Journal of Petroleum Science and Engineering 149 (2017) 591–602

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Sedimentary characteristics of shallow-water braided delta of the Jurassic, Junggar basin, Western China

Xiaomin Zhu[a,b,*], Shunli Li[a,b], Dong Wu[c], Shifa Zhu[a,b], Yanlei Dong[a,b], Dongna Zhao[d], Xulong Wang[e], Qin Zhang[a,b]

[a] College of Geosciences in China University of Petroleum, Beijing 102249, China
[b] State Key Laboratory of Petroleum Resources and Prospecting, Beijing 102249, China
[c] Shengli Oilfield Company, Sinopec, Dongying 257015, China
[d] Shell China Exploration and Production Co. Ltd., Beijing 100004, China
[e] Xinjiang Oilfield Company, Petrochina, Karamay 834000, China

ARTICLE INFO

Keywords:
Geological settings, Facies scheme, Shallow-water braided delta
Depositional environment, Jurassic
Junggar Basin

ABSTRACT

The shallow-water braided deltas are hot topic in global sedimentology. In China, this depositional environment forms an important reservoir and exploration target within the basins. Therefore, geological and sedimentologic settings of the Jurassic shallow-water braided deltas in the Junggar basin of western China have attracted much attention in recent years based on the comprehensive analysis of geological and geophysical data acquired. These braided deltas deposited in the shallow Junggar lacustrine basins with gentle slope gradients and prograded towards to the central basin from northeast to southwest (more than 10 km). This kind of Jurassic delta was characterized by coarse grain-size (sand to pebble), large cross-beddings, discontinuous fining-upward successions vertically, high percentage of sandstone ratios (up to 70%), very unique distributary channels with few distributary mouth bars, and seismic facies of shingled with a progradational reflections. Based on the detailed research on basin evolution and sedimentary characteristics of deltaic sub-facies, this paper presents the relationship between the shallow-water braided deltaic deposition and lithologic traps predicted to be the favorable and explorable lithological traps in the Junggar Basin.

1. Introduction

The term “shallow-water delta” was first defined in the modern Mississippi Delta by Fisk (1954). Donaldson (1974) regarded water depth as one of the important controlling factors for deltas, and furthermore presented a classification of river-dominated delta. Then, Postma (1990) proposed a classification system in a steady-state environment that includes shallow-water deltas and deep-water deltas, and additionally eight prototype deltas were attributed to shallow-water deposits. In recent years, study of the shallow-water deltas has mainly focused on sub-environments, sedimentary features, formation mechanisms, and reservoir architectures (Reading, 1996; Lemon and Chan, 1999; Plint, 2000; Zelilidis et al., 2002; Overeem et al., 2003; Dela, 2005; Fielding et al., 2006; Ganil and Bhattacharya, 2007; Lee et al., 2007; Howell et al., 2008; Zeng et al., 2015). The relevant study in China began in the 1980's (Gong, 1986). More recently, the shallow-water deltas have been widely identified in the lacustrine basins in China. The delta is primarily composed of subaqueous distributary channels (Olariu and Bhattacharya, 2006; Li et al., 2009), and is more similar to a transitional type between delta and river (Lou et al., 1998). Petroleum exploration in China during the last decades suggests that large scale sand bodies of shallow-water deltas in lacustrine basin are interest focus during lithological traps expedition and also key to discover large oil-gas fields (Zou et al., 2006). Interactions between the paleoclimate, paleotopography, and paleocurrent on shallow-water deltas have been discussed respectively in the Songliao, Bohai Bay, Sichuan, and Ordos Basins (Lou et al., 1999; He et al., 2001; Zhu et al., 2008, 2012, 2013a, 2013b; Liu et al., 2009; Li et al., 2011; Dong et al., 2015). Therefore, study on the shallow-water deltas has become more and more necessary and popular in sedimentology (Zhu et al., 2013a, 2013b; Zhang et al., 2014; Zeng et al., 2015).

The Junggar basin is a large petroliferous, superimposed basin in West China, covering approximately 130,000 km^2 in area. It has experienced four tectono-sedimentary periods: Hercynian, Indo-Chinese, Yanshan, and Himalayan, which was filled with the Carboniferous, Permian, Triassic, Jurassic, Tertiary, and Quaternary strata with thickness up to 14,000 m (Zhai, 1996; He et al., 2004).

Since petroleum geologists started to work in the Junggar basin in

* Corresponding author at: College of Geosciences in China University of Petroleum, Beijing 102249, China.
E-mail address: xmzhu@cup.edu.cn (X. Zhu).

http://dx.doi.org/10.1016/j.petrol.2016.10.054
Received 18 March 2016; Received in revised form 17 October 2016; Accepted 29 October 2016
Available online 02 November 2016
0920-4105/

the 1950s, oil and gas exploration has continuously and considerably advanced. Lots of research results in the fields of petroleum geology and sedimentology have been acquired including: (1) potential of source rocks controls on abundance of oil and gas in the Permian, Triassic and Jurassic strata, (2) the closer to the source rocks, the richer petroleum resource is, (3) reservoir quality influences the storage abundance and scale of pools, (4) depositional environments in the Jurassic were characterized by large-scale, shallow water depth, multi-sources, gentle slopes, and long-distance streams. Therefore, alluvial fans were restricted along the basin margins and changed into fluvial systems. During the Early to Middle Jurassic, large scale deltas and swamps were developed due to both of the wide lake-basin and warm humid climate (Zhu et al., 2013a, 2013b). Particolored fluvial sediments were accumulated during the Late Jurassic because of the restricted lake-basin and arid climate (Zhang and Zhang, 1998; Zhang et al., 2000, 2002; Gao et al., 2001; Qiu et al., 2002; Liu and Wang, 2004; Xu, 2005).

Like the Cretaceous shallow braided deltas formed in low accommodation in the Alberta Basin of West Canada (Reading, 1996; Zelilidis et al., 2002; Dela, 2005), the Jurassic shallow-water braided deltas in the Junggar basin show typical features of delta deposits, and affect the distribution and enrichment of principal oil producing successions. Given this, our study takes the Junggar basin as an example (Fig. 1), using comprehensively data of convectional cores from 26 wells, 2D seismic data (about 15,000 km of seismic lines, survey grid of 1×1 km), and 200 wells with drilling and well logging data, in order to study sequential the features of shallow-water braided deltas of the Shinan and Mobei basins, of the region. Based on the data collection, this study aims to (1) summarize the geological settings for developing shallow water delta in the Junggar Basin; (2) identify lithofacies and sedimentary facies of shallow water delta; (3) characterize facies distribution and reconstruct depositional model of shallow water delta.

2. Data sets and methods

Data sets used in this investigation consist of seismic profiles, well logs, and convectional cores. The relatively high quality two-dimensional seismic profiles covered most of the Junggar basin with total length of 15,000 km, and no three-dimensional seismic data has been collected. The Sangonghe Formation of the Jurassic in the Junggar Basin is the study object, which were penetrated by 290 wells. Among them 80 key wells with drilling data were selected on the basis of core coverage and geographical distribution. Gamma ray (GR), acoustic (DT), resistivity (RD, RS, and RMSL), and spontaneous potential logs (SP) from the well logging data were selected in this research. About 1260 m of cores from 26 key wells have been observed and described for identifying sedimentary facies.

Based on the tectonic and palynologically analysis, favorable geological settings including paleogeography and paleoclimate for development of the shallow-water braided delta in the Sangonghe Formation of the Jurassic, which is an objective of this study, can be understood in the Junggar Basin. The depositional systems, the other objective of this study, were distinguished by using the comprehensive data.

3. Geological settings

3.1. Low rate and steady of subsidence, forming wide and gentle basin

The Jurassic palaeogeographic settings of the Junggar basin were distinguished by three aspects. To the north of basin, the Luliang, Mobei and Mosuowan areas were characterized by wide, gentle slopes. To the south, the basin presented feature of steep slopes. To the east, slopes showed medium gradients. To the northwest edge, slopes were characterized by medium- to high-gradients (Fig. 1). Moreover, the tectonic evolution of the Juggar Basin could be divided into four stages including foreland (P1), depression (P_2-T_{1+2}), open basin (T_3-K), and extinction (E-Q). The Jurassic strata were formed in the third stage (T_3-K), which were dominated by lacustrine and fluvial facies (Zhai, 1996). Deposits were developed in a wide, deeper lake during the Late Triassic. During the Badaowan time of the Early Jurassic, the basin topography was flat with oscillated rise of basement, making the water depth either deep or shallow. However, the mean water depth was still much shallower than that in the Late Triassic. In the Sangonghe time of the Early Jurassic (Fig. 2), the basin subsided entirely, developing fluvial, deltaic, and lacustrine depositional systems under gentle slopes and shallow-water environments (Zhai, 1996; Zhu et al., 2013b). Obviously, these geological settings with steady tectonic subsidence (50 m/Ma, Fig. 2) and shallow-water conditions were favorable to develop the braided deltas, especially in the north part of the basin.

3.2. Jurassic humid climate and multi-cycle of water depth change

The climate in the Junggar Basin evolved from tropic-subtropic humid in the Early Jurassic to hot and arid in the Late Jurassic. During the Badaowan and Sangongehe depositional time (Fig. 3), the Lower Jurassic was filled with clastic rocks with coal beds. Spores were dominated by **Cyathidites,** and the pollens were dominated by pine bivesiculate pollens, which suggest the warm and humid climate in the Early Jurassic. The appearance of considerable **Cycadeoidea, Araucaria**, **Cyatheaceae**, and **Osmundaceae** within the Xishanyao Formation also could be seen as evidence of tropical humid weather in the Middle Jurassic. Likewise, the presence of abundant drought-enduring **Gymnospermae classopollis** within the Toutunhe Formation in the Middle Jurassic and the Qigu Formation in the Upper Jurassic indicated that the climate had been changed obviously from humid to hot and arid (Fig. 3). It is apparent that the humid weather in the Sangonghe time was favour of sufficient detrital material supply.

Association of fossil records could not only reflect the change of paleoclimate, but also indicates the alternation of the palaeosedimentary environments and change of lake level. The Junggar basin experienced four water cycles during the Jurassic, water depth of the sedimentary environment changed from shallow to deep and to shallow again (Fig. 3), that is to say, there were four transgressive events in the Junggar basin during the Jurassic. The first one occurred in the middle of Badaowan time, and a thick set of lacustrine layers were deposited containing **Bivalvia** fossils. The second one was developed in the early of Sangonghe time; deposits of deeper lake were formed, enriched with **Bivalvia** and **Conchostraca** fossils. The third one happened in the late of Sangonghe time, and the transgressive scale was broad, showing steadily distributed lacustrine sediments. The forth one occurred in the middle of the late of Middle Jurassic, the lake was restricted, and **Bivalvia, Gastropod** and **Ostracoda** fossils were prevalent.

Apparently, the deepening of water depth could provide more accommodation for sediments. The change of water depth was favorable to progradation of abundant clastic material towards the central basin and development of braided delta in the Jurassic.

3.3. Sequence stratigraphic framework

The Jurassic in Junggar basin is comprised of seven 3rd-order sequences as shown in Fig. 3. Our target strata in the Junggar basin, which is named Sangonghe Formation as mentioned above, can be subdivided into four 4th-order sequences from bottom to top, SSQ1, SSQ2, SSQ3, and SSQ4 (Fig. 3). Generally the 4th-order sequences are separated by certain unconformity surfaces. Termination pattern of seismic reflection events and lithologic changes on well logs are very helpful to reveal these unconformity surfaces.

SSQ1 corresponds to transgressive systems tract (TST), and SSQ2 corresponds to highstand systems tract (HST) of the SQII. Compared