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Petroleum accumulation: from the continuous to discontinuous

Jingzhou Zhao*, Qing Cao, Yubin Bai, Chuang Er, Jun Li, Weitao Wu, Wuxian Shen

School of Earth Sciences and Engineering, Shaanxi Key Laboratory of Petroleum Accumulation Geology, Xi'an Shiyou University, Shaanxi 710065, China

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ABSTRACT

Based on the extensive studies of conventional and unconventional hydrocarbon accumulations, the concept, classification and formation as well as distribution of petroleum reservoirs are discussed. The revised concept defined the petroleum reservoir as a continuous hydrocarbon accumulation in a single or a set of reservoirs with an independent or uniform pressure system. In terms of the pattern of hydrocarbon accumulation and distribution, the hydrocarbon accumulations are classified into three basic types, i.e., the continuous accumulation, the quasi-continuous accumulation and the discontinuous accumulation. The hydrocarbon accumulation was demonstrated as a process from continuous accumulation to discontinuous accumulation, and therefore these three basic types of hydrocarbon accumulations were identified. The continuous hydrocarbon accumulation is principally formed in source rocks, and typical examples are shale hydrocarbon reservoirs and coal-bed methane reservoirs; it is mainly characterized by tight-ultra tight reservoirs with permeability of nanodarcy to millidarcy; the hydrocarbons occurred in free, adsorbed or dissolved state; a continuous accumulation comprises actually only a single reservoir, and hydrocarbons are extensively and continuously distributed within the scope of effective source rocks; the accumulation has neither defined boundaries nor bottom or edge water; oil and gas mainly accumulate in situ or near the generation of hydrocarbons with no prominent migration; this hydrocarbon accumulation process is basically not controlled by traps. The quasi-continuous hydrocarbon accumulation mostly occurs in the tight reservoirs adjacent to source rocks, and typical examples are most of tight hydrocarbon reservoirs; the hydrocarbons are distributed quasi-continuously in large areas, and each quasi-continuous hydrocarbon accumulation includes numerous adjacent small- to medium-size reservoirs; reservoirs of this kind of hydrocarbon accumulation have no defined boundaries, no or only local edge and bottom water distribution, and no regional oil-gas-water inversion; hydrocarbons are pervasively charged in large areas, and oil and gas accumulation is caused by primary migration and short-distance secondary migration; the hydrocarbon migration and accumulation is principally driven by non-buoyant forces in non-Darcy flow; and the hydrocarbon accumulation is basically not controlled by anticline traps, but largely by non-anticline traps, especially lithological traps. The discontinuous hydrocarbon accumulation is also named as the hydrocarbon accumulation of the conventional-trap type, and typically occurs in conventional reservoirs, but some tight hydrocarbon reservoirs, coalbed methane reservoirs and even possible shale hydrocarbon reservoirs also belong to this kind of hydrocarbon accumulation; the hydrocarbon reservoirs are distributed discontinuously, and have clear boundaries and complete edge water or bottom water; the hydrocarbon migration and accumulation is mainly driven by buoyancy and secondary migration is usually indispensable; the hydrocarbon accumulation is strictly controlled by various traps, especially structural traps. In a petroliferous basin, above three types of hydrocarbon accumulation may coexist, andhydrocarbons are often derived from a common source kitchen(s). Therefore, these three types of hydrocarbon accumulation should be considered and studied as a whole to maximize hydrocarbon exploration efficiencvy.

1. Introduction

Hydrocarbon reservoirs in the crust can be divided into the conventional type and unconventional type. Global exploration and development of oil and gas evolve from the conventional reservoirs

* Corresponding author.
E-mail address: jzzhao@xsyu.edu.cn (J. Zhao).

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to the unconventional reservoirs.

In recent years, with the increasing exploration and development of both conventional and unconventional hydrocarbon resources worldwide (Zhao, 2013), especially with continuous discoveries and intensive studies of unconventional hydrocarbon reservoirs, it has been found that the traditional petroleum geological theories based on conventional hydrocarbon reservoir studies were difficult to meet new situation of hydrocarbon exploration and development, and many important petroleum geological concepts and theories (e.g., concept, classification and accumulation theories of hydrocarbon reservoirs) needed to be reconsidered and improved urgently. Moreover, it has been revealed that the conventional reservoirs and unconventional reservoirs were closely related in terms of the formation and distribution, and contrary to the process of global hydrocarbon exploration and development, the formation of hydrocarbon reservoirs was usually a process from the unconventional hydrocarbon accumulation to conventional hydrocarbon accumulation or from the continuous hydrocarbon accumulation to discontinuous hydrocarbon accumulation. This process result in formation of the continuous, quasi-continuous and discontinuous hydrocarbon accumulations, which were representative of the basic types of hydrocarbon reservoirs in the Earth's crust (Zhao et al., 2015). In a petroliferous basin, the conventional and unconventional reservoirs, or the continuous, quasi-continuous and discontinuous hydrocarbon accumulations often coexist, indicating close relationships and unique distribution laws among them. Thus, in order to advance the current and future exploration of conventional and unconventional hydrocarbon reservoirs, it is necessary and important to carry out a study on the whole process of hydrocarbon reservoirs from continuous to discontinuous accumulation, so as to reveal the internal relationships between conventional and unconventional hydrocarbon reservoirs as well as the characteristics and distribution laws of hydrocarbon accumulation. As a result, the concept and classification of hydrocarbon reservoirs, the continuous to discontinuous accumulation process, and the characteristics, relationships and distribution laws of all types of hydrocarbon accumulations are discussed in this paper.

2. Definition of petroleum reservoir

Petroleum geologists from different eras, countries or regions usually have different understandings of the petroleum reservoir concept, definitions of petroleum reservoir proposed by some domestic and foreign scholars are shown in Table 1.

In the textbook of Petroleum Geology in China, the petroleum reservoir was regarded as the hydrocarbon accumulation in a single trap with a unified pressure system and oil (gas)-water interface. In the definition of petroleum reservoir in many textbooks, particularly since the 1990s, two elements were commonly emphasized, i.e., "the single trap" and "the unified pressure system and oil (gas)-water interface" (Chen, 1994; Zhang et al., 1999). Although the importance of trap was emphasized, however, "the unified oil-water interface" was not mentioned in and before 1980s, as indicated in the Petroleum Geology written by Northwestern University (1979) and the Petroleum Geology written by Zhang and Zhang (1981).

Unlike scholars in China, scholars from some other countries do not emphasize "the unified pressure system and oil (gas)-water interface" and even "the trap" in the definition of petroleum reservoirs. The oil or gas in a single ore bed was called an oil or gas reservoir (Levorsen, 1967). A single hydrocarbon accumulation was considered as a petroleum reservoir (Hobson and Tiratsoo, 1981). Chapman (1983) proposed that a single hydrocarbon accumulation could be considered as a petroleum pool sometimes, but the term "pool" were not recognized worldwide. Only the petroleum reservoir defined by North (1985) emphasized the characteristic of "the single trap".

However, it is important to note that the above concepts were proposed primarily on the basis of conventional hydrocarbon reservoirs. With discovery of more and more unconventional hydrocarbon reservoirs, it is gradually recognized that many unconventional hydrocarbon reservoirs, including tight unconventional hydrocarbon, shale hydrocarbon and coal bed methane, generally had no edge or bottom water (Schmoker, 1995; Zhao, 2012; Zhao et al., 2013). In this case, the concept of a petroleum reservoir with unified oil (gas)-water interface is obviously inapplicable to the unconventional hydrocarbon reservoirs. In addition, it is also demonstrated by some scholars that the continuous accumulations, including tight unconventional hydrocarbon, shale hydrocarbon and coal bed methane, had no obvious traps and cap rocks (Schenk, 2002, 2005). Nevertheless, the formation of tight hydrocarbon reservoirs is still controlled by traps to a certain extent, while most of hydrocarbon accumulations in source rocks, such as shale hydrocarbon and coal bed methane, have no obvious traps or basically are not controlled by traps (detailed hereinafter). Based on such understandings, the traditional trap-centered concept of the petroleum reservoir was not applicable to some

Table 1
Definitions of petroleum reservoir.

Authors (year)	Publications	Definition
Wilson (1934)	Proposed classification of oil and gas Reservoirs	Oil (gas) reservoir is a natural container storing commercial oil and/or gas
Levorsen (1967)	Geology of petroleum	The oil or gas content of a single deposit is called an oil or gas pool
Northwest University (1979)	Petroleum geology	The oil and gas reservoir is a basic unit of oil and gas accumulation, and exists in an independent trap, where the oil and gas has a certain distribution law and a uniform pressure system
Hobson and Tiratsoo (1981)	Introduction to petroleum geology	A single hydrocarbon accumulation is a hydrocarbon reservoir.
Zhang and Zhang (1981)	Petroleum geology	The petroleum reservoir is defined as oil and gas accumulation in a single trap
Chapman (1983)	Petroleum geology	Hydrocarbon accumulation in a single bed is an oil and gas pool sometimes
North (1985)	Petroleum geology	The petroleum pool is a single and isolated hydrocarbon accumulation in a single trap of a single reservoir
Chen (1994)	Geology of oil and gas	The petroleum reservoir is referred to as oil and gas accumulated in a single trap with a uniform pressure system and oil (gas)-water interface
Zhang et al. (1999)	Petroleum geology	The petroleum reservoir is a basic unit of oil and gas accumulated in the Earth's crust and it was the accumulation of oil and gas in a single trap with a uniform pressure system and oil (gas)-water interface
Zhao et al.	This paper	The petroleum is accumulated in a single or a set of reservoirs with an independent or uniform pressure system

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