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One feature of the activated southern Ordos block: the Ziwuling small earthquake cluster

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Abstract: Small earthquakes ($Ms > 2.0$) have been recorded from 1970 to the present day and reveal a significant difference in seismicity between the stable Ordos block and its active surrounding area. The southern Ordos block is a conspicuous small earthquake belt clustered and isolated along the NNW direction and extends to the inner stable Ordos block; no active fault can match this small earthquake cluster. In this paper, we analyze the dynamic mechanism of this small earthquake cluster based on the GPS velocity field (from 1999 to 2007), which are mainly from Crustal Movement Observation Network of China (CMONOC) with respect to the north and south China blocks. The principal direction of strain rate field, the expansion ratefield, the maximum shear strain rate, and the rotation rate were constrained using the GPS velocity field. The results show that the velocity field, which is bounded by the small earthquake cluster from Tongchuan to Weinan, differs from the strain rate field, and the crustal deformation is left-lateral shear. This left-lateral shear belt not only spatially coincides with the Neo-tectonic belt in the Weihe Basin but also with the NNW small earthquake cluster (the Ziwuling small earthquake cluster). Based on these studies, we speculate that the NNW small earthquake cluster is caused by left-lateral shear slip, which is prone to strain accumulation. When the strain releases along the weak zone of structure, small earthquakes diffuse within its upper crust. The maximum principal compression stress direction changed from NE-SW to NEE-SWW, and the former reverse faults in the southwestern margin of the Ordos block became a left-lateral strike slip due to readjustment of the tectonic stress field after the middle Pleistocene. The NNW Neo-tectonic belt in the Weihe Basin, the different movement character of the inner Weihe Basin (which was demonstrated through GPS measurements) and the small earthquake cluster belt reflect the activated southern margin of the Ordos block, which was generated through readjustment of the tectonic stress field after the middle Pleistocene.

Key words: Weihe Basin; small earthquake cluster; tectonic background; strain rate; GPS measurement

1 Introduction

In contrast to the stable Ordos block, its surrounding areas have undergone intense active rifting and frequent earthquakes. As one of the most important strong earthquake hazard areas in China, historic records show that many devastating earthquakes with $M > 8$ occurred in the circum-Ordos block[1-4].

A significant difference in seismicity between the stable Ordos block and its active surrounding area was revealed by small earthquake records ($Ms > 2.0$), which have been recorded from 1970 to the present day (Fig. 1). However, in the southern Ordos block, a conspicuous small earthquake belt cluster is isolated along the NNW trend (Fig. 2) and extends to the inner stable Ordos block. It coincides with the Ziwuling;

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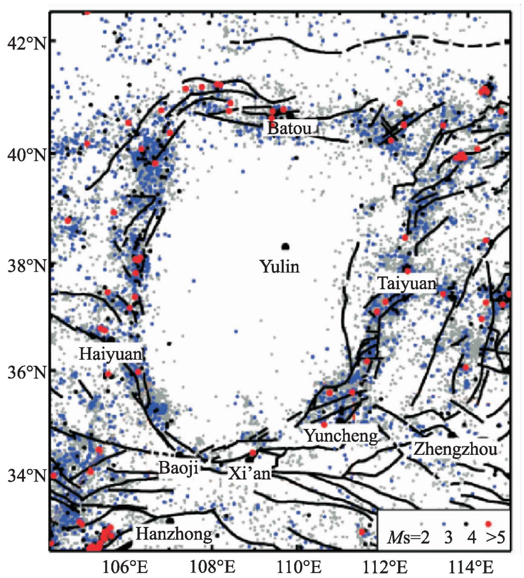


Figure 1 The epicenters of the cirum-ordos block and its vicinity (from Jan., 1970 to Nov., 2011)

thus, it is commonly known as the Ziwuling small earthquake cluster. Notably, no active fault can match the Ziwuling small earthquake cluster. Furthermore, the possibility of a mineral earthquake can be eliminated due to the small earthquakes clustered deeper than 5 km beneath the crustal surface (Fig. 3). A previous study focused on the relationship between the Neo-tectonic characteristic and site of the Ziwuling small earthquake cluster[5]. However, the mechanism underlying the Ziwuling small earthquake cluster was unknown until now.

A dynamic crustal velocity field and its size can be resolved at high resolutions through GPS measurements, which play an important role in portraying the crust horizontal movement[6-8]. In this paper, the GPS velocity field over a long period of time (from 1999 to 2007) was used to probe the Ziwuling small earthquake

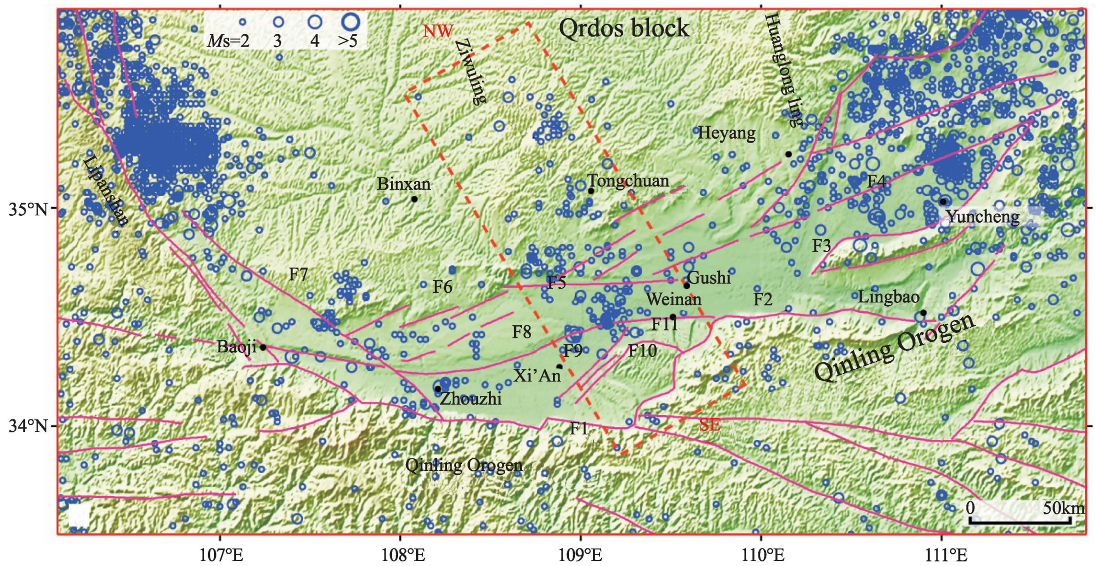


Figure 2 Geotectonic map and earthquake distribution schematic for the southern Ordos block from Jan., 1970 to Nov., 2011 (F1-The northern margin fault zone of Qingling; F2-the frontal fault zone of the Huashan mountain; F3-the frontal fault zone of the Zhongtiaoshan mountain; F4-Shuangquan-Linyi fault; F5-Guanshan-Kouzhen fault; F6-Qianxian-Fuping fault; F7-Qishan-Mazhao fault; F8-Weihe fault; F9-Lintong-Chang'an fault; F10-the frontal fault zone of the Lishan; F11-the frontal fault zone of the Weinan tableland)

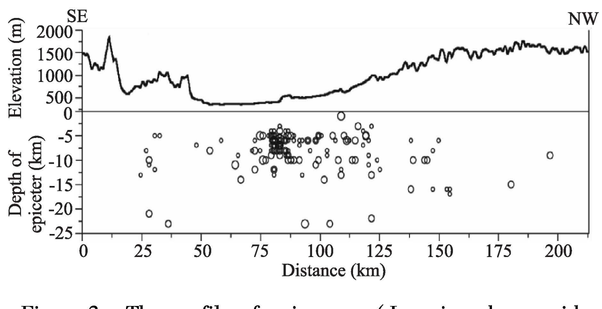


Figure 3 The profile of epicenters (Location shown with red dash rectangles in Fig.2)

cluster mechanism by integrating its Neo-tectonic characteristics, previous studies in this region, and its geodynamic mechanism[5, 9].

2 The Weihe Basin GPS horizontal velocity field

2.1 GPS data and processing

The GPS data used in this study were mainly based on Crustal Movement Observation Network of China (CMONOC) from 1999 to 2007, including four campaigns that included all sites in 1999, 2002, 2004 and 2007, respectively. The research area was not influenced by a strong earthquake during this period; thus, the GPS velocity field for this time interval is more effective for studying long-term crustal deformation. The GPS data were processed using GAMIT/GLOBK software[13, 14]. All of the observational data for a given day were combined, and GAMIT software was used to determine the loosely constrained daily station coordinates, polar motion and satellite orbits. Next, the daily solutions for the local stations were combined with loosely constrained global solutions from the Scripps Orbital and Position Analysis Center (SOPAC, http://sopac.ucsd.edu/) using the QOCA software. The stable global IGS sites around China were used as reference stations for ITRF2005 to obtain tight constraints on the positions. Finally, a time series for the positions with respect to ITRF2005 was obtained for each station[10]. 33 GPS stations located around the Weihe Basin and its vicinity were used here (Fig. 4).

1.2 A characteristic of the GPS horizontal velocity fields

The north and south China blocks (NC-SC) move as a whole with respect to the Eurasia plate; thus, we calculated the GPS velocity field by removing the entire NC-SC motion. As a result, the motions among the inner micro-plates are much clearer[11,12].

The Weihe rift is located in the southern margin of the Ordos block and consists of the Weihe, Yuncheng, and Lingbao Basins, and its overall strike changes from EW to NE and west to east. The GPS velocity field (Fig. 4) reveals that the Weihe Basin generally moves eastward with respect to the stable Ordos block. Furthermore, the zone from Tongchuan to Weinan can be subdivided into two parts based on the GPS velocity field. Crossing this zone, the overall direction of the GPS velocity field changes from EW to NE. Northward, this zone coincides with the cluster of small earthquakes (based on instrumental records) referred to as the Ziwuling small earthquake cluster.

To further determine the discrepancy of the crust horizontal movement on both sides of the Ziwuling small earthquake cluster, the GPS velocity field was decomposed into components that are perpendicular and parallel to the strike of the Ziwuling small earthquake cluster (Fig. 5). These two components clearly differ, and their different maximum values are 1.5 mm/a and 1.8 mm/a, respectively. This area includes a left-lateral slip in the crustal deformation.

2.3 GPS horizontal strain rate field

We adopt the method in Shen et al[13,14] to calculate the strain rate field for the Weihe Basin (Fig. 6). East of the Ziwuling small earthquake cluster, the overall principal direction of the strain rate trends in a NE extension; furthermore, the rotation rates are dominated

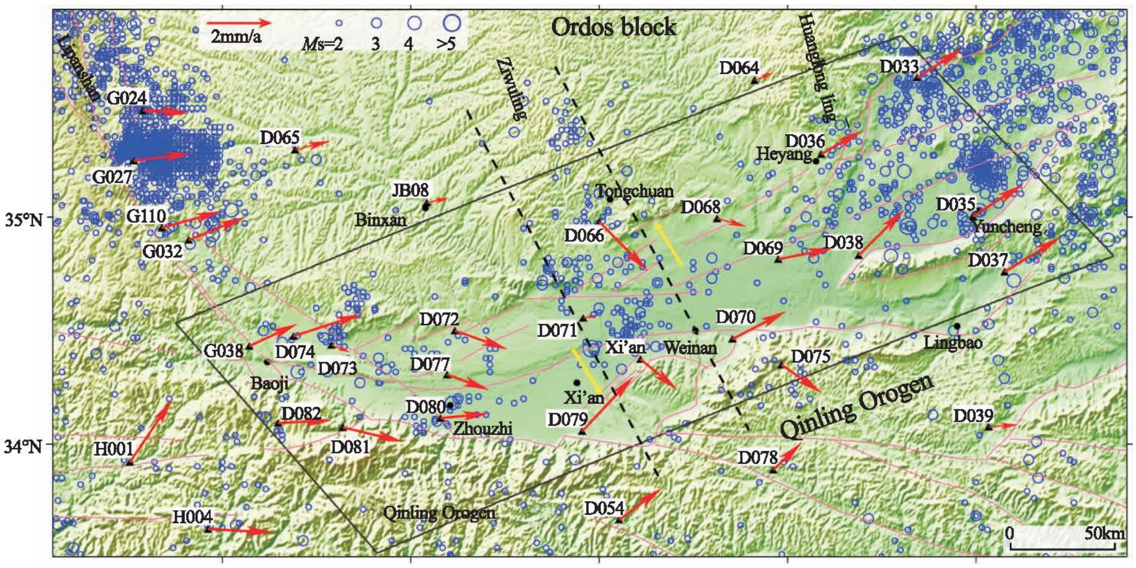


Figure 4 GPS velocity fields in the Weihe rift (with respect to the SC-NC block)

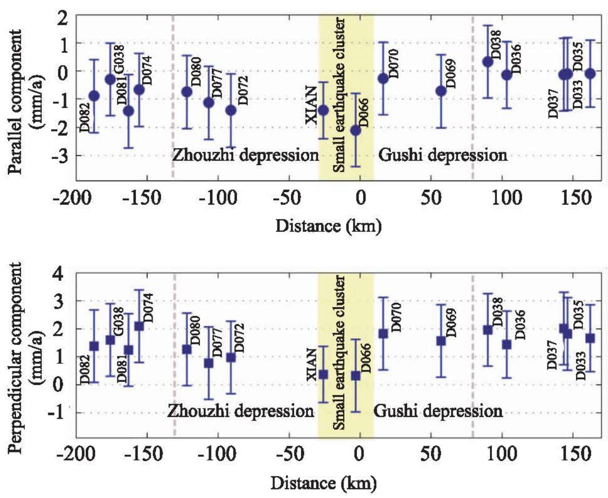
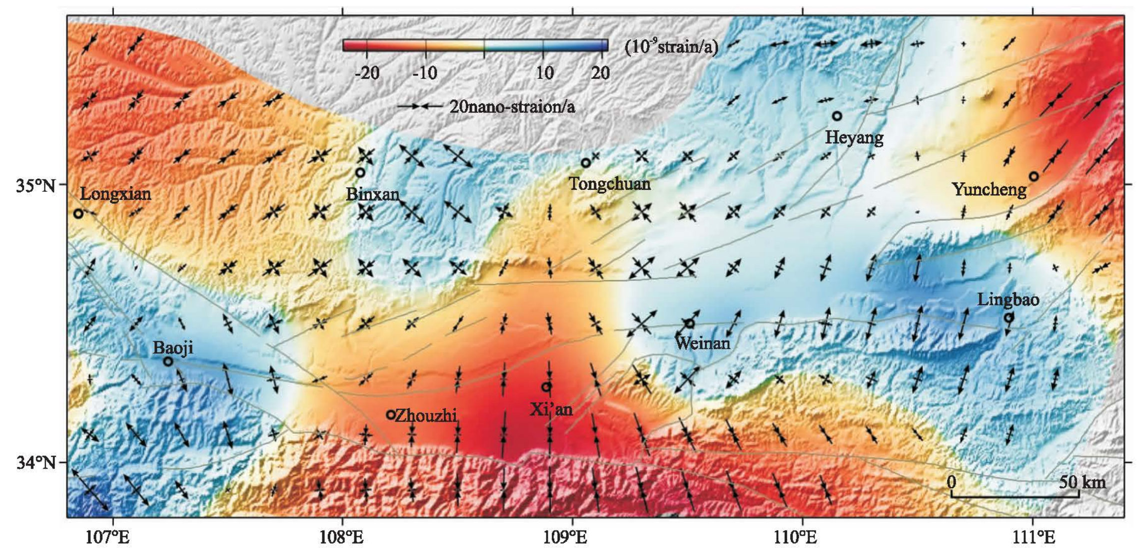
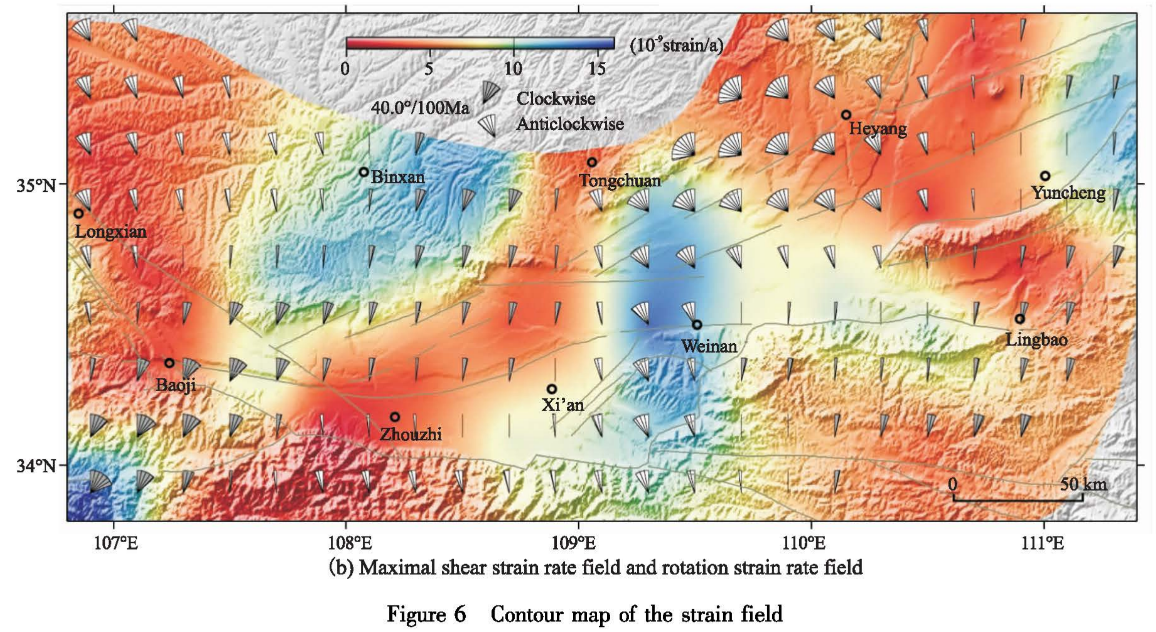


Figure 5 GPS velocity profile across the Ziwuling small earthquake cluster

by anti-clockwise motions, and the expansion rate is up to 15×10^{-9}/a in the Weinan vicinity. On the other side of the Ziwuling small earthquake cluster, the overall principal direction of strain rate trends toward a SN compression, and the rotational rates are dominated by clockwise motions that decrease gradually from Baoji to Xi'an. Bounded by the Weihe fault, the compression component dramatically increases in the southern Weihe Basin, and the expansion rate is up to -20×10^{-9}/a in southern Xi'an. The high gradient zone of the maximum shear strain rate is located along the northern margin of the Weihe Basin and Ziwuling small earthquake cluster. The peak value of the maximum shear strain rate lies in the vicinity of Weinan, and the gradient zone is located along the Weihe fault.



(a) Principal strain rate field and surface dilatation strain rate field



(b) Maximal shear strain rate field and rotation strain rate field

Figure 6 Contour map of the strain field

3 Geology and geomorphology characteristic

3.1 Regional tectonic background

The Ziwuling small earthquake cluster is located in the Weibei uplift and the southern margin of the North Shanxi slope, and it extends via a SE trend to the Weihe Basin (Fig. 7). As a positive tectonic unit, the Weibei uplift should have begun between the end of the early and late cretaceous period (approximately 114–83 Ma)[15-17]. Tectonic analyses (Fig. 7) show that the NE and NW trend thrust fault system formed during the middle and end of the Yanshan movement, which established the overall structural framework for this region. The southern part of the thrust fault system reformed during the Himalayan period, and a set of new normal faults trending NW in the direction formed in the eastern part of the Weibei uplift.

There is a distinct discrepancy among the tectonic features on both sides of the Chunhua-Binxian (Fig. 7). In contrast to the west side, the structural deformation is much stronger and more distinct (more thrust and normal faults as well as folds), in addition to the large discrepancy in the optimal direction of the fault. Furthermore, spatially, this structurally changing zone corresponds well with the Ziwuling small earthquake cluster.

3.2 Characteristics of the Cenozoic tectonic and mechanism

The previous studies reveal that the main characteristic of the Cenozoic tectonic in the southern part of the Ordos block includes deposit centers of the Quaternary system that are located among the NW transverse uplifts[5].

From west to east, the Liupanshan, Ziwuling and Huanglongling uplifts are distributed along the southern part of the Ordos block. The Ziwuling uplift trend continuously extends to the interior of the Weihe Basin (Fig.8). As the most primary Quaternary system deposit center of the Weihe Basin, the Zhouzhi and Gushi depressions are located on both sides of the basin[3] (Fig. 8).

The tectonic evolution and regional geodynamics changed significantly in the later Miocene, and the effects and reformation driven by the Tibetan Plateau became much stronger[15, 18, 19]. The multi-stage and accelerated Liupanshan uplift (8.1 Ma, 5.2 Ma and 3.8 Ma) in addition to the Ziwuling and Huanglongling uplifts are the tectonic responses to the rapid uplift and NE compression of the Tibetan Plateau[5, 20].

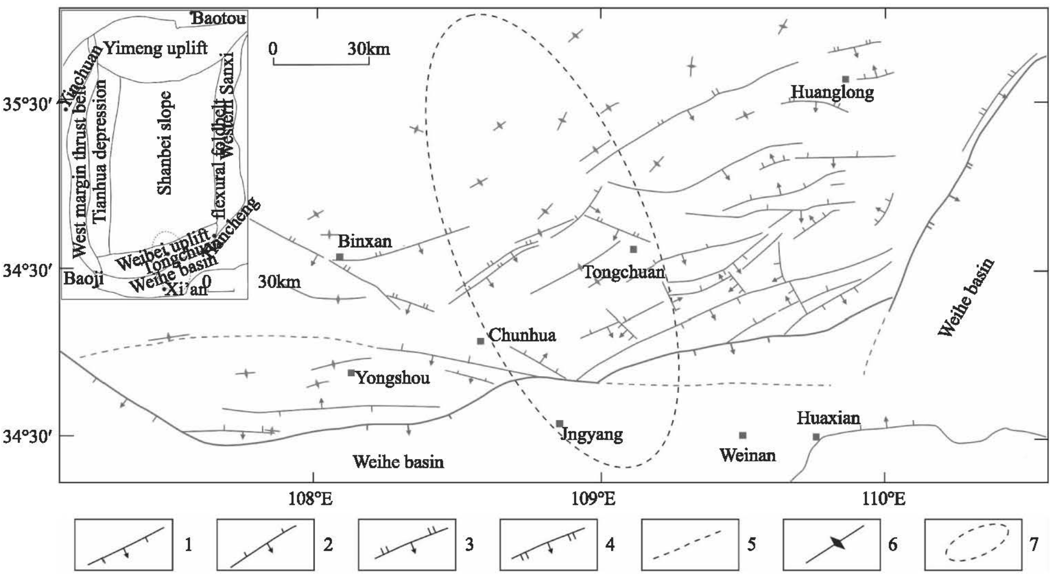


Figure 7 Main fracture and fold distribution of the Weibei uplift (1-normal fault; 2-reverse fault; 3-normal fault interpreted by seismic material; 4-reverse fault interpreted by seismic material; 5-conjectural fault; 6-anticline; and 7-the cluster of small earthquake)

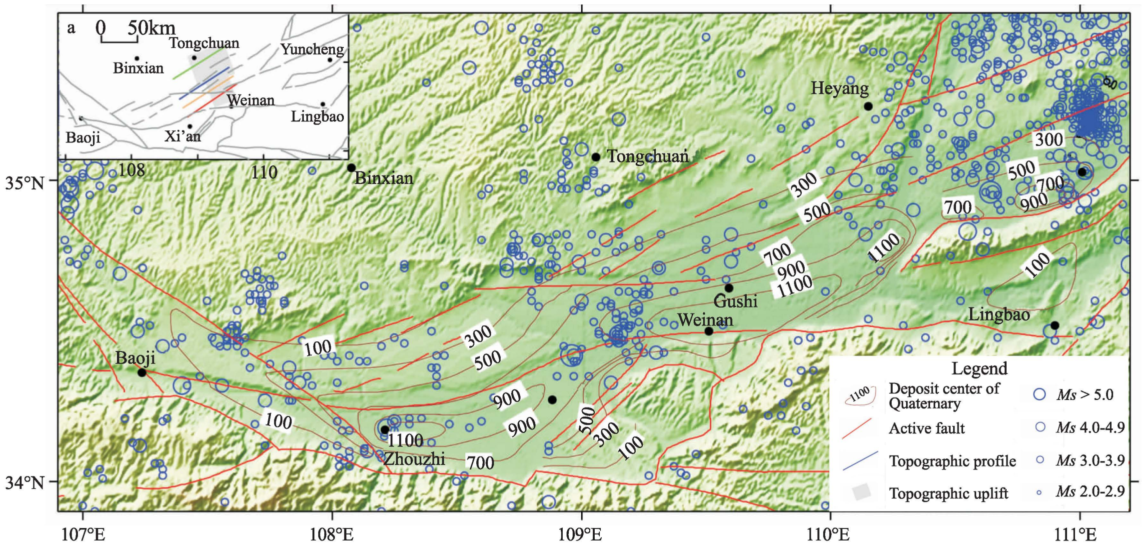


Figure 8 Geomorphologic and isopachous map of the Quaternary system in the Weihe Basin

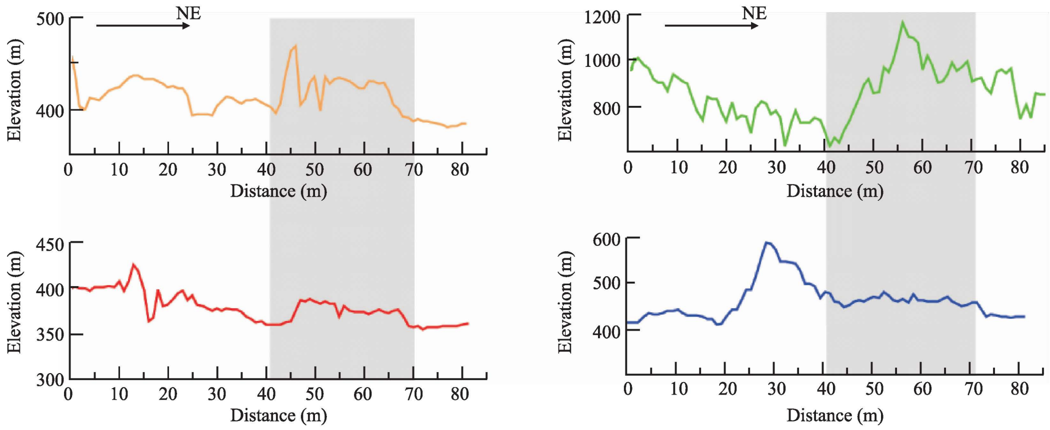


Figure 9 Topography profiles (the colored lines represent the profile locations according to Fig. 8(a)

The NE trend compression of the Tibetan Plateau and eastward extrusion along the southern margin of the Ordos block were revealed through GPS observations (Fig. 4). Furthermore, the crust for both sides, which is bounded by the NW transverse uplift in the Weihe Basin, includes left-lateral strike-slip characteristics that formed the echelon-like Quaternary system deposit center and NW transverse uplift in the Weihe Basin.

4 Discussion and conclusion

The different characteristics of recent horizontal crust movement on both sides of the Ziwuling small earthquake cluster in the Weihe Basin were determined using a GPS velocity field (from 1999 to 2007). Bounded by the Ziwuling small earthquake cluster, the overall direction of the GPS velocity fields changed from EW to NE in the Weihe Basin. The crust movement of both sides is characterized by left-lateral shear slip motion (Fig. 4).

Regional structural studies show that the Ziwuling small earthquake cluster is located in a transformational zone where the NW and NE structural frames converge[16]. Both the structural styles and extent of the tectonic reform differ on both sides of this zone. The Ziwuling and NW trend uplifts in the Weihe Basin are controlled by NE trend compression and left-lateral shear slip, respectively. As a former weak crustal zone, it would be more sensitive to relative crustal deformation[5].

The Ziwuling small earthquake cluster mechanism is related to the different crust movements in the Weihe Basin and the former structural characteristics. The left-lateral shear slip along the NNW trend transverse uplift in the Weihe Basin can accumulate strain energy. Furthermore, due to the weakness of the Ziwuling uplift and NNW trend transverse uplift in the Weihe Basin, the accumulated strain energy controlled by the left-lateral shear slip in the crust would lead to the cluster of small earthquakes diffused along this zone.

The resistance of the Ordos block to the NE continuous compression from the Tibetan Plateau caused the overall EW direction movement in the Weihe Basin[12, 23]. After the middle Pleistocene, the tectonic stress field readjusted, the maximum principal compression stress direction changed from NE-SW to NEE-SWW, and the former reverse faults in southwestern margin of the Ordos block became left strike-slip faults[22]. The NNW neotectonic belt in the Weihe Basin, the different movement characteristics of the inner Weihe Basin revealed through GPS measurements and the small earthquake cluster belt reflect the activated southern margin of the Ordos block due to readjustment of the tectonic stress field after the middle Pleistocene.

References

[1] Liu Mingjun, Fan Jichang, Han Yanjie, et al. Relationship between the movements of Ordos and Tarim blocks and strong earthquakes in China continent.2011.31(1): 128-134.(in Chinese)

[2] Zhang Peizhen, Deng Qidong, Zhang Guoming, et al. Active tectonic blocks and strong earthquake activities in the continent of China. Science in China (Ser. D), 2003, 46(suppl.):13-24. (in Chinese)

[3] The Research Group on Active Fault System around Ordos Massif, State Seismological Bureau. Active fault system around Ordos massif.Beijing: Seismological Press,1988. (in Chinese)

[4] Deng Qidong, Chen Shaoping, Min Wei,et al. Discussion on Cenozoic tectonics and dynamics of Ordos block. Journal of Geomechanics, 1999, 5(3):13-20. (in Chinese)

[5] Feng Xijie and Wang Ping. Three dimensional cross structure and seismicity of Weihe Basin. Northwestern Seismological Journal, 2001,23(2):160-163. (in Chinese)

[6] Zhang Peizhen, Gan Weijun, Shen Zhengkang, et al. A coupling model of rigid-block movement and continuous deformation. Patterns of the present-day deformation of China's continent and its vicinity. Acta Geologica Sinica. 2005,79(6):748-756. (in Chinese)

[7] Wang Min, Shen Zhengkang, Gan Weijun, et al. GPS monitoring of temporal deformation of the Xianshuihe fault. Science in China(Ser D),2008,51(9):1259-1266. (in Chinese)

[8] Cui Duxin, Wang Qingliang and Wang Wenping,et al. Determination of movement boundary belt of Gansu-Qinghai block. Journal of Geodesy and Geodynamics, 2007,27(1):24-30. (in Chinese)

[9] Dai Wangqiang, Ren Jun, Zhao Xiaomao, et al. Characteristics of horizontal crustal movement in Weihe Basin and adjacent zones by GPS observation. Acta Seismologica Sinica, 2004,26(3): 256-260. (in Chinese)

[10] Wang Min. Analysis of GPS data with high precision study on present-day crustal deformation in China. PhDThesis. Institute of Geology, China Earthquake Administration, Beijing,2009. (in Chinese)

[11] Cui Duxin, Wang Qingliang, Hu Yaxuan, et al. Lithosphere deformation and deformation mechanism in northeastern margin of Qinghai-Tibet Plateau. Chinese Journal of Geophysics, 2009, 52 (6):1490-1499. (in Chinese)

[12] Hu Yaxuan, Cui Duxin and Ji Lingyun. Seismic anisotropy of upper mantle in Ordos block and adjacent regions. Chinese Journal of Geophysics, 2011, 54(6):1549-1558. (in Chinese)

[13] Shen Zhengkang and Jackson D D. Optimal estimation of geodetic strain rates from GPS data. EOS Transactions AGU, 2000,81 (19):406.

[14] Shen Zhengkang,Jackson DD and Ge B X.Crustal deformation across and beyond the Los Angeles Basin from geodetic measurements. J Geophys Res., 1996,101:27957-27980.

[15] Liu Chiyang, Zhao Hongge, Gui Xiaojun, et al. Space-time coordinate of the evolution and reformation and mineralization response in Ordos Basin.Acta Geologica Sinica, 2006,80(5): 617-638. (in Chinese)

[16] Wang Jianqiang, Liu Chiyang, Yan Jianping, et al. Development time and evolution characteristics of Weibei uplift in the south of Ordos basin. Journal of Lanzhou University(Natural Sciences), 2010,46(4):22-29. (in Chinese)

[17] Xu Liming,Zhou Lifa,Zhang Yikai,et al. Characteristics and tectonic setting of tectono-stress field of Ordos basin. Geotectonica et Metallogenia, 2006,30(4):455-462. (in Chinese)

[18] Deng Qidong and You Huichuan. The structural activity and formation mechanism of the down-faulted basins around the Ordos block.Research on Recent Crustal Movement (1). Continental Rift and Deep Internal Processes. Beijing: Seismological Press.?, 58-78(in Chinese)

[19] Zhang Yueqiao, Liao Changzhen, Shi Wei, et al. Neotectoic evolution of the Peripheral zones of the Ordos Basin and geodynamic setting.Geological Journal of China Universities, 2006,12(3): 285-297. (in Chinese)

[20] Song Yougui, Fang Xiaomin, Li Jijun, et al. Discussion of the uplifting course of Liupanshan in late Cenozoic. Science of China,? 31(supp.): 142-148. (in Chinese)

[21] Zhang Peizhen, Zhen Dewen, Yin Gongming, et al. Discussion on Late Cenozoic and rise of northeastern margin of the Tibetan Plateau. Quaternary Sciences, 2006,26,(1):5-13. (in Chinese)

[22] Xie Furen, Shu Saibin, Dou Suqin, et al. Quaternary tectonic stress field in the region of Haiyuan-Liupanshan fault zone to Yinchuan fault-depression. Seismology and Geology, 2000,22(2): 139-146. (in Chinese)

[23] Chen Xiaobin, Zang Shaoxian and Wei Rongqiang. Is the stable Ordos block migrating as an entire block? Chinese Journal of Geophysics, 2011, 54(7):1750-1757.(in Chinese)