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ПРОМЫСЛОВЫЕ И РАЗВЕДОЧНЫЕ
ГЕОФИЗИЧЕСКИЕ ИССЛЕДОВАНИЯ

PROMYSLOVYE I RAZVEDOCHNYE GEOFIZICHESKIE ISSLEDOVANIYA

INDUSTRIAL AND EXPLORATORY GEOPHYSICAL PROSPECTING

CONTENTS

THE FOLLOWING SOVIET JOURNALS CITED IN THIS BOOK
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Russian Title	English Title	Publisher
Atomnaya énergiya	Soviet Journal of Atomic Energy	Consultants Bureau
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Doklady Akademii Nauk SSSR	Proceedings of the Academy of Sciences of the USSR, Section: Chemistry	Consultants Bureau
	Doklady Earth Sciences Sections	American Geological Institute
	Soviet Physics – Doklady	American Institute of Physics
Izvestiya Akademii Nauk SSSR: Seriya geofizicheskaya	Bulletin (Izvestiya) of the Academy of Sciences USSR: Geophysics Series	American Geophysical Union

EXPERIENCE IN USING RADIOMETRIC DATA FROM DRILL HOLES FOR EVALUATING RESERVOIR PROPERTIES OF BEDS IN THE SEARCH FOR SUBSURFACE STORES OF GAS IN THE KALUGA REGION

V. V. Larionov

It is well known that the quantitative evaluation of the reservoir properties of rocks is one of the basic problems of industrial geophysics, which includes radiometric measurements in drill holes, and is of great significance in the national economy. The fundamental possibility of determining rock porosity by neutron logging and of evaluating clay content by natural radioactivity (gamma-ray logging) was long ago demonstrated by a number of investigators.

But in the Soviet Union this possibility has been almost ignored in practical work until recently. Only a single example is known of the successful use of neutron logging for approximate determination of porosity of unsilted reef limestones in the region of the Ishimbai oil field. Attempts to use such data for evaluating porosity in other regions have generally proved unsuccessful. No determinations of clay content have been made anywhere from gamma-ray logs. The explanation of this lies chiefly in the fact that, despite numerous investigations in this direction, no single method of interpreting the radiometric data from drill holes, considering all the manifold factors, has yet been established.

This paper gives a short description of an experiment in Laboratory No. 1 at the Moscow Institute of the Petroleum-Chemistry and Gas Industry of using neutron logs and gamma-rays logs for determining clay content and porosity of reservoir rocks in searching for underground stores of gas in the Kaluga region. Attention is focused chiefly on the method of approaching a solution to these complex and important problems.

Drill holes in the investigated Kaluga structure have cut rocks of various ages, from Archean rocks of the crystalline basement to Quaternary formations at the top. Among these formations the requirements for possible storage of gas (sufficiently high reservoir properties, presence of impermeable cap, shallow occurrence, etc.) are met to some degree by sandstones of the Gdov strata and of the undifferentiated Devonian sequence, limestones of the Semiluki strata, and permeable varieties of Devonian breccia. Our investigations were confined to the interval in which these horizons occur.

The determination of clay content and porosity in reservoir rocks by electrical methods of logging holes has been difficult here because of the variable mineralization of formational waters, both vertically and areally, because of lack of any connection between self-potential data for rocks and the porosity of the rocks, and because of the inadequate quality of the logging data.

The most effective methods of solving these problems at the Kaluga area have proved to be neutron logging and gamma-ray logging, especially in view of the fact that many of the holes drilled here had been cased before the special investigations were made at the Moscow Institute of the Petroleum-Chemistry and Gas Industry.

DETERMINATION OF CLAY CONTENT OF RESERVOIR ROCKS FROM GAMMA-RAY LOGS

In developing a method of determining shale content, p_l, of rocks from gamma-ray logs, it was necessary to consider the effect of J_γ, on these logs, to evaluate changes in design of the drill holes, and to construct a sufficiently reliable standard curve of the relationship $J_\gamma = f(p_l)$.

Nomograms prepared by Blankhardt and Dewan [2] may be used for reducing gamma-ray readings to values for individual wells, or one may use a curve showing the relationship between the correction factor η and the surface density of the medium separating the instrument from the walls of the drill holes [6], prepared by the All-Union Institute of Exploratory Geophysics (VIRG).

As may be seen in Table 1, the values of the correction factor η, determined by the first and second methods, first reduced to individual standard conditions, are in rather good agreement for changes in drill-hole diameter from 20 to 30 cm.

TABLE 1. Comparison of Values of the Correction Factor η Reduced from Gamma-Ray Readings to Individual Standard Conditions by the Nomogram of Blankhardt and Dewan and by the Data of VIRG

Diameter of drill hole, cm	Uncased drill hole		Cased drill hole	
	for nomogram	for VIRG	for nomogram	for VIRG
20	0.87	0.76	1.30	1.32
25	0.95	0.95	1.70	1.65
30	1.09	1.17	2.10	2.00
35	1.20	1.40	2.60	2.40

This confirms their universal applicability and the possibility of making practical use of them.

When the diameter of a hole is greater than 30 cm, the values of the correction factor diverge noticeably (approximately 15%). The reduction of J_γ to the conditions of a single well should therefore be made for all wells by just one of the indicated methods.

In our example the reduction has been made by the nomograms of Blankhardt and Dewan.

Figure 1 shows a comparison of the intensity of J_γ, reduced to individual measurements and expressed in relative units, with the clay content pl of sandstones in the section at the Kaluga area, determined by grain-size analysis of the core. As may be seen, there is a rather close connection between these parameters. However, the number of points on which this comparison was made is clearly insufficient for making a generalized (averaged) curve that reliably reflects the true nature of the relationship $J_\gamma = f(pl)$, especially since the number of core samples on which the clay content of the investigated parts of the section was defined was also clearly insufficient (less than one sample per meter). Consequently, the curve of the relationship $J_\gamma = f(pl)$ in Fig. 1 may be used for practical determination of clay content only after it has been refined or confirmed.

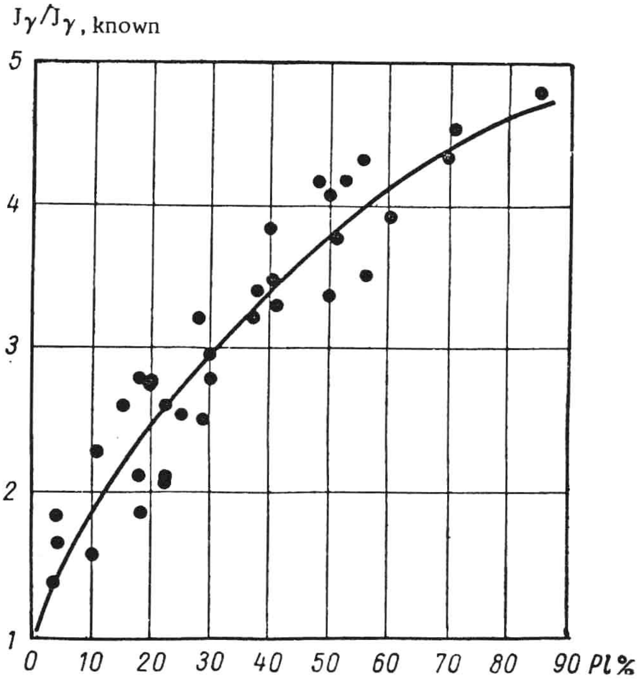

Fig. 1. Relationship of relative intensity of natural gamma radiation to clay content of Devonian and Cambrian sandstones in the Kaluga area.

Refinement or confirmation may be made by comparing the indicated curve of $J_\gamma = f(pl)$ with similar curves constructed for other parts of the Soviet Union.

Figure 2a illustrates such a comparison, plotted with the coordinates

$$x = pl, \quad y = I_\gamma = \frac{J_\gamma - J_\gamma^{pl=0}}{J_\gamma^{pl=100} - J_\gamma^{pl=0}},$$

which permit one to eliminate the effect of lack of uniformity in conditions of measurement, with data from other regions for which curves of the relationship $J_\gamma = f(pl)$ have been plotted. It is clear that most of the points in the relationship $I_\gamma = f(pl)$ are in good mutual agreement. This confirms the existence of a functional connection between the clay content of rocks and their radioactivity, and it permits one to draw an average curve, which may be used for approximate determination of the clay content (pl) of rocks, not only in the Kaluga area, but also in the Volga-Ural province, on the Russian platform, and in the Caspian basin.

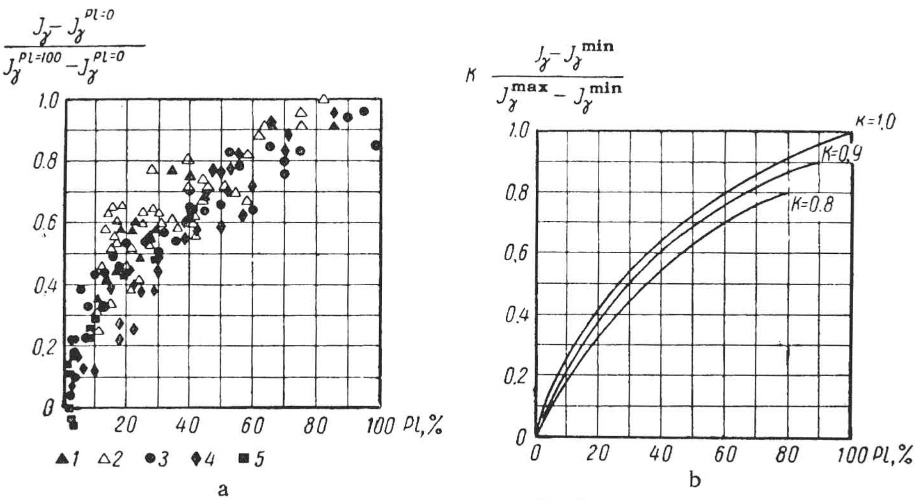

Fig. 2. Comparison of the parameter $\frac{J_\gamma - J_\gamma^{pl=0}}{J_\gamma^{pl=100} - J_\gamma^{pl=0}}$ with the clay content of sand-silt rocks. a) For various regions of the Soviet Union: 1) Paleozoic rocks of the Ural-Emba region (after L. S. Polak [5]), 2) the same, from laboratory studies of L. S. Polak [3], 3) Devonian rocks of Bashkiria (after A. V. Zolotov [4]), 4) Devonian and Cambrian rocks of the Kaluga region, 5) Devonian rocks of the Stepnovskoe oil field; b) generalized (averaged) curves of the relationship

$$\frac{J_\gamma - J_\gamma^{min}}{J_\gamma^{max} - J_\gamma^{min}} = f(pl).$$

In determining the clay content of rocks from a gamma-ray log of the investigated hole, intervals of minimum and maximum intensity of J_γ are chosen; these are recomputed to values reduced to the conditions of individual holes, to J_γ^{min} and J_γ^{max}, and then, assuming that the clay content of the interval characterized by the intensity J_γ^{min} is near zero and the clay content of the interval J_γ^{max} approaches 100%, the relative intensity I_γ of the investigated bed is found.

When the content of the pelitic fraction (pl) in clays, which are characterized by the maximum intensity of J_γ^{max}, does not equal 100%, the ratio

$$\frac{J_\gamma - J_\gamma^{min}}{J_\gamma^{max} - J_\gamma^{min}}$$

should be multiplied by the factor k, and the clay content of the rock is determined by the curve of $kI_\gamma = f(pl)$, corresponding to the given value of k.

According to grain-size analysis of the rocks in the section of the Kaluga area, the maximum content of the pelitic fraction in clays does not exceed 94%, and on the average it is 90%. In keeping with this, the clay content was determined by the curve of Fig. 2b computed for a value of k = 0.9.

DETERMINATION OF ROCK POROSITY FROM NEUTRON LOGS

In developing a method of determining the porosity k_r of rocks from neutron logs, a method that might be applicable to conditions in the Kaluga area, it is necessary:

1) to choose the optimum conditions of measurement;

2) to determine the effect of mineralization of the formational waters and the effect of changes in this mineralization through the section on the recorded intensity of J_n;

3) to develop a method of computing the clay content;

4) to determine the effect of changes in hole diameter, observed throughout the section, on the intensity of J_n; and

5) to prepare standard curves for the relationship of neutron logs to porosity of rocks separately for cased and uncased wells.

Since the absolute value of mineralizations of the formational waters in strata of the Kaluga area is relatively small (~ 50 g/liter), the porosity of these rocks by neutron logs may be determined only by measuring the hydrogen content of the rocks. At the same time, it is known that an increase in the differentiating capacity of the method of measuring hydrogen content and, consequently, an increase in precision of determining k_r may be obtained by increasing the thickness of the lead filter between the neutron source and the gamma-ray indicator and by selecting the proper size of sonde. All investigations were therefore made with an instrument that differs in design somewhat from the standard NGGK type, particularly in the thickness of the lead filter, which was increased to 20 cm; a VS-11 type radiation counter was used for the gamma-ray indicator.

To avoid possible reaction between gamma-ray channels and neutron-log channels in the radioactive logging apparatus, all measurements were made by a single channel. The holes were logged at a rate of 300 m/hr. The

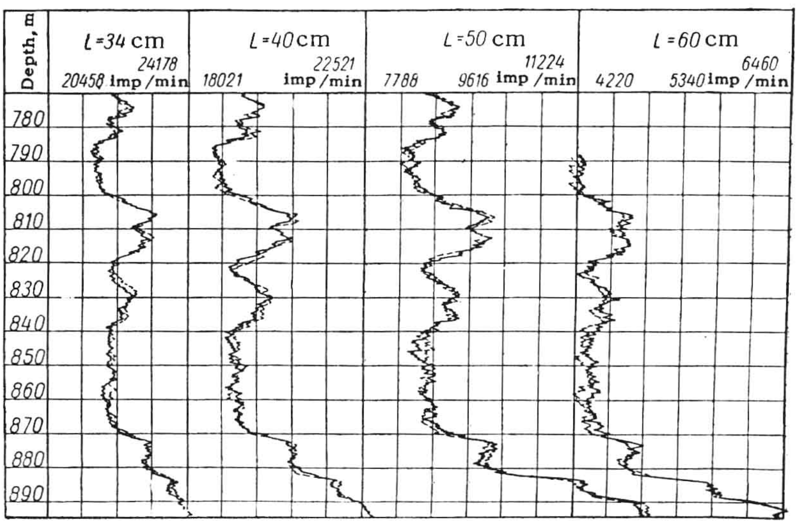

Fig. 3. Example of reproducibility of neutron curves in well 24.

time constant τ was 18 sec in all cases. In this logging the error of measurement did not exceed 1.7%, and the relative variation in recorded intensity J_n opposite the densest rock in the section, the crystalline basement, and opposite diffuse clays, exceeded 100% for L = 60 cm (Figs. 3 and 4). A series of measurements with sondes of different sizes was made in order to select the best sonde for the given conditions. As seen in Fig. 4, in which the results of these measurements are used to plot curves of the relationship $I_n = f(L)$ (ratios I_n of the intensity of gamma radiation J_n opposite the investigated beds to the intensity $J_{n, cl}$ opposite washed-out clays in relation to the size of the sonde), the maximum sensitivity to change of hydrogen content in rocks of the given region is obtained in sondes 55-65 cm long. The 60-cm sonde was therefore chosen as the basis for neutron-log measurements.

The curves of the relationship $I_n = f(L)$, shown in Fig. 4, also permit one to determine the effect of mineralization of the formational water on the value of J_n. It had been demonstrated earlier [5] that in beds for which the

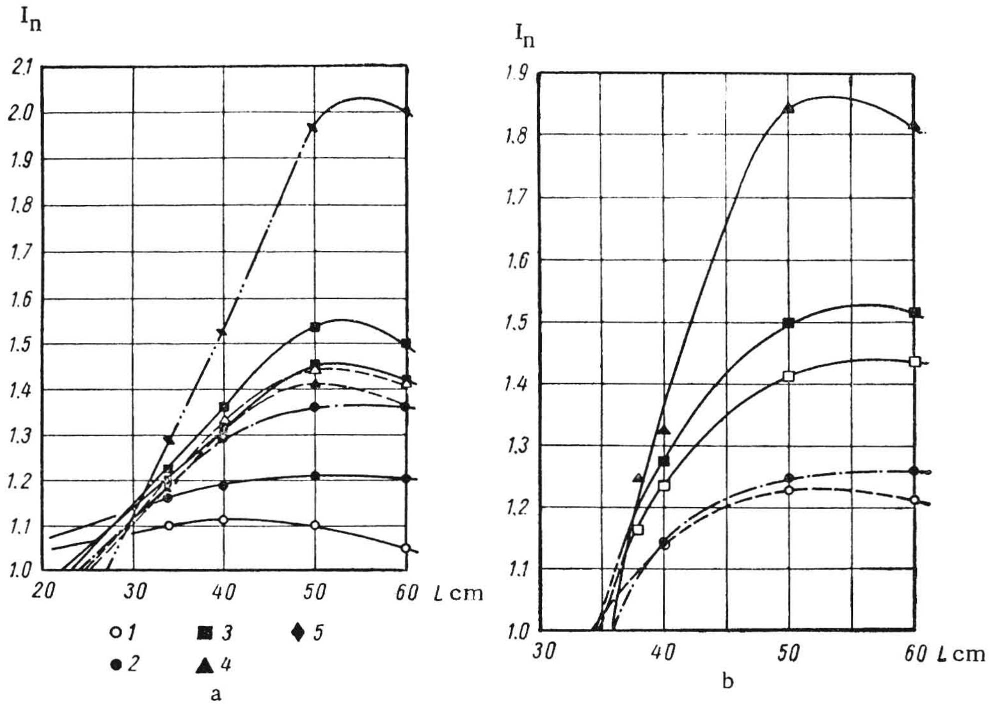

Fig. 4. The relationship $I_n/I_{n,cl} = f(L)$. a) Well 24, uncased; b) well 15, cased: 1) clay and sandy clay ($C_{Cl} = 0$), 2) sandstone, 3) limestone, 4) breccia, 5) crystalline basement.

curves of $I_n = f(L)$ intersect the abscissa axis ($I_n = 1.0$), there is practically no effect of mineralization of the formational liquid (at values of L greater than the value corresponding to the point of intersection) on the curve for highly porous artesian beds with a chlorine content near water (this point characterizes the dimension of the inversion sonde L_i) [3].

This effect holds only for beds for which the $I_n = f(L)$ curves at $L = L_i$ are characterized by a relative intensity $I_n > 1$.

From Fig. 4 it may be seen that the $I_n = f(L)$ curves for artesian beds, defining the inversion sonde (clayey varieties of sandstone, characterized by low values of I_n on sondes of large dimensions), are intersected by the abscissa axis in the region of L values smaller than such values for the Gdov sandstones, the Semiluki limestones, and other permeable rocks in the part of the section in which the chlorine content might be expected to be high. Consequently, the effect of mineralization of formational liquid on neutron-log data is negligibly small in the sections of drill holes of the Kaluga area.

The computation of clay content in reservoir rocks, made in determining the porosity k_r by neutron-log data, involved the equation

$$k_r = \omega_\Sigma - \omega_{cl} pl,$$

where ω_Σ is the total hydrogen content in the investigated rock (the porosity as determined by neutron logging), ω_{cl} is the total content of bound water (hygroscopic and crystallization) in the clay fraction of the investigated beds [3], and pl is the percentage of the clay fraction in the investigated beds.

The average value $\omega_{cl} = 13.75\%$ for strata in the Kaluga area was determined by laboratory studies of four samples of the clay fraction taken from these strata.

The value of the clay content pl was determined from gamma-ray logs.

As caliper logs have shown, the diameter of the wells d_0 opposite sandstones and limestones in the Kaluga section ranges from 21 to 24 cm; it is 22.5-23 cm on the average. In most records (80%), deviation from the average does not exceed 1 cm. Furthermore, according to investigations of Dewan [7], a change in diameter of 1 cm, in uncased wells, opposite rocks with a porosity of 10% is accompanied by a change in neutron-log reading of 1.3%, and with a porosity k_r = 20% of only 0.8%. In cased wells this change is even less. Consequently, the effect of changes in diameter of well may be neglected in our examples.

In developing a method of determining porosity, we first of all investigated the possibility of constructing standard curves of $J_n = f(k_r)$ for each hole individually. This method, widely followed in foreign countries and recommended by some soviet investigators, involves the following.

In the investigated section two distinctive guide horizons were selected, uniform throughout the area and having contrasting porosities. Then, on the basis of the exponential character of $J_n = f(k_r)$, a straight line was drawn through the two points corresponding to the intensities of J_n opposite these horizons; the coordinates of the system were $x = \log k_r$ and $y = J_n$, and the line became the standard for the given well.

In investigating the cased wells of the Kaluga area, the washed-out clays might be used as one of the distinctive horizons with uniform porosity; the diameter of the well opposite this horizon exceeded 45-50 cm. The water content of the cement filling the cavities might be taken tentatively as 45-50%. However, to use the washed-out clays as one of our guide horizons for investigation of uncased wells and to assume the water content of the clays to be k_r = 100%, as N. A. Per'kov recommends [4], is impossible. The reason it is impossible involves, first, the fact that the exponential nature of $J_n = f(k_r)$ in the range of water saturation greater than 40-60% is disrupted [3] and, secondly, the fact that the instrument does not move through the middle of widened parts of the hole when the hole is not cased, but rather moves along the wall, and the total water content of the medium surrounding the instrument will therefore be equivalent to a porosity essentially less than 100%. The approximate order of this water content may be determined from the relationship

$$\bar{k_r} = k_{r,m} \frac{\Delta V_m}{V} + k_{r,cl} \frac{\Delta V_{cl}}{V} ,$$

where $k_{r,m}$ and $k_{r,cl}$ are, respectively, the volumes of water content of the drilling mud and the investigated clay, recalculated as porosity, V_r, V_{cl}, and V are, respectively, the volume of drilling mud, clay, and total volume of the medium surrounding the instrument, within the depth range of the method, determined by the radius of the zone of investigation.

When the instrument is moved along the wall of a widened part of the hole, the diameter of which is greater than 40 cm, the radius of the zone of investigation in the drilling mud does not exceed this diameter. In considering that the radius of the zone of investigation is proportional to the slowdown distance of the neutrons L_f, the total water content of the cavernous widening, equivalent to the porosity k_r, may be determined approximately from the relationship

$$\bar{k}_r = k_{r,m} \frac{(L_{f,m})^3}{(L_{f,m})^3 + (L_{f,cl})^3} + k_{r,cl} \frac{(L_{f,cl})^3}{(L_{f,m})^3 + (L_{f,cl})^3} .$$

When $k_{r,m}$ = 100%, $k_{r,cl}$ = 40%, $L_{f,m}$ = 8 cm, and $L_{f,cl}$ = 16 cm, the average water content of the medium surround the neutron-logging instrument in the cavity is equivalent to a porosity k_r = 0.5% to k_r = 10-12%.

It has thus proved impossible to use the method of plotting standard curves of $J_n = f(k_r)$ for each hole.

Because of the absence of sufficient core data it is also impossible to use the method of plotting a standard curve from extensive comparisons of neutron curves with porosities determined from the core. However, it is possible to construct such a curve from comparisons of neutron logs with porosities determined from electric logging of holes [3]. In order to eliminate the effect of power source and possible changes in the effectiveness of the recording apparatus, the values have been expressed in relative units, $I_n = J_n/J_n^{cl}$, where J_n and J_n^{cl} are recorded intensities (after deduction of the intensities of natural gamma radiation) opposite the investigated bed and opposite the washed-out clays, where the diameter of the hole exceeds 40 cm.

In the comparisons, the volume of bound water in the investigated reservoir rocks was added to the porosities k_r:

$$\omega_{bd} = \omega_{cl}\, pl = 13.75\ pl.$$

Thus, the curves of Fig. 5 show the relationship between readings on the neutron log and total water saturation $\omega_\Sigma = k_r = \omega_{bd}$ of the investigated reservoir rocks. In solving the reverse problem – determining the porosity from the generalized curve $I_n = f(k_r)$ – the value 13.75 pl, computed for the investigated bed, is subtracted from the value of ω_Σ.

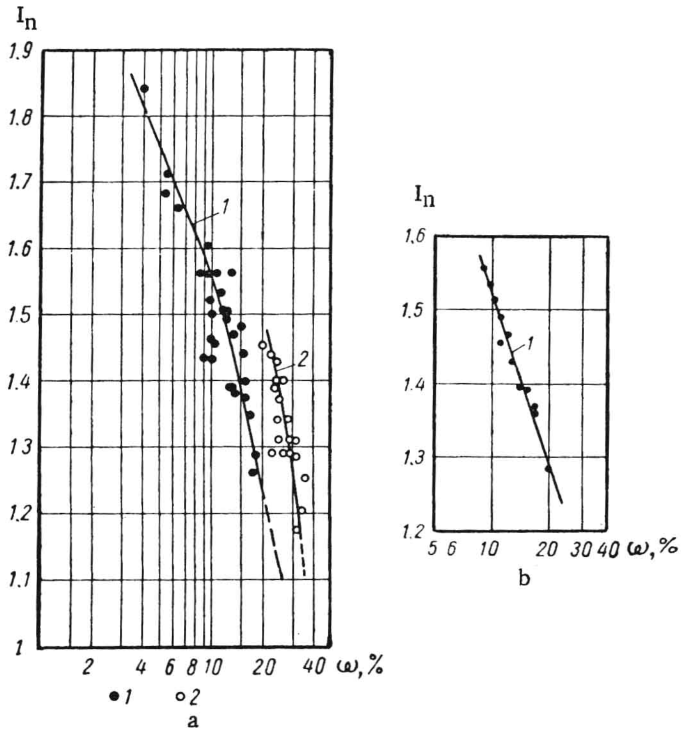

Fig. 5. Relationship between relative intensity I_n and total content of water ω_Σ in rocks of the Kaluga section. a) Uncased holes, $9^3/_4$ inches in diameter; b) cased wells, $9^3/_4$ inches in diameter, collar 6 inches in diameter; 1) for limestones, 2) for sandstones. L = 60 cm.

As seen from Table 2, the porosity values of the investigated rocks, determined from curves for $I_n = f(k_r)$ as illustrated in Fig. 5, agree satisfactorily with core analyses and with electric-log data.

Neutron-log data was widely used in investigating changes throughout the area in the porosity of rocks supposed to form underground reservoirs of gas; they were also used for computing the amount of gas that may have accumulated in these rocks.

Apart from the practical application, the comparisons shown in Fig. 5 permit us to clarify and define individual problems in regard to method.

From Fig. 5a it may be seen that the nature of the relationship $I_n = f(k_r)$ for carbonate and sand-clay rocks is fundamentally different, and this difference increases with decrease in porosity of the rocks. This circumstance, having great practical significance, and contradicting widely accepted views at the present time, is in good agreement with the physical basis of neutron measurements in drill holes.

Actually, as seen from Table 3, the slowing-down distance of neutrons L_f, their average life span τ, and the number of gamma quanta q emitted by the rock during the capture of a neutron, i.e., the parameters determining the spatial distribution of neutron density and neutron gamma-ray intensity in the hole, are different for limestones and sandstones, the difference increasing with reduction of porosity.

Consequently, in developing a method for determining rock porosity by neutron-log data, standard curves for $J_n = f(k_r)$ for sand-clay rocks and carbonate rocks must be prepared individually.

TABLE 2. Comparison of Porosity Values Determined from Radioactive Logging, Electric Logging, and Core Analyses

Well No.	Investigated interval, m	k_r, %				
		from neutron log	core analysis	from latero-log	from micro-log	from normal resistivity log
7	430—438	12.0	—	11.0	12.5	—
21	426—439	9.0	—	10.0	—	9.5
	618—649	31.0	—	31.4	—	25.4
	1010—1013.6	27.0	—	27.0	—	27.0
	1060—1064.4	21.0	—	20.0	—	16.0
22	398—410	12.0	—	12.5	12.5	—
	576.6—601.4	22.0	—	32.5	28.0	—
	805—809	21.0	—	23.0	20.0	—
	811.5—815.2	20.0	—	19.0	18.0	—
29	394,5—401,6	10.0	—	13.5	—	12.0
	401,6—414	6.0	—	10.0	—	8.0
	869—872.7	24.0	23.6	30.0	—	30.0
	875.6—878.3	19.0	21.8	24.0	—	22.0
30	386.7—393	15.0	—	14.0	—	12.5
	600—616	31.0	—	31.0	—	32.0
	872.3—878.4	26.0	23	27.5	—	27.0
	881—886	25.5	17—25	22.0	—	22.5
31	401,3—410	16.5	—	17.0	—	—
	410—422	12.0	—	12.5	—	—
	922—926.2	26.5	23.5	24.0	—	—
	928.6—933.7	22.5	22	22.0	—	—
32	400—412	16.5	—	15.0	—	12.5
	416—422.4	5.7	—	8.0	—	10.5
	610—622	31.0	—	36.0	—	36.0

From Fig. 5a it may also be seen that in investigating uncased wells with a 60-cm sonde the curve of $I_n = f(k_r)$ for limestones on the coordinates $x = \log k_r$ and $y = I_n$ departs noticeably from a straight line. No such deviation is observed on the curve for a cased well (Fig. 5b).

TABLE 3

k_r, %	L_f		τ		q	
	sandstones	limestones	sandstones	limestones	sandstones	limestones
1	30.90	34.93	9.14	5.80	2.26	2.07
10	23.80	25.22	6.96	4.99	1.97	1.92
20	19.80	20.45	5.49	4.32	1.81	1.80
30	17.30	17.69	4.54	3.81	1.70	1.71

The experience of using radioactivity data from drill holes in the Kaluga district shows that, when one approaches the method of investigating and interpreting the data correctly, radioactive methods (neutron logging and gamma-ray logging) permit him to make sufficiently reliable quantitative determinations of clay content and porosity of rocks in cased and uncased boreholes.

This method of determining clay content and porosity of rocks, with the introduction of proper corrections, may be applied to other parts of the Soviet Union.

REFERENCES

1. Barsukov, O. A., Blinova, N. M., et al. Radioactive Methods of Investigating Oil and Gas Wells [in Russian] (Gostoptekhizdat, 1958).
2. Blankhardt, A. and Dewan, I. G. "Standardization of measurements of natural gamma radiation," Collection: Questions on Industrial Geophysics [Russian translation] (Gostoptekhizdat, 1957).
3. Larionov, V. V. Analysis of the Combined Effect of Absorption and Dissemination of Neutrons in Rocks on the Values of Neutron-Log Data from Oil and Gas Wells, and Measures for Increasing the Geological Effectiveness of Such Methods [in Russian], Author's abstract of dissertation (I. M. Gubkin Moscow Institute of the Petroleum-Chemistry and Gas Industry, 1959).
4. Per'kov, N. A. Interpretation of Logs from Oil Wells [in Russian] (Gostoptekhizdat, 1958).
5. Polak, L. S. "Some systematic patterns of natural radioactivity in the Mesozoic and Tertiary Rocks of the Caspian basin," Prikladnaya geofizika, No. 17 (Gostoptekhizdat, 1957).
6. Radiometric Methods of Prospecting and Exploring for Uranium Ores [in Russian] (Gosgeolizdat, 1957).
7. Dewan, J. T. "Neutron log correction charts for borehole conditions and bed thickness," Petr. Techn. No. 2 (1956).

THE RELATIONSHIPS AMONG POROSITY, SURFACE CONDUCTIVITY, DIFFUSION-ADSORPTION, AND ADSORPTION PROPERTIES IN CLASTIC ROCKS

B. Yu. Vendel'shtein

The relationships connecting the parameter of porosity P_r, surface conductivity C, diffusion-adsorption activity A_{da}, and adsorption properties of rocks have already been discussed in publications [1,* 3, 8].

In connection with studying the nature of diffusion-adsorption potentials [2], it is necessary to pursue the study of the interdependence among the basic parameters P_r, C, and A_{da}, which determine the character of the resistivity and self-potential (SP) curves in sections of clastic rocks. Investigations were made on samples of sandstones and siltstones of the Devonian productive sequence, and determinations were made of the resistivity ρ_r of samples impregnated with solutions of NaCl of three different concentrations (c_w = 3.9, 0.43, and 0.38 N); determinations were also made of the adsorption-diffusion emf U_{da} for samples in groups having solutions of NaCl with concentrations of c_1 = 0.4 N and c_2 = 4 N and values of c_w = 3.9 and 0.43 N. Known formulas [3] were then used to compute the parameter of porosity P_r and diffusion-adsorption activity A_{da} on the basis of the measured ρ_r and U_{da}, for the particular values of c_w. The adsorption capacity of the samples was determined from the reduced adsorption capacity q, expressing the number of milligram-equivalents of adsorbed cations of a double layer in 1 cm^3 of pore volume. The value of q was also determined experimentally [4].

SOME PECULIARITIES OF THE PARAMETER OF POROSITY OF ROCKS

From three determinations of ρ_r and P_r for each sample at three different concentrations c_w of the solution impregnating the samples, approximate experimental graphs were constructed of $\rho_r = f(c_w)$ (Fig. 1) and $P_r = f(c_w)$ (Fig. 2) for each sample. The curves of $P_r = f(c_w)$ confirm the conclusion that the parameter of porosity varies with changes in the mineralization of the solution impregnating the sample, ranging between wide limits [1, 8]. The degree of change in P_r, as is well known, becomes larger as the clay content of the sample increases. Let us consider the nature of this phenomenon.

By definition [3, 4], the parameter of porosity P_r is the ratio of resistivity of a sample 100% saturated with water, $\rho_{w.r.}$, to resistivity of the water ρ_w impregnating the samples, or it is the product of ρ_r and the conductivity of the water $\varkappa_w$:

$$P_{r.f.} = \frac{\rho_r}{\rho_w} = \rho_r \varkappa_w, \tag{1}$$

in which $P_{r.f.}$ is considered to have a constant value, for a given rock, not depending on the mineralization of the water; that is, on the values of ρ_w and c_w, and is determined by the structure of the pore space and by the porosity k_r.** The solid frame of the rock is assumed to be nonconductive.

It has been shown experimentally [1, 8] that for most sedimentary rocks, the value of P_r, when computed by Eq. (1), varies for any particular rock depending on the value of c_w. This phenomenon is explained by the electrical conductivity of the pore channels $\varkappa_{chan}$ being determined not only by the conductivity of the free solution $\varkappa_w$ but also by the conductivity of the double layer $\varkappa_1$:

$$\varkappa_{chan} = \xi \varkappa_w + \varkappa_1 (1 - \xi), \tag{2}$$

*Papers of M. Wyllie and P. Southwick, H. Hill, and I. Milbern, H. Brennon, F. Perkins, and W. Winsauer.

**Here $P_{r.f.}$ is fictive computed parameter of porosity in contrast to the true $P_{r.t.}$.

where ξ and $1-\xi$ are parts of the pore space occupied respectively, by free solutions and the double layer.

Equation (2) is valid for "parallel connections" of electrical conductivity in the free solution and the double layer, and this apparently corresponds to the actual conditions.

It is obvious that a more precise definition of P_r will be

$$P_{r.t.} = \rho_r \varkappa_{chan}. \tag{3}$$

The value of $P_{r.f.}$ varies noticeably with changes in c_w, since, in the general case, $\varkappa_w \neq \varkappa_1$, and the value of $P_{r.f.}$ is computed from Eq. (1). The true value $P_{r.t.}$ does not depend on c_w, and may be obtained by using Eq. (3); but for this it is necessary to know the value of $\varkappa_1 \xi$. The value of $P_{r.f.}$, being computed from Eq. (1), should be considered a fictive parameter of porosity, which may differ from the true parameter of porosity by several hundred percent.

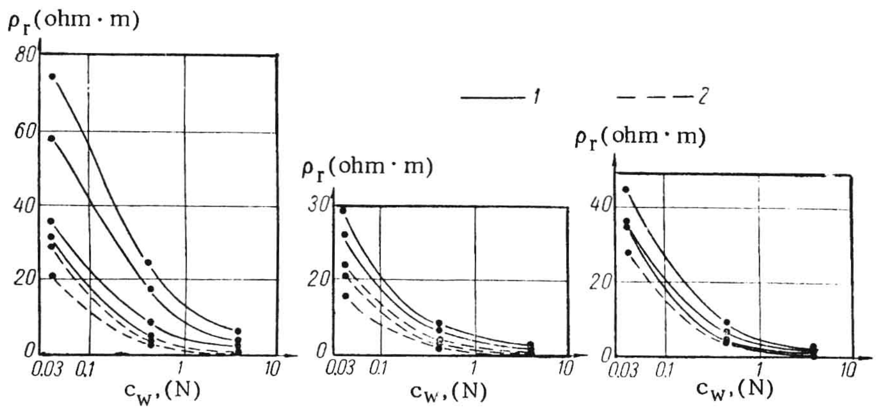

Fig. 1. Experimental graphs of $\rho_r = f(c_w)$ for sandstones and siltstones of the Devonian productive sequence at the Tuimazy field. 1) Curves corresponding to clayey sandstones and siltstones, 2) curves corresponding to sandstones.

The limits of variation of P_r with increase in c_w will be wider the greater the role played by $\varkappa_1$ in the total conductivity $\varkappa_{chan}$, i.e., the greater the volume of the pore channels occupied by the double layer. Since an increase in pore volume occupied by the double layer occurs when the radius of the pore channels diminishes in more

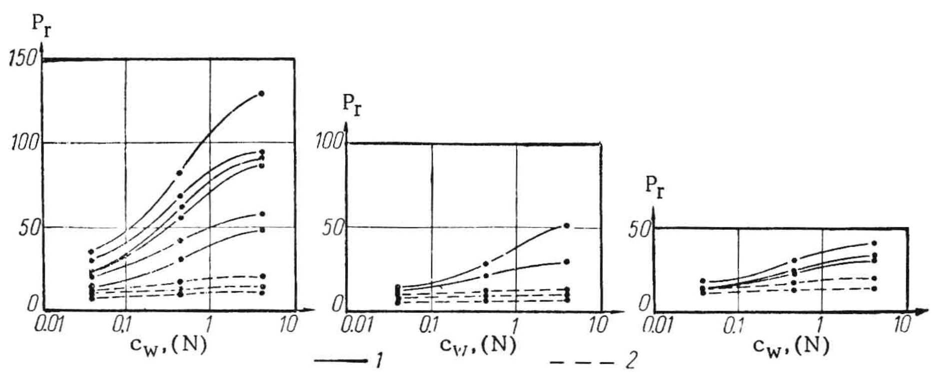

Fig. 2. Experimental relationship of $P_r = f(c_w)$ for sandstones and siltstones of the Devonian productive sequence at the Tuimazy field. 1) Curves corresponding to clayey sandstones and siltstones, 2) curves corresponding to sandstones.

highly dispersed rocks, the degree of variation with increase in mineralization is greater the higher content of clayey or other highly dispersed material in the rock. This concept is graphically illustrated by data (Fig. 2). With an in-