Research Article

Liu Zongli*, Wang Zhuwen, Zhou Dapeng, Zhao Shuqin, and Xiang Min

Pore Distribution Characteristics of the Igneous Reservoirs in the Eastern Sag of the Liaohe Depression

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Abstract: In the Es3 formation (third section of the Shahejie) of the Eastern sag section of the Liaohe Depression, basalt and trachyte are predominant in the igneous rock. The reservoir consists of complex reservoir space types. Based on the porosity bins of nuclear magnetic logging and the porosity distribution of electric imaging logging, the pores’ sizes and distribution, as well as the mutual connectivity of the reservoir, were analyzed. Also, the characteristics of the different reservoirs were summarized. In regards to the oil reservoirs, large pores (PS>10) were found to account for the majority of the reservoir spaces, and the pore distribution was concentrated and well connected. However, for the poor oil reservoirs, the large and small pores were found to alternate, and the pore distribution was scattered and poorly connected. Within the dry layers, the smaller pores (PS<10) were predominant. The pore distributions were found to be influenced by lithology, facies, and tectonism. The reservoirs of the pyroclastic flow of the explosive facies had good connectivity, and the interlayer heterogeneity was relatively weak. This reservoir’s pore distributions were found to be mainly dominated by the larger pores (PS10-PS13), which displayed a concentrated distribution mainly in one porosity bin. Therefore, it was taken as a favorable facie belt in the eastern sag of the Liaohe Depression. The examination of the pore distribution characteristics of the igneous rock was the key to the evaluation of the properties and effectiveness of the igneous reservoirs in this study, which potentially has great significance to the future exploration and development of igneous rock.

Keywords: Eastern Liaohe basin; igneous rock; reservoir space types; lithofacies; pore distribution; mercury injection curve

1 Introduction

Igneous reservoirs are widely distributed in many countries in the world and are becoming an important new field of global oil and gas exploration and development [1–4]. In terms of the age distribution, igneous rock reservoirs are mainly distributed in the Cenozoic, followed by the late Paleozoic, and it is related to global frequent volcanic activity in the Cenozoic [5–7]. At present, there are many igneous reservoirs in Songliao, Bohaiwan, Junggar and Sichuan Basins which show great exploration potential [8, 9]. In recent years, great progress has been made in the examinations of volcanic reservoirs, including studies regarding the classifications of lithology and lithofacies [10–14], variations in porosity and permeability [15, 16], classification of reservoir space types [17–19], forming mechanisms [20–23], reservoir seismic identification [24–27], reservoir evaluation and prediction [9, 12, 18, 21], and so on.

The study of pore structure is an important method for reservoir evaluation and prediction [28–30], yet few studies have been made regarding volcanic reservoirs’ pore structures. The conventional methods for examining the pore structures of igneous rock include core observation, cast thin sectioning, scanning electron microscopy, conventional mercury injections, constant velocity mercury injections, and so on. The pore structures of the acidic igneous rock in the northern Songliao Basin have been divided into four types, namely wide forms, less wide forms, rather narrow forms, and narrow forms, using cast sheet and constant velocity mercury injection methods. Also, the pore structures of the igneous rock have been analyzed using conventional mercury injection and nuclear magnetic resonance imaging methods. These previous studies...
have achieved good results in practical applications [31–33]. However, the aforementioned research was based on the core of the igneous rock, and due to the igneous rock’s strong heterogeneity, the core test results were not very effective in measuring the reaction storage layer characteristics. The igneous rock cores were found to be fragile, and presented increased difficulties for the testing procedures. These methods which are based on core are very limited in scope, and they cannot describe the pore structure in the longitudinal direction, and in addition the test cost is high and test period is long.

In the present paper, based on the porosity bins of the NMR logging, and the porosity distribution of the electrical imaging, the relationship between the pore structure and reservoir quality were analyzed. The method can reflect the pore structure in detail. There is continuity in the longitudinal direction, which can accurately reflect the pore characteristics of the entire reservoir. In addition, it can also reflect the heterogeneity of reservoir. Then, further evaluations of the reservoirs’ properties and effectiveness were conducted. Based on the results, we can evaluate the reservoir properties and effectiveness.

Figure 1: Location of the eastern sag and distribution of the wells

2 Regional geological setting

The eastern sag is one of seven secondary tectonic units of the Liaohe Depression. The Liaohe Depression is located in the Tanlu Fault Zone, which experienced frequent tectonic movement and strong fault activity. Therefore, the Liaohe Eastern Depression developed a series of NE trending faults, including the Jiazhengsi and Tiejianglu Faults (Fig. 1). Due to influences of the Tanlu Fault, six tectonic movements have occurred in the eastern sag of the Liaohe Depression since the Cenozoic period, all of which were accompanied by volcanic activity of varying intensities. These movements caused igneous rock to widely develop, which included mainly trachyte and basalt. In accordance with the available data regarding the cores, thin sections, and well logs, the igneous rock has been divided into six facies and 16 sub-facies, which has laid the foundation for further research studies in this area. In recent years, the exploration and development has shown that the effective reservoirs are mainly concentrated in the E3 section. Also, the igneous rock of the E3 can be vertically divided into five stages. With the exception of the third stage which consists of trachyte, the other sections have been determined to be mainly composed of basalt.

The igneous reservoir space types in the E3 formation of the eastern sag of the Liaohe Depression are complicated in nature. In accordance with the pore origin of volcanic rock reservoirs, it can be divided into two categories: primary reservoir spaces, and secondary reservoir spaces [19, 34] (Table 1). The primary reservoir spaces include the pores and holes formed during the process of igneous rock diagenesis. During the magma eruptions and crystallizations, a large number of gases were produced. When these touched the surrounding formations, airflows were generated. Following the cooling and condensing of the magma, fissures and intergranular pores were formed. The primary reservoir spaces mainly include the primary pores, intergranular pores, condensing shrinkage fractures, and broken fractures. The secondary reservoir spaces were formed by tectonic stress, fluid action, and the weathering effects following the formation of the igneous rock. They mainly include the dissolved pores (phenocryst and groundmass), along with dissolution, crypto-explosive, and tectonic fractures.

3 Pore distribution of the igneous rock reservoir

In this study, the nuclear magnetic logging provided the porosity bins information, which corresponded to the different rock pore sizes. The amplitudes from the binned $T_2$ distribution (transverse relaxation times) were accumulated from right to left. At the same time, the value of the $T_2$ was from small to large. It was found to be helpful to
Table 1: Reservoir space types of the igneous rock in the Es_3 formation

<table>
<thead>
<tr>
<th>Reservoir space types</th>
<th>Genetic interpretation</th>
<th>Typical picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pores</td>
<td>Gas expansion overflow in the diagenetic process</td>
<td>Fig. 1(a)</td>
</tr>
<tr>
<td>Intergranular pores</td>
<td>Rock forming mineral framework</td>
<td>Fig. 1(b)</td>
</tr>
<tr>
<td>Contraction fractures</td>
<td>Magma condensing shrinkage, magma at the bottom of the upwelling, damage caused by the upper lava during the process of condensing shrinkage</td>
<td>Fig. 1(c)</td>
</tr>
<tr>
<td>Spalled joint</td>
<td>Phenocryst burst</td>
<td>Fig. 1(d)</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissolution pores</td>
<td>Minerals such as feldspar dissolution</td>
<td>Fig. 1(e)</td>
</tr>
<tr>
<td>Dissolution fractures</td>
<td>Fluid and rock interaction along the fracture</td>
<td>Fig. 1(f)</td>
</tr>
<tr>
<td>Crypto-explosive frac-</td>
<td>High pressure fluid entering host rock caused by crypto explosions</td>
<td>Fig. 1(g)</td>
</tr>
<tr>
<td>Tectonic fracture</td>
<td>Tectonic stress</td>
<td>Fig. 1(h)</td>
</tr>
</tbody>
</table>

Figure 2: Reservoir space types of the igneous rock in the Es_3 formation

obtain the changing of the binned porosities visually with the depth (second column from the right in Fig. 3).

The imaging logging data were converted into porosity images following a scale of resistivity and porosity. Similar to the binned T_2-distribution of NMR log interpretation, the porosities in the different bins were statistically analyzed. Then, the effects of the different pore sizes on the total porosities were intuitively analyzed (first column from the right in Fig. 3).

As shown in Fig. 4, the curve abcd is the capillary pressure curve, abc is the mercury injection curve, cd is the mercury withdrawal curve, and the ab section is a continuous mercury injection section. The more concentrated the pore size and the better the sorting will be while the longer the continuous mercury injection section (ab section) and the closer to the abscissa axis is, and vice versa. According to the capillary pressure curve, the parameters of reservoir pore structure can be obtained (Table 2).

In this study, the pores with T_2 of more than 33 ms were the large pores, and others were considered to be the small pores. For the porosity distribution of the electric image logging, the pores with porosities of more than 10% (PS10) were considered to be the large pores.

3.1 Trachyte pore distribution

The location of the Y70 well was less than 200 m from the Jiazhangsi Fault (Fig. 1). The lithology between 4,372 and 4,417 m was determined to be trachytic breccia. The litho-
Table 2: Pore structure evaluation parameters

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
<th>Unit</th>
<th>Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pore throat size</td>
<td>Maximum pore throat radius</td>
<td>µm</td>
<td>The larger the pore throat radius is, the better the connectivity will be, and the easier it will be for the fluid to enter the pore and output</td>
</tr>
<tr>
<td></td>
<td>Average pore throat radius</td>
<td>µm</td>
<td></td>
</tr>
<tr>
<td>Pore throat sorting</td>
<td>Sorting coefficient</td>
<td>1</td>
<td>The smaller the sorting coefficient is, the more uniform the pore throat size will be</td>
</tr>
<tr>
<td>Connectivity of the pore throat and the control of fluid motion</td>
<td>Maximum mercury saturation</td>
<td>%</td>
<td>The higher the maximum mercury saturation is, the better pore structure and the larger proportion of the effective porosity will be.</td>
</tr>
<tr>
<td></td>
<td>Displacement pressure</td>
<td>Mpa</td>
<td>The displacement pressure is low which indicates that the rock has good physical properties</td>
</tr>
<tr>
<td></td>
<td>Mercury withdrawal</td>
<td>%</td>
<td>The larger the mercury withdrawal is, the more uniform the pore throat size and the better the reservoir performance will be</td>
</tr>
</tbody>
</table>

Figure 3: Trachyte pore distribution of the Y70 well
facies belonged to the pyroclastic flow subfacies of the explosive facies. The pore distributions provided by the NMR and electric imaging logging showed that the large pores played a dominant role in this section, the vertical connectivity was good, and the heterogeneity was relatively weak. This explained how the formation possessed both good physical and oil properties, and the results of the log interpretation and oil testing also confirmed it was a good oil-bearing formation.

The porosity provided by the NMR was 15-17%. Therefore, based on the T<sub>2</sub> porosity bins, the smaller pores accounted for a lower percentage. The porosity of the electric imaging was 11-14%. Also, in the pore distribution, the proportion of large pores was obviously found to be more than the proportion of small pores, and most of the large pore belonged to the PS10-PS13 porosity bin. These results indicated that the large pores were uniform, and that there was almost no vertical barrier section in the small pores, which caused the connectivity to be better and the heterogeneity was relatively weak. The conventional well logging curves, including DEN (density), CNL (neutron porosity), and AC (slowness), displayed no obvious fluctuations, which indicated that the heterogeneity of the trachyte was relatively weak (Fig. 3).

The results of the core pressure mercury test indicated that the test section had a large pore throat structure, and the pore distribution was concentrated. It was determined from the core and thin section photographs that dissolution pores, intergranular pores, and broken fractures of the trachyte were well developed. Due to the dissolution and connections of the pores, the trachyte was found to possess good physical properties in this section. The displacement pressure of the capillary pressure curve was 2.036 MPa. The maximal radius of the pore throats was 0.356 µm, and the average pore radius of pore throats was 0.075 µm. These findings confirmed that the trachyte had large pore structures. The section injecting mercury (section ab in Fig. 4) in the middle was smooth and long. Also, its slope was small, and the pores displayed good sorting and even distribution. The maximum mercury saturation was determined to be 91.51%, and the efficiency of mercury ejection was 27.97%. These results indicated that the pore size was uniform, and the proportion of effective pores was large (Fig. 4). This was found to be consistent with the conclusions regarding the pores’ distribution.

The location of the Ho25 well was approximately 1 km from the Jiazhangsi Fault, a location which was further away from the fault than the Y70 well (Fig. 1). The lithology between 4,321 and 4,345 m was determined to be trachyte and trachytic breccia. The lithofacies were the tabular flow subfacies of effusive facies. The pore distribution of the electrical imaging logging showed that the reservoir was dominated by small pores, with a concentrated distribution. These results suggested that the formation possessed some poor physical and oil properties. The results of the log interpretation and oil testing confirmed that this location was not a good oil-bearing formation.

The porosity of the electric imaging was 6-9%. The pore distribution indicated a predominance of small pores, and the pore distribution was found to be concentrated in bin PS7-PS10. Some large holes existed only in the top and bottom of the layer with a contact surface made up of the surrounding rock. The conventional logging curve was smooth. These results indicated that the layer heterogeneity was weak. In general, the layer’s physical properties displayed poor oil characteristics and were determined to not be an effective reservoir (Fig. 5).

To summarize the above results, the trachyte layer heterogeneity was found to be weak, and displayed the following characteristics: in the oil reservoir, the large pores accounted for a higher proportion of the total pores. The pores’ sizes were found to be uniform, and the connectivity was better in the vertical direction. The formation possessed some good physical and oil properties. In regards to the dry layers, the small pores constituted the majority, and the formation was found to not be an effective oil-bearing formation.

It was also determined that near the fracture, the secondary effect was strong, and the large pores were more developed. The physical properties and oil content of the pyroclastic flow subfacies were better than those of the tabular flow subfacies, and the large pore development was more obvious. These conclusions can potentially be used to indicate favorable facies for the further exploration and development in the study area.

### 3.2 Basalt pore distribution

The J31 well was located approximately 260 m from the Jiazhangsi Fault (Fig. 1), and the 3,708 to 3,790 m lithology was determined to be basalt. The lithofacies were the compound flow subfacies of the effusive lava flow facies. The pore distribution characteristics of the electrical imaging showed that the pores were of different sizes, alternative development, and poor connectivity. The reservoir’s intraformational heterogeneity was strong, and the barrier layer was frequently interbedded. These results explained why this basalt formation was a poor oil-bearing formation. The oil testing also confirmed that this was a poor oil reservoir.
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core depth: 4373.9m, displacement pressure (MPa): 2.063, maximum pore throat radius (μm): 0.356, average pore throat radius (μm): 0.075, sorting coefficient: 0.049, Maximum mercury saturation (%): 91.51, efficiency of mercury withdrawal (%): 27.97.

Figure 4: Trachyte capillary pressure curve and the core of the Y70 well.

Figure 5: Trachyte pore distribution of the Ho25 well.
The porosity of the electric imaging was 8-18%, the range is large. In regard to the pore distribution, the proportion of large pores was roughly equivalent to that of the small pores, and both contained multiple porosity bins, which explained the pores’ size scattering. In a longitudinal direction, the two types of pores alternatively existed. Due to the blocking of the small pores, the connectivity was found to be poor, which led to the poor quality of the basalt reservoirs. The conventional logging curves changed violently, and took on of the shape of multiple fingers. These results explained why the basalt formation was strongly heterogeneous (Fig. 6).

The results of core pressure mercury test indicated that the test section had large pores, and the pore distribution was more dispersed. It was determined from the core that the formation displayed interlayers of vesicular and tight basalt. In the porous sections, the pores were found to be considerably developed. However, zeolite and other minerals were also observed. This reservoir possessed some poor physical properties. For example, in the tight sections, there were almost no pores present, which also influenced the connectivity of the porous sections. Therefore, the basalt was found to possess poor physical and reservoir properties.

The displacement pressure of the capillary pressure curve was 0.299 MPa. The maximal radius of the pore throats was 2.456 µm, and the average pore radius of the pore throats was 0.294 µm. These findings confirmed that the structure contained large pore throats. The mercury saturation increased gradually along with the increase of the pressure. Also, its (section ab) slope was large, which manifested into pore throats with different sizes. The maximum mercury saturation was 40.23%, and this was found to be lower when compared to the value of the trachytic. The efficiency of the mercury ejection was 8.37%. These results confirmed that the pores with different sizes were poorly sorted, and that the pores were poorly connected (Fig. 7). This was consistent with the conclusions of the pores’ distribution.

The Ho28 well was located approximately 240 m from the Jiazhangsi Fault. The formation consisted of basalt and altered basalt at 3,708 to 3,790 m. The lithofacies were the compound flow subfacies of the effusive lava flow facies. The pore distribution showed that small pores accounted for the main percentage of the pores, and the pores with different sizes displayed alternative development and poor connectivity. These results explained why the basalt formation was a poor oil-bearing formation, and the oil testing confirmed that this formation was dry.

The porosity of the nuclear magnetic was 6-12%, and the binned T2-distribution was entirely composed of small pores, which were distributed in different bins. The porosity of the electric imaging was 713%, and the proportion of small pores was fairly large. There were some large pores observed, and the pores were spaced apart. The conventional logging curves displayed a finger-type superposition. In general, the reservoir heterogeneity was strong, and it was considered to be a non-effective reservoir (Fig. 8).

From the above assessment results, it was determined that the basalt layer heterogeneity was strong, and some of the characteristics were as follows: the basalt formations were mainly determined to be poor reservoirs, with alternating large and small pores. The formation was quite heterogeneous, and thus the conservation of oil and gas was difficult. The physical properties of the compound flow subfacies were determined to be good. However, although the oil content was determined to be poor, it may be considered for exploration and development in the study area.

4 Discussion of the pore distribution in the igneous rock reservoir

4.1 Relationship between lithology and pore distribution

In recent years, the exploration and development processes have found the effective reservoirs are mainly concentrated in trachyte formations. The physical properties and oil content of the trachyte formations have been found to be superior to that of the basalt formations (Table 3). The basaltic pores develop to a greater extent, due to the lack of fracture connectivity. However, most of these are isolated, and filled with secondary minerals. The pore distributions showed that the pores had different porosity bins. The fractures of the trachyte also were well developed, and the pores were connected. The pore distributions showed that the pores were more concentrated in certain porosity bins.

First, the basalt was dominated by dark minerals, such as plagioclase, pyroxene, and olivine, and following alterations, the basalt generated chlorite, saponite, and calcite, which seriously filled the pores (Fig. 7d). The trachyte usually consisted of light minerals. Under low temperature hydrothermal conditions, these minerals were altered, and zeolites were created. These fractures and pores will typically not be filled with zeolite. Second, the light minerals were more brittle than the dark minerals. There-
fore, in the trachyte formations, the fractures formed more easily (Fig. 4c). In addition, the trachytic magma was viscous, and flowed with difficulty. The trachytic was usually thick in a vertical direction, and the surrounding rock only minimally eroded and changed it, which was propitious to the conservation of the reservoir spaces. In contrast, the basalt magma flowed, and often formed into sills, where the surrounding rock eroded it, and secondary changes occurred.

4.2 Relationship between the facies and pore distribution

The compound flow subfacies of the effusive lava flow facies were favorable facies belts of the igneous reservoirs [35]. However, the pore distribution provided by the NMR logging was found to be mainly characterized by small pores. Also, the pore distribution characteristics of the electrical imaging logging showed that the large and small pores alternately existed (Figs. 6 and 8). The results indicated that the oil content of the reservoir was poor, and the oil test results also confirmed low productivity oil layers or dry layers. The volcanic clastic flow subfacies of the explosive facies (Fig. 3), with large pore development, good pore connectivity, and weak heterogeneity,
Pore Distribution Characteristics of the Igneous Reservoirs

Core depth: 3733.5 m, displacement pressure (MPa): 0.299, maximum pore throat radius (μm): 2.456, average pore throat radius (μm): 0.294; sorting coefficient: 0.455. Maximum mercury saturation (%) 40.23, efficiency of mercury withdrawal (%): 8.37.

Figure 7: Basalt capillary pressure curve and the core of the J31 well

Figure 8: Basalt pore distribution of the Ho28 well
along with good physical and oil reservoir properties, were the most favorable reservoirs.

The diatreme of the volcanic conduit facies featured fractures, dissolution pores, and tectonic fracture development (Fig. 9). The pore distribution provided by the NMR and electrical imaging logging showed that there were some large pores, and the large pores were found to be concentrated in bin PS10-PS13. The conventional logging curves with smoothed logging curves of DEN, CNL and AC indicated that the longitudinal heterogeneity was weak. The well log interpretation was that an oil-water reservoir existed, and this could potentially be used as an effective reservoir for future exploration and development (Fig. 10).

4.3 Relationship between the tectonic action and pore distribution

The Eastern sag of the Liaohe Depression experienced many tectonic movements. The faults were very developed, and the closer to the fault, the stronger the structure. A large number of fractures had been generated by the strong tectonic action, which promoted the activity of
Table 3: Controlling factors of igneous reservoir

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Lithology</th>
<th>Subfacies</th>
<th>Facies</th>
<th>Distance from fault</th>
<th>Oil testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ho26</td>
<td>basalt</td>
<td>compound flow</td>
<td>effusive lava flow</td>
<td>1.3 km</td>
<td>low-productivity</td>
</tr>
<tr>
<td>Ho22</td>
<td>basalt</td>
<td>compound flow</td>
<td>effusive lava flow</td>
<td>0.7 km</td>
<td>gas reservoir</td>
</tr>
<tr>
<td>Ho23</td>
<td>basalt</td>
<td>compound flow</td>
<td>effusive lava flow</td>
<td>0.3 km</td>
<td>oil-water</td>
</tr>
<tr>
<td>Ho23</td>
<td>basalt</td>
<td>compound flow</td>
<td>effusive lava flow</td>
<td>0.8 km</td>
<td>low-productivity reservoir</td>
</tr>
<tr>
<td>Jia31</td>
<td>basalt</td>
<td>compound flow</td>
<td>effusive lava flow</td>
<td>0.3 km</td>
<td>low-productivity reservoir</td>
</tr>
<tr>
<td>Y71</td>
<td>basalt</td>
<td>compound flow</td>
<td>effusive lava flow</td>
<td>3.5 km</td>
<td>dry reservoir</td>
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<tr>
<td>Ou48</td>
<td>trachyte</td>
<td>intermediate</td>
<td>extrusive dome</td>
<td>0.1 km</td>
<td>oil reservoir</td>
</tr>
<tr>
<td>Ou51</td>
<td>trachyte</td>
<td>outer - intermediate</td>
<td>extrusive dome</td>
<td>0.1 km</td>
<td>oil reservoir</td>
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<tr>
<td>Ou52</td>
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<td>extrusive dome</td>
<td>0.2 km</td>
<td>oil reservoir</td>
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<tr>
<td>X23</td>
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<td>extrusive dome</td>
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<td>X24</td>
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<td>intermediate</td>
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<td>intermediate</td>
<td>extrusive dome</td>
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<td>extrusive dome</td>
<td>1.5 km</td>
<td>dry reservoir</td>
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<td>Y70</td>
<td>trachyte</td>
<td>pyroclastic flow</td>
<td>explosive</td>
<td>0.2 km</td>
<td>oil reservoir</td>
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<tr>
<td>Ho25</td>
<td>trachyte</td>
<td>tabular flow</td>
<td>effusive lava flow</td>
<td>3.4 km</td>
<td>dry reservoir</td>
</tr>
</tbody>
</table>

the underground fluid. The fluid activity produced various types of dissolution pores, holes, and joints, which improved the connectivity between the pores, and optimized the pore structure of the reservoir.

As shown in Table 3, the oil productivity near the fractured wells was better than that of the wells away from the fault. From Fig. 1 it can be seen that the oil production wells were located in or near the fault, which indicated that the reservoir was the development of large pores. The Y70 well was closer to the fault than the Ho25 well. The pore distribution of the Y70 igneous rock formation was dominated by large pores and oil production. However, the Ho25 well with small pores was the main well, and the entire igneous rock section of the well was determined to be without oil and gas production. The J31 and Ho28 wells were located approximately 250 m from the Jiazhanshi Fault, which was further away than the Y70 well, and closer than the Ho25 well. The pore distribution of the igneous rock showed that different sized pores existed, and both igneous rock formations displayed oil production.

5 Conclusions

The binned T2-distribution directly reflected the effects that the different sizes of pores had on the total porosity. The porosity distribution by electric imaging provided the proportions of the different bins of the pores. The combination of both more effectively showed the distribution of the reservoirs’ pores, as well as the connectivity of the pores, and can potentially be effectively used to evaluate igneous reservoirs. In regard to the oil reservoirs, continuous large pores were in the majority, and there were almost no barriers of small pores observed. Also, the connectivity was found to be good. For the poorer reservoirs, both the large and small pores were alternated, and the connectivity was poor. In regard to the dry layers, there were only small pores present, and few or no large pores were observed, which led to a disconnectedness.

The characteristics of the pore distribution were obtained according to NMR and imaging logging, and can be applied to the interpretation and evaluation of other unconventional oil and gas reservoirs, such as igneous reservoirs. They can also be used for reservoir classification, pore structure evaluation and heterogeneity. In contrast, the oil and gas reservoirs are different due to different diagenesis and later transformation, and the classifications of the porosity bins are different as well. Therefore, it is necessary to focus on the analysis of the classification of porosity bins for different reservoirs.

The pore distributions were found to be influenced by lithology, tectonism and facies. The trachyte pore distributions were relatively concentrated, and the basalt pore distributions were determined to be rather highly dispersed. The large pores were more developed closer to the fault zone, which rendered these reservoirs more favorable to oil accumulations. In addition, diatreme subfacies, pyroclastic flow subfacies, large pore development, and good connectivity can all be used as indicators of favorable fa-
cies belts for the further exploration and development of igneous rock in the Eastern sag. Also, pyroclastic flow subfacies should be taken as major exploration targets in the examination of volcanic reservoirs.

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