Current Status and Future Prospects of Oil and Gas Exploration of PetroChina

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As the exploration of the remaining hydrocarbons in PetroChina's petroleum basins have become challenging and difficult in recent years, PetroChina has commissioned a number of comprehensive studies on seven large oil and gas basins with particular emphasis on lithologic reservoir plays, foreland basins, the deeper parts of super-positioned basins, and some mature hydrocarbon basins. With an improved understanding of the regional petroleum geology and well planned seismic surveys in the pre-phase exploration, a series of important discoveries have been made. In the past few years the oil and gas reserves have been increasing at a steady rate and the development of some large natural gas fields are well under way. The past decade has been the best period for oil and gas exploration for PetroChina. Although most of the major oil and gas basins have already been developed, it is predicted that there is still much remaining reserve to be discovered. In future exploration, it is foreseen that large to giant oil and gas fields may be found in frontier basins and the hydrocarbon reserve in PetroChina will maintain a steady increase.

Lacustrine Sequence Stratigraphy and Its Application in Lithostratigraphic Hydrocarbon Trap Exploration

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A comprehensive procedure for studying lacustrine sequence stratigraphy and relevant techniques has been developed based on the recent field application in the lithostratigraphic hydrocarbon trap exploration within the China National Petroleum Corporation (CNPC). The procedure comprises six steps including (1) background sedimentary analyses, (2) sequence division and correlation, (3) sequence boundary interpretation, (4) facies analysis, (5) seismic lithology prediction and (6) stratigraphic trap appraisal within sequence frameworks. Such an investigation procedure emphasizes that the lacustrine sequence stratigraphic analysis should pay particular attention to the unique geological features in non-marine basins, and the utilization of seismic data and modern seismic interpretation methodologies to improve the accuracy of lithology prediction and stratigraphic trap appraisal. Successful examples from the Songliao Basin and the Erlian Basin, northeastern China, demonstrate that this comprehensive sequence stratigraphic analysis approach is particularly useful in lithostratigraphic hydrocarbon trap exploration.

Quantitative Evaluation Techniques for Petroleum Systems and Their Application

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Quantitative evaluation of petroleum system analysis is to reconstruct the temporal-spatial evolution of the essential elements and relevant geological processes that are responsible for the formation of effective petroleum systems. On the basis of petroleum system modeling and through subdivision and detailed analysis of hydrocarbon migration- accumulation units (MAU) both the resource potential and the distribution of target plays can be quantitatively assessed. During the PetroChina's recent hydrocarbon reserve assessment, quantitative modelling and analyses of petroleum systems and their MAU were widely performed in the major petroliferous basins of PetroChina. This has greatly enhanced the objectivity of exploration target prediction and significantly reduced hydrocarbon exploration risks.

Hydrocarbon Accumulation in Three Different Types of Foreland Basins, Central and Western China

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The foreland basins in the central and western China can be divided into three different types, namely superimposed foreland basin (thrust belt), presenile foreland basin (thrust belt) and reformed foreland basin (thrust belt). Because the three kinds of foreland basins are different in the source rock, reservoir rock, caprock, accumulation time of hydrocarbon and the remolding of hydrocarbon reservoir after accumulation, the favorable exploration area in these foreland basins are also different. The superimposed foreland basins are characterized by two types of source rocks deposited in the early foreland basin and fault-trough lake basin formed between two stages of foreland basin development, and the hydrocarbon in them accumulated in multi-stage, but mainly in late stage. The source rocks in presenile foreland basins were deposited during the foreland basin developing and the hydrocarbon accumulated mainly in early stage. There is only one kind of source rock in reformed foreland basin, namely the lacustrine source rock deposited in fault-trough lake basin before the development of reformed foreland basin, and hydrocarbon mainly accumulated in late stage. The matching level of thrust belt and center of hydrocarbon-generation and the overlying caprocks always determine the exploration potential in these foreland thrust belts.

Dispersed Soluble Organic Matters--An Important Direct Source for Natural Gas in Superimposed Basins

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Natural gas has a great variety of biogenetic and abiogenetic origins, of which biogenetic origin is the main origin for the natural gas of commercial exploitation. As for the biogenetic natural gas, the sapropel organic and humic organic matters can generate natural gas directly. The liquid product (soluble organic matter)

formed during the evolution of kerogen can also generate gas by thermal cracking. Simulation experiments show that although the kerogen can generate a great deal of hydrocarbons, with increasing thermal evolution degree, the ability in hydrocarbon generating of kerogen decreases. At the high evolution stage, the hydrocarbon gas is mostly generated from the scattered or accumulated soluble organic matters derived from kerogen early, and the hydrocarbon generating ability of kerogen is weak. Moreover, because of the weaker mineral catalysis and the need for high temperature and lower conversion rate, the geological condition required to produce thermogenic gas from hydrocarbons of accumulated soluble (e.g. oil pool) is extremely rigorous even though the crude oil can generate hydrocarbon gas in the course of its cracking. However, the scatted soluble organic matters (SSOM) preserved in the reservoir rocks and along migration pathways have enormous hydrocarbon generating potential because the catalytic inorganic mineral contacted with them can greatly lower the activation energy and increase the transformation efficiency of hydrocarbon generation. SSOM distributes in a wide range, and is one of important direct sources of natural gas in the superimposed basin.

Characteristics of Oil and Gas Distribution in Sedimentary Basins of China

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There are three main zones of oil and gas accumulation in sedimentary basins of China. They are termed east zone, middle zone and west zone separated by two mountain ranges: the Daxinganling-Taihang-Wuyi mountains and Helan-Longmen mountains.

The east zone, including the Songliao-Baihaiwan basins, is dominated by oils generated from the Mesozoic and Cenozoic source rocks. The middle zone exemplified by the Ordos and Sichuan basins is dominated by primarily gas generated from Paleozoic and Mesozoic source rocks. The west zone, such as the Tarim and Junggar basins, is characterized by both oil and gas generated from the Paleozoic, Mesozoic and Cenozoic source rocks. The distribution of oil and gas are primarily within the thrust-and-fold belts in the foreland basins, in the ancient uplifts and slopes in the cratonic basins, and in the uplifts in sedimentary depressions within the rift basins. The favorable hydrocarbon accumulation belts are the uplifts and slopes in the superimposed basins, foreland basins and their thrust-and-fold belts, and in the large stratigraphic traps of deltas and reefs.

Current Status of SINOPEC's Exploration on Marine Facies and Subtle Trap Plays

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SINOPEC has recently made significant progress in hydrocarbon exploration in marine facies and subtle trap reservoirs and has maintained a steady annual growth in proven reserves. The exploration success is attributed to the improved understanding on a number of challenging issues relating to marine facies and subtle trap plays.

In the marine facies exploration SINOPEC made three major findings. (1) shale, calcareous shale and marl with Type II-I kerogen and TOC over 0.5% are required to form giant or large fields in marine sequences, and marine carbonate requires higher thermal maturity for kerogen cracking but lower maturity for oil cracking compared with siliciclastics; (2) three major stages of Caledonian Karsting are recognized in addition to the Hercynian Karsting, in Tarim Basin, extending the exploration scope to the Ordovician carbonate; (3) the recognition of the importance of the structural-lithologic reservoir plays led to the discovery of the largest gas field so far in the Sichuan Basin with a single-field proven reserve of $114.4X10^9$ m^3.

In the investigation of subtle traps, we proposed the concept of "slope break zone-lowstand fan" plays and "meshwork-carpet" style hydrocarbon migration and accumulation models for the non-marine rifted basins, which led to the discovery of over 100 million tonnes additional oil reserves annually in the Shengli Oilfield for several years. In the Junggar Basin, a major exploration breakthrough was achieved by employing a reservoir-control model of "uplifting-control, facies-control and double faulting-pressure-control" and has discovered over 200 million tonnes of oil reserves.

Investigation on High-Potential Oil Source Kitchen in Non-marine Basins, China

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The definition of an oil source kitchen in non-marine basins has been a controversy among Chinese geologists. It is widely perceived that any dark-colored mudstones with TOC > 0.3% may be source rocks. According to these criteria the thickness of source rocks is over 1000 m in most non-marine basins in east China.

On the basis of detailed sedimentological and geochemical investigation of the dark-coloured mudstones in both rift basins in east China and evaporative basins in northwest China, we have found that only those with very high TOC contents and are within oil windows, called high-potential source rock (HPSR), may actually contribute to hydrocarbon generation and accumulation. In most source kitchens, the HPSR shales are characteristic of thin-layered (<1m) and their accumulative thickness is normally no more than 200 m. The TOC in the HPSR is generally over 2% in the rift basins and over 1% in the evaporative basins. It is critical to identify the HPSR shales from the vast volume of dark-colored mudstones in a basin in order to accurately predict hydrocarbon reserves. A quantitative approach involving the use of well-log analysis integrating with geological and geochemical interpretation is formulated, which provides a high resolution dataset (8 points of TOC, HI and Ro per meter) for detailed characterization of source kitchens. The source kitchens of the Jiyang Basin in east China and in the Qaidam Basin in northwest China are evaluated in details.

Characteristics of Chinese Lithostratigraphic Reservoir Traps and Future

Exploration

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Chinese lithostratigraphic reservoirs have been widely developed in four types of sedimentary basins including (1) rift basins, (2) depression basins, (3) foreland basins, and (4) cratonic marine basins; and three types of reservoirs (e.g. siliciclastic, carbonate and volcanic). This paper attempts to synthesize the formation mechanisms and distribution characters of these lithostratigraphic reservoirs in continental petroleum basins from four aspects namely (1) reservoir development and evolution, (2) origin of the trap development and distribution, (3) reservoir-forming dynamics, and (4) distribution patterns of oil and gas of different basin types and prediction of the favorable exploration plays. In the past three years, the proven numbers of Chinese lithostratigraphic reservoirs have accounted for approximately 60% of the total proven reserves. We predict that the additional numbers of such play types may account for up to 50% of the total additional proven petroleum reserves in China.

The Neogene Meshwork-Carpet Oil and Gas Pooling System in the Jiyang Depression, East China

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Taking oil and gas pool characters in the Neogene of the Jiyang depression as an example, the concept of “meshwork-carpet” oil and gas pooling system is put forward. The system comprises of a three-layered structure: (1) the lower section is a meshwork layer for hydrocarbon source passages, (2) the middle section is a carpet storage layer and (3) the upper section is a meshwork layer for hydrocarbon accumulation. This unique structure is determined by the changes of the depositional capacity from small to large in the course of fluvial sequence development.

The basic prerequisite for the development of the “meshwork-carpet” oil and gas pooling system is the unique fluvial sequence architecture which often has an enormously thick “carpet” like transportation layer at the base and “branched” sandstone lens superimposed on top. The effective hydrocarbon migration upward within the “meshwork-carpet” oil and gas pooling system is facilitated by the existence of a fault meshwork connecting to the oil source and linking to the storage layer and oil and gas accumulation layer. Effective hydrocarbon trapping in the storage layer and accumulation layer are critical for the formation of secondary oil and gas pools. This new concept of hydrocarbon accumulation provides new insight for exploring secondary oil and gas pools. Sedimentary basins with similar geological regimes as the Jiyang Depression may also have “meshwork-carpet” oil and gas pooling system.