PETROLEUM EXPLORATION AND DEVELOPMENT
Volume 40, Issue 6, December 2013
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: PETROL. EXPLOR. DEVELOP., 2013, 40(6): 687–695.

RESEARCH PAPER

Formation, distribution and potential of deep hydrocarbon resources in China

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Abstract: The onshore exploration realm has been continuously expanded to (ultra-) deep oil and gas recently in China. New comprehension and significant breakthroughs have been made in understanding generation and preservation conditions, reservoirs formation mechanisms, exploration potential, petroleum resources assessments, and exploration engineering technology of deep oil and gas. Deep oil and gas reservoirs include clastic, carbonate and volcanic settings. The temperature of deep oil can be up to 295 °C. Long term shallow burial and rapid deep burial at late stages help preserve the porosity in deep clastic rocks, and dissolution and fracturing effects improve their reservoir properties. Affected by faulting, hydrothermal karst processes, dolomitization and early oil and gas injection, carbonate rocks have good reservoir properties even at depths of 8 000 m. Controlled by tectonism, volcanism, diagenesis and diagenetic reconstruction during supergene and burial stages, primary and secondary weathering types of reservoirs develop deep volcanic reservoirs. Deep oil and gas resources in China are distributed mainly within three main practical areas of carbonate, clastic and volcanic areas. Dominated by gas, some of the more productive areas include the Tarim, Ordos, Sichuan, Junggar, Songliao, Santanghu and Bohai Bay basins. Deep oil and gas exploration in China has entered an age of breakthrough and discovery. Relevant engineering technology, such as ultra deep well drilling and ultra high temperature drilling fluid techniques have facilitated the ability to find (ultra-) deep oil and gas.

Key words: deep oil and gas; reservoir formation mechanism; resources potential; exploration engineering technology

Introduction

With the development of the global petroleum industry, oil and gas exploration regions and target stratum have been extended quickly from land to deep water, from intermediate and shallow zones to deep and ultra-deep zones and from regular resources to unconventional resources, ultra-deep water drilling at depths of over 3 000 m, onshore ultra-deep zones with buried depths of over 6 000 m. Ultra-tight oil & gas accumulations with pore throats less than 1 000 nm and other new types of plays will become the strategic "three kinds of newness" in the development of the petroleum industry [1]. Deep zones will be one of the most important fields of the petroleum industry in the future, and the most strategic and practical fields leading oil and gas exploration and development for China. Based on previous work and the author's research achievements, this paper has obtained a series of new realizations and new progress in deep oil and gas formation and preservation conditions, formation mechanism of reservoir intervals, exploration potential and resource assessment and exploration technology. The paper points out key issues to be solved in deep-zone oil and gas exploration development in terms of geological understanding and technological demands.

1 Significant discovery of deep-zone oil and gas exploration in the world

Different countries and different organizations do not have the same agreement on definitions of deep zones. The definition of a deep zone accepted internationally is a buried depth of no less than 4 500 m [2–3]; in 2005, the Specifications for Calculation of Petroleum and Gas Reserves issued by the Ministry of State of China defines strata with buried depths within a range of 3 500–4 500 m as a deep zone and buried depth over 4 500 m as an ultra-deep zone [4]; in drilling engineering, strata with buried depths of 4 500–6 000 m are defined as deep zones, and strata with buried depths of over 6 000 m are defined as ultra-deep zone intervals [5].

Although agreement on depth boundaries is not the same, the importance of deep oil & gas exploration has been taken on. At present, over 70 countries are drilling oil and gas in

Received date: 24 Feb. 2013; **Revised date:** 28 Aug. 2013.
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Foundation item: Supported by the National Science and Technology Major Project (2011ZX05001-002); National Key Basic Research and Development Program (973 Program), China (2009CB219304).

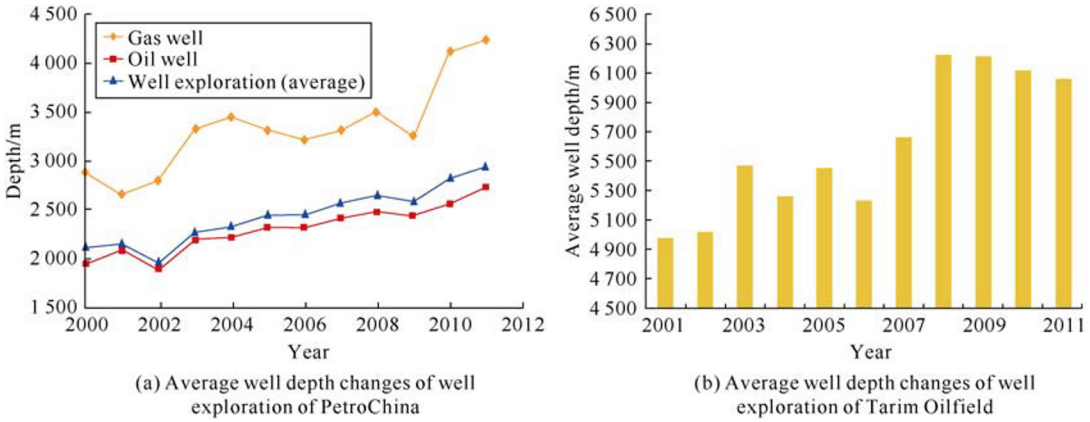
strata with depths over 4 000 m [6]. More than 200 to 300 oil and gas reserves have been discovered in over 80 basins and the burial depth is greater than 4 000 m, including over 30 large deep-zone oil and gas fields (large oil field: recoverable reserves of over 8500×10^3 t; large gas field: recoverable reserve of over 85×10^9 m^3). Of those, 75 industrial oil and gas reserves [7] were discovered in 21 basins with buried depths over 6 000 m. Kaskida oil and gas field in the Gulf of Mexico is the deepest offshore sandstone oilfield in the world, and the with buried depth is between 7 356 m and 9 146 m. If calculated from the sea level, the burial depth can reach 9 146 m. The recoverable reserves (oil equivalent) approach 1×10^8 t [2,8].

In mature exploration areas, deep-zone strata targets are the key replacement fields. For example, in the Middle East, the most significant discoveries in recent years are located in the deep zone, and a series of huge and ultra-large oil and gas fields [7] like Pars, Masjid, Esoleiman, Shaikan1, Kurdamir-1 and Ferdowshave have been discovered in deep zones with depths of over 3 000 m. Moreover, significant discoveries of deep-zone explorations have been maken in the offshore of the Gulf of Mexico, and high-precision seismic methods are used to improve the subsalt formation imaging quality. Results have enabled the imaging of the Tertiary Wilcox Formation, to define oil and gas formation characteristics of the ultra-deep zone, which results in the discovery of the Davy Jones gas reserve in 2009 [7].

More than 1000 oil and gas fields with buried depths of 4 500 to 8 103 m have been discovered all over the world [2–4,6–8]. At present, the Augur oil field in the Gulf Coast Basin of the U.S. is the deepest oilfield (buried depth of 6 511–6 540 m) in the world [2]. Mills Ranch Gas Field in the Anadarko Basin in the U.S. is the deepest gasfield in the world [2], and the buried depth of Ordovician dolomite is 7 663–8 103 m. The porosity is 5% to 8%, and average permeability is 7.0 mD. The gas production is 6×10^4 m^3/d/well and recoverable reserve reaches 36.5×10^9 m^3.

Targets of onshore petroleum exploration in China is developing towards deep-zone/ultra-deep zone [9], and there have been a series of significant breakthroughs in the deep hydrocarbon exploration after the 21st century. Large oil & gas fields are found in the carbonate/salt formations in Lunnan-Tahe, Tazhong and other marine facies, and the clastic formations in North Tarim, Keshen and other continental facies. The Puguang, Longgang, Gaoshiti and other carbonate/ salt formations have been discovered in Sichuan Play; and carbonate/salt, volcanic rock and clastic rock formations in the Ordos, Bohai Bay and Songliao basins are of great potential. Moreover, significant exploration discoveries have been made at depths of over 4 500 m in the eastern area and over 6 000 m in the west. Global depth of oil and gas exploration has been extended downwards for 1 500 to 2 000 m, and deep zone exploration has become a key replacement area for oil and gas exploration in China [9].

PetroChina Company Limited (hereinafter referred to as PetroChina) have increased the average well depth from 2 119 m in 2000 to 2 946 m in 2011. The depths of exploration wells in the Tarim oilfield have exceeded 6 000 m for the last 4 years (Figure 1) and some wells breached 8 000 m (e.g., the depth of Well Keshen No.7 is 8 023 m); and exploration well depths in eastern basin have exceeded 6 000 m (the depth of Well Niudong No.1 is 6 027 m). In the past 10 years, China has completed 22 wells with depths of over 7 000 m, of which 19 wells have been completed since 2006, accounting for 86%. At present, the deepest well is Well Tashen No.1 Well, and the completed drill depth reaches 8 408 m. Active oil shows are seen at approximately 8 000 m and some gas are produced. Well logging and core observation substantiates corrosion cavities and excellent reservoir properties with temperature of 175–180 °C. The deepest industrial gas flow well is Well Bozi No.1 in the Kuche Depression of the Tarim Basin. Using 5 mm oil nozzle, the daily gas production is 25.1×10^3 m^3 and daily oil production is 30 t from 7 014–7 084 m when the oil pressure in the well is the 64MPa. It is a typical condensate gasfield in clastic rocks.The deepest industrial oil well is Well Tuopu No.39 in Tarim Basin, with daily oil production of 95t and gas production of 1.2×10^4 m^3 in the well from 6 950–7 110 m.



(a) Average well depth changes of well exploration of PetroChina

(b) Average well depth changes of well exploration of Tarim Oilfield

Fig. 1 Average well depth drilled by PetroChina