ISSN: 2157-7463
Journal of Petroleum & Environmental Biotechnology

OPEN ACCESS Freely available online

Research Article

Study on Reservoir Quality Differences in Keshen Area Based on Discrete Element Stress Numerical Simulation

Wenhui Zhu1[1], Zhaolong Liu[2*], Peng Zhou[1], Changchao Chen[1], Yuqi Liu[1], Reyimu Wufuer[1], Chunlei Hu[1], Bing Fang[1], Deyu Cui[1]

[1]*Department of Petrochina Research Institue of Petroleum Exploration and Development, University of Petrochina Tarim Oilfield, Tarim Basin, China;*[2]*Department of Petrochina Research Institute of Petroleum Exploration and Development, University of Beijing, Beijing, China*

ABSTRACT

In order to provide theory gist for exploration zone optimization and well placement, the zoning and segmentation characteristics and different control factors of reservoir in Bashijiqike Formation in Keshen area were studied with logging, core, casting thin section, confocal laser scanning and other available data by means of discrete element stress numerical simulation. The results show that there are obvious zoning features bounded by Keshen 8 fault in reservoir physical property and pore throat structure. In the north of the fault, the buried depth of the reservoir is mostly between 6000 m and 7400 m, with the effective porosity mainly distributed between 4.0% and 12.0%, and type-IIand type-III pore throat structure predominant. However, in the south of the fault, the buried depth of the reservoir is mostly between 7400 m and 8000 m, with the effective porosity mainly distributed between 4.0% and 9.0%, and type-III and type-IV pore throat structure predominant with less type-II. The influence factors on reservoir in Keshen area are horizontal extrusion and vertical compaction. Reservoir quality is mainly controlled by horizontal extrusion in the north of Keshen 8 fault. And in the south of Keshen 8 fault, reservoir quality is mainly controlled by horizontal extrusion and vertical compaction.

Keywords: Reservoir quality; Geostress; Control factor; Segmentation

INTRODUCTION

In recent years, Kelasu structural belt, as the main gas source of west-to-east gas transmission, is the key zone of gas accumulation and production in Tarim basin. The burial depth of cretaceous Bashijiqike formation in this area is concentrated in 6000-8000 m, which belongs to ultra-deep tight sandstone reservoir. A lot of work has been done on reservoir research in this area, mainly focusing on the prediction of lower limit of effective reservoir burial depth, prediction of favorable area, analysis of reservoir controlling factors, rules for fractures distribution and so on [1-7]. With the continuous improvement of exploration degree, it is found that although Keshen area is rich in gas, its internal reservoir quality shows obvious “zonation and segmentation”. That is, the Keshen 8 fault is bounded on the plane, and the buried depth is about 7400 m in the vertical direction. The reservoir quality and single well productivity are different obviously. At present, the research on zonation of Kelasu tectonic belt mainly considers the difference of reservoir stress environment, and it is divided into Kelasu tectonic belt and Keshen tectonic belt from north to south with Kelasu fault as the boundary [8,9]. But there is little analysis on the difference of reservoir inside Keshen zone and its causes. Therefore, based on multi-scale data such as logging, core, casting thin section and laser confocal, and by means of discrete element stress numerical simulation technology, the characteristics of reservoir zonation and segmentation in Keshen area are clarified, and the controlling factors of reservoir difference are discussed, providing theoretical basis for exploration zone selection and well location deployment.

MATERIALS AND METHODS

Regional geological survey

Keshen area is located in Keshen section of Kelasu structural belt in the north of Kuqa Depression, Tarim Basin, which is sandwiched between Kelasu fault and Baicheng fault (Figure 1a). From top to bottom, the strata are divided into Quaternary, Neogene, Paleogene Suweiyi formation and Kumgliemu group, Mesozoic Cretaceous Bashijiqike formation, Baxigai formation, Shushanhe formation and Yagegliemu formation. Bashijiqike formation of the

Correspondence to: Zhaolong Liu, Department of Petrochina Research Institue of Petroleum Exploration and Development, University of Petrochina Tarim Oilfield, Tarim Basin, China, Email Id: dqpiaugust@163.com

Received: 20-Sep-2022, Manuscript No: JPEB-22-18109, **Editorial assigned:** 26-Sep-2022, PreQC No: JPEB-22-18109 (PQ), **Reviewed:** 10-Oct-2022, QC No: JPEB-22-18109, **Revised:** 17-Oct-2022, Manuscript No: JPEB-22-18109 (R), **Published:** 24-Oct-20 22, DOI: 10.35248/2157-7463.22.13.476

Citation: Zhu W, Liu Z, Zhou P, Chen C, Liu Y, Wufuer R, et al (2022) Study on Reservoir Quality Differences in Keshen Area Based on Discrete Element Stress Numerical Simulation. J Pet Environ Biotechnol. 13:485.

Cretaceous is the main reservoir in this area, which can be divided into the first, second and third member from top to bottom. The first and second member develop braided river delta front subfacies, and the third member develops fan Delta front surfaces. The overlying thick gypsum rock of Paleogene Kumgolemu group is a regional high quality cap rock. Under the influence of the strong south-north compression in the Cenozoicera, Kelasu structural belt shows the characteristics of stratified deformation. The salt-related folds of the salt-paste layer as the detachment layer were dominant in the super salt structure, and the subsalt structure was dominated by imbricate thrust, forming a giant wedge thrust belt (Figure 1b), which provide favourable conditions for the formation of large trap [10].

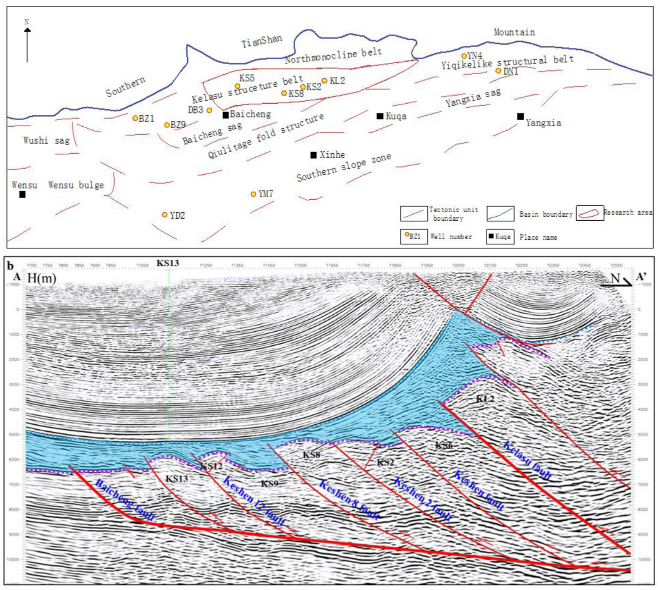

Figure 1: (1a) Location and structural profile of Keshen zone of Kelasu thrust belt in Kuqa depression, (1b) salt-related folds of the salt-paste layer as the detachment layer were dominant in the supersalt structure, and the subsalt structure was dominated by imbricate thrust, forming a giant wedge thrust belt.

Study on the difference of reservoir

Lithological characteristic: The analysis and statistics of 370 rock slices in the study area show that the rock types of Bashijiqike Formation in Keshen area are mainly lithic arkose, followed by arkose lithic sandstone, and the grain size of Bashijiqike formation is mainly medium-fine. Quartz content is generally 40%~60%. Feldspar is mainly potassium feldspar with the content of 15%~25%, and the content of plagioclase is 5%~15%. The cuttings are mainly metamorphic rock cuttings with a content of 10%~15%. The total content of interstitials is 4%~15%, among which the total amount of cementation is 2%~9%, mainly composed of dolomite and calcite. The miscellaneous base is mainly brown or black mud, with the content of 1%~10%, and the average is less than 5%. Grain sorting is moderate, grinding is medium, and composition maturity is low-medium. In general, from the first to the third member of Bashijiqike Formation, the composition of rock ore changes little, and the content of quartz and feldspar is relatively stable. On the plane, from north to south, the quartz content of the Cretaceous Bashijiqike Formation is roughly the same from Keshen 6, Keshen 2, Keshen 8 to Keshen 9, Keshen 13 well area. But the feldspar content is relatively higher. The rock debris content is relatively decreased, and the sorting and grinding of particles have been greatly improved.

Reservoir space characteristic

According to the comprehensive observation and analysis of cores, cast thin sections, scanning electron microscopy, laser confocal microscopy and other data from 35 Wells, the reservoir space types of Cretaceous Bashijiqike Formation of different structures in Kesen area are mainly intergranular pores, including intergranular dissolved pores and residual primary intergranular pores (Figure 2), accounting for 70% to 90% of the total pore types. The pore shape is irregular angular quadrilateral, polygon or strip. The second is the dissolved pores in grains, which are mainly composed of feldspar, mica, carbonate cuttings and the cuttings containing aluminosilicate minerals which are dissolved in different degrees and form pores of different sizes and shapes in grains, accounting for 10%~30% of the total pore types. Micropores are less developed, accounting for about 3% of the total pore types. In terms of pore development, Keshen 6, Keshen 2, Keshen 8 well areas in the north are better than Keshen 9, Keshen 13 well areas in the south, bounded by Keshen 8 fault.

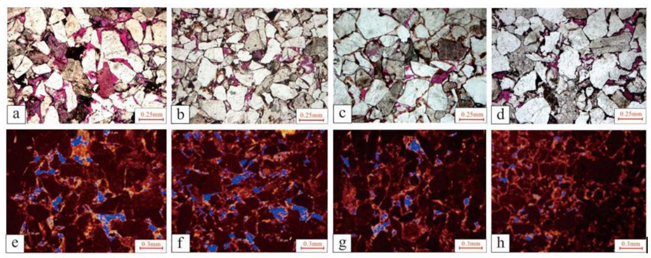

Figure 2: Pore types of Cretaceous Bashijiqike Formation reservoir in different structures in Keshen area
a. KS6 Well, 5620.55m, K1bs1, casting thin section, primary intergranular pores, intergranular dissolved pores are widely distributed. b.KS8-8Well, 6865.52m, K1bs2, cast thin section, intergranular dissolved pores developed. c.KS13Well, 7344.16m, K1bs1, cast thin section, intergranular dissolved pores developed, a few intrgranular dissolved pores and micropores. d.KS904 Well, 7734.05m, K1bs1, cast thin section, intergranular dissolved pores dominated. e.KS201Well, 6509.67m, K1bs1, laser confocal microscopy, interparticle dissolved pores dominated, interpore connectivity was good. f. KS206 Well, 6706.5m, K1bs2,laser confocal microscopy, intergranular dissolved pores, primary intergranular pores, good interpore connectivity. g.KS802Well, 7326.95m, K1bs2, laser confocal microscopy, intergranular dissolved pores, primary intergranular pores, throat and pore network connectivity. h.KS904 Well, 7736.58m, K1bs1, laser confocal microscopy, primary intergrain pore dominated, pore connectivity is relatively poor.

Pore structure characteristic

Based on the analysis of 130 mercury injection samples, the pore and throat structures of the Bashijiqike Formation reservoir in the study area are diverse. According to the drainage pressure, matrix porosity, permeability, maximum pore and throat radius and average pore and throat radius, the pore and throat structures of the reservoir matrix can be divided into four typical types (Table 1). The pore structure parameters of reservoirs with different burial depth are different. The displacement pressure of matrix pores in 6000~7400 m reservoir is generally (1.00~10.00) MPa, with an average of 5.76 MPa. The maximum pore throat radius is generally (0.10~2.00) μm, with an average of 0.46 μm.

Table 1: Pore structure parameters of different reservoir types in Bashijiqike Formation, Keshen area.

Type	Matrix porosity ／%	Matrix permeability ／10^{-3} μm²	Displacement pressure ／MPa	Maximum pore throat radius ／μm	Average pore throat radius ／μm	Pore structure
Type- Ⅰ	＞9.00	＞1.00	＜0.10	＞0.40	＞0.50	Low displacement pressure-big pore throat-low porosity-low permeability
Type- Ⅱ	9.00~6.00	1.00~0.10	0.10~5.00	0.40~4.00	0.03~0.50	Medium sized displacement pressure- medium sized pore throat-very low porosity-very low permeability
Type-Ⅲ	6.00~4.00	0.10~0.05	3.00~10.00	0.10~1.00	0.02~0.20	High displacement pressure- low pore throat-very low porosity-very low permeability
Type-Ⅳ	＜4.00	＜0.05	＞5.00	＜0.50	＜0.05	Very high displacement pressure-very low pore throat-very low porosity-very low permeability

The average pore throat radius is mostly (0.01~0.10) μm, with an average of 0.07 μm. The pore-throat structures are mainly II and III, accounting for 50% and 35% respectively. The matrix pore displacement pressure of reservoirs below 7400 m is larger, ranging from (2.00~15.00) MPa, with an average of 8.27M Pa. The maximum pore throat radius is relatively small, generally ranging from (0.05~0.50) μm, with an average of 0.13 μm. The average pore throat radius is mostly ranging from (0.01~0.10) μm, with an average of 0.02 μm. The pore-throat structures are mainly III and IV, and a small amount of II, III and IV accounted for 15%, 30% and 55%, respectively.

Physical property and productivity characteristic

Because the buried depth of the reservoir in Keshen area is generally more than 6000 m, it is difficult and costly to coring, and core analysis data is limited. In order to ensure the reliability of physical property statistics, the logging interpretation porosity data calibrated by core analysis is used in this paper to carry out reservoir physical property analysis, and the coincidence rate is up to 90%. The analysis and statistics of 40822 data points from 19 Wells in the study area show that the reservoir physical properties are obviously segmented in vertical direction. As shown in Figure 3, the effective porosity of the reservoir with a burial depth of 6000~7400 m is mainly 4.0%~12.0%, with an average porosity of 7.5%. Secondary pore zones are mostly developed, mainly located in the Keshen 6, Keshen 2 and Keshen 8 well areas north of Keshen 8 fault. When the burial depth is more than 7400 m, the porosity of the reservoir decreases obviously, mainly in 4.0%~9.0%, with an average porosity of 6.5%, and decreases obviously with the increase of burial depth. Secondary pore zones are locally developed, and their sizes are small, mainly distributed in Keshen 9 and Keshen 13 Wells. The drilling data shows that the productivity of the gas Wells in the high structural position in the north of Keshen 8 fault is high, and the conventional open flow rate of the completion is above 60 × 104 m³/d. The conventional open flow rate of the Wells in the high structural position in the south Keshen 9 well is generally lower than 50 × 104 m³/d. The test open flow rate of the high structural part of Keshen 13 well only reached 50 × 104 m³/d after sand fracturing.

Research on reservoir difference based on discrete element stress simulation

The Keshen area in Kelasu tectonic belt formed a large scale thrust nappe structure under the strong organic action of southern Tianshan Mountain in the middle and late Kuqa period, which has a unified regional stress field [11]. It is determined that the direction of maximum principal stress is nearly north to south by means of structural analysis of field measured profile and finite element simulation [12]. Under the same tectonic stress field and sedimentary environment, bounded by Keshen 8 fault, the physical properties pore structure and productivity of the north and south reservoirs are obviously different. In previous studies, it was believed that the stress environment could not be ignored in the reconstruction of pre-salt reservoirs [8,13], but it mainly focused on the stress environment difference between Kela and Keshen area, and there were few studies on the interior of Keshen area. In order to clarify the difference of reservoir quality in Keshen area, discrete element stress simulation technology is used in this paper as research method, and the influence of stress environment on reservoir quality is discussed based on seismic and geological analysis.

Discrete element numerical simulation (DEN) is determined by time-displacement finite difference method of discrete particle shape and displacement of the variable, then simulate the elastic-plastic deformation process between particles [14], which has the advantages of high efficiency, strong operability, dynamic analysis of tectonic deformation and stress changes, and has been widely used in the field of geological research in recent years [15-18]. The selection of relevant parameters in this model design is mainly based on the main seismic profile in Keshen area (AA' profile in Figure 1), and the structural evolution process is restored by balanced profile and area depth method. It is clear that the overall tectonic compression shortening of Kelasu tectonic belt is 35%~40% [19,20], and the regional stress field is nearly north-south. Experimental parameters mainly refer to the comprehensive selection of physical simulation, finite element simulation and discrete element simulation results in the structural research of Kuqa area (Table 2). During the extrusion process, the structural morphology and stress distribution at 10%, 20% and 40% shrinkage were recorded (Figure 4).

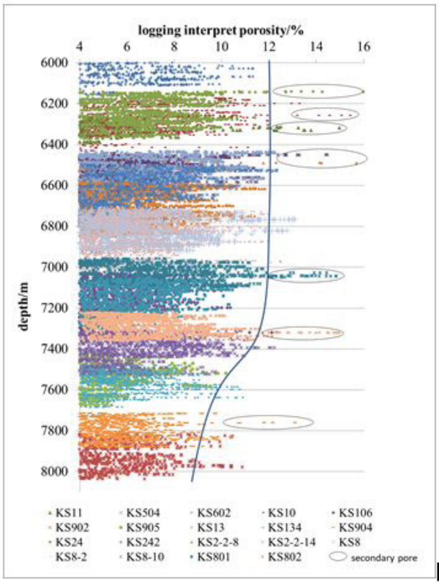

Figure 3: The relationship between porosity interpreted by logging and burial depth of Bashijiqike Formation reservoir in Keshen area.

Table 2: Selection of relevant parameters for discrete element simulation.

	Particle radius /m	Tensile strength /10^3MPa	Shear strength /10^3MPa	Shear elasticity /10^3MPa	Young modulus /10^3MPa
Salt formation	45	/	/	8	19
Surrounding rock	45	/	/	29	69
Basement	45	/	/	32	76
Interparticles of surrounding rock	/	3	6	2	4.8
Interparticles of basement	/	4	8	2	4.8

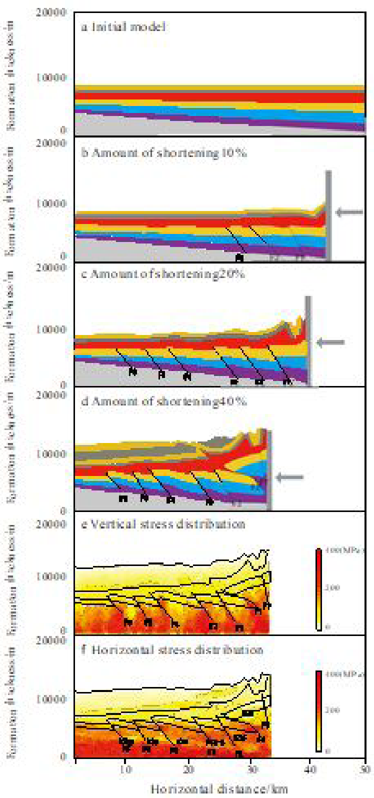

Figure 4: Discrete element numerical simulation and stress distribution in Keshen zone.

The simulation results show that the extrusion front zone is the concentrated area of the model's initial deformation. Under the influence of extrusion, a deep and large fault with basement involvement-Kelasu Fault (F1) is first formed in the north of the profile. The deformation propagates from north to south along the deep detachment layer as the extrusion continues. As a result, a series of high-angle secondary thrust faults (F2-F7) and fault-related folds were formed in the subsalt, and the fault distance from north to south gradually decreased, and the amplitude of structural bending decreased. In this process, the salt strata mainly developed wide and slow folds, and the deformation was relatively simple. Salt rock plays the role of detachment layer, plastic shrinkage deformation occurs, and salt layer thickness gradually decreases from north to south. Stress simulation results show that, when the shortening amount reaches 40%, the vertical stress of Keshen 6, Keshen 2 and Keshen 8 Wells located in the north of Keshen 8 fault (F4) is mainly distributed in 50-80 Mpa, and the horizontal stress is 60-110 Mpa. The stress value distribution is relatively concentrated, and the overall performance is a low stress area, corresponding to the reservoir buried depth of 6,000-7400 m. The main types of reservoir space are primary intergranular pores, followed by secondary dissolution pores. The pore throat structure is mainly II and III, and the effective porosity is concentrated in 4.0%-12.0%. In the southern Keshen 9 and Keshen 13 Wells, the vertical stress is mainly distributed in 80-110 MPa, and the horizontal stress is 90-150 MPa. The stress value is relatively high, and it still increases southward. The corresponding reservoir burial depth is 7400-8000 m, and the reservoir space type is mainly primary intergranular pores, with a small amount of secondary dissolution pores. The pore throat structure is mainly III and IV, and the effective porosity is concentrated in 4.0%-9.0%.

The numerical simulation results are consistent with the actual drilling data. The calculation results of Kelasu high and steep-ground stress after in-situ stress calibration show that the maximum principal stress of Keshen 6, Keshen 2 and Keshen 8 Wells north of Keshen 8 fault ranges from 130 Mpa to 180 MPa with an average of 155 MPa, and the minimum principal stress ranges from 115 Mpa to 160 MPa with an average of 135 MPa. The vertical stress ranges from 140 MPa to 165 MPa, with an average of 155 MPa. The maximum principal stress of Keshen 9 and Keshen 13 Wells south of Keshen 8 fault ranges from 170 MPa to 210 MPa, with an average of 190 MPa. The minimum principal stress ranges from 140 MPa to 180MPa, with an average of 160 MPa. And the vertical stress ranges from 175 MPa to 190 MPa, with an average of 185 MPa.

RESULTS AND DISCUSSION

Analysis of reservoir controlling factors

According to drilling data and numerical simulation results, the quality of ultra-deep subsalt reservoir in Keshen area is mainly controlled by horizontal compression and vertical compaction. Influenced by the uplift of the southern Tianshan Mountains and the plastic detachment layer, a series of thrust imbricate structures were formed in the subsalt. With the continuous horizontal compression, the high stress zone spread from north to south. In general, the larger the fault distance is, the higher the degree of structural bending deformation is. The horizontal extrusion stress is constantly converted into the dynamic force for the fault block to move upward along the fault, which effectively reduces the horizontal extrusion strength and presents a low value of horizontal extrusion stress. At the same time, the plastic flow of salt rock is beneficial to the release of tectonic stress, which makes the obvious low-value stress area appear under the salt structure, which reduces the compaction diagenesis of sandstone by the tectonic compression stress, and shows the protection of the salt rock stratum to the pre-salt reservoir.

North of Keshen 8 fault, horizontal compressive stress is low with big fault displacement and tectonic bending amplitude. The thickness of salt layer is large, more concentrated in the 800 ~ 2500 m, average thickness of about 1600 m. The largest single layer thickness of salt rocks is about 380 m. The density of gypsum rock is small and stable, which makes the compaction degree of the underlying layer low. The vertical compaction has little effect on the reservoir, and the reservoir protection degree is high. In the south of Keshen 8 fault, with the attenuation of stress, the fault distance and the tectonic bending amplitude decrease. The extrusion stress inside the reservoir cannot be effectively released, and the horizontal extrusion stress is strong. The thickness of salt rock is obviously reduced, mostly in 200-500 m, with an average thickness of 320 m, and the maximum thickness of single layer salt rock is 100 m, which enhances the effective vertical pressure and reduces the quality of its internal reservoir.

CONC LUSIONS

1. The Cretaceous Bashijiqike Formation reservoirs in Keshen area have similar petrological characteristics and reservoir space types. The rock types are mainly lithic arkose sandstone, and the reservoir space types are mainly intergranular pores, followed by intergranular dissolved pores and micropores.

2. The physical property and pore-throat structure of reservoir are segmented by Keshen 8 fault. In the north of Keshen 8 fault, the reservoir burial depth is mainly in the range of 6000-7400 m, the effective porosity is mainly in the range of 4.0%-12.0%. The secondary dissolution zone is mainly developed, and the pore throat structure is mainly of II and III types. In the south of Keshen 8 fault, the burial depth of the reservoir is mainly in the range of 7400-8000 m, and the effective porosity of the reservoir decreases obviously, mainly in the range of 4.0%-9.0%, and tends to decrease with the increase of burial depth. The secondary pore zone is developed locally, and the pore throat structure is mainly III and IV types, with a small amount of II type.

3. The reservoir difference in Keshen area is mainly controlled by horizontal compression and vertical compaction. In the north of Keshen 8 fault, the reservoir quality is mainly controlled by horizontal compression due to the large thickness of salt rock and low vertical compaction degree. In the south of Keshen 8 fault, due to weak tectonic deformation, strong horizontal compression stress, small thickness of salt rock and high vertical compaction, the reservoir quality is controlled by the dual effects of horizontal compression and vertical compaction.

FUND PROJECT

China National Petroleum Corporation's Major Projects: Deeping of Petrolum geology theory and evaluation of exploration target in Kuqa Foreland basin (2018E-1801); Science and Technology Research Project of Petro China Company Limited: Research on Water-control and EGR Technology for Deep or Ultra Gas Reservoir Development (2020DJ1005).

REFERENCES

1. Pan R, Zhu X, Zhang J. Lower physical property limit and controlling factors on deep effective clastic reservoirs in Kelasu structure zone. Journal of Jilin University (Earth Science Edition). 2015; 45(4):1011-1020.

2. Sun Yonghe, Wang Duo, Fu Xiaofei. Comprehensive evaluation on petroliferous potential of the fault traps in the Kelasu structural belt of Kuqa depression [J]. Special Oil & Gas Reservoirs. 2013; 20(4):5-9.

3. Jie F, Yan S, Zhenxue J, Baoshuai L, Feng L. Diagenetic evolution and major controlling factors for sandstone in Bashijiqike Formation of the Keshen area in the Tarim Basin. Special Oil & Gas Reservoirs. 2017; 24(1):70-5.

4. Yang XZ, Mao YK, Zhong DK, Li Y, Neng Y, Sun HT, Liu YL. Tectonic compression controls the vertical property variation of sandstone reservoir: An example of Cretaceous Bashijiqike Formation in Kuqa foreland thrust belt, Tarim Basin. Natural Gas Geoscience. 2016; 27(4):591-9.

5. Denglin H, Zhong L, Jianfeng S, Weifeng L. Reservoir Heterogeneities between structural positions in the anticline: a case study from Kela-2 gas Field in the Kuqa Depression, Tarim Basin, NW China. Pet Explor Dev. 2011; 38(3):282-286.

6. Denglin H, Ruizhe Z, Zhong L, Weifeng L. The characteristic of diagenetic compaction induced by multiform geodynamic mechanisms in reservoir: an example from Cretaceous sandstone reservoir in Kuqa Depression, Tarim Basin. Chinese Journal of Geology. 2015; 50(1):241-248.

7. Shuo W, Dai Junsheng WK. Analysis the Control of Fracture Development Based on Numerical Simulation. Special Oil & Gas Reservoirs (in chiese). 2016; 23(1):76-80.

8. Yangang TA, Peng ZH, Zhenping XU, Hongwei YI, Wenhui ZH, Yani XI. The influence of stress environment on reservoir under salt in Kelasu structure belt. Geological Journal of China Universities. 2017; 23(1):95-103.

9. Guang-zhen CH, Shi SH, Long yi SH, Hai-ying WA, Zhen-hua GU. Contrastive Study on Geological Characteristics of Cretaceous Bashijiqike Formation in Keshen2 and Kela2 Gas Fields in Kuqa Depression. Geoscience. 2014; 28(3):604-610.

10. Jiafu Q, Ganglin L, Minggang L, Yongxing G. Analysis of structure model and formation mechanism of Kelasu structure zone, Kuqa depression. Geotectonica et Metallogenia. 2009; 33(1):49-56.

11. Yuan N, Huiwen X, Tairong S, Ganglin L, Lili X. Structural characteristics of Keshen segmentation in Kelasu structural belt and its petroleum geological significance. China Petroleum Exploration. 2013; 18(2):1-6.

12. Zheng C, Hou G, Zhan Y, Yu X, Zhao W. An analysis of Cenozoic tectonic stress fields in the Kuqa depression. Geological Bulletin of China. 2016 Jan 15; 35(1):130-139.

13. Zhong L, Lijuan Z, Jianfeng S, DengLin H, Yang S, HuiLiang Z. Structural strain and structural heterogeneity of sandstone diagenesis: A case study for the Kuqa subbasin in the northern Tarim basin. Acta Petrologica Sinica. 2009; 25(10):2320-2330.

14. Dean SL, Morgan JK, Fournier T. Geometries of frontal fold and thrust belts: Insights from discrete element simulations. J Struct Geol. 2013; 53:43-53.

15. Yunjiang DU, Shaoying HU, Weibo LI, Huifang ZH, Xiaodan MA, Feiran LI. Using Discrete Element Numerical Simulation Method to Study Salt Tectonic Deformation Mechanism of Kelasu Structural Belt. Xinjiang Petroleum Geology. 2017; 38(4): 414-419.

16. Naylor M, Sinclair HD, Willett S, Cowie PA. A discrete element model for orogenesis and accretionary wedge growth. Journal of Geophysical Research: Solid Earth. 2005; 110(B12).

17. Yin H, Zhang J, Meng L, Liu Y, Xu S. Discrete element modeling of the faulting in the sedimentary cover above an active salt diapir. Journal of Structural Geology. 2009; 31(9):989-95.

18. Shenyang CA, Hongwei YI, Changsheng L, Dong JI, Zhuxin WW. Technology of strain analysis and fracture prediction based on DEM numerical simulation. Geological Journal of China Universities. 2016; 22(1):183-193.

19. Xie HW, Yin HW, Tang YG, Wang W, Wei H, Wu Z, et al. Research on subsalt structure in the central Kelasu structure belt based on the area-depth technique. Geotectonica et Metallogenia (in Chinese). 2015; 39(6):1033-1040.

20. Anming XU, Chao WU, Jiangwei SH. Application of area-depth method in studies on the deformation of subsalt structures in the northern Kuqa Depression. Natural Gas Industry. 2015; 35(6):37-42.