Sedimentary characteristics and exploration direction in the south of the central block in Pre-Caspian Basin

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Abstract. The Pre-Caspian Basin experienced the history from the Late Paleozoic craton margin to the Mesozoic-Cenozoic depression. It has been explored for a long time. It is the most important oil and gas producing area in Kazakhstan, and a large number of oil and gas fields have been discovered in it. The oil and gas discoveries are located in clastic rock and platform carbonate rock below the Lower Permian salt domes. The study area is located at the eastern margin of the Pre-Caspian Basin, where reservoirs are deposited in an open carbonate platform in the shallow sea. The most developed subfacies are intraplatform shoals and sea between shoals. The microfacies in the intraplatform shoals include bioclastic shoals and algae shoals, and represent dominant high-quality reservoirs. The central gentle zone and the eastern slope zone in the study area are potential targets for exploration and evaluation. All reservoirs are structural-lithologic reservoirs controlled by high lithologic barriers or updipped pinch-outs.

1. Introduction
As one of the world's largest oil-bearing basins, the Pre-Caspian Basin, covering about 580,000 km², and the most part of which located in Kazakhstan and less in Russia, is rich in oil and gas, but less explored [1]. The basin had ever been a pre-Devonian rift, and received sediments of 20 km thick in its center. The basin is characterized by extensive development of very thick Lower Permian salt domes, and the salt structures control hydrocarbon accumulation in the basin. The subsalt reservoirs are mainly Carboniferous, Lower Permian, and Upper Devonian carbonate rocks and organic reefs. The reservoirs are thick, widely distributed, and good in physical properties, so they are advantageous for accumulation of large subsalt oil and gas reservoirs. The most important reservoir is the Devonian-Carboniferous carbonate reservoir of platform facies below the giant Permian salt dome [2].

The central block on the eastern margin of the Pre-Caspian Basin is located in the southeastern part of the Zhanazhol oilfield in Aktobe, Kazakhstan (Figure 1), and covers an exploration area of about 2,700 km². Administratively, it belongs to the Mugojar region of Aktobe and lies between the Mugojar River and the Enba Rivers. The landform is grassland with gentle hills and valleys, generally 125-270 m above sea level, low in the west and north, and high in the east and south. It is the main exploration block at present. The study area is located in the southern part and has an area of about 1,500 km². The primary target is the Carboniferous carbonate rock, which is stable and characterized by successive development. The Lower Permian P1as formation is a secondary target [3].
The aims of the study is predict the sedimentary faces’ distribution and determine the next exploration targets. The study method is using the seismic attribute distribution to prediction the sedimentary based on the analysis of the well core, single well’s sedimentary face, wells’ comparison.

2. Summary of exploration

Exploration in the study area began in 2011 and 11 wells have been drilled so far. In April 2012, Well X-1 in the southern uplift of the central block produced 27 m$^3$ of oil per day during the well test. Then the Tucker oil-bearing structure was found. In the study area, oil and gas reservoirs were drilled in the Lower Permian P1as and Carboniferous formations, and commercial oil/gas flows were tested in seven wells. The highest oil production tested in Well X-3 is 36.5 m$^3$/d from the P1as formation. Well X-5 got flowing production from the Carboniferous B3 initially at 108 m$^3$/d of oil production and 43,000 m$^3$/d of gas production. It is first time that reservoirs in the Carboniferous B3 has been discovered in the central block. It declared a new exploration area. Although well tests are successful, the several exploration wells could not produce sustainably. After analyzing the sedimentary characteristics of the Carboniferous formation in the study area, Well X-13 was drilled in the eastern part of the block, and commercial hydrocarbon flow was obtained during testing the P1as and Carboniferous formations. It started exploration in the eastern part and defined the direction of future exploration.

3. Sedimentary characteristics

3.1. Regional sedimentary environment

The Early Carboniferous in the Pre-Caspian Basin was deposited in the transgressive environment since the Devonian, while regression occurred in the Middle Carboniferous. The Early Carboniferous are mainly coral limestone, algal limestone, and dolomite limestone. In the Middle Carboniferous, as the scale of transgression expanded, the non-compensated sediments continued to advance to the south of the basin. Deep-water sediments gradually replaced the Upper Devonian continental shelf carbonate rocks deposited in the northern uplift belt. As the paleo-shelf area shrank, biolithite limestone was sedimented on some large gentle uplifts. The biocoenoses include coral, moss, sponge, creep, foraminifera, brachiopods, sea lilies, algae, and other organisms. From the Late Carboniferous, the regional structure of the entire Pre-Caspian Basin underwent great changes with the formation of the adjacent Hercynian fold belt. The Carboniferous water was strong and grain shoals were developed, creating an open carbonate platform facies in the shallow sea [5] (Figure 2). Intraplatform shoals and dolomite flats are favorable sedimentary facies belts with developed reservoirs in the study area.

![Distribution of subsalt reservoirs in the Pre-Caspian Basin [4].](image)
3.2. Reservoir characteristics

The reservoirs in the study area are mainly sparry limestone with relatively developed intergranular pores and intergranular dissolved pores, and dissolved vugs are visible in some layers. They are porous carbonate rocks with strong heterogeneity (Figure 3). The reservoir lithology is mainly light gray micrite, powder crystal limestone, and sparry limestone. The rock types include sparry grain limestone and micrite shell algae pellet limestone with intragranular pores. According to well logging data, the average porosity is about 9%; the average permeability is about 0.5 mD; the natural gamma value is 8-20 API; the density is 2.51-2.62 g/cm³; and the resistivity is 30-60 Ω.m.

3.3. Sedimentary microfacies

Based on the observation to thin sections of rock samples, drilled cores and logging response characteristics, the sedimentary characteristics of cored intervals in the study area were analyzed from microscopic to macroscopic. The Carboniferous sedimentary facies in the study area is considered to be open carbonate platform in the shallow sea, and the favorable sedimentary microfacies include the following four types: arenite shoals, oolitic shoals, bioclastic shoals, and algal shoals.

3.3.1. Oolitic shoals

The lithology of oolitic shoals is mainly sparry oolitic limestone with a small amount of sandy clastics, and the pores are mainly mold pores, intragranular pores, etc. The porosity is relatively high. The lateral change of physical properties is fast. The reservoirs in oolitic shoals are classified as Class I reservoirs (Figure 4).
3.3.2. arenite shoals. The lithology of arenite shoals is mainly sparry calcarenite. The pores are mainly mold pores and intragranular pores. The porosity is high. The lateral change is fast. Reservoirs in arenite shoals are classified as Class I reservoirs (Figure 5).

Figure 4. Markers of oolitic shoal facies of B5 in Well X-5.

Figure 5. Markers of arenite shoal facies of B3 in Well X-4.

3.3.3. bioclastic shoals. Bioclastics in bioclastic shoals are mainly ostracods and foraminifera, containing a small amount of sand debris. The pores are mainly intergranular dissolved pores, organic pores, and intragranular dissolved pores. Effective reservoirs may be formed after dissolution. Reservoirs in bioclastic shoals are classified as Class II reservoirs (Figure 6).

3.3.4. algae shoals. The lithology of algae shoals is dominated by various algae bonding structures, and dissolved pores are not developed. The reservoir is tight, and the effective reservoir is thin. Reservoirs in algae shoals are classified as Class II reservoirs (Figure 7).

3.4. Reservoir analysis
Based on the analysis of the cores’ picture and the well log, the well’s sedimentary face can be predicted. Figure 8 shows the division plan of the reservoirs in the KT-II interval in Well X-5. The KT-II interval is of open platform facies. It can be divided into intraplatform shoals and sea between shoals. The intraplatform shoals are dominated by sparry grained limestone shown as bioclastic and algae shoals, and the reservoirs are moderately developed. The rock types in the sea between shoals are mainly composed of massive micrite grain limestone interbedded with sparry grain limestone and a small amount of micrite limestone. They are tight. Primary pores were not developed, and later weak diagenetic dissolution was not conducive to the development of secondary pores. Vertically, affected by the rise and fall of the sea level, intraplatform shoals and sea between shoals are alternative, and accordingly developed reservoirs and tight intervals are alternative too. They form better reservoir-caprock assemblages.
**Figure 6.** Markers of bioclastic shoal facies of Г6 in Well X-7.

**Figure 7.** Markers of algae shoal facies of Г1 in Well X-5.

**Figure 8.** Sedimentary faces prediction prolife in Well X-5.
Then according to the actual data and considering the structures, source supply and sedimentary characteristics in the study area, the profile of the primary sedimentary facies was established under the guide of macroscopic seismic reflection characteristics, in order to clarify the lateral and vertical laws of the sedimentary facies.

On the EW and NS across-well reservoir profiles, reservoirs are mainly concentrated in the upper part of the Carboniferous strata, and the reservoir interval is relatively stable in the study area. The lower part of the interval mainly has bioclastic shoals and algae shoals. The reservoirs are thin and the lateral connectivity is poor, which reflects the heterogeneity of carbonate reservoirs. Reservoirs in the upper part of the interval are high or low, and instable in thickness, indicating the heterogeneity of carbonate reservoirs. The shoals are almost arenite and oolitic. The top was subjected to later weathering and leaching. The reservoirs are relatively developed (Figure 9 and Figure 10).

Figure 9. Across-well reservoir profile in south-north direction.

Figure 10. Across-well reservoir correlation profile in the east-west direction.
Through the analysis of sedimentary facies and reservoirs, it is easy to find that the genesis of carbonate reservoirs is mainly affected by sedimentation, diagenesis, and tectonism [6-7]. First, the sedimentary facies has a controlling effect on the reservoir distribution. As the Carboniferous sedimentary environment has undergone a continuous evolutionary process, the distribution of intraplatform shoals has been continuously migrated in the lateral direction. The oolitic rocks in large bioclastic shoals are relatively thick and laterally stable, which lays a good foundation for reservoir development. In addition, diagenesis has a transforming effect on reservoir development. The granular limestone and oolitic limestone became the most favorable reservoirs after the transformation of mixed water dolomitization and burial dissolution associated with the ancient exposed surface. The pores in these reservoirs are mainly intergranular pores, intragranular pores, and secondary pores such as intercrystalline dissolved pores and super large dissolved pores. However, granular limestone and oolitic limestone without dolomitization and burial dissolution are generally tight limestone or tight dolomite. Constructive diagenesis is mainly dissolution, and destructive diagenesis mainly includes compaction-pressure dissolution, cementation, and filling.

4. Plane distribution of sedimentary facies
Based on cores, well logging facies, and profiles of single wells and connected wells, comprehensive analysis was carried out on the sedimentary facies. The Carboniferous sedimentary facies in the study area is an open platform, which mainly developed subfacies like intraplatform shoals and sea between shoals [8]. The microfacies in the intraplatform shoals is dominated by arenite shoals and oolitic shoals. A number of arenite shoals and oolitic shoals are developed in the middle of the study area, and shown as stripped and irregular lobates, where high-quality reservoirs are developed (Figure 11).

Figure 11. The distribution map of the seismic attribute (left) and the sedimentary faces(right).

5. Conclusions
Based on the analysis of the well core, well sedimentary face, wells’ comparison, the sedimentary facies distribution can be predicted combined with the seismic attribute distribution map [9]. The Carboniferous strata in the study area were deposited in an open carbonate platform environment with strong energy and grain shoals developed. The subfacies like intraplatform shoals and sea between shoals are dominant. The microfacies in intraplatform shoals include bioclastic shoals and algae shoals, which are the primary facies of high-quality reservoirs. Reservoirs are relatively undeveloped in the sea between shoals. Thus the bioclastic shoals and algae beach are the best exploration targets.

The central gentle zone and the eastern slope zone of the study area are potential targets for exploration and evaluation. All reservoirs are structural-lithologic reservoirs controlled by high lithologic barriers or updipped pinch-outs. The Carboniferous reservoir in the east part is obviously better, and it is the primary target for future exploration.
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