frontiers | Frontiers in Earth Science

TYPE Editorial
PUBLISHED 30 November 2022
DOI 10.3389/feart.2022.1082316

OPEN ACCESS

EDITED AND REVIEWED BY
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SPECIALTY SECTION
This article was submitted to Structural Geology and Tectonics,
a section of the journal
Frontiers in Earth Science

RECEIVED 28 October 2022
ACCEPTED 01 November 2022
PUBLISHED 30 November 2022

CITATION
Li C, Zheng W, Yuan D and Zhang Z (2022), Editorial: Active faults and earthquake due to continental deformation.
Front. Earth Sci. 10:1082316.
doi: 10.3389/feart.2022.1082316

Editorial: Active faults and earthquake due to continental deformation

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KEYWORDS

continent dynamics, late Cenozoic deformation, active block boundary, active faults, earthquake hazard

Editorial on the Research Topic
Active faults and earthquake due to continental deformation

Introduction

The kinematics and dynamics of continental deformation are fundamentally different from those of plate boundary deformation. Continental tectonics is complex and as a result we have been unsuccessful in fully understanding them. Deformation of continental lithosphere is not restricted to a narrow belt like plate boundaries, but can be distributed over small or large regions (e.g., Wernicke et al., 2008). Understanding how structures are distributed in continental tectonic systems is key to interpreting the continental deformation and assessing earthquake hazards. Neotectonic studies have shown that the crustal deformation in continental China is driven by forces due to the motions of neighboring plates (Molnar and Tapponnier, 1975; Tapponnier and Molnar, 1977; Wesnousky et al., 1984; Ye et al., 1985; Xu et al., 1993; Zhang et al., 1998, 2003).

The primary pattern of late Cenozoic tectonic deformation of continental China is characterized by relative movements and interactions of active tectonic blocks bounded by major active faults (Deng et al., 2002; Zhang et al., 2003). Tectonics of these blocks shares significant similarities with that of plate tectonics, that is, concentrations of earthquakes and tectonic activity within narrow boundaries, but no significant deformation within the rigid blocks, such as the Ordos block and the active blocks in and around the Tibetan plateau. Historical records also reveal that most of the strong earthquakes have occurred along these block boundaries (Zhang et al., 2003). A necessary step in understanding the movement of the blocks is to document the late Cenozoic activity and kinematics of the major faults along the block margins. Tibetan Plateau and the active Ordos block are the most active areas of intra-continental deformation in China and serve as natural

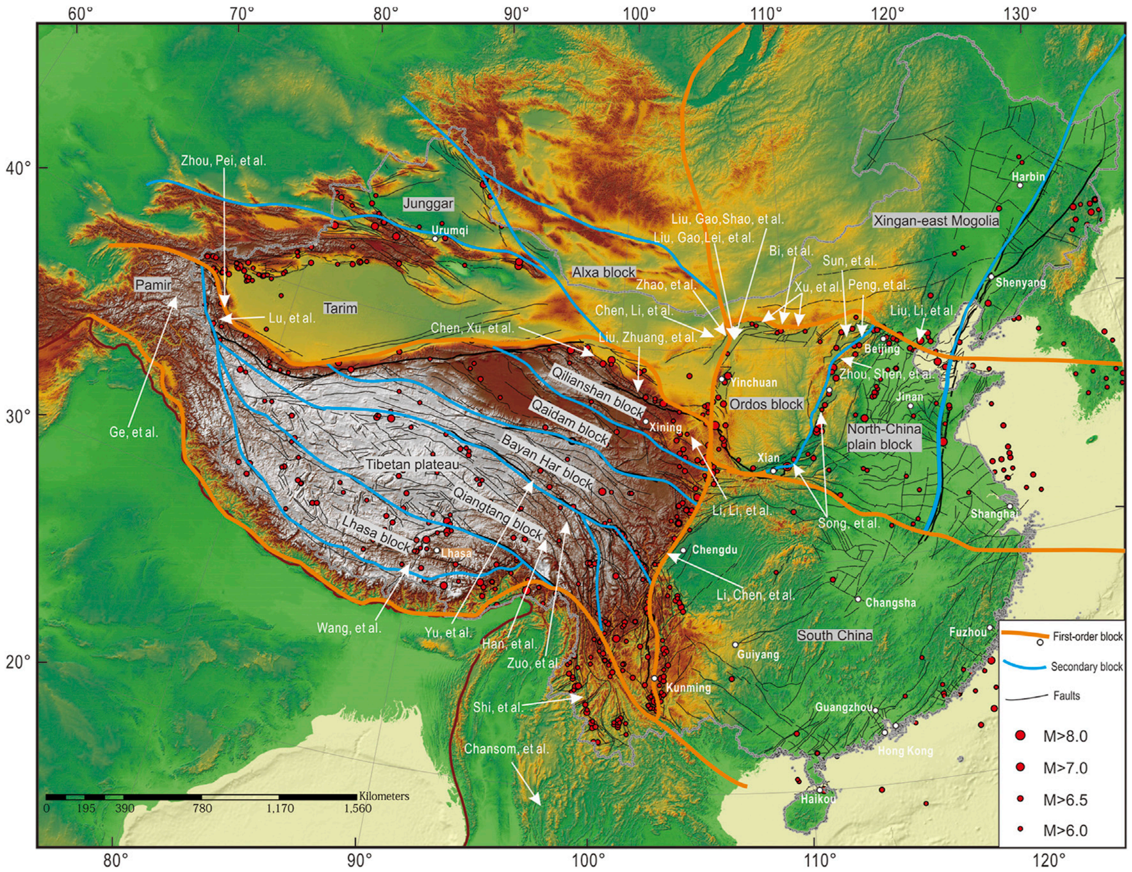

FIGURE 1
Active blocks, active faults and major earthquakes (M>6.0) in China continent. Division of the active tectonic blocks follows the pattern proposed by Zhang et al. (2003). Locations of the 24 studies presented in this Research Topic are shown.

laboratories to better understand continental deformation. The majority of the 24 articles collected in this Research Topic mainly focus on present-day deformation in and around the Tibetan plateau and Ordos regions and try to cover much of the new research progress in this field (Figure 1).

Tectonic deformation along boundaries of active blocks in Tibetan plateau region

Cenozoic tectonics in Tibetan plateau region is clearly controlled by the Indo-Asian collision, which was separated by the roughly E-W–oriented fault zones into a series of blocks. The Bayan Har block in central Tibetan plateau is no doubt the most striking active block due to its intense fault activity. Field investigation obtains new evidence of the later Quaternary activity and recent large earthquake ruptures of the Garzê-Yushu fault that connects the Xianshuihe fault zone and constitutes the southern boundary of the Bayan Har block in west. The determined left-lateral slip-rate of 6.3 ± 1.9 mm/yr in the Holocene along the fault (Yu et al.) is very close to the estimated average slip rate for the Xianshuihe fault. Surface ruptures with a length of ~100 km of the 1,738 earthquake have been discovered along the Dangjiang segment (Yu et al.), which demonstrates that the individual segments of the faults bounding the southern boundary of the Bayan Har block are all able to produce large earthquakes. The eastern margin of the Tibetan plateau is bounded by the Longmen Shan fault zone that is also the eastern boundary of the Bayan Har block and hosted the devastating Wenchuan earthquake in 2008. However, this structure once had been assigned a moderate-to-low seismic hazard rating before the 2008 event because it is slowly slipping (Zhang, 2013). Another impression making this fault zone seem innocuous and less significant seismic hazard is that the co-seismic displacements along its southern segment were very small and thus the southern segment is defined as a minor surface-rupture fault (Li et al.). Using scanning electron microscope and X-ray diffraction methods, Li et al. discovered that the fault gouge of the Dachuan-Shuangshi fault (the southern Longmen Shan fault zone along which the Lushan M7.0 earthquake occurred in 2013) greatly differs to that of the Yingxiu-Beichuan fault (hosted devastating Wenchuan earthquake and produced significant surface ruptures) in the microstructure and mineral composition. This finding can be used as an auxiliary indicator to identify minor-surface-rupture faults.

The tectonic deformation of northeastern Tibetan plateau also exhibits a unique pattern. For the Haiyuan fault, the characteristics of the crustal deformation before the 2022 Menyuan Ms 6.9 earthquake and the future seismic hazards on this fault zone are analyzed using GPS-derived velocity data combined with the distribution of small earthquakes along the fault (Liu et al.). This study shows that the earthquake may link the Lenglongling and Tuolaishan faults, and that the present-day crustal deformation in the northeastern margin of the Tibetan plateau characterizes as the crust-shortening distributed in the Qilian Shan region and the left-lateral strike slip localized in the Haiyuan fault zone. Work from geomorphologic study to the west shows similar results (Chen et al.). Based on the slip rates derived from slope profiles and dating of the deformed river terraces across the NWW-trending faults in the western Qilian Shan, the study also suggests that the crustal shortening is widely distributed in the northern Qilian Shan region, while the strike-slip faults accommodate the sinistral strike-slip of the Altyn Tagh fault that bounds the northern Tibetan plateau block. To access the earthquake hazard in the northeastern margin of the Tibetan plateau, Li et al. Constructed a three-dimensional fault model concerning eight major faults by using multidisciplinary data and computer-aided modeling and optimization technique. Based on this 3D fault model, this study finds four fault segments with relatively higher potential to rupture in strong earthquakes in this region and illustrates the high complexity of a strike-slip dominant fault system developing along the boundary between active tectonic blocks.

Neotectonics, Cenozoic kinematics and geodynamics of the Tibetan plateau also have been studied recently in the western and southern Tibetan plateau, which can lead to a better understanding of the tectonic settings in these regions. By reviewing and reanalyzing the geologic, geodetic and seismic data, Ge et al. proposed the multi-spatiotemporal evolution of deformation patterns of the Pamir salient in western Tibetan plateau since the Late Cenozoic and thus provide a new view to understand the Cenozoic kinematics and geodynamics in this region. The northward motion of the Pamir salient may have caused the intense uplift of the Northeastern Pamir from 4.9 to 1.9 Ma, according to a detailed magnetostratigraphic investigation at the southwestern margin of the Tarim Basin (Zhou et al.). Using a fault scarp degradation model, Lu et al. constrained earthquake history of the Muztagh Ata and Tahman faults in the northern Pamir. The recurrence interval of ~1,000 years and the vertical slip rate of 2.2 ± 0.3 mm/yr across the Muztagh and Tahman fault suggest strong active faulting and earthquake activity in this region. In southern Tibet plateau, time constraints from thermochronology dating of the Yadong-Gulu rift supports the viewpoint that these rifts had been formed by the east-westward extension of the Tibetan plateau, which was induced by a combination of strike slipping and thrusting along the main faults in southern Tibetan block (Wang et al.).

Tectonic deformation along the boundary of Ordos block

In the Ordos region, the major driving forces for active crustal deformation are complicated, and the main influence is from both the Indo-Eurasian collision and subduction of the Pacific (Deng et al., 2002; Zhang et al., 2003). The rates of Quaternary crustal deformation are much lower than those in western China. In contrast to the well-studied western and southern margins along which the great historic Pingluo and Huaxian earthquakes occurred, less work has been conducted on active faulting in the northern, northwestern and northeastern margins of the Ordos block. In northwestern margin of the Ordos block, the late Quaternary slip rate of the Zhuozishan West Piedmont fault (ZWPF) and the extension rate across the northwestern edge were determined by using an unmanned aerial vehicle system for measurement and optically stimulated luminescence (OSL) dating methods, which suggests that extensional deformation is mainly concentrated on the western side of the basin (Liu et al.). To access the regional seismic hazard potential, Liu et al. determined seven earthquake events along the fault through trenching and OSL dating methods. According to the calculated recurrence interval and the elapsed time of the latest earthquake, they suggest that the seismic hazard potential in the northwestern corner of the Ordos block should not be underestimated. To the west, broadband magnetotelluric (MT) exploration across the Linhe basin bounded by the ZWPF on the east revealed that the Langshan Piedmont fault bounds the Linhe basin rift on the west, and is also one of the main boundary faults separating the Alxa and Ordos blocks and that the Linhe basin rift has experienced continuous and strong extension since the Cenozoic era (Zhao et al.). To the southwest, the late Quaternary activity and paleoseismicity of the nearly-north-striking, dextral Bayanhaote fault that separates the Alxa and Ordos blocks in western piedmont of the Helan Mountains were studied on the basis of analysis of the geomorphic features and trench excavations, which helps to better understand present-day deformation of this active boundary (Chen et al.).

By correlating the offset stratigraphic markers exposed in the footwall with those discovered by borehole drilling in the hanging wall, Xu et al. calculated the vertical slip rates of three faults (the Seertengshan piedmont, Wulashan piedmont, and the Daqingshan piedmont faults) bounding the northern margin of the Ordos block, which are ~1–3 mm/yr since 65 ka. Based on the slip rates and paleoearthquake results, they assessed a high seismic hazard on these faults. Another study on the Wulashan piedmont fault obtained similar results (Bi et al.). In that study, the paleoseismicity of the fault was constrained through statistical analysis of the morphology of fault scarps extracted from high resolution LiDAR topography, and the average recurrence interval estimated for the identified seven paleoseismic events also indicates a high potential seismic hazard on the Wulashan piedmont fault. Six paleoearthquake events recognized by trench excavations in late-Quaternary along the Liulengshan fault suggest that tectonic deformation in the northeastern edge of the Ordos block is also strong (Sun et al.). The three-dimensional deep structures of this region were revealed by electromagnetic inversion. The results indicate that the deep electrical structure in the western part of the northeastern Ordos is laterally heterogeneous and the migration of mantle thermal material into the middle and upper crust results in active faulting and moderate-strong earthquakes in this region (Peng et al.).

The present-day crustal deformation across the Weihe and Shanxi grabens that constitute the southern and eastern margins of the Ordos block was studied on the basis of a kinematic finite-element model constructed by joint fitting of the geological slip rate, GPS velocity field, and principal compressive stress data, which shows that this region is a low-strain kinematic setting and there is a prominent dextral shear mode along the central Shanxi graben (Song et al.). Recent one short-period seismic array study across multiple rift-basins and their boundary faults within Huai'an-Zhangjiakou region near the north end of the Shanxi graben unveils not only the low-velocity zones at the bottom of the upper crust but also the fractured Moho and crust beneath the graben, which indicates that the upwelling of the locally reheated mantle magma intrudes into the crust and thus may explain how thermal and material circulation in mantle wedge drives the crustal extension and the normal faulting along the Shanxi graben (Zhou et al.).

Active faulting and mid-strong earthquakes within blocks

Some faults in the interior of the active blocks also exhibit strong tectonic and earthquake activity. In contrast to the faults bounding the blocks, these faults within the blocks have drawn relatively less attention. They typically have low slip rates of less than 4 mm/yr and with an averaged recurrence interval of more than 1,000 years. For examples, the Nantinghe fault in the southeastern Tibetan Plateau region shows such a low slip rate (Shi et al.) and the Yangda-Yaxu fault was constrained to have a recurrence interval of ~4,000 years for major earthquakes (Han et al.). Although not as active as the faults along the block boundaries, faults within the blocks also play important roles in accommodating crustal deformation. Surface ruptures recognized along these faults suggest that the earthquake hazard on this kind of faults is also substantial (Zuo et al.). Some earthquakes with magnitude of ~7.0 occurred within the blocks, such as the Ludian Ms 6.5 earthquake in Yunnan in 2014 (Xu et al., 2015) and the historic earthquakes including the 1948 Litang M7.3 earthquake with long surface ruptures on the Litang fault within the Qiangtang block (Gao et al., 2022). The Tangshan Ms7.8 earthquake occurring in the North China Plain block may be the largest earthquake ever recorded within a block. Through shallow seismic exploration combined with borehole-drilling exploration and trench excavation, Liu et al. obtained a detailed structural model of the seismogenic structure of the Tangshan earthquake and suggests that the shallow part of the structure corresponds to the strike-slip Guye-Nanhu Fault. Study of the Mae Hong Son fault in northern Thailand is another example that moderately active faults with a moderate-strong earthquake potential can develop within the active blocks (Chansom et al.).

Summary

The papers collected in this Research Topic mainly cover the following subjects: 1) late Cenozoic deformation along active block boundary, 2) geometry, surface ruptures and segmentation of active faults, 3) chronology, faulted landforms, and slip rate of active faults, 4) paleo-earthquake and large earthquake studies on the major faults along block boundary, 5) numerical models of geodynamic process of the active blocks, 6) geophysical exploration of three-dimensional deep structure, and 7) great earthquake hazard potential on the major faults along block boundary. Despite the uncertainties, we believe that these studies of this Research Topic will shed important light on the tectonic deformation pattern and dynamic model of the active blocks.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding

The work throughout the conception, design and publication of this Research Topic was supported by the

National Key Research and Development Program of China (2017YFC1500101), the Second Tibetan Plateau Scientific Expedition and Research Program (STEP) (2019QZKK0901) and the National Natural Science Foundation of China (42072250).

Acknowledgments

We would like to thank all reviewers and authors for their contributions to this Research Topic. We also thank the entire team of Frontiers in Earth Science for their dedicated effort in guiding the revision and detailed editing of the papers of the Research Topic.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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