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Aspects Regarding the Reinterpretation of the Conventional Electrical Logs

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Abstract

The resistivity of a formation is necessary for determination hidrocarbon saturation. Conventional electrical logs measure the aparent resistivity with normal and lateral devices. The long of the spacing give the invetigation deep into the formation. With this resistivities, usualy, they made a calitative interpretation. Using a actual software we can made a cantitative interpretation and obtine value of water saturation. For this, they made a processing of the resistivity curves.

Key words: *electrical log, lateral electrical log BKZ, lateral electrical log DRR, true rezistivity, water rezistivity, porosity, water saturation*

Introduction

For a large number of wells drilled on mature oil fields, minimal programs of geophysical investigation were done, consisting of standard and lateral electrical logs. This diagraphies was manually interpretated (qualitative and partially quantitative).

Prezent interpretation programs (Interactive Petrophysics, Petrel etc.) ofer te possibility of a complex and complete in processing and interpretation of the geophysical diagraphies, provided that an optimal investigation program exist. This program should consist of an resistivity logs (DIL-dual induction, DLL-dual laterolog), CNL-Compensated Neutron Log, BHC-Sonic Log, RHOB-Density Log etc.

Ways of using these softs for the conventional diagraphies obtained from the minimal programs of investigation are suggested and analyzed in this papers.

One of the basic objectives of log interpretation is the determination of the content in water. The sequence of operations to calculate the content in hydrocarbons is presented as a sketch in Fig. 1 and is proper for clean formations and also for argillaceous ones. The content in hydrocarbons is determined by the formula:

$$S_h = 1 - S_a \tag{1}$$

A various number of methods are used to evaluate the collectors' content in water, based on the collector's content in shale (clean formations, shally formations), the well logs investigation program, the physical model and the mathematical formula that were used.

The formulas used to calculate the content in water both in the uninvaded zone "Sw" and in the flushed zone "Sxo" are a function of the collector's petrophysical properties and can be expressed the following way:

$$Sw = f\left(\Phi, Rt, Rw, Rsh, Vsh, C_j\right) \tag{2}$$

$$Sxo = f\left(\Phi, Rxo, R_{z(fn)}, Rsh, Vsh, C_i\right) \tag{3}$$

where *Rt* represents the true rezistivity, Rw- the water rezistivity, Rsh – the shale resistivity, Rz - rezistivity of the mixture between mud and water; V_{sh} the shale volum, $C_{j(i)}$ constants that depend on the lithologic constitution and the mathematical formula that was used, Φ porosity.

In clean formations, water saturation is calculated with Archie's ecuation.

For the uninvaded zone, "Sw":

$$S_w^2 = F.Rw/Rt \tag{4}$$

For the flushed zone "Sxo":

$$S^2xo = F.R_{fn}/Rxo \tag{5}$$

where *F* is the formation factor of the rezistivity.

The explicit mathematical formulas used to determine the clay collectors' content in water are presented in expert papers [xx]. Four types of mathematical formulas to calculate saturation derives:

$$\text{Type 1: } \frac{1}{Rt} = \alpha S_w^n + \gamma \tag{6}$$

$$\text{Type 2: } \frac{1}{Rt} = \alpha S_w^n + \gamma S_w^s \tag{7}$$

$$\text{Type 3: } \frac{1}{Rt} = \alpha S_w^n + \beta S_w^r + \gamma \tag{8}$$

$$\text{Type 4: } \frac{1}{\rho_R} = \alpha S_w^n + \beta S_w^r + \gamma S_w^s \tag{9}$$

Where *r* and *s* are saturation exponents and are comprised between 1 and 2. For all four types, the saturation exponent *n* has the value 2.

Also, a series of techniques and methods to determine saturation in water were elaborated, especially for clean formations with homogeneous, intergranular porosity, based on Archie's ecuation. Some of these methods are shown below: rezistivity-porosity graphics, apparent water rezistivity method, rezistivity ratios method, porosity comparison, curves superposition technique

These formulas cannot be used unless all the measurments presented before are known. As a result, wells' investigation programs must contain all methods through which petrophysical parameters required to determine water saturation are calculated.

A very large number of old wells, especially those drilled in Eastern Europe, have been investigated with minimal programs, consisting mainly of conventional electrical logging. Under these circumstances, water saturation cannot be determined using the previous formulas because collectors' porosity values cannot be calculated.

The objective of this paper is a solution to determine water saturation for wells investigated with conventional electrical logs. One of the possible methods, where knowing the porosity is not necessary, is rezistivity reports one. This can only be used for clean formations. The following are required:

- the presentation of the geophysical diagraphies that resulted from old wells investigation;
- the comparative analysis of the obtained results and establishing the precision degree of the performed calculus.

Conventional electrical log

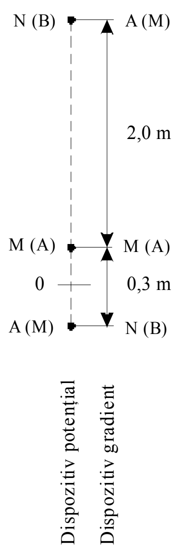
Almost without exception, in exploitation wells drilled on oil structures from Romania, the investigation program consisted in:

- electrical log
- lateral electrical log (BKZ until 1968 and DRR afterwards) performed on the well objective

Electrical log

Standard electrical logs consists of a diagraph's recording. A spontaneous potential curve and two apparent rezistivity curves, one recorded with a potential device and one with a gradient device. The characteristics of the devices used in standard electrical logging are presented in Table 1.

Table.1. The characteristics of the devices used in standard electrical logs

Devices	Symbol	Depth scales	Spacing divice	Radius of investigation	Scales of measurement
	1)SP (ΔE_{PS})	1:1000	-	-	$n_{PS} = 12{,}5\Omega m/cm$ (25 mV / 2cm)
	2).*Ra* Potential Device A0,3M2,0N (M0,3A2,0B)		$L_p = \overline{AM}(\overline{MA}) = 0{,}3m$	$r_{inv,p} = 2\overline{AM}(\overline{MA}) = 0{,}6m$	n_{ρ_A} 1/1 = 2,5Ωm/cm (0-20Ωm / 8 cm)
	3).*Ra* Gradient Device N0,3M2,0A (B0,3A2,0M)		$L_g = \overline{0A}(\overline{0M}) = 2{,}15m$	$r_{inv,g} = \overline{0A}(\overline{0M}) = 2{,}15m$	1/5 -12,5Ωm/cm (0 – 100Ωm/8cm) 1/25 - 62,5 Ωm/cm (0 – 500Ωm/8cm)

The symbols included in brackets are for bipolar devices and are marked from bottom to top. The distances between electrodes are in meters.

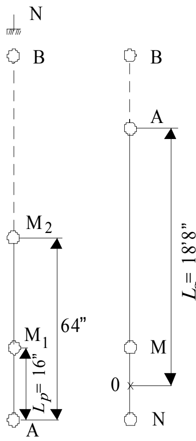
The standard electrical diagraphy is formed of:

- PS curve (ΔE_{PS}) written on the first trace of the diagram
- the apparent rezistivity curves written on the second trace:
- with potential device A0,3M2,0N (M0,3A2,0B) with full line and
- with gradient device N0,3M2,0A (B0,3A2,0M) positioned over the potential curve, with a dotted line.

The special electrical log consists of the recording of a ΔE_{PS} curve and 3 apparent rezistivity ones.

- two rezistivity curves with ideal potentials devices having the lengths $\mathbf{L}_{p1}$= $\mathbf{AM_1}$ **=** 16in (0,4 m) and $\mathbf{L}_{p2}$= $\mathbf{AM_2}$ **=** 64in (1,6 m); at first, a third potential curve was recorded $\mathbf{L}_{p3}$= $\mathbf{AM_3}$ **=** 38in (0,95 m) written on the third trace
- a rezistivity curve with a gradient device with the length of L_g= 18ft and 8 in (5,7 m). The characteristics of special electrical logging devices are briefly shown in Table 2.

Table 2. The characteristics of special electrical diagraph devices

Devices	Symbol	Depth Scales	Spacing divice	Radius of investigation	Scales of measurement
	1)SP – (ΔE_{PS})		-	-	n_{PS} = 10mV/div
	2). *Ra* Potential Device A16''M1 $R_{16"}$	1:1000 And/or 1:200	L_{p1} = AM1 = 16'' (≅ 0,4m)	$r_{inv,p1}$ = 2AM1 = 32'' (= 0,4m)	1/1 n_ρ = 2Ωm/div (0-20Ωm / 10 div.)
	3). *Ra* Potential Device A64''M2 $R_{64"}$		L_{p2} = AM2 = 64'' (≅ 1,6m)	$r_{inv,p2}$ = 2AM2 = 128'' (= 3,2m)	1/10 n_ρ = 20Ωm/div (0 –200 Ωm / 10 div)
Disp. potențiale Disp. gradient	4).*Ra* Gradient Device AO=18`8” $R_{18'8"}$		L_g = 0A = 18'8'' (≅ 5,7m)	$r_{inv,g}$ = 0A = 18'8'' (= 5,7m)	

The special electrical logs representation form.

The special electrical diagraph is represented on three diagram traces and is compounded of:

- PS curve (ΔE_{PS}) recorded in the left side of the diagram (on the first trace of 10 divisions)

- apparent rezistivity curves with potential devices (also known as normal curves), on the second trace of 10 divisions: the curve with potential device $\mathbf{L_{p1}}$= $\mathbf{AM_1}$ **=** 16in (0,4 m) is represented with full line (ρ''_{16} or 16"N) and the curve with potential device $\mathbf{L_{p2}}$= $\mathbf{AM_2}$ **=** 64in (1,6 m) is represented with dotted line (ρ''_{64} or 64"N)

Lateral electrical log

BKZ method

Between 1948 and 1968, the lateral electrical logging, BKZ method was applied in Romania. During this procedure, well investigation was accomplished using a sequence of six gradiente devices. (see Table 3). An inconsecutive gradient device (a roof one) is given in the sequence as to a better separation of the layers after the rezistivity curves recorded, and also the gradient device from the usual electrical logging (M 2 A 0,3 B).

The BKZ diagraph's form of presentation in a geological section with a relatively simple lithological sequence is given in fig. 1.

Table 3. The characteristics of the devices used for BKZ method

Devices (Symbol)	Type of devices	Spacing divice	Radius of investigation	Scales of measurement	Depth Scales
B0,3A0,5M	Gradient	L_g = 0,65 m	r_{ivg} = 0,65 m	n□ = 2,5Ωm/cm	1:500
B0,3A1M	Gradient	L_g = 1,15 m	r_{ivg} = 1,15 m		
B0,3A2M	Gradient	L_g = 2,15 m	r_{ivg} = 2,15 m		
B0,3A4M	Gradient	L_p = 4,15 m	r_{ivp} = 4,15 m		
M6A1B	Gradient	L_g = 6,5 m	r_{ivg} = 6,5 m		
B1,3A8M	Gradient	L_p = 8,65 m	r_{ivp} = 8,65 m		

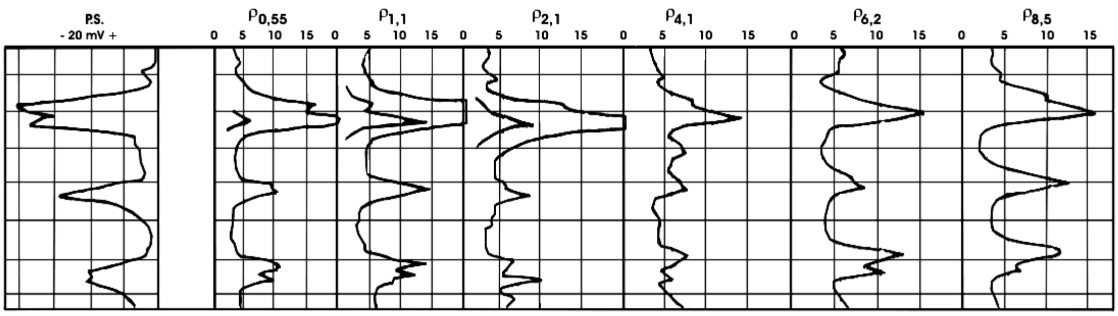
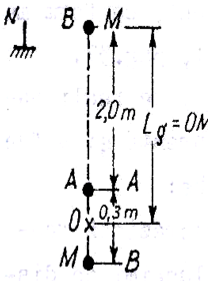
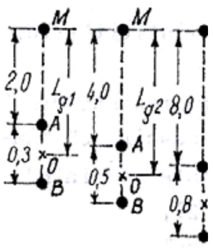


Fig. 1. The BKZ diagraph's form of presentation

DRR method

The DRR method consists of recording the rezistivity with three gradiente devices, with different device lengths and a potential device. The characteristics of the devices and the obtained diagraphies are given in Table 4.

Table 4. The characteristics of the DRR devices

Device	Curves	Symbol	Depth Scale	Spacing device	Radius of investigation	Scales of measurement
Standard electrical log	1)SP(ΔE_{PS})	SP		-	-	n_{PS} = 12,5mV/cm
	2). *Ra* Potential Device $(R_{0,3})$	M0,3A2B		$L_p = \overline{MA}$ = 0,3m	$r_{inv,p}$ = 2MA = 0,6m	n_ρ = 2,5Ωm/cm (0-20Ωm / 8cm)
	3).*Ra* Gradient Device $(R_{2,15})$	B0,3A2M	1: 1000	$L_g = \overline{0M}$ = 2,15m	$r_{inv,g}$ = 0M = 2,15m	
DRR method	1). ΔE_{PS}	SP		-	-	n_{PS} = 12,5mV/cm
	2). *Ra* Gradient Device $(R_{2,15})$	B0,3A2M		$L_{g1} = \overline{0M}$ = 2,15m	$r_{inv,g}$ = 0M = 2,15m	
	3). *Ra* Gradient Device $(R_{4,25})$	B0,5A4M	1: 500	$L_{g2} = \overline{0M}$ = 4,25m	$r_{inv,g}$ = 0M = 4,25m	n_ρ = 2,5Ωm/cm (0-20Ωm / 8cm)
	4). *Ra* Gradient Device $(R_{8,4})$	B0,8A8M		$L_{g3} = \overline{0M}$ = 8,4m	$r_{inv,g}$ = 0M = 8,4m	

The DRR diagraph's form of presentation: is given for a relatively simple lithological sequence in fig. 2. The standard electrical diagraph, in a special recording way and the three gradiente curves that form the actual complete DRR are given separately at the scale of 1:500 - detail scale.

A qualitative interpretation is given with these loggings, which consists of:

- geological correlation of wells profiles consists of recognizing the geological formations ran by wells after the diagraph aspect, compared to wells from the same structures

- establishing the geologo-geophysical (markers) guide marks and geological limits, based on which structural maps and geological sections are built.
- collectors separations, layers' limits and widths determination, the estimation of the content in fluids of poros-permeabile rocks or other mineral substances, fluids separation limits determination, establishing the intervals' depth and width that will put in the production process

Lateral electrical logging allows the real rezistivity determination with a better precision degree than the electrical logging and, in consequence, a better estimation of the collectors' content in water. On the mature fields the wells were investigated with this metod.

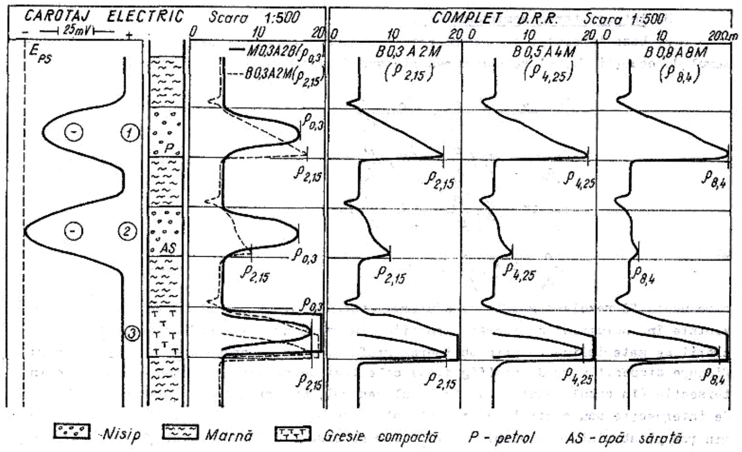


Fig. 2. The standard electrical diagraphy and DRR diagraph's form of presentation

Interpretation

Interactive Petrophysics program includes the following features: Data Management and Editing, Clay Volume Analaysis, Porosity and Water Saturation Analysis, Catoff and Summation, Multiwell processing.

For using this software it is necessary to have a full set of logs, electrical log (ILD or DLL), CNL, DL, SL. For the old wells there are not such logs, so that the interpretation of logs have to make with the conventional logs, show page up. There are a few modules which we can use for make an interpretation of this logs: Temperature Gradient, Rw from SP, Clay Volume from SP and resistivity curves, User Defined Formula and Batch Formula, Estern European Resistivity Correction, Multi Line Formulae, Basic Log Analysis.

Using these modules we can made an interpretation and to obtaine parameters: Clay Volume, Porosity and Water Saturation for clean formation, but this parameters can use also in clay formation.

The well XX. has the following diagraphies: SP, CG, RD, RS, CN, show in figurs nr.3. This curves had obtained:

- RD from DRR, using module Estern European Resistivity and is true resistivty,
- RS taken from normal curve recordind with device A0,3M2,0N , this values are aproximately with flushed zone resistivity and,

- CN the neutron – epithermal neutron log. The procesing this curve allow determitation values of porosity.

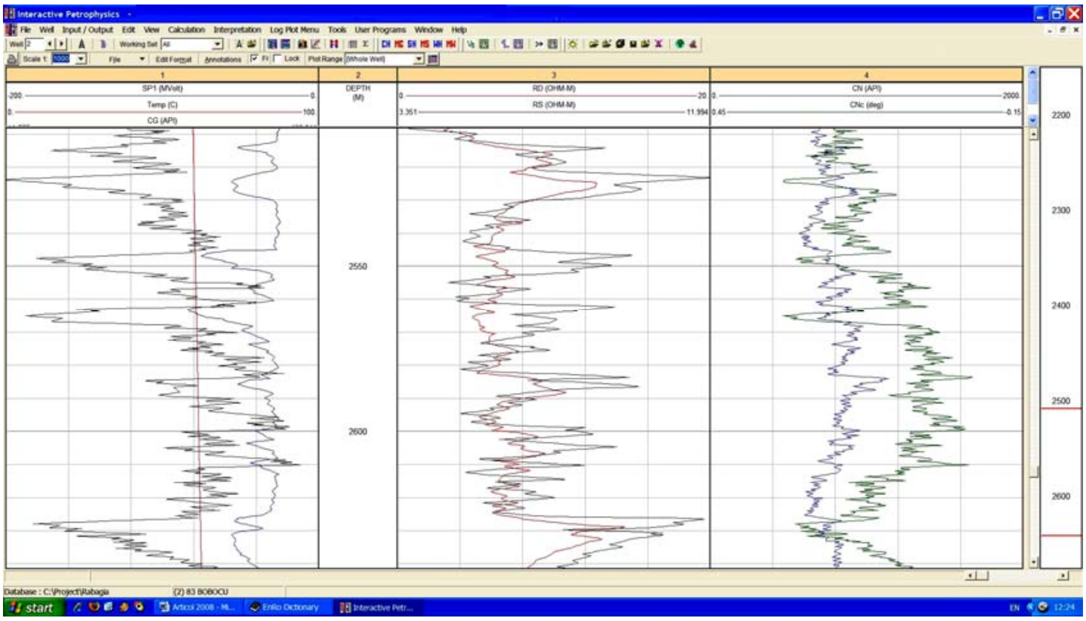


Fig. 3. The diagraphies: SP, CG, RD, RS, CN, for the well XX

From the GR was determined the volume of clay, and i tis show in figure 4.

Porosity and water saturation is show in fig. 4. The values was calculated using for porosity neutron log and for the others parameters we obtained from resistivty logs. For calculate water saturation is necessary all parametrers show up page. The approximation was made for flushed zone because have not a microresistivity device.

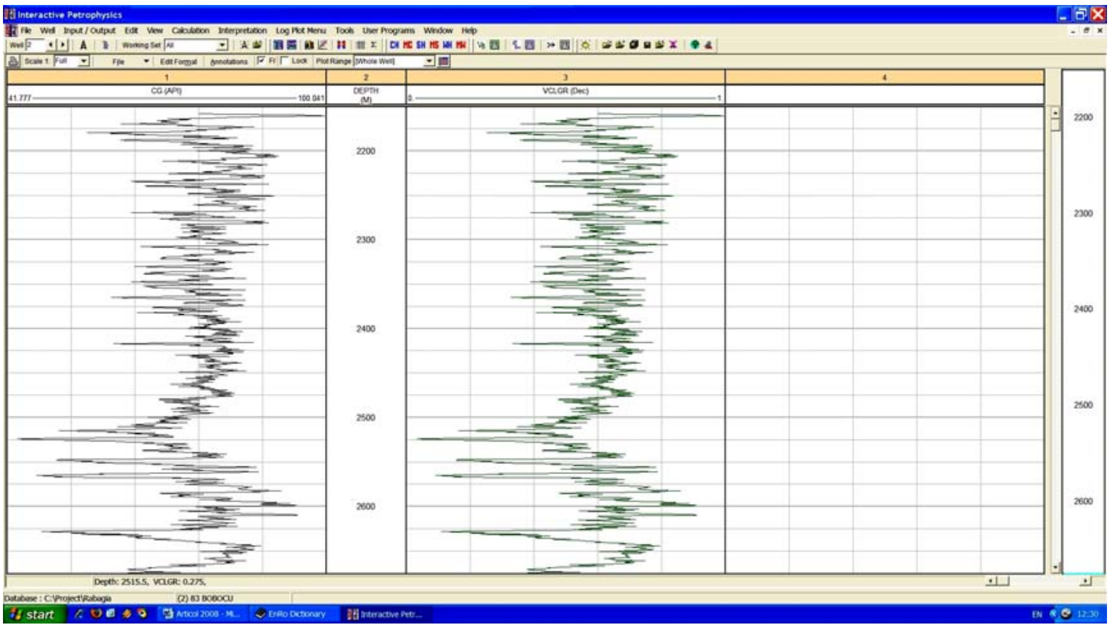


Fig. 4. The volume of clay from GR

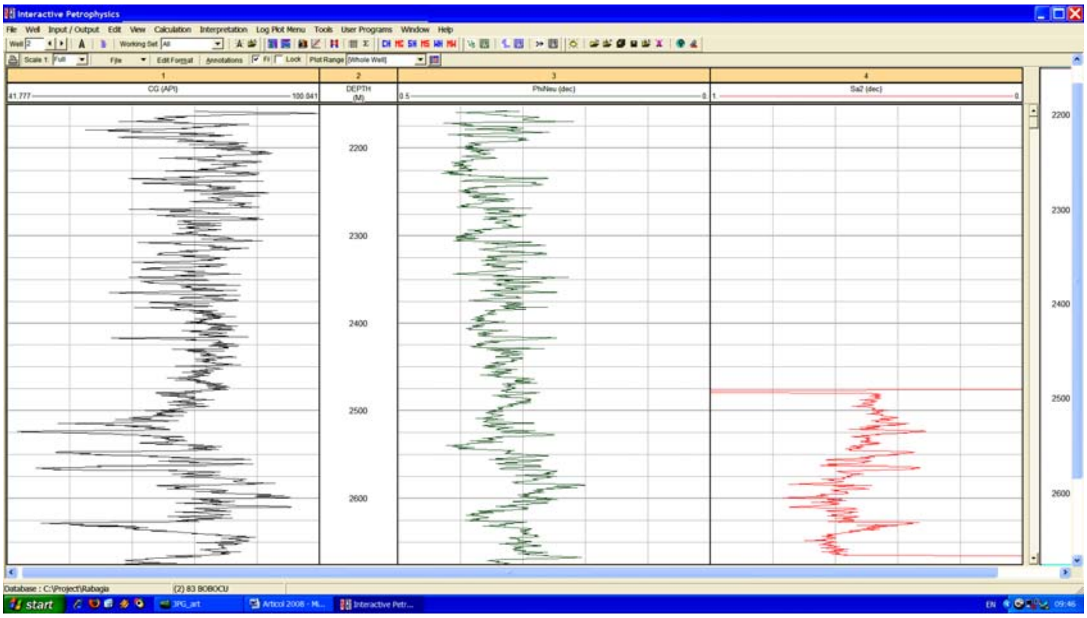


Fig. 5. The porosity and water saturation

Conclusions

The parameters show up are wery good and allowed to calculate the water saturation of formation. This was an example by interpretation conventional logs with Interactive Petrophysics, what can use for all wells with a minimal programs of geophysical investigation. The combined the logs with dates from cores and production give the posibility to make a very good cantitative interpretation. For the wells where was not recording neutron log for porosity, we can use others method, like us resistivity index or rezistivity ratios method.

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Aspecte privind reinterpretarea diagrafiei electrice convenționale

Rezumat

Marea majoritate a sondelor săpate pe structurile mature au avut un program de investigare minim constând în general din carotaj electric standard, carotaj electric lateral BKZ, DRR. În sondele de cercetare se mai înregistra un carotaj radioactiv format dintr-o curbă gama natural şi o curbă neutronică (neutron gama, neutron neutron cu neutroni termici sau epitermici. Pe baza acestei diagrafii se putea face o interpretare calitativă şi în condiții favorabile semicantitativă. În această lucrare s-a efectuat o interpretare cantitativă pe baza unei diagrafii convenționale utilizând programul INTERACTIVE PETROPHYSICS. Rezultatele sunt prezentate sub formă grafică şi prezintă un grad bun de încredere.