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Tertiary Reefs of the South China Sea and Their Oil-Gas Bearing Characters

Key words: South China Sea, Tertiary reef, component factor of the source, reservoirs and capping, condition of migration, trap and preserve.

The South China Sea, located at the juncture of Eurasia, Pacific and Indo-Australian plates, is of special tectonic-geological setting. Since Mesozoic, there occurred extension, congregation, strike-slip, spreading and subduction in this area, resulting in the formation of the rhombus oceanic basin and the four typical structural margins. They are characterized at the extensional zone or passive margin in the north, the condensing zone in the south, the shear zone in the west and the subduction zone in the east. Because of the appropriate climate, environment and paleogeography during Tertiary, the development of carbonate rocks and reefs had the dominant position. The various types of the Tertiary reefs mainly develop in Cenozoic basins, namely Zhujiangkou Basin, Qiongdongnan Basin, Yinggehai Basin, Wanan Basin, Zengmu Basin and Balawang Basin, which are situated in the northern, western and southern structural zones of the South China Sea. It is confirmed that the locations of these reefs were distinctly controlled by the paleo-structures. The reefs in the northern margin distributed obviously along the positive tectonic zones trending NE. In the western, they grew roughly on the upper sides of the large strike-slip extensional faults or their branching. And in the southern, their developments depended upon features of the basement. The growth and distribution of these reefs were also influenced by the large river systems in that time.

Distribution, type and lithology of the reefs

Yinggehai Basin

The reef limestones generally develop at the littoral-neritic zone with the main type of platform-edge reef. The reef-building organisms are both incrustation red algae and bryozoan that formed twine texture according to the drilling data.

Qiongdongnan Basin

The reefs and organic banks roughly develop in isolation at the upwelling parts of the fault depressions and their locations were distinctly controlled by the basement fractures. The types of the reefs are mainly patch-reef, atoll (fig.1) and platform-edge reefs, being of the reef-building organisms of the incrustation red algae, bryozoan, coral and sponge.

Zhujiangkou Basin

There are a large number of reefs growing at the carbonate platforms of Dongsha uplift and Shenhua uplift and their types are greatly pyramidal-reef, massive-

reef, platform-edge reef and so on. The various types of these reefs cause the difference in organism and lithology. The reef-building organism can be sum up into ten types that is red algae, green algae, protozoa, sponge, coelenteron, bryozoam, brachia, mollusk, arthropoda, etc. And the reef lithology is concluded as boundstone, grainstone, packstone and wackestone.

Wanan Basin

The reefs primary distribute in the middle and the south of this basin and the types are characterized as massive-reef, pyramidal reef as well as platform-edge reef (fig.2), overlaid by the grainstone and packstone of 5m thickness deposited in the deep sea. The biohermal facies belongs to skeletal bioclastic limestone developing at the sea of 10-50m bathimetry.

Zengmu Basin

The growing area of the reefs can be separated into two parts that are Xibu platform

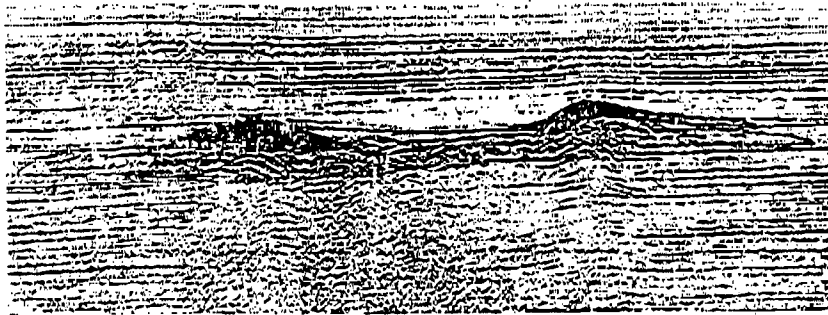


Fig1. Atoll located in Qiongdongnan Basin

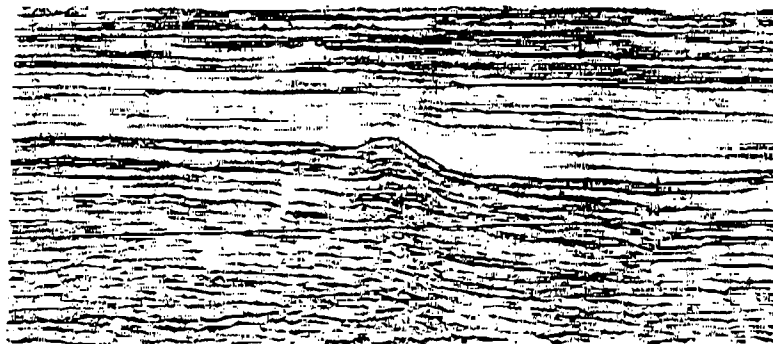


Fig.2 Platform-edge reef located in Wanan Basin

and Nankang platform. The type developing at the first is distinctly pyramidal reef with the reef-building organisms of red coral, algae, echinoderm, mollusk, plankton foraminifera and ostracoda and the later are mainly platform-edge reef, pyramidal-reef and massive-reef with the reef-building organisms of coral polyp and coral-algae, which forming the wave-resisting framework. A lot of reef rocks became the grain

dolostone because of dolomitization in the evolution of the diagenetic and epigenetic stage.

Balawang Basin

The reefs distributed at both inner neritic platform and outer neritic platform. The character of the reefs, which types are mainly pyramidal ones, are of big thickness and good physical property. The reef limestone is made up of skeletal packstone, skeletal grainstone and boundstone with the reef-building organisms of coral, bryozoan, mollusk, red algae and foraminifera.

Oil-gas bearing characters of the reefs

Good assemblage of hydrocarbon generation, reservoir and capping strata and great conditions of migration, trap and protection can make the basins to be worthy of oil-gas bearing ones.

Zhujiangkou Basin

The sediments of this basin are composed of Cenozoic strata with thickness of ten thousand meters and the reefs developed in Miocene are of fine forming conditions of oil-gas deposit.

Hydrocarbon generation

The three oil-generating beds in Zhujiangkou Basin are Eocene Wencang Formation, Oligocene Zhuhai Formation and lower Miocene Zhujiang Formation. The shale of Wencang Formation with the parent source material of sapropel and mixing kerogen and 1.72% of TOC abundance is the best oil-generating rock, being of high maturity and great potential source. Enping Formation is consisted of limnetic and littoral argillites with the parent source material of humic and mixing kerogen and the TOC abundance is 1.03-1.16%. The parent source material of Zhujiang Formation which are composed of the marine argillite is characteristics of sapropel kerogen and low maturity, the potential source of it is lower than the two firsts.

Reservoir

The reef-limestone developing at the Dongsha Uplift and Shenhu Uplift in early Miocene are 307m-563m thick. According to the drilling data, the natural gamma-ray logging at the reef-showing segment displays low figure and little undulation and the tadpole plot of dip log at the same segment shows irregular chaotic shape. These illustrate the pores and holes of the reef reservoir containing coral and red algae. The 561.1m thick of the limestone reservoir at the big reef oil-field, Liuhua 11-1, are made up of foraminifera-coral packstone with the pore types of intergranular, intragranular and intercrystal pores, hole and fissure, being of the porosity of 5.6-22.9% and the permeability of 50×10^{-3} - 260×10^{-3} v m². The average porosity of the reef-reservoirs of this basin is 14.4-29.3% and the average permeability of these, 65.6×10^{-3} - 830.4×10^{-3} v m².

Capping

The argillites of Zhujiang Formation in middle Miocene are of the most thickness of 895m and the general thickness of about 500m, which are fine capping strata with very good continuous layer except the west-northern fringe of this basin and the center of the old-delta. All most reefs grew in early Miocene, so the argillites deposited in middle Miocene give rise to the fine capping strata.

Trap

The reef traps of this basin can be divided into three types. 1) The reef rock traps: that is the reef rocks developed at the swelling basement, such as Huizhou 33-1 Reef Rock in upper early Miocene, which oil-pool distributed at the bottom of the reef limestone of 174.5m thick in Zhujiang Formation. 2) The lithologic-reef trap: the assemblage that the reef rock overlaid by fine-grained sediment gives rise to the further barrier and the increase of height and volume of the trap, resulting in the formation of this trap. 3) The structure-reef trap: the structure occurred after the reef had grown, leading to the formation of the trap.

Migration

The hydrocarbon migrated through the surfaces of unconformities and faults as well as through the continuous reservoir layers in this basin. Zhuhai and low Zhujiang Formations depositing over the oil-producing layers and overlaid by upper Zhujiang Formation are composed of the coarse sediments in marine facies, which lead to the passageways of petroleum migration. There is abundance of accumulating hydrocarbon in Liuhua 11-1 Reef Rock Field, situated at Dongsha Uplift. This area is apart from the domain of the source layers at a distance of 40-50km and the faults cannot play the part of long migrating passageway, so the hydrocarbon migration depended principally on the great marine reservoir layers.

Yinggehai Basin

The mainly oil generating layers are Paleogene ones containing an organic-carbon average of 1.95% with II kerogen. Patch-reefs and platform-edge reefs are the reef-reservoirs with the porosity of 5.40-14.43% and the most permeability of $16.94 \times 10^{-3} \text{ } \mu\text{m}^2$, average permeability of $0.12 \times 10^{-3} \text{ } \mu\text{m}^2$, belonging to the low permeability ones. The cause of the low permeability of the reef-reservoirs is that the reef rocks with the little thickness and the lack of secondary pores did not undergo the perfect dolomitization at the diagenetic stage and never through out exposure.

Qiongdongnan Basin

The mainly oil generating layers are Paleogene ones in this basin like Yinggehai Basin. The organic-carbon in the argillite of Yacheng Formation is of an average of 1.16% with II-III kerogen, which is the fine oil-produce layer, and the organic-carbon in the coal-layer in this formation, an average of 39.25% with III kerogen. The organic-carbon in the argillite of Lingshui Formation is of an average of 0.6% with II 2 kerogen and, in the coal-layer of this formation, of 52.53% with III

kerogen. The distribution of the oil-product strata developing in the segmental depressions are controlled by faults, causing the reef-pools located first at the inside of the depression and then, at the uplift closing to the depressions. The argillite overlying the rock reservoirs is the capping layer.

Wanan Basin, Zengmu Basin and Balawang Basin

The three basins situated at the south of the South China Sea are of different oil-bearing character.

Oil-generating rocks.

The hydrocarbon resources of the three basins are primary made up of the argillite and shale, a little marl of littoral-neritic and limnetic facies in Oligocene. The oil-generating strata in Wanan Basin contain organic-matter with II-III kerogen and a lot of terrestrial plant shard. Because the organic-matter is in mature stage and high mature stage, drainage hydrocarbon ratio is high. So the oil-generating strata are provided with the abundance hydrocarbon source. The oil-generating strata with TOC abundance of 0.33-2.48% in Balawang Basin are made up of limestone and calc-shale of intertidal zone and neritic zone and are provided with the fine oil-producing source. The oil-generating strata in Zengmu Basin are made up of coal and shale of lacustrine and limnetic facies. There are three oil-producing depressions in the basin that is Kangxi depression, Nankang platform and Balinjian depression.

Reef-reservoirs and capping strata and others

The reservoirs are distinctly reef rocks in Oligocene as well as Niduo Reef in Balawang Basin. The various types of middle-late Miocene reefs in Zengmu Basin characterized by large areas and thickness and high porosity and permeability. The reef reservoirs with a lot of secondary pores are all fine, being of the porosity of 15-30% and average permeability of $3.94 \times 10^{-3} \text{ v m}^2$. There are three causes of the forming secondary pores; one is the freshwater dripping, next, CO_2 dissolve and the third, dolomitization. The developing of the secondary pores is also related to the primary texture. The bio-limestone is the best rock forming secondary pores and grainstone, the next. There are well conditions of oil-gas migration, trap and preserve together with the combination of the source, reservoir and capping rocks giving rise to the formation of the reef oil-gas agglomerate zones in the basin. The basins are provided with good area capping strata and/or part capping strata because of the fine sediments that deposited in deep sea including the mudstone of 1000-5000m thick which distribute a large area. In Wanan Basin, the developing of the oil field is been going in these reefs now. The component factor of the source, reservoir and capping is fine in this basin, but there is no the long-distance migration, resulting that the traps far from the source rocks are all invalid ones.

The reefs of these basins in The South China Sea are of different oil-gas bearing characters, which can be separated into three varying degrees, that is Zhujiangkou Basin and Zengmu Basin is the most, Wanan Basin and Balawang Basin, next, Yinggehai Basin and Qiongdongnan Basin, the third.