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Issue Article

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ISOLATION OF CARBONATE RESERVOIRS AND ASSESSMENT OF THEIR CAPACITIVE PROPERTIES BY ACOUSTIC AND NEURAL GAMMA LOGGING

***Abstract**: the article summarizes the results of experimental and methodological work carried out over a number of years of geophysical research, describes methods for determining porosity by acoustic, neural gamma logging; extreme values of gamma and neutron gamma logging, as well as methods for isolating and evaluating reservoirs of complex structure. These techniques and methods of interpretation are intended for the study of carbonate deposits of the Jurassic and Cretaceous deposits of Turkmenistan and are recommended for testing in all geophysical organizations conducting research on complex carbonate reservoirs.*

Prospecting and exploration for oil and gas in Turkmenistan is mainly associated with Mesozoic sediments lying at depths up to 5000 m or more, represented by both terrigenous and carbonate rocks. These deposits are exposed in difficult geological and technical conditions; the reservoir is predominantly of complex structure, which makes it difficult to isolate them due to the poor knowledge of geophysical dependencies and petrophysical security of geophysical dependencies.

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Introduction

On the territory of Turkmenistan, carbonate deposits have a widespread distribution and stratigraphically belong to the Upper Jurassic and Lower Cretaceous ages. A large range of depth variations, clay content varying in section and area, complex tectonic and thermobaric conditions, and heterogeneous mineral composition led to the development of reservoirs of various types: pore, pore-fractured, pore-cavernous or pore-fractured-cavernous with a predominance of one or another type of porosity, which are established by geophysical data [1, 2].

Analysis of the geophysical characteristics of the tested objects showed that in most cases these are reservoirs with a predominance of intergranular porosity exceeding 5-6% and only in some cases the porosity coefficient is 3.5-5% (Fig.1).

The established boundary values of the geophysical parameters ΔJny and $\Delta J\gamma$ (double difference parameters of neutron-gamma logging (NGL) and gamma logging (GL), respectively) are 0.75 and 0.35.A comparison of the core analysis data (K_p, K_{per}) also indicates the validity of the above data (Fig. 2) [3, 4, 5].

In the carbonate deposits of the Central and Western part of Turkmenistan, reservoirs are mainly represented by low-power boards (1-3 m). The proportion of reservoirs with a capacity of 4 m or more is an insignificant part, therefore, lateral electrical sounding is extremely rarely used to isolate reservoirs [6].

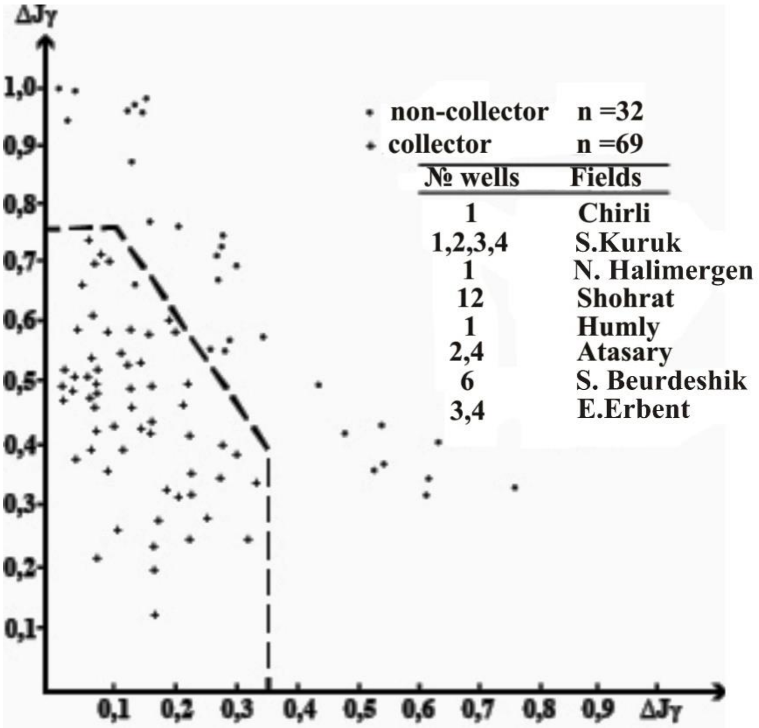

Fig.1. Determination of the boundary ΔJny and ΔJy for the separation of carbonate rocks of the Mesozoic of the Central part of Turkmenistan into reservoirs and non-reservoirs according to tested objects.

The main signs of pore-type reservoirs are the presence of negative PS (spontaneous polarization) anomalies, low values and increments of AR (apparent resistivity) in microcarotage diagrams, a decrease in the diameter of the well due to the formation of a clay crust [7-10].

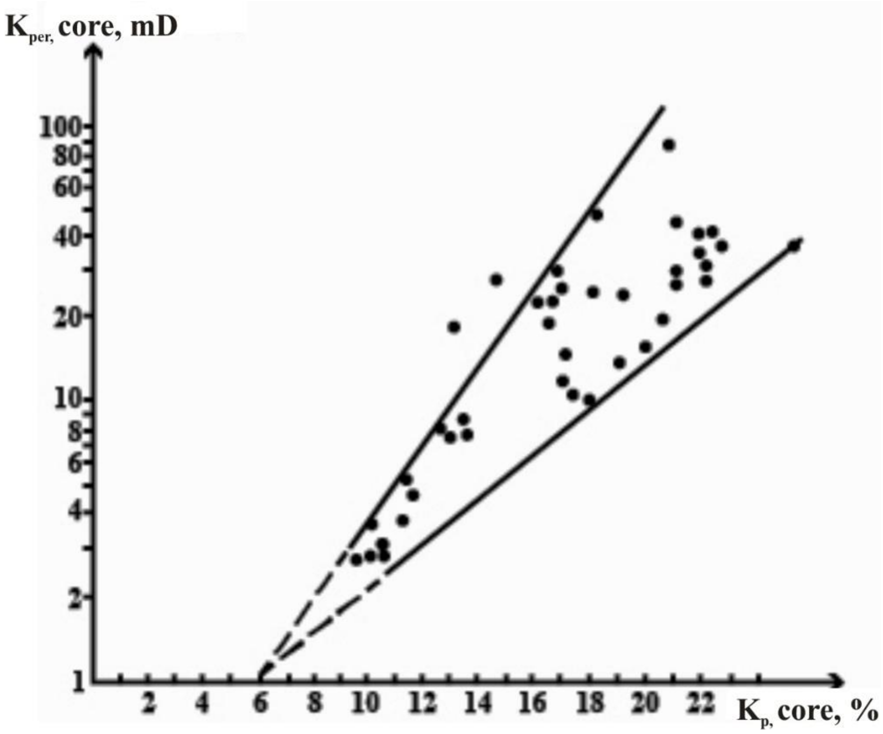

Fig. 2. Comparison of the open porosity of the K_p and the permeability of the K_{per} of carbonate rocks of the productive horizons of the Beurdeshik field

However, with a decrease in reservoir capacity, the efficiency of reservoir allocation according to the listed criteria also decreases. In these cases, as well as to isolate collectors of complex structure, temporary measurements of electrical logging, simultaneous studies with devices having different radial characteristics (MLL-LL), and mechanical logging data are used [11, 12].

Determination of porosity by acoustic logging. The average time equation has become the most widespread in the practice of field and geophysical research to determine porosity

$$K^{AL}{}_{P} = \frac{\Delta T = \Delta T_{sk}}{\Delta_{liq.} = \Delta T_{sk}} \qquad (1)$$

Its application presupposes knowledge of three values; the interval time of the longitudinal wave in the studied formation - ΔT, the time in the mineral skeleton of the rock - ΔT_{sk} and in the liquid filling the rock vapor in the research area AL - ΔT_{liq}. However, it should be borne in mind that the above equation is not a functional, but an approximate empirical dependence V_p=f(K_p), and the closest to the actual values of porosity are obtained with the correct choice of the initial values ΔT_{sk} and ΔT_{liq}.

For pure monomineral rocks, the values of ΔT_{sk} are well maintained for various oil and gas bearing regions of the globe. For the studied deposits of the Lower Cretaceous and Jurassic (dolomites, limestones, anhydrides, sandstones), a comparison of $\rho^{LL}{}_4$ and ΔT was performed. The values of ΔT, which practically correspond to the layers of dolomites, limestones, anhydrides, sandstones with zero porosity, are respectively 142 mcs/m, 155, 164, 172 mcs/m. It is recommended to use these values as ΔT_{sk} [13, 14, 15].

In the vast majority of cases, the radius of the acoustic logging probe is located within the penetration zone, where the pores of the rock are filled with a mixture of filtrate and reservoir fluid. The interval time depends on the mineralization of the mixture, pressure and temperature and can be calculated from the following ratios:

$$T_{liq.} = [1410 + 1{,}21t = 0{,}037(t)^2 + 1{,}148 + 0{,}18P\kappa\,]I_x 10^6 \quad (2)$$

or

$$T_{liq.} = [1557 - 0{,}0245(75 - t)2 + 0{,}80C_{liq.} + 0{,}19P_{liq.}\,]I_x 10^6 \quad (3)$$

where t - temperature of the mixture, °C; S - salinity of the mixture, %; $R_{liq.}$ - hydrostatic pressure, kg/cm^2; $C_{liq.}$ - mineralization of the mixture, g/l.

In 1975, based on laboratory data, the dependences of $\Delta T_{liq.}$ on pressure and temperature for fixed values of $C_{liq.}$ were constructed.

In 1979, according to formula (2), a complex pallet was calculated and constructed to determine $\Delta T_{liq.}$ at a temperature change of up to 240 °C and a pressure of 650 kg/cm^2. The values of $\Delta T_{liq.}$ determined by various methods for the geological and technical conditions of the studied deposits vary within the range of 590-610 mcs/m.

For practical purposes, when determining the K_p, it is recommended to use ΔT_{liq} = 600 mcs/m, while the absolute error when changing the K_p from 2% to 9% increases from 0.05% to 0.2%; when changing the K_p from 9% to 22.5% - from 0.2% to 0.5%. In all cases, the relative error does not exceed 5%.

Determination of porosity by neutron gamma logging. In Turkmenistan, the technique of two support layers using a relative parameter has found the greatest application in determining porosity coefficients from neutron gamma γ-logging.

$$\Delta J_{n\gamma} = \frac{J_{n\gamma}lay. - J_{n\gamma}min}{J_{n\gamma}max - J_{n\gamma}min} \qquad (4)$$

where $J_{n\gamma\ lay.}$, $J_{n\gamma\ min}$, $J_{n\gamma\ max}$ - NGL readings in the studied and support layers, respectively.

Knowing the value of the relative parameter $\Delta J_{n\gamma}$ according to the dependence $\Delta J_{n\gamma} = f(K_p)$, it is defined as $K^{AL}{}_P$ (Fig.3).

The support layers must comply with the following instructions. A limestone or dolomite formation with maximum NGL readings should be sufficiently powerful (h ≥ 3 m), non-clay, the porosity of which is assumed to be 1-3%. The specified range of changes in the porosity of the support layer introduces a significant error in determining the $K^{NGL}{}_p$, since in this case the range of changes in $J_{n\gamma}$ can reach one conventional unit. It should also be borne in mind that the studied carbonate deposits lie at considerable depths (3000-4500 m or more). The specific electrical resistances of formations with maximum NGL readings reach 1000 and more than 0mm, therefore, their porosity coefficients are significantly lower than 1%.

Clay layers, where the diameter of the well is eroded to 50 cm or more, should be used as support layers with minimal NGL readings [16, 17, 18]. The porosity of such layers is considered to be equivalent to 35-48%. There are practically no formations with such parameters in the studied sections. It is not uncommon for there to be no support layers at all in the intervals of the NGL study that meet the above requirements.

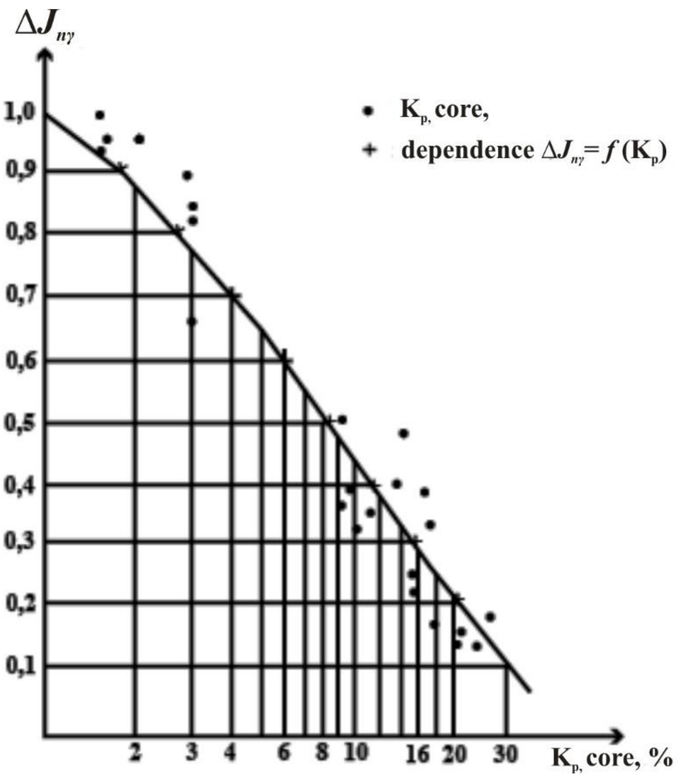

Fig. 3. Dependence of the relative parameter $\Delta J_{n\gamma}$ on the core porosity $K_{p.core}$

To increase the reliability of the results of quantitative interpretation of NGL materials, the following method is proposed for determining the extreme values of the support layers [19, 20]. The values or $P_{пи}$ of NGC for the studied formations are compared in a semi-logarithmic coordinate system (Fig. 4). For formations with granular porosity, numerous studies have established a relationship close to linear in such a coordinate system.

An averaging dependence line is drawn along the points characterizing non-clay formations with granular porosity, moreover, the position of the point for a formation with K_p = 48% is determined by the coordinates P_p=5+10 and 1 conventional unit in the NGL diagram [21]. The correctness of the choice of this point is confirmed by the results of determining the values of the pairs *Jnγ* and ω cl. (Kp $^{proc.}$) in clay layers in the range 2308-2320m, 2254-2260m, 2287-2290m, 20184-2020m (well.2-Dengli), which are characterized by the following parameters:

1. d c = 26 cm *Jnγ* = 1,80 conv. un. ω cl = 22 Pp = 38
2. d c = 26 cm *Jnγ* = 1,66 conv. un. ω cl = 26 Pp = 26
3. d c = 29 cm *Jnγ* = 1,60 conv. un. ω cl = 27 Pp = 23
4. d c = 43 cm *Jnγ* = 1,40 conv. un. ω cl = 37 Pp = 10

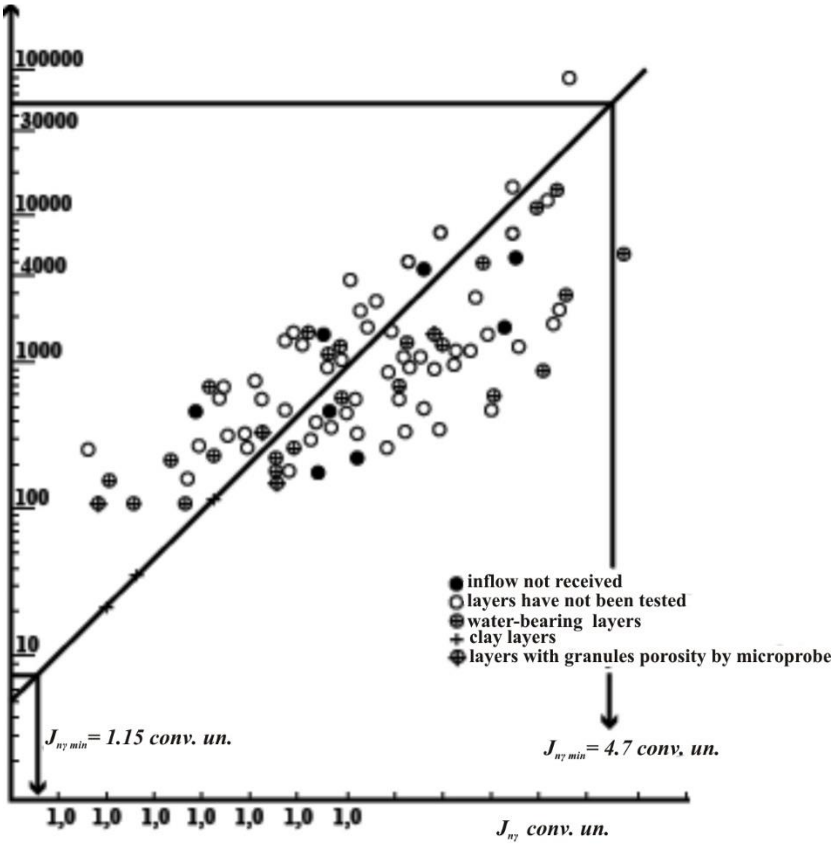

Fig. 4. Determination of the extreme values of NGL (well 2, Dengli square)

These strata, stratigraphically dated to the Aptian-Albian age, are regionally traced in the studied areas, and can be used for monitoring when conducting a line of granular rocks [22, 23]. In addition, limestone and dolomite layers with granular porosity, highlighted in microprobe diagrams, are used for this purpose.

We find the extreme values of NGL. To determine the position of a formation with a porosity of 1%, it is necessary to continue the line of granular rocks to the intersection with the ordinate – $P_{p.d.}$ = 60000 (K_p = 1%). Thus, we obtain the value of $J_{n\gamma\,max}$ = 4.70 cont.units. The minimum value of $J_{n\gamma\,min}$, corresponding to $\omega_{cl.}$ = 40%, will be characterized by a relative resistance equal to 7.5, which through the dependence $P_p = f(J_{n\gamma})$ they are transferred to the abscissa axis (Fig. 4).

It will correspond to 1.15 conventional units on the scale of the diagram. Porosity is determined by the value of the relative parameter ΔJny according to the dependence $\Delta J_{n\gamma}=f(K_p)$ or by the porosity scale plotted directly on the diagram according to the known extreme values of NGL [24, 25].

The choice of extreme values of NGL according to the above methodology will provide a unified approach to the selection of support layers, eliminate subjectivity, which will lead to an increase in the reliability of the results of quantitative interpretation of materials.

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