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Characteristics and genetic models of Lower Ordovician carbonate reservoirs in southwest Tarim Basin, NW China

Gao Zhiqian [a,*], Liu Zhongbao [b], Gao Shanlin [b], Ding Qunan [c], Wu shiqiang [b], Liu Shilin [b]

[a] School of Energy Resource, China University of Geosciences, Beijing 100083, China
[b] Research Institute of Exploration and Production, SINOPEC, Beijing 10083, China
[c] National Geological Library of China, Beijing 100083, China

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ABSTRACT

Lower Ordovician carbonate successions in the Taxinan area are intensively cemented and filled. Matrix porosity and permeability are low in the Lower Ordovician carbonate reservoirs of the Taxinan area, and reservoir space is composed of karst vugs and fractures. The reservoir space is dominated by four types of karst vug, including vesicular vugs, enlarged dissolved vugs along fractures, tabular vugs and isolated vugs, and three types of fractures, including medium-high-angle fractures, low-angle and horizontal fractures as well as irregular fracture networks. The quality and scale of reservoirs in different zones of the Taxinan area are obviously different, and the best reservoir rock is developed in the eastern part of the Taxinan area. These karstic reservoirs can be divided into three types according to the reservoir formation mechanism, including buried-hill vug-fracture reservoirs, vug reservoirs below unconformity surfaces and deep bedding underflow karst vug reservoirs. Different types of reservoir developed in significantly different successions and areas and are controlled by different factors. Buried-hill vug-fracture reservoirs are mainly developed in the Yingshan Formation and distributed in the fault-uplift zones of the eastern part of the Taxinan area. Their formation is controlled by paleogeomorphology and tectonic movement. Vug reservoirs beneath unconformity surfaces are developed in the Yingshan Formation and distributed in the gentle zone in the central-western Taxinan area. Their formation is controlled by the scale and erosion intensity of the unconformity. Deep bedding underflow karst vug reservoirs are mainly developed in the Penglaiba Formation and distributed in the fault-sag zones between the NE-trending fault-uplift zones in the eastern part of the Taxinan area. Their formation is controlled by paleogeomorphology, rifting and unconformity. Guided by this geological model of reservoir development, combined with drilling, well logging and seismic data, the distribution of favourable high-quality reservoirs in the Taxinan area is predicted. The results showed that the flanks of the fault-uplift and fault-sag zones in the eastern part of the Taxinan area and the haystack hills and karst highlands in the central-western parts of the Taxinan area are favourable reservoir exploration areas.

1. Introduction

1.1. Exploration history and objectives

The Tarim Basin is located in the southern part of the Xinjiang Uygur Autonomous Region in northwest China and between the Tianshan and Kunlun Mountains (Fig. 1a), occupying an area of 56×10^4 km^2. It is the largest petroliferous superposed basin in China, characterized by a long history of deposition, a thick stratigraphic succession (Gao et al., 2006; Fan et al., 2007), abundant hydrocarbon resources, and a complex tectonic history. The Taxinan area in southwestern Tarim Basin (Fig. 1b) is bounded to the northwest by the South Tianshan Mountains, to the northeast by the Tumuxiuke Fault and to the south by the North Kunlun Mountains and is bordered by the Sag and Tanan Uplift (Fig. 1c). The western part of the Taxinan area is a valley between the South Tianshan Mountains and North Kunlun Mountains, which continues westward towards the Ferghana Basin of Central Asia (Fig. 1c; Zhang and Song, 1996; Mu et al., 2001; Liu et al., 2001; Gao and Fan, 2014). Within a total area of approximately 20×10^4 km^2, the Taxinan area includes four secondary physiographic structural elements: the Bachu Uplift, Markit Slope, Kashi Sag and Yecheng-Hetian Sag (Fig. 1c). The Yingshan and Penglaiba Formations are located in the Lower Ordovician of the southwest Tarim basin. T_8^0 is the base of the Ordovician, T_7^8 is the base of the Lower Ordovician Yingshan Formation, and T_7^4 is the top of the

* Corresponding author.
E-mail address: gzq@cugb.edu.cn (G. Zhiqian).

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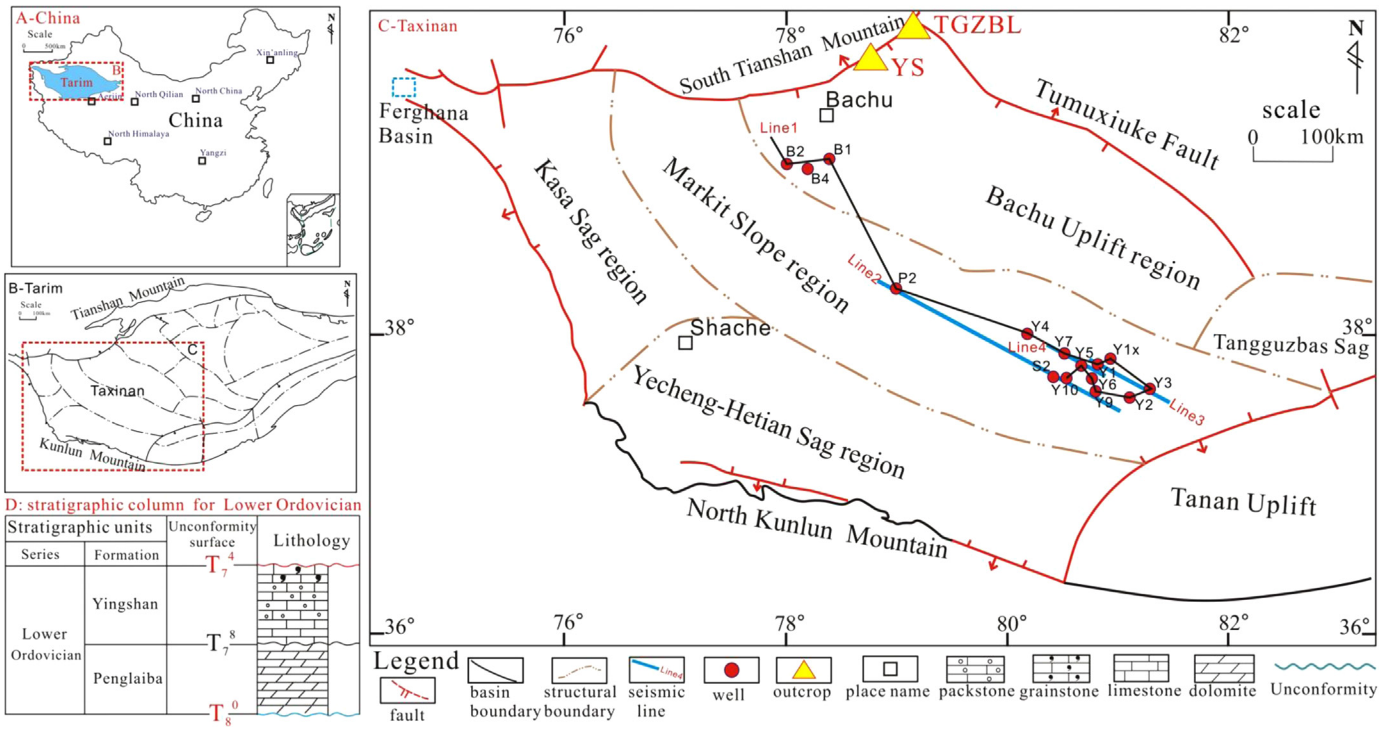

Fig. 1. Location of Taxinan area of Tarim basin, NW China. (a) The location of the Tarim Basin in China. (b) The location of the Taxinan area in Tarim Basin. (c) The tectonic units of the Taxinan area. These uplifts, slopes and sags in (c), such as Bachu Uplift, Markit Slope, and Kas Sag, are tectonic units of the Taxinan area. Line 1 is the multiple-wells correlated section. Line 2, Line 3 and Line 4 are all seismic lines. (d) The stratigraphic column of Lower Ordovician. T_8^0 is base of Ordovician, T_7^8 is base of Early Ordovician Yingshan Formation, and T_7^4 is base of Late Ordovicians.

Lower Ordovician (Fig. 1d).

The Taxinan area is one of several active sites of hydrocarbon exploration within Tarim Basin, where hydrocarbon exploration in carbonate successions began in the 1980s and where the Basituo oil-field, Niaoshan gas-field and other oil–gas fields were discovered in stratigraphically shallower Carboniferous formations (Zheng, 1995; Liu and Yuan, 2002; Yang et al., 2003; Ma et al., 2006; Zheng et al., 2007). Exploration for deeper carbonate petroleum reservoirs that have experienced multiple tectonic movements was not successful until SinoPEC discovered commercial oil in the Lower Ordovician in the Markit Slope area (well Y1) in 2010 (Fig. 1c). Since then, the Taxinan area has undergone more active hydrocarbon exploration (Gao et al., 2011; He et al., 2011; Wu et al., 2012). Until 2014, a total of 27 exploration wells targeting Ordovician strata have been drilled in the Taxinan area, among which 6 exploration wells have struck oil and gas flows and multiple wells have found good oil trace and abnormal gas log displays, indicating that this region has good prospects for exploration (Liu et al., 2013, 2014).

Extensive research has been done on the Lower Ordovician carbonate reservoir of the Tarim Basin (Yu et al., 2007, 2011; Wu et al., 2008; Zhao et al., 2012), mainly focused on the Tahe area in the north part of the Basin and the Tazhong area in the central part (Xiao et al., 2003; He et al., 2006; Zhang et al., 2010; Yang et al. 2011, 2012; Wu et al. 2012). Substantial studies have not been conducted on the Lower Ordovician reservoir in the southwest part of the Tarim Basin, especially in the Markit Slope region. The reservoir's development characteristics and its relationship with oil–gas accumulation, as revealed by existing wells, indicate that the distribution of Ordovician oil and gas pools in the Taxinan area is significantly controlled by variations in reservoir development history. Different regions, different fault belts, and even the fold ridges and sags in the same fault belt have significantly different reservoir development degrees. The oil and gas exploration deployment for the study area is severely impeded by unclear reservoir genetic type and distribution features. Thus, how to find high-quality reservoir development zones is an urgent problem to be solved for oil and gas exploration of the Taxinan area. In this paper, based on outcrop, core, drilling (well logging), image logging, seismic and various types of analytical test data, we analyse the reservoir characteristics and genetic mechanisms of the Taxinan area reservoirs, beginning with fundamental research, describing the mechanism of formation, and finally predicting hydrocarbon distribution. Our study on Lower Ordovician carbonate rocks of the Taxinan area has the following aims: to analyse the geological factors influencing reservoir development, including lithofacies, diagenetic alteration, faulting, unconformity distribution and paleo-high evolution; to correctly recognize and identify reservoir genetic types; to clarify the distribution of reservoirs; to establish an evolutionary model for the reservoirs; and to predict the locations of favourable reservoir development belts for hydrocarbon exploration. Insights gained concerning the reservoir formation mechanism in the Taxinan area will also be applied to improve understanding of the implications of karst reservoirs for hydrocarbon exploration in this and other carbonate-dominated basins.

1.2. Data sources and methods

Data sources include 2 outcrop sections (YS and TGZBL sections in Fig. 1), 15 well logs with cores (Line 1 in Fig. 1), 12 seismic lines (seismic Line 2, seismic Line 3 and seismic Line 4 in Fig. 1), and imaging logging data for 6 wells. A total of 165 thin sections were observed using a polarizing microscope (XPL-50), and reservoir property data (permeability and porosity) of over 150 samples were measured with permeability and porosity analysers (MFA-170 and SMP-200). These samples were cut from the cores of the well Y5 (Fig. 1) as well as from 14 other wells and 2 outcrop sections.