Marine and Petroleum Geology 78 (2016) 759–765

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Prediction of ultrathin lacustrine sandstones by joint investigation of tectonic geomorphology and sedimentary geomorphology using seismic data

Hongliu Zeng [a,*], Ligui Xu [b], Guizhong Wang [b], Xiugang Pu [c]

[a] *Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, United States*
[b] *BGP of CNPC, China*
[c] *PetroChina Dagang Oilfield Company, China*

ARTICLE INFO

Article history:
Received 21 May 2014
Received in revised form
11 May 2015
Accepted 2 July 2015
Available online 10 July 2015

Keywords:
Seismic interpretation
Tectonic geomorphology
Sedimentary geomorphology
Cretaceous
Thin bed

ABSTRACT

Weak seismic signals from ultrathin (1–7 m) sandstones increase uncertainties of thickness estimation, imposing a significant challenge for accurate prediction of subtle hydrocarbon reservoirs. These types of uncertainties, however, can be reduced by a combined use of kinematic (travel time) and dynamic (amplitude) information extracted from 3D seismic data. In this case study in the Kuqa Depression of the Tarim Basin, China, we conducted an investigation of seismic-based tectonic geomorphology and then sedimentary geomorphology in four steps: (1) reconstruction of basin-floor paleogeomorphology using a residual structure map of a closely underlain erosional unconformity, (2) study of seismic lithology by seismic modeling and 90° phase adjustment of seismic traces, (3) mapping of geomorphologic patterns of depositional systems on stratal slices, and (4) combined analysis of tectonic geomorphology and sedimentary geomorphology for a better understanding of depositional history and reservoir distribution. Results show a good match between valley and lowland systems on the basin floor, sandstone thickness trend, and lobate sedimentary geomorphologic patterns, indicating a widespread, yet laterally highly variable, ultrathin sandy fan-delta system.

1. Introduction

Tectonics is a basic control on basin geometry and basin-bottom geomorphology, both of which in turn exert great influence on sediment-dispersal patterns. Tectonic sedimentology is the study of sedimentary response to tectonic events (Frostick and Steel, 1993). Previous studies have shown that different structural geometries lead to distinct sequence-stratigraphic architecture and stacking patterns, depositional facies distribution, and distribution of potential reservoir and source rocks (e.g., Crossley, 1984; Dawers et al., 1993; Gawthorpe and Leeder, 2000). Similar relationships between tectonic geomorphology and depositional styles in lacustrine basins in China have also been discussed (e.g., Zhu et al., 2013).

On the other hand, seismic geomorphology (Posamentier, 2000) is a valuable tool for high-resolution facies imaging using horizontal seismic displays made from 3D seismic data. Especially if combined with seismic lithology study, seismic facies can be converted to sedimentary-rock signals, processes, and depositional systems (seismic sedimentology, Zeng et al., 1998; Zeng and Hentz, 2004). Typical resolution of reservoir mapping by seismic sedimentology has been around 10 m.

If an even higher resolution (e.g., 1–5 m) is needed for exploration and production of subtle hydrocarbon resources, we would be forced to work with low signal-to-noise seismic information because the seismic signal extracted from ultrathin reservoirs will be substantially weaker compared to the signal from thick beds. Such data are more difficult to interpret, causing great uncertainties in reservoir prediction. Reducing these uncertainties is a challenge. One possible solution is to study the relationship between tectonic geomorphology at the basin floor and sedimentary geomorphology of mapped depositional systems, thus predicting reservoirs by using both travel-time and amplitude information. A clear correlation between the tectonic geomorphology and sedimentary geomorphology would greatly reduce interpretation uncertainties.

A 3D seismic data set of 100 km^2 with sparse well control in the Yudong area of the Kuqa Depression, Tarim Basin, China (Fig. 1), has

* Corresponding author.
E-mail address: hongliu.zeng@beg.utexas.edu (H. Zeng).

http://dx.doi.org/10.1016/j.marpetgeo.2015.07.003
0264-8172/

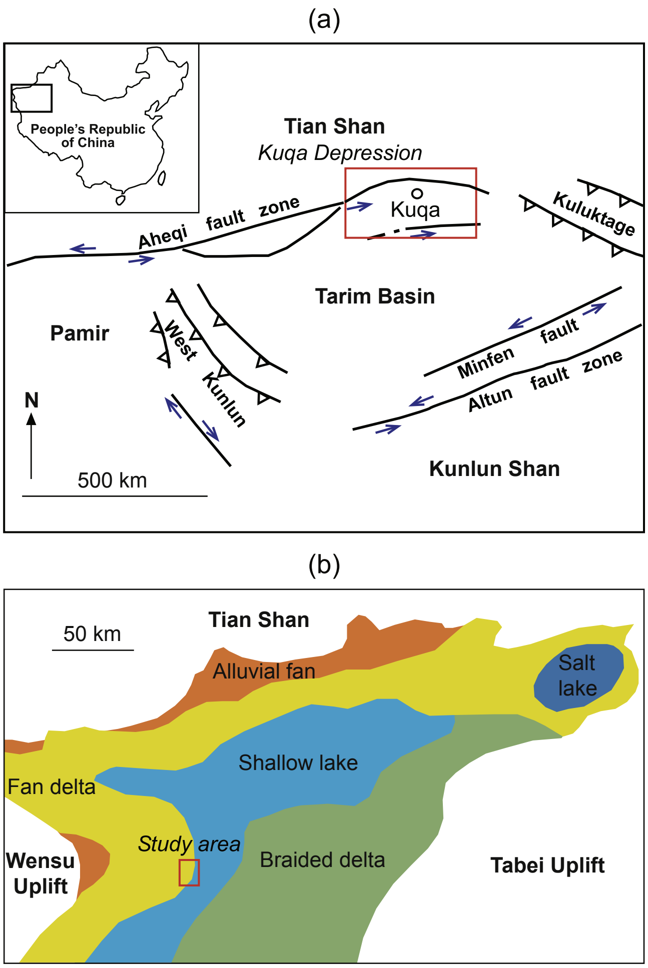

Fig. 1. Tarim Basin, Kuqa Depression, and study area. (a) Tectonic setting of Tarim Basin (modified from Jia et al., 1998) and location of Kuqa Depression. Red box indicates location of Kuqa Depression. (b) General facies map of Kumugeliemu Group in Kuqa Depression (modified from Zhao, 2011). Red box refers to location of Yudong 3D survey area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

provided an opportunity for such a study. An area with proven reservoir quality (Sun, 2004) and oil accumulation in commercial quantity (Zhang and Xue, 2002), and currently undergoing active exploration, the Yudong oil field is produced from some ultrathin (2–7 m) but also highly productive lacustrine sandstone reservoirs, which were deposited on top of a major uniformity with complex erosional geomorphology (Zeng et al., 2013). Drilling has been based on regional sequence-stratigraphic and facies models with limited success. The outcome of this study would encourage more exploration activities in this area.

2. Geologic setting

The Kuqa Depression (Fig. 1b) is a large (30,000 km^2) Tertiary foreland depression developed during the Himalayan orogeny (Jia et al., 1998). Flanked by Tian Shan to the north, the Tabei Uplift to the east and southeast, and the Wensu Uplift to the west, the Kuqa Depression accumulated thick (3000–6000 m) Tertiary sediments of predominantly lacustrine origin (Table 1), including sandstones, shale, and evaporates, all formed in shallow lake and arid environments. A previous study by Zhao (2011) recognized and correlated nine third-order sequences in Tertiary sediments in the Depression. Our study interval, the Paleocene-Eocene Kumugeliemu Group, is correlated to third-order sequence ESQ1 at the base. Major depositional systems in the Kumugeliemu Group included alluvial fan, fan delta, braided delta, shallow lake, and salt lake (Fig. 1b) (Zhao, 2011). The study area is in the fan-delta-front to shallow-lake transition zone in the west of the basin, with a sediment supply from the Wensu Uplift to the west.

In a well cross section (Fig. 2), four sand groups have been identified in the Kumugeliemu Group. The pay zone, the third sand group, is one of several high-frequency sequences in the Kumugeliemu Group, which overlies Cretaceous clastic (sandstones and shale) strata. A regionally traceable evaporite unit is distributed above the first sand group, serving as a stratigraphic correlation marker in the area. Separated by the fourth sand group, the distance from the base of the third sand group to the Cretaceous unconformity surface is about 10–15 m. There are no obvious seismic onlaps recognized above the unconformity in this area, probably because of the limit of seismic resolution. Erosion of top Cretaceous rocks, however, has been observed in other areas of the basin.

3. Tectonic geomorphology

Paleogeomorphology, combined with sediment supply, controls sediment dispersal pattern in a basin (Martin, 1966; Seidel et al., 2007; Masini et al., 2011). Tectonic activities have significant control on basin architecture and paleogeomorphology (Gawthorpe and Leeder, 2000; Leeder, 2011). Paleogeomorphology is the composite response of various processes, such as structural deformation, sedimentation, differential compaction, and erosion (Zhu et al., 2013). In Kuqu Depression, Kumugeliemu Group underwent minor erosion but significant structural deformation after deposition. As a result, removal of structural deformation is crucial for restoration of paleogeomorphlogy.

As seen in a seismic section (Fig. 3a), paleostructure at the Cretaceous unconformity is severely altered by tectonic movement. A time-structure map of the unconformity (Fig. 3b), therefore, does not represent the paleotopography of the sedimentary basin during the Paleocene-Eocene time. Neither can the paleotopography at the unconformity be restored by a compaction-calibrated isopach of the Kumugeliemu Group because the evaporate beds above the first sand group are plastic in nature and have been laterally moved and deformed since deposition.

A compromise solution would be to remove the regional trend from the time-structure map (Fig. 3b), assuming that the smoothed-structure map of the unconformity closely represents the tectonic alteration to the paleotopography of the unconformity (Fig. 4). The resultant residual-structure map (Fig. 5a) can be used as an approximation of the relative paleotopography at the time of deposition with two limitations: Firstly, the size of the smoothing cell —3750 × 3750 m—restricts the maximum size of paleolandforms to about 14 km^2. Secondly, the estimated height of the landforms (vertical distance between highs and lows) has only relative meaning. Thirdly, the operation eliminates the regional slope of paleodepositional landforms, which would exist originally. Cautions should be exercised when using the result.

A 3D view of the residual-structure map (Fig. 5b) highlights paleogeomorphologic units, or hills and valleys, on the unconformity surface. These features are inferred on the basis of the relative relief between topographic highs and lows on the map, which can be as large as 30 ms, or 60 m except at the edge in the north and the corner at southwest where the relief of residual structure is exaggerated because of the edge effect. Second-order, subtle hills and valleys with 10–30 m reliefs can also be recognized along the main hills, making a complex lowland valley system in the study area.