Lower permian reef-bank bodies’ characterization in the pre-caspian basin

Zhen Wang¹, Yankun Wang, Jiquan Yin, Man Luo and Shuang Liang
Research Institute of Petroleum Exploration and Development, PetroChina, Beijing

¹Wangzhen1@cnpcint.com

Abstract. Reef-bank reservoir is one of the targets for exploration of marine carbonate rocks in the Pre-Caspian Basin. Within this basin, the reef-bank bodies were primarily developed in the subsalt Devonian-Lower Permian formations, and are dominated by carbonate platform interior and margin reef-banks. The Lower Permian reef-bank present in the eastern part of the basin is considered prospective. This article provides a sequence and sedimentary facies study utilizing drilling and other data, as well as an analysis and identification of the Lower Permian reef-bank features along the eastern margin of the Pre-Caspian Basin using sub-volume coherence and seismic inversion techniques. The results indicate that the sub-volume coherence technique gives a better reflection of lateral distribution of reefs, and the seismic inversion impedance enables the identification of reef bodies’ development phases in the vertical direction, since AI (impedance) is petrophysically considered a tool for distinguishing the reef limestone and the clastic rocks within the formation (limestone exhibits a relatively high impedance than clastic rock). With this method, the existence of multiple phases of the Lower Permian reef-bank bodies along the eastern margin of the Pre-Caspian Basin has been confirmed. These reef-bank bodies are considered good subsalt exploration targets due to their lateral connectivity from south to north, large distribution range and large scale.

1. Introduction
The reef-bank reservoir is considered as the emphasis and hotspot of oil & gas exploration underneath the Permian Kungurian salt dome in the Pre-Caspian Basin. Some large scale or extra-large scale oil/gas fields with excellent reef-bank reservoirs have been discovered in the peripheral areas of the basin, e.g., Zhanarol, Kenkyak, Astrakhan and Tengiz (Figure 1). The reef body reservoir is composed of hummocky to lenticular or reef-bank carbonate masses that are believed to be of biogenic origin, comprising two end members: the organic reef that has the organic framework structure and the grain bank that lacks the bio-framework structure. This type of reservoir is considered as one of the most important exploration domains because of its good reservoir conditions and broad distribution range. The reef’s seismic response has moundy shape and onlap on the lateral boundary with a steep foreslope and a moderate back-slope. There are discontinuity and wild reflection with an abnormal high velocity within the reef. Seismic facies change at the boundary of the reef(Figure 2). The reef is the best reservoir with good physical property in the marine sediment, and it is our main exploration target[1]. Although the reef has some features in the seismic profile, it is very difficult to outline the reef’s boundary and its distribution due to the poor quality of seismic data. In general, the difference of reef lateral layers’ occurrence is bigger than 100°, so the reef’s boundary and width can be determined using the dip and azimuth introduced by the sub-volume coherence technology.
2. Sedimentary facies analysis

The sedimentary study of individual well illustrates the presence of the carbonate platform margin, continental shelf facies and delta facies in the Lower Permian Series at the eastern margin of the Pre-Caspian Basin. Organic reef facies was developed at the platform margin. The tidal flat facies, restricted platform facies, platform margin facies in which carbonate reef bodies are present, and front slope facies were developed from east to west along the eastern margin of the Pre-Caspian Basin[2-4]. In addition, the tidal channel and coastal delta facies are present in the central segment of the middle block at the eastern margin. The platform margin reef (bank) is located in a transition zone between the platform and the deep- or deeper-water slope, with the water depth at and near the wave base, where good circulation of water body is available. This environment provides a strong hydrodynamic force, due to the joint control of wave and tidal, and hence allows grain-dominated bank facies bodies to deposit, with locally present organic reefs formed by substantial in-situ biogroups. The platform margin reef (bank) facies sedimentary bodies are commonly distributed discontinuously and parallel to the shoreline. These large-scale bodies are expressed as thick- to very thick-bedded grainstone or hummocky reef limestone in strata. This sedimentary facies belt is considered favorable for reservoir formation and evolution, due to the presence of abundant intergranular pores, organic framework pores and organic visceral pores, since they were deposited under a strong hydrodynamic condition. However, whether these bank bodies can eventually form the reservoir bodies depends on the reworking of later-stage diagenesis. When these bodies were frequently exposed from water body, the
contemporaneous-penecontemporaneous dolomitization and dissolution would occur due to the reworking of the meteoric water and mixed water, with abundant abundant inter-crystalline pores, inter-crystalline dissolved pores, inter-granular pores, intra-granular dissolved pores and moldic pores developed, forming excellent reservoir bodies. With the water depth commonly ranging from a few tens of meters to a hundred meters, the carbonate shelf is above the oxygenation level, where normal salinity and good circulation are available. Since the seabed is located in the proximity of the normal wave base, the sediments at the topographic high have been primarily reworked by wave action, and the majority of zones have been reworked by intermittent storms[4-5]. Wells YKT-1 and E-Zha-1 have encountered a variety of rocks, including marlstone, limestone and argillaceous limestone. Of these rocks, the limestone is mostly developed, as Well YKT-1 penetrated the 863 m thick (1135-1998 m) continuous section of the subsalt Lower Permian limestone. This section exhibit a strong response to seismic. Within the 3D seismic area, carbonate shelf facies is predominately located at the southeastern side, shows a banding distribution from north to south, and is surrounded by outer shelf facies that are broadly distributed across the central and western parts (Figure 3).

![Integrated histogram of the Permian Asselian sedimentary facies in Well E-Zha-1](image-url)
3. Geophysical identification of the lower permian reef bodies

Based on the several years' petroleum exploration, the recognition technologies of the Lower Permian reef-bank in the eastern margin of the Pre-Caspian Basin have been found. The technologies were used to determine the distribution of the Lower Permian reef-bank, such as sub-volume coherence, rock physics analysis, seismic inversion and strata thickness analysis.

Identification of reef-bank using the sub-volume coherence technique: The sub-volume coherence technique has provided a new idea for and proved effective in identification of special geological anomalies-reef bodies in this area. The seismic sub-volume of 3 (traces) × 3 (traces) × 3 (ms) is selected to compute the coherence, azimuth and dip attribute volumes using the location-related mid-value correlative algorithm, and then these attribute volumes are displayed through an image pixel...
combination technique (Figure 4). The azimuths (0°-360°) of different strata are stretched in different colors in Figure 3, and the right figure provides much more detailed formation information than the left figure. The merged image of the sub-volume coherence, azimuth and dip provides a clearer characterization of reef body than the ordinary coherence map. As depicted in Figure 4, the azimuths of the formations at both sides of the reef body are 175° (in purple) and 15° (in green), differing by more than 100°, the top of the reef body is located at the point where the purple changes suddenly to the green, and the reef body is nearly NS-trending. The incoherence belt in the eastern part of the image is representative of the abnormal reef body, of which the formations at both sides have the azimuth of about 175° (in purple) and 15° (in green), differing by more than 100°. Thus, the green to purple transition zone is considered the boundary of the abnormal reef body, and its distance is the actual width of the abnormal reef body. Although traditional coherence maps may illustrate the distribution of the abnormal reef body, they cannot indicate its boundary or width. For example, the boundary marked by the white arrow is basically missed on traditional coherence maps.

![Figure 4](image)

**Figure 4.** Coherence horizon slice (left) and merged image of sub-volume coherence, dip and azimuth (Right) of the Lower Permian reef body in the middle block.

Identification of reef-bank body with seismic inversion technique: The petrophysical analysis of drilling data suggests that AI (impedance) provides a tool for distinguishing the limestone from the clastic rock (limestone has a higher impedance than the clastic rock), density can serve as an indicator for distinguishing the gypsum rock from other lithologies (gypsum has the highest density among all the lithologies), and Lambda (shear modulus) can be used to distinguish the limestone from the clastic rock (clastic rock has low shear modulus than limestone).

The impedance data obtained from the sparse pulse inversion of the eastern margin of the Pre-Caspian Basin enables the resolution to be enhanced significantly and provides a quantitative characterization of the morphological characteristic of reef body. On inversion section, the relatively
high impedance portions of the Asselian Formation stretched in red and yellow represent the carbonate lithologic body, illustrate the boundary and shape of the organic reef, and define the main range of the reef (about 1-1.5 km wide); the relatively low impedance portion in green represents the argillaceous carbonate rock, with the lithology consisting of argillaceous limestone or limy mudstone; and the minimal impedance portion in blue is the mudstone section. As showed on the through-well section, Well YKT-1 is located at reef core, where organic reefs grow vertically. Depositional hiatus exist among multiple phases of organic reefs, with thin-bedded marlstone or mudstone deposited between organic reef beds. The Asselian stratum thins from east to west, with platform facies, reef-bank facies, shelf facies and basin facies deposits present. The shelf facies mudstone also thins towards the west. The carbonate-free deep sea sediments, present in west of the shelf facies, are likely to be deposited below CCD (Calcite Compensation Depth) and interpreted as undercompensated. The impedance inversion section reveals the presence of vertically superimposed reef-bank bodies of different phases in the Lower Permian Series at the eastern margin of the Pre-Caspian Basin (Figure 5).

![Impedance inversion section showing the Lower Permian reef-bank body at the eastern margin of the Pre-Caspian Basin.](image)

**Figure 5.** Impedance inversion section showing the Lower Permian reef-bank body at the eastern margin of the Pre-Caspian Basin.

### 4. Discussion and conclusions
Organic reef-bank body becomes increasingly important in oil exploration of carbonate rocks. Wells YKT-1 and CT-52 drilled at the eastern margin of the middle block produced oil & gas flow from the Lower Permian reef-bank body, which has proven to have good reservoir physical properties. This indicates the significant exploration potential of the Lower Permian reef-bank body at the eastern margin of the Pre-Caspian Basin. As this area is increasingly explored, greater hydrocarbon discovery is believed to arise. The methods used in the basin can be applied to the domestic exploration of the reef flat.

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