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Research paper

Seismic geomorphology study of the Paleogene Hetaoyuan Formation, central-south Biyang Sag, Nanxiang Basin, China

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ABSTRACT

The main objective of this article is to demonstrate the utility of stratal slice images for exploring the sequence stratigraphy and sedimentology of complex depositional systems. A seismic sedimentological study was performed to map sediment dispersal characteristics of the Paleogene Hetaoyuan Formation in the central-south Biyang Sag, located in the Nanxiang Basin of China. The Biyang Sag is underlain by a productive, petroleum-prone, non-marine Cenozoic-age stratigraphic section. Data including wireline logs and 3D seismic profiles are available for this area. The main study strata, the upper member 3 of the Hetaoyuan Formation, were divided into four fourth-order sequences. Four types of depositional systems, near-shore subaqueous fans, braided deltas, slumped turbidite fans and shallow to deep lacustrine systems, were identified from well-based analysis of sedimentary facies. The seismic sedimentological study of the Hetaoyuan Formation in this study area highlights the distribution of the most important reservoirs. The gentle northward-sloping tectonic zone is composed of braided deltas. The steeply sloping south tectonic zone is composed of near-shore subaqueous fans. In the deep central depression of the Biyang Sag, the Hetaoyuan Formation is composed of slumped turbidite fans and shallow to deep lacustrine deposits. The predicted most favorable exploration sedimentary facies are braided delta fronts, middle fans of near-shore subaqueous fans and slumped turbidite fans.

1. Introduction

The Nanxiang Basin, situated between 111°00′ and 113°30′E longitude and between 31°80′ and 33°00′N latitude, is a small rifted basin that developed in the Mesozoic and Cenozoic Eras (Fig. 1a, 1b). This basin is 160 km long and 110 km wide, extending through two provinces of China, with a total area of approximately 17,000 km^2. The basin is filled with dominantly Paleogene strata, which serve as the main petroleum source and reservoir system. The Nanxiang Basin consists of three uplifts (Shigang Uplift, Sheqi Uplift and Xinye Uplift) and three sags (Nanyang Sag, Biyang Sag and Xiangzao Sag). The Biyang Sag is a relatively independent secondary structural unit in the Nanxiang basin. Its area is approximately 1000 km^2 (50 km by 30 km), and it is bounded by Tongbai Mountain to the southeast, the Sheqi Uplift to the north, and Funiu Mountain to the northeast (Fig. 1b).

Historically, the exploration of the Biyang Sag began in 1974. In 1975, the first well, B1, was completed, and it confirmed that there are thick layers of resource rocks and multiple layers indicating the presence of petroleum in the Paleogene Hetaoyuan Formation. In 1976, a high-capacity reservoir was found from the B4 well, and the Shuanghe Oilfield began to be developed. After more than 30 years of exploration, another eight oilfields have been developed; they are the Wangji, Xiaermen, Zhaowa, Jinglou, Gucheng, Yanglou, Xinzhuang and Dupo Oilfields. By the end of 2008, 8660 km of 2D seismic data (the survey density is 1 km by 1 km) and 1704.5 km^2 of 3D seismic data were collected in the Biyang Sag. The ratio of 3D

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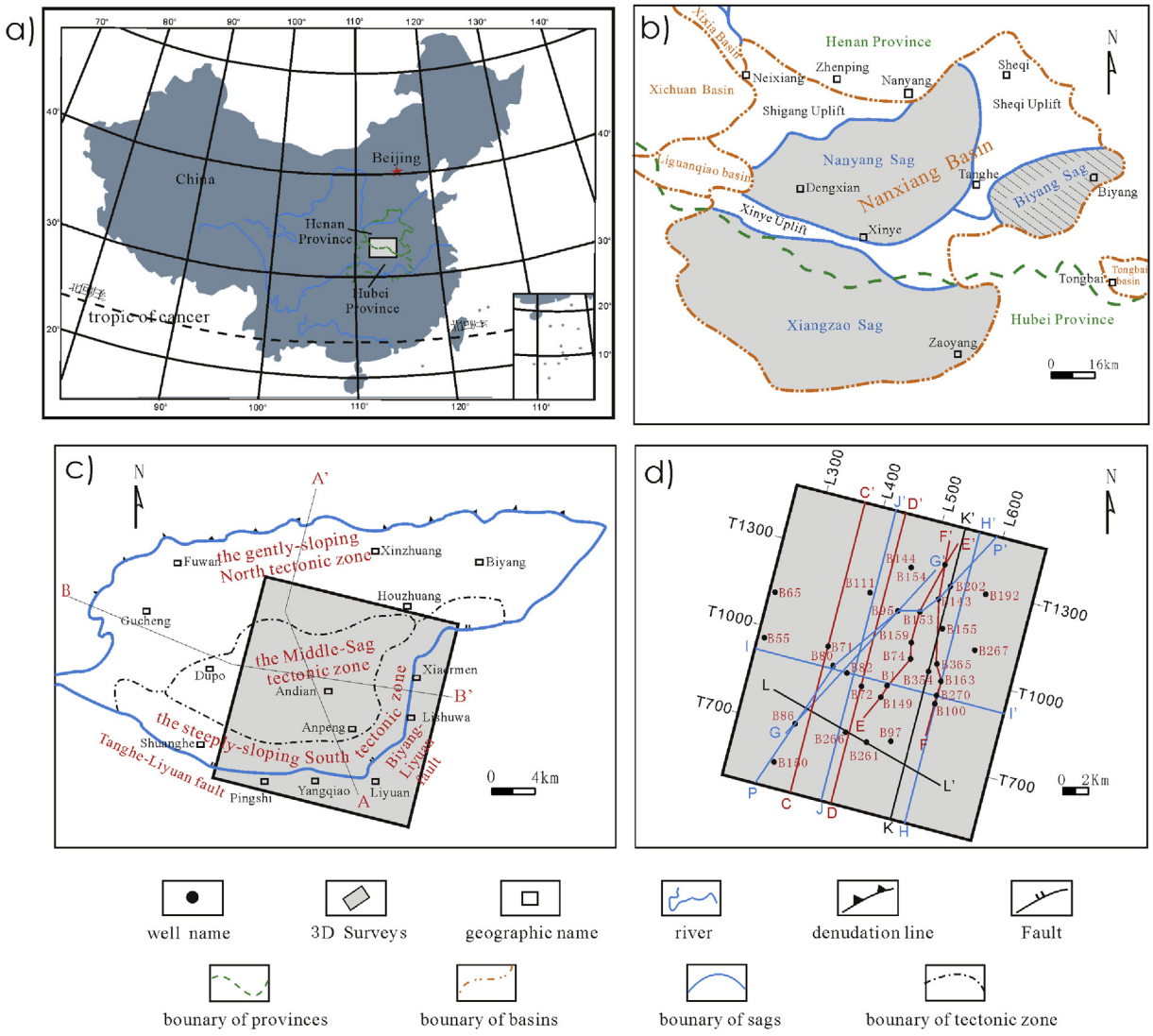

Figure 1. Maps showing the: (a) Location of the Nanxiang Basin in China. (b) Location of the Biyang Sag. (c) General structure of the Biyang Sag and the outline of 3-D seismic shown in (d). (d) 3-D seismic surveys and wells used in the study.

seismic data to the data for the whole sag is 170%. In addition, more than 900 wells penetrate the study strata, with more than 1.38×10^6 m of area drilled. As a result, the Biyang Sag has been highly explored. The most important factor is that the percentage of proved reserve relative to that of petroleum is up to 69.5%, which shows that the oil and gas reserves in the Biyang Sag are abundant even though the sag is not very large (Luo, 2003; Qiu et al., 2005; Luo et al., 2008; Gang et al., 2012). However, after more than 20 years of exploration and development, numerous structural traps have been found, and exploration of lithostratigraphic plays has been relatively weak. In 2010, well B354, which was drilled in a slumped turbidite fan formed in deep water and located at a depth of 2761.4–2777.9 m, produced 106 m^3 of oil and 2530 m^3 of gas per day with a well bean of 5 mm. This production verified that the slumped turbidite fan is the principal reservoir and the deep depression is the main area of remaining reserves with substantial potential.

Several previous studies have been completed on the sequence stratigraphy and sedimentary facies of the Biyang Sag (Hu, 1998; Jin et al., 2002; Chen et al., 2006; Liu et al., 2013). However, previous work has not quantified the shapes, boundaries, genetic types, distribution and evolution of the thin-bedded sand bodies that are believed to provide much opportunity in the basin. The ability to fully characterize such thinly bedded reservoirs is problematic when relying only on drilled well data and conventional seismic data.

The development of seismic geomorphology, when exercised within a framework of sequence stratigraphy, can reveal the subtle sedimentology of these sands, aid in identifying subtle stratigraphic traps and enable production of new resources from lower-quality reservoirs in existing fields (Dong et al., 2014). The objectives of the present study are as follows: (1) construct a high-frequency 3D sequence-stratigraphic framework, (2) define general depositional systems with various fourth-order sequences and clarify their distribution and evolution based on stratal slices and wireline-log facies patterns, and (3) develop sequence stratigraphy and sedimentary models to predict favorable areas for further exploration and development. This study is an example of the integration of sequence stratigraphic concepts, core and wireline-log analysis, and depositional system interpretations from seismic stratal slices.