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CURRENT TECTONIC DEFORMATION SYSTEM IN REGIONAL CRUST OF THE NORTHEASTERN QINGHAI-XIZANG PLATEAU ——A NEW CONGNITION ON THE CAUSES OF SHALLOW CRUSTAL EARTHQUAKES

DAI Hua-guang, CHEN Wen-bin, ZHANG Jie, CHEN Yong-ming,
SU Xiang-zhou, LIU Hong-chun
(*Lanzhou Institute of Seismology*, *CSB*, *Lanzhou* 730000, *China*)

Abstract: Based on the data of earthquakes ($M_S \geqslant 7$), earthquake deformation zones, active faults and active tectonic system in northeastern Qinghai-Xizang Plateau, combined with the theories and methods of the earth system science, geological mechanics, seismogeology and modern seismology, the ‘commonness’ of the strong earthquakes in the region is discussed. A new concept, named as contemporary tectonic deformation system of the regional crust characterized by three dimensional dynamics is proposed. A new cognition on the mechanism and distribution of the earthquakes in the region is presented.

Key words: Qinghai-Xizang Plateau; Crustal deformation; Tectonic earthquake; Seismogenesis
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0 Introduction

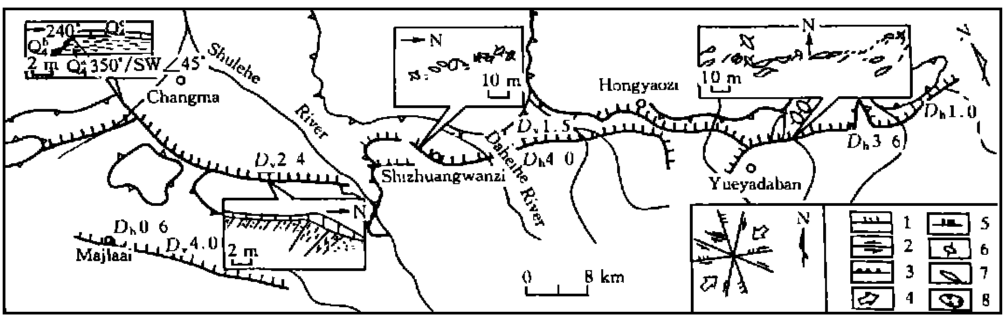
Northeastern Qinghai-Xizang Plateau is one of the most tectonically active regions in China or even in the whole Eurasian continent. It's also one of the regions where strongest earthquakes occur most often (28 $M_S \geqslant 7$ earthquakes, including 6 $M_S \geqslant 8$ earthquakes, occurred since 780 B.C.). The first author has been studying earthquake deformation zones, seismotectonics, active faults and active tectonic system in this region since 1970. Based on 30 years' investigations and studies, the author obtained some understanding about ‘individuality’ and ‘commonness’ of these earthquakes and characters of modern tectonic movements in the whole region. This paper aims at putting forward our opinion on the problem of how to reveal the ‘commonness’ of these great earthquakes.

1 NNW-trending Active Tectonic System

1.1 Earthquake Deformation System

The tectonic deformations formed on the earth's surface during great earthquakes ($M_S \geqslant 7$) in the northeastern Qinghai-Xizang Plateau have so large scales, abundant types, clear shapes and clear combination regularity which can be seldom seen elsewhere in China or even on all global continents. When comprehensively analyzing the earthquake deformation systems of 28 great earthquakes[1][2], the authors surprisingly found that most deformation systems are apparently similar, the compressive stress directions deduced by earthquake deformation systems are either NEE-SWW or NE-SW. Does this mean that the preparations and occurrences of these great earthquakes had certain organic relations? Maybe the relations provide geological support for us to reveal the 'commonness' of these earthquakes and modern tectonic deformation features of the whole northeastern Qinghai-Xizang Plateau. The 1932 Changma M_S7.6 earthquake's tectonic deformation system is a particularly typical example. In the epicentral area, all kinds of structural planes such as compressive, extensional and torsional planes are very distinctive.

The epicentral area of the Changma earthquake is located in the Changma-Xishuixia basin 40 kilometers south to the western segment of the Qilian Mt. front fault zone. The basin is 120 kilometers long and 10—20 kilometers wide with basic trending direction of N75°W. The south margin of the basin is the Changma-Xishuixia fault zone, south side of which is Daxueshan Mountains. There are 4 NNW-trending uplifts that are separated by roughly the same distance of several kilometers in the long and narrow basin. The eastern margins of the uplifts are 4 roughly parallel faults that formed in the early Cenozoic era. Because of the uplifts' separating, the basin looks like a string of beads. The 1932 Changma M_S7.6 earthquake formed grand deformation zone along the Changma-Xishuixia fault and 4 NNW-trending faults (Fig. 1). These deformation zones and secondary deformations constitute a relatively integral ground deformation system, with which the compressive stress direction can be deduced to be NEE-SWW (Fig. 1).



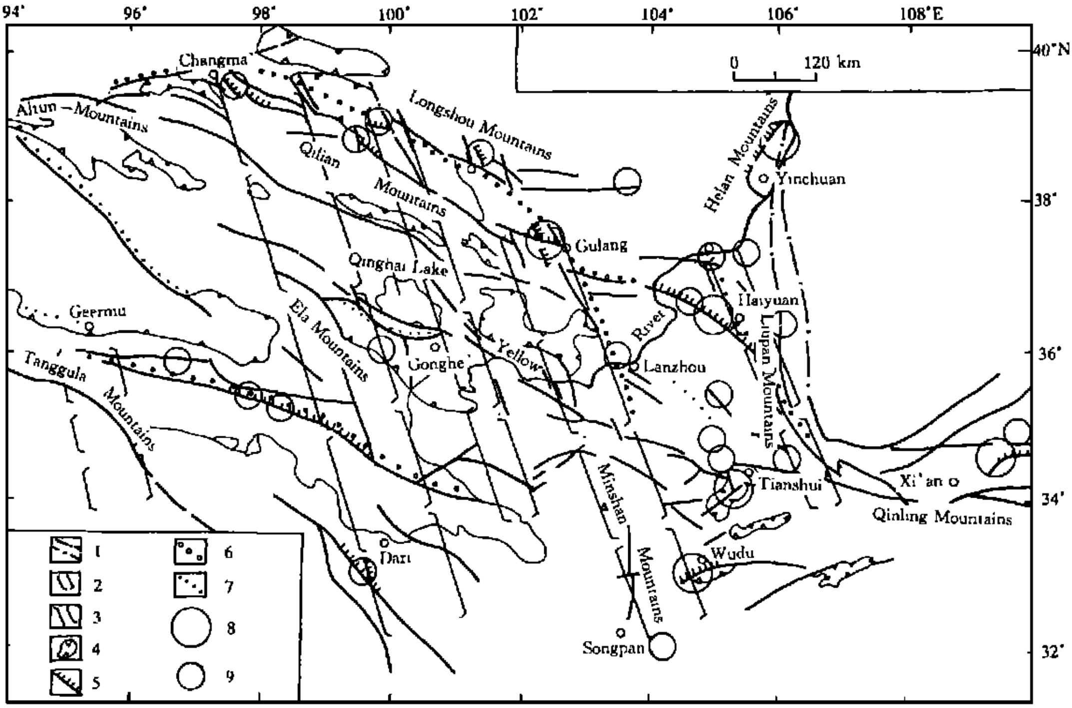
1 compression with dextral component; 2 horizontal twisting motion; 3 tensile twisting motion; 4 direction of principal compressive stress; 5 seismic deformation band; 6 seismic bulge; 7 seismic fissure; 8 basin boundary; D_h——horizontal dislocation/m; D_v——vertical dislocation/m

Fig. 1 Deformation bands caused by the Changma M_S7.6 earthqauke in 1932.

1.2 NNW-strending Active Tectonic System

Any great earthquake and its deformation system are not lonely geological phenomena, but an epitome of contemporary regional tectonic movement. For instance, the tectonic configuration in the epicentral area of the Changma earthquake is quite similar to that of the Hexi Corridor. The Hexi Corridor is a noticed, wholly NWW-trending tectonic basin between the Qilian and Longshou Mountains. Owing to several approximately-equal-distance-apart NNW-trending uplifts, the corridor basin is separated into 4 secondary basins——the Jiuxi, Jiudong, Zhangye-Minle and Wuwei basins. These uplifts are the Jiayuguan, Yumushan, Dahuangshan and Lenglongling uplift zones. They intercross with the NWW-trending Qilianshan tectonic zone. At all the intercrossing points, the tectonic image changes: the striking directions of strata and faults turn into NW, forming a counter S-shaped swerve. This made sedimentation centers of the secondary basins of the Hexi Corridor located prevalently to southeastern corners. This obviously shows the alteration to old structures caused by the NNW-trending uplifts.

Similarly, the secondary subsiding zones separated by the NNW-trending uplifts are not sole or local phenomena. Along each SSE-extending part of the zones, similar tectonic features can be seen. These tectonic traces can reach the Qinling and eastern Kunlun Mountains to the south, the Liupan Mountains to the east and the Tanggula Mountains to the west. These uplift zones, subsiding zones and their secondary uplifts and subsiding zones, together with active faults of different striking directions and types, compose basic pattern of contemporary active tectonic system in the Qinghai-Xizang Plateau, i.e., the NNW-trending active tectonic system (Fig.2).



1 fault and buried fault; 2 upwarded zone; 3 subsidence zone; 4 basin; 5 seismic deformation zone; 6 Moho mutation zone; 7 gravity gradient zone; 8 $M_S \geqslant 8.0$ earthquake; 9 $7.0 \leqslant M_S \leqslant 7.9$ earthquake

Fig. 2 Distribution of the $M_S \geqslant 7.0$ earthquakes and NNW-striking avtive tectonic systems in the northeast Qinghai-Xizang Plateau.

The NNW-trending active tectonic system is a new huge system that had formed on all old structures since the Himalayan movement. Its scope /extension almost covers the whole northeastern Qinghai-Xizang Plateau. The time when the system finally formed ranges from the end of mid Pleistocene to the beginning of late Pleistocene[2]. In the huge system, the axes of the NNW-trending uplifts and subsiding zones, and NNW-trending faults on the two sides of the uplifts reveal dominant compressive structural planes; the NEE-trending tensional rift basins and NEE-trending tensional-and-lateral active fault zones reveal dominant tensile structural planes; generally developed NWW-EW-trending compresso-shear rift basins and active faults on two sides of every basin, especially those on southern side, are the indicator of the reverse strike-slip structural planes; NNE-trending earthquake deformation zones which often appear in $M_S \geqslant 7$ earthquake deformation system[3] might be the indicator of normal strike-slip structural planes. The dynamical conditions of the four groups of structure planes reveal the modern tectonic stress field in northeastern Qinghai-Xizang Plateau. They also controlled modern tectonic physiognomy of this region. Among the four groups of structural planes, the former three played controlling parts in the latest tectonic deformation of the region. NWW- and NEE-trending planes are usually formed by using or altering old planes. The time when last alteration of habitude occurred was mostly between the end of mid-Pleistocene and the beginning of late Pleistocene.

2 The Relation between the Preparation and Occurrence of Earthquakes and NNW-trending Active Tectonic System

The gestations and occurrences of 28 $M_S \geqslant 7$ earthquakes in northeastern Qinghai-Xizang Plateau are associated with modern movement of the NNW-trending active tectonic system, which shows in the following aspects:

(1) The directions of dominant compressive stress deduced by epicentral tectonic stress fields based on every huge earthquake' s deformation system are mostly NEE-SWW or NE-SW. This is consistent with the dominant compressive stress' directions reflected by the NNW-trending active tectonic system. The structural planes reflected by the deformation zones of different directions or types in each great earthquake' s deformation system are consistent with those reflected by different types of tectonic deformation traces in the NNW-trending active tectonic system. So it can be reasonably believed that the deformation systems and the NNW-trending active tectonic system are the products under the same stress field. They are part of geological signals which are obviously the most active nowadays in the active tectonic system. Also they are an epitome of the modern activity traces of the tectonic system. The deformation systems of the Haiyuan $M_S 8.5$, Gulang $M_S 8.0$, Changma $M_S \geqslant 7.6$ and Tuosuohu $M_S 7.5$ earthquakes are typical examples.

(2) Clustering of earthquakes is another aspect of overall movements of the NNW-trending tectonic system. For example, 8 $M_S \geqslant 7$ earthquakes including strong aftershocks of the Haiyuan M_S 8.5 earthquake occurred in this region from 1920 to 1954. The Haiyuan earthquake and its strong aftershocks of $M_S \geqslant 7$ occurred on the Xiangshan-Liupanshan NNW-trending uplift and its western side; the Gulang M_S 8 earthquake occurred at the north end of the Lenglongling-Minshan NNW-trending uplift zone; the Changma $M_S \geqslant 7.6$ and Dari M_S 7.75 earthquakes occurred at the north and south ends of the Qilianshan' s peak-Animaqingshan NNW-trending uplift zone; the Tuosuohu M_S 7.5 earthquake occurred on the Animaqingshan NNW-trending uplift zone and its west side; the Shandan M_S 7.25 earthquake occurred on the east side of the north end of the Dahuangshan-Polamading secondary NNW-trending uplift zone (Fig. 2). From a view of the overall movement of the NNW-trending active tectonic system, the internal relations among those earthquakes are quite clear.

(3) The places where $M_S \geqslant 7$ earthquakes occurred are not stochastic, but at regular tectonic

positions: ① earthquakes generally occurred at the ends of NNW-trending zones or secondary NNW-trending zones, such as the Changma M_S7.6, Dari M_S7.75, Gaotai M_S7.5, Gulang M_S 8, Shandan M_S 7.25, Zhongwei M_S 7.5, Zhongning M_S 7.25 and Wudu M_S 8 earthquakes; ② earthquakes always occurred at the positions where NNW-trending zones intersect with tectonic basins, such as the Tuosuohu M_S 7.5, Dulan M_S 7, Hongyapu M_S7.25, Lanzhou M_S 7, Wudu M_S 8, Haiyuan M_S 8.5, and Tianshui M_S 7 earthquakes; ③ there exists a Huajialing-Motianling NNW-trending zone between the Xiangshan-Liupanshan zone and Lenglongling-Minshan zone. Owing to being covered with loess, its scope is still not clear, but its existence is unimpeachable. The obvious evidence is that it works as the watershed between Weihe River and Jialingjiang River. The earthquakes associated with this zone are the Tongwei M_S 7.5, Longxi M_S 7, Gangu M_S7 and Luojiabao, Tianshui, M_S 8 earthquakes.

(4) There exists clear discrepancy in activity for different grades of structure planes in the NNW-trending active tectonic system, which is clear in that the positions of different grade of earthquakes are different. ① All of $M_S \geqslant 8$ earthquakes occurred on the Lenglongling-Minshan NNW-trending zone and its east. The greatest 1920 Haiyuan M_S 8.5 earthquake occurred on the Xiangshan-Liupanshan zone in the easternmost part of the system. This suggests the characteristics according to which the overall activity of the system is strong in the east and week in the west. The strongest places are on the active tectonic zone along the easternmost margin. ② The $7.5 \leqslant M_S \leqslant 8.0$ earthquakes mostly occurred in the NNW-trending zone or the tectonic zones associated with secondary zones. ③ The $7 \leqslant M_S \leqslant 7.5$ earthquakes mostly occurred in the secondary (second grade) NNW-trending zones or the tectonic zones associated with the secondary zones.

3 The Modern Tectonic Deformation System of Regional Crust in the Northeastern Qinghai-Xizang Plateau

Either from the view of modern movement of the NNW-trending active tectonic system or from the view of the ‘individuality’ and ‘commonness’ of the earthquakes in this region, the modern regional crustal tectonic deformations and the gestations and occurrences of the earthquakes in the northeastern Qinghai-Xizang Plateau are the result under the action of modern crustal tectonic stress field. Therefore, there exists intrinsic relation among them. In order to reveal the relation, the authors propose a concept called modern tectonic deformation system in regional crust.

3.1 **Current Tectonic Deformation System in Regional Crust**

The modern tectonic deformation system in regional crust is an integer set up based on modern active tectonic system of regional crust. The difference between the system and Professor Li Si-guang’s active tectonic system[4] lies in that the former not only includes tectonic deformation traces of various forms, grades and types correlated under modern regional tectonic stress field (i.e., active tectonic system), and the gestating, forming and developing of the traces (earthquakes gestate and occur in this process), but also includes various changes of geophysics, geochemistry, biology and climate in the process (anomalies of earthquake precursors are part of the changes), and the results and tendency of the process (seismological and geological disaster is the inevitable outcome of the result; earthquake prediction is the reasonable prediction to the developing tendency). Therefore, the modern tectonic deformation system in regional crust is a three dimensional, dynamical nonlinear system. Each kind of tectonic deformation traces and their forming process are constituted by associated secondary factors. They are also the components of higher-level 'integer'. Those factors of various levels and the 'integer' compose an even higher integer that came into beings under a unitary regional stress field, i.e., the modern tectonic deformation system in regional crust.

3.2 New Knowledges

When bringing earthquakes, deformation zones, earthquake disaster, active faults, active tectonic system, regional crustal tectonic stress field and other things associated with the earthquakes into the modern tectonic deformation system in the region, the authors gained the following understandings:

(1) In the NNW-trending active tectonic system's developing process, earthquakes, especially those $Ms \geqslant 7$, are a kind of mechanisms in which stress and strain are adjusted by mains of rocks' breaking. Because of the earth's rotation and revolution around the sun, the regional crust in the northern Qinghai-Xizang Plateau is incessantly under running up condition. Owing to inhomogeneity of the crustal material and the earth's running speed and unevenness of the stress in the crust, a variety of tectonic deformation traces such as uplifts, depressions, folds, faults and cracks will form. Like other natural things, each kind of deformation trace is not an insular geological event, but related with other events. The organic combination of those correlated tectonic traces made up an active tectonic system, such as the NNW-trending active tectonic system in the northeastern Qinghai-Xizang Plateau. In this active tectonic system, breaks of strata and rocks are a special type of deformations, which generate new faults, and/or make original faults develop in depth, width and length. The process in which new faults generate is the process in which the conflict between stress and rocks' strength at the position becomes acute. When stress exceeds rocks' strength limits, the rocks will break. This makes the crust vibrate. Such a phenomenon is called earthquake.

If rocks are obviously dislocated after breaking, the breaks are called faults (otherwise they are called cracks). Whether hidden underground or basseting on the surface, the faults will compressively, extentionally or torsionaly spread out regularly in the regional crust.

Earthquakes' occurrences not only release the accumulated strain energy, but also facilitate development of all kinds of tectonic deformation traces in regional active tectonic system. Therefore, earthquakes are a kind of mechanism for adjusting stress and strain in the forming and developing of regional active tectonic system. Such an adjusting mechanism is necessary not only for the development of regional tectonic system, but also for the crustal relative stability. Only by this way can the strain energy accumulated in regional crust every moment during the earth's high-speed movement be released, can the regional crust be stabilized. Such stabilization is also a critical condition for all creatures including human being on the earth.

(2) The rupture deformations on different grade and type of structural planes in the NNW-trending active tectonic system result in the magnitude difference. ① The clearly dislocated rup-

tures on the dominantly compressive structural planes associated with the NNW-trending uplifts were direct tectonic cause of the $M_S \geqslant 7$ earthquakes. The ruptures were of right-reverse-slip character. They can be newly generated reverse-slip fault planes or can be original ones developed in depth, width and length. Whether for new faults or for old ones, the evident signs are vertical displacements higher than 0.5 meters, such as one meter in the Shandan M_S 7.25 earthquake, 5.4 meters in the Changma M_S7.6 and 6.2 meters in the Guliang M_S8, or more than one meter displacements on shear-fracture planes or on principally extensional structural planes accommodated to the dominantly compressive planes, such as from 9 to 11 meters displacement in the Haiyuan M_S8.5 earthquake and from 6 to 8 meters displacement in the Tuosuohu M_S7.5 earthquake. Though the extent of the rupture displacements on the revease-strike-slip, normal-strike-slip and extensional structural planes is always bigger than that of vertical displacements, they should be the result of accommodating themselves to compressive planes. Therefore, these features of the ruptures do not stand for the real nature of the great earthquakes. ② The compression strengths of strata such as sandstone or rocks such as granite under normal condition are nearly ten times as large as shearing strengths, and about fifty times as large as extensional strengths. On the other hand, the energy will enhance ten times as magnitude enhances 0.5. Therefore, if rupture deformations with obvious displacements on dominantly compressive structural planes of the NNW-trending uplifts take M_S 7.0 earthquakes as the base, the magnitudes of events caused by the rupture deformation on the shearing planes corresponding to dominantly compressive structural planes and dominantly extensional structural planes should be from 6.0 to 6.5. ③ In tectonics those cracks are called joints. Like faults, they also can be divided into the compressive, extensional and torsional. They are also the products during fracturing deformation of rocks under regional tectonic stress field. Compared with fault, the energy needed is much smaller. ④ The faults on the principally compressive, shearing and extensional structural planes as well as all kinds of lower-class faults and cracks associated with the three kinds of faults compose the rupture deformation system under tectonic stress field in northeastern Qinghai-Xizang Plateau. This rupture deformation system should be the main cause why shallow earthquakes occur.

(3) During certain geological time, the stress field in a regional crust should be relatively stable. Such relative stability provides basic forces for the forming and developing of active tectonic system in regional crust, and for great earthquakes' preparations and occurrences. All the new tectonic traces and great earthquakes' deformation systems in the northeastern Qinghai-Xizang Plateau indicate that the modern regional stress field is the continuing and developing of the stress field since the end of the late Pleistocene or the beginning of the early Pleistocene. So the modern tectonic deformation system is the continuing and developing of the system since the end of the late Pleistocene or the beginning of the early Pleistocene. It makes the northeastern Qinghai-Xizang Plateau become one of the areas where crust movement and great earthquake activity are most violent. Only by determining the basic condition of the modern stress field of the northeastern Qinghai-Xizang Plateau can we reasonably establish the modern regional tectonic deformation system, can we probe the preparation and occurrence process, distribution regularity and tendency of great earthquakes, and thereby realize the 'three-elements' prediction to future earthquakes

and forecast earthquake disaster.

(4) The modern crustal tectonic deformation system in the northeastern Qinghai-Xizang Plateau is established based on the tectonic deformation phenomena formed by 28 $Ms \geqslant 7$ earthquakes and the latest regional crustal tectonic deformations; supported by nearly 50 years' successive data of investigations and studies, combined with the theories and methods of modern seismology, seismogeology, geological mechanics and the earth' systematic science[5]. It is a larger-scope, high-level and dynamic integer. It aims at revealing the 'commonness' of all great earthquakes in the region. Such revealing of the 'commonness' is neither summing-up of phenomena, nor extrapolating from the 'individuality' of one or some great earthquakes, but combining the tectonic deformation phenomena of every great earthquake with the latest tectonic deformations all over the region, and probing into their 'commonness' in a high-level integer. The revealing of the 'commonness' among earthquakes is a process from individual to general, from local to whole, from phenomena to nature, and from perceptual to rational. Such a process is the 'leap' bound to occur when studies on great earthquakes' 'individuality' reach certain level. Once the 'leap' comes true, every earthquake's 'individuality' and the relationship among the 'individualities' can be probed into from a high-level view, and the veil of earthquakes can be uncovered layer by layer. With 50 years' contribution by generations of seismologists, the condition to carry on the 'leap' in the northeastern Qinghai-Xizang Plateau is met. To establish the modern tectonic deformation system is a resultful way to realize the 'leap'.

4　Epilogue

With the presentation of global environment problem, in the early 1980s a new science, the global systematic science, emerged. This indicated that geoscience had developed to a new step. Its most obvious feature lies in stressing the concept of integer, and intercrossing and pervasion among related sciences. The 'modern regional crustal deformation system' in the northeastern Qinghai-Xizang Plateau is presented by combining the theories and methods of global systematic science, geological mechanics, seismogeology and modern seismology in order to meet the demand to research the 'individuality' and 'commonness' of great earthquakes from a high-level view. To be sure, it still remains to be perfected, but its vigour is obvious. It not only differs from the theories and methods prevalently used in seismogeology, but also represents some new theories and methods which are available to earthquakes' cause, distribution regularity, earthquake prediction and disaster mitigation. These new theories and methods will make seismogeological research on the northeastern Qinghai-Xizang Plateau step into the 21st century with a new visage.

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青藏高原东北部地区的区域地壳现今构造形变系统
——陆壳浅源构造地震成因的新认识*

戴华光, 陈文彬, 张 杰, 陈永明, 苏向洲, 刘洪春
(中国地震局兰州地震研究所, 甘肃 兰州 730000)

摘要: 依据青藏高原东北部地区的大震($M_S \geq 7$)、大震形变带、活动断裂和活动构造体系的资料, 以地球系统科学、地质力学、地震地质学、现代地震学的理论和方法为主线, 对该区内大震的"共性"进行了探讨, 提出了具有三维空间动态的区域地壳现今构造形变系统的新概念, 并对该区内地震的形成机制、分布规律等科学问题提出了新的见解.

主题词: 青藏高原; 地壳形变; 构造地震; 地震成因

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* 中国地震局兰州地震研究所论著编号: LC2000014
作者简介: 戴华光(1945—), 男, 副研究员, 从事地震地质研究工作.