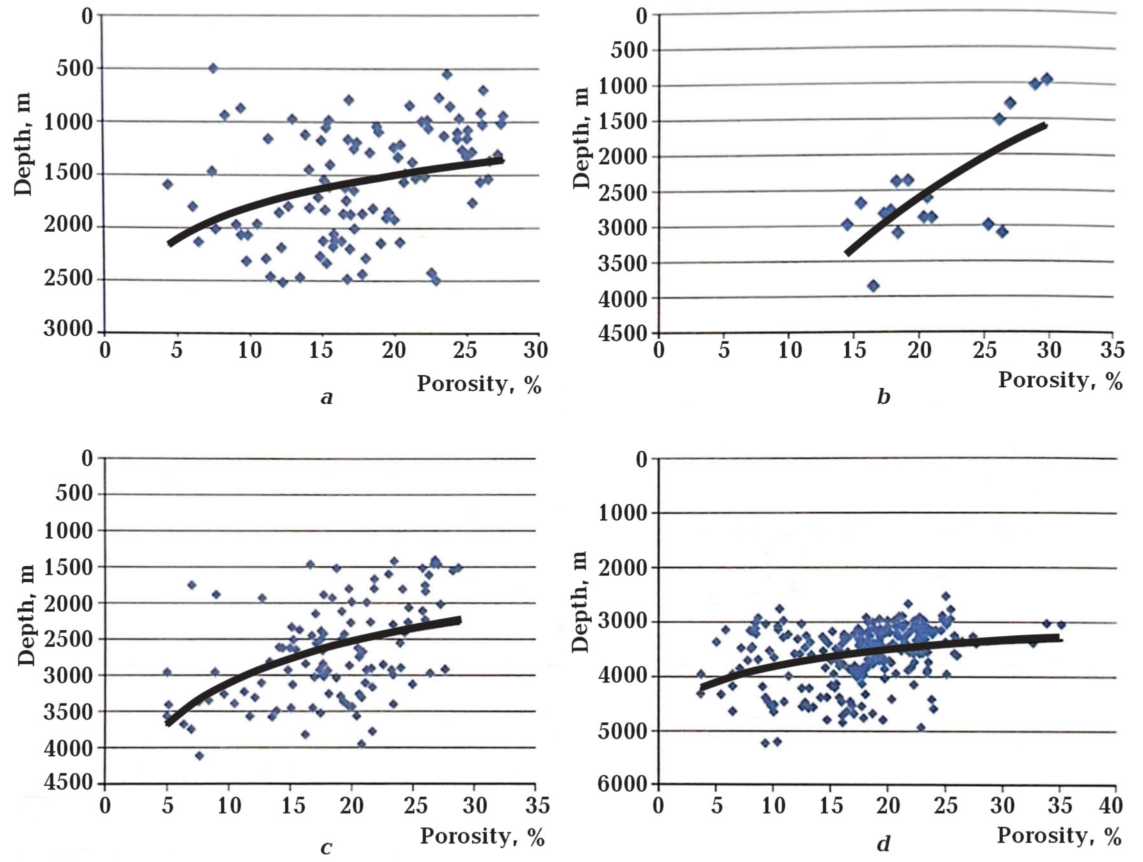
Models of horizon I (Surakhani formation) over the Kalmas area show the mosaic structure of the reservoir. Most of the area has sediments with mostly low and very low reservoir properties and lacks reservoir rocks.

The moderately poor reservoir properties of the PS LKD deposits are also clearly demonstrated in the scanning electron microscope image of the rocks of the analogue of the Balakhani formation, Kalamadin area.

The distribution of porosity of PS rocks by depth shows that the most studied samples with good capacitive properties ($15\,\% < K_{pores} < 25\,\%$) are in the interval of 3—4 km (Fig. 7).

The most hypsometrically high deposits are located in the PS areas of Kalamadin, Khilli, and Neftchala; hypsometrically low deposits — Kyursangi, Southern Kyursangi, and Garabagly.

No dependence of the porosity on depth can be traced. An explanation can be that



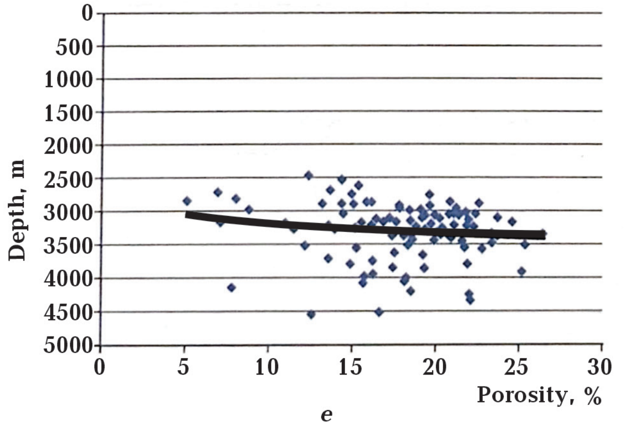


Fig. 8. Distribution of porosity of sediments of the productive series of the Lower Kura Depression by depth: *a* — Kalamadin, *b* — Neftchala, *c* — Kurovdag, *d* — Kyursangi, *e* — Garabagly.

this diagram summarizes the results for many areas, and rocks with the same capacitive properties are located at different hypsometric levels.

When separately analyzing the distribution of porosity across the depths of individual areas, a clear picture emerges, which was already mentioned above (Fig. 8).

The porosity of the rocks decreases most intensively from the upper intervals of the section to a depth of 3.5—3 km (Fig. 8, *a*, *b*, *c*). From 3 to 4 km, either the decrease in porosity occurs in an insignificant volume, or a reverse process of decomposition is observed.

The improvement of reservoir properties at great depths due to post-sedimentation processes is also confirmed in the SEM image of the XX horizon sediments (analogous to the Fossil Formation) of the Neftchala area. In these rocks, primary porosity is partially preserved (7 %) during compaction and is significantly improved by complete or partial dissolution of grains (6.7 %).

Coarse clastic, sandy-silty, clayey, unsorted and pyroclastic rocks, described below, take part in the structure of the PS sections.

Sandy-silty rocks in the PS deposits make up 20—50 % of the section. In the LKD, they are represented by polymict (quartz-feldspar-graywacke and feldspathic-quartz-graywacke) varieties with a predominance of rock fragments.

LKD rocks are characterized by high clay content and the development of authigenic montmorillonite, which is the main reason for their low permeability.

Conclusions. Strong variations in reservoir properties across the section of individual areas are explained by changes in the location of the Kura from the main channel, accompanied by repeated changes in lithofacies conditions in the section of the PS LKD. Towards the offshore part of the basin, the transition to the clayey Kura delta was naturally expressed in a sharp deterioration in the quality of reservoirs in offshore areas.

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Аналіз колекторних властивостей порід Нижньокуринської западини (Азербайджан)

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У статті проаналізовано особливості, що характеризують Нижньокуринську западину. У цьому нафтогазоносному районі виявлено низку родовищ вуглеводнів, а також знаходиться підземне сховище газу Калмазске з найбільшим об'ємом в Азербайджані. У Нижньокуринській западині всі світи продуктивної товщі простежуються в усьому розрізу свердловини.

Для вивчення особливостей району розглянуто колекторні властивості порід. З метою вивчення колекторних властивостей пластів за розрізом свердловин на родовищі використано дані комплексу методів геофізичних досліджень свердловин (боковий каротаж, каротаж потенціалів спонтанної поляризації, індукційний каротаж, гамма-каротаж, нейтронний каротаж, акустичний аналізу зразків гірських порід

Побудовано графіки для оцінювання взаємозв'язку петрофізичних величин (пористість, проникність та ін.), визначених у породах розрізу свердловин об'єкта дослідження. Складено та проаналізовано карти пористості, проникності та розподілу фракцій понад 0,1 мм у породах продуктивної товщі Південно-Східного Гобустану та Бакинського архіпелагу, що складають Нижньокуринську западину. Побудовано графіки, що відображають розподіл пористості порід Нижньокуринської западини за глибиною.

За колекторними властивостями район розділено на шість груп, у кожній з них визначено проміжні значення коефіцієнта пористості та проникності. Загалом коефіцієнт пористості коливається в межах 5—25 %, проникність 1—250 мД. Колекторні властивості гірських порід за площею змінюються від гіршого на краще.

Вивчено ємнісно-фільтраційні властивості гірських порід. Під час аналізу зразків гірських порід було виявлено породи з хорошими та поганими колекторними властивостями.

Для вивчення варіації визначальних факторів складено карти розподілу показників колекторних властивостей (фракції понад 0,1 мм; пористість і проникність у піщано-алевролітовмісних породах) за площею, з'ясовано їх причини шляхом порівняння з іншими нафтогазовими родовищами. Встановлено, що з віддаленням від гирла р. Кура (у напрямку правого і лівого берегів) колекторні властивості порід погіршуються. Це пов'язано із збільшенням кількості глини в гірських породах. Уточнено, що зміна коефіцієнта пористості залежить від глибини. Вміст піщано-алевролітового складу у породах за розрізом становить 20—50 %.

Ключові слова: колектор, пористість, глинистість, свердловина, мапа, родовище.