International Journal of Petroleum Science and Technology
ISSN 0973-6328 Volume 11, Number 2 (2017), pp. 65-77

http://www.ripublication.com

Fault-Block Mountain Oil Reservoirs and Reservoir Heterogeneity of Tongbomiao Formation in Tanan SAG

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Abstract:
The oil productivity of each developed block in Tanan Oilfield varies to a great deal and moreover is seriously influenced by the reservoir heterogeneity. Taking the palaeo-fault-block mountain oil reservoirs in Tongbomiao Formation of Tanan Sag as the cut-in point, with the help of the well-seismic assemblage, core observation and cast thin section analysis, on the basis of the division of the reservoir type, the reservoir reforming model and heterogeneity were researched, thus the adjustments of the developing program were guided. The achievements show that according to the fault scale and formation dip, the oil reservoirs can be classified into two types: deep-fault high-dip type and shallow-fault low-dip type; for different kinds of the fault-block oil reservoir, two types of the reservoir reforming models can be classified: high-angle two-lateral reforming type and slope leaching type; the inner-layer heterogeneity of the reservoir is controlled by the original sedimentary conditions, inter-layer heterogeneity of the reservoir is dominated by the unconformity, the planar heterogeneity of the reservoir is controlled by the structural location and fractures. The development of the former type of the reservoir takes the progressive out-stepping of the fault slope as the adjusting method, while the development of the latter regards the partial infilling in the structural high area as the adjusting measure.

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Keywords: Tanan Sag; Tongbomiao/Tsagaantsav Formation; block/fault-block mountain oil reservoir; heterogeneity

INTRODUCTION

For Hailar-Tamtsag Basin(Haita Basin), through many years of the exploration, it has entered into the fine development stage up to now, the tests of the exploratory oil and production of the developing wells showed that for two arranged well location, even with the similar structural characteristics, their productivities are various to a great deal, and moreover so are the distributions of the oil and water for the petroleum reservoir, these properties prove that the reservoirs possess much strong heterogeneity. Many scholars have researched the heterogeneity of the sandstone reservoir and provided several classifying programs[1-5], and furthermore the characterized achievements of the reservoir heterogeneous property often refer to the original sedimentary conditions and later diagenesis of the reservoir. The original physical properties of the reservoir in Tamtsag Basin are rather poor, the reservoir spaces are mostly the fractures and secondary dissolved pores resulted from the later tectonic actions and weathering and leaching[6-10], therefore to establish and develop the unique characterizing method for this kind of the oil reservoir is very necessary. The reservoirs in Tanan Sag of Tamtsag Basin are mainly Nantun and Tongbomiao Formations, generally taking the latter as the study object, the heterogeneity of the pyroclastic rock reservoir was explored in the paper. With the help of the combined method between the fault scale and formation dip, the block-mountain type oil reservoirs can be divided into two kinds, at the same time, two different reconstructing models were initially established for the two kinds of block mountain stated above, and furthermore the controlling factors and developed positions were made clear for the high-quality reservoirs in different reconstructing models. In a word, much better effects were obtained for both the progressive out-stepping wells and partial-infilling wells in the typical blocks, thus the theoretical evidences were provided for the development adjustment of the other developing blocks in Tamtsag Oilfield.

1 Brief introduction to the region geology

Hailar-Tamtsag Basin belongs to the splice between Argun Block (West) of West Siberia Plate and Mongolian-Daxing'anling Fold Belt (East). Tanan Sag is located in the southwestern end of the Central Fault Depression Belt of the basin, is the important secondary structural unit in the basin, is the typical multiple sag with the

eastern faults and western wide-flat overlap, and is characterized by EW belting and SN zoning. In detail, it can be divided into West Slope, West Subsag, West Buried-hill Faulted Belt, Central Subsag, Central Faulted Buried-hill Belt, East Subsag and East Faulted Nose from west to east. The structural evolution of Tanan Sag has experienced the following stages: fault depression, fault sag and depression, and moreover the matrix, Cretaceous and Paleogene and Neogene formations are well developed from top to bottom. Lower Cretaceous Series (In detail, they are further divided into Tongbomiao, Nantun, Dameguaihe and Yimin Formations from top to bottom.) are mainly well-developed in Tanan Sag. Specifically Tongbomiao Formation is the sedimentary infilling of the initial fault-sag subsidence activities, the contact relationships of the formations are unconformities for the top and bottom surfaces. Due to the influences of the activities of the NEE sag-controlling faults, the differential subsidences among the faults are rather obvious, thus a great number of the palaeo-fault-mountain structures are formed. With the large-area volcanic eruption, the sedimentary types are the shallow basin and proximal fan delta taking the pyroclastic rocks as the principal form. Tongbomiao Formation is the general reservoir and oil-bearing series of the strata.

2 Characteristics of the original formations

2.1 Sedimentary characteristics

Tongbomiao Formation is the early sediments of the fault depression lake basin. In the background of the shallow faults and multiple sags, the whole sag takes the fan delta sedimentation as the main form, the lacustrine sedimentation is developed partially. The multi-analyses of the seismic and well-logging phases and core observation show that Tongbomiao fan delta is the most of the near-mountain one with the end of the alluvial fan directly entering the lake [11-14]. The data points in Fig. C-M are parallel to Base-line C=M, this condition reflects that the fan bodies are mainly characterized by the gravity flow sedimentation (Fig.1). The grain sizes of the sediments are rather coarse, they are generally the glutenite and gravel-bearing sandstone with the block-like bedding and graded bedding (Fig.2). The single-period observed sandstone thickness in the coring well is generally 15-20cm, due to the overlaid appearance of the multiple-period sandstone, 5-10m sedimentary complex is developed and characterized by hachsaw box-like curves on the well logging.

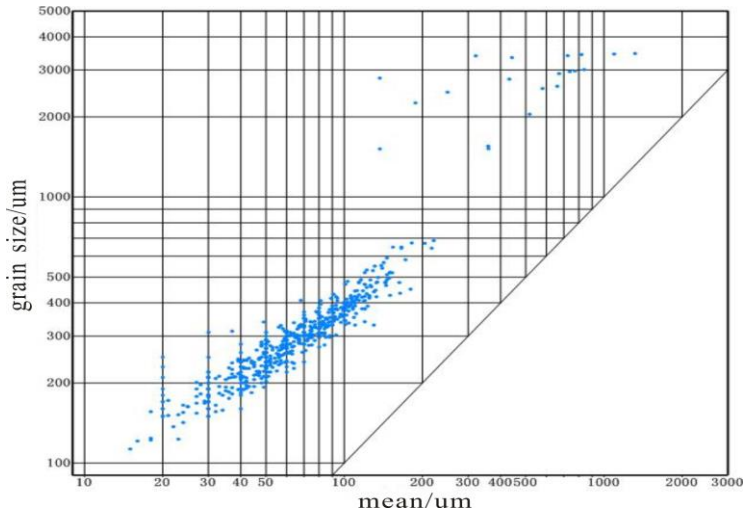


Figure.1: C-M diagram of Tsagaantsav Formation in Tanan Sag

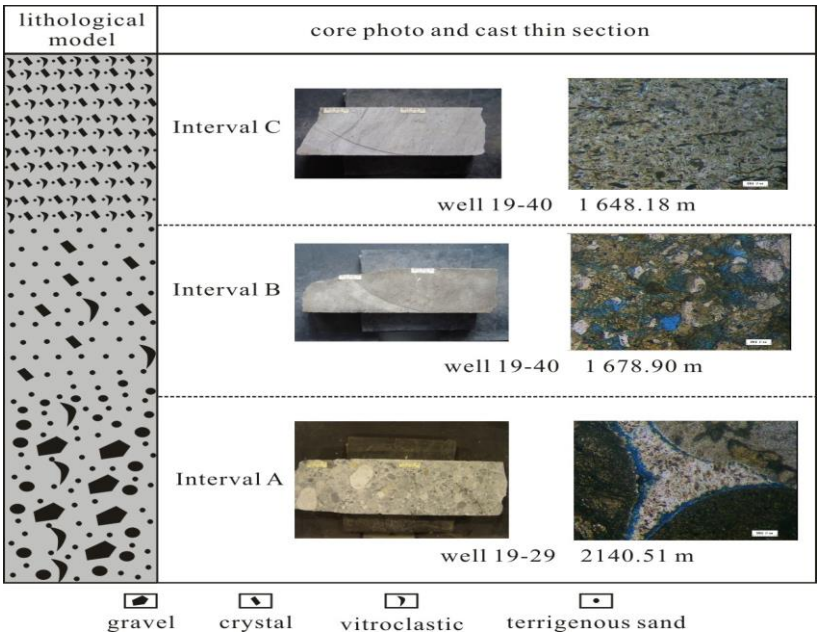


Figure.2: Petrological characteristics of Tsagaantsav Formation in Tanan Sag

2.2 Properties of the petrology

Tongbomiao-Formation reservoirs belong to the transformational type from the pyroclastic rocks to sedimentary rocks (Fig.2), mainly include tuffaceous

conglomerate, tuffaceous sandstone and bedded tuff [15-17]. In detail, the contents of the terrigenous clastics are principally the feldspar and debris, the pyroclastics are mainly crystal and vitroclastics. The crystals are generally classified into anorthose, alkali feldspar, quartz and so on, which are taking angular form. The vitroclastics are plastic ones with the irregular, granular, flame shapes and so forth. Under the condition of the single-period gravity flow, influenced by the sedimentary hydrodynamism, three lithological intervals(A, B,C) form from bottom to top. Interval A is vertically and mostly composed of tuffaceous glutinite with poor gravel psephicity and slight graded bedding, and moreover the sandy and muddy sediments are infilled among the gravels, the cast thin section is tightly cemented and the original pores are not well developed; Interval B is the one of the tuffaceous sandstone, the oil occurrences are often shown in the cores and furthermore the block bedding and particle sorting are obviously better than those of Interval A, the solution pores and intragranular dissolved pores can be found, but the connectivity among the pores is rather poorer; for Interval C, because of the weak hydrodynamics, the bedded tuff interval occurs. Due to the high-content volcanic materials without any oil, the cores occur gray white and with tight block shape, even with few pores by the thin section observation. The continuous coring and cutting logging show that the strong reservoir heterogeneity is displayed within the single-period sandbodies. The oil and gas occurrences are often shown in Interval A and B, for Interval C, there is a little oil.

3 Genesis, identification and classification of the fault-block mountain

After the sedimentation of Tongbomiao Formation, Tamtsag Basin undergoes serious structural deformation[18]. Tongbomiao-Formation horizons deposited in the early period of the fault depression were cut into many paleo-fault-block structures by a set of mainly NE well-developed faults. The dips of the most fault-block-mountain structural faults are opposite to the ones of the horizons, thus the reverse fault block or reverse fault step structural pattern was formed. The fault-block-mountain structures can be clearly recognized on the NW-SE seismic profiles by means of the seismic phase combination（Fig.3）. The disorder reflections are mostly leaped by the faults in Tongbomiao Formation, and moreover Tongbomiao-Formation horizons are overlaid by Nantun Formation in the form of the sheet parallel or sub-parallel to the seismic phase horizons.

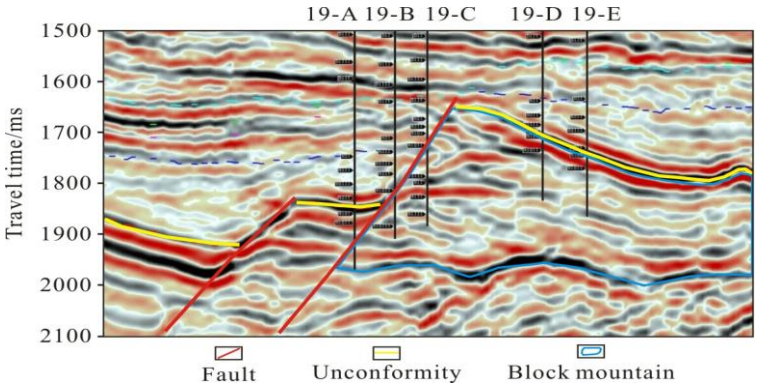


Figure.3: Seismic reflections of the block-mountains in Tsagaantsav Formation of Tanan Sag

According to the fault throws and stratigraphic dips, the paleo-fault-block mountains in Tanan Sag can be divided into two types: deep-fault high-dip one and shallow-fault low-dip one. For the first type, the much bigger normal fault throws of the main faults controlling the fault- block-mountain oil reservoirs result in the rather steep top or bottom surfaces of the reservoirs; for the latter, there are smaller normal fault throws generally controlling the fault-block-mountain oil reservoirs, the top or bottom surfaces of the reservoirs decline, but the decline angles are pretty small. Constrained by the geological conditions for different types of the fault block mountain, two kinds of typical accumulating patterns are established: high-angle two-side reconstructing pattern and slope leaching pattern (Fig.4）. For a fault block oil reservoir, one side of the fault is named the fault slope, one side of the oblique connection between the top surface of the block reservoir and the fault is defined as the slope, with the changes of the fault and formation, the reservoirs of the fault block mountain structure develop into different constructing patterns. When the fault throws and stratigraphic dips are rather bigger, the first pattern becomes the main form, two types of the accumulating types are developed i.e. fractures and solution pore-holes along the one side of the fault slope, but the secondary type is only developed along the one side of the slope; when the fault throws are pretty smaller and the dips are rather flat, the secondary pattern is formed. The fracture and solution actions are not well developed along the one side of the fault slope, the leaching action is principally taken place on the slope. The properties and performances of the two kinds of the leaching pattern are greatly various in the slope reservoir. Controlled by the structural activities, when the fault throws are rather big, the formations on the two walls of the former fault deform, the stratigraphic dip offset is prone to result in the micro-fractures, because of the steep

formation, the vertical construction of the atmosphere leaching water is mainly taken place in the high position of the structures, while in the low position, the gravity controlled atmosphere water generally flow downward along the earth surface, so the constructing action on the reservoirs is rather weak; the dip of the latter is pretty small, the vertical constructions of the atmosphere water possess in the high and low positions of the structure. Therefore the secondary pores and holes of the former are principally located in the high position of the structure, while the secondly constructed area of the latter is greatly wide.

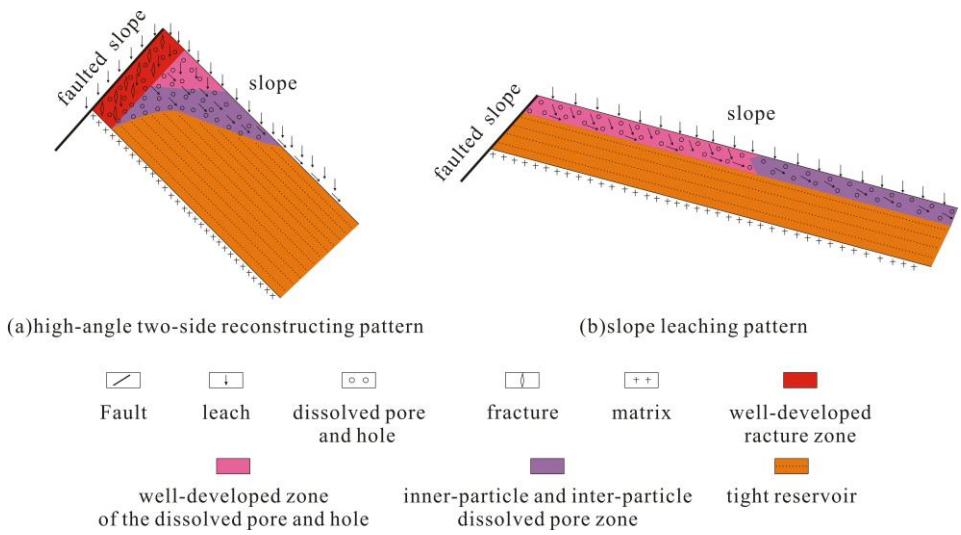


Figure 4: Reconstructed patterns of Tongbomiao/Tsagaantsav Formation in Tanan Sag

4 Characteristics of the reservoir heterogeneity

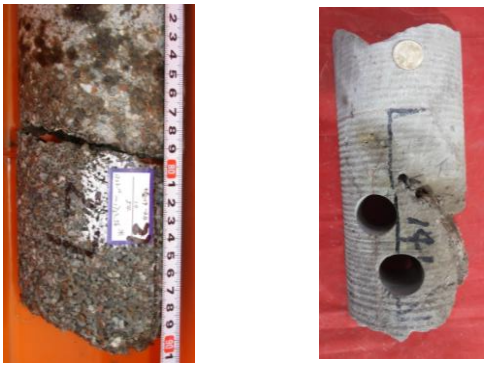
4.1 Inner-layer heterogeneity

With the help of the core observation and cast thin section analysis, the accumulating space types are further divided into solution pore and hole, intergranular and intragranular solution pores in the feldspar. Because the secondary construction of the reservoir is often controlled by the original sedimentary conditions, when the tuffaceous conglomerate interval (Interval A) sedimentating, the hydrodynamic power is the strongest and the big solution holes and cavities are frequently observed on the cores. In the period of the tuffaceous sandstone interval (Interval B) sedimentation, the hydrodynamic power is weaker than that of Interval A, so the holes and cavities

are seldom seen by the naked eyes on the cores, but the intergranular and intragranular solution pores in the feldspar can be found on the cast thin section. The bedded tuff interval (Interval C) mostly refers to the underwater sedimentation of the pyroclast and volcanic ash, the hydrodynamic power is the weakest, the deposition grain size is rather fine, the original pores are not well developed, so are the secondary pores. In a word, the heterogeneity characteristics of the normal rhythm reservoir are completely responded under the single hydrodynamic conditions.

4.2 Inter-layer heterogeneity

After deformed at the late stage of Tongbomiao Formation sedimentation, the fault slope and slope of the fault block mountain were appeared to the earth surface for quite a long time, thanks to the long-time weathering and leaching actions, the accumulating property of the rocks is greatly improved[19-21]. In the position of 0-20m below the unconformity, the porosity is pretty higher, while the porosity drops gradually toward the deep part, the sandstone and mud stone among the gravels are often flushed away and the secondary sieve-like structures of the gravels are formed（Fig.5）, the abnormal high-pore belts beneath the unconformity are the favorable accumulating space for the oil and gas. With the rise of the depth, the secondary construction of the reservoir is gradually weak, the solution pores and cavities seen by the naked eyes are turned into the intergranular and intragranular solution pores in the feldspar in the size of the cast thin section. So the unconformity is the main controlling factor to the inter-layer heterogeneity of the reservoirs.



(a) Dissolved pores and holes (b) Reservoir fracture

Figure.5: Reconstructed reservoir of Tongbomiao/Tsagaantsav Formation in Tanan Sag (Well 19-40)

4.3 Planar heterogeneity

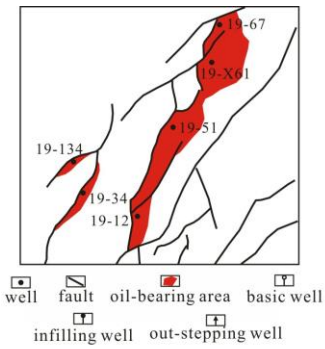
The reservoir sandbodies in the fault block mountain structures of Tanan Sag are well developed, but the original physical conditions are rather poor, so the planar heterogeneity of the reservoirs is controlled by the secondary construction of the reservoirs. The fine analysis on the developed blocks in the study area was conducted, the high-quality reservoirs in the block mountain are principally distributed in the high position of the mountain. During the sedimentation of Tongbomiao Formation, the basin was dominated by the severe extension, after the deposition of Tongbomiao Formation, the strong structural reversion happened in Tanan Sag, the many reverse fault blocks were formed by the even uplifts. When whole uplift of Tanan Sag, the fault block mountains appeared to the surface, thanks to the long-time weathering and leaching of the atmosphere water for the reservoirs in the high position of the structures, they were well improved. But the water stores in the low part of the structures, the reservoir reconstruction was rather weak.

4.4 Controlling action of the fault on the reservoir heterogeneity

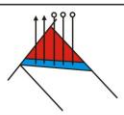
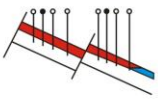
The structural activities can provide the dynamic mechanism for the formation and evolution of the basin, and then result in the formations of the fracture and structural crack, and moreover the physical properties and original pores of the reservoirs are changed as well. Tanan Sag experiences multiple periods of the structural activities, and the complex geological structures overlaid by the multi-type and multi-period/time faults are developed. Along with the formation of the multi-period/time faults, the multi-period/time fractures are developed in the horizons[22-23]. The coring wells in the block structures expose that the centimeter-grade fractures are well developed in Tongbomiao Formation, some fractures are infilled by the calcite and other minerals, the oil-bearing property of some fractures is pretty obvious（Fig.5）. According to the location analyses between the coring wells and faults, the closer the distance is, the more well developed the well fractures will be, the stronger the productivity of the oil well will be[24-26], the conditions are opposite when the distance is far away. Therefore the existence of the natural fractures has enhanced the filtrating and penetrating capacity of the reservoirs, and also increase the heterogeneous characteristics of the reservoirs.

4.5 Influence of the heterogeneity on the developing adjustment

Controlled by the heterogeneous conditions of the reservoirs, there are pretty obvious differentials for the developing adjustments of different types of the fault-block-mountain oil reservoir. The belt-like oil reservoirs are distributed along the faults for the deep-fault high-dip type mountain, the oil column is higher vertically, while the planar distribution is rather narrow (Fig.6); the fracture-bearing reservoirs on the fault slope are the main remained potential area for this kind of the oil reservoir, so the progressive stepout on the fault slope is the key method to conduct the developing adjustment. On the contrary, the oil column in the shallow-fault low-dip mountain is not as good as the former, but the planar distribution is pretty wider (Fig.6), and the weathered crust type of oil reservoirs which are wide and flat are accumulated. As stated above, the solution pores and cavities are well developed in the high position of the structure for this type of the oil reservoir, while the connectivity among the pores is rather poorer, so the partial infilling in the high position of the structures is the main measure of the developing adjustment. From the viewpoint of the reservoir heterogeneity, both developing adjustments for the two kinds of the oil reservoirs have achieved much better effects.



(a)Planar distribution of the block-mountain reservoirs

type of the block mountain	typical block	reservoir section	reservoir characterization
deep-fault high-dip type	19-12 19-34 19-134		block bottom-water oil reservoir, high-quality reservoir well-developed on the one side of the faulted slope, progressive out-stepping adjustment measure
shallow-fault low-dip type	19-51 19-67 19-X61		bedded edge-water oil reservoir, high-quality reservoir well-developed on the high part of the slope, partial infilling adjustment measure

(b) Developing adjustment measures

Figure.6: Main block-mountain reservoirs and their developing adjustment measures for Tongbomiao Formation in Tanan Sag

5 Conclusion

(1) The original pores are not well-developed for Tongbomiao-Formation reservoirs in Tanan Sag, the secondary dissolved pores and fractures are the main reservoir spaces.

(2) According to the fault throw and dip, the palaeo-block mountain oil reservoir in Tongbomiao Formation of Tanan Sag can be divided into two types: deep-fault high-dip type and shallow-fault low-dip type. Different reservoir reconstructing modes are correspondingly to the above two block mountains i.e. High-angle two-side pattern and slope leaching pattern. The two patterns of the reservoir possess various heterogeneous characteristics.

(3) The original sedimentary conditions control the inner-layer heterogeneity of the reservoir, the unconformity dominates the inter-layer heterogeneity of the reservoir, the structural positions and fractures control the planar heterogeneity of the reservoir.

(4) The development adjusting measure of the deep-fault & high-dip-type block-mountain oil reservoir shows as the progressive out-stepping of the faulted slope; while that of the shallow-fault & low-dip-type block-mountain oil reservoir is the partial infilling in the high parts of the structures.

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