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Original research paper

Architecture and quantitative assessment of channeled clastic deposits, Shihezi sandstone (Lower Permian), Ordos Basin, China

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Abstract

Lower Permian Shihezi sandstone in Ordos Basin is the largest gas reservoir in China. Architecture elements of channel, overbank and floodplain facies of braided channel deposits were identified through an outcrops survey, and their proportion of channel facies have been quantitatively estimated from well logging. Characteristics of architecture elements, such as sand thickness, bounding surfaces and lithofacies were investigated through outcrops and core. Petrology of Shihezi sandstone has also been studied in detail. Analysis on sandstone components shows that monocrystalline quartz with approximately 76% bulk volume, and lithic up to 5%–45% bulk volume, are the two main components. Litharenite and lithic quartz sandstone are the main rock types. Compaction is concluded by former researchers as the control factor of low permeability. Examination through thin section reveals that secondary pores developed well in coarse sand. Inter-granular dissolution is included as the positive effect to increasing porosity, and is concluded as the control factor to the generation of net pay. Scale of coarse grained channel fills and channel bar sandstone bodies are quantitatively estimated. Strike-oriented, dip-oriented, and vertical distribution of channel fills and channel bar sandstone bodies have been investigated. The geometry of sand bodies can be depicted as an elongated lens. Subsurface mapping reveals that channel sandstone bodies distribute widely from both lateral and longitudinal cross section profiles, and are poorly connected.

Keywords: Shihezi sandstone; Lower Permian; Ordos Basin; Architecture elements; Petrology; Quantitative assessment

1. Introduction

Modern fluvial sedimentology had its beginnings during the World War II, with the work of H. N. Fisk [1] and his colleagues on the depositional framework of the Mississippi River [2]. Researches began on architecture of channeled reservoir in 1980s [3] and facies analysis techniques for the detailed description and interpretation of channel-fill architecture have been improved [4]. Over the past 20 years, outcrop analogs have also been integrated in reservoir characterization and reservoir modeling to reduce uncertainties and to understand heterogeneities of deposition units in three dimensions [5–7]. Geological characterization including elements, pattern and deposition mechanisms derived from outcrops have been proved to be valuable information which can be used as conditioning data in the recognition and description of subsurface fluvial architecture [5,8].

Ephemeral-fluvial braided systems constitute one of the main reservoirs in many oil and gas fields around the world [8–13]. Reservoir architecture elements and its characteristics are control factors in accumulation and recovery of hydrocarbon [14,15].

The widespread distribution of braided fluvial Shihezi sandstone bodies in the Ordos Basin and their potential as hydrocarbon reservoir warrant a better understanding of the fluvial processes involved in their development. Most published descriptions of the Ordos Basin Shihezi sandstone are

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piecemeal and two-dimensional, and are insufficient to reconstruct adequately their sedimentary architecture as well as to infer the processes associated with bar formation and migration, and channel incision and filling. Outcrops located in Liulin County, eastern of Ordos Basin allowed a detailed, three dimensional description of one Shihezi sandstone body. With more exploration and development wells drilled, sufficient log and experimental data of core analysis makes reservoir characterization feasible.

The purpose of our study is to provide geoscientists and engineers with qualitative description and quantitative data from Lower Permian channeled sandstone deposits. This data set is of great importance to success rate of exploration well and field development strategy.

In this paper, we demonstrate a comprehensive approach to architecture elements analysis integrated with outcrop investigation and reservoir characteristics of different units including lithofacies, stratal geometries, and petrophysical properties derived from laboratory analysis on core samples.

2. Data and methods

Braided stream deposits consist of numerous interconnected channels, separated by bars [16] and dominated by coarse-grained sediments such as sands and gravel [17]. The entire channel complex may contain water and the bar may be submerged during high water period. During periods of drought, only one channel, or even no channel, is active. Thus, multi-cycle sandstone and gravel sheets are deposited in a braided channel and its width may vary widely with respect to its thickness. With respect to depth, an upper limit of width can be estimated [18].

By outcrops investigation, qualitative and quantitative data such as bedform geometry, bedset thickness, and lateral continuity can be obtained by determining the individual geobody dimensions of fluvial sandstone and are used to guide the reservoir characterization [5,19,20]. Through Field survey, thickness of different channel facies can be estimated and lithofacies can be identified.

Complete sets of logs (Latero Log Deep, Latero Log Shallow, Formation Density Compensated Log, Compensated Neutron Log, Bore Hole Compensated Sonic Log, Spontaneous Potential Log, and Gamma Ray Log) for the reservoir units were digitized. Eletrofacies zonation through well logging extrapolation helps to estimate scale of multi-storey channels and single-storey channels and log interpretation can be used to construct cross section maps.

Cores obtained from drilling provide direct and detailed information such as lithology, lithofacies, and sedimentary structures which are symbols of sedimentary environment and thin section analysis is the efficient way for pore structure analysis and pore space characterization.

Quantitative data for calculating the proportions of facies and scale of sandstone bodies were collected by different spacing well logs from cross section. Well logs are commonly close to actual measured sections [21]. Eighty well logs were used to make the calculations.

3. Geological setting and stratigraphy

Ordos Basin with area of about 32×10^4 km^2 is one of the largest sedimentary basins in China. Although once wrongly regarded as a relatively stable cratonic sedimentary basin [22,23], it is now widely considered as a Gondwana-derived fragment of continental crust on the western edge of the North China block [24]. Complex tectonic and sedimentary evolutions of the basin have resulted in the formation of various structural units consisting of highly tectonic fold-thrust belts and horst-graben features forming mountainous outer rim of the Ordos Basin (Fig. 1). Six first-grade tectonic units can be identified: Weibei Uplift, Yimeng Uplift, Jingxi Flexing Belt, Tianhuan Depression, Western Margin Thrust Belt and Yishaan Slop. In contrast, inner part of Ordos Basin shows minor tectonic deformation. Microcontinental amalgamation from Middle to Late Paleozoic provided a broad, gently subsiding craton on which were deposited terrigenous shelf, deltaic and fluvial clastics and associated coals.

The regional stratigraphy of the Ordos Basin is illustrated in Fig. 2. The basement of the basin comprises Archaean and Lower Proterozoic crystalline rock. Middle and Upper Ordovician, Silurian, Devonian and Lower Carboniferous units are absent within the major part of the basin. According to fission

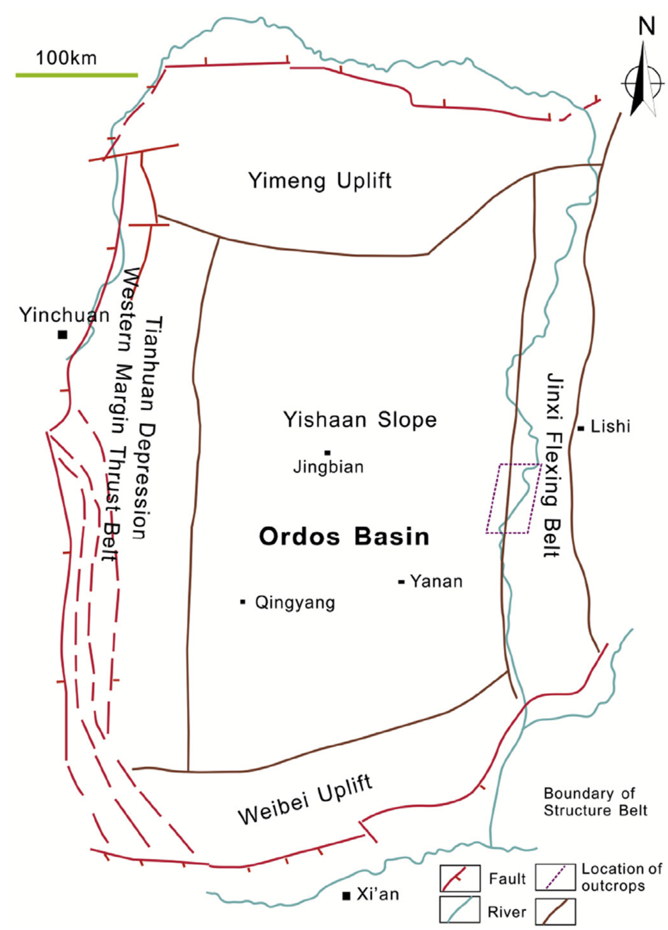

Fig. 1. Simplified geological map of the Ordos Basin and location of the outcrops (Modified from Ref. [25], 2003).

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