PETROLEUM EXPLORATION AND DEVELOPMENT
Volume 44, Issue 4, August 2017
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: PETROL. EXPLOR. DEVELOP., 2017, 44(4): 603–614.

RESEARCH PAPER

Progress and prospects of reservoir development geology

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Abstract: This paper deals with the main scientific problems, academic connotation, progress and prospects of reservoir development geology. The reservoir development geology involves the key scientific problems of reservoir connectivity, flow ability, and time variability. Its research focuses on the forming mechanism and distribution model of geological factors controlling the reservoir development, the control mechanism of geological factors to oil and gas production, the rule of reservoir dynamic evolution during development, and the reservoir characterization and modeling technology. Important progress has been made on theory and technology of reservoir development geology in high water-cut reservoirs, low permeability and tight shale reservoirs, fracture-cavity reservoirs, which makes the reservoir development geology grow as an independent academic subject already. With the development expansion in areas of deep-strata, deep-water, and unconventional hydrocarbon reservoirs, and the increasing difficulties of high water-cut reservoir development, the theory and technology of reservoir development geology remain to be developed in order to support efficient and economic development of hydrocarbon fields with a sustainable growth.

Key words: development geology; scientific problem; research progress; development geologic factor; reservoir development

Introduction

The reservoir development geology is the basis for economic and effective development of hydrocarbon reservoirs and enhancing oil recovery. To a large extent, the success or failure of reservoir development depends on the research degree of reservoir development geology[1].

The reservoir development geology has developed for more than 70 years since the 1940s. In the 1940s, re-injection of sewage method (i.e., water injection) was first applied to develop the hydrocarbon reservoirs. The change of development approach makes it realized that the continuity and connectivity of reservoirs have a great influence on the oil-gas development, which brings much attention to the study of reservoir development geology. In the 1960s, Daqing oilfield first proposed the sub-layer correlation and oil sandbody description method to study the reservoir heterogeneity, which greatly improved the development effects of continental oilfields. In 1976, Schlumberger Corporation first proposed the concept of reservoir description, and pioneered the systematic research procedures of reservoir development geology, which integrated the single well to multi-well study, qualitative to quantitative study, computerization of research processes and visualization of results. МАКСИМОВ from the Soviet Union wrote a book named Geological Basics of Oilfield Development[2]; and Dicky from the Tulsa university published a book named Petroleum Development Geology[3], which marked the establishment of the subject of reservoir development geology. In the 1980s, with the deepening of reservoir development, especially the refined tapping of high water-cut reservoirs and the development of tertiary oil recovery, the reservoir development geology has entered into a rapid developing stage. Since 1986, China has carried out numerous researches of reservoir description and promoted their application in a large scale. Thus, the reservoir geology research has become one of the key works in the area of reservoir development. In 2006, China first built the academic group of reservoir development geology, Petroleum Geology Committee, Chinese Petroleum Society, which marks the subject of reservoir development geology stepping into a new stage.

This article systematically elaborates the academic connotation of reservoir development geology, and summarizes its research progress and prospects, with a purpose of promoting the development of this subject.

Received date: 15 Nov. 2016; **Revised date:** 08 Jun. 2017.
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Foundation item: Supported by the National Key Basic Research and Development Program (973 Program), China (2011CB201003); the National Natural Science Foundation of China (41372116).

1. Academic connotation and research content

The reservoir development geology is a subject which studies the geological elements controlling the oil-gas development and their evolution, and it is an interdiscipline of geology and reservoir development.

Oil and gas are produced in the multi-scale, multi-time and multi-field coupling reservoirs. The reservoir connectivity, flow ability and time variability are the key geological characteristics influencing the reservoir development, and they are also the important scientific problems of reservoir development geology research. The reservoir connectivity represents the way reservoirs are contacted with each other in space and its connected degree. Flowing barriers, such as shale interlayers and closed faults, could prohibit the fluid flow within the reservoirs, exerting great impacts on the arrangement of well pattern and injection-production relation in reservoir development. The flow ability refers to the flowing capacity within the connected units, which is affected by multiple factors, including reservoir properties, fluid properties, drive type and energy, artificial fracturing and other factors. The time variability refers to the dynamic change of fluid properties, reservoir properties, as well as the sealing of fault and fracture during development. Therefore, it is necessary to study both the static reservoir geological characteristics at the beginning of development, and the dynamic change of reservoir geological factors and fluid distribution in the production period.

Based on the above scientific problems (reservoir connectivity, flow ability and time variability), the research content of reservoir development geology includes the following three aspects: (1) the mechanism and distribution model of geological factors controlling the reservoir development; (2) the controlling mechanism of geological factors on the reservoir development and the dynamic evolution rule; (3) reservoir characterization and modeling technology.

1.1. The mechanism and distribution model of geological factors controlling the reservoir development

Reservoir development is mainly controlled by multiple factors such as structure, reservoir, fluid, and so on. Structural factors mainly include structural form, fault, burial depth and ground stress. Reservoir factors mainly include reservoir scale, lithology, petrophysical properties, pore structure, pore-caves, fractures, interlayers, and oil-gas surface properties. Fluid factors include fluid distribution, properties, reserves, pressure, and temperature. Geological controlling factors vary from different reservoir types and different developing stages[4–6]. Among them, there are four controlling factors showing strong distribution heterogeneity, and it is necessary to deepen the study of their genetic mechanism and distribution model.

1.1.1. Low-order faults

Low-order faults refer to the 4th-order and lower-order faults, such as the faults between small fault blocks in a fault block region, the faults inside a small fault block, etc. With smaller fault offset (several meters to tens of meters) and shorter extension (several hundred meters), these faults are difficult to identify in conventional seismic profiles. The distribution and sealing of low-order faults play an important role in controlling the subsurface fluid movement and remaining oil distribution.

1.1.2. Reservoir architecture

Reservoirs consist of hierarchical architecture units (reservoir units and flowing barriers). For the meandering river reservoirs in a sub-layer, for example, the architecture hierarchy can be divided into channel sandstone/interlayer, meandering belt sandstone/flood plain mudstone, single point bar sandstone/abandoned channel mudstone, lateral accretion sandstone/lateral accretion mudstone, and other smaller hierarchies. The reservoir units and flowing barriers of different hierarchies always show differential shape, scale, direction and spatial superimposition, which lead to the variations in reservoirs compartmentalization and connectivity. Such variation controls the subsurface fluid flow, especially the formation and distribution of macroscopic remaining oil.

The reservoir architecture characteristics are controlled by both the high frequency sequence and sedimentary environment. It is necessary to focus on the spatial distribution pattern and quantitative scale relationships of the architecture units.

1.1.3. Reservoir space and petrophysical property

Hydrocarbon mainly occurs in the clastic and carbonate reservoirs, whose reservoir space types include pore, fracture and cave. The reservoir space of clastic reservoirs is dominated by pore and fracture, while carbonate reservoirs have all the three types of reservoir space.

The pore structure affects the fluid flow in reservoirs, and governs the microcosmic displacement efficiency in the water-injection development (gas injection, polymer, etc.). Petrophysical properties (porosity and permeability) are the macroscopic expression of pore structure. The permeability contrast between layers, in plan view and inner layers controls the fluid flow capacity, and further controls the differential distribution of subsurface oil, gas and water. The pore structure is mainly affected by sedimentary factors (rock texture and composition) and diagenetic environment (burial depth, temperature, pressure, fluid).

Fractures are not only important reservoir space, but also important flow channels. During the reservoir development, the fracture development degree determines the initial hydrocarbon productivity. During the water injection, fractures are easy to become crossflow channels. For tight and shale reservoirs, natural fractures directly influence the fracturing effect. There are many types of natural fractures, such as tectonic fractures, diagenetic fractures, weathered fractures, and so on. These fractures of different origins have differential controlling factors and distribution law. Tight and shale reservoirs are