Journal of Asian Earth Sciences 92 (2014) 157–167

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Lacustrine tempestite and its geological significance in the Cenozoic study of the Qaidam Basin

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ARTICLE INFO

Article history:
Received 22 November 2013
Received in revised form 14 March 2014
Accepted 25 June 2014
Available online 8 July 2014

Keywords:
Tempestites
Paleogeography
Sedimentary
Qaidam Basin
Qinghai-Tibet Plateau
Uplift

ABSTRACT

During the Cenozoic a typical lacustrine tempestite deposition was developed in the Lulehe and Xichagou sections of the Qaidam Basin. The sedimentary structures of these two sections above are examined here in detail, which consist of storm erosion, storm tear, storm wave and rapid storm-generated sedimentary structures after storm processes, such as groove casts, scour structures, cutoff structures, hummocky cross-stratification (HCS), parallel bedding and graded bedding. On the basis of these sedimentary characteristics and the vertical facies sedimentary sequence, the causes of the sedimentary succession are analyzed and a Cenozoic sedimentary model of the Qaidam Basin containing shallow proximal, transitional and deep distal tempestites is established. According to the tempestite scale and HCS wavelength, the Cenozoic storm was obviously more intense in the basin's Upper Ganchaigou formation than that in the Lower Youshashan formation. This variation indicates that a paleoclimatic transition largely corresponded with the second uplift of the whole Qinghai-Tibet Plateau. The discovery of a Cenozoic tempestite in the Qaidam Basin is significant in the paleogeographic, paleoclimate and paleostructural fields, which provides a new insight in further study of the Qinghai-Tibet Plateau uplift.

1. Introduction

Storms are generally forming on oceans near the equator, and tempestites are well documented in relation to marine succession, where they have aided paleoecological and paleogeographic interpretation (Kelling and Mullin, 1975; Ager, 1981; Johnson, 1989; Monaco, 1992; Baarli, 1998; Ito et al., 2001; Pochat et al., 2005). Although Ocean storms rarely reach the land, the storm waves that eventually land still have an effect on sedimentation and the profiles of non-marine basins, such as lacustrine basins. As it is well known, non-marine tempestites, such as lacustrine tempestites, have hardly been mentioned in geologic records. Despite all this, lacustrine tempestites can provide key information in terms of basin evolution and paleogeographic reconstruction. In recent years, an increasing number of lacustrine tempestites have been found (Li et al., 2007; Guo and Guo, 2011; Liu et al., 2012) during land petroleum exploration and geological survey. Only a few occurring from normal terrestrial convective storms (Myrow et al., 2008) have been commonly seen in the Midwestern United States, whereas most of observed lacustrine tempestites have been interpreted as ocean storm origin.

According to the recognition of lacustrine tempestite by Liu et al. (2012), there are many Cenozoic lacustrine tempestites in the Xichagou and Lulehe sections (Fig. 1) of the Qaidam Basin, with scale of local tempestites decreasing from Paleogene to Neogene. Previous studies of lacustrine tempestites only described sedimentary structures from drilling cores, whereas no section data in the Qaidam Basin are available. Based on recent studies, storms are generally formed in oceans between 5° and 20° for both north and south latitude, and even the biggest storm can never affect the area over 35° (Marsaglia and Klein, 1983). According to this result, the tempestites documented in this area indicate that Qaidam Basin is in the south of 35°N with low altitudes during the Cenozoic. The Qaidam Basin is located in the north of Qinghai-Tibet Plateau, over 3000 m high, and nowadays its southernmost boundary is beyond 35°N. This suggests that Qaidam Basin could have experienced certain geological processes and migrated to the regions with high latitude and high altitude, which may relate to Qinghai-Tibet Plateau's northward movement and uplift under Indian plate subduction. In addition, it is likely to have an effect on the storm which can be seen from storm deposits. Therefore, this research on tempestites in the Cenozoic of Qaidam Basin may help recover its paleographic position, and analyze its paleotectonics as well as paleoclimate. Furthermore, it can explore potential influence of Qinghai-Tibet Plateau's uplift over the

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http://dx.doi.org/10.1016/j.jseaes.2014.06.020
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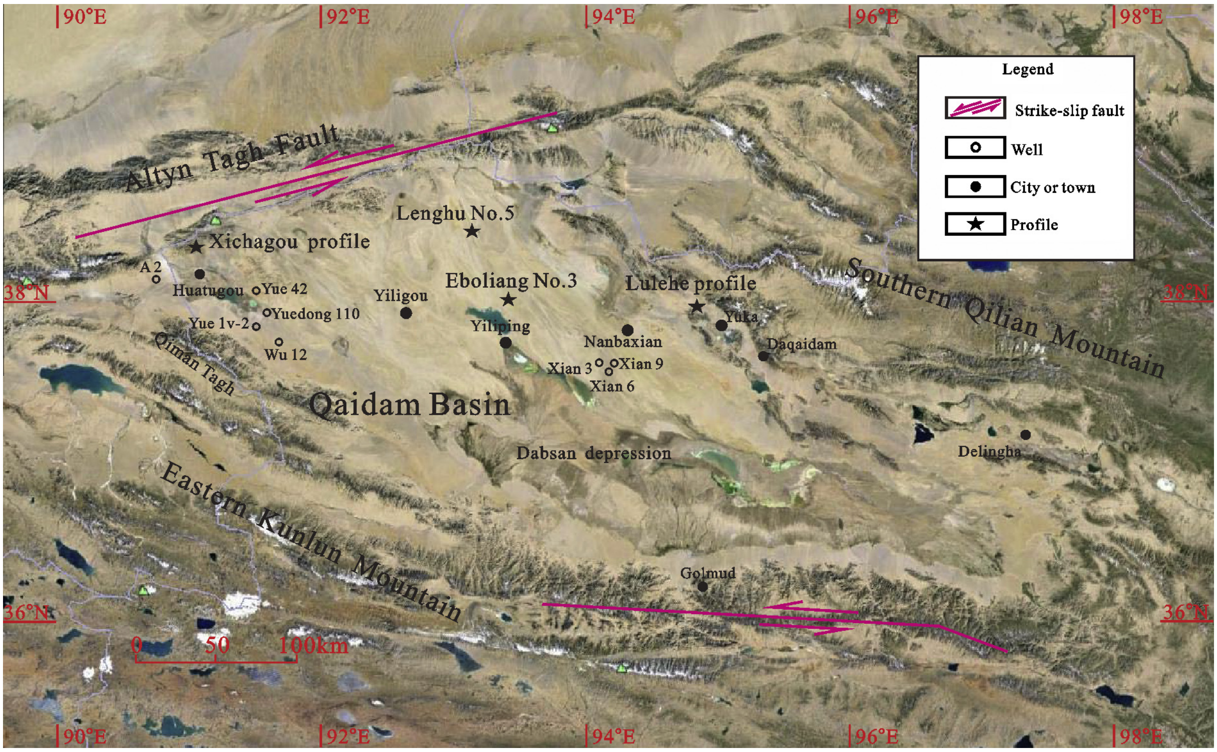

Fig. 1. Local profiles and boundary of the Qaidam Basin (based on Wang et al., 1999 and edited).

Qaidam Basin and thus open up a new way in the research for Qinghai-Tibet Plateau's uplift.

2. Geological background

With an average elevation of 3000 m, the Qaidam Basin is located in the northeastern corner of the Qinghai-Tibet Plateau, which represents a large continental sedimentary basin. It is formed under Indian plate northward squeezing, and is bordered by three large fault systems, including the Kunlun thrust belt to the south, the left lateral strike-slip Altyn Tagh fault to the northwest and the Qilian Mountain/Nan Mountain thrust-and-fold belt to the northeast (Lu and Xiong, 2009). The structural evolution of Qaidam Basin plays a big role in influencing its sedimentation, and can be generally divided into three stages (Tang et al., 2000; Yu et al., 2002; Zhao et al., 2004; Li et al., 2012): (1) In the Paleocene Eocene-middle Oligocene, lake basin started to form. During this time, the Indian plate sank beneath the Eurasian Plate, causing the uplift of Altyn Mountain and Kunlun Mountain. Also, a set of red clastic rocks in proluvial–fluvial facies was deposited accompanying with the sinking process of the basin. (2) The late Oligocene–Miocene is the stationary phase during the basin sinking period. Under the left lateral shearing action, Qaidam Basin has the characters of rift basin with thrust fault as its border. Meanwhile, Kunlun Mountain's uplift and Indian plate's northward subduction caused the lake basin to expand to the northeast and to move in the same direction as depocenter did. Also, deep lake deposits overrode coastal lake as well as shallow lake deposits. (3) Owing to the uplift of Kunlun Mountain and arid climate, the lake basin had shrunk a lot since the Miocene and it continued to shrink until the middle-late Pliocene when halite were formed.

Based on the study of Xichagou and Lulehe sections (Yang and Ma, 1992) and paleomagnetic times researches of Xichagou, Honghansan (Sun et al., 2004; Song, 2006) and Dahonggou (Lu and Xiong, 2009) area, the Cenozoic stratigraphy of Qaidam Basin was divided into seven formations (in ascending order), including Lulehe (53.5–42.9 Ma), Lower Ganchaigou (42.9–31.5 Ma), Upper Ganchaigou (31.5–22.0 Ma), Lower Youshashan (22.0–14.9 Ma), Upper Youshashan (14.9–8.2 Ma), Shizigou (8.2 ~ <2.9 Ma) and Qigequan (>2.6 ~ <0.4 Ma) (Yang and Ma, 1992; Sun et al., 2004; Song, 2006; Lu and Xiong, 2009; Ma et al., 2010). The ages and correlations of strata are shown in Table. 1.

Qaidam Basin is a typical lacustrine basin (Zhao et al., 2004) and mainly consists of delta, coastal lake and shallow lake facies (Fig. 2). Previous work by petroleum geologists (Wang and Zhao, 2001; Zhao et al., 2004; Li et al., 2012) over the last 50 years has established a basin-wide lithostratigraphic and sedimentary facies framework for the Qaidam Basin. The 298–1300 m thick Lulehe formation consists of brownish red coarse clastic rock, including conglomerate, pebbly sandstone, fine sandstone with sandy mudstone and argillaceous siltstone. The Lower Ganchaigou formation is 200–1400 m thick and consists largely of brownish red, yellow-gray and gray conglomerate, with sandy mudstone and little muddy sandstone, sandstone as well as siltstone. The 300–1390 m thick Upper Ganchaigou formation consists mainly of cyclic alternations of gray-green laminated or bedded siltstone and brown mudstone. The Lower Youshashan formation is 200–1220 m thick and consists largely of alternating brown laminated or bedded mudstone and gray-green massive sandstone, or conglomerate, or multi-colored (gray-white to yellowish) siltstone. The Upper Youshashan formation is 350–1420 m thick and mostly consists of interbedded

Table 1
The stratum system of the Qaidam Basin.

Epoch	Age (Ma)	Stratigraphic units	Duration (Ma)
Pleistocene	1.806	Qigequan formation	>2.6 ~ <0.4
Pliocene	5.332	Shizigou formation	8.2 ~ <2.6
Miocene	23.03	Upper Youshashan formation	14.9–8.2
		Lower Youshashan formation	22.0–14.9
Oligocene	33.9	Upper Ganchaigou formation	35.5–22.0
Eocene	55.8	Lower Ganchaigou formation	43.8–35.5
Paleocene	65.5	Lulehe formation	65–43.8