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Research paper

Application of multi-seismic attributes analysis in the study of distributary channels

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ABSTRACT

During the exploration of stratigraphic reservoirs, the key to locating these reservoirs is to identify the sandstone distribution. Seismic data can be used to recognize large-scale distributary-channel sedimentary bodies; however, depiction of sedimentary bodies in small distributary channels using traditional interpretation data from seismic profiles is extremely difficult. In the Upper Cretaceous first sandstone bed of the third member of the Nenjiang Formation (called the Nen 3 member for simplicity) in the XB area of the southern Songliao basin, distributary channels are the main sedimentary facies. The distributary channels migrate frequently; therefore, it is difficult to precisely depict the morphology of the channel and the distribution of sandstone. In this study, we investigated the deposition of distributary channels using equal-scale formation plane seismic attributes such as post-stack amplitude, instantaneous amplitude and seismic waveform classification, analyzed well logging data from target formations, and mapped the distribution of distributary channels. This study shows that seismic sedimentological study and stacking multiple attribute analysis can identify the distribution of distributary channels precisely and effectively. The attributes of equal-scale strata slices are evidently superior to those of time and horizon slices; Attribute extraction and selection of equal-scale formation slices is an essential step. The comprehensive selection of seismic attributes that show a good correlation to a single-well can be used to clearly depict channel bodies. The overlap of the 40-Hz single-frequency energy and the RMS amplitude depicts the sedimentary characteristics and shapes of sandstone bodies in main channels as well as small-scale distributary channels more clearly than a single attribute. These attributes show that the first sandstone bed of the Nen 3 member was from distributary channels with complex shapes. The distributary channels cut across each other vertically and laterally. It indicates that, during the deposition of the Nen 3 member in XB area, the direction of the main channel is from north to south, and the provenance could be from north and east. The method of this paper may provide some helpful suggestions to the geologist using seismic attributes to undertake research on sedimentary environment at other places in the world.

1. Introduction

The concept of “seismic attribute” was first used in the 1970s, but for many reasons, there had been no standard definition or translated name for “seismic attribute” in China in the past decades. Terms such as “seismic characteristic,” “seismic mark,” and “seismic parameter” were used in difference circumstances. Until recent years, starting from the first use of the term “seismic attribute” by Chen (Chen and Sidney, 1997), as attribute analysis techniques were rapidly developed and widely applied, the term “seismic attribute” has gradually been accepted. Due to the rapid development of the seismic attribute technique, it has been widely applied in seismic tectonic interpretation and lithological interpretation (Wu et al., 2009; Kovac et al., 2013; Li and Zhang, 2011; Perov and Bhattacharya, 2011; Raeesi et al., 2012; Stright et al., 2009; Van Hoek et al., 2010; Zeng et al., 2011). More importantly, multiple case studies indicate that this approach can depict channel sandstone with the highest resolution seismic attributes (Carter, 2003; De Matos et al., 2011; Fang et al., 2015; Li, 2014; Zeng, 2013a;

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Zeng et al., 2013; Zhu et al., 2014).

The study area located in Fig. 1. The Songliao basin is a large-scale compound rift basin, with grabens controlled by faults of multi -stages in the Meso-Cenozoic beds of eastern China (Ding et al., 2013; Sun et al., 2013; Zhang et al., 2011a). The Nenjiang Formation is a significant hydrocarbon-bearing formation in the graben of the southern Songliao basin (Zhao et al., 2011; Feng et al., 2006). Distributary-channel sandstone are significant oil and gas reservoirs (Huang et al., 2013). However, as channels migrate frequently during sedimentation, the channel sandstone have complex shapes and distributions (Bhattacharya and Walker, 1992; Olariu and Bhattacharya, 2006; Tye and Coleman, 1989). Depiction of sandstone distribution is a critical but tricky issue when delineating lithological traps and looking for lithological hydrocarbon reservoirs (Zhang et al., 2012; Mo et al., 2012). Based on the analysis of multiple seismic attributes, in combination with the sedimentary facies of single-well sandstone and the cross-section of multiple wells, we depicted the distribution of distributary channel.

2. Seismic geology

Regional geological information shows that the sediments of the Nenjiang Formation were sourced from the north (Mo et al., 2012; Huang et al., 2013; Zhang et al., 2012). The regional sedimentary facies are mainly lacustrine, delta, and distributary-channel facies (Zhang et al., 2011b). The Nen 1 and Nen 2 members mainly represent deep lacustrine facies, and were deposited in the early stages of the Nenjiang Formation. The deep mudstone layers of these members are good source rocks for the Nen 3 and Nen 4 members. The Nen 3 and Nen 4 members are the main layers in which sandstone are developed. They were deposited in the early and middle stages of the Nenjiang Formation, respectively. The sediments were generally deposited from north to south. These members are effective oil and gas reservoirs, and the well-developed faults that exist through the entire Nenjiang Formation are nice conduits for oil–gas migration. The oil and gas in the Nen 1 and Nen 2 members migrated into the Nen 3 and Nen 4 members through these faults, forming stratigraphic reservoirs. Identification of the distribution of sandstone and of the locations of channels is important in exploration. Therefore, in a channel-dominated delta sedimentary region, understanding the vertical and lateral distributions of sandstone is critical for reservoir prediction.

From Fig. 2, the well log curves of the first sandstone bed of the Nen 3 member show coarsening-upward patterns, i.e., inverse cycles. The lower part of the member is mudstone overlain by argillaceous siltstone, siltstone, and fine sandstone, with mudstone, siltstone, and fine sandstone above. The resistivity of the lower inverse cycle (R2.5) is low and gradually increases upward. The spontaneous potential (SP) curve shows the lower values. The first sandstone bed has a sharp contact with the upper part of the formation. In this bed, the SP curve has a box or bell shape. The first sandstone bed is formed in distributary channel and overbank facies. In the second sandstone bed, the SP curve has typical bell shapes with stable distribution, and can be correlated across the region. Although the second sandstone bed is thin, it shows an inverse-cycle aggradational sequence, and its sedimentary facies are the same as those of the first sandstone bed. In the third sandstone bed, the lithology consists of lacustrine facies sandstone with overlying mudstone, and the SP curves are generally flat and straight. This bed represents overbank deposition with local thick sandstone and fine sandstone and siltstone.

As shown in Fig. 3, because most of the rocks in the Nen 3 and Nen 4 members represent lower delta plain distributary channel sedimentation, the strata in the XB area have poor continuity, and thus it is difficult to trace and interpret sequences. However, the seismic profile shows some lenticular features, which are reflection features of the channel sandstone. As shown in Fig. 4, the distributary channels can be distinguished according to the log curve signature.

3. Analysis of multiple seismic attributes

Many types of seismic attributes can be extracted and applied (Chopra and Marfurt, 2005, 2007; Chopra and Alexeev, 2006; Ker et al., 2011; Sullivan et al., 2006; Zeng et al., 2007); Generally, seismic attributes are grouped into four types: time, amplitude, frequency, and absorption attenuation. In addition, they can be classified into physical attributes and geometric attributes. In some

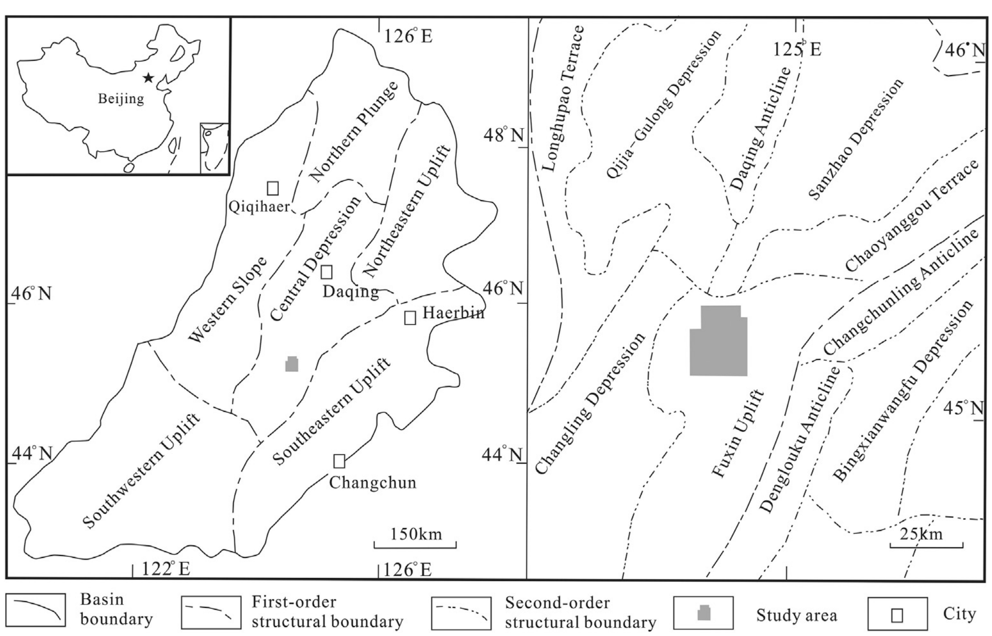

Fig. 1. Study area of Songliao basin.