Further Recognition of Petroleum Exploration Potential of Marine Carbonates in Western Tarim Basin

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Abstract: A series of significant discoveries in marine carbonate rocks show great petroleum exploration potential in the Tarim Basin. However, the oil and gas fields discovered in the carbonate rocks are mainly distributed around the Manjiaer Sag in the eastern Tarim Basin. Some explorations occurred and no oil or gas field was discovered around the Awati Sag in the western Tarim Basin. Information from wells and outcrops reveals that there are excellent oil and gas source rock conditions around the Awati Sag. Transformed reef-shoal reservoirs could be formed in the Ordovician carbonate rocks with paleo-geographic background and hydrothermal conditions. Therefore, it is necessary to make a systematical study and overall evaluation of the potential of the periphery of the Awati Sag in terms of source rock evolution, resource potential, high-grade reservoir formation and distribution, and main factors controlling hydrocarbon migration and accumulation.

Key words: Marine carbonate rocks, petroleum exploration potential, Awati Sag, western Tarim Basin

1. Introduction

Well Shachan-2 located in the Tabei Uplift first got commercial hydrocarbon flow from Sinian marine carbonate rocks in 1984. Then well Tazhong-1 also got commercial flow from Ordovician carbonate rocks in the Tazhong Uplift in 1989. To this day, in the Tarim Basin not only the huge Lunnan-Tahe oil and gas field was discovered in marine carbonate rocks, but also a series of carbonate oil and gas fields were discovered in the Tabei, Bachu and Tazhong uplifts (Fig. 1). The Ordovician reef-bank complex discovered on the north

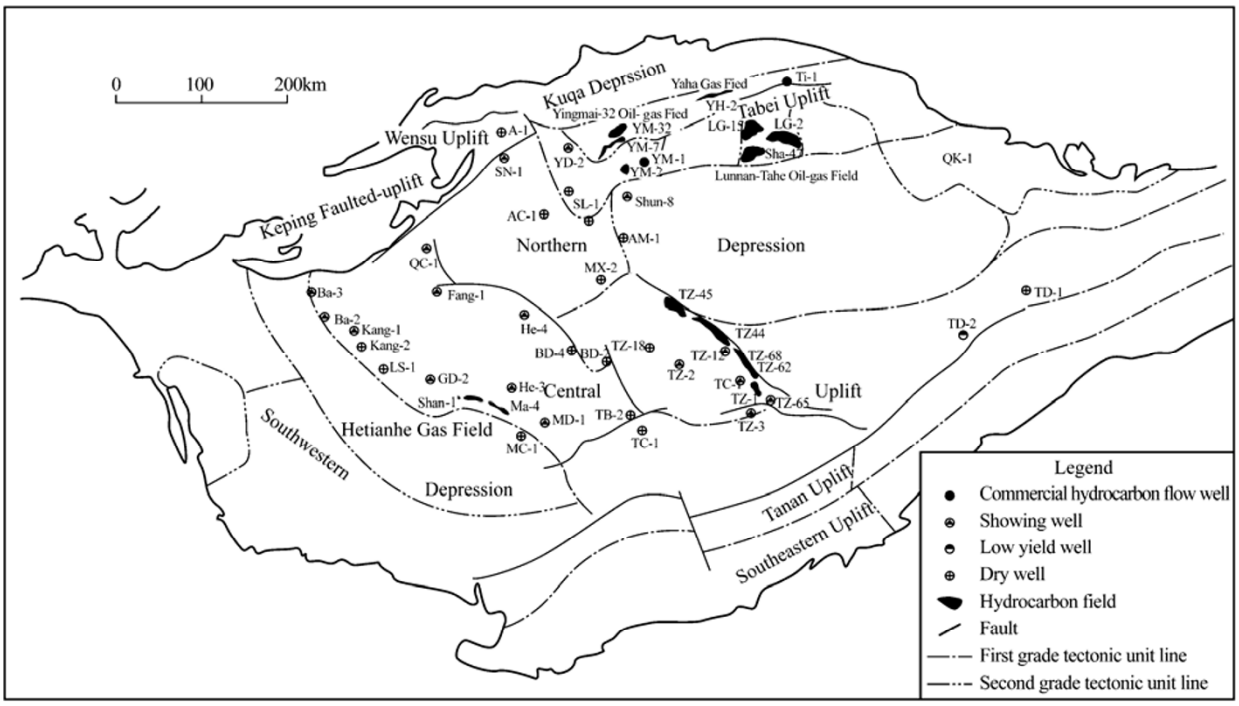

Fig. 1 Sketch map of oil and gas fields in marine carbonates in the Tarim Basin

slope of the Tazhong Uplift (Tazhong I slope break zone) in 2005 has the characteristics of high output in a single well and large reserves (Zhou, *et al.*, 2006). According to the exploration practice in the last decade, it is practicable to find huge oil and gas fields in marine carbonate rocks. The hydrocarbon discoveries in marine carbonate rocks in the Tarim Basin are mainly concentrated in the Tabei Uplift Belt and the Central Uplift Belt (which comprises the Bachu Faulted-uplift, Tazhong low uplift and Tadong low uplift), in the south-north direction. And these discoveries are mainly distributed in the eastern Tarim Basin, that is to say, they are mainly distributed around the Manjiaer Sag. However, the Awati Sag and its peripheral area, which are located in the western Tarim Basin, cover about 14×10^4 km^2. There has been little important successful exploration in exploration and little information has been acquired in this region. As the hydrocarbon exploration in carbonate rocks in the Manjiaer Sag and its peripheral area in the eastern Tarim Basin has made breakthrough again and again, it is necessary to investigate the exploration potential in carbonate rocks in the western Tarim Basin, i.e. around the Awati Sag, though no important exploration finds have been made in the past years.

2. Exploration status

For the exploration in marine carbonate rocks, the western Tarim Basin discussed in the paper includes mainly the Awati Sag and its peripheral structures which consist of Bachu Uplift (or Faulted-uplift), Keping Faulted-uplift, Wensu Uplift and Awati-Manjiaer transitional belt (Shuntuoguole low uplift). The Awati Sag was developed from Cambrian-Ordovician to Carboniferous-Permian. The floor has a maximum depth of 12,000 m in the sag (Jia, 1997).

All the study areas were covered by seismic sections, the seismic grid reached 4×4km^2-8×8km^2 in the main region, and the local region was covered by 1×1km^2-2×2km^2 of seismic section. All of the Keping Faulted-uplift was covered by seismic sections. From seismic data, a series of structural traps (including carbonate rocks) and buried hill traps were discovered in the prior period of exploration.

As early as 1963, well A-1 was drilled in the Wensu Uplift. This well drilled through the Paleogene and into the Permian volcanics, but no hydrocarbon was discovered. Above all things, since the intensive oil exploration in the Tarim Basin in 1989, a number of exploratory wells were drilled around the Awati Sag. The main drilling work was primarily concentrated in the Bachu Uplift (Pi-1, QC-1, Qiao-2, Fang-1, He-1, He-2, He-3, He-4, HC-1, BD-2, BD-4, Shan-1, Shan-2, Kang-1, GD-1, GD-2, LS-1, FN-1, SL-1, MN-1, MC-1, M-2, M-3, M-4, M-5, M-6, M-8 wells), and next in the Awati-Manjiaer transitional belt (AM-1, AM-2, MX-2, Shun-1, Shun-2, Shun-8 wells). All the exploratory wells have not got commercial hydrocarbon flow, and only a part of them got oil and gas show. However, quite a few wells did not drill into Ordovician carbonate rocks. Well WC-1 (located in the Wensu Uplift), finished drilling in 2005, had penetrated into carbonate rocks, but no hydrocarbon was discovered. This reflects the structural complexity of the Wensu Uplift, and the uncertainty of hydrocarbon reservoirs has not been well known.

For the carbonate rocks in the western Tarim Basin, only the Hetianhe Gas Field, with the Ordovician carbonate burial hill as one of the main target strata, and the Niaoshan Gas Reservoir were discovered in the Mazatage Fault Belt in the southern edge of the Bachu Uplift. Gas-source rock correlation indicates that the gas came from the deep Cambrian source rocks in the Maigaiti Slope (Qin, *et al.*, 2002; Zhao, 2002), and a small amount of mobile oil discovered came from Carboniferous source rocks. So hydrocarbon show was discovered from the ground surface to the drilling hole, but no oil and gas field was discovered.

3. Prospects

There are abundant hydrocarbon sources around the Awati Sag: 1) Wells He-4 and Fang-1 penetrated into the Cambrian in the Bachu Uplift reveals that the source rocks in the Cambrian have high organic matter abundance (Fig. 2). 2) Well SN-1 located at the northern edge of the Awati Sag got some crude oil in the Triassic glutenite and oil-source rock correlation indicates that the oil came from the Ordovician source rocks. 3) Seepage oil was developed widely in the Keping Faulted-uplift and there was mobile oil in the fractures and holes in Ordovician carbonate rocks at the Qingsongling Quarry (Fig. 3). 4) The Wuluqiao seepage oil which was discovered on the ground of the Awati Sag was from the Cambrian source rocks, which is proved by oil-source rock correlation. 5) The hydrocarbon of the Tahe Oilfield came from the southwest direction (Wang, *et al.*, 2004b) and the hydrocarbon in the Carboniferous and Silurian in the Tazhong Uplift also came from the southwest direction (Liu and Kang, 1999; Chen, *et al.*, 2004). All these facts indicate that there are plenty of hydrocarbon sources around the Awati Sag.

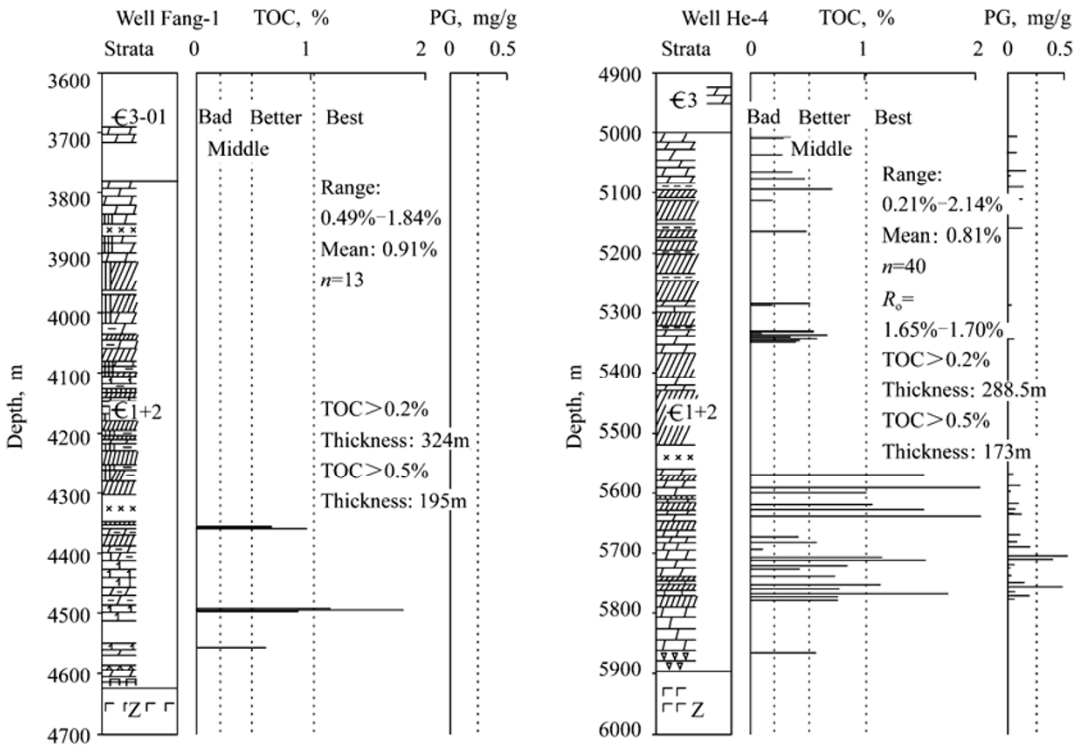

Fig. 2 Profiles of source rocks in the Bachu Faulted-uplift (after Zhang, *et al.*, 2004)

Fig. 3 Keping Outcrop showing mobile oil in Ordovician carbonate rocks

Approximately thirty wells were drilled in this region but no oil and gas was found. The reason for this is that the migration and accumulation of oil and gas in this region is complex. For example, for several exploratory wells drilled in the Awati-Manjiaer transitional belt, the deepest one was up to 6,500 m and finished drilling in the Silurian. Logging data demonstrates that the gas log show was quite widespread. An important reason for the lack of hydrocarbon discovery in the Carboniferous and Silurian rocks was the shortage of huge faults communicating with the hydrocarbon source rocks. This is just one of the reasons that one should pay attention to the deep carbonate rocks. And it shows that the hydrocarbon in the Ordovician carbonate rocks had not been destroyed. The gas log show in the Silurian and Carboniferous may be the result of the gas in Ordovician diffusing upwards. Because of serious heterogeneity and poor connectivity in the lateral direction, it is difficult for hydrocarbons to migrate a long distance (Pu and Qing, 2003). As seen by the oil and gas reservoirs discovered in the carbonate rocks in the Tarim Basin, the Ordovician was the main hydrocarbon source rocks (Zhang, *et al.*, 2000). Because of the short distance between Ordovician source rocks and Ordovician reservoir rocks, hydrocarbon may be accumulated in the Ordovician reservoir rocks and did not migrate further.

It was encouraging for the exploration in the Awati-Manjiaer low uplift that a reef-bank complex reservoir with high quality in the Ordovician was discovered in the northern slope break belt (named Tazhong I fault belt) between the Tazhong Uplift and the Manjiaer Sag. It is not an isolated case that slope break belts appear on the edge of the deep sag. The reef-bank distribution has the characteristic of being in

rows or in belts, such as the atoll reef in the Permian Basin of the USA (Cao, 1993). Additionally, the volcano activities in the Permian were developed in the western Tarim Basin (Wen, *et al.*, 2005) and deep hydrothermal activities existed in this region (Zhang, 1997; Jin, *et al.*, 2002; Wang, *et al.*, 2002; Yu, *et al.*, 2002; Huang, *et al.*, 2004a; 2004b; Zhu, *et al.*, 2005). The geothermal fluids obviously improved the carbonate reservoirs by exchanging matter and energy between minerals to form hydrothermal dolomite, porous calcium fluorite, thus improving the preservation capability further (Lü, *et al.*, 2004; 2005; Wang, *et al.*, 2004a; Yang, *et al.*, 2005).

4. Suggestions

Some suggestions were made for systematical study and overall evaluation of the periphery of Awati Sag.

1) Recognition of the resource potential. The evolution of hydrocarbon kitchens and the resource potential should be re-evaluated. The resource potential could be estimated by studying the hydrocarbon expelling time, intensity and quantity of hydrocarbon kitchens in the Awati Sag and its peripheral area. The structural variation had influenced widely the periphery of the Awati Sag. The quantity of hydrocarbon destroyed should be estimated and the residual resources potential may be determined.

2) Recognition of the formation mechanisms and distribution of high-quality reservoirs in marine carbonate rocks. The development and distribution of favorable reservoirs (such as the reef-bank complex discovered in the northern slope of the Tazhong Uplift) should be studied from both sedimentology and restoration of lithofacies palaeogeography. The favorable distribution region of the secondary reservoirs could be estimated in terms of improvement of reservoirs by structural and hydrothermal activities.

3) Recognition of the main factors controlling hydrocarbon migration and accumulation. Because of a big difference in the nature and activity history of the palaeohighs around the Awati Sag, they should be studied separately. The Awati-Manjiaer transitional belt was a sustained low uplift, the Bachu Uplift was an active palaeohigh, the Keping Faulted-uplift began to override on a large scale in the Paleogene period, and the Wensu Uplift was raised highly and denuded deeply. Trap formation, reservoir development, and late preservation should be studied according to different conditions of the object to be evaluated. Consequently, the key factors controlling and restricting the migration and accumulation of hydrocarbon should be evaluated.

4) Recognition of favorable exploration targets. There are few exploratory wells aimed at the carbonate rocks on the periphery of the Awati Sag. For example, a few wells drilled at the Awati-Manjiaer transitional belt aimed at Carboniferous and Silurian, and well SN-1 aimed at Triassic. There are only a few exploratory wells which aimed really at the Cambrian-Ordovician carbonate rocks in the Bachu Uplift and a primary reason for the unsuccessful wells is that they did not drill into excellent reservoirs. For selecting main exploration target strata and favorable zones, re-evaluation is necessary. The carbonate rocks in the Awati-Manjiaer transitional belt are worth considering seriously.

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