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Strategies of Efficient Exploration and Development of Deepwater Oil and Gas Overseas

Abstract Deepwater offshore area, with rich oil and gas resources, has currently become the hot area for oil and gas exploration and the main battlefield where global oil majors compete with each other. This article summarizes the current situation of deepwater oil and gas exploration and development overseas from the perspectives of exploration history, exploration achievements and technical progress, and analyzes the difficulties and challenges faced by the industry, such as low level understanding of hydrocarbon accumulation conditions, global security and environmental challenges. And then, several feasible implementation strategies have been proposed on how to actively deal with the challenges, promote Chinese oil companies' overseas exploration, and realize efficient exploration and development of deepwater oil and gas fields overseas. These strategies consist of three aspects: profit-oriented operation principle, exploration ideas supported by theory and technology, and exploration strategy that puts safety first. In the era of low oil prices, Chinese oil companies must build up confidence, seize the opportunity and face the challenge while taking efforts to innovate technologies and theories, updates strategic ideas, and cultivate deepwater talents so as to be in an active position in global deepwater exploration and development industry in the future.

Keywords: deepwater, exploration and development, operation principle, exploration idea, exploration strategy

1 Introduction

Oil and gas resources are very rich in offshore areas globally. According to statistics, the oil and natural gas resources in global offshore areas are about $1,350\times10^8$ t and 140×10^{12} m^3 respectively (Li, 2008). The global hydrocarbon exploration trend during the last 20 years indicates that oil and gas found in offshore areas give increasing contributions to the global reserve growth, and over 60% of the offshore oil and gas reserves are distributed in water areas deeper than 500 m. Currently, though the resource potential in deepwater area is higher, the exploration degree is low. Meanwhile, with the development of global oil and gas exploration, the exploration potential is becoming limited and the exploration is becoming more difficult in onshore and shallow water area. Therefore, deepwater and ultra-deepwater areas have become the hotspots in oil and gas exploration.

Deepwater exploration and development ability has become one of the most important symbols of a first-class international oil company. With China's remarkable economic growth, dependency on importing oil and gas is increasing and it is suggested that Chinese oil companies should participate in oil and gas hotspots exploration around the world. However, the three gigantic Chinese oil companies are confronted with many kinds of bottlenecks and challenges when they encounter great engineering difficulties and high cost of hydrocarbon exploration and development in deepwater area because of their late start in this domain. It is necessary to advance some effective countermeasures so as to accelerate hydrocarbon exploration and development business in overseas deepwater area and enhance economic benefits. As a result, it will improve national energy security and economic development.

2 Current situation of exploration and development of oil and gas in deepwater overseas

Compared with exploration and development in onshore and shallow water, those for oil and gas in deepwater area have such characteristics as: high technical requirements and operational difficulties, large investment and high exploration risk (Lv, He, Wu, Sun, & Wang, 2006). However, reserves of single discovery in deepwater are usually large because the degree of exploration is low, thus

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the unit cost of reserves found is not that high and it will be gradually lower along with the progress of technology and improvement of infrastructure in deepwater oil and gas exploration and development.

2.1 History of oil and gas exploration in deepwater area

Offshore hydrocarbon exploration started in the 18th century when the first well was drilled in California offshore with only several meters deep. As exploration level advances, marine oil and gas exploration developed toward deepwater area. In 1975, Shell discovered Congac oilfield with 313 m, which was the beginning of deepwater oil and gas exploration in the Gulf of Mexico (GoM). The drilling depth kept racking up since the 1980s. In the 21st century, global deepwater exploration has boomed and 50% deepwater well is over 1,200 m in depth. With the development of technology and economics, particularly in 2003, the water depth of well Toledo1 in GoM was up to 3,051 m, which marked the new era of the deepwater exploration. In 2013, Transocean broke the record with a drilling water depth of 3,174 m in India offshore (Yang, 2014). It was reported that an ultra-deepwater Semi-submersible Drilling Platform, maximum working water depth up to 3,658 m, was constructed in Yantai, Shandong province, China, which meant deepwater exploration entering a much deeper area.

2.2 Achievements of oil and gas exploration in deepwater

According to statistics, over 100 countries around the world have explored oil and gas in marine and more than 50 of them have been drilling in deepwater area. However, over 90% of reserves discovered in deepwater area are concentrated in Brazil, West Africa, The GoM, Norway and Australia (Lv, He, Wu, Sun, & Wang, 2006). Brazil was one of the hottest areas in deepwater oil and gas exploration in the last decade. For example, exploration in Santos Basin, beginning in 1930s, only acquired recoverable reserves of 5.8×10^{10} bbl cumulatively till 2000; while Tupi (now known as Lula), a super-giant oil and gas field with recoverable reserves up to 7.13×10^{10} bbl, was discovered in 2006 in the deepwater area of Santos basin. As the exploration investment rises, 23 oil and gas fields have been discovered subsequently, including 6 super giant oil and gas fields with recoverable reserves up to 1.5×10^{10} bbl individually, and all these discoveries make the recoverable reserves of Santos Basin up to 39.7×10^{10} bbl. The deepwater areas of West Africa are also the battleground for major oil companies. According to additional reserves statistics, from 2005 to 2015, 2.86×10^{10} boereserves were acquired in deepwater area of Kwanza Basin. Block 21 oilfield has recoverable reserves of 780×10^{6} bbl; 2.82×10^{10} boereserves have been acquired in Cote d'Ivoire Basin; and the largest oil field, Jubilee, has recoverable reserves of 889×10^{6} bbl. So, deepwater areas are rich in hydrocarbon resources and possess large exploration potential.

2.3 Deepwater exploration and development technology

Exploration and development in deepwater are difficult and costly, and so reducing investment by improving technology is basic for deepwater exploration and development.

The advancement of geophysical technologies improves the recognition of deepwater sedimentation and structure. For example, high-resolution seismic data acquisition and processing technology can produce clear images for the sedimentary body. Besides, the development of seismic acquisition and processing technologies improves the subsalt imaging and reliability of pre-salt trap. Also, slant streamer acquisition technology can suppress ghost of detection point and broaden the bandwidth. Moreover, the deeper sinking depth of the streamer could reduce the low-frequency noise caused by the water surface and benefit to the acquisition of effective low-frequency signals; orthogonal directions seismic acquisition technology can avoid complex salt body to illuminate the subsalt strata; technologies such as Pre-stack depth migration and reverse time migration can effectively solve the problems of steep salt structure imaging and strong velocity variations, and they can also improve the imaginary of salt surface and salt suspension. It is the advancement of geophysical technologies that guarantees the major breakthrough of deepwater subsalt exploration in South America and West Africa offshore.

Over the past 30 years, deepwater drilling and production equipment, especially the drilling and production platform and system, has been continuously developed and progressed, which has significantly decreased the cost and risk of the development of deepwater oil and gas fields and met the demands of the drilling and production of oil and gas fields in different reserves scale and water depth (Yang & Cao, 2008). At the same time, deepwater drilling platform has become more diversified and integrated. Diversity means performance improvement and pattern innovation, including enhancing stability and strength of drilling platform, improving form of pontoon, floating structure, and technology of deepwater risers; while integration can reduce the development cost by linking several marginal oil and gas fields together to one integrated platform.

Development of oil and gas field in deepwater has stepped into a new stage with the development of deepwater engineering technology as well as the decrease in costs of infrastructure construction and installation. The technology progress of infrastructure construction and technological engineering in the process of drilling and production, such as the choice of slurry, the gas processing, the surface leak-proof and well cementation, prevents marine rise from cooling to make sure the fluid could flow, reduces the costs and risk of development.

The advent of HYSY981 drilling platform makes China the third country that possesses the comprehensive ability to design, construct, debug and utilize an integrated ultra-deepwater semi-submersible drilling platform after USA and Norway. Based on the rough sea conditions of South China Sea, the drilling platform is designed, with maximum working ability of 3,000 m water depth, 10,000 m drilling depth and 9,000 t variable loads. It can resist the worst typhoon of the past 200 years and has a world-leading combination property, which marks China's reaching the leading level in the world in deepwater drilling equipment.

3 Challenges of deepwater exploration and development

With the rising of the global exploration degree, oil and gas exploration is becoming more and more difficult. During the past 20 years, deepwater oil and gas exploration and development have achieved significant progress and become hot spot of global oil and gas exploration in spite of great engineering difficulties and high economical cost. With the increasing of the exploration water depth and the rising of exploration degree, deepwater oil and gas exploration and development are confronted with greater challenges.

3.1 Great difficulties of oil and gas exploration and development

The realization and breakthrough of deepwater oil and gas exploration, first of all, have benefited greatly from the development of deepwater drilling engineering technology. However, with the exploration activity moving from deep water into ultra-deepwater (deeper than 1,500 m), the drilling engineering becomes more difficult. With the increasing of water depth, the drilling rig needs to carry larger loads and needs more advanced dynamic positioning and mooring mode; in order to improve the ability against large velocity ocean currents, subsea control and operation equipment should have higher precision, flexibility and intelligence (Sun, 2013); at the same time, with the increasing of water depth and drilling depth, the decrease of the formation fracture pressure gradient results in narrow window between the fracture pressure gradient and the pore pressure gradient, which greatly increases the risk of leakage and blowout and results in other complex situations. Besides water depth, subsea cryogenic, gas hydrates, shallow gas, shallow water flow, shallow unconsolidated formations, unstable seabed and rugged sea floor all have brought great difficulties in deepwater and ultra-deepwater drilling and engineering (Zhou, 2013). With the restriction of limited cost, plus the low oil price situation, and the increasing water depth, deepwater drilling engineering is confronted with great challenges.

Just because deepwater drilling engineering is difficult and costly, there are fewer wells in deep water area, and deepwater oil and gas exploration strongly depends on seismic technology. The breakthrough of deepwater exploration, especially deepwater subsalt exploration, is also the result of seismic exploration technology advancement. The advancement of seismic acquisition and processing improves the deepwater subsalt imaging, which makes sags, stratigraphy and traps to be able to be characterized and confirmed correctly, and the potential target can be identified exactly so as to guarantee the exploration success of the GoM, Brazil and West Africa deepwater. However, with the development of deepwater exploration, and more complex salt related structure and deeper water, the current seismic imaging technology cannot meet the requirements of future deepwater oil and gas exploration, which has become a key problem restricting the deepwater subsalt exploration on both sides of the Atlantic (Zhang, Han, Fan, Hu, & Cao, 2013).

In addition, with more deeply launching of deepwater exploration and development, high-wax, high-viscosity and extra heavy oil continues to be found. For example, deepwater heavy oil reservoirs with considerable reserves have been found in the Lower Congo Basin in West Africa, Canada-North Sea and west Brazil in South America (Lv, He, Wu, Sun, & Wang, 2007). A lot of technical problems for development of deepwater high-viscosity reserves posed great challenges to deepwater oil and gas development, such as resistance to the non-organic deposit, difficulties of reservoir evaluation, high-viscosity and poor fluidity and high development cost.

3.2 Poor understanding of hydrocarbon accumulation conditions

Due to more complex structure of offshore drilling engineering equipment, its cost is very high, and deepwater exploration economic threshold is higher. For deepwater oil and gas exploration, the larger scale oil and gas discovery is just commercial, so its risk is also far higher than that of onshore and shallow water.

Just because of the higher investment of deepwater drilling, the number of deepwater wells and their corresponding geological data, such as cores and log curves, are extremely scarce; at the same time, the overseas exploration cycle is relatively short. All of the above factors have greatly increased the difficulties of geological and geophysical research work. Even many basic geological conditions for oil and gas exploration issue cannot be studied. Firstly, due to the more deepwater drilling difficulties and high cost, almost no well penetrates deeper hydrocarbon source rock in the deepwater area; secondly, reservoir and cap rock conditions are hard to be confirmed. Because the above basic geological conditions of oil and gas exploration are not clear, it is very difficult to find large-scale oil and gas discovery and the risks of deepwater oil and gas exploration further increase.

At the same time, the sedimentary theory and geological model closely related to the deepwater oil and gas exploration are quite different from those related to the onshore and shallow water area, so the research about deepwater sedimentary and geological model needs to be supported by brand-new theory. In recent years, with the development of deepwater exploration, the theoretical research has also made great progress, but there are still many problems. In terms of deepwater sedimentary theory, based on different classification criteria, scholars have put forward a variety of classification schemes and related terms about gravity flow, which result in no uniform standard in researching gravity flow deposits; in terms of geological model, Walker put forward comprehensive fan model in 1978, and it was widely used in petroleum industry, but Walker gave up the model in 1992; since the 1990s, Shanmugam has introduced the concept of sandy debris flow after re-evaluating the fan model, which caused the widespread concern in the academic circles. In general, although fan model has been developed for about 40 years, there has been no unified, mature and widely recognized deepwater fan model to guide oil and gas exploration until now. All of these restricts the development of deepwater oil and gas exploration and development and results in the lower commercial success rate of deepwater oil and gas exploration.

Due to the data and technical reasons mentioned above, even as the same geological conditions with onshore and shallow areas, trap characteristics and oil/water system of reservoirs cannot be fully understood in deepwater. Faced with higher cost and greater difficulty of deepwater drilling, how to obtain more large-scale oil and gas discovery by fewer wells within the shortest period to improve the economic benefit is the biggest challenge of deepwater oil and gas exploration and development in the future.

3.3 Uncertainties on the ground

In addition to technical challenges of exploration and development and drilling engineering, Chinese petroleum enterprises are also facing various risks of world political, economic, legal policy, international terrorism, and environmental protection. The political risk is the highest risk and difficult to be controlled. Unexpected political events or other political factors could cause economic loss, because they bring changes in the investment environment of the host country for international investment enterprises (Yun, 2013). The political risk is very complex, and it could include war, political violence, the deterioration of the relationship with the investors' nations, ideology and international public opinion made by international interest groups. It is most difficult for Chinese oil companies to predict the political risk during the exploratory process overseas. Once the political environment deteriorates, oil companies will suffer huge and irreparable economic loss. Besides political risks, economic risks cannot be ignored. Economic risks refer to the possibility of the gap between the predicted investment returns and the actual investment returns of the overseas investment projects due to the uncertainties of oil price, exchange rate and financing rate. In addition, economic risks usually interact with political risks. In addition, with the continuous progress of human society, the ecological environment has attracted more attention all over the world, and the relevant laws and policies are made out to protect ecological environment. Especially after BP oil leakage event in the GoM, the world's major oil companies pay more attention to the issue. In addition, the legal policy, international terrorism and other potential risks are also need to be considered for risk assessment. Factors mentioned above tend to be determining factors for the success of deepwater oil and gas exploration.

4 Strategies of efficient exploration and development of deepwater oil and gas overseas

Under the challenges existing in deepwater exploration and development overseas, feasible implementation strategies must be proposed to promote Chinese oil companies to explore overseas and compete with international oil giants.

4.1 Profit-oriented deepwater operation principle overseas

The older generation of explorers accumulated a wealth of exploration experience on onshore and shallow water exploration which was oriented by exploration studies, based on the in-depth analysis of geological assessment and hydrocarbon accumulation conditions to select the best prospect to conduct drilling program. There makeable results have been obtained by the above experience in the domestic exploration, while because of the characteristics of high cost and short exploration cycle of the overseas deepwater exploration, corresponding adjustments must be made to the domestic experience before application overseas.

4.1.1 Strengthen investment and risk analysis to form operation ideas for overseas deepwater exploration guided by economy

For the special geographic environment, offshore exploration cost is very high, generally several times that of onshore, offshore exploration belongs to high risk and high return investment business. Deepwater exploration drilling cost frequently reaches $\$100\times10^6$ per well, development investment is even more, and the total project investment is over billions of US dollars. So pre-investing risk analysis for deepwater project, including integrated evaluation and feasibility study on underground geologic resources and related fiscal policy, regulations, laws, business model and political stability of resources-holding country, is very important and necessary. Especially under the economic background of low oil price, investment in exploration and development has been cut down substantially by oil companies, the business model of building consortium among companies should be an effective strategy to withstand and disperse risks.

4.1.2 Focus on economy and grasp the key geological problems to push forward overseas deepwater exploration strategy

Nowadays the giants, such as BP, Petrobras, Statoil, ExxonMobil, Shell, Chevron and Total, possess clear overseas deepwater exploration strategy and mature core technologies (Jiang, et al., 2008a, 2008b), and occupy the main deepwater market. These companies grasp the key geological problems of reservoir and trap scale to promote overseas deepwater exploration rapidly. This improves the efficiency greatly. Although Chinese oil companies have mastered the initial exploration and development technology on deepwater exploration and development, because of short timeliness of overseas project, it is very hard for them to occupy a position in this field within a short time. So building strategic partnership with these giants and learning from them are the most effective methods.

4.2 New exploration ideas supported by theoretical and technological innovations

As we know, the most outstanding characteristics of deepwater exploration and development are great difficulties on drilling and engineering and high costs. So, proven large volume of reserves by a single well is a guarantee for economic benefit of the project. For instance, in the scenario of deepwater complex faulted block reservoir with complex sedimentary system and multi-oil/water system, it is hardly commercial by drilling faulted block one by one to prove hydrocarbon potential in accordance with the domestic experience. Therefore, the biggest challenge with in deepwater exploration is how to prove and produce oil and gas as much as possible with fewer wells.

4.2.1 Breaking through the bottleneck of deepwater hydrocarbon accumulation cognition and theory

Hydrocarbon accumulation in deepwater is controlled by geological conditions as well, and deepening study of sedimentary model and geological understanding are the basis of exploring oil and gas enrichment law, and this work can usually help to form breakthrough. For example, the improvement of understanding of ancient sedimentary model and of ancient salt structure restoration have greatly increased exploration success rate in the deepwater GoM, and made exploration in GoM sustain at high level; proposition and in-depth research on Jurassic Norphlet Aeolian sand deposition model in eastern GoM have opened up new opportunities for deepwater GoM, and major discoveries have been found so far (Zhao, Lu, Liu, & Zhang, 2014). Another example, soon after proposition of the new understanding that high constructive delta sand body is the major place for hydrocarbon enrichment in offshore Rovuma Basin, oil and gas exploration activities in east Africa got great breakthrough, and eleven giant gas fields were found in offshore east Africa merely in 2010–2012 with new gas recoverable reserves over 2.8×10^{12} m^3 (Zhao, Zhang, Liang, T., Liang, Y., & Li, 2014).

For the future exploration practice, researchers should free the mind, bring forth new ideas, hypothesize boldly while prove it carefully. Especially, researches on these key aspects should be strengthened, including controlling the prototype basin by plate evolution, marine source rock, deepwater sedimentary model and heterogeneity of reservoir, hydrocarbon migration and accumulation model. Based on these deep going studies, a new round of deepwater discoveries will be found through breaking through the bottleneck of deepwater oil and gas accumulation cognition and theory.

4.2.2 Innovating deepwater oil and gas exploration and development technology

With the development of deepwater exploration, the geological conditions become more and more complex. Special conditions such as deep water, deep target, rugged sea floor, complex salt movement and salt diaper, emerge commonly, but seismic data quality in these areas are often poor. Moreover, because of low degree of exploration in these areas with sparse wells, the original data of drilling and logging are quite limited, and most of the information needed by exploration and development are acquired from seismic data. So, progress and innovation of seismic imaging technology is crucial to the study on basin structure, sedimentary model, even exactly delineation of large structural or stratigraphic traps. Taking the deepwater GoM as an example, for the reason of thick salt layer overburden and complex salt structures, conventional seismic acquisition and processing effect was not ideal. Therefore, the technologies of seismic acquisition, processing, reacquisition and reprocessing were tried and experimented over and over again. In the end, subsalt imaging technology was improved greatly, which not only deepened the imaging depth, but also made detailed features of subsalt structure clearer (Zhao, Lu, Liu, & Zhang, 2014). This technical improvement dramatically increased exploration success rate, as well as shortened the cycle from discovery to production. Benefiting from the breakthrough of subsalt imaging technology, subsalt exploration in offshore areas of eastern Brazil developed rapidly during the last decade, and a series of giant oil and gas fields, such as Lula and Libra, were discovered.

In addition, compared with onshore oil and gas exploration, offshore exploration, especially the deepwater exploration needs to overcome the influence of marine environment, typhoon and huge waves. Also, there is limited space on the drilling rig or platform for exploration personnel. Because the target formation is usually thousands of meters deep, drilling engineering and equipment must be able to withstand the impact of waves, tides, currents, sea ice, tsunamis and storm surges (Wang, Chen, & Zhao, 2010), and overcome severe challenges of bottom current, water depth, deep burial, plastic formation, HTHP, and long term operation. So the structure of engineering equipment is very complicated, and a little carelessness will result in a huge loss. In July 2005, the Thunder Horse Platform in deepwater GoM was inclined 22° after suffering the hurricane Dennis, and the repairing work to make the platform resume production was expensive (Jiang, et al., 2008a, 2008b). In summary, only when technology and equipment performance meet the requirements of deepwater or ultra-deepwater operation, deepwater drillings can be conducted successfully, and exploration and development activities can be guaranteed to advance to deepwater or ultra-deepwater area. The drilling platform HYSY981, with independent intellectual property rights by CNOOC currently, has reached operation range of 3,000 m water depth and 10,000 m target depth. The improvement of supporting structure and operational levels provides a reliable technical guarantee for deepwater exploration and development overseas.

Under the extremely complex geological conditions of deepwater, drilling engineering still has very wide scope to develop to solve many problems, especially many critical scientific problems, such as statistical model and stochastic evolutionary model of extreme wave, cyclone, internal waves and circulation, formation mechanism and prediction technology of shallow geological hazard, multi-gradient drilling pressure distribution characteristics and control technology in deepwater drilling, and integrated design and control technology of deepwater taut mooring system.

4.2.3 New ideas of taking the sedimentary body as a unit to prove maximum reserves by fewer wells in deepwater exploration

Based on the innovations of geological understanding and theory mentioned above, analysis shows that commercial success of deepwater exploration depends on the development of reservoir. Given that the reservoir exists, widely developed faults in the structure scope lead to high exploration success rate. Therefore, within the scope of a structural trap, if oil and gas have been discovered in the sedimentary body, even if the sedimentary body has been faulted, it is still possible that the whole sedimentary body should be oil bearing. Hence, the exploration evaluation idea in deepwater area has been determined, and that is confirming structural trap along faults, taking the sedimentary body as an unit to do resources assessment and exploration well deployment, trying to prove maximum reserves by fewer wells to reduce exploration cost and improve economic efficiency (Han, Deng, Yu, Wang, & Chen, 2012).

4.3 Exploration strategy of safety first

With the rapid development of economy, people's lives and the environment are changing dramatically; the deteriorating ecological environment makes it important and urgent to protect the environment. The requirements of environmental protection from resources-holding country are also getting more stringent. For the oil and gas exploration and development industry, the special attentions should be paid to. Also, any safety accident related to safety will result in very serious consequences, it will cause a lot of damage to the ecological environment, and lead companies to face huge economic penalties. So in deepwater oil and gas exploration and development, safety and environmental protection are the most important issues. In a word, the oil companies should take safety and environmental protection seriously, and strengthen the HSE management to achieve zero accidents, zero damage and zero pollution so as to achieve the healthy and sustainable development of deepwater oil and gas exploration and development.

5 Concluding remarks

It is the general trend of the global oil and gas exploration and development that deepwater area become the main strategic replacement area and the main battlefield where global oil Majors compete. In order to occupy an active position in deepwater exploration and development in the future, Chinese oil companies should make full use of the development opportunities under the background of low oil price, strengthen the technology and theory innovation, update strategy ideas and cultivate deepwater talents.

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