Comprehensive identification method of volcanic gas and water layer in Anda area

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Abstract. The structure of Anda area is located in the north of Xujiaweizi fault depression, which is a NNE trending depression, with west fault and East exceeding. The main target reservoir in this area is volcanic reservoir of the third member of Yingcheng formation. The reservoir lithology is complex, the physical property changes greatly, and the heterogeneity is strong, which brings some difficulties to the gas and water layer identification in this area. Due to the special influence of lithology and pore structure of volcanic rock, the relationship between gas and water in volcanic reservoir is relatively complex. Gas wells show different productivity characteristics and water production characteristics in the production process. Based on logging, logging and gas testing data, this paper analyzes the response characteristics of gas and water layer logging, establishes gas and water layer identification chart, comprehensively identifies gas and water layers, further deepens the understanding of gas reservoir geology in this area, and improves the gas well development efficiency.

1. Introduction
The deep stratigraphic sequence in Anda area develops from bottom to top Paleozoic basement, Cretaceous Huoshiling formation, Shahezi Formation, Yingcheng Formation, Denglouku formation and the first and second members of Quantou Formation. The target layer is Ying3 formation of Yingcheng Formation, which is composed of a set of acid eruptive rocks and a set of intermediate basic eruptive rocks, with multi-layer sedimentary layers inside, with small thickness and unstable distribution. The reservoir lithology is complex, the physical property changes greatly, and the heterogeneity is strong. The volcanic rocks in the third member of Yingcheng Formation are mainly composed of lava and pyroclastic rock. The lava is distributed from basic, neutral to acidic. The upper part of ying-3 member is mainly acidic rhyolite, and the lower part is mainly basic and medium basic basalt, andesite basalt and andesite; pyroclastic rocks include volcanic breccia, fusion tuff and tuff. The porosity of acid volcanic rock is mainly distributed in 4.97-7.76%, with an average of 6.90%, and the average permeability is 0.034md; the porosity of medium basic volcanic rock is mainly distributed in the range of 2.44-7.26%, with an average of 4.68%, and the average permeability is 0.024md, belonging to low porosity and low permeability reservoir.

2. Gas and water layer identification
The relationship between gas and water is one of the key factors to determine the type of gas reservoir. The identification of gas and water layer can provide important basis for gas bearing evaluation, reserve
calculation and gas water relationship research. The relationship between gas and water in volcanic reservoir of Yingcheng formation is complex, and the logging response of gas and water layer is easily affected by the changes of lithology and pore structure. Therefore, based on the logging response mechanism of gas and water layer, based on gas testing data, combined with logging and logging data, an interpretation chart of volcanic gas and water layer is established to comprehensively identify the reservoir fluid properties of the untested gas interval.

2.1. Logging response characteristics

According to the gas test and production test data of gas wells, the gas bearing property of reservoir is evaluated, and the logging curves of single well are comprehensively interpreted.

1) The response characteristics of gas reservoir logging include the increase of formation resistivity, decrease of neutron porosity, decrease of density, increase of acoustic wave or jump wave. Fig. 1 shows the logging response characteristics of typical gas reservoirs in well A1, with daily gas production of $5.6 \times 10^4$ m$^3$/D, which is an industrial gas reservoir.

2) Response characteristics of water layer logging: compared with gas reservoir, the resistivity of water layer is low, and the change trend and degree of three porosity (neutron, density, acoustic wave) are consistent. Fig. 2 shows the logging response characteristics of typical water layer in well A2. The daily water production of gas testing is 2.1m$^3$/d, which is the water layer.

3) Logging response characteristics of gas water layer: it is between gas reservoir and water layer, and the deep and shallow lateral curve shows obvious low resistance invasion. Fig. 3 shows the logging response characteristics of typical gas and water layers in well A3. The daily gas production and water production of well A3 are $4.1 \times 10^4$ m$^3$/D and 28.8m$^3$/d, respectively.

4) Dry layer logging response characteristics: poor physical properties, logging curve with relatively high resistivity, low acoustic transit time, high density, density curve shape similar to acoustic curve. Fig. 4 shows the logging response characteristics of typical dry layer in well A4. After gas pressure test, the daily gas production is 93m$^3$, which is the dry layer.

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![Fig. 1 logging response characteristics of gas reservoir (well A1)](image1)

![Fig. 2 Water layer logging response characteristics (well A2)](image2)

![Fig. 3 Gas water layer logging response characteristics (well A3)](image3)

![Fig. 4 Response characteristics of dry layer logging (well A4)](image4)
2.2. Intersection plate method

According to the logging response characteristics of gas and water layer, it can be seen that volcanic gas and water layer have good display in resistivity, density, acoustic time difference and so on. Therefore, through the bivariate cross plot of these curves, volcanic gas and water layer can be well identified. There are many kinds of lithology coexisting in the volcanic rock development interval, including normal sedimentary rock, volcanic sedimentary rock, acid volcanic lava and pyroclastic rock, intermediate basic volcanic lava and pyroclastic rock. Different reservoir lithology, the corresponding logging response values are also different, and the rock electrical relationship is complex (Fig. 5, 6, 7). Therefore, the identification charts of gas and water layers should be established according to lithology. Based on the data of gas testing, logging and logging, the deep lateral resistivity, density, acoustic time difference, gas logging ratio and other response values of gas testing layer are read. Gas and water layer identification plates are established according to the acid volcanic rocks in the upper and middle basic volcanic rocks in the lower sub member of Yingcheng formation. The results show that there are obvious regular differences in the log response values of gas reservoir, low gas production layer, gas water same layer, water layer and dry layer, which can comprehensively and effectively identify gas and water layers.

![Volcanic rock lithology identification chart (gr-ild)](image1)

**Fig. 5** Volcanic rock lithology identification chart (gr-ild)

![Volcanic rock lithology identification chart (dt-den)](image2)

**Fig. 6** Volcanic rock lithology identification chart (dt-den)
Based on the data of gas testing, logging and gas logging of 65 layers in 26 wells in the study area, the fluid properties of acid volcanic reservoir in Anda area are determined. At the same time, the ratio of resistivity to deep gas layer (8.85%) and deep gas layer (8.8%) is used to distinguish the deep layer from the deep layer 8.4%.

Because the reservoirs with poor physical properties in the study area often need to be fractured to have a certain production capacity, the reservoirs falling in the gas and dry layer boundary area are likely to obtain a certain production capacity after fracturing, and the reservoir falling in the gas water layer boundary area has a high possibility of water production in the later stage.

(2) Fluid identification chart of intermediate basic volcanic reservoir

Based on the data of gas testing, logging and gas logging of 47 layers in 21 wells in the study area, the fluid properties of intermediate basic volcanic reservoir in Anda area are determined. Taking deep lateral resistivity as ordinate and density as abscissa, the crossplot of deep lateral resistivity and density (Fig. 11) of medium basic volcanic reservoir in Anda area is established. At the same time, the crossplot of deep lateral resistivity and acoustic transit time (Fig. 12) and the cross plot of deep lateral resistivity and gas logging ratio (Fig. 13) are used to distinguish gas reservoir, water layer and dry layer. The accuracy of the chart is 91.4% and 90.2%, 91.4%.
3. Gas water distribution relationship

Yingcheng Formation gas reservoir in Anda area belongs to multiple volcanic rocks formed by multi-stage volcanic eruption. There are many different gas-water systems between them. The gas reservoir is controlled by "structure lithology" and the relationship between gas and water is complex. According to the analysis of gas testing results and well logging data, there is no uniform gas water interface in Yingcheng Formation gas reservoir in this area, which is characterized by upper gas and lower water. The industrial gas flow layer is mainly distributed on the top of volcanic rocks. The height of gas column at the high part of the structure is relatively large, and the height of the gas column at the low part is small. The gas and water interface does not match with the structural trap. The gas and water in the whole section is mainly composed of two types: ① the whole section of pure gas: for example, well B4, B7, B10 are pure gas layer; ② upper gas and water (or the same layer of gas and water): such as well B5, B6, B8, B11, etc. Well. On the plane, the relationship between gas and water is complex and controlled by lithology. The industrial gas flow layer is distributed on the top of the weathered and denuded volcanic remnant, and the same is relatively high part of the structure, indicating that the gas reservoir is controlled by both structure and volcanic distribution (FIG. 14).
4. Conclusion
(1) Through the comprehensive data of gas testing, logging and logging, the comprehensive interpretation of single well logging curve and the study of gas and water logging response characteristics can effectively identify the fluid properties of volcanic reservoir in Yingcheng Formation in Anda area;
(2) According to the acid volcanic rocks and intermediate basic volcanic rocks of Yingcheng Formation, the gas and water layer identification plates are established respectively, which can effectively identify gas and water layers, and the accuracy of the chart is more than 85%;
(3) The volcanic gas reservoir of Yingcheng Formation belongs to many volcanic rocks formed by multi-stage volcanic eruption. There are many different gas-water systems. The gas-water relationship is complex. The gas-water system is mainly controlled by volcanic rock mass in plane, and it is characterized by gas-water-bearing in vertical direction.

The lithology of volcanic rocks in Yingcheng Formation of Anda area is complex, and it is difficult to identify gas and water layers. In this paper, through analyzing the logging response characteristics of gas and water layers, the identification chart of gas and water layers for acid volcanic rocks and medium basic volcanic rocks is established, which can comprehensively and effectively identify reservoir fluid properties, optimize favorable gas bearing horizons, and improve the exploration and development effect of gas reservoirs.

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