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Reservoir quality variations within a conglomeratic fan-delta system in the Mahu sag, northwestern Junggar Basin: Characteristics and controlling factors

Haibo Jia[a], Hancheng Ji[a,*], Linsheng Wang[b], Yan Gao[b], Xinwei Li[c], Hang Zhou[d]

[a] College of Geosciences, China University of Petroleum-Beijing, Beijing 102249, China
[b] PetroChina, Xinjiang Oilfield, Karamay 834000, China
[c] Shanxi Yanchang Petroleum(Group) Corporation, Xi'an 710000, China
[d] PetroChina, Petroleum Industry Press, Beijing 100009, China

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ABSTRACT

The conglomeratic reservoir in the Mahu depression, northwestern margin of the Junggar basin, Northwestern China has become an important exploration target. In this study, we use well and core data to investigate the characteristics and controlling factors of conglomeratic fan-delta reservoirs. The reservoir studied here developed in a retreating fan-delta complex that is dominated by conglomerate lithofacies and conglomeratic sandstone lithofacies. A petrological analysis shows that the reservoir exhibits poor compositional maturity and textural maturity. A physical property analysis shows that the reservoir exhibits extremely low porosity and extremely low permeability, as well as strong heterogeneity in the vertical and planar views. The depositional environment and compaction result in extremely low porosity and extremely low permeability in the reservoir. About 66% porosity was destroyed by the compaction. Fan-delta evolution and provenance control the macroscopic variations in reservoir quality. Muddy matrix content, grain size and dissolution control the microscopic variations in reservoir quality. About 52.5% porosity was induced by the dissolution. This reservoir study can be compared to fan-deltas that developed in marine-connected rift basins during early stages of extension and to nearshore subaqueous fans in East China. Additionally, the results of this study may provide a reference for such systems and provide a subsurface case for similar fan-delta outcrop studies and facies reservoir modelling.

1. Introduction

Conglomeratic reservoirs are widely developed around the world, including the Lower Cretaceous Falher Member shoreface conglomerates in Canada (Clifton, 2003; Hart and Plint, 2003; Schmidt and Pemberton, 2004; Zonneveld and Moslow, 2004), the Garfield conglomerates in Central Kansas (Rogers, 2007), Paleogene Miocene conglomerates in Romania (Krézsek et al., 2010), Permian alluvial fan conglomerates in Junggar basin, Fute conglomerates in Er'lian basin, Daxi conglomerates in Bohai Bay basin and Xujiaweizi conglomerates in Songliao basin (Liang et al., 2000; Zhu et al., 2003a, 2003b; Cao et al., 2005; Li et al., 2006; Wang et al., 2006; Hong et al., 2007; Wen et al., 2008a, 2008b). They have become increasingly important and gained more attention worldwide (Arnott, 2003; Zonneveld and Moslow, 2004; Wang et al., 2006; Hong et al., 2007; Rogers, 2007; Şen et al., 2009). These examples show that conglomerates have become an important reservoir type, and our study is a significant contribution to hydrocarbon exploration in conglomerates.

Some conglomerate reservoirs have low porosity and permeability because they exhibit strong anisotropy (Li et al., 2006; Wen et al., 2008a; Zhang et al., 2009). Previous studies have shown that the reservoir conditions of conglomerate reservoirs are controlled by sedimentary facies (Rogers, 2007; Li, 2008), diagenesis (Li, 2008; Zhang et al., 2009; Krézsek et al., 2010), rock-fluid interactions (Rogers, 2007; Zhang et al., 2009), structure movement (Li, 2008; Zhang et al., 2009) on a macroscopic scale, matrix type, filling model (Wang et al., 2006; Hong et al., 2007; Rogers, 2007), grain size distribution (Wang et al., 2006; Zhang et al., 2009) and support type (Zhang et al., 2009). Although many studies have discussed the sedimentology, stratigraphy and controlling factors of retreating fan-delta systems, reservoirs within retreating fan-delta systems, especially regarding subsurface cases, have not been well studied (Patranabis-deb

* Corresponding author.
E-mail address: jiahaibohb@163.com (H. Ji).

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and Chaudhuri, 2007; Rohais et al., 2008). Our study provides analogues between a subsurface case and outcrop cases documented in previous studies. The role of provenance in controlling the conglomerate reservoir quality has not been detailed documented.

Our study area is located in the northwestern margin of the Junggar basin, which was dominated by conglomeratic successions during the early Triassic (Carroll et al., 1990, 1995). In recent years, the study area has become a target of hydrocarbon exploration and a 100 billion tons of oil equivalent has been found (Tang et al., 2014; Lei et al., 2014). Many studies have focused on the tectonics, depositional system and stratigraphy of the study area, however, the reservoir has not been well studied (He et al., 2004; Xian et al., 2008; Tang et al., 2014). Therefore, studying the reservoir characteristics and controlling factors is a significant contribution to hydrocarbon exploration in the northwestern Junggar basin and worldwide.

2. Regional setting

2.1. Tectonic

The Junggar Basin is a superimposed basin of late Palaeozoic to Cenozoic age and is located in the southern part of the Central Asian Orogenic Belt (CAOB), which is bound to the south by the Tianshan Mountains, to the north by the Altai Mountains, to the east by the Kelameili Mountains and to the west by the Zhayier Mountains (Fig. 1A, B and C). The study area is located on the northwestern margin of the Mahu Sag in the Central Depression and adjoins the Wuxia fault belt, which is manifested by a large number of east-west-trending low-middle-angle thrust faults (Fig. 1D). He et al. (2013) suggest that the Junggar Basin can be divided into six first-order tectonic units, namely, the Wulungu Depression, Luliang Uplift, Western Uplift, Central Depression, Eastern Uplift and North Tianshan Thrust Belt. The evolution history of Junggar Basin can be subdivided into four stages: (i) foreland oceanic basin (Late Carboniferous-Early Permian), (ii) foreland continental basin (Middle-Late Permian), (iii) intracontinental depression (Triassic-Cretaceous) and (iv) rejuvenated foreland basin (Paleogene-Quaternary) (e.g., Carroll et al., 1990; Chen et al., 2002). This study focused on the latter portion of the Triassic during the third stage (Fig. 2).

2.2. Stratigraphy

The basin infill of the northwestern margin of Mahu Sag, Junggar Basin is subdivided into five main units (Fig. 2): (i) a group composed of volcanic and clastic deposits, (ii) a group composed of clastic rocks with some volcaniclastic rocks in the lower portion, (iii) a group that includes sandstone, conglomerate, siltstone, mudstone and shale, and (iv, v) a group consisting of fluvio-lacustrine deposits. Between every two groups, a regional unconformity exists (Carroll et al., 1990, 1995; Zhao, 1992; EGOX, 1998).

According to Li et al. (2010) and Cohen et al. (2013), below the study interval is Permian (approximately 252.0 Ma), the study interval is Triassic (approximately 252.0 Ma to 201.3 Ma), above the Triassic is Jurassic (approximately 201.3 Ma to 145.0 Ma) and the uppermost group is Cretaceous. The stratigraphic architecture of the Baikouquan formation has been extensively documented by Xian et al. (2008), and a detailed analysis of the paleoenvironmental evolution was provided by Zhao et al. (1992).

The Baikouquan formation, which directly overlapped the unconformity between the Permian and Triassic, is subdivided into three groups: (i) a lower group medium-term sequence cycle 1 (MSC1), (ii) a middle group medium-term sequence cycle 2 (MSC2) and (iii) an upper group medium-term sequence cycle 3 (MSC3).

3. Data sets and methods

3.1. Data sets

The primary source of data used in this study is well data from the northwestern margin of the Mahu Sag in the Junggar Basin (Fig. 1). The data are provided by Xinjiang Oilfield, CNPC. The well data include 305 thin sections, X-ray diffraction data, petrophysics data, approximately 214.84 m of core data taken from 37 wells and well-log data, including Gamma Ray (GR), RT, DEN, CNL and dipmeter logs. Core data and well-log data were calibrated.

3.2. Methods

Lithofacies determination can be carried out based on detailed analyses of core data. Petrological studies can be carried out by analysing thin sections, which are also used for diagenesis analysis. X-ray diffraction data are used to analyse the physical properties of the reservoir. Cross plots are used to study the correlation between reservoir quality and other reservoir parameters, such as muddy matrix content, grain size and detrital composition. Dip-oriented profiles of wells are created to show lithofacies shifts in vertical and planar views. Oil-trap data are also used in this study to determine reservoir variations.

4. Characteristics of reservoirs within the fan-delta complex

4.1. Lithofacies types

Core descriptions show that the lithofacies type of the fan-delta system is complex and includes three rock types. Based on the grain size, sedimentary structure and texture, the lithofacies types of the fan-delta system are grouped into three main types that are further divided into twelve subtypes (Table 1). The lithofacies classification is based on Miall, (1977, 1990).

4.1.1. Conglomerate lithofacies

The conglomerate lithofacies is the main lithofacies type in the study area (Table 2). This type of lithofacies is dominated by gravel clasts with sandy or muddy matrices and display massive structures, cross-bedding and normal grading. Based on the differences in the sedimentary structures and supporting mechanisms, seven lithofacies subdivisions are identified.

(1) Matrix-supported conglomerates (Gm)

This lithofacies is characterized as poorly sorted and massive with gravels suspended in the matrix. The mud matrix in this lithofacies is brown or reddish-brown. According to the type of matrix, two subtypes are identified, namely, muddy matrix-supported conglomerates (Gmm) and sandy matrix-supported conglomerates (Gms). This lithofacies is interpreted to represent debris flow deposits.

(2) Clast-supported conglomerates (Gc)

Sedimentary structures are not well developed in this lithofacies. According to rock texture, two subtypes are identified. The first is well-sorted, massive, clast-supported granule (Gcs), representing tractive current deposits that developed in braided channels. The second is poorly sorted, massive, clast-supported conglomerates (Gcm), representing flood deposits that developed in the lower part of the braided channel. The first lithofacies is one of the main reservoir types, while the second has the lowest porosity and permeability.

(3) Imbricated conglomerates (Gi)

This lithofacies is dominated by a sandy matrix and imbricated gravels that are well sorted. This lithofacies represents tractive current deposits that developed in subaqueous distributary channels.