The Seismic Induced Soft Sediment Deformation Structures in the Middle Jurassic of Western Qaidamu Basin

LI Yong[1, 2 *], SHAO Zhufu[3], MAO Cui[3], YANG Yuping[3] and LIU Shengxin[3]

1 *Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640*
2 *Graduate school, Chinese Academy of Sciences, Beijing 100010*
3 *School of Geo-Science, China University of Petroleum, Qingdao 266580, Shandong,*

Abstract: Intervals of soft-sediment deformation structures are well-exposed in Jurassic lacustrine deposits in the western Qaidamu basin. Through field observation, many soft-sediment deformation structures can be identified, such as convoluted bedding, liquefied sand veins, load and flame structures, slump structures and sliding-overlapping structures. Based on their genesis, soft-sediment deformation structures can be classified as three types: seismic induced structures, vertical loading structures, and horizontal shear structures. Based on their geometry and genesis analysis, they are seismic-induced structures. According to the characteristics of convoluted bedding structures and liquefied sand veins, it can be inferred that there were earthquakes greater than magnitude 6 in the study area during the middle Jurassic. Furthermore, the study of the slump structures and sliding-overlapping structures indicates that there was a southeastern slope during the middle Jurassic. Since the distance from the study area to the Altyn Mountain and the Altyn fault is no more than 10km, it can be also inferred that the Altyn Mountain existed then and that the Altyn strike-slip fault was active during the middle Jurassic.

Key words: Soft-sediments deformation structure, sliding-overlapping structure, paleoseismology, Altyn strike-slip fault

1 Introduction

Soft Sediment Deformation Structures (SSDS) are formed close to the surface in an unconsolidated state, during or shortly after deposition and before significant diagenesis (Zhao and Liu, 1988; Du et al., 2007; Du, 2011; Owen and Moretti, 2011). Many alternative names have been proposed for this category of sedimentary structures, such as soft-rock deformation, sedimentary deformational structures, penecontemporaneous deformation, synsedimentary deformation, early-diagenetic deformation, and pre-lithification deformation (Maltman, 1984, 1994; Van Loon, 2009; Owen and Moretti, 2011). As a kind of widespread structure, soft-sediment deformation structures have been studied by many authors in the last twenty years. The mechanisms for soft-sediment deformation include uneven loading, gravity sliding or slump, sediment fluidization, and liquefaction (Leeder, 1987; Moretti et al., 2002; Montenat et al., 2007; Obermeier et al., 2009; Owen and Moretti, 2011). Earthquakes have been considered as the main trigger for the formation of soft-sediment deformation structures and have been studied by experiments, field observation and genesis analysis (Nichols, 1994; Owen, 1992, 1996; Moretti et al., 1999; Yan et al., 2009; Qiao and Guo, 2013). Also, based on their deformed time relative to an earthquake, SSDS can be divided into three types: syndepositional, penecontemporaneous, and epigenetic deformation (Du, 2011). Some authors also relate soft-sediment deformation structures to the frequency and intensity of earthquake (Rodríguez-Pascua et al., 2000; Qiao and Li, 2008; Qiao and Guo, 2011, Qiao et al., 2012). Intervals of SSDS have been found and well-exposed in Jurassic lacustrine deposits in the western Qaidamu basin. Since the study area is quite near Altyn mountains and the Altyn strike-slip fault, the identification and analysis of the soft-sediment deformation structures can not only restore the Jurassic paleogeography of the Qaidamu basin but also determine the tectonic movement of the Altyn Mountain and the Altyn strike-slip fault.

* Corresponding author. E-mail: yong77_li@hotmail.com

2 Geologic Setting

The study area is located in the west of Qaidamu basin, southeast of the Altyn Mountains and the Altyn strike-slip fault (Fig. 1). Until today there are still some debates on the earlier and middle Jurassic tectonic setting of the Qaidamu basin. Some authors consider it as a foreland basin under the compression diving force (Wu et al., 1997, Zhai et al., 1997, Xia et al., 1998). Others regard it as an extended fault basin (Jin et al., 2006; Duan et al., 2007a; Luo, 2008). Here we take the latter opinion and regard it as an extended fault basin. The Honggouzi area is a Mesozoic-to-Cenozoic fault-nose structure with a strike running 300° to the WNW. It is composed of middle-lower Jurassic and Paleogene strata (Fig. 1) and was formed during the Neogene.

As one of the main target zones of oil and gas exploration, lower-middle Jurassic strata can be as thick as 6300 m based on outcrop and geophysics data (Duan, 2007b). Soft-sediment deformation structures are exposed in the lower-middle Jurassic deposits in the study area.The strata of the study area can be divided into three layers (Fig. 2). The bottom alluvial fan deposits are mainly composed of dark greenish-grey conglomerate interbedded in irregular yellowish-green sandstone. The pebbles are mainly metamorphic or igneous rocks. Plant fossils and mega trough cross-bedding can be found in this layer, and an erosion surface can be seen at the bottom. The middle layer is composed of dark grayish carboniferous shale, carboniferous mudstone and laminar siltstone of moderate-to-deep lake facies. The top deposits are composed of interbedded grayish-green granules and yellowish-green sandy shale in the lower section and granules in the upper section. The facies sequence of the alluvial fan, lacustrine, and fan delta depositional system from bottom to top reflects one complete tectonic sequence. Based on lithologic analysis, the lower-to-middle Jurassic strata are dark coal deposits of a lacustrine swamp facies from a warm and humid environment.

3 Soft-Sediment Deformation Structure

Soft-sediment deformation structures of the Honggouzi Area developed at the south-eastern limb of the Honggouzi anticline with a strata occurrence of 238°∠29°. The cross section with the soft-sediment deformation structures is about 30 m high and 130 m long. Soft-sediment deformation structures developed in a zone about 2 m thick and are interbedded between upper and lower undeformed layers (Fig. 2, Plate I-1). The lithology of the soft- sediment deformation structures includes sand and mud layers. The vertical sequence can be divided into 6 distinct zones (Fig. 2). The bottom zone is composed of 5–6 layers of light grey granules 15–40 cm thick with a particle-supported texture, and poor sorting and roundness. The gravels in these zones are 3–5 mm in diameter and mainly composed of quartzite and flint. The second zone is composed of a set of reddish-brown calcareous mudstone and calcareous shale interbedded by thin bedded limestone 6–7 mm in thickness deposited on the shore and shallow lake bed. This zone is called a sliding-overlapping structure zone due to the sliding overlapping structures that are developed inside it. Above the sliding-overlapping structure zone, there is a 0.8 m thick olistostrome deposit which is composed of a mixture of red, brown, and yellowish-green mudstone, sandstone, and conglomerate. The fourth layer contains turbidite beds 30–40 cm in thickness which are composed of fine sandstone, siltstone, muddy siltstone, and mudstone

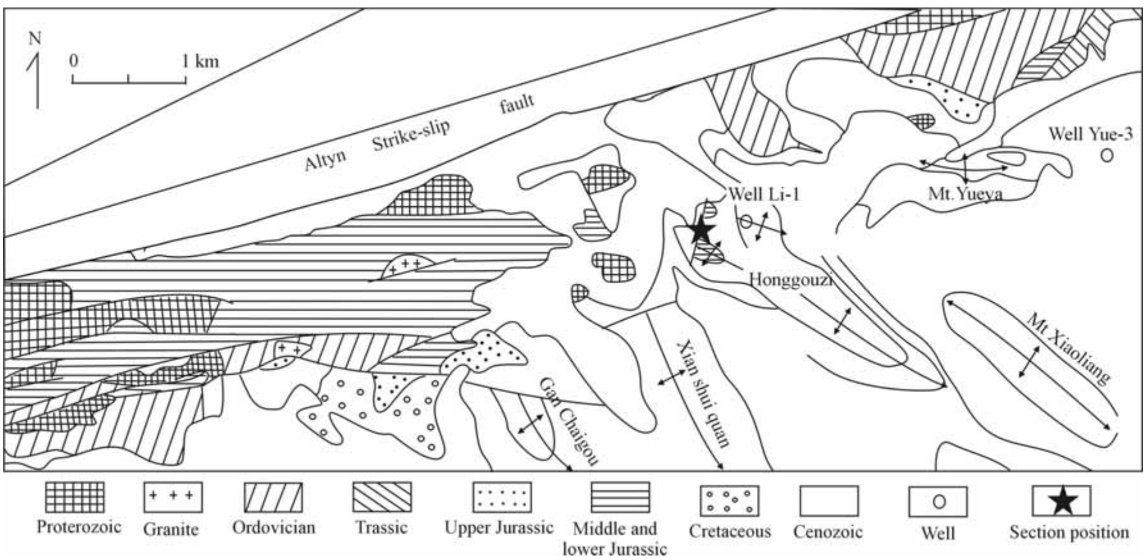

Fig. 1. Location of the study area.

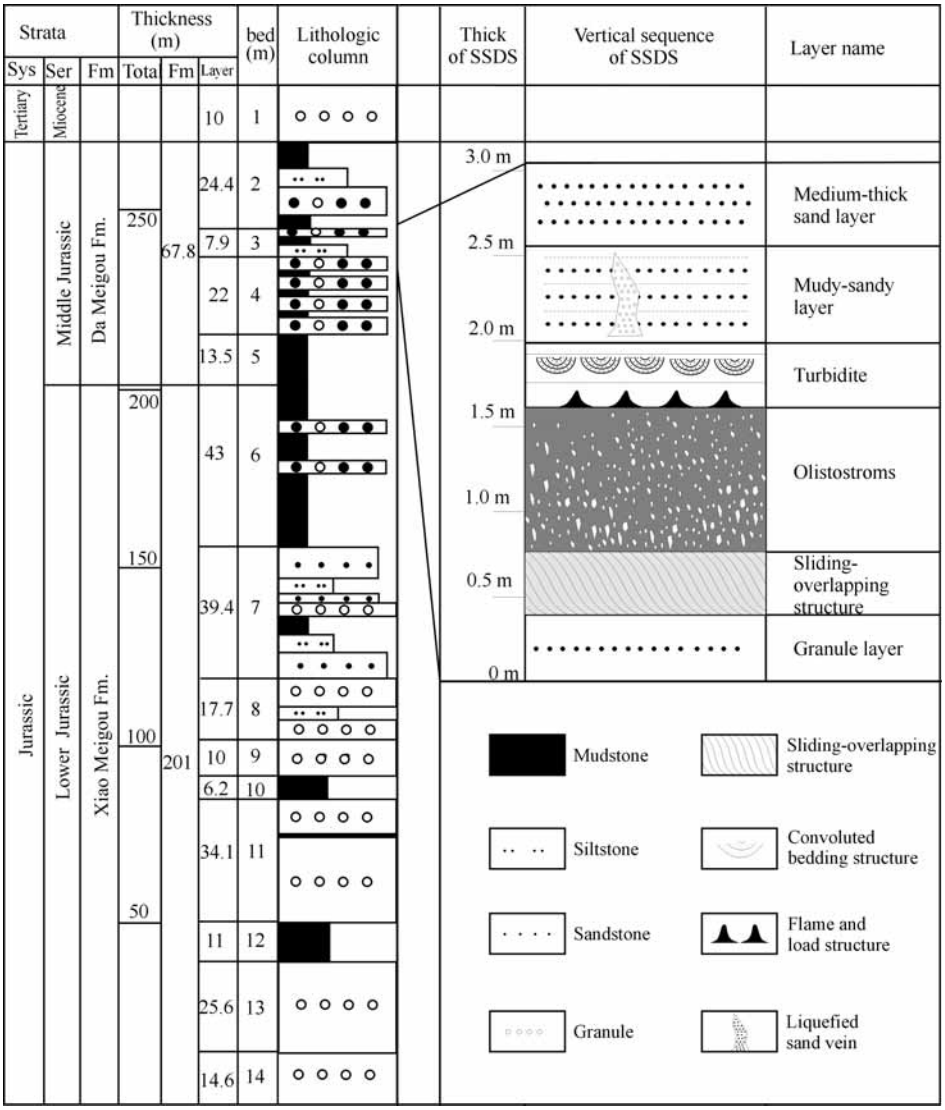

Fig. 2. The strata column of the study area and the position of soft sediment deformation structure

with flame structure and load structure inside. Based on the Bouma sequence, this zone can be divided into 3 cycles. Then, a zone of sand and mud combination delta faces deposits above this. The top zone is a set of medium-to-thick sandstone.

Through field observation and detailed analysis, many soft- sediment deformation structures can be identified, such as convoluted bedding, liquefied sand veins, load and flame structures, slump structures, and sliding-overlapping structures. Based on their genesis, three types can be classified as seismic-induced structures, vertical loading structures, and horizontal shear structures.

3.1 Seismic-induced structure

3.1.1 Convoluted bedding structure

A convoluted bedding structure is composed of a series of narrow antiforms and open synforms of upward concave silts or fine sand layers limited by upper and lower normal layers (Zhao and Zhu, 2001). In the study area, the convoluted bedding structures are small scale with 7 cm height and 12 cm width (Plate I4-5). The sediments included in the convoluted bedding structures are siltstone and fine sandstone. The singular bodies are regular and bent upwards in the cross section with the original bedding parallel to the bottom surface of the layer to form the synform. The convoluted bedding occurs at rather regular intervals across 130 m long sand beds to form a series of laterally connected synforms and antiforms. Many mechanisms have been proposed for the formation of the convoluted bedding structure, but the earthquake is the main factor during the formation of the convoluted bedding structure (Liu, 1992; Zhong et al., 1999; Zhao and Zhu, 2001). Based on shake table experiments (Owen, 1996), it requires at least a magnitude 6 earthquake to liquefy the sand and form a convoluted bedding structure. Thus, it can be inferred that there was an earthquake with magnitude greater than 6 in the Honggouzi Area during the middle Jurassic era.

3.1.2 Liquefied sand veins

Liquefied sand veins are formed when sand intrudes into horizons of distinct lithology. In the study area, there is only one small-scale liquefied sand vein (Plate I-6) which is composed of a larege lower part and a small upper part. The vertical lower part is plate-like with 4 cm width and 10cm height and is cut by a bedding shear joint at its bottom, which move the lower part 1 cm to the left and incline it to the left. The 5 cm-high upper sand vein is sausage-like with a wider bottom of 1cm, and it pinches out at the top. The whole sand vein terminates in sandy shale. On the left of the sand vein, there is a 2 cm-thick sand layer, but it has disappeared on the right. Liquefied sand veins are typical seismic-induced deformation structures (Obermeier et al., 2005; Owen, 1996; Moretti et al., 2002; Yan et al., 2009; Qiao and Li, 2009, Du, 2011) and it is accepted that these sand veins are formed in the late earthquake period. In the study area, the confined horizons are sandy shale. Since only a vertical sand vein is found in the study area, a seismic-related genesis can be postulated. Formation of this kind of sand vein requires an earthquake greater than magnitude 6, which also indicates that there was an earthquake with magnitude greater than 6 in the Honggouzi Area during the middle Jurassic era.

3.2 Vertical load structure (load structure and flame structure)

Flame structure and load structure are formed due to gravity acting on an area with reverse density when a denser, coarser sand bed is deposited on mud or siltstone. The sand body will subside into the underlying plastic mudstone and push the deformed and intruded mudstone into the upper coarser sandstone when the mudstone cannot support the overloading weight of the denser sandstone. Many authors have discussed the genesis of load structures and related them to earthquakes (Moretti et al., 2002, 2007; Yan et al., 2007; Qiao and Li, 2008, 2009). The load structure and flame structure are common in the sand-and-mud-interbedded layers in the study area. They are distributed along the bottom of the turbidite zone. On a small scale, the flame structure and load structure in the study area are 1–2 cm high and 2–3 cm long (Plate I-7). Above the flame structure, it is a massive A-division fine sandstone layer of the upper turbidite. There is also a kind of special load structure which is composed of coarser granules 10 cm wide and 3 cm high (Plate II-1) .

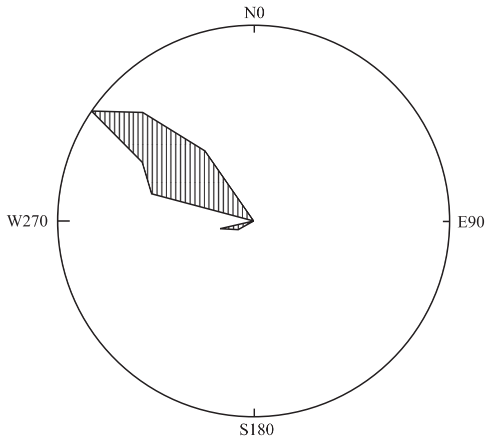

Fig. 3. The dipping direction Rose map of the sliding overlapping structure.

3.3 Horizontal shear deformed structure

3.3.1 Slump structure

The slump structure is a common deformed structure in any unstable slope environment (Maltman, 1984, 1994; Collinson, 1994; Strachan and Alsop, 2006; Debacker et al., 2001, 2009; Waldron and Gagnon, 2011). One slump structure can be found in the study area. Located at the southeastern part of the cross section, it is composed of brown shale, mixed gravel, and sandstone with 40–50 cm thick and 1 m wide. It dips to the northwest at an angle of 35°, and it can be inferred that the slump comes from the northwest.

3.3.2 Sliding-overlapping structure

One special structure, the sliding-overlapping structure, is well exposed in the study area. The sliding-overlapping structure is composed of a series of S- or Z-shaped and plate-type sandy mudstone, that overlap each other (Plate II3-6). The type and morphology of the sliding overlapping structure in the study area are quite complicated, and the slices are composed of laminar siltstone, sandy mudstone, mudstone, shale, or laminar limestone. The slices are 0.5–2 cm thick, 5–6 cm wide, and are plate-like or lenticular. The sliding overlapping structures in the study area are distributed stably along the zone in the whole section with a thickness of 30 cm. Based on the dipping direction data of the slices, the average dipping direction is around 301.2° NW with the dip angle of 54.71 (Fig. 3).

The sliding overlapping structure in the study area is quite special, yet it is rarely discussed in the literature. Some authors took it as the S- or Z-shaped structures or duplex structure (Morris, 1973; Shanmugem, 1988). Shanmugem (1988) proposed that it could have been formed in the underlying unconsolidated mudstone due to shear traction force when the slump body slid along the basal surface. Some authors suggested that it was

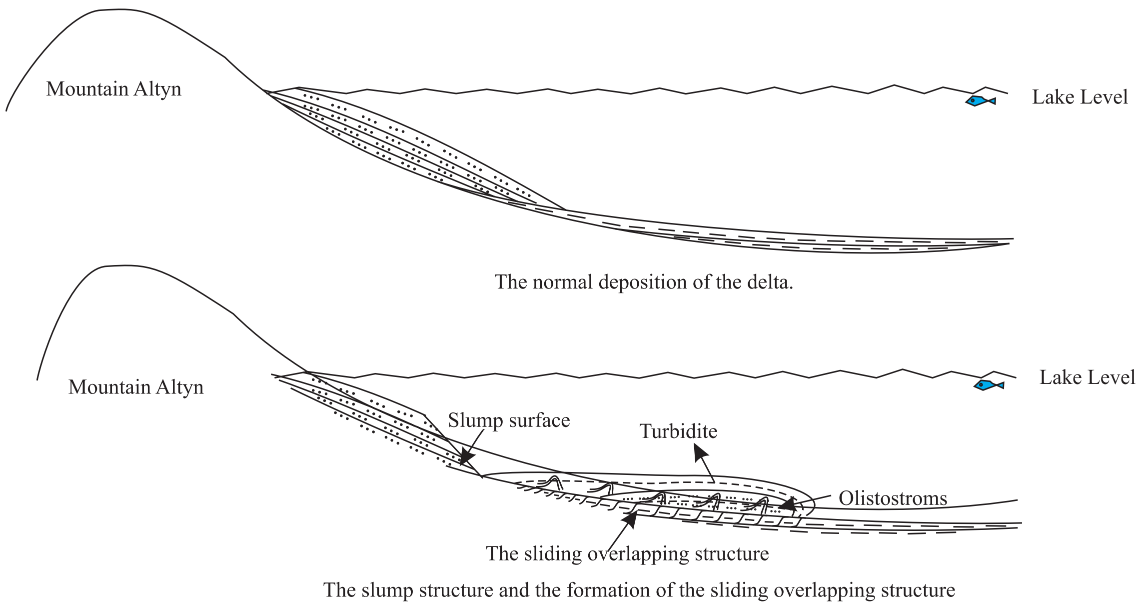

Fig. 4. The genesis mode of the sliding overlapping structure.

associated with the seismic-induced slump structure (Odonne et al., 2011; Alsop and Marco, 2011). Through detailed field description and analysis, a genetic mode of the sliding overlapping structure is proposed in which the unstable deposits of the delta frontier or flank may have collapsed due to a strong earthquake and slid along the unconsolidated mudstone in the bottom of a lake, and at the same time, the shear force could have caused the underlying mudstone to compress and deform to form the sliding overlapping structure (Figs. 4–5).

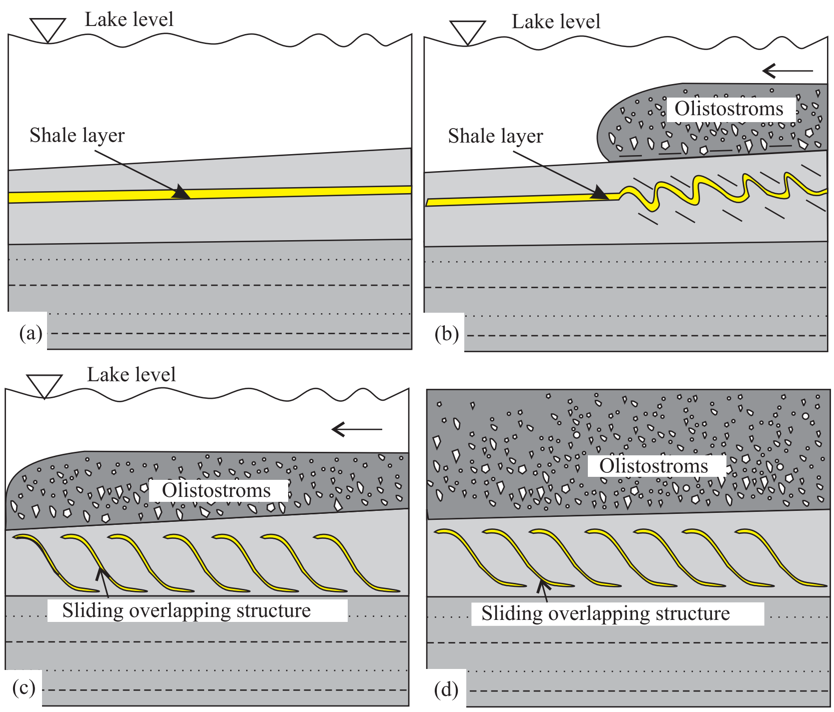

Fig. 5. Deformation mechanics of the sliding-overlapping structure.
a, Deposition of shales before the Olistostrome deposition; b, deposition of Olistostrome and the deformation of shales; c, after the Olistostrome deposition; d, after the burial of the sliding-overlapping structure.

4 The Significance of the Soft-Sediment Deformation Structure

The study of soft-sediment deformation structures can be used not only for palaeogeography such as the palaeocurrent, and palaeotopography (Mills,1983; Zhao and Liu, 1988; Van Loon, 2009), but also for the palaeoseismic activity (Qiao and Li, 2008，2009; Qiao and Guo, 2011; Du et al., 2007; Du, 2011). Since the study area is approximated 5 km from the Altyn fault and Altyn Mountains, the study of the soft-sediment deformation structures in the study area has great significance for the reconstruction of the movement of the Altyn fault and the uplift of the Altyn Mountains. Until now, there are still some debates on the activities of the Altyn fault and Altyn Mountains. Some authors have proposed that the Altyn fault had been active since the Proterozoic (Zhou et al., 1998, Zhou and Pan, 1999; Yu et al.,1998). Others suggested that the Altyn fault has been active since the late Jurassic (Wang, 1997; Guo et al., 1998; Guo et al., 1998; Xing et al., 1999; Yue et al., 2001; Ren et al., 2003). Intervals of soft-sediment deformation structures are well-exposed in the Jurassic deposits in the western Qaidamu basin. Based on their genesis, the 3 types can be classified as the seismic-induced structures, vertical loading structures, and horizontal shear structures. Through detailed field description and analysis, they are all seismic-induced structures. Thus it can be inferred from the convoluted bedding structure and sand veins that there are ancient earthquakes greater than magnitude 6 near the study area during the early-middle Jurassic (Rodriguez-Pascua, 2000; Qiao and Li, 2009, Qiao and Guo, 2013). It can be also inferred that there is distinct movement of the Altyn fault in the early-middle Jurassic era. Furthermore, based on the dip direction of the sliding-overlapping structure, it slides from northwest, where the Altyn Mountains are located.. We can postulate that the Altyn Mountains are the result of an uplift in early-middle Jurassic.

5 Discussions

The soft-sediment deformation structures in Honggouzi area are quite complicated. Three simple types: seismic induced structures, vertical loading structures, and horizontal shear structures are classified in this paper based on their genesis. But it is difficult to derive earthquake factors from the latter two types since the mechanism for the SSDS deformation are complex. Due to its relations to earthquake, soft-sediment deformation structures have been used to restore the tectonic movements. For example, Qiao et al. (2012) identified seismic-induced SSDS in the upper Triassic series of Long menshan region and restored the ancient tectonic movements into three stages. And, based on the locations of the identified liquefaction-induced soft-sediment deformation structures and their distances to the Wenchuan-Maoxian fault, the author estimated that the magnitude of the paleoseism occurred in the Norian Xiaotangzi formation was about Ms7.2. So the active movement of the Altyn Mountains and the Altyn fault in Jurassic can be postulated. But the estimation of paleoseismic magnitude in Altyn area requires more field study in the future.

6 Conclusions

Through the field description and analysis of the soft-sediment deformation structures in the Honggouzi Area of the western Qaidamu basin, the following conclusion can be drawn:

(1) Intervals of soft-sediment deformation structures are well-exposed in Jurassic deposits in the western Qaidamu basin. Based on their genesis, three types can be classified as the seismic induced structures, such as convoluted bedding structure and liquefied sand veins; vertical loading structures, such as the flame structure and load structure; and horizontal shear structure, such as slump and sliding-overlapping structure.

(2) Based on the seismic-induced convoluted bedding structure and liquefied sand vein, there are the palaeoseismic activities during the early and middle Jurassic. It can also be inferred that the Altyn strike-slip fault may have been active in the early-middle Jurassic.

(3) The sliding-overlapping structure has been found in the study area, which can be an indicator for the palaeoslope. Based on the field observation, there shall be an ancient Uplift in the northwest of the study area in the middle Jurassic. Since the Altyn Mountains are located in the northwest portion of the study area, it can be postulated that the Altyn Mountains were uplifted after the middle Jurassic.

Acknowledgments

Thanks are given to The National Natural Science Fund (No: 41172093) and the research fund (No: 20030425008; 20060425509) for the doctoral program of higher education from Ministry of Education for their financial support. Thanks are also given to Professor Zhong Jianhua for his precious suggestions and help during this research.

Manuscript received May 29, 2012
accepted Dec. 15, 2012
Edited by Fei Hongcai

Reference

Alsop, G.I., and Marco, S., 2011. Soft-sediment deformation within seismogenic slumps of the Dead Sea Basin. *Journal of Structural Geology*, 33: 433–457.

Collinson, J., 1994. Sedimentary deformational structures. In: Maltman, A.J. (ed.), The Geological Deformation of Sediments. Chapman and Hall, London, 95–125.

Debacker, T.N., Dumon, M., and Matthys, A., 2009. Interpreting fold and fault geometries from within the lateral to oblique parts of slumps: a case study from the Anglo-Brabant Deformation Belt (Belgium). *Journal of Structural Geology*, 31: 1525–1539.

Debacker, T.N., Sintubin, M., and Verniers, J., 2001. Large-scale slumping deduced from structural and sedimentary features in the Lower Palaeozoic Anglo-Brabant fold belt, Belgium. *Journal of the Geological Society of London*, 158: 341–352.

Du Yuansheng, Shi G., Gong Yiming and Xu Yajun, 2007. Permian soft sediment deformation structures related to earthquake in the Southern Sydney Basin, Eastern Australia. *Acta Geologica Sinica*, 81(4): 511-518(in Chinese with English abstract).

Du Yuansheng, 2011. Discussion about studies of earthquake event deposit in China. *Journal of Palaeogeography*, 13(6): 581–586(in Chinese with English abstract).

Duan Hongliang, Zhong Jianhua1, Ma Feng, Zhang Yuezhong, Li Yong and Wen Zhifeng, 2007a. Prototypes and evolution of the Mesozoic basin in Western Qaidam. *Acta Geologica Sinica*, 28 (4): 356–368(in Chinese with English abstract).

Duan Hongliang, Zhong Jianhua1, Ma Feng, Zhang Yuezhong, Li Yong and Wen Zhifeng. 2007b. Reconstruction of the Mesozoic prototype basin in the west Qaidam basin. *Acta Geologica Sinica*, 25(1): 65–74(in Chinese with English abstract).

Guo Shunmin and Xiang Hongfa, 1998. A study on spatial temporal distribution of the fault sinistral displacement in the Altun structure system since Oligocene-Miocene. *Seismology and Geology*, 20(1): 9–17(in Chinese with English abstract).

Guo Zhaojie, Zhang Zhicheng and Wang Jianjun, 1998. The Sm-Nd isochron age and tectonic significance of Ophiolite belt along the northern margin of the Altun Mountains. *Chinese Science Bulletin*, 43(18): 1981–1984(in Chinese with English abstract).

Jin Zhijun, Li Jingchang, Tang Liangjie, Yu Yixin, Jiang Bo, Zhang Mingli, You Fubao and Zhang Bingshan, 2006. Cenozoic wave processes and their relationships to Hydrocarbon in the Qaidam basin. *Acta Geologica Sinica*, 80 (3): 359–365(in Chinese with English abstract).

Leeder, M.R., 1987. Sediment deformation structures and the palaeotectonic analysis of sedimentary basins, with a case-study from the Carboniferous of northern England. In: Jones, M.E., and Preston, R.M.F. (eds.), *Deformation of Sediments and Sedimentary Rocks*. Geological Society, London, Special Publication, 29: 137–146.

Liu Baojun, 1992. *Sedimentary Petrology*. Beijing: Geological Publishing House. 91–93 (in Chinese).

Luo Qun, 2008. Discussion of basin genetic types of the Qaidam basin. *Petroleum Geology and Experiment*, 30(2): 115–120 (in Chinese with English abstract).

Maltman, A.J., (ed.), 1994. *The geological deformation of sediments*. Chapman and Hall, London, 362–363.

Maltman, A.J., 1984. On the term 'soft-sediment deformation. *Journal of Structural Geology*, 6: 589–592.

Mills, P.C., 1983. Genesis and diagnostic value of soft-sediment deformation structures-a review. *Sedimentary Geology*, 35: 83–104.

Montenat, C., Barrier, P., Ott d'Estevou, P., and Hlbsch, C., 2007. Seismites: An attempt at critical analysis and classification. *Sedimentary Geology*, 196: 5–30.

Moretti, M., Alfaro, P., Caselles, O., and Canas, J.A., 1999. Modelling seismites with a digital shaking table. *Tectonophysics*, 304(4): 369–383.

Moretti, M., Pieri, P., and Tropeano, M., 2002. Late Pleistocene soft-sediment deformation structures interpreted as seismites in paralic deposits in the city of Bari (Apulian forland, Southern Italy). In: Ettensohn, F.R., Rast, N., and Brett, C.E.(eds.), *Ancient Seismites: Boulder, Colorado*. Geoloical Society of America Special Paper, 359: 75–85.

Moretti, M., and Ronchi, A., 2011. Liquefaction features interpreted as seismites in the Pleistocene fluvio-lacustrine deposits of the Neuquén Basin (Northern Patagonia). *Sedimentary Geology*, 235: 200–209.

Moretti, M., and Sabato, L., 2007. Recognition of trigging mechanisms for soft-sediment deformation in the Pleistocene lacustrine deposits of the Sant Arcangelo Basin (Southern Italy): Seismic shock vs. overloading. *Sedimentary Geology*, 196: 31–45.

Moretti, M., 2000. Soft-sediment deformation structures interpreted as seismites in middle-late Pleistocene aeolian deposits (Apulian foreland, southern Italy). *Sedimentary Geology*, 135: 167–179.

Morris, R.C., 1973. Flysch facies of the Quachita trough-with examples from the splillway at Degray Dam, Arkansas. In: Stone, C.G., Haley, B.R., and Viele, G.W. (eds.), *A guidebook to the geology of the Quachita Mountains: Little Rock*. Arkansas Geological Commission, 158–168.

Obermeier, S.F., Olson, S.M., and Green, R.A., 2005. Field occurrences of liquefaction-induced features: a primer for engineering geologic analysis of paleoseismic shaking. *Engineering Geology*, 76: 209–234.

Odonne, F., Callot, P., Debroas, E.J., Sempere, T., Hoareau, G., and Maillard, A., 2011. Soft-sediment deformation from submarine sliding: Favourable conditions and triggering mechanisms in examples from the Eocene Sobrarbe delta (Ainsa, Spanish Pyrenees) and the mid-Cretaceous Ayabacas Formation (Andes of Peru). *Sedimentary Geology*, 235: 234–248.

Owen, G., and Moretti, M., 2011. Identifying triggers for liquefaction-induced soft-sediment deformation in sands. *Sedimentary Geology*, 235: 141–147.

Owen, G., 1992. A shaking table for experiments on soft-sediment deformation. *Journal of sedimentary Petrology*, 62: 733–734.

Owen, G., 1996. Experimental soft-sediment deformation: structures formed by the liquefaction of unconsolidated sands and some ancient examples. *Sedimentology*, 43: 279–293.

Qiao Xiufu and Li Haibin, 2008. Pillow, ball-and-pillow structures: paleo-seismic records within strata. *Geological Review*, 54(6): 721–730 (in Chinese with English abstract).

Qiao Xiufu and Li Haibin, 2009. Effect of earthquake and ancient earthquake on sediments. *Journal of Palaeogeography*, 11(6): 593–610 (in Chinese with English abstract).

Qiao Xiufu and Guo Xianpu, 2011. On the Lower Jurassic Soft-sediment Deformation of Southwestern Tianshan Mountains, Xinjiang, China. *Geological Review*, 57(6): 761–769 (in Chinese with English abstract).

Qiao Xiufu, Guo Xianpu, Li Haibing, Gou Zonghai, Su Dechen, Tang Zhemin, Zhange Wei and Yang Guang, 2012. Soft-sediment Deformations in the Late Trassic and the Indosinian Tectonic Movements in Longmenshan. *Acta Geologica Sinica*, 86(1): 133–156 (in Chinese with English abstract).

Qiao Xiufu and Guo Xianpu, 2013. Early Jurassic soft-sediment deformation interpreted as seismites in the Wuqia pull-apart basin and the strike-slip Talas–Ferghana fault, Xinjiang, China. *Acta Geologica Sinica* (English edition), 87(3): 730–737.

Ren Shoumai, Ge Xiaohong and Liu Yongjiang, 2003. Progress in Altyn fault belts research. *Advance in Earth Sciences*, 18(3): 386–391 (in Chinese with English abstract).

Rodríguez-Pascua, M.A., Calvo, J.P., De Vicente, G., and Gómez-Gras, D., 2000. Soft-sediment deformation structures interpreted as seismites in lacustrine sediments of the Prebetic Zone, SE Spain, and their potential use as indicators of earthquake magnitudes during the Late Miocene. *Sedimentary Geology*, 135: 117–135.

Shanmugam, G., Moiola, R.J., and Sales, J.K., 1988. Duplex-like structures in submarine fan channels, Ouachita Mountains, Arkansas. *Geology*, 16: 229–232.

Strachan, L.J., and Alsop, G., 2006. Slump folds as estimators of palaeoslope: a case study from the Fisherstreet Slump of County Clare, Ireland. *Basin Research*, 18: 451–470.

Van Loon, A.J., 2009. Soft-sediment deformation structures in siliciclastic sediments: an overview. *Geology*, 15: 3–55.

Waldron, J.W.F., and Gagnon, J.F., 2011. Recognizing soft-sediment structures in deformed rocks of orogens. *Journal of Structural Geology*, 33: 271–279.

Wang Erchie, 1997. Displacement and timing along the northern strand of the Altyn Tagh fault zone, northern Tibet. *Earth and Planetary Science Letters*, 150: 55–64.

Wu Hanning, Liu Chiyang, Zhang Xiaohui and Ren Zhanli, 1997. Using the palaeogeomagnitude data to study the tectonic evolution of the Qaidamu block. *Science in China*(Ser.D,), 27 (1): 9–14 (in Chinese with English abstract).

Xia Wenchen, Zhang Ning, Yuan Xiaoping, Meng Ke, Zhang Bingshan and Peng Xiaoqun, 1998. Jurassic tectonic sequences of Qaidam and foreland basin evolution. *Oil and Gas Geology*, 19(3): 173–180 (in Chinese with English abstract).

Xing Chengqi, Zhang jie and Lu Dehui, 1998. Discussion on change and its mechanism of movement forms of the active fault zone along north margin of Mt. Altun. *Northwest Seismological Journal*, 20(2): 52–57 (in Chinese with English abstract).

Yan Jihua, Cui Yongbei and Chen Shiyue, 2009. Identification of Common Facies Indicators of Seismites in Simulated Experiments. *Acta Sedimentologica Sinica*, 27(6): 1131–1137 (in Chinese with English abstract).

Yu Haifeng, Lu Songnian, Zhao Fengqing, Li Huaikun and Zheng Jiankang, 1998. Litho-structural evidences of ancient altyn tagh and its significance. *Progress in Precambrian Research*, 21(4): 10–15 (in Chinese with English abstract).

Yue Yongjun, Bradley D. Ritts and Stephan A. Graham, 2001. Initiation and long-term slip history of the Altyn Tagh fault. *International Geology Review*, 43: 1–7.

Zhai Guangming, Xu Fengyin and Li Jianqing, 1997. A reconfirmation of Qaidam basin for a great breakthrough in oil and natural gas exploration. *Acta Petrolei Sinica*, 18(2): 1–7 (in Chinese with English abstract).

Zhang Zhitao, 1985. On the geological characters of the Altun fault. *Bulletin Xi'an Institute Geology Mineral Research*, Chinese Academy of Geological Sciences, (9): 20–32 (in Chinese with English abstract).

Zhao Chenglin and Zhu Xiaomin, 2001. *Sedimentary Petrology*. Beijing: Petroleum industry press, 87–88(in Chinese).

Zhao Chenglin, Liu Menghui. 1988. Contemporaneous deformed structures in Lacustrine sedimentary rocks and their geological significance. Acta Petrologica Sinica, 1988(4): 14–24 (in Chinese with English abstract).

Zhong Jianhua, Hou Qijun and Zhong Yanqiu, 2001. Genesis of the (Sluicing) Convolute Bedding in the Yellow River Delta. *Geological Review*, 45(3): 306–313 (in Chinese with English abstract).

Zhou Yong and Pan Yusheng, 1998. Determination of the dextral slip of Mangya-Subei segment of Altun fault. *Scientia Geologica Sinica*, 33(1): 9–15 (in Chinese with English abstract).

Zhou Yong and Pan Yusheng, 1999. The initial shear sense of the Altun fault and its timing. *Geological Review*, 45(1): 1–9 (in Chinese with English abstract).

Plate I

1, The exposed position of the Honggouzi soft sediments deformation structures, which can be seen in the black frame.
2, The Olistostroms layer above the sliding-overlapping structure, which is composed of pebbles, sands and mud with the total thickness of 80 cm(the black dash on the bottom left of the photo is a scale of 2 cm for the following photo).
3, The turbidite layer above the Olistostroms, which is composed of three 10cm thick turbidite layers.
4–5, The convoluted bedding structure in the study area with 7cm high and 12cmwide.Two types of convoluted bedding can be identified in the study area, one is composed of fine sand and the other is composed of find sand and mudstone.
6, The liquefied sand vein structure, which is cut and moved towards the left have two parts with the max width of 4cm and 10cm high.
7, The flame structure and load structures in the turbidite.

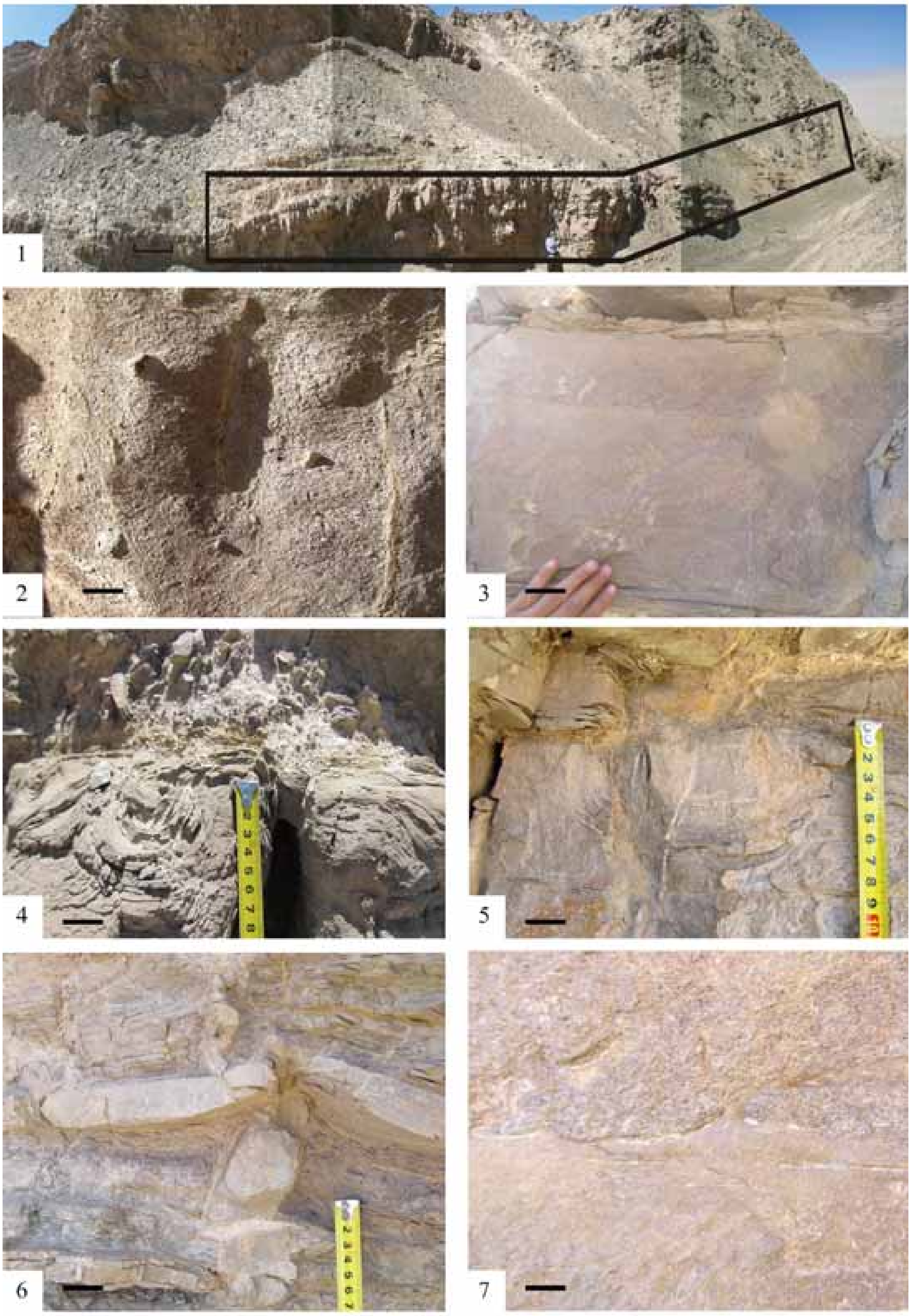

Plate II

1, The pebble load structure.

2, The slump structure in the study area have 4–50 cm thick and 1 m wide, which is made of red shale and sand.

3–6, The different kind of the overlapping structures in the Honggouzi area.