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Deep-lacustrine transformation of sandy debrites into turbidites, Upper Triassic, Central China

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ABSTRACT

Deep-lacustrine transformation of sandy debrites into turbidites in the downslope direction is evident in the Upper Triassic Yanchang Formation of the Ordos Basin, central China. This facies trend is used as a template for predicting the distribution of reservoir facies of the Huaqing oilfield, which contains 100-million-tonnes of oil reserves. Based on examination of conventional cores from 30 wells, four major types of lithofacies have been recognized: (1) fine-grained massive sandstone with floating mudstone clasts and planar clast fabric (sandy debrite); (2) fine-grained sandstone and siltstone showing contorted bedding, sand injection, and ptygmatic folding (sandy slump), (3) fine-grained sandstone with thin layers of normal grading and flute casts (turbidite), and (4) mudstone with faint laminae (suspension fallout). Thick sandy debrite units occur beneath the delta-front facies, implying progradation. The lake margin is dominated by sandy debrites, whereas the lake center is dominated by turbidites. In our study area, sandy debrites constitute the producing petroleum reservoirs, but turbidites are non reservoirs. The proposed model is characterized by (1) delta-fed multiple source (line source), (2) absence of channels, and (3) downslope transformation of proximal sandy debrites into distal turbidites. This downslope transformation of sandy debrites into turbidites may be applicable to other deep-lacustrine basins worldwide for predicting reservoir distribution.

1. Introduction

The concept of sandy debris flow was first introduced by Hampton (1972) and recently reviewed by Shanmugam (2012). This concept is becoming increasingly popular ((Nemec, 1990; Shanmugam, 1996; Shanmugam et al., 1994, 1995, 2009; Shanmugam and Moiola, 1995; Gee et al., 1999; Jennette et al., 2000; Stow and Johansson, 2000; Surlyk and Noe-Nygaard, 2001; Mellere et al., 2002; McHugh et al., 2002; Purvis et al., 2002; Amy et al., 2005; Gervais et al., 2006; Mitchell et al., 2007; Talling et al., 2007; Draganits et al., 2008; Encinas et al., 2008; Le Roux et al., 2008; Li et al., 2010; Migeon et al., 2010; Olson and Damuth, 2010). However, there is a major controversy between the concept of high-density turbidity currents (Lowe, 1982) and that of sandy debris flows (Shanmugam, 1996). Because both concepts are used for explaining the origin of deep-water massive sands (Stow and Johansson, 2000), and because the massive sand constitute a major type of lithofacies in our study area, we discuss the distinction between the two concepts here. Later, we will consider these two concepts in interpreting massive sand lithofacies in our study area.

Lowe (1982) defined high-density turbidity currents based on three grain-size populations. Population 1 is composed of clay to medium sand, in which grains are supported by flow turbulence. Population 2 is composed of coarse sand to pebble-sized gravel, in which grains are supported by both flow turbulence and hindered settling. Population 3 composed of pebble- and cobble-sized clasts, in which grains are supported by dispersive pressure and buoyant lift. Deposition from these three populations occurs in a series of discrete sedimentation waves, first from traction, then from mixed frictional freezing and suspension sedimentation, and finally from direct suspension sedimentation. As a consequence, deposits of high-density turbidity currents develop an ideal vertical sequence in an ascending order with the following divisions: R2, R3, S1, S2, and S3 (Lowe, 1982, his Fig. 11).

Shanmugam (1996, 2000) defined sandy debris flow as a sediment flow with plastic rheology and laminar state from which deposition occurs through “freezing” en masse. Sandy debris flows have particle or grain (>0.06 mm) concentration value of 20% and above by volume. These flows represent a continuous spectrum of processes between cohesive and cohesionless debris flows. Therefore, multiple support mechanisms, such as matrix strength, dispersive pressure, hindered settling, and buoyant lift, are involved. Deposits of sandy debris flow can be recognized using the following criteria: (1) concentration of rafted mudstone clasts near the tops of sandstone beds, (2) inverse grading of clasts, (3) planar clast fabric, (4) preservation of fragile shale clasts, and so on. Furthermore, flume experiments of sandy debris flows were conducted to understand the deposition mechanism (Shanmugam, 2000; Marr et al., 2001). The importance

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of experimental studies is that they showed that sandy debris flows can operate with a low mud concentration as low as 0.7% by weight (Marr et al., 2001). This is important because traditional debris flows are considered to be mud-rich flows.

The debrite vs. turbidite controversy of massive sands has direct implications for developing deposition models of deep-water sands (Shanmugam and Moiola, 1995). The concept of sandy debris flows is helpful for interpreting deep-water massive sands (Stow and Johansson, 2000). Turbidites, for example, dominate both proximal and distal settings in submarine fan models (Bouma, 1962; Mutti and Ricci Lucchi, 1972). However, sandy debrites also dominate both proximal and distal settings in debrite models (Shanmugam, 2000, his Fig. 33).

To understand ancient deep-lacustrine facies in the Ordos Basin, central China (Fig. 1), we have evaluated the world's deepest (1637 m) Lake Baikal in Russia (Nelson et al., 1999) and North America's second deepest (622 m) Crater Lake in Oregon (Nelson et al., 1986). In the Lake Baikal, tectonically influenced half-graben morphology controls the amount and type of sediment supply. Steep border-fault slopes (footwall) on the northwest sides of half-graben basins provide a limited supply of coarser grained clastic material to multiple small fan deltas. These multiple sediment sources provide sediment for sand-rich aprons at the base-of-slope settings on the lake floor. The basin plain turbidites in the center of the linear lake are controlled by rift-parallel faults. The Crater Lake lies in the collapsed caldera of Mount Mazama of the Cascade Mountain Range in southwest Oregon. In proximal areas, debris chutes funnel sediment into base-of slope aprons with coarse-grained facies deposited by a variety of gravity-driven processes that include rockfall, landslides, slumps, grain flows, debris flows, and turbidity currents. These processes evolve into distal sheet-flow turbidity currents downslope (Nelson et al., 1999).

The significance of our study is that we propose an unconventional model in which sandy debrites dominate the proximal setting and turbidites prevail in the distal setting. This deep-lacustrine transformation of sandy debrite into turbidite may be more common in the geologic

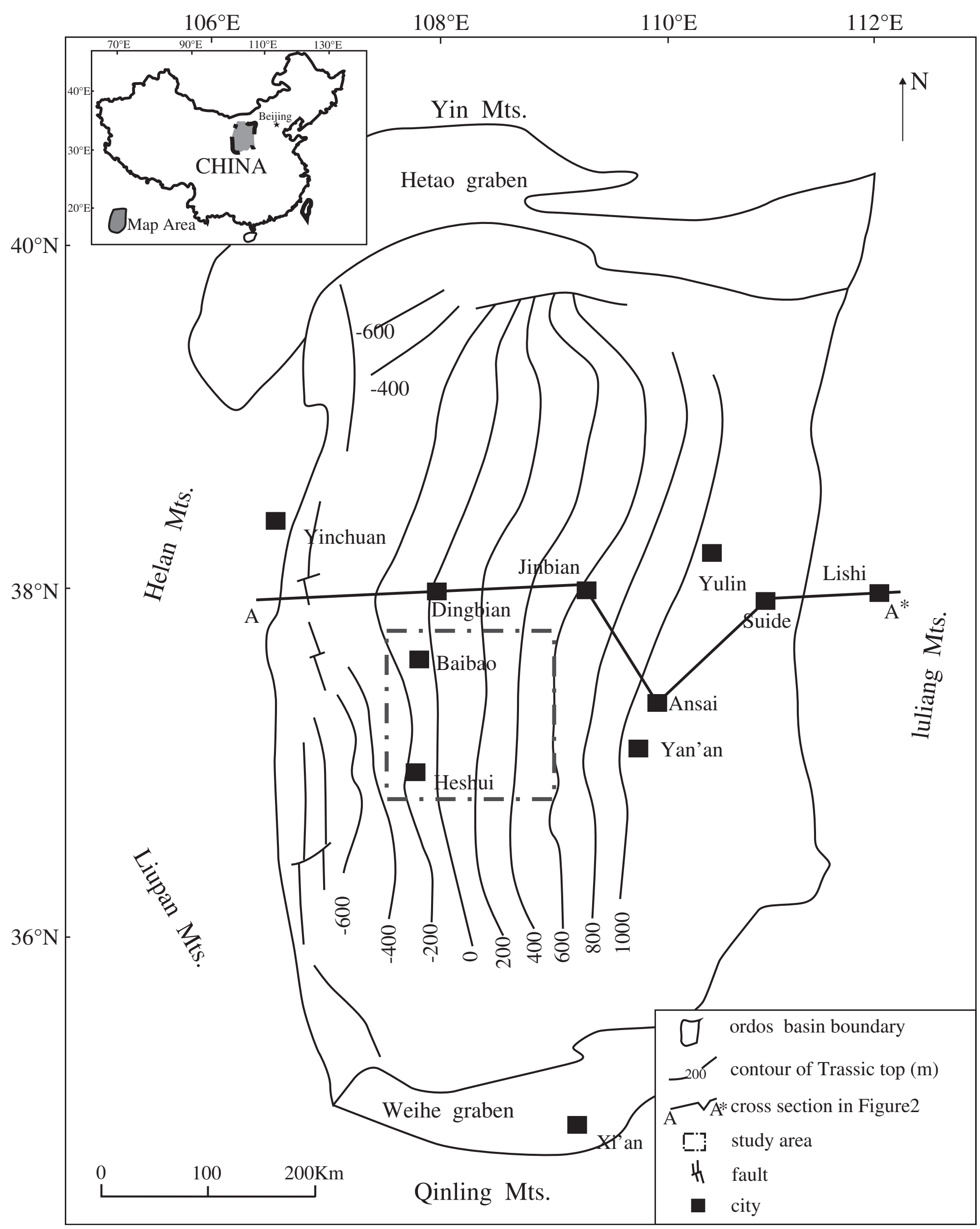

Fig. 1. Map showing location of the Ordos Basin in central China and index map of Ordos Basin including structure contours of the Triassic top, location of the study area (boxed area).