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Tectonic evolution of North Seram Basin, Indonesia, and its control over hydrocarbon accumulation conditions

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Abstract: Based on previous studies of plate evolution and analysis of regional geological characteristics in the North Seram Basin, Indonesia, the basin evolution was divided into four stages, i.e. Early Triassic initial rifting, Middle Triassic–Middle Jurassic rifting, Late Jurassic–Middle Miocene passive continental margin, and Late Miocene–Quaternary thrusting. Then, the control of tectonic evolution during different stages over hydrocarbon accumulation conditions was discussed in order to provide references for exploration in the Banda Arc area. Affected by Mesozoic tectonic activities, the North Seram Basin experienced a sedimentary evolution from carbonate ramp to platform during the rifting stage, and major source rocks in the Upper Triassic–Middle Jurassic Saman Saman Formation were developed under the control of the paleotectonic framework and distributed throughout the restricted platform during the rifting stage. The favorable Manusela Formation carbonate reservoirs that were developed during this stage on the highs in the south of the basin are the primary exploration targets. Varying tectonic activities during the thrusting stage both led to differences in the thermal evolutions of the source rocks and influenced the trap types and their distribution in tectonic belts. Moreover, the reactivated faults and micro-fractures improved the physical properties of the carbonate reservoirs, and together with the Pliocene unconformity, they constituted the main hydrocarbon migration pathways.
Key words: control, hydrocarbon accumulation conditions, tectonic evolution, the North Seram Basin, Indonesia

The North Seram Basin is located in the Seram Island and the Seram Sea at the northern margin of Banda Arc, eastern Indonesia. It has an area of 5.3×10^4 km^2 and a maximum depth of over 2000 m. According to the data of the United States Geological Survey (USGS)[1], the Banda Arc area mainly refers to the North Seram Basin and the Timor Basin, and it is expected to hold an undiscovered oil and gas resource content of $(2015.1–11134.6)\times10^6$ bbl, thus showing certain exploration potential. The North Seram Basin is the only proven Mesozoic petroliferous superimposed basin in the Banda Arc area, and its exploration practices are of great significance when contemplating how to guide production and research in this zone. Many scholars and experts have contributed a large number of achievements and papers focusing on this basin. However, the North Seram Basin is far less explored; there is less and unsystematic analysis on the hydrocarbon accumulation rules in this basin, and some disagreements exist regarding the evolution of the basin's regional tectonics and the geological structure of the basin. Some scholars[2] believe that the Bird Island micro landmass to which the North Salem Basin belongs is extrinsic. They believe that due to regional extension and rifting in the Early Permian-Middle Triassic, this micro landmass drifted towards the northeast of the Timor Island until it reached its present position. Moreover, they also believe that the Middle Tethys that formed in this period affected the structural and depositional evolution of the North Seram Basin. Other scholars[3–4] hold that the Bird Island micro landmass was native, and so it did not experience a large relative movement as a whole. They believe that there was block rotation and movement within the micro landmass, but their understandings differ regarding the palaeotectonic location of block during its reconstruction. In the Mesozoic, the North Seram Basin stayed near the margin of the palaeo-continent for a long time; thus, it was influenced greatly by the sea. In addition, there are many geological theories regarding the origin of the Seram trough at the northern boundary of the North Salem Basin, such as subduction trench[5], intracontinental thrust belt[6–7], and foredeep[8–9]. These varying understandings are the root cause of the differences in the analysis of basin tectonic styles by different scholars.

Based on previous studies, together with drilling data and other data, this paper systematically analyzes the tectonic evolution of the North Seram Basin and its controlling effect on the geologic conditions of hydrocarbon accumulation in order to provide references for oil and gas exploration both in this basin and in other similar basins in the Banda Arc area.

1. Regional geological setting

Tectonically, the North Seram Basin is located in the

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Australian plate, adjacent to the Banda micro plate in the south and in the margin of the arc-continental collision belt. The northern part of the basin is bounded by the Seram trough in the north, the Ruru strike-slip fault belt in the west, a group of NWW-SEE Kawa strike-slip fault belts and metamorphic thrust belts in the south, and the Tarera- Aiduna strike-slip fault belt in the east (Fig.1).

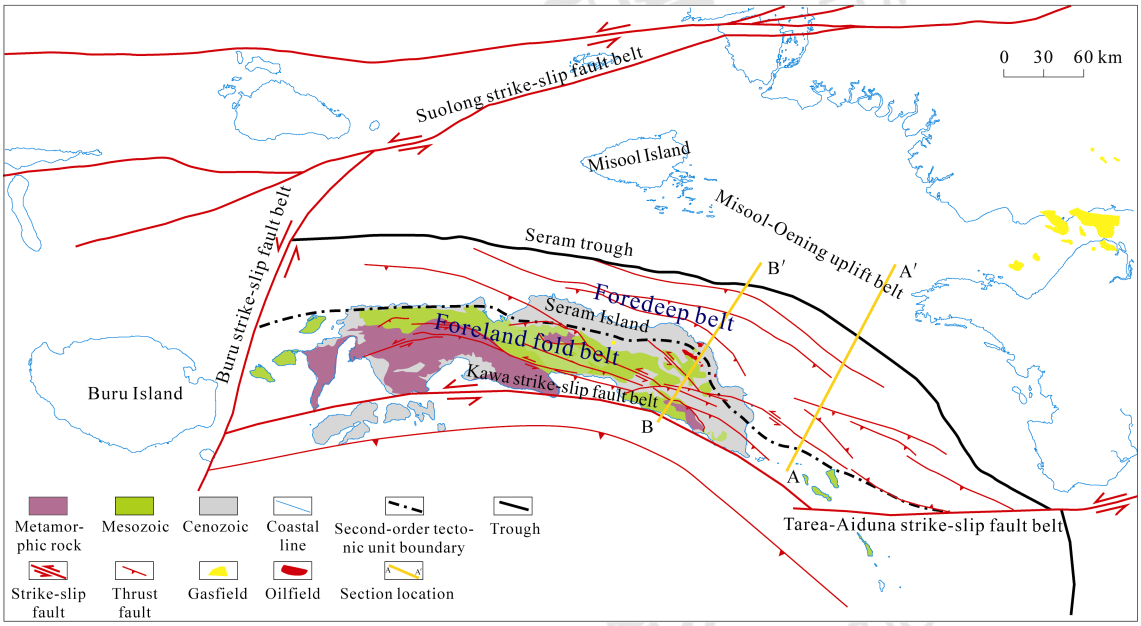

Fig. 1 Location of the North Seram Basin (Redrew based on [6-11])

The North Seram Basin is a complex superimposed basin formed in the Mesozoic and the Cenozoic, and it has features of a foreland basin. It is a part of the ramp foreland basin belt in the Bird Island region, eastern Indonesia. According to its structural characteristics, the basin can be divided into two second-order tectonic units (Fig.1): foreland fold thrust belt and foredeep belt. In the foreland fold thrust belt, the Cenozoic is commonly absent, and the Mesozoic is widely outcropped; the NWW-SEE strike-slip faults and high-angle thrust faults are developed, forming a series of imbricate fan and thrust folds that are currently the major targets of deep exploration. In the foredeep belt, the Cenozoic becomes thinner eastwardly, and there are gentle folds, imbricate fans, thrust uplifts and other structures; the offshore area was the prominent field for early shallow exploration, which discovered oil and gas[12].

2. Feature of tectonic evolution

The formation of the North Seram Basin was started in the Permian, which was intimately related to the division of landmass in the northwestern Australian palaeo-continent and the matching of the Seram micro landmass. According to previous research[6–11] and analysis of available geological and seismic profiles, the tectonic evolution of the basin can be divided into four periods, i.e. initial rifting, rifting, passive continental margin, and thrusting.

2.1. Initial rifting period

In the Paleozoic, the North Seram Basin was located at the margin of the Australian palaeo-continent and near the ocean crust. It was dominated by schist, gneiss and other metamorphic rocks. In the early Triassic, the Australian palaeo-continent was drifting northwardly. Due to the expansion of the Middle Tethys, there were some lowly-metamorphosed clastic rocks and/or limestones in the structural depressions that were formed under the tension of the continental margin. These rocks are usually regarded as the oldest sedimentary rocks in the basin (Fig.2a).

2.2. Rifting period

In the Middle Triassic, with the intensifying expansion of the Middle Tethyan, the rifting was strengthened. As a result, multiple horst-graben systems controlled by normal faults were formed, and they controlled the distribution of the Mesozoic. During this period, transgression enhanced, and a set of flysch deposits, namely the Kanikeh Formation, with a thickness of 1000 m, was developed under the background of the continental shelf[6–8]. The Kanikeh Formation is mainly composed of gray and dark gray medium-fine sandstone interbedded with shale and locally, with coal, thus showing its potential as a source rock.

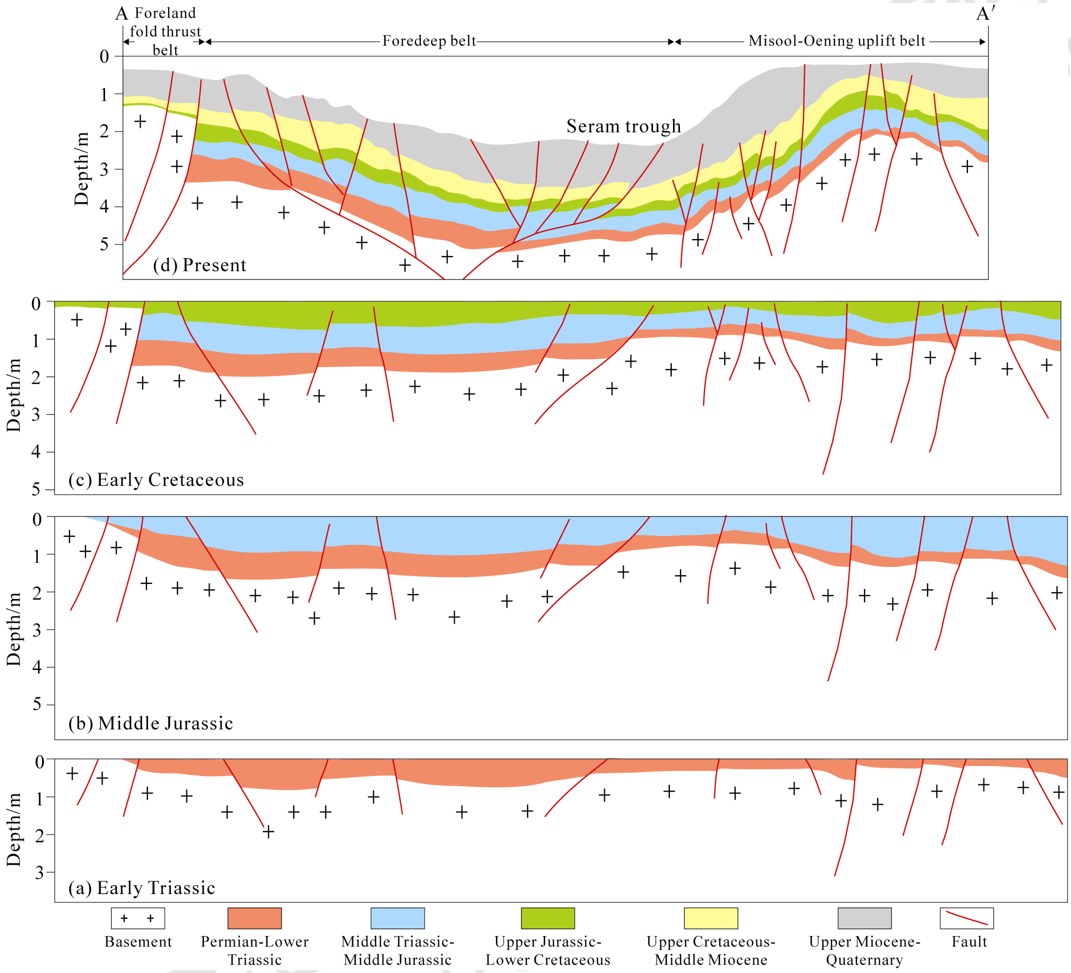

Fig. 2 Tectonic evolution of the North Seram Basin (section location marked in Fig.1)

In the Late Triassic-Middle Jurassic, the Myanmar, Malaysia and other micro landmasses began to separate from the Australian palaeo-continent, and the tension of the northern margin of the Australian palaeo-continent was intensified, which gave rise to a horst-graben system (Fig.2b). The North Seram Basin drifted to areas with middle and low latitudes, and the whole area began to transform into a carbonate platform deposition system. Influenced by low-amplitude swelling and local uplifting, some high-energy carbonate deposits were formed in the southern highlands of the basin, of which most were reefs, skeletal limestones and oolitic limestones; this formed the Manusela Formation. In the middle-northern part of the basin, the sedimentary environment was transformed into a restricted sea which was dominated by gray and dark gray marl, dolomite and mudstone intercalated with some chert deposits; this formed the Saman Saman Formation. It interacts or overlaps with the Manusela Formation in the basin, forming a good source-reservoir assemblage.

2.3. Passive continental margin period

In the early stage of the Late Jurassic, the whole area was uplifted again, and the sea level descended, causing a depositional hiatus. In the late Jurassic, due to the fact that the Myanmar, Borneo and other micro landmasses were separated from the Australian palaeo-continent, the prototype of the Banda Sea was formed and the basin was quickly transgressed and turned into a slope sedimentary environment. The thermal subsidence stage started and a set of gray and gray-green shale was formed in the basin. After that, the northern margin of the Australian palaeo-continent showed tectonic uplift and denudation as well as local severe volcanic activity. In the late stage of the Early Cretaceous, each micro landmass was far away from the Australian palaeo-continent and regional tectonic activity tended to be peaceful. The basin entered a stable continental drifting period, presented as a stable open ocean sedimentary environment (Fig.2c). A thick set of deep-water marl, siliceous shale, and chert-bearing strata was deposited in the area.

In the Paleocene-Middle Miocene, the Australian palaeo-continent continued to drift northward, and the northern margin began to collide with Caolin and other micro landmasses. In this period, the structure was characterized by frequent alternation of uplifting and subsidence, which resulted in intermittent deposition and erosion. The gray and dark gray shales, marls and limestones were the sedimentary bodies.

2.4. Thursting period

In the Late Miocene, a strong collision occurred in the surrounding plate, and the normal fault in the rifting period was reactivated and turned into a reverse fault. The North Seram Basin entered a stage of evolution characterized by contracting structures, and regional uplifting and denudation events were obvious. From the late stage of the Miocene to the early stage of the Early Pleistocene, the strong subduction collision of the Banda Arc made the Seram Island and other areas move continuously toward the northeast, and the southern part of the basin shrunk and uplifted, resulting in a foreland fold thrust belt. In the northern part of the basin, a set of structures related to the detachment thrust faults was formed and gradually evolved into the foredeep belt. The deposition and evolution of the foredeep belt was controlled by the thrust napping of its adjacent foreland fold thrust belt [13]. In this period, volcanic activity in the southern part of the basin was intense, forming a large area of volcanic rocks. Since the rapid uplifting and denudation in the southern part of the basin brought in a large quantity of sources, a set of slumping sediments were formed in the foreland locally.

From the end of the Pliocene to recent, the continuous contraction caused by the plate collision stopped being absorbed by the thrust belt, and the sinistral strike-slip has become the main structural style in the region (Fig.2d). The Tarera-Aiduna strike-slip fault belt at the eastern boundary of the North Seram Basin was formed. The denudation material from the uplifting of the foreland fold thrust belt continuously filled into the foredeep belt, and a set of mudstone, siltstone and conglomerate strata rapidly filled in the central-northern part of the basin. In the Pleistocene, a set of delta facies-neritic clastic rocks was deposited in the foredeep belt, and with the local development of reefs and so on, formed the Fufa Formation.

3. Control of tectonic evolution on hydrocarbon accumulation conditions

3.1. Control on formation and thermal evolution of source rock

The information on source rocks in the North Seram Basin is not derived from the direct study of source rock samples in the region but is rather mostly indirectly derived from geochemical analysis of oil and gas wells or oil and gas seepages and from analogies of outcrop data in related areas. The results of previous studies show that the Saman Saman Formation of the Upper Triassic-Middle Jurassic in the rifting period of the North Seram Basin is the major source rock, as it contains type II sulfur-rich algal kerogen. In general, it is a marine sedimentary environment dominated by the contribution of aquatic organisms. Therefore, based on analysis of the regional tectonic evolution and combined with data from analogical analysis in related areas, the regional depositional pattern in the North Seram Basin in this period should be analyzed, as it would be beneficial towards predicting the distribution and development characteristics of source rocks and reservoirs in the basin in the rifting period.

The wells in the Osir oilfield in the North Seram Basin revealed part of the Saman Saman Formation, but the analysis of sidewall coring samples showed an average organic carbon content of 0.48% and poor quality source rocks. Since the samples taken from Well Osir-1 are not located in favorable sites for the source rocks, these samples are not representative. However, some strata coeval with the development of the Saman Saman Formation source rock are outcropped in the Buru Island, Misool Island, Timor Island, and other islands, all of which have similar tectonic and sedimentary evolutions to that of the Seram Island, and these strata have had numerous geochemical analytical data collected on them (Table 1). Firstly, it is indicated by analysis of the outcrop data of Timor Island that the neritic marine marl in the Upper Triassic-Lower Jurassic Aitutu Formation contains an organic carbon content of 2.85%–9.16% (averaging 6.69%), a hydrogen index of 291–555 mg/g (averaging 434 mg/g), and an average hydrocarbon generation potential of 31.9 mg/g. It is of high-quality Type II kerogen with oil-prone characteristics. In contrast, the Aitutu Formation shale shows a relatively poor quality of organic matter, with an average organic carbon content of 0.87%, a hydrogen index of up to 13 mg/g, and an average hydrocarbon generation potential of 0.18 mg/g. Secondly, there is a large set of Middle-Lower Jurassic black mudstone outcropped in the Misool Island, and it is speculated to have some hydrocarbon-generating potential, but corresponding geochemical analysis data is unavailable. Thirdly, the outcrops in the Buru Island reveal that the Upper Triassic-Lower Jurassic Ghegan Formation contains deep marine calcareous mudstone, asphaltic shale and limestone, with an organic carbon content of up to 16% and a hydrogen index of up to 539 mg/g, indicating Type II algal kerogen. The outcrop data in the above areas indicate that the Saman Saman Formation source rocks of the Upper Triassic-Middle Jurassic in the North Seram Basin may have similar qualities and thus would be excellent source rocks.

According to the tectonic evolution of the North Seram

Table 1 Characteristics of source rocks within the areas around the Seram Island[7–9,14–17]

Region/area	Horizon	Lithology	Organic matter content/%	Hydrocarbon-generating potential /(mg·g^{-1})	Hydrogen index/(mg·g^{-1})	Kerogen type	Sedimentary facies
Timor Island	Upper Triassic-Lower Jurassic Aitutu Formation	Marl	2.85–9.16, averaging 6.69	8.4–45, averaging 31.9	291–552, averaging 434	Type II	Neritic
		Shale	0.23–1.5, averaging 0.87	0.15-0.2, averaging 0.18	10–13, averaging 11.5	Type III	Estuary or neritic
Misool Island	Middle-Lower Jurassic	Black mudstone	-	-	-	-	Restricted sea
Buru Island	Upper Triassic-Lower Jurassic Ghegan Formation	Calcareous shale, bituminous shale and limestone	16	-	539	Sulphur-rich type II algae kerogen	Deep sea

Basin during the rifting period, in the Late Triassic-Middle Jurassic, the neritic continental shelf and restricted platform in the central-northern part of the basin had the background favorable for the formation of high-quality carbonate source rocks. In the Late Triassic, transgression started in the basin, causing it to adopt acarbonate gentle slope sedimentary model. The water circulation was relatively good and some organic matter-rich marl was developed in deep waters with low energy locally. In the Middle Jurassic, carbonate build-up in the southern part of the basin was gradually formed, restricting the circulation of the water body in the northern part and causing it become a restricted platform (Fig.3). Furthermore, the horst in the north of the basin controlled by the normal fault in the Misool-Oreon uplift belt also affected the input of terrestrial materials. During this period, the basin was in the middle and low latitudes, thus placing it under a hot and humid climate, which favored the bloom of algae. Finally, a set of carbonate rocks with organic-rich marls was formed in the central-northern part of the area, serving as the high-quality source rock.

In the North Seram Basin, crude oil was formed when the R_o of source rock was 0.7%–1.2%, and wet gas and condensate oil began to occur when the R_o was 1.3%–2.0%. The depth for the oil window is 3658–6069 m[14–15]. The deep burial and thermal evolutions of the Saman Saman Formation source rocks were controlled by the late compressional tectonic events. In the Late Miocene, the overlaying of the foreland fold thrust belt and the Mesozoic thrust made the burial depth of the Saman Saman Formation source rock reach 3–5 km, causing it to entering the oil window. Due to the increase of t compressive strength in the Pliocene, the depth of the source rock further increased, reaching a depth of 7 km or even deeper. It entered the highly mature stage and started to generate and discharge large quantities of hydrocarbons. However, due to the differences in the overlay thickness of the Mesozoic strata in different fault blocks, the maturity of hydrocarbon source rock varied, and thus there were multiple periods of hydrocarbon generation and expulsion. The Paleocene-Pleistocene, which is a few kilometers thick in the foredeep belt, was the key load for the thermal evolution of the source rock. It pushed the burial depth to 4–5 km or even deeper, thus entering the mature stage.

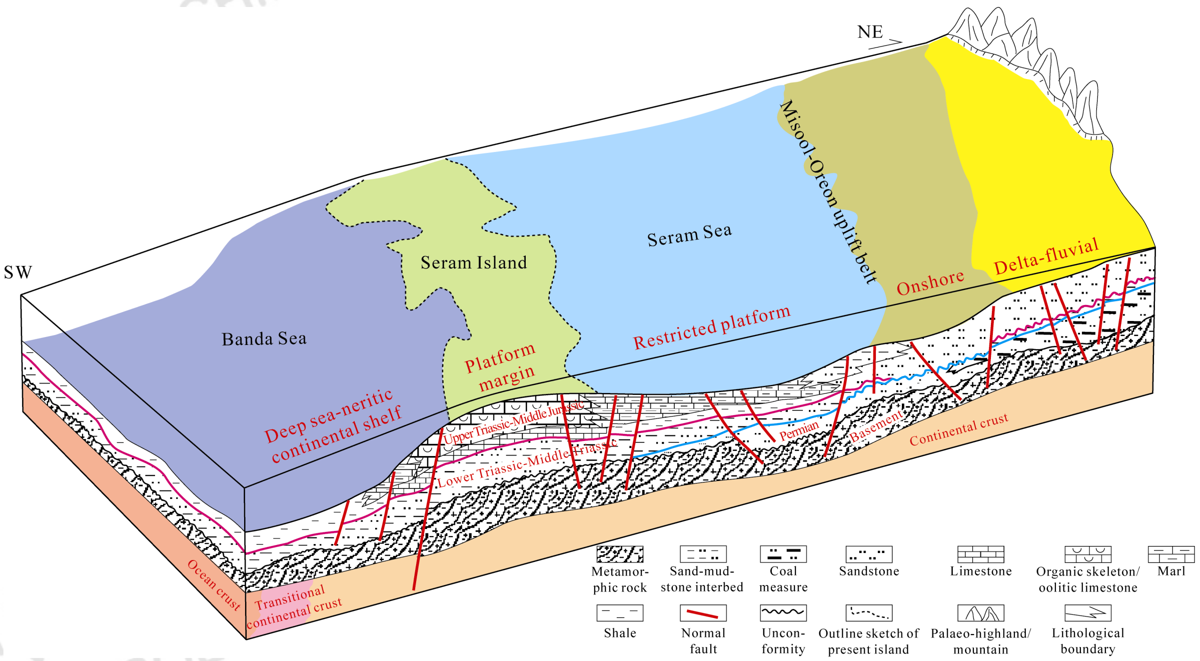

Fig. 3 Sedimentary model of the Middle Jurassic carbonate in the North Seram Basin

3.2. Control on reservoir formation

The formation and evolution of reservoirs in the North Seram Basin are closely related to two periods of tectonic events. During the rifting period, the rift system was well developed, and the water bodies in the horsts and some structural highs in the southern margin of the basin were relatively shallow. The carbonate productivity was high and the reef-biotite communities were well developed, gradually forming a carbonate built-up. It caused the separation of the continental shelf and the differentiation of sedimentary facies. The southern part of the basin transformed into platform margin facies. The organic skeletal limestone, oolitic limestone and other high-energy carbonate rocks were well developed, making this part the most important reservoir development area identified in the basin (Fig.3). This set of limestone, namely the Manusela Formation limestone, mainly contains intergranular pores, intragranular pores, and dissolved pores. However, it has poor physical properties due to cementation and dolomitization. Specifically, the porosity is 2.3%–9.2%, averaging 5.6%, and the permeability is less than 482 mD. During the thrusting period, the tectonics effectively improved the physical properties of the reservoir, and a series of fractures and reverse faults were formed, presenting a network-shaped distribution and serving as important reservoir spaces.

The Pleistocene Fufa Formation in the North Salem Basin was the earliest exploration target. In the thrusting period, the uplift belt in the southern part of the basin provided an abundant source of detritus, and the foredeep belt in the northern part became the unloading area, where a thick layer of uncemented delta-shallow clastic sedimentary systems was formed. Specifically, some bioherms were formed in an uplift with shallow water bodies and a local scarcity of detritus sources, marking it asan excellent reservoir as well. The average porosity of the Fufa sandstone reservoir in Bula oilfield is 28%, and its average permeability is 72 mD.

3.3. Control on cap rock

During the period of passive continental margin, as a result of the extension of the Neo-Tethys, the region suffered rapid transgression and the basin largely subsided. The Upper Jurassic-Lower Cretaceous shale, formed in the continent slope background, was well preserved and less destructed by the tectonic movement during the thrusting period. Thus, it became the excellent regional cap rock for the underlying Mesozoic carbonate rocks.

The inter-strata cap rocks were mainly developed in the Pleistocene Fufa Formation during the thrusting period. When the sandstone and reef limestone reservoirs of the Fufa Formation were rapidly deposited , many thin layers of shallow marine shales were formed, forming an important local cap rock.

3.4. Control on trap formation

The tectonic movement of the North Seram Basin in the thrusting period finally determined the type and distribution of traps in the basin and affected the development of the Fufa Formation reef traps. In the thrusting period, the structural deformation of the North Seram Basin transformed from thick-skinned basement in the south to thin-skinned structure in the north, following the pattern of weakening thrusting intensity. The foreland fold thrust belt in the southern part of the basin was characterized by intense contraction and deformation, high-angle reverse faults were mainly developed, and many reverse fault-related structures, such as imbricate fans and fault-extensional folds, were formed. Thus, the southern part became a favorable target for deep exploration, and it is there where the Osir oilfield was found (Fig.4).

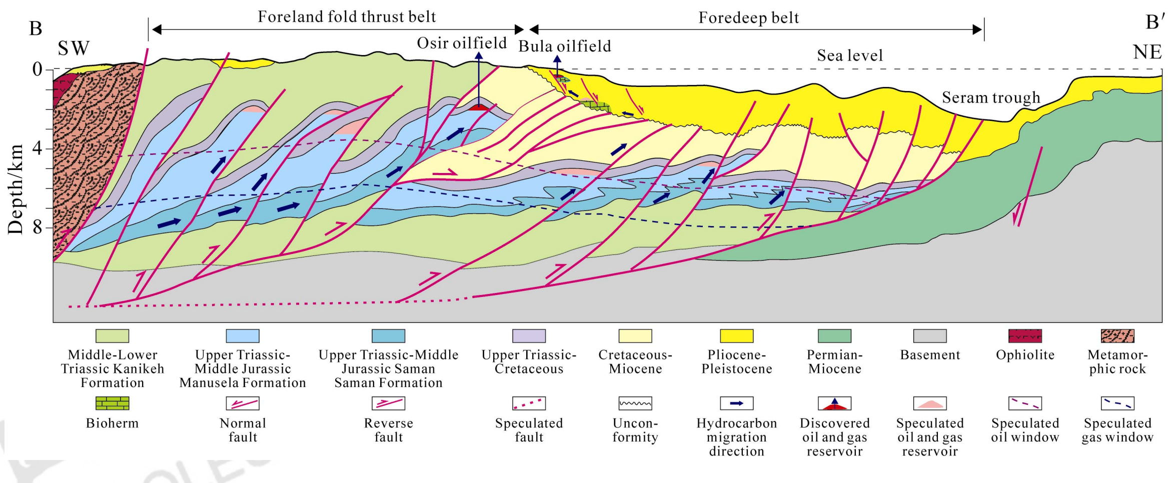

Fig. 4 Hydrocarbon accumulation model of the North Seram Basin (section location marked in Fig.1)

The foredeep belt of the basin was influenced by the boundary detachment thrust fault, and more and stronger thrust structures occur southwardly. Many wide and gentle anticlines controlled by the SW-dipping thrust faults were formed in the central-western part of the foredeep belt, and they are distributed in line and zones along the north-west (Fig.1); there are many "Y"-shaped back thrust systems developed in the eastern part of the foredeep belt, and they have many imbricate structures and thrust uplifts (Fig.2d), thus serving as important trap types in the eastern seas. There are also some fault traps and reef formation traps associated with the normal faults in the Pliocene-Pleistocene of the foredeep belt (Fig.4), and they are also a focus of oil and gas exploration.

3.5. Control on oil and gas migration

The rifting period and the passive continental margin period provided the material basis for the formation of oil and gas in the North Seram Basin. However, in the thrusting period, the North Seram Basin transformed into a complex foreland background and formed the present tectonic pattern, making it the critical period of hydrocarbon accumulation. The basin experienced two periods of hydrocarbon migration and accumulation. The source rocks in the Saman Saman Formation entered the oil-generating window in the Late Miocene, and the main hydrocarbon migration and accumulation events occurred from the Pliocene to recent.

The compression in the Late Miocene made the Manusela Formation reservoir and the Saman Saman Formation source rock further superimposed, providing a more favorable source-reservoir assemblage. Some faults associated with rifting in the early stage were reactivated and turned into reverse faults, causing them to become important source channels. The source rock in the foreland fold thrust belt entered into the oil window. Generated hydrocarbons migrated along the reactivated thrust faults and the newly formed fractures in the Manusela Formation carbonate rocks, and then they accumulated in the traps associated with the thrust faults (Fig.4). In the Pliocene, the depths of the source rocks in the thrust blocks differed based on the compressive strengths. The source rocks near the southern orogenic belt of the Seram Island were relatively deep and had a high level of maturity. The oil and gas discovered in the North Salem Basin might have come from different thrust blocks. Differences in the thermal evolutions of the source rocks is one of the main factors leading to differences in the oil and gas types. For example, in the Osir oilfield in the eastern part of the foreland fold thrust belt and the Bula oilfield in the foredeep belt in the offshore area, where crude oil is dominant, the oil and gas may have mainly come from the Saman Saman Formation source rock, which had a moderate maturity in the middle thrust fault block of the foreland fold thrust belt; in the Luofen gas field in the middle of the foreland fold thrust belt, which is a pure natural gas field, the natural gas might have been generated from the Saman Saman Formation source rocks, which had a deeper burial depth and a higher maturity in the southern part of the basin. Due to uplifting and denudation in the Pliocene, some oil and gas reservoirs were damaged and biodegradated. The previously formed oil and gas and the more mature oil and gas migrated along the thrust fault to the shallow layer, and then they were conducted laterally along the Pliocene regional unconformity, forming a reservoir in the Fufa trap (Fig.4). The thrust faults of the North Seram Basin trend mostly southwestward; therefore, the best migration direction of oil and gas was northeast. The reservoir forming conditions of the Mesozoic in the northern part of the foreland fold thrust belt are well matched, presenting it as a favorable oil and gas accumulation area. The unconformity of the Pliocene has a trend of uplifting toward the southwest, and the best convergence direction for the shallow oil and gas was near the coastline. In addition, the wide and gentle folds of the Mesozoic in the foredeep belt were prospective for hydrocarbon accumulation.

4. Conclusions

(1) The North Seram Basin is located in the Australian plate, and its tectonic evolution is closely related to the separation of blocks at the northern margin of the Australian palaeo-continent, the extension and formation of the Tethys and the collision of the Banda micro landmass with the Australian palaeo-continent. Its evolution can be divided into 4 stages: Early Triassic initial rifting, Middle Triassic-Middle Jurassic rifting, Late Jurassic-Middle Miocene passive continental margin, and Late Miocene-Quaternary thrusting.

(2) The tectonic evolution of the North Seram Basin played an important role in controlling the distribution of source rocks, reservoir-cap rock development and trap formation. The source rocks of the Upper Triassic-Middle Jurassic Saman Saman Formation are mainly distributed in the shallow continental shelf and the sedimentary facies of the restricted platform in the central-north part of the basin as a result of a horst-graben tectonic pattern in the rifting period. The ancient highlands at the southern margin of the basin controlled the development and distribution of high quality carbonate reservoirs in the Manusela Formation. The tectonic action in the thrusting period controlled the present foreland tectonic style and the main traps of the basin. The

foreland fold thrust belt mainly contains anticlines and fault traps related to high-angle thrust faults. The foreland fold thrust belt is dominated by wide and gentle anticlines and imbricate fans along with some reef stratigraphic traps locally.

(3) The tectonic evolution of the North Seram Basin controlled hydrocarbon generation, migration, accumulation and distribution. Tectonic movements during the thrusting period resulted in great differences in the depths of the Saman Saman Formation major source rocks in different areas of the basin, causing the source rocks to demonstrate both different thermal evolutions and hydrocarbon generation and expulsion in multiple stages. The two major oil and gas migration pathways in the basin, i.e. the reverse fault and the Pliocene unconformity, controlled the hydrocarbon migration and accumulation direction.

References

[1] USGS. Assessment of Undiscovered Oil and Gas Resources of Papua New Guinea, Eastern Indonesia, and East Timor, 2011. http://energy.usgs.gov/Oil Gas/Assessments Data/World Petroleum Assessment. aspx, 2012.

[2] Chatlton T R. Permian-Jurassic palaeogeography of the SE Banda Arc region [J]. Berita Sedimentologi, 2012, 7(24): 5–17.

[3] Metcalfe I. Pre-Cretaceous evolution of SE Asian terranes [J]. Tectonic evolution of Southeast Asia, 1996, 106(1): 97–122.

[4] Hall R. Late Jurassic-Cenozoic reconstructions of the Indonesian region and the Indian Ocean [J]. Tectonophysics, 2012, 570-571(10): 1–41.

[5] Karig D E, Barber A J, Charlton T R, et al . Nature and distribution of deformation across the Banda Arc-Australian collision zone at Timor [J]. Geological Society of America Bulletin, 1987, 98(1): 18–32.

[6] Darman H, Reemst P. Seismic expression of geological features in Seram Sea: Seram trough, Misool-Onin ridge and sedimentary basin [J]. Berita Sedimentologi, 2012, 7(23): 28–34.

[7] Charlton T R. The petroleum potential of inversion anticlines in the Banda Arc [J]. AAPG Bulletin, 2004, 88(5): 565–585.

[8] Hill K C. Tectonic and regional structure of Seram and the Banda Arc [J]. Berita Sedimentologi, 2012, 23: 5–16.

[9] Pairault A A, Hall R, Elders C F. Structural styles and tectonic evolution of the Seram Trough, Indonesia [J]. Marine and Petroleum Geology, 2003, 20(10): 1141–1160.

[10] Riadini P, Sapiie B, Surya Nugraha A M. The Sorong faultzone kinematics: implication for structural evolution on Salawati Basin, Seram and Misool, West Papua, Indonesia [J]. Berita Sedimentologi, 2012, 7(24): 61–72.

[11] Sapiie B, Hadiana M, Patria M, et al. 3D structural geology analysis using integrated analogue sandbox modeling: a case study of the Seram Thrust-Fold Belt [C]. Indonesia Petroleum Association 36st Annual Convention Proceedings, Jakarta, 2012: 1–14.

[12] Tong Xiaoguang, Yang Fuzhong. Oil and gas resource and occurrence of PetroChina’s block in Indonesia [J]. China Petroleum Exploration, 2005, 10(2): 58–62.

[13] Liu Chuanpeng, Luo Liang, Qi Jiafu, et al. Geological and hydrocarbon accumulation characteristics in piedmont zone [J]. Geoscience, 2013, 27(5): 1033–1041.

[14] Peters K E, Fraser T H, Amris W, et al . Geochemistry of crude oils from Eastern Indonesia [J]. AAPG, 1999, 83(12): 1927–1942.

[15] Yang Xiaolan, Liu Xiaoping. Oil resource of east Seram island, Indonesia [J]. Petroleum Exploration and Development, 2008, 35(2): 244–256.

[16] Yao Yongjian, Lv Caili, Kang Yongshang, et al. Characteristics of hydrocarbon source rocks and their main controlling factors in southeast Asia [J]. Earth Science-Journal of China University of Geosciences, 2013, 38(2): 367–378.

[17] Permana A K, Kusworo A, Prastian A H. Characteristics of the Triassic source rocks of the Aitutu Formation in the (West) Timor Basin [J]. Indonesia Journal on Geoscience, 2014, 1(3): 165–174.