Mechanism of Secondary Pore Formation and Prediction of Favorable Reservoir of Paleogene in Jiyang Sag, Eastern China

Zhu Xiaomin* (朱筱敏), Chen Huanqing (陈欢庆), Zhong Dakang (钟大康), Zhang Qin (张琴)
State Key Laboratory of Petroleum Resource and Prospecting, China University of Petroleum, Beijing 102249, China

Zhang Shanwen (张善文), Lü Xixue (吕希学)
Shengli Oilfield Company, SINOPEC, Dongying 257061, China

ABSTRACT: Jiyang (济阳) sag is an oil rich basin, consisting of Huimin (惠民), Dongying (东营), Zhanhua (沾化), and Chezhen (车镇) depressions. The clastic rock of Paleogene has undergone early and middle diagenetic stages and now the main clastic reservoir is in the middle diagenetic stage. Primary and secondary pores are developed in Paleogene sandstone, the latter is generated from the dissolution of feldspar and calcite cement in rocks owing to the organic acid from the matured source rock, but the materials dissolved are different in different depressions. The reservoir secondary pores of Dongying depression are generated from the dissolution of calcite cement, the ones of Zhanhua and Huimin depressions from the dissolution of feldspar, the secondary pores of Chezhen depression from the dissolution of feldspar in upper section, and the dissolution of calcite cement in the lower section of Paleogene, respectively. The secondary pores are developed in two depths and the depth goes down from west to east, from south to north in Jiyang sag. The major controlling factors for secondary pore development are maturity and location of source rock. Lastly, the favorable reservoirs are evaluated according to reservoir buried depth, sedimentation, and diagenesis. The reservoir with high quality is located in the northern and central parts in Dongying depression; there are some good reservoirs in Gudao (孤岛), Gudong (孤东), and Gunan (孤南) areas in Zhanhua depression, and the favorable reservoirs are located in the north steep slope and the south gentle slope of Chezhen depression and central uplift, south gentle slope of Huimin depression.

KEY WORDS: Jiyang sag, Paleogene, secondary pore, mechanism, prediction.

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*Corresponding author: xmzhu@cup.edu.cn

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GEOLOGICAL SETTING AND METHODOLOGY

Jiyang sag, which belongs to Bohai Bay basin, is an important province of oil and gas production, and is a typical faulted basin during Mesozoic and Cenozoic deposition. It lies in the southeast of Bohai Bay basin. To its east is Tancheng-Lujiang (Tanlu) rift zone, and to the south is Luxi uplift. The Chengning uplift lies in its northwest, and Huanghua sag lies in its north. The surface area of Jiyang sag is 29 000 km². The tectonic
trend of Jiyang sag is northeast and is dispersed in northeast, restrained in northwest. Jiyang sag consists of Dongying, Zhanhua, Huimin, Chezhen, and several other uplifts.

More than several billion tons of petroleum resources have been found in Jiyang sag since the 1960s, and fine seismic exploration across the sag and more than 6 000 exploration wells have been completed. Thus, Jiyang sag is a sedimentary basin with highly explored maturity in petroleum (Li et al., 2003). During the process of petroleum exploration, the predecessors carried out extensive research about the reservoir characteristics in Jiyang sag. Zhou and Lü (1987) and Lü (1985) not only pointed out that there developed secondary pores in Paleogene, but also raised their types and distinguishing symbols. In recent years, Zhu et al. (2007, 2006, 2004) and Zhong et al. (2004, 2003a, b) completed the synthesis study of reservoir pore types and diagenesis mechanism in Dongying and Huimin depressions and other depositions, and pointed out that the Paleogene sandstone reservoirs had different mechanisms of pore formation and different rock types for reservoir. Gravel sandstone, medium sandstone, and fine sandstone were fine reservoir rocks. Then, the development of the pore was determined, and the area and the horizon of beneficial reservoir were forecasted. In these depressions, reservoir rocks were formed in the depositions such as aluvial fan, fan delta, deep-water turbidite fan, slump turbidite fan of delta front, beach bar, delta sandstones in different areas and horizons, and the distributary channel and mouth bar sandstone reservoirs of delta front were the best ones. The good reservoirs were in fan delta sandstone, beach bar, and fluvial sandstones.

By surveying about 4 200 m core from 78 wells, more than 2 400 specimens of the reservoir were analyzed; the article synthetically analyzes the Paleogene reservoir pore types and pore development as well as distribution in different depressions in Jiyang sag, and evaluates and forecasts the beneficial reservoir distribution of different depositional sequences in different depressions.

### RESERVOIR PORE TYPE AND ITS EVOLUTION

#### Pore Type of the Paleogene Reservoir

By analyses of thin sections, SEM, and other experiments, the Paleogene reservoir pores in Jiyang sag could be divided into two groups, which are primary pore and secondary pore, respectively (Table 1 and Fig. 1).

#### Primary pore

The pore was formed when the rock was deposited. This kind of pore could be separated from the surplus compaction pores between grains and pores of

<table>
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<th>Table 1</th>
<th>Pore types of Paleogene reservoir in Jiyang Sag</th>
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<td>Pore type</td>
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<td>Cementation surplus pore between grains</td>
<td>Surplus pore between grains after cementation of primary pore between grains</td>
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<td>Matrix micro-pore</td>
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<tr>
<td>Dissolution pore between grains</td>
<td>Formed by the dissolution of matrix between grains and cement material</td>
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<tr>
<td>Dissolution pore in grains</td>
<td>Formed by partly corrosion inside grains</td>
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<tr>
<td>Casting pore</td>
<td>Formed by corrosion of the whole grains</td>
</tr>
<tr>
<td>Super-macrovoid pore</td>
<td>Formed by corrosion of the whole grains, cement material or matrix</td>
</tr>
</tbody>
</table>
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Figure 1. Microphotographs showing diagenetic characteristics and pore types of Paleogene sandstone of Jiyang sag. (a) The L-911 well, 3 202.9 m, grain point-line contact of arkose; (b) the L-985 well, 2 128 m, arkose cemented by calcite; (c) the Y-170 well, 3 808.8 m, filled by quartz overgrowth; (d) the C-111 well, 1 925.3 m, filled by vermicular kaolinite; (e) the SH-641 well, 2 467.4 m, secondary pore formed by feldspar dissolution; (f) the D-801 well, 2 316.5 m, secondary pore formed by feldspar dissolution; (g) the D-55 well, 2 999.7 m, secondary pore formed by calcite cement material dissolution; (h) the D-1105 well, 2 987.9 m, secondary pore formed by feldspar dissolution.

cementation surplus. The pores in Paleogene reservoirs are buried shallower than 1 500 m or the primary pores between grains that remained in the later period of cementation are formed by sediment compaction,
carbonate cementation, quartz overgrowth, clay mineral cementation (Fig. 1), and the micro-pore in matrix also belonged to this kind.

Secondary pore

The secondary pore was formed by all kinds of diagenesis, tectonism, dehydration, and other geology factors after sedimentation. In the secondary pores, intergranular dissolved pores, dissolved pores within grains, casting pores, and super-macrovoid pores hold the main position. Secondary pores of Paleogene reservoir in Jiyang sag were mainly formed by the dissolution of feldspar grains and carbonate cement, and they mainly developed in the depth of 1 500–3 500 m; however the depth of secondary pores and dissolved material are different in different depressions (Figs. 1, 2).

Reservoir Pore Evolution

By the research of thin sections, SEM, cathodoluminescence, materiality, content of carbonate and several other data, it is believed that the pore evolution of Paleogene reservoir in Jiyang sag experienced the process from primary to secondary ones. The process from primary to secondary pores is different in different depressions of Jiyang sag. There are mainly primary pores in the depth shallower than 1 650 m in Dongying depression. The primary pores in Zhanhua and Chezhen depressions are mainly distributed in the depth shallower than 1 900 m, mainly distributed in the depth shallower than 1 400 m in Huimin depression, and the depth is shallower than the former three depressions. Obviously, from west to east, and from south to north, the depths of primary pores are buried in more and more deep strata (Fig. 2).

MECHANISM OF SECONDARY PORE FORMATION

Owing to the difference of the ancient diagenetic field, ancient geothermal gradient, water-rock reaction, and buried history in different structural units, there are different mechanisms of formation and development of secondary pores (Dutton, 2008; Ehrenberg and Nadeau, 2008; Birkle et al., 2003; Franca et al., 2003; Baedecker et al., 1993; Barth and Bjorlykke, 1993; Surdam et al., 1989; Pittman, 1979). The secondary pore formation of the Paleogene sandstones in Jiyang sag is also controlled by the diagenesis of buried history of the basin. Secondary pores of Paleogene reservoir in Huimin depression, which located in the western part of Jiyang sag, are mainly developed in the depth of 1 500–2 400 m. To the Dongying depression in the eastern part of Jiyang sag, these are mainly developed in the depth of 1 650–2 450 m, and to the Zhanhua depression, these are developed in the depth of 2 300–3 500 m. The depth of secondary pores in Chezhen depression is in the range of 2 200–2 700 m, and the different distribution characteristics of the secondary pores are formed by the different migrations of the deposition and subsidence centers, and different buried histories (Fig. 2).

Formation Mechanism and Distribution of Secondary Pores in Dongying Depression

Secondary pores of Paleogene reservoir in Dongying depression are developed, and their formation is firmly related with the dissolution of the carbonate, feldspar, and lithoclast grains. By the thin-section analysis, most secondary pores are formed by the dissolution of the carbonate cement. The dissolved carbonate is calcite that formed in the early stage of diagenesis, and Fe-calcite and Fe-dolomite that formed in the later period of diagenesis. The numerical value of porosity and permeability has a good mirror image relationship with the carbonate content. High porosity and permeability in the reservoirs are exactly corresponding with the one of lower carbonate content (Fig. 2a). The higher the carbonate content, the poorer the reservoir quality. On the contrary, the lower the carbonate content, the better the reservoir quality. Especially when the carbonate content is lower than 15%, the values of porosity and permeability are increasing obviously. For example, in the north steep belt of Dongying depression, there are considerable secondary pores developed in the depth of 1 650–2 500 m, and the carbonate content is very low (Zhong et al., 2003a, b).

Some secondary pores of Paleogene reservoir are formed by the dissolution of feldspar (plagioclase and potash feldspar), pyroclast, and matrix. This kind of
secondary pore is mainly one dissolved inside of grains, casting pore, and super-large pore. This can be indirectly proved by the law of the kaolinite content change in depth. Kaolinite content is abnormally high in the depth of 1 600–2 500 m where secondary pores developed. Kaolinite content can reach up to 70%–90% in the depth of about 2 000 m, however, this content falls obviously to about an average of 30%. These prove that there is enough feldspar dissolved in the depth of 1 600–2 500 m, and that the dissolved feldspar is changed into authigenic kaolinite.

Secondary pores of Paleogene sandstone reservoir in Dongying depression mainly developed in the depth of 1 650–2 450 m in the north steep belt. There probably exists another secondary pore development belt in the depth of about 2 800–3 500 m. Secondary pores in the central uplift belt are distributed in the depth under 1 650 m, and are especially developed in the depth of 1 850–2 500 m. Secondary pores in the south gentle slope belt are mainly developed in the depth of 1 900–2 600 m. It is indicated that the development depth of secondary pores of Paleogene reservoirs has a trend of increasing in Dongying depression from north to south, but the depth extent of development is clearly weakened. Secondary pores in south gentle slope belt are developed poorer than the north steep belt and the central uplift belt (Fig. 2a).

**Formation Mechanism and Distribution of Secondary Pores in Zhanhua Depression**

The formation of secondary pores in Paleogene reservoir in Zhanhua depression is mainly related with the feldspar dissolved, and considerable feldspar dissolution can be found from the depth of 2 000 to 3 500 m (Fig. 2b). At the same depth, quartz is overgrowth, kaolinite is precipitation, but the dissolution of carbonate cement material is little. For example, in the depth of 2 467 m of the Sh-641 well and 2 316 m of the D-801 well, the dissolution of feldspar is very se-
rious when the dolomite cement filled between grains keeps good crystal form in the same one specimen, which indicates few dissolution effects to dolomite (Fig. 1).

The depth of secondary pores in Zhanhua depression is a bit deep basically at the depth of 2 300–3 500 m. The curve of porosity to depth begins to deviate from normal tendency with depth close to 2 000 m (Fig. 2b), and this continues to the depth of about 3 500 m. Secondary pores are developed in different areas and depths in this depression. The Paleogene pores can reach up to 30% in the depth of 3 000 m in Bonan area. At Chengdao, Laohekou, Gudong, and Zhuangxi areas, secondary pores are basically distributed in the depth of 2 300–3 500 m, but these are not clearer than Bonan area. Especially at Zhuangxi area, the reservoir quality is poorer than Bonan area. For example, at Chengdao, Laohekou, and Gudong areas, the average of sandstone porosity is up to 20%, but only 17% at the depth of 3 000 m in Zhuangxi area (Fig. 2b).

**Formation Mechanism and Distribution of Secondary Pores in Chezhen Depression**

The first member of secondary pore development in Paleogene reservoir in Chezhen depression is mainly formed by feldspar dissolution, and the carbonate dissolution is weak, such as in the C-16 well, the feldspar is dissolved following the cleavage in the depth of 2 060 m, and at the same depth, authigenic kaolinite with low crystallinity is precipitated. Quartz overgrowth is relatively weak, and only partly dissolution phenomenon of calcite cement appears. The second member of secondary pore development is mainly formed by feldspar and carbonate dissolution. Feldspar is continually dissolved at the former dissolved feldspar and shows honeycomb structure after dissolution (Fig. 1). The dissolution of calcite cement is more clearly increasing than the first member of secondary pore development. Calcite crystal is basically incomplete. The distribution of kaolinite also illustrates the obvious dissolution of the feldspar. Authigenic kaolinite concentrates mainly in the depth of 2 200–3 300 m, and the depth of secondary pore formed by feldspar dissolution is identical with this depth.

Secondary pores in Chezhen depression are mainly developed in the second member. At Dawangzhuang and Dawangbei areas that lie in the east of Chezhen depression, the first member of secondary pore development lies in the depth of 2 100–2 700 m, and the second deeper than 3 000 m. Secondary pores are developed at the depths of 2 000–2 600 m and 3 000–3 700 m in the west of Chezhen depression (Fig. 2c).

**Formation Mechanism and Distribution of Secondary Pores in Huimin Depression**

Secondary pore of Paleogene reservoir in Huimin depression is mainly related with the feldspar dissolution. Secondary pores formed by the carbonate cement dissolution are less important, which is different from secondary pore formation mechanism in the Dongying depression (Fig. 2a). There are three kinds of evidence to prove this standpoint: firstly, honeycomb structure of feldspar dissolution can be clearly seen with the microscope, and quartz overgrowth and authigenic kaolinite precipitation appear at the same depth, and carbonate cement is basically not dissolved (Fig. 1). In the first member of secondary pore development, because of unclear feldspar dissolution, quartz overgrowth is weak, and crystallinity of the authigenic kaolinite is low, for example, the sandstone dissolution in the fourth member of Shahejie Formation at the depth of 1 800–2 450 m of the P-45 well. With the depth increasing, the dissolution level of feldspar increases, and the level of quartz overgrowth and crystallinity of authigenic kaolinite also increase. Sometimes, small crystals of quartz can appear between grains. The characteristic reservoir dissolutions at the depth of 2 000–2 500 m of the Sh-641, T-11-5 wells, and the depth about 3 000 m of the X-326 well are all good examples. Secondly, peak content of kaolinite formed by the feldspar dissolution can be found in the depth, which is completely corresponding with the depth of the secondary pore development. These can also prove the firm relationship between the two secondary pore members and the feldspar dissolution in Huimin depression (Zhu et al., 2004). Thirdly, in the secondary pore development member, clearly corresponding low carbonate content does not exist. These also indirectly prove that the carbonate dissolution had
little contribution to the formation of secondary pores. There are two secondary pore members in Huimin depression: the first is in the depth of 1,400–2,500 m, the average porosity of the reservoir is up to 30%, and the beginning depth shallower than the depth in Dongying depression; the second is in the depth of 2,700–4,000 m, the porosity is up to 25% (3,500 m), and the average porosity is about 14%. The change trend of secondary pore development in north and central parts is identical. At the depth shallower than 3,500 m, the reservoir quality in north part is better than that in central part, however, when the depth is more than 3,500 m, the reservoir quality in north part is poorer than that in the central part (Fig. 2).

Totally, the secondary pore formation of Paleogene sandstone in Jiyang sag is mainly related with the dissolution of organic acid from the source rock matured. The lower the free energy of chemical reaction, the more easily the mineral dissolved by organic acid. The free energy of the feldspar is lower than that of the calcite, and therefore, the organic acid dissolves feldspar considerably easier than calcite. Anorthite is firstly dissolved in plagioclase because the free energy of the anorthite is lower \(\triangle G = -154.49\) kJ/mol. The following dissolution of organic acid is potash feldspar \(\triangle G = -17.92\) kJ/mol) and carbonate cement \(\triangle G = 46.89\) kJ/mol). Therefore, the feldspar dissolution is the major one of Paleogene sandstone in Jiyang sag; carbonate dissolution is only relatively strong in Dongying depression (Fig. 2).

There is a difference of secondary pore occurrence in vertical and plane because of the difference of strata buried history, ancient geothermal gradient, and tectonic development in different depressions of Paleogene in Jiyang sag (Fig. 2).

**FACTORS CONTROLLING SECONDARY PORE DEVELOPMENT AND PREDICTION OF BENEFICIAL RESERVOIRS**

Secondary pore development of Paleogene sandstone in Jiyang sag is often controlled by various factors, such as sedimentary environment (component, grain size, granularity, sorting, psphicicity, matrix content between grains) and a series of compaction, cementation, dissolution, and metasomatism that are experienced in the process of rock buried. Reservoir quality is also influenced by other factors, such as diagenesis stages, paleotemperature and pressure, hydrocarbon migration, the location of depositional center, fracture, fault, composed texture of sandstone and mudstone, unconformity, etc. (Zhu et al., 2007, 2006, 2004). It is demonstrated that secondary pore development of Paleogene sandstone in Jiyang sag is mainly influenced by source rock maturity and acid water movement fashion.

**Vertical Distribution of Secondary Pore Controlled by Source Rock Mature Time**

Depositional centers of Paleogene are continuously migrated from west to east in Jiyang sag. During the deposition period of Kongdian Formation and the fourth member of Shahejie Formation in the Lower Paleogene, the depositional center lies in Xinyang sub-depression in the west of Huimin depression, it moves to Dongying depression during the third to the second members of Shahejie Formation. From the deposition period of the first member of Shahejie Formation to Dongying Formation in the Upper Paleogene, it moved to Zhanhua depression, and lastly, to Chezhen depression during Guantao and Minghuazhen formations in Neocene. These migration processes controlled the source rock mature time and acid fluid removed time in which it was the earliest in Huimin depression, and it moves to Dongying depression during the third to the second members of Shahejie Formation. From the deposition period of the first member of Shahejie Formation to Dongying Formation in the Upper Paleogene, it moved to Zhanhua depression, and lastly, to Chezhen depression during Guantao and Minghuazhen formations in Neocene. These migration processes controlled the source rock mature time and acid fluid removed time in which it was the earliest in Huimin depression and the latest in Zhanhua and Chezhen depressions. As a result, the formation time of secondary pores is the earliest and the depth of secondary pores is the shallowest (1,400–1,500 m) in Huimin depression. Following this is Dongying depression and the secondary pore formed in the depth of 1,950 m. The development depth of secondary pores of Paleogene in Zhanhua and Chezhen depressions is the deepest of 2,200–2,300 m because of the late source rock maturity (Fig. 2).

**Plane Distribution of Secondary Pore Controlled by Acid Headwater Plane Position**

In Huimin depression of Jiyang sag, generative source center lies in south Linnan sub-depression, therefore, secondary pores developed better in south close to Linnan sub-depression than in the north steep slope belt. In Dongying depression, generative source center lies in north Lijin sub-depression, and secon-
dary pores developed better in Lijin, Binnan, and Shengtuo areas of the north steep slope belt than in the south gentle slope belt (Fig. 2b), which formed bright contrast with the Huimin depression. There are similar laws in Zhanhua and Chezhen depressions. Secondary pores generally develop poorly in sandstone, which is far away from the generative source center because of the lack of the acid water action.

Forecast of Beneficial Reservoir Area

Forecast and evaluation of beneficial reservoirs are not only the final aim of reservoir research, but also the main basis of oil and gas exploration. Correct evaluation of reservoir is very important to oil and gas exploration. Evaluation and forecast of Paleogene reservoir in Jiyang sag is mainly based on the studies of the reservoir diagenesis stages, pore evolution, characteristics of pore structure, sandstone type, and natural capacity of container rock (Table 2).

According to the standard of comprehensive evaluation (Table 2), Paleogene reservoir quality of different strata is different in different areas of Jiyang sag. There develop large areas of good to fairly good reservoirs in the middle part of the third member to the first member of Shahejie Formation, Paleogene in Dongying depression (Fig. 3). The reservoir under the third member of Shahejie Formation is fairly inferior. Some favorable sandstone reservoirs develop in Dongying Formation, but beneficial reservoirs in Dongying Formation mainly develop in south gentle slope belt of Bamiyanhe oil field, north steep slope belt of Shengtuo, Binnan, Dongxin, and Yong’anzhen oil fields, part strata of west Gaoqing oil field. The reservoir quality of Dongying Formation in central basin belt is fairly inferior.

Reservoir of Shahejie Formation in Zhanhua depression is developed with large area. The sandstone reservoir quality of the upper part of third member to the lower part of the second member of Shahejie Formation is the best (Fig. 3). Fairly good and medium reservoir excessively develops in the north steep slope belt in Zhanhua depression. Large area of good reservoir occurs in the edge of Gudao uplift and Gudong area. Small area of fairly good reservoir distributes in the south gentle slope belt. The turbidite sandstone in central basin is inferior reservoir.

The areas of sandstone reservoir of Shahejie Formation and Dongying Formation in Chezhen depression are considerably smaller than those in Zhanhua depression. The upper part of the third member of

<table>
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<th>Grade index</th>
<th>Excellent reservoir</th>
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<td>diagenetic facies</td>
<td></td>
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<tr>
<td>Types of pore structure</td>
<td>Big pore with fairly thick throat and big pore with middle-thin throat</td>
<td>Middle pore with fairly thick throat</td>
<td>Middle small pore with thin throat and small pore with extremely thin throat</td>
</tr>
<tr>
<td>Belt of lithologic facies</td>
<td>Alternating beds of argillaceous sandstone facies</td>
<td>Alternating beds of argillaceous sandstone to arenaceous mudstone facies</td>
<td>Alternating beds of arenaceous mudstone to mudstone facies</td>
</tr>
<tr>
<td>Sandstone type</td>
<td>Lower normal cyclothem sandstone of fan delta subaqueous distributary channel and middle-thin sandstone of main part of mouth bar</td>
<td>Higher normal cyclothem sandstone of fan delta subaqueous distributary channel, and siltstone, silt fine sand of main part and the side edge of marginal mouth bar and delta front strome and middle fan braided stream arenaceous conglomerate of turbidity fan</td>
<td>On the top of the mouth bar, mainly argillaceous siltstone deposition of turbidity fan braided interfluve, argillaceous siltstone deposition of delta front subaqueous distributary interfluve, natural levee, distal bar and mainly argillaceous sandstone and calcareous sandstone deposition of external fan inferior facies of turbidity fan</td>
</tr>
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</table>

Table 2  Comprehensive evaluation of Paleogene reservoir in Jiyang sag
Shahejie Formation to the lower part of the second member of Shahejie Formation is the best reservoir in quality (Fig. 3). The reservoir of the second member of Dongying Formation is fairly good. The reservoir quality of the middle part of the third member in Shahejie Formation is relatively poor. The sandstone with large area of subaqueous fan and fan delta is fairly good and medium reservoir in north steep slope belt in Chezhen depression. The delta sandstone with small area in Dawangzhuang and Guojuzi is good reservoir. Delta and fan delta sandstone reservoir quality is fairly good. Turbidite fan and beach bar reservoir developed in central basin is poor.

Large area of relatively good and fairly good reservoir develops in the third member of Shahejie Formation and the lower part of the second member of Shahejie Formation in Huimin depression (Fig. 3). Reservoir quality of the second member and the first member of Shahejie Formation is fairly inferior. The figures of reservoir porosity and permeability are generally high in Linpen oilfield of central uplift belt and Xiakou faulted belt of south gentle slope belt in Huimin depression. The average porosity is around 23%-27% and the average permeability is above $450 \times 10^{-3} \mu m^2$. The reservoirs in Linpen and Xiakou areas are overlapped in vertical. In addition, the part strata of the west part in north steep slope in Xinyang sub-depression are fairly good reservoir, however, figures of porosity and permeability in central sub-depression are generally low and reservoir quality is poor.

**CONCLUSIONS**

1. Generative types of reservoir in different depressions of Jiyang sag are mainly fluvial, fan delta, delta, beach bar, subaqueous fan, and others, and the reservoir with best quality is from the subaqueous distributary channel and distributary mouth bar of fan delta or delta front.

2. Sandstone reservoir of Paleogene in Jiyang sag experienced the diagenes is process of early and middle diagenetic stages. At present, most reservoir is at the A stage of middle diagenetic stage. Primary and secondary pores developed in sandstone reservoir. The latter mainly developed at the depth of 1 500–3 500 m. Secondary pores of sandstone were mainly formed by that the feldspar grains and carbonate cement were dissolved by the organic acids from matured source rock, but in the different depressions, both the depth of secondary pore development and the object of dissolution are different.

3. There are two members in depth for secondary pore development of Paleogene reservoir in Jiyang sag. The depth range for secondary pore development deepens from west to east, from south to north; the position of the secondary pore development is
controlled by generative source region. Secondary pores in sandstone are developed close to the generative source center.

(4) The forecast of beneficial reservoir has been made by good reservoir developed in north steep slope belt and center uplift belt in Dongying depression. The reservoir quality is fairly good in the upper part of the third member of Shahejie Formation to the third member of Dongying Formation in Gudao, Gudong, and Gunan regions in Zhanhua depression. Fine reservoir is also developed in the upper part of the third member of Shahejie Formation to the first member of Shahejie Formation in the north steep slope belt, and south gentle slope belt in Chezhen depression. Fairly good reservoir is developed in the lower part of the third member to the lower part of the second member of Shahejie Formation in the central uplift belt and the Xiakou faulted belt in Huimin depression.

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