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Low Resistivity Contrast Gas Bearing Formation Identification from Conventional Logs in Tight Gas Sandstones

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Abstract

It's a great challenge in identifying gas bearing formation from conventional logs in tight gas sandstones due to the low resistivity contrast caused by high irreducible water saturation. Based on the difference of the principles of three kinds of porosity logs (density, neutron and acoustic logs), three porosities difference method, three porosities ratio method, correlation of neutron and density logs and the overlap method of water-filled porosity and total porosity are introduced to identify tight gas bearing reservoirs. In gas bearing formations, the difference of three porosities is higher than 0.0, the ratio of three porosities is higher than 1.0, the correlation between density and neutron logs is negative, and the water filled porosities are lower than total porosities. On the contrary, in water saturated formations, the difference of three porosities is lower than 0.0, the ratio of three porosities is lower than 1.0, the correlation between density and neutron logs is positive, and the water filled porosities are overlapped with total porosities. Considering the complexity of in-suit formation, when the proposed identification criterion are mainly meet, the pore fluid should be determined, field examples show that the proposed techniques are applicable in tight gas formation identification.

Key words: Low resistivity contrast gas bearing formation; Tight gas sandstones; Identification; Difference of three porosities; Ratio of three porosities; Correlation of neutron and density logs

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INTRODUCTION

It's a great challenge for petrophysicists and well log analysts in identifying tight gas reservoirs by using conventional logs due to the low resistivity contrast, which is caused by high irreducible water saturation (Tang *et al*., 2013). The resistivity difference between gas bearing formations and water saturated reservoirs is lower than 2.0, this is quite different with the conventional reservoirs (Ouyang *et al*., 2009; Xiao *et al*., 2012). From resistivity log response, tight gas sands cannot be identified accurately. Between gas bearing formations and water saturated layers, three different kinds of porosities are different. In gas bearing reservoirs, porosity obtained from acoustic log is higher than the true value, the density derived porosity is also higher, while the neutron porosity is lower than the true porosity due to the effect of Hydrogen index. In water saturated layers, these three derived porosities are equivalent, and they all equal to true formation porosity. Hence, these three porosities, and the derivative methods can be used to identifying gas bearing formations with low resistivity contrast. In this study, based on these three porosities, three methods, which are three porosities difference method, three porosities ratio and the neutron and density logs correlation method, are proposed to identifying low resistivity contrast gas bearing formations. In the meanwhile, two porosities overlap method, which is established based on the water filled porosity and total porosity, is also used. The results illustrate that these methods are all effective in tight gas sands.

1. METHODS OF IDENTIFYING LOW RESISTIVITY CONTRAST GAS BEARING FORMATIONS IN TIGHT GAS SANDS

1.1 Three Porosities Difference Method

In gas bearing formations, three porosity logs (density, neutron and acoustic log) all cannot be used to reflect true formation porosity due to the effect of natural gas. Porosities obtained from acoustic and density logs are higher than true formation porosity, while porosity derived from neutron log is lower. In water saturated layers, porosities calculated from acoustic, density and neutron logs are equivalent (Gao *et al*., 1999). In this paper, a parameter is established to reflect the difference of these three kinds of porosities, gas bearing zones can be identifying, and this parameter is named as the difference of three porosities, which is calculated by using Equation 1.

$$B=PHIS+PHID-2\times PHIN \tag{1}$$

Where, B is the difference of three porosities; PHIS is porosity obtained from acoustic log; PHID is porosity estimated from density log, PHIN is porosity calculated from neutron log, the unit of them is %. To obtain the parameter of B, three kinds of porosities should be estimated by using Equation 2 to Equation 4.

$$PHIS=(DT-DT_{ma})/(DT_f-DT_{ma})\times 100 \tag{2}$$

$$PHID=(\rho_b-\rho_{ma})/(\rho_f-\rho_{ma})\times 100 \tag{3}$$

$$PHIN=\varphi_N+1.5\% \tag{4}$$

Where, DT is the measured interval transit time, which is obtained from the acoustic log tool; DT_{ma} is the interval transit time of rock skeleton, DT_f is the interval transit time of pore fluid, the unit of them is µs/ft. ρ_b is the measured formation density, ρ_{ma} is the density of rock skeleton, ρ_f is the density of pore fluid, the unit of them is g/cm^3. φ_N is the measured formation neutron porosity in %.

By combining with Equations 1 to 4, B can be estimated. In gas bearing formations, the value of B is higher than 0.0, while in water saturated layers, its value is equal to 0.0. By using the value of B, gas bearing formations can be identified.

1.2 Three Porosities Ratio Method

Three porosities ratio method is another method of identifying gas bearing formations by using these three different kinds of derived porosities. The principle of this method is introduced another parameter C, which is defined as the multiplication of density and acoustic derived porosities divided by the square of neutron porosity, as is expressed as Equation 5.

$$C=PHIS+PHID-PHIN^2 \tag{5}$$

Where, C is defined as the ratio of three porosities.

In gas bearing formations, the value of C is higher than 1.0, and in water layers, its value is equal to 1.0. By using the value of C, gas bearing formations can be identified.

1.3 Correlation Factor Method of Density and Neutron Logs

As is expressed above section, in gas bearing formations, the density derived porosity is overestimated, and the neutron porosity is underestimated, in other words, the density porosity and neutron porosity is reverse related. Based on this analysis, Mao *et al.* (2002) pointed out that the correlation of these two porosities can be represented quantitatively and estimated from conventional logs, the corresponding correlation function also proposed, and it is expressed as follows (Mao, 2012):

$$R(\phi_D,\phi_N)=\frac{n\sum_{i=1}^{n}\phi_{N_i}\times\phi_{D_i}-\sum_{i=1}^{n}\phi_{N_i}\times\sum_{i=1}^{n}\phi_{D_i}}{\sqrt{n\sum_{i=1}^{n}\phi_{N_i}^2-(\sum_{i=1}^{n}\phi_{N_i})^2}\times\sqrt{n\sum_{i=1}^{n}\phi_{D_i}^2-(\sum_{i=1}^{n}\phi_{D_i})^2}} \tag{6}$$

Where, R is correlation function of neutron and density porosities; ϕ_N is neutron porosity, ϕ_D is density porosity, the unit of them is %; n is the amount of measure points that used for correlation factor estimated, its value is always designed as 10.0. ϕ_D and ϕ_N can be estimated by using Equations 3 and 4.

Using Equation 6, the correlation factor of density and neutron logs can be estimated. With this correlation factor, tight gas bearing formations and water saturated layers can be easily identified. In tight gas bearing formations, the value of R is negative, and on the contrary, in water saturated layers, the value of R is higher than 0.0.

1.4 The Overlap Method of Water Filled Porosity and Total Porosity

In 1942, Archie proposed a formula that relate resistivity and porosity, this formula is named as Archie's equations, one of the Archie's equation can be expressed as follows (Mao, 2012).

$$F=\frac{R_0}{R_w}=\frac{a}{\varphi^m} \tag{7}$$

With some Transformation, Equation 7 can be rewritten as follows:

$$\varphi=\sqrt[m]{\frac{a\times R_w}{R_o}} \tag{8}$$

R_0 is the rock resistivity with fully water saturated, R_w is the formation water resistivity, the unit of them is Ω.m; F is the formation factor; φ is the rock porosity in fraction; a is the factor that related with lithology, m is the cementation exponent, the values of a and m are obtained from rock resistivity experiments.

If R_0 is replaced by R_t, an apparent porosity φ_w can be estimated, it is named as water filled porosity.

$$\varphi_w=\sqrt[m]{\frac{a\times R_w}{R_t}} \tag{9}$$

In water saturated layers, R_t is equal to R_0, and φ_w is equivalent with total porosity, while in gas bearing formations, R_t is higher than R_0, and φ_w is lower than total porosity. If water filled porosity and total porosity is overlapped together, tight gas bearing formations will be identified.

2. CASE STUDIES

By using the proposed methods, several field examples are processed, the reliability of the mentioned methods is verified. Figure 1 illustrates the field example of identifying tight gas bearing formation by using the proposed methods. It can be observed that in the interval of xx39 to xx58 m, the value of B is higher than 0.0, C is higher than 1.0, water filled porosity (PHIW) is lower than total porosity (POR), the correlation factor of density and neutron porosities is negative, all these indicate that this interval is gas bearing formation, this is confirmed by drill stem testing data, in the interval of xx39 to xx51, 10.68×10^3 m^3/day of gas production is acquired and without any water out.

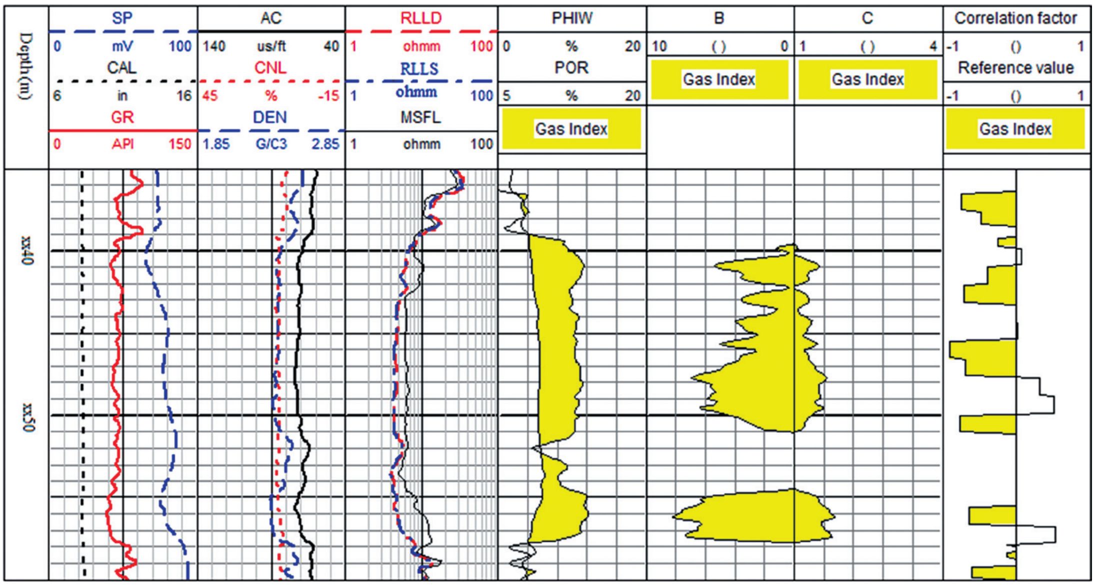

Figure 1
Field Example of Identifying Tight Gas Bearing Formation by Using the Proposed Methods

Figure 2 is another field example of identifying water saturated layer by using the proposed technique. From the processed result, it can be observed that the value of B is lower than 0.0, C is lower than 1.0, PHIW is close to POR, and the correlation factor of density and neutron porosities is positive, all these results indicate that in the interval of xx36 to xx88 m, only water can be produced. This is verified by the drill stem testing data.

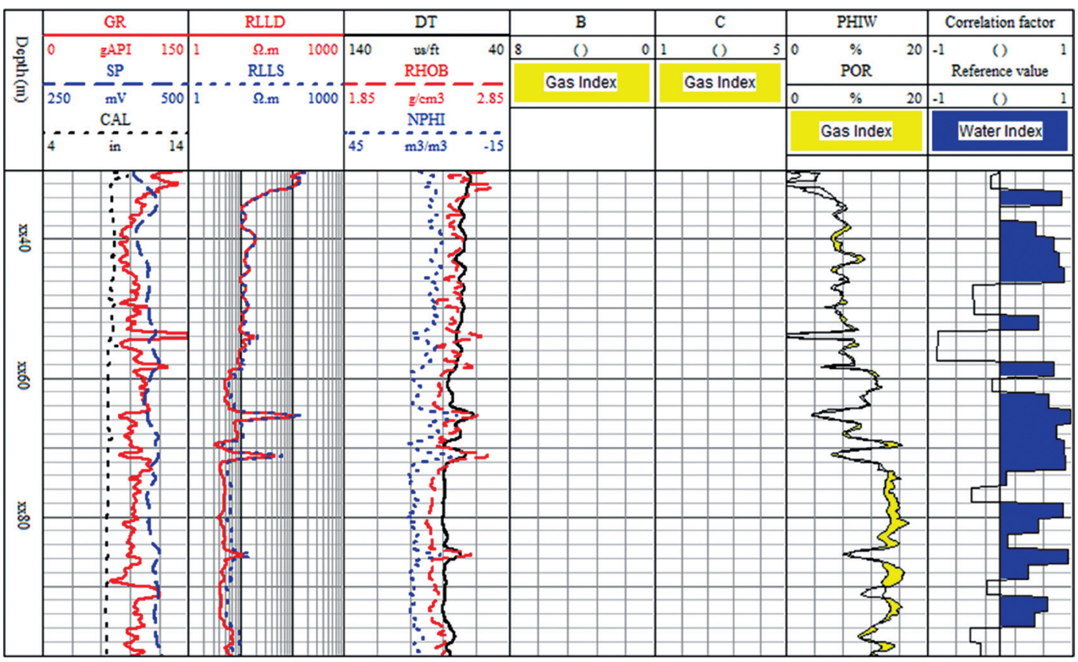

Figure 2
Field Example of Identifying Water Bearing Formation by Using the Proposed Method

CONCLUSIONS

(1) It is difficult in identifying tight gas bearing formations from resistivity response due to the low contrast, the difference of resistivity between gas bearing formation and water saturated layer is lower than 2.0.

(2) In gas bearing formation, porosities derived from acoustic and density logs are overestimated, and neutron log will underestimate reservoir porosity, based on this difference, three porosities difference and three porosities ratio methods are proposed to identifying tight gas bearing formations. The correlation factor method of density and neutron logs can also be usable.

(3) The overlap method of water filled porosity and total porosity is usable in identifying gas bearing reservoirs from pure water layers.

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