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**Analysis of the world deepwater oil and gas exploration situation** 

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**Abstract:** The global trends in deepwater oil and gas exploration, characteristics of deepwater oil and gas discovery, and lay-out of deepwater oil and gas exploration business by seven major international oil companies are systematically analyzed using commercial databases (e.g. S&P Global and Rystad) and public information of oil companies. The deepwater area is currently the most important domain for global oil and gas exploration and discovery, with the most discoveries and reserves in passive conti-nental margin basins. The deepwater discoveries have the greatest contribution to the total newly discovered oil and gas reserves in the sea areas, with an increasing number of lithological reservoirs discovered, and oil and gas discoveries mainly distributed in the Mesozoic–Cenozoic. The seven major international oil companies are widely active in various aspects of deepwater oil and gas exploration and development, and play a leading role. Based on years of theoretical understanding of global oil and gas geology and resource evaluation, it is proposed that favorable deepwater exploration areas in the future will mainly focus on three ma-jor areas: the Atlantic coast, the Indian Ocean periphery, and the Arctic Ocean periphery. Six suggestions are put forward for expanding overseas deepwater oil and gas exploration business: first, expand the sources for obtaining multi-user seismic data and improve the scientific selection of deepwater exploration areas; second, increase efforts to obtain deepwater exploration projects in key areas; third, adopt various methods to access into/exit from resource licenses flexibly; fourth, acquire licenses with large equity and operate in “dual-exploration” model; fifth, strengthen cooperation with leading international oil companies in deepwater technology; and sixth, improve business operation capabilities and gradually transform from “non-operators” to “operators”.

**Key words:** world petroliferous basins; deepwater; oil and gas; exploration situation; international oil companies; favorable ex-ploration areas

**Introduction**

The offshore oil and gas reserves newly discovered in the past ten years account for 60% of the total oil and gas reserves of the world, and the oil and gas reserves dis-covered in deep and ultra-deep waters account for 61.99% of the total offshore oil and gas reserves. The deepwater domain is and will be playing a dominant role in global oil and gas exploration. Currently, the extent of offshore oil and gas exploration is still low, offshore areas have enormous resource potential, and the deepwater domain has even broader prospects [1–2]. Since China is a large pro-ducer and consumer of oil and natural gas, strengthening overseas oil and gas exploration is an important measure to ensure the security of its oil and gas development strategy. Major international oil companies are speeding

up access to the deepwater domain and making great efforts in this domain. Under such background, the situation of global deepwater oil and gas exploration is analyzed using the commercial databases of agencies such as S&P Global and Rystad and the public informa-tion disclosed by oil companies, and several recommen-dations on the development of overseas deepwater oil and gas exploration business are made based on the theoretical understanding of global oil and gas geology and resources gained through evaluations over the years to assist Chinese oil companies in developing their over-seas exploration business.

1. **History of global offshore oil and gas exploration**

Over more than a century, offshore oil and gas

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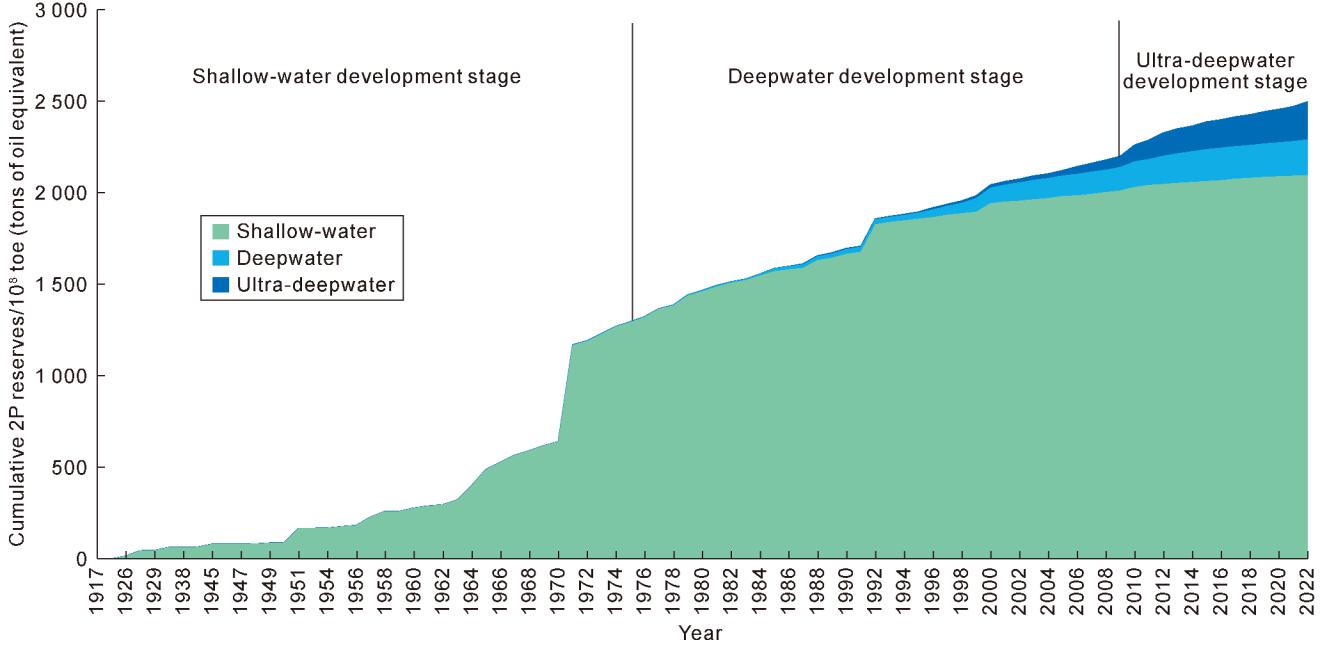
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**Fig. 1.** **History and development stages of global offshore oil and gas exploration [5].**

exploration has moved from shallow waters (0–500 m) to deep (500–1500 m) and ultra-deep (more than 1500 m) waters. Based on an analysis of the process of growth/ change in new oil and gas reserves, the history of global offshore oil and gas exploration can be divided into three development stages (as shown in Fig. 1).

**1.1. Shallow-water development stage (from 1917 to**

**1976)**

In 1917, the Cabimas Oilfield was discovered in Lake Maracaibo, Venezuela. This oilfield is located in a lake with a depth of 4.57 m. A wooden drilling platform was built to extract underwater oil deposits. It is considered the first fixed offshore platform in the world. Before the 1940s, due to the limited level of development of offshore equipment and instruments, offshore oil and gas explo-ration activities were mainly performed via wooden platforms and artificial islands built with civil engineer-ing technology [3]. For this reason, offshore operations were mainly carried out in offshore areas and inland lakes, usually at depths below 20 m. During the period from the 1940s to the end of the 1960s, with the devel-opment of the steel industry and welding technologies, the United States of America discovered and developed tens of oil and gas fields in the Gulf of Mexico [3]. Subse-quently, drilling units such as submersible drilling plat-forms, jack-up platforms, drill ships, and semi-submer-sible drilling rigs emerged successively. These units greatly facilitated offshore oil and gas exploration. Since the 1960s, many oil and gas exploration activities have been carried out in offshore areas such as the North Sea, the Persian Gulf, the Gulf of Mexico, African offshore areas, the northern slope of Alaska, the Black Sea, and the

coasts of Southeast Asian countries, and many offshore oil and gas fields have been discovered. However, most of these offshore oil and gas exploration activities were car-ried out in offshore areas with water depths below 500 m, and offshore oil and gas exploration after the 1960s was generally at the shallow-water development stage.

**1.2. Deepwater development stage (from 1977 to 2009)**

The first deepwater oil/gas field in the world is the Mississippi Canyon Block 0311 gas field, which was dis-covered by the USA in the Gulf of Mexico in 1968, with an operating water depth of 701.04 m. However, it was not until 1976 that continuous deepwater oil and gas fields were discovered. In the following 20 years, more and more deepwater oil and gas fields were discovered. Dur-ing the deepwater development stage, besides the oil and gas exploration activities in Gulf of Mexico, the explora-tion activities in Brazil also entered the deepwater do-main, and major discoveries were made in the deepwater zones of the Campos Basin. In addition, the Gulf of Mex-ico, the Vøring Basin in the North Sea, the Campos Basin in Brazil, northwestern Australia, and the Lower Congo Basin in Africa became key areas for deepwater oil and gas exploration. The development of sequence stratigra-phy and petroleum system theories in the 1970s and the development of deepwater sedimentology in the 1990s [4] have provided a solid theoretical foundation for the pro-gress in deepwater oil and gas exploration. Additionally, the development of 3D seismic technology, rotary steer-able drilling systems, floating production, storage and offloading units, compliance towers, fourth-generation semi-submersible drilling rigs, and tension leg platforms has laid a technical foundation for the rapid progress in

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deepwater oil and gas exploration.

1. **3. Ultra-deepwater development stage (from 2010 to the present)**

Since 2010, the maturation of deepwater oil and gas geological theories and the development of offshore equipment such as Spars (deep-draft caisson vessels), fifth-generation semisubmersible drilling rigs, drill ships, and intelligent deepwater drilling platforms have greatly promoted oil and gas exploration in ultra-deep water [3]. At the ultra-deepwater development stage, the number and reserves of new oil and gas fields discovered in ul-tra-deep water are much greater than those of oil and gas fields in shallow and deep waters and are increasing year by year. This trend is closely related to the discovery of giant offshore oil and gas fields in the Brazilian pre-salt region, East Africa, and the Eastern Mediterranean. At this stage, global ultra-deepwater oil and gas exploration activities are mainly concentrated in the Gulf of Mexico, West Africa (the Niger Delta Basin, the Lower Congo Ba-sin, the pre-salt section of the Kwanza Basin pre-salt, the Côte D’Ivoire Basin, the Senegal River Basin, etc.), Brazil (the Campos Basin, etc.), the Rovuma Basin in East Africa and the basins of Tanzania, the Guyana-Suriname Basin, the Vøring Basin in Norway, the deepwater areas of Southeast Asia, the South China Sea (the Pearl River Mouth Basin and the Qiongdongnan Basin), the Levant Basin in the Eastern Mediterranean, the Nile Delta Basin, the Barents Sea, and the North West Shelf of Australia. After more than ten years of development, the oil and gas reserves in ultra-deep water are still increasing, and the ultra-deepwater domain has become one of the most

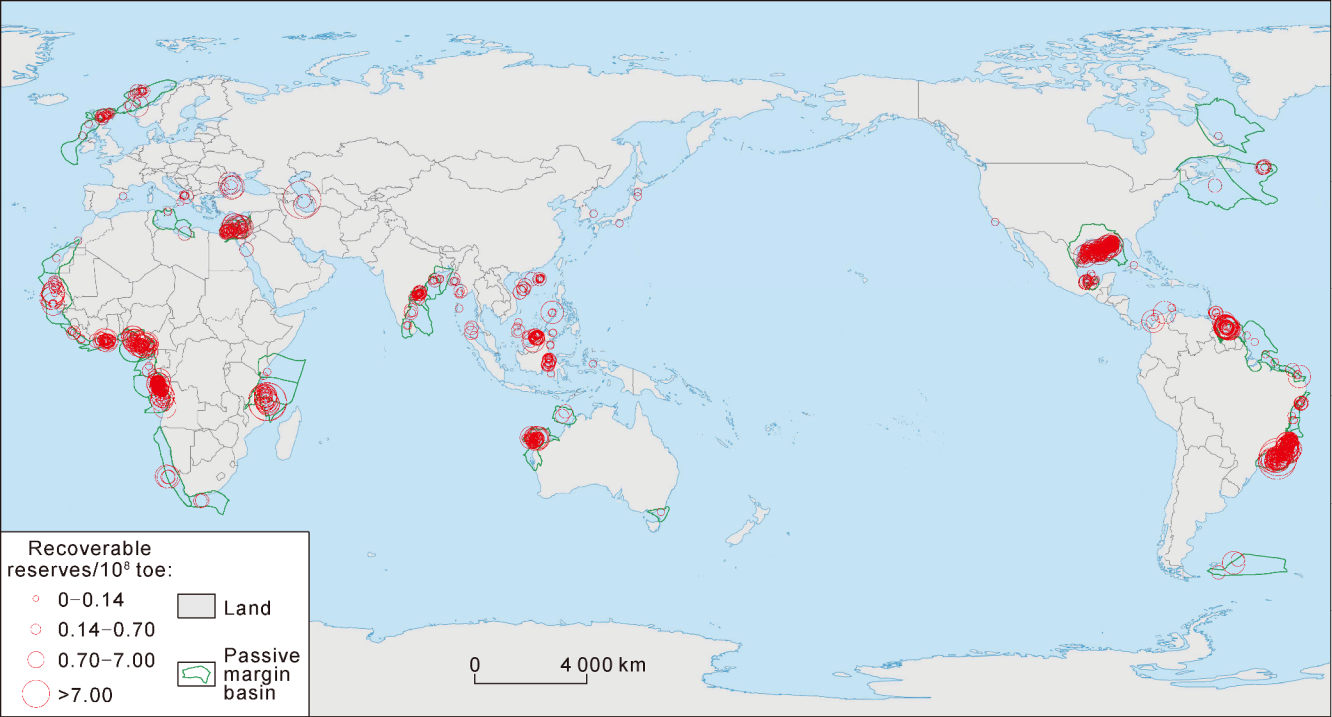
important fields for global oil and gas exploration and for increasing oil and gas reserves and production.

1. **Global oil and gas exploration and discoveries in deep and ultra-deep waters**

As of 2023, 1372 deepwater/ultra-deepwater oil and gas fields (hereinafter referred to as deepwater fields) have been discovered around the world, with total recoverable reserves of 408.01 108 toe (tons of oil equivalent). These fields are mainly distributed in regions such as the Gulf of Mexico, the eastern and western coasts of the Atlantic, East Africa, North Africa, the Black Sea, the South Cas-pian Sea, the Bay of Bengal, the North West Shelf of Aus-tralia, and the South China Sea [5] (Fig. 2). In recent years, breakthroughs have been made continuously in oil and gas exploration in deepwater areas, especially the areas around Africa, the Atlantic Ocean in South America, the Black Sea, and the South Caspian Sea, which have be-come key areas for increasing global oil and gas re-serves [2, 6 18]. In general, global deepwater oil and gas exploration has four characteristics.

**2.1. The oil and gas reserves discovered in the deepwater zones of passive margin basins are the greatest**

Passive margin basins are widely distributed around the globe. There are 130 passive margin basins around the world, with a total deposition area of 3350 × 104 km2. The total offshore deposition area is 3016 × 104 km2, of which nearly 75% are located in deep water. The hydro-carbon exploration and development activities in these offshore areas started later than those in onshore areas [14].



**Fig. 2. Distribution of deepwater fields around the world.**

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**Table 1.** **Statistical table of the types and regional distribution of deepwater oil and gas fields/basins around the world [5]**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Basin type |  |  |  |  | Recoverable reserves/108 toe | |  |  |  |  |
|  | Africa | Latin America | North America | Asia-Pacific Middle East | | Europe | Central Asia-Russia | Total |  |
|  |  |  |
| Passive margin basin | | 145.04 | 137.07 | 46.07 | 20.94 | 10.31 | 10.12 |  | 369.55 |  |
| Back-arc basin | |  | 1.21 |  | 14.14 |  |  |  | 15.35 |  |
| Fore-arc basin | |  |  | 0.03 | 0.060 |  |  |  | 0.09 |  |
| Rift basin | | 0.52 |  |  | 0 | 0.27 |  |  | 0.79 |  |
| Foreland basin | |  | 2.68 |  | 1.13 | 6.65 | 1.64 | 10.13 | 22.23 |  |
| Total | | 145.56 | 140.96 | 46.1 | 36.27 | 17.23 | 11.76 | 10.13 | 408.01 |  |



By 2023, 1215 oil and gas fields have been discovered in the deepwater zones of passive margin basins. The total recoverable reserves of oil and gas in these fields are 369.55 108 toe (Table 1), which account for 90.57% of the total deepwater oil and gas reserves and are much greater than those in other types of basins. The oil and gas reserves of passive margin basins are very unevenly distributed in various regions. The oil and gas reserves of passive margin basins around Africa and in the eastern waters of Latin America rank first, amounting to about 140 108 toe.

**2.2. Large oil and gas discoveries contribute most to oil and gas reserves**

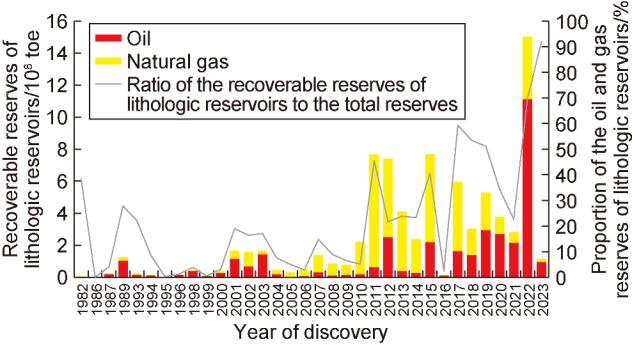
As of 2023, 121 large oil and gas fields have been dis-covered by oil companies in deep waters around the globe, accounting for 8.89% of the total number of offshore oil and gas fields. The total recoverable reserves of oil and gas in these deepwater fields are 252.92 108 toe, ac-counting for 61.99% of the total offshore oil and gas re-serves. In 1979, ExxonMobil discovered a giant gas field with recoverable reserves of 3370.08 108 m3 in the Car-narvon Basin, namely, the Scarborough gas field. This discovery is the first major breakthrough in deepwater oil and gas exploration in the world. In 1984, Petrobras dis-covered Albacora, the first large oilfield in the Campos Basin, and then successively discovered another seven large oil and gas fields in the basin, with total recoverable reserves of 115.59 108 toe. During the period from 1995 to 2005, 31 large deepwater oil and gas fields were dis-covered, including 17 in Africa. These 17 fields are mainly distributed in the Niger Delta Basin in West-Central Af-rica and the Lower Congo Basin in Central Africa. The subsequent major breakthroughs and discoveries made in deep water are mainly concentrated in Latin America and areas around Africa. These major discoveries include the Tupi oilfield, which is the first large pre-salt oilfield dis-covered by Petrobras in the Santos Basin in 2006, the Jubillee oilfield, which is a large Cretaceous sandstone oilfield discovered by Kosmos Energy in the Côte D’Ivoire Basin in 2007, the Tamar gas field, which is a large Mio-cene sandstone gas field discovered by Nobel Energy in the Levant Basin in 2009, the Lavani gas field, which is a large Cretaceous-Paleogene sandstone gas field discov-ered by Equinor in the Tanzania Basin in 2012, the Zohr gas field, which is a giant Cretaceous biohermal gas field discovered by Eni in the Eratosthenes Basin in 2015, and

the Venus oilfield, which is a giant Cretaceous sandstone oilfield discovered by TotalEnergies in the Southwest African Coastal Basin in 2022.

**2.3. More and more lithologic reservoirs are discovered**

The first deepwater oil/gas field in the world is a structural reservoir. Structural-lithologic composite res-ervoirs were discovered successively in the following years. In the past ten years, with the continuous devel-opment of ultra-deepwater deposition theories and seis-mic, drilling and exploration technologies, lithologic traps dominated by slope fan/submarine fan gas reser-voirs have been discovered in deep and ultra-deep waters, and the oil and gas reserves of such reservoirs have been increasing continuously (Fig. 3).

The lithologic reservoirs discovered at early stages are mainly distributed in the Campos Basin, the Santos Basin, the Sergipe-Alagoas Basin in Latin America, and the deepwater basin of the Gulf of Mexico in North America. In 1989, Petrobras discovered the first large oil and gas field formed by a lithologic trap in the Campos Basin, namely, the Barracuda Field. In the ensuing 10 years, various oil companies carried out deepwater exploration activities and successively discovered a number of deep-water lithologic reservoirs in the Niger Delta Basin in West Africa, the Lower Congo Basin in Central Africa, and the Ionian Basin in the Eastern Mediterranean. After 2000, several lithologic reservoirs were discovered in four basins off the coast of Brazil, including the Campos Basin where a large oil and gas field named the Jubarte Field was discovered. Since 2010, oil companies have succes-sively made breakthroughs in the exploration of deep-water lithologic reservoirs in new basins, and the oil and



**Fig. 3. Oil and gas reserves of deepwater lithologic reservoirs around the world and the proportion of such reserves.**

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gas reserves in lithologic reservoirs have risen to a higher level (Fig. 3). During the period from 2010 to 2014, seven lithologic gas reservoirs/fields were discovered in the Rovuma Basin in the waters of East Africa, with the total recoverable reserves of 1.85 1012 m3. The recoverable reserves of oil and gas in the lithologic reservoirs discov-ered in the Guyana Basin and Senegal Basin on both sides of the Mid-Atlantic during the period from 2015 to 2023 amount to 17.96 108 toe [5]. In the Orange Basin in the South Atlantic Ocean, TotalEnergies achieved great suc-cess in the Lower Cretaceous basin-floor fan in the Na-mibian sea area in 2022. In addition, during the period from 2022 to 2023, Shell discovered three lithologic res-ervoirs in the same sea area, with total recoverable re-serves of 8.79 108 toe [5].

**2.4. In terms of geological age, pay zones are mainly Mesozoic and Cenozoic reservoirs.**

The statistics of the geological ages of deepwater oil and gas reservoirs (Table 2) show that the oil and gas reserves in Mesozoic-Cenozoic reservoirs account for 99.98%, most of which come from Cretaceous, Paleogene, and Neogene reservoirs. The recoverable reserves of oil and gas in Cretaceous, Paleogene, and Neogene reservoirs are 180.78 108, 74.19 108, 143.87 108 toe, accounting for 97.76% of the total deepwater oil and gas reserves. By analyzing the characteristics of the spatial distribution (Fig. 2) and geological ages (Table 2) of the discovered oil and gas reservoirs, it can be found that these reservoirs are closely related to the process of plate tectonic evolu-tion since the breakup of Pangaea. According to the re-search of Scotese et al. [19] on the history of plate tectonic evolution, the Mesozoic and Cenozoic reservoirs around the Atlantic Ocean and the Indian Ocean have always been subjected to extensions involving rifts and passive continental margins, which is favorable for hydrocarbon accumulation.

1. **Layout of deepwater oil and gas**

**exploration business of the seven major international oil companies**

The seven major international oil giants, namely, Exx-onMobil, bp, Shell, TotalEnergies, Chevron, Equinor, and

and Eni, were the first to participate in deepwater oil and gas exploration [20–21]. Relying on their experience in the development of shallow-water oil and gas fields, these seven major international oil companies are constantly proceeding to the field of oil and gas exploration in deeper waters. After years of continuous operation, these companies have become highly active and play a leading role in all aspects of deepwater oil and gas exploration and development.

**3.1. Taking the lead in developing deepwater oil and gas exploration business, actively deploying deepwater exploration blocks, and attaching importance to the participation in bidding activities in key areas**

According to statistics, in the field of deepwater oil and gas exploration, the seven major international oil com-panies directly participated in 50% of the exploration wells drilled in waters deeper than 400 m around the world during the period from 1990 to 2022 and acted as operators for 38% of these exploration wells. In addition, 74% of the recoverable reserves discovered through ex-ploration are directly related to these seven major inter-national oil companies, and 35% of deepwater oil and gas discoveries are directly owned by these companies [5].

International oil companies generally attach great im-portance to the layout of deepwater oil and gas explora-tion business and are highly active in mergers and acqui-sitions. Statistics show that the seven major international oil companies attach high importance to participating in the bidding activities launched by the major host coun-tries of deepwater oil and gas resources. During the pe-riod from 2018 to 2022, all of the seven major interna-tional oil companies participated in the bidding activities launched for deepwater oil and gas projects in countries and regions such as the Gulf of Mexico (USA), Brazil, and West Africa. bp acquired interests in 155 blocks in the USA, with a total area of 3440 km2; ExxonMobil acquired interests in 25 blocks in Brazil, with a total area of 9346 km2; Shell acquired interests in 23 blocks in Brazil, with a total area of 10 439 km2.

By participating in bidding activities for deepwater oil and gas projects, international oil companies continue to take the lead in deepwater oil and gas exploration. Eni is

**Table 2. Statistical table of the geological ages and regional distribution of deepwater oil and gas reservoirs around the world [5]**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Erathem | System | Africa | Latin America | North America | Asia-Pacific | Middle East Europe | | Central Asia-Russia | Total |  |
| Cenozoic | Quaternary | 0.03 |  | 0.47 | 0.23 |  | 0.10 |  | 0.83 |  |
| Neogene | 51.72 | 13.58 | 30.84 | 18.03 | 17.23 | 2.34 | 10.13 | 143.87 |  |
|  | Paleogene | 42.95 | 14.86 | 10.37 | 0.66 | 0 | 5.35 |  | 74.19 |  |
| Mesozoic | Cretaceous | 50.86 | 112.52 | 4.38 | 9.24 |  | 3.78 |  | 180.78 |  |
| Jurassic |  |  | 0.02 | 0.87 |  | 0.10 |  | 0.99 |  |
|  | Triassic |  |  |  | 7.24 |  |  |  | 7.24 |  |
| Paleo- | Carboniferous |  |  |  |  |  | 0.07 |  | 0.07 |  |
| Silurian |  |  | 0.02 |  |  |  |  | 0.02 |  |
| zoic |  |  |  |  |  |  |  |
| Cambrian |  |  |  |  |  | 0.02 |  | 0.02 |  |
|  |  |  |  |  |  |  |  |
| Total |  | 145.56 | 140.96 | 46.10 | 36.27 | 17.23 | 11.76 | 10.13 | 408.01 |  |

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one of the leading international oil companies that are highly specialized in deepwater oil and gas exploration. In recent years, Eni has been focusing on the acquisition of resources for deepwater oil and gas exploration and the acquisition of exploration assets in countries such as Egypt, Angola, and Ghana, and it has acquired a large number of deepwater oil and gas exploration assets in the Gulf of Mexico. After entering the deep waters of Egypt, Eni discovered three deepwater gas fields in 1999 and then continued to participate in the bidding for oil and gas exploration in Egyptian waters. After acquiring the block, it actively carried out in-depth geological research, re-collected seismic data, and finally made several major discoveries including the Zohr gas field by performing fine-scale seismic interpretation and modeling and drill-ing exploration wells. In general, Eni’s success is the re-sult of its long-term continuous efforts in conducting follow-up studies, its emphasis on the acquisition of first-hand data, and its long-term persistence in carrying out activities in an in-depth and careful manner in the basin area.

**3.2. Most international oil companies enter exploration blocks through bidding at the early stage before oil and gas discoveries are made, and a few oil companies enter exploration blocks through mergers and acquisitions at high prices after discoveries are made**

Statistics show that most international oil companies enter deepwater oil and gas exploration blocks through bidding at the early stage before oil and gas discoveries are made, and a few oil companies enter exploration blocks through mergers and acquisitions at high prices after discoveries are made. Early entry into deepwater oil and gas exploration blocks can often enable oil compa-nies to gain dominant advantage over competitors and introduce partners at later stages to share exploration risks. For the 10 large deepwater oil and gas projects led

by international oil companies, most of the international oil companies acting as operators entered the blocks be-fore oil and gas discoveries were made (Table 3). For example, Shell entered ExxonMobil’s Stabroek Block in Guyana in 2009 and exited the block in 2015. Later, Hess Corporation and CNOOC Nexen Petroleum Guyana Ltd entered the block as new partners and made large oil and gas discoveries in the same year. The Leviathan project in Israel is an example of entry through mergers and acqui-sitions by operators. After making its early entry into the Leviathan project and making oil and gas discoveries, Nobel Energy made active efforts to sell its interests in the project due to large investments in continuous ex-ploration and evaluation at the later stage and future development. Later Chevron entered the project through the acquisition of Nobel Energy.

1. **3. Attaching importance to the accumulation of technologies for deepwater oil and gas exploration and strengthen cooperation in the supply chain of deepwater exploration technology**

Technological progress is an important driving force for the rapid development of deepwater oil and gas ex-ploration business. The seven major international oil companies have been engaged in the field of deepwater oil and gas exploration for decades and have been gradu-ally developing and growing relying on their experience in shallow-water oil and gas exploration and develop-ment accumulated over the years [14]. In terms of the his-tory of global offshore oil and gas exploration, most in-ternational oil companies began to take shape in the field of shallow-water oil and gas exploration and development in the 1970s; international oil companies began to par-ticipate in deepwater oil and gas exploration and devel-opment in the 1990s and initiated oil and gas production in ultra-deep water in the first decade of the 21st century.

The experience of major international oil companies in

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 3. Ten large deepwater oil and gas projects led by international oil companies [5]** | | | | | |  |  |  |  |
| Large deepwater oil |  | Operators (companies) entering the | | | |  | Main partners (companies) enter- | |  |
|  | project at different times | | |  |  | ing the project at different times | |  |
| and gas projects led | Company making |  |  |
|  |  | After the final | |  |  |  |  |
| by international oil | the discovery | Before | After |  |  | After |  |
| investment deci- | |  | Before discovery |  |
| companies |  | discovery | discovery |  | discovery |  |
|  |  |  |  | sion is made | |  |  |  |  |
| Starbroke block | ExxonMobil, CNOOC, | ExxonMobil |  |  |  |  | CNOOC, Hess |  |  |
| Hess Corporation |  |  |  |  | Corporation |  |  |
|  |  |  |  |  |  |  |  |
| Gorgon Project | ExxonMobil |  | Chevron |  |  |  | ExxonMobil, Shell |  |  |
| Block 58 (Suriname) | Apache Corporation | TotalEnergies |  |  |  |  | Apache Corporation |  |  |
| Leviathan | Nobel Energy |  |  | Chevron | |  | Ratio Energies, |  |  |
|  |  |  | NewMed Energy |  |  |
|  |  |  |  |  |  |  |  |  |
| Abadi | Inpex | Inpex |  |  |  |  |  | Shell |  |
| Browse | Woodside Energy, bp, | Woodside |  |  |  |  | Shell, bp | CNPC |  |
| Chevron, Shell | Energy |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| Yakaar | bp, Kosmos Energy | bp |  |  |  |  | Kosmos Energy |  |  |
| OML 118 (Bonga Fields) | Shell, ExxonMobil, Eni, | Shell |  |  |  |  | ExxonMobil, Eni, |  |  |
| TotalEnergies |  |  |  |  | TotalEnergies |  |  |
|  |  |  |  |  |  |  |  |
| OML 133 (Erha and Bosi) | ExxonMobil, Shell, bp | ExxonMobil |  |  |  |  | Shell |  |  |
| Ormen Lange | Shell, Equinor, | Shell |  |  |  |  | Norway State | PGNiG, |  |
| ExxonMobil, bp |  |  |  |  | DFI, Equinor | Eni |  |
|  |  |  |  |  |  |  |



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setting deepwater oil and gas exploration records con-tinuously shows that maximizing the use of highly quali-fied suppliers and actively building preferred service partnerships is the best practice adopted by these com-panies to improve competitiveness in the field of deep-water oil and gas exploration. Taking Chevron’s Tahiti Spar as an example, the design of the topside is under-taken by Mustang Engineering, the integration of the topside and the hull is undertaken by J. Ray McDerrmott, and the contract for the floating system is undertaken by Technip as a general contractor. In addition, some tech-nical service and equipment providers have been con-stantly responding to the needs of international oil com-panies and have made a series of technological break-throughs through continuous research in deepwater drill ships, pipe-laying vessels, subsea production systems, etc.

**3.4. International oil companies adopt strategies that enable them to take the lead or follow the practices of other companies and share risks with other companies through extensive cooperation in the field of deepwater oil and gas exploration**

International oil companies have their own advantages in different deepwater oil and gas exploration areas. For example, Shell and bp have great advantages in the Gulf of Mexico; Chevron plays a dominant role in Australian waters; Eni and Total have significant advantages in Af-rican waters. In deepwater areas where they do not have competitive advantages, international oil companies usu-ally follow the practices of, and actively cooperate with, local national oil companies and international oil com-panies having competitive advantages. For example, in recent years, international oil companies have been fre-quently acquiring exploration blocks in Brazilian waters and cooperating with Petrobras in most of the explora-tion blocks acquired by them.

Cooperation between major international oil compa-nies is also a remarkable characteristic of deepwater oil and gas exploration. The seven major international oil companies cooperate with other similar companies for 52% (on average) of the oil and gas reserves wherein the interests are held by them. The percentage of oil and gas reserves operated by Equinor in cooperation with other companies is 83%, the percentages of oil and gas reserves operated by Chevron and Eni in cooperation with other companies are greater than 60%, and the percentage of oil and gas reserves operated by ExxonMobil in coopera-tion with other companies is close to 50%.

1. **Geological characteristics of deepwater oil and gas reservoirs around the world**

The deepwater oil and gas reservoirs around the world are mainly distributed in passive margin basins. There-fore, the geological characteristics of passive margin ba-

sins basically represent the geological conditions of deepwater oil and gas reservoirs.

**4.1. Source rocks**

The passive margin basin considered herein has un-dergone the vertical stacking of three prototype basins, and all depositional sequences may become high-quality source rocks (Table 4). As confirmed through exploration, the following five suites of source rocks may have been formed in these depositional sequences and the pre-rift strata: the lacustrine/marine source rocks formed during the rifting stage, the marine/lagoon source rocks formed during the transition stage, the marine source rocks formed during the early drift stage, the deltaic source rocks formed during the late drift stage, and the source rocks formed during the pre-rift stage. Among these source rocks, the lacustrine/marine source rocks formed during the rifting stage, the marine source rocks formed during the early drift stage, and the deltaic source rocks formed during the late drift stage contribute most to oil and gas reserves [22].

The lacustrine/marine source rocks formed during the rifting stage are mainly distributed in two types of basins, namely, faulted and fault depression basins. These source rocks are also present in the lower narrow-rift sequences of salt-free (transformed) depression-type basins, but the distribution range is limited. If delta reformed basins and inverted basins were of faulted type or fault-depression type before reformation, rifting-stage source rocks would exist in these two types of basins.

The lacustrine source rocks formed during the rifting stage are mainly distributed in the passive margin basins on both sides of the South Atlantic Ocean. During the rifting stage, rifting occurred within the continent, which is similar to the case of the present-day East African Rift. Due to the warm climate near the equator, abundant sediment supply along the periphery, and the closed an-oxic environment of the faulted lake basin, the algae-rich organic matter was preserved. These lacustrine source rocks are among the source rocks of best quality in the world, which were distributed in a north-south intracon-tinental faulted lake basin during the rifting stage, and the main types of kerogens in these rocks are type I and type II. The source rocks of the Lower Cretaceous Melania Formation in the Gabon Coastal Basin in West Africa belong to this suit of lacustrine source rocks, with average TOC (total organic carbon) of 6.1%, maximum TOC of 20%, average content of chloroform bitumen “A” ranging from 0.072% to 0.365%, and an average SPI (Source-Potential Index) value of 46 t/m2. 95% of the crude oil found in the basins along the east coast of Brazil comes from this suite of lacustrine source rocks, whose TOC mainly ranges from 5% to 12%, with a maximum of 24.5%.

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**Table 4. Geological characteristics of deepwater oil and gas reservoirs in various types of passive margin basins around**

**the world [22]**

|  |  |  |  |
| --- | --- | --- | --- |
| Basin type |  | Representa- | tive basin |
| Inverted | basin | Levant | Basin |
| Delta | reformedbasin | Niger Delta | Basin |

|  |  |  |  |
| --- | --- | --- | --- |
| - | type basin | Senegal RiverBasin |  |
| bearingdepression | Basin |  |
| Salt- |  | Scotia |  |
| Salt-freedepression-typebasin | | Côte D’IvoireBasin |  |
| Salt-bearing fault-depression-typebasin | | Basin Congo Basin |  |
|  |  | Santos |  |
| Salt-free fault-depression-typebasin | | TanzaniaBasin |  |
| Faulted | basin | CarnarvonBasin |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Major source rocks | Major reservoirs | Seals (cap rocks) | Main types of |  |
| traps |  |
|  |  |  |  |
| Oligocene-Miocene marine | Oligocene*–*Miocene Tamar Forma- |  | Structural trap, |  |
| tion basin-floor fan turbidite sand- |  |  |
| mudstone, type II, |  | structural- |  |
| stones, net reservoir thickness: 140 | Messinian rock salt |  |
| TOC: 0.5% 1.5%, | lithologic |  |
| m, average porosity: 25%, perme- |  |  |
| *HI*: 300 mg/g, *S*2: 2 mg/g |  | composite trap |  |
| ability: 1000 10 3 μm2 |  |  |
| Middle/Pliocene (deltaic) prodeltaic | Paleogene *–*Neogene sandstones, | Shales of the Akata |  |  |
| shales, type II/III, TOC: 0.2% 4%, | porosity: generally 22% 32%, | Formation with |  |  |
| maximum porosity: 40%, average | Structural trap |  |
| *HI*: 55 350 mg/g, *S*2: 5 20 mg/g, | thickness ranging |  |
| porosity: 25%, permeability: |  |  |
| thickness: more than 3000 m | from 17 m to 270 m |  |  |
| (500 1000) 10 3 μm2 |  |  |
| Upper Cretaceous (depression | Upper Cretaceous clastic rocks/ |  |  |  |
| reservoirs, maximum porosity: 35%, | Upper Cretaceous | Rollover anticline, |  |
| strata) pelagic mudstones, type II, |  |
| TOC: 1.3% 8.7%, *HI*: 300 700 | permeability: hundreds of millidarcy | (Turonian) and | fault block, salt |  |
| (mD); Jurassic*–*Lower Cretaceous | Miocene marine | structure, and litho- |  |
| mg/g, *S*2: 3 75 mg/g, thickness: |  |
| carbonate platform reservoirs, po- | shales | logic trap |  |
| 300 700 m |  |
| rosity: 10% 23%. |  |  |  |
|  | Interlayered, laterally |  |  |
| Upper Jurassic (depression strata) | Upper Jurassic*–*Lower Cretaceous |  |  |
| continuous marine and |  |  |
| pelagic mudstones, type II/III, TOC: | Mi’kmaq Formation and Missis- | prodeltaic shales of the | Fault-lithologic |  |
| 0.5% 4%, *R*o: 0.8%, *HI*: 150 400 | sauga Formation sandstones (main |  |
| mg/g, *S*2: 3 5 mg/g, thickness: | reservoirs), porosity: 4.8% 20%, | Mi’kmaq, Mississauga, | composite trap |  |
| and Logan Canyon |  |  |
| 150 1000 m | permeability: (0.01 200) 10 3 μm2 |  |  |
|  | Lower Cretaceous Aptian*–*Albian | formations | Upper Cretaceous: |  |
|  |  |  |
| Lower Jurassic (depression strata) | sandstones, porosity: 17% 22%, |  | structural-lithologic |  |
| pelagic mudstones, type II/III, TOC: | permeability: 2000 10 3 μm2; | Upper and Lower | composite trap; |  |
| 0.5% 3.7%, *R*o: 2.1%, *HI*: 21 331 | Upper Cretaceous Turonian- | Lower Cretaceous: |  |
| Cretaceous shales |  |
| mg/g, *S*2: 2 50 mg/g, | Cenomanian lower turbidite | fault block, anticline, |  |
|  |  |
| thickness: 700 m | sandstones, porosity: 19% 21%, |  | and structural- |  |
|  | permeability: (200 500) 10 3 μm2 |  | lithologic trap |  |
| Post-salt (Upper Cretaceous, de- | Top of Lower Cretaceous Aptian*–* | Albian shales and |  |  |
| pression strata) neritic shales, type | Albian dolomites, limestones and | Toulonian thick- |  |  |
| II, TOC: 4.6%, *R*o: 1.4%, | sandstones, and Oligocene- | bedded marine |  |  |
| *HI*: 571 mg/g, thickness: 400 m | Pliocene sandstones | shales | Structural and lith- |  |
| Pre-salt (Upper Cretaceous, rift | Lower Cretaceous Lucula Formation |  |  |
|  | ologic traps |  |
| strata) lacustrine shales, type I/II, | sandstones, porosity: 30%, permeabil- | Lower Cretaceous |  |
|  |  |
| TOC: 7%, *R*o: 1% 2.4%, *HI*: | ity: 700 10 3 μm2; Barremian Toca | mudstones and |  |  |
| 100 890 mg/g, *S*2: 13 mg/g, | Formation limestones, porosity: 16% | rock salt |  |  |
| thickness: 70 1800 m | 20%, permeability: 600 10 3 μm2 |  |  |  |
| Post-salt (Upper Cretaceous, de- | Upper Cretaceous turbidite |  |  |  |
| pression strata) pelagic mudstones, | Upper Cretaceous |  |  |
| sandstones: porosity: 20% 33%, |  |  |
| type II/III, TOC: 0.2% 2.5%, *R*o: | pelagic argillaceous | Lithologic traps |  |
| permeability: (1000 4000) |  |
| 0.5% 0.8%, *HI*: 30 295 mg/g, *S*2: 3 | shales |  |  |
| 10 3 μm2 |  |  |
| 12.9 mg/g, thickness: 200 1000 m |  |  |  |  |
| Pre-salt (Upper Cretaceous, rift | Lower Cretaceous carbonate |  | Structural- |  |
| strata) lacustrine shales, type I/II, | reservoirs, porosity: 5% 25%, av- | Upper Cretaceous |  |
| stratigraphic |  |
| TOC: 2% 6%, *HI*: 900 mg/g, *S*2: 13 | erage porosity: 16%, | evaporitic salt rock |  |
| composite traps |  |
| mg/g, thickness: less than 1500 m | permeability: (1 2000) 10 3 μm2 |  |  |
| Lower Cretaceous (depression |  |  |  |  |
| strata) marine shales, type III, TOC: | Paleocene*–*Miocene sandstones | Paleogene-Neogene |  |  |
| 1.78% 12.2%, *R*o: 1.2%, *HI*: 129 mg/g and Cretaceous sandstones, aver- | | marine argillaceous | Structural and |  |
| Jurassic (rift strata) neritic shales, | age permeability: 40 | shales and shales of | stratigraphic |  |
| type II/III, TOC: 0.3% 10%, | 10 3 μm2, porosity: 10% 30%, | the Upper Cretaceous | traps |  |
| non-maturity-over-maturity, | average porosity: 23% | Ruaruke Formation |  |  |
| *HI*: 40 1000 mg/g |  |  |  |  |
| Jurassic (rift strata) marine | Middle*–*Lower Jurassic reservoirs, | Jurassic transgressive |  |  |
| mudstones, type II/III, TOC: | thick-bedded mud- | Stratigraphic- |  |
| 2.2% 13.9%, *R*o: 0.6% 1.6%, | porosity: 11% 35%, permeability: | stones and Lower |  |
| lithologic trap |  |
| *HI*: 100 600 mg/g, *S*2: 9 11 mg/g, | (20 5000) 10 3 μm2 | Cretaceous neritic |  |
| thickness: 800 m |  | shales |  |  |

The marine source rocks formed during the rifting Ocean periphery and in the North Atlantic Ocean and the

stage are mainly distributed in the basins on the Indian Eastern Mediterranean. Rifting occurred at the periphery

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of the continent, making the communication with sea-water and the deposition of marine sediments easier. For example, during the intracontinental rifting stage from the Early Jurassic to the Middle Jurassic, the North West Shelf had been situated at the southern margin of the Paleo-Tethys Ocean, and organic-rich argillaceous shales were formed in faulted ocean basins such as the Bona-parte Basin and the Northern Carnarvon Basin. These shales contain type II and type III kerogens and mainly generate gas, with TOC ranging from 2.2% to 13.9%. They are the main source rocks in large gas fields.

Besides faulted passive margin basins, the marine source rocks formed during the early drift stage are also widely distributed in the other six subtypes of basins. These source rocks were mainly formed in the early drift stage as the sea level of the narrow ocean rose. Unlike the source rocks formed in the rifting phase, these source rocks are widely distributed in continental slope zones and even continental uplift zones. For example, the Early Jurassic Tithonian source rocks in the basins in the Gulf of Mexico and on its periphery are such source rocks, which are distributed outside the range of the oceanic crust. The main type of kerogen is type II, the TOC gen-erally ranges from 0.5% to 5.0%, with a maximum of 16%, and the hydrogen index (HI) generally ranges between 200 and 800 (mgHC/gTOC). These rocks mainly generate oil and are the most important source rocks in depres-sion-type basins, delta reformed basins, and inverted basins.

The deltaic source rocks formed during the late drift stage can mature and effectively supply hydrocarbons only in delta reformed (passive margin) basins. It has been confirmed that the oil and gas discovered in five delta basins (the Niger Delta Basin, the Nile Delta Basin, the Rovuma Basin, the Lower Congo Basin, and the McKinsey Basin), it has been found that oil and gas mainly originate from pre-deltaic argillaceous shales. Taking the Niger Delta Basin as an example, the TOC of the source rocks in this basin generally ranges from 0.2% and 6.5%, with an average of 2.6%, and their SPI value (*S*1

* *S*2) is 7.5 kg/t, indicating that they are good-excellent source rocks.

**4.2. Reservoir-seal assemblages**

The passive margin basin considered herein has un-dergone the vertical stacking of three prototype basins. Therefore, lithofacies change rapidly, resulting in the formation of many types of reservoir rocks and cap rocks in large oil and gas fields, and multiple types of reser-voir-seal assemblages have been formed within the strata in the vertical direction [22].

It has been confirmed that the reservoir rocks of large oil and gas fields are of various types. These reservoir rocks can be classified into the following three major

types: fluvial–deltaic sandstone, (micro) biogenic lime-stone and bioclastic oolitic limestone in the high-energy zones of shallow-water carbonate platforms, and gravity-flow gravely sandstone (carbonate rock). The main types of cap rocks include rock salt, gypsum, and argillaceous shale. In the discovered recoverable reserves of oil and gas, the oil and gas reserves in fluvial–deltaic sand bodies, gravity-flow gravely sandstones, and shallow-water car-bonate rocks account for 37%, 35%, and 28%, respectively.

The reservoir-seal assemblages in large oil and gas fields in various types of passive margin basins have dif-ferent characteristics (Table 4). For faulted basins in ar-eas such as the northwestern margin of Australia, reser-voir-seal assemblages consisting of fluvial-deltaic sand-stones and transgressive shales are the major type of reservoir-seal assemblage, which include two types of assemblages, namely, assemblages composed of reservoir rocks and cap rocks within intracontinental-intercon-tinental rift sequences (such as the Lower-Middle Juras-sic reservoirs in the Carnarvon Basin, which have poros-ity ranging from 11% to 35% and permeability ranging from 20 10 3 μm2 to 5000 10 3 μm2) and assemblages composed of reservoir rocks at top of rift sequences and cap rocks formed during the drift and depression stages (such as the Cretaceous reservoirs in the Browse Basin, which have porosity ranging from 7% to 27% and per-meability ranging from 8 10 3 μm2 to 1000 10 3 μm2). The second type is more enriched with hydrocarbons. For salt-free faulted basins such as the Tanzania Coastal Ba-sin, reservoir-seal assemblages consisting of gravity-flow sandstones and marine shales are the major type of res-ervoir-seal assemblage, all of which are located within the strata formed during the drift and depression stages. It is speculated that reservoir-seal assemblages also exist in faulted basins in the lower part.

However, these reservoir-seal assemblages have not been confirmed because they are deeply buried and dif-ficult to explore. Two types of reservoir-seal assemblages have been formed in salt-bearing fault-depression basins such as the Santos Basin. The first type is the reser-voir-seal assemblage formed by carbonates and evapo-rites at top of intracontinental-intercontinental rift strata. For these assemblages, the reservoir porosity ranges from 5% to 25%, the maximum thickness of a single pay zone is more than 400 m, and the overlying rock salt layer is stably distributed in the horizontal direction, with a length of 650 km from south to north, a width of 380 km from east to west, a large thickness, and a strong sealing capability. The second type is the reservoir-seal assemblage formed by gravity-flow sandstones and ma-rine shales within the strata formed during the drift and depression stages. For these assemblages, turbidite sand-stones are reservoir rocks, which have porosity ranging from 20% to 33% and permeability ranging from 1000

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10 3 μm2 to 4000 10 3 μm2, and the Cretaceous (Aptian) rock salt and Paleogene marine argillaceous shale are cap rocks. In salt-free (transformed) depression-type basins such as the Côte D’Ivoire Basin, most reservoir-seal as-semblages are composed of turbidite sandstones and marine shales formed during the depression stage, and a few assemblages are formed by carbonates and marine shales. All reservoir-seal assemblages in salt-bearing de-pression-type basins such as the Senegal Coastal Basin are located within the strata formed during the depres-sion stage. However, due to the existence of rock salt and carbonate rocks, these assemblages are of various types, including both assemblages formed by gravity-flow sand-stones and rock salt and those formed by gravity-flow sandstones and marine shales. As the extent of explora-tion increases, reservoir-seal assemblages consisting of reef-shoal complexes and marine shales or tight lime-stones will definitely be found. Taking the Miocene tur-bidite sandstones and Upper Cretaceous (Maastrichtian) sandstones as examples, the Upper Cretaceous clastic reservoirs comprise few mudstone interlayers and have porosity of up to 35% and permeability of hundreds of mD; as a potential reservoir, the Jurassic-Lower Creta-ceous carbonate platform has high porosity ranging from 10% to 23%. Delta reformed basins are the most complex type. Taking the Niger Delta Basin as an example, the reservoir-seal assemblages in this basin are all located within the deltaic strata formed during the late drift stage, the well-developed reservoir-seal assemblages formed by deltaic sandstones and transgressive shales are located in the growth fault zone of the inner ring, and all of the reservoir-seal assemblages in the plastic diapirism zone of the inner ring, the thrust and fold belt of the outer ring, and the foredeep gentle slope zone are com-posed of gravity-flow sandstones and marine shales with porosity ranging from 22% to 32% and permeability ranging from 500 10 3 μm2 to 1000 10 3 μm2. The res-ervoir-cap combination of the reverse reformed basin is exactly the same as that of the pre-reformation basin. The types of the reservoir-seal assemblages in inverted basins are completely identical with those formed before the reformation of such basins.

**4.3. Types of the traps**

The traps in different types of passive margin basins vary greatly in type (Table 4), especially in the Northern Gulf of Mexico, where both rock salt and highly con-structive deltaic basins are formed. In such basins, vari-ous types of traps that are favorable for hydrocarbon ac-cumulation can form under the action of gravity-induced detachment and plastic diapirism. The three major types of traps are structural traps, lithologic traps, and struc-tural-lithologic composite traps. The available exploration results show that the oil and gas reserves in these three

major types of traps account for 39%, 35%, and 26% of the total reserves of oil and gas stored in traps. Structural traps mainly include anticlines, faulted anticlines, fault noses, fault blocks, anticlines penetrated by rock salt, post-salt drape anticlines, salt pillows, and turtle anti-clines; lithologic traps mainly include updip pinch-outs and lenses; structural-lithologic composite traps are traps formed under the combined effects of structural and lith-ologic factors [22].

The specific types of traps in various types of passive margin basins are described below. In faulted passive margin basins, besides structural traps similar to those in rift basins (such as rollover anticlines and fault blocks), there are more structural-stratigraphic traps associated with regional unconformities resulting from thermal up-lift caused by intense magmatic activities during the in-tercontinental rifting stage.

In salt-free fault-depression basins, drilling can only reveal the reservoir-seal assemblages within the strata formed during the depression stage due to large sediment thickness of the strata. Therefore, in addition to the lithologic traps and fault-lithologic composite traps re-lated to deepwater gravity-flow sandstones, attention should also be paid to the structural traps and struc-tural-stratigraphic traps in the lower undrilled rift se-quence that are similar to those in faulted basins.

In salt-bearing fault-depression basins, large oil and gas fields are mainly concentrated in the carbonate se-quences of post-salt drape anticlines, and in the pre-salt section, hydrocarbons are mainly concentrated in the lithologic traps and fault-lithologic composite traps re-lated to gravity-flow sand bodies.

In salt-free (transformed) depression-type basins, hy-drocarbons are mainly concentrated in lithologic reser-voirs controlled by gravity-flow sand bodies in the strata formed during the depression stage, and the structural traps related to intracontinental rift sequences and car-bonate traps in paleo-uplift zones related to transition formations also have favorable conditions for hydrocar-bon accumulation.

Due to the existence of rock salt and carbonate rocks, the types of traps in salt-bearing (extensional) depres-sion-type basins are complex. Composite reservoirs re-lated to salt structures and gravity-flow sand bodies and lithologic traps formed by gravity-flow sand bodies below the steep slopes of carbonate platforms have been proven to be the two most important types of traps. In the future, the stratigraphic traps formed by reef-shoal complexes on carbonate platforms should also be explored.

The types of traps in delta reformed basins are most complex, and the reservoirs in various structural zones are of different types. Taking the Niger Delta Basin as an example, the large oil and gas fields in the growth fault zone of the inner ring are mainly concentrated in struc-

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tural traps such as rollover anticlines, faulted anticlines, fault noses, and fault blocks; the lithologic traps formed by gravity-flow sand bodies are the major type of trap in the plastic diapirism zone; compressional anticlinal traps are the main type of trap in the thrust and fold belt of the outer ring; the lithologic traps formed by gravity flow channel-fan systems are the main type of trap in the foredeep gentle slope zone. If rock salt occurs, the types of reservoirs in the middle ring can be much more com-plex. In addition to the lithologic reservoirs (traps) re-lated to gravity-flow sand bodies in secondary sags re-sulting from salt tectonics, there are also other types of reservoirs related to salt tectonics, such as puncture an-ticlines, drape anticlines, salt pillows, and turtle anti-clines.

The traps in inverted basins are related to both the types of these basins before reformation and the extent of reformation. For example, on the landward side of the Tampico-Misantla Basin, the Veracruz Basin, and the Sureste Basin on the southwestern periphery of the Gulf of Mexico, the compressed structure underwent moderate inversion, and the reservoirs formed by compressional anticlines are therefore the main type of reservoir; as the structure extended eastward into deep water, the envi-ronment gradually transformed into an extensional tec-tonic setting, providing the same conditions for the for-mation of traps as the surrounding unreformed basins.

1. **Favorable exploration areas in the future**

In general, global deepwater oil and gas exploration is still in the stage of risk-taking exploration with a very low extent of exploration and is characterized by imbal-ance [22 23]. Favorable offshore exploration areas differ from one another in terms of basin location, source-res-ervoir-seal assemblage favorable for hydrocarbon accu-mulation, and the scale of oil and gas resources. In this

paper, the favorable areas for deepwater oil and gas ex-ploration in the future are systematically investigated based on a statistical analysis of more than 1300 deep-water oil and gas fields discovered around the world and the geological characteristics and resource potential of deepwater oil and gas reservoirs in various offshore areas.

**5.1. Eastern and western coasts of the Atlantic**

The eastern and western coasts of the Atlantic are the areas with the largest number of deepwater oil and gas discoveries and the largest reserves in the world [22]. By the end of 2022, 998 deepwater oil and gas fields had been discovered, with total oil and gas reserves of 283 108 toe. These deepwater oil and gas fields account for 73% of the total number of deepwater fields discovered around the globe, and the oil and gas reserves in these fields account for 70% of the world’s total deepwater oil and gas reserves (Table 5) [24]. The top ten basins ranked by discovered oil and gas reserves include the Santos Basin, the Gulf of Mexico deepwater basin, the Campos Basin, and the Niger Delta Basin (Fig. 4) [24]. Most of the aforementioned basins have been explored to low-medium extents and have huge resource potential. The extents of research, understanding and exploration of the eastern and western coasts of the South Atlantic are higher than those of the coasts of the Mid-Atlantic and the North Atlantic.

There are various types of basins on both sides of the South Atlantic Ocean, which can be subdivided into the southern, middle, and northern sections. The degree of hydrocarbon accumulation varies greatly from one section to another. The middle section is dominated by salt-bear-ing fault-depression basins where hydrocarbons are most highly concentrated. These basins have the greatest re-source potential. Basins such as the Santos Basin, the Campos Basin, and the Kwanza Basin will still be the key targets of deepwater oil and gas exploration in the future.

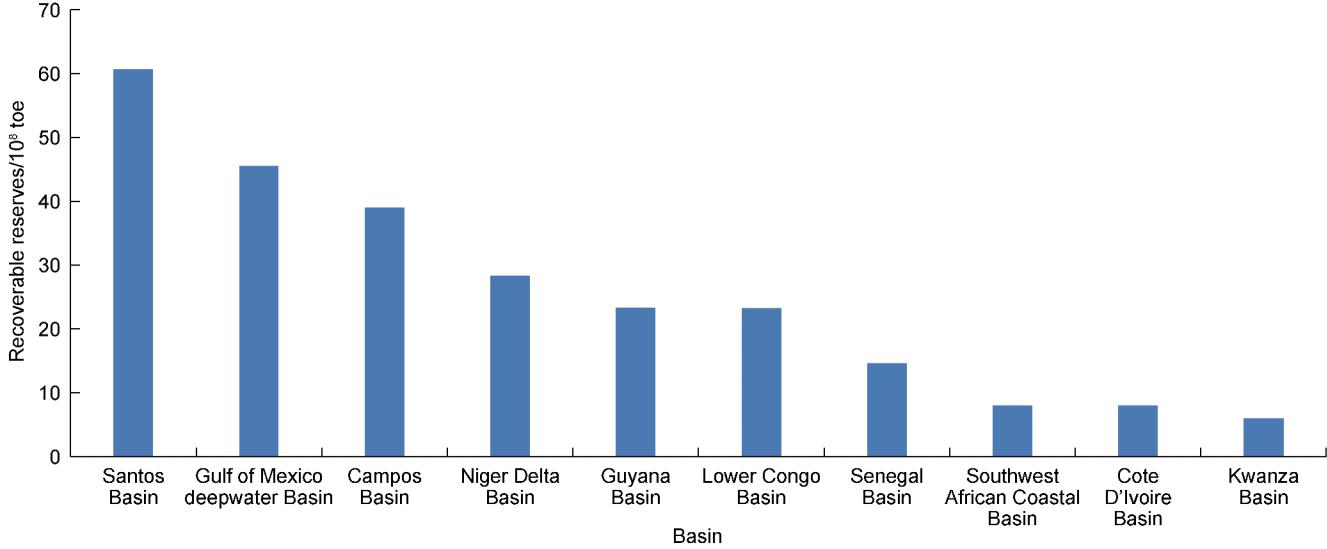
**Table 5.** **Statistical table of deepwater oil and gas fields discovered in various regions around the world**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Number of | Recoverable | Proportion of | Number of | Time of | Recoverable | Proportion of |  |
| Region |  | oil and gas | reserves/ | oil and gas | large oil and | reserves/ | oil and gas |  |
|  | discovery |  |
|  |  | fields | 108 toe | reserves/%① | gas fields | 108 toe | reserves/%② |  |
| Eastern and western | | 998 | 283.00 | 70 | 93 | 1984 2022 | 171 | 60 |  |
| coasts of the Atlantic | |  |
|  |  |  |  |  |  |  |  |
|  | East African | 30 | 41.00 | 10 | 11 | 2010 2013 | 37 | 90 |  |
| Indian | waters |  |
|  |  |  |  |  |  |  |  |
| Ocean | Eastern pe- |  |  |  |  |  |  |  |  |
| periphery | riphery of the | 154 | 25.00 | 6 | 6 | 1971 2006 | 10 | 41 |  |
|  | Indian Ocean |  |  |  |  |  |  |  |  |
| Arctic Ocean periphery | | 1 | 0.02 | 0 |  |  |  |  |  |
| Western Pacific Coast | | 112 | 14.00 | 3 | 2 | 1989, 2003 | 2 | 12 |  |
| Remnant Tethys | | 79 | 43.00 | 11 | 11 | 1999 2021 | 33 | 76 |  |
| Ocean Basin | |  |
|  |  |  |  |  |  |  |  |

Notes: ① The ratio of the oil and gas reserves of deepwater oil and gas fields discovered in each offshore area to the total reserves of deepwater oil and gas fields; ② The ratio of the oil and gas reserves of large deepwater oil and gas fields discovered in each offshore area to the total reserves of deepwater oil and gas fields discovered in the offshore area.

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**Fig. 4. Histogram of the oil and gas reserves of deepwater oil and gas fields discovered in the top ten basins on both sides of the Atlantic.**

Post-salt deepwater gravity flow deposits and pre-salt carbonate assemblages have broad prospects for succes-sive major oil and gas discoveries [10, 22]. The southern sec-tion is dominated by faulted basins. Currently, the deep-water exploration activities in this section are limited to Southwest African waters and the periphery of the Falk-land Islands. It has been confirmed that the traps related to the top structure of the Lower Cretaceous rift sequence are hydrocarbon-rich and have good prospects for explo-ration. In addition, two large discoveries, namely, the Venus and Graff oil discoveries, were first made in the Lower Cretaceous basin-floor fan sandstone reservoirs in the deep water of the Southwest African Coastal Basin in 2022 [25], revealing new exploration areas with great prospects. The northern section is dominated by salt-free depression-type basins, and it has been less explored than the middle and southern sections. The range of distribution of rift se-quences in such basins is relatively small. The Upper Cretaceous channel-fan depositional systems formed during the drift stage should be the favorable exploration targets. The main favorable exploration areas include the Côte D’Ivoire Basin, the Benin Basin, the Guyana Coastal Basin, the Suriname Basin, and the French Guiana Coastal Basin. Salt-bearing depression-type passive margin basins are dominant on both sides of the Mid-Atlantic. These basins have similar conditions for hydrocarbon accumu-lation. The extent of exploration in this area is generally low, except for the Gulf of Mexico. Only a small number of wells have been drilled in deep water, and most of these wells are located in the continental shelf region. The analogous study shows that Jurassic-Early Creta-ceous carbonate platforms were formed in the basins on both sides of the Mid-Atlantic during the early depression stage and submarine fans had been developing very well along the steep slope fronts of carbonate platforms since the Late Cretaceous. It is speculated that the Cretaceous

submarine fans and Paleogene-Neogene lithologic asso-ciations have the greatest exploration potential. In addi-tion, the Jurassic-Lower Cretaceous carbonate facies zone is also a favorable future exploration target. Faulted pas-sive margin basins are dominant on both coasts of the North Atlantic Ocean. In the Vøring Basin, Møre Basin, Faroe-West Shetland Basin, and Ssese Islands Basin on the eastern coast, 43 deepwater oil and gas fields have been discovered, with recoverable oil and gas reserves of 6.5 108 toe. Marine argillaceous shales (serving as cap rocks) formed during the drift and depression stages are widely distributed in the deepwater zone along the west-ern coast. The Jurassic- Cretaceous fault-block structures and structural-lithologic associations on the east coast of Greenland have good prospects for exploration.

**5.2. Indian Ocean periphery**

During the period from 1971 to 2010, deepwater oil and gas exploration activities around the Indian Ocean were mainly concentrated in Indian waters on the eastern pe-riphery and along the North West Shelf of Australia, and six large deepwater oil and gas fields were discovered. The subsequent new discoveries made through explora-tion are mainly small oil and gas fields, and the explora-tion activities performed in East African waters on the western periphery during this period are very limited. In 2010, the giant gas field Prosperidade was discovered in the deep water of the Rovuma Basin. Since 2010, 30 gas fields have been discovered in the deep waters of Kenya, Tanzania, and Mozambique in East Africa, with recover-able gas reserves of 41 108 toe. Among these gas fields, 11 fields are large gas fields with recoverable gas reserves of 37 108 toe [24]. East African waters have become an emerging deepwater field rich in natural gas and an im-portant new domain that will play a leading role in in-creasing natural gas reserves in the future.

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East African waters are located on the western pe-riphery of the Indian Ocean, where the following three types of passive margin basins are well-developed: faulted basin, salt-free fault-depression basin, and delta reformed basin. Currently, the extent of exploration in East African deep waters is still very low [22], and deep-water oil and gas discoveries are mainly concentrated in the Rovuma Basin and the Tanzania Basin [23]. The deep-water gravity flow channel-slope fan systems are most enriched in hydrocarbons. The Somali Basin, the Mo-rondava Basin, and the Mahajanga Basin are faulted pas-sive margin basins, where no exploration breakthroughs have been made. The structural traps in the rift se-quences of these basins are the main favorable explora-tion targets [22]. Jurassic rock salt is well-developed in the Mahajanga Basin. In addition to the structural assem-blages in pre-salt rift sequences, carbonate reef-shoal complexes are also worthy of attention. The Tanzania Basin is a salt-free fault-depression (passive margin) ba-sin, and the structural traps in its rift sequences and the traps in depression zones related to gravity-flow sand bodies are all favorable exploration targets. It has been confirmed by drilling that the structural-lithologic com-posite traps in the south-north trending offshore shear zone are hydrocarbon-rich. Future exploration targets include the lithologic traps in the upper and lower slope zones and the carbonate reefs formed during the transi-tion stage [22]. Delta reformed (passive margin) basins include the Rovuma Basin, the Lamu Basin, and the Mo-zambique Coastal Basin, and the four annular zones are all favorable exploration targets. The extents of explora-tion in the deepwater and ultra-deepwater zones of the Rovuma Basin are relatively high. Gas-rich zones have been discovered in the foredeep gravity-flow sand bodies. These zones involve low exploration risks and are there-fore reliable areas for increasing oil and gas reserves and production. In addition, large gas fields have been dis-covered along the fold and thrust belt in the outer annu-lar zone. This belt has considerable exploration potential. As predicted based on studies, four large annular hydro-carbon accumulation zones may have been formed in deep water in the northern part of the offshore Paleo-cene-Miocene Lamu Delta of the Lamu Basin [22]. The sediment thickness can reach 12 000 m in the Mozam-bique Coastal Basin, especially the northern offshore area of the basin, which is comparable to the thickness of sediments deposited in the Niger Delta Basin in West Africa. The deepwater deltaic sandstones and foredeep gravity-flow sand bodies are favorable exploration targets.

**5.3. Arctic Ocean periphery**

The Arctic Ocean periphery is dominated by faulted passive margin basins. Due to reasons such as harsh natural conditions and ownership, these basins have been studied and explored to very low extents. The discovered

oil and gas fields are mainly distributed in the East Bar-ents Sea Basin, the Barents Sea Platform Basin, and the Sverdrup Basin. Only one small deepwater oil and gas field has been discovered in the Sverdrup Basin up to now [24]. The deepwater basins around the Arctic Ocean contain abundant oil and gas resources. The undiscov-ered oil and gas resources in these basins are predicted to exceed 300 108 toe [26]. Regional geological studies [22, 27 31] show that a series of back-arc extensional-foreland basins were formed in this region during the period from the Late Paleozoic to the Late Cretaceous, and in the Late Cretaceous, this region entered the rift-transition-drift-depression evolution stage, during which passive margin basins were formed. In the vertical direction, multiple suites of favorable source rocks are connected by faults formed in the rifting phase, creating favorable assem-blages together with the large structure traps formed in the rifting phase. These assemblages have great explora-tion potential and provide favorable conditions for the formation of large reservoirs. The future exploration prospects of the Jurassic-Neogene assemblages in the East Barents Sea Basin, the Barents Sea Platform Basin, and the Kara Sea are worthy of special attention.

1. **Recommendations for expanding overseas oil and gas exploration business**

The extent of exploration is generally low in offshore areas around the globe, and the undiscovered offshore oil and gas resources account for about 43% of the total un-discovered resources of the world. In this paper, several recommendations for developing new deepwater explo-ration projects are made based on the follow-up studies conducted in recent years.

**6.1. Expanding the channels for acquiring multiuser seismic data and improving the level of scientific selection of deepwater exploration areas.**

Currently, the evaluation and study of new overseas deepwater projects are mainly based on the analysis and comparison of secondary data such as public documents and commercial databases, and there is a lack of primary data, especially seismic data. The seven major interna-tional oil companies usually conduct preliminary selec-tion of exploration blocks by reviewing multiuser seismic data and then purchase seismic data for detailed evalua-tions. The annual expense for reviewing offshore multi-user seismic data ranges from 3 to 5 million US dollars (USD), and the annual expense for purchasing seismic data can reach USD 50 million. To avoid following inter-national oil companies in the evaluation of new projects under a cooperation framework, Chinese oil companies need to actively expand the channels for acquiring mul-tiuser seismic data, establish annual exploration funds to purchase multiuser seismic data, strengthen cooperation with multiuser seismic data acquisition companies such

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as TGS and ION, and establish cooperation mechanisms for on-demand data review in order to preselect deepwa-ter exploration areas in a more targeted and timely manner and provide first-hand data for the scientific selection and evaluation of favorable exploration areas.

**6.2. Strengthening efforts to acquire deepwater exploration and development projects in key areas such as the eastern and western coasts of the South Atlantic Ocean, East Africa, and the Arctic Ocean and accelerating the process of business arrangement for global deepwater oil and gas exploration**

Characterized by favorable conditions for hydrocarbon accumulation, low extent of exploration, and great ex-ploration potential, the large deepwater oil and gas fields around the world have become the major fields for mak-ing large oil and gas discoveries. Therefore, continuously expanding deepwater oil and gas exploration business is the inevitable choice. Chinese oil companies should make prior arrangements for deepwater oil and gas exploration and strengthen efforts to acquire exploration blocks with a focus on the three deepwater regions, namely, the east-ern and western coasts of the South Atlantic Ocean, East African waters, and the western coast of the Arctic Ocean.

In recent years, oil and gas discoveries have been made successively in Brazil, Guyana, Suriname, and South Af-rica on both sides of the South Atlantic Ocean. So far, two assemblages, namely, the pre-salt carbonate rock assem-blage and the post-salt deepwater slope fan assemblage, have been confirmed. The first assemblage is character-ized by large reserves and high single-well production. In 2023, the Brazilian National Agency of Petroleum, Natu-ral Gas and Biofuels (ANP) promulgated new adminis-trative measures for block contracting and bidding, an-nouncing the initiation of permanent bidding for 561 blocks in 10 offshore basins without limit on the deadline for submission of bids. In addition, Argentina, Suriname, and other countries will also invite bids for new offshore blocks. Argentina has the opportunity to negotiate bids in cooperation with YPF for early entry into new blocks. In East African waters, there are three passive margin ba-sins, namely, the Rovuma Basin, the Mozambique Basin, and the Somali Basin. Among these basins, the Rovuma Basin has been explored to the largest extent, and multi-ple submarine fans with total recoverable reserves of 4.28×1012 m3 have been discovered in the basin. The geo-logical conditions of the other two basins are generally similar to those of the Rovuma Basin. No well has been drilled in the other two basins, but these two basins have great exploration potential. It is recommended to strengthen efforts to acquire deepwater blocks in the aforementioned areas and enter the few large frontier basins in the world at the lowest cost by undertaking exploration projects in order to consolidate resources and provide a solid foundation the development of deepwater

oil and gas exploration business.

1. **3. Entering and exiting exploration blocks flexibly by multiple means**

International oil companies already started to engage in overseas offshore oil and gas exploration business 40 years ago. Their business scope is very wide, and they have made business arrangements in frontier exploration fields and hotspots. In terms of entry methods and strategies, international oil companies usually acquire exploration blocks in batches by multiple means such as negotiation, bidding, and equity participation. Bidding is the main means of entry into exploration blocks, and the blocks entered by means of bidding account for 60.3%. Entering and exiting blocks flexibly is a common practice adopted by international oil companies to carry out cross-border exploration activities. After obtaining ex-ploration blocks, they will exit the blocks in due course if the exploration results are not as good as expected. Since the 1970s, international oil companies have acquired a large number of exploration blocks in offshore areas, especially the eastern and western coasts of the Atlantic, East African waters, and North African waters, but they exited most of these blocks before exploration break-throughs were made. Apart from unsatisfactory geologi-cal conditions, the reasons for exit also include the limi-tations posed by the quality of seismic data, technologies for identifying sand bodies, and geological understanding. After breakthroughs in geological understanding and exploration and development technologies are made, international oil companies may re-enter the blocks that they have exited if such re-entry is consistent with their development strategies. ExxonMobil’s re-entry into the Guyana Basin and Eni’s re-entry to the Côte D’Ivoire Ba-sin are good examples of such practice.

**6.4. Acquiring blocks as large equity holders and operate blocks under the “dual exploration model”**

In terms of business strategy, most international oil companies enter exploration blocks as large equity hold-ers (35% 100%). After oil and gas discoveries are made, they operate and manage their exploration blocks under the “dual exploration model”, sell some shares, and thereby recover costs rapidly and gain considerable eco-nomic benefits before the initiation of oil/gas production. For example, Eni acquired 74 deepwater blocks around Africa through bidding, with a total area of 38 × 104 km2. After discovering the Zohr gas field in the deep water of Egypt, Eni transferred 50% of its equity shares and re-tained 50% of its shares for gas field development. By doing so, Eni not only quickly recovered the investment of about USD 300 million made by it in the exploration phase, but it also realized a net profit of USD 2.7 billion. Eni’s practice has become a paradigm of the “dual explo-ration model”. Such practice not only allows oil compa-

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nies to recover costs quickly, but it can also enable ex-ploration projects to generate great economic benefits before they are put into operation.

**6.5. Strengthening cooperation with leading international oil companies having advanced deepwater technologies in asset transactions to improve the technical level and increase the oil and gas reserves of exploration blocks**

ment activities, cooperate with geophysical companies (such as CGG, TGS, and PGS) and the three major oilfield service companies (Transocean, Stena Drilling, and Noble Drilling), make continuous progress in the organization and management of deepwater oil and gas exploration activities, business operations, engineering technology, talent pooling and team building, and gradually trans-form from “non-operators” to “operators”.

The leading oil companies in the field of global deep-water oil and gas exploration include major international oil companies such as Eni, Shell and Equinor, small and medium-sized independent oil companies such as Tullow Oil, Nobel Energy and Ophir Energy, and national oil companies represented by Petrobras and Petronas. There are three optional methods to enter exploration blocks. The first option is to enter exploration blocks with oil and gas discoveries and great exploration potential through asset swaps. The second option is to enter unexplored blocks with great potential by paying historical explora-tion costs. The third option is to follow Shell’s practice in its acquisition of bp and acquire small independent oil companies which are in financial distress and whose stock prices are low and volatile (such as Ophir Energy and Cobalt Energy). These methods can rapidly improve the levels of technologies and equipment for deepwater exploration blocks and accelerate the development of offshore oil and gas exploration business.

**6.6. Improving business operation capabilities and gradually transforming from “non-operators” to “operators”**

Block operators have the right to speak in oil and gas exploration and the space for flexible business operations, which is favorable for them to gain benefits from explo-ration activities. China’s three major oil companies started to engage in the deepwater oil and gas explora-tion business in 2005, successively acquired 32 explora-tion and development projects in 14 countries including Australia, Myanmar, and Brazil, and achieved prelimi-nary results in the operation of some deepwater projects, such as the rapid increase in oil and gas reserves and production of the projects in Angola and Guyana, the remarkable exploration results of the Libra project in Brazil, and the highlights in large-scale exploration of the Aram project. However, the three major Chinese oil companies participate in these projects as non-operators and small equity holders, which is not favorable for im-proving the level of deepwater operations and creating benefits from exploration activities. It is recommended to improve business operation capabilities, follow the oper-ating model of international oil companies under which specialized engineering and technical service companies are hired to perform offshore exploration and develop-

1. **Conclusions**

Based on the process of change in new oil and gas re-serves, the history of global offshore oil and gas explora-tion can be divided into the following three development stages: shallow-water development stage (from 1917 to 1976), deepwater development stage (from 1977 to 2009), and ultra-deepwater development stage (from 2010 to the present). The deepwater domain is currently the most important domain for carrying out global oil and gas exploration and increasing oil and gas reserves and pro-duction. Deepwater oil and gas discoveries are mainly distributed in the Gulf of Mexico, the eastern and western coasts of the Atlantic, East and North African waters, the Black Sea, the South Caspian Sea, the Bay of Bengal, the North West Shelf of Australia, and the South China Sea. Passive margin basins are the most important source of reserves of large oil and gas discoveries and additional reserves in deep waters, and oil and gas resources are mostly found in Mesozoic-Cenozoic lithologic reservoirs.

The seven major international oil companies are highly active in all aspects of deepwater oil and gas exploration and development and play a leading role in the develop-ment of global deepwater oil and gas exploration busi-ness. The strategies for deepwater oil and gas exploration include (1) taking the lead in the development of deep-water oil and gas exploration business, actively making arrangements for deepwater exploration blocks, and at-taching importance to the participation in bidding for key areas; (2) prioritizing early entry into exploration blocks through bidding before oil and gas discoveries are made, and considering entry into exploration blocks through mergers and acquisitions at high prices after discoveries are made; (3) attaching importance to the accumulation of oil and gas exploration technologies and strengthening cooperation in the supply chain of tech-nologies for deepwater oil and gas exploration; (4) adopting strategies that enable oil companies to take the lead or follow other companies in deepwater oil and gas exploration and share risks with other companies through extensive cooperation.

The favorable deepwater exploration areas around the world are mainly distributed along the eastern and western coasts of the Atlantic, the Indian Ocean periph-ery, and the Arctic Ocean periphery. Deep waters are key areas for oil companies to arrange for the implementa-

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tion of their global oil and gas exploration strategies. In this paper, the following recommendations for develop-ing overseas oil and gas exploration business are pro-posed: (1) expanding the channels for acquiring multiuser seismic data and improving the level of scientific selec-tion of deepwater exploration areas; (2) strengthening efforts to acquire deepwater exploration and develop-ment projects in key areas such as the eastern and west-ern coasts of the South Atlantic Ocean, East Africa, and the Arctic Ocean, accelerating the process of business arrangement for global deepwater oil and gas exploration;

1. entering and exiting exploration blocks flexibly by multiple means; (4) acquiring blocks as large equity holders and operating blocks under the “dual exploration model”; (5) strengthening cooperation with leading in-ternational oil companies having advanced deepwater technologies in asset transactions to improve the technical level and increase the oil and gas reserves of exploration blocks; (6) improving business operation capabilities and gradually transforming from “non-operators” to “operators”.

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