REVIEW AND PROSPECT OF SEISMO-GEOLOGIC RESEARCH IN CHINA

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Summary

The active tectonics research in China has been focused on the average recurrence interval and potential maximum magnitude of strong earthquake along a whole fault or specific segment of a fault. They can be calculated on the basis of reliable data on fault displacement, average slip rate, the maximum and average displacement of historic strong earthquake, as well as the segmentation of fault rupture. The paleo-seismic research has been extended from the paleoevents of an individual fault to regional paleo-seismicity of a seismically active region. The research of the coupling relation between the shallow and deep-seated seismogenic structures has been carried out in the extensional basin region of North China and in the compressive convergence tectonic zone of Northwest China. The fault-genarated pseudotachytyte exposed at the eastern foot of Dabieshan Mountains demonstrate a relatively complete Paleo-seismic source body and has been investigated in detail.

Introduction

China is a country of high seismic activity. Taiwan Island and Qinghai-Tibet Plateau of China are just located at plate collision boundary, where strong earthquakes frequently occur. China's continent is one of the most active region of intraplate earthquake in the world. China Seismological Bureau was set up in 1970. Geologists are the important component part of the whole seismic research ranks. They are involved in various aspects of seismic research work including post-earthquake observation, investigation of historical strong earthquake regions, regional seismo-geologic research, seismic intensity determination and zoning, comprehensive analysis of precursory phenomena, as well as numerical and physical simulation of seismic process etc. It is confirmed that most shallow earthquakes in China bear a genetic relation to active faults and active faulted basins. In the national symposium on seismo-geology held in 1978, the research orientation of seismo-geology has been clearly defined as " from old structures to young structures, from static analysis to dynamic analysis, from shallow structures to deep-seated structures, and from qualitative research to quantitative research". The first monograph on seismo-geology, "An outline of seismogeology of China" was published in 1975, while "The Map of seismic intensity zoning of China (1: 3,000,000)" and "Seismo-tectonic map of China (1: 4,500,000)" were published in 1977 and 1979, respectively.

Seismogeologic research in China has been booming since 1980's, with the rapid development of international corporation and exchange. Since then, a large number of publications have been issued, such as "Lithospheric dynamics atlas of China", "An atlas of active faults in China", 10 monographs on active fault zones as the component parts of "Special issues of the research of active tectonics in China", and the results of 6 geo-transects organized by China Seismological Bureau. All these results were highly appraised by international academic circles. In addition, the 1: 50,000 seismo-geologic mapping of 17 major active faults in China have been successively completed.

The principal subjects and contents of seismo-geologic research in China can be briefly summarized as follows:

Research of active tectonics

The focal point of the research of active tectonics in China has been transferred from the simple appraisal of Quaternary active faults to the quantitative study of the faults which have been active since late Pleistocene (0.02~0.03Ma). The 1: 50,000 seismogeologic mapping and comprehensive study of the major active faults all over the country have been carried out, while complete and systematic actual data on the evolution, geometry and kinematic features of active faults have been obtained through this work. Furthermore, the average recurrence interval and the potential maximum magnitude of strong earthquake along the whole fault or specific segment of the fault can be calculated on the basis of reliable data on fault displacement, average slip rate, the maximum and average displacement of historical strong earthquake, as well as the segmentation of fault rupture.

An insight into the characteristics of the development of neotectonics and the general features of active tectonics in

individual major regions of China have been gained through the research of active tectonics of various ranks. Especially for the northeast margin of Qinghai-Tibet Plateau, Sichuan-Yunnan region, and North China extensional region, the recognition of the features of block movement, the division of the periods of tectonic movement since neotectonic time, crustal stress field and its evolution, as well as the tectonic conditions of the occurrence of strong earthquake have been significantly deepened. A blind thrust type seismogenic model (it is called also fold type earthquake) on the faulted slope beneath active fold-thrust belt revealed in Tianshan and Qilianshan mountain front of Northwest China, provides a reasonable explanation for a specific earthquake type in compressional tectonic region.

Much has been done on the application of the results of active tectonic research to long-term earthquake prediction in China. A modified calculation model of recurrence probability of strong earthquake applicable to intraplate earthquake in China has been proposed on the basis of various probability prediction models suitable for plate margin earthquake world-wide. The conditional and cumulative recurrence probabilities of strong earthquake in forthcoming 30-50 years have been calculated by taking the Xianshuihe-Anninghe-Zemuhe fault zone as an example. The stress and strain features of the northern part of North China have been calculated on the basis of 3-dimensional geologic structural model and dynamic data of crustal deformation by using finite element method, while the seismic risk area of different classes have been divided.

Research of paleo-seismicity

Paleoseismic events along fault zone of different natures in various regions are revealed by employing many approaches. For example, along fault scarps of active fault developed in alluvial fan along Helanshan mountain front 4 seismic events (the latest one is the Pingluo M=8 earthquake in 1739) have been recognized through the detailed investigation of slope break on topographic profile of fault scarps, the knick point of gully, the development features of terrace in the uplifting wall, and the colluvial wedges outcropped on fault-crossing trench profile. Along the Haiyuan fault zone a large scale combined trenching was used to investigate various deformations and displacement in 3-dimensional space produced in individual geologic bodies along the strike-slip fault. Along the frontal faults of Tianshan and Qilianshan Mountains, the sequences of paleoseismic events were determined through the detailed observation of fault scarp, different stratohorizons crossed by the fault, and the colluvial wedge produced by the reverse fault.

Based on a wealth of experience accumulated for years, Chinese scientists have set up reliable diagnostic indications for paleoearthquake. They can be classified into 4 categories: (1) Deformation indications, such as multi-episodic displacements of the beds of different strata, the abrupt increase or decrease of different stratigraphic units on the same fault plane, and the variation of the degree of folding in different sedimentary layers etc.; (2) Depositional indication, such as colluvial wedge, tectonic filling wedge, and sag-pond deposits etc; (3) Geomorphic indications, such as slope break of fault scarp, offset or abandoned gully, the asymmetric development of geomorphic surfaces of terraces or alluvial fan on both sides of the fault, uplifted terrace and subsidence of tectonic origin along the coastal zone, as well as fault-related corrosion surface etc; (4) Other indirect phenomena related to paleo-seismic events, such as fossil collapse and landslide produced by paleo-seismic event, fossil liquefaction of sand body, deformation and damage of historic relics, as well as the environmental variation of the growth of coral reef in the vicinity of subduction zone.

Over the past few years, the research of paleoearthquake in China has focused on the regional paleoseismicity of seismically active region, instead of an individual place or fault zone. For example, paleoseismic research on 3 arcuate fault zones on the northeastern margin of Qinghai-Tibet Plateau and in Yunchuan Basin, have indicated that paleoseismicity is characterized by sub-periodic recurrence and oriented migration with time.

The results of paleoseismic research greatly expand the recognition of recurrence behavior of large earthquake in a seismically active belt or region. In early 1980's, a concept of characteristic earthquake was proposed by American scientists based on their discovery in the research of the paleoseismic events along the San Andreas Fault zone. They suggested the probability of the recurrence of large earthquake with similar maximum magnitude along a fault or fault segment. The variability of the behavior of seismic slip, however, has been discovered by the subsequent research work. The research of paleoseismicity in

China has indicated that under the conditions of the assemblage of complicated intraplate block structures with the faults, it seems that the probability of the occurrence of characteristic earthquake within the similar time interval is relatively small. In contrast, the seismicity may inhibit a sub-periodic recurrence or clustered occurrence of large earthquakes. Further study is needed, however, to answer the problem of what kind of recurrence model the seismicity of individual region will follow. Undoubtedly, the research of paleoseismicity will play an important role in this study. The progress of the research in these fields is of great significance to long-term earthquake prediction and seismic zoning.

Research of the coupling relation between the shallow and deep-seated seismogenic structures

According to statistics, most of the shallow earthquakes in China occurred within a depth range of 5~20km, and especially within 10~15km. A long-standing problem that should be resolved by seismogeologists is concerning the relationship between the supracrustal active tectonics and seismogenic structures at focal depth. In North China region, the focal mechanism solutions consistently indicate the predominant strike-slip motion of seismogenic fault, and the steep dipping of the fault plane, which are incompatible to the listric normal fault observed on the earth surface. A great deals of geophysical prospecting has been carried out in North China since 1960,s. And especially in the past decade, comprehensive geophysical prospecting of multi approaches, from shallow to deep sounding, has been conducted in Xingtai earthquake area, Yanqing-Huailai Basin, Linfen Basin, and Tangshan large earthquake region. The applied approaches include deep seismic reflection profile, shallow seismic reflection profile, wide band mobile seismic array, magnetotelluric sounding, and electro-magnetic array prospecting. Interesting phenomena have been revealed by the results of prospecting. For example, it is revealed that in Xingtai area a large scale detachment exists in the middle crust, overlain by a basin and range structures bounded by listric normal fault in upper crust, which is terminated into the detachment. In addition, a high angle fault and an intrusive body penetrating from below accompanied by thermal process exist beneath the detachment structural belt. The focus of 1966 Xingtai large earthquake was roughly located at the junction of detachment structure belt and high angle fault beneath the Xinhe listric fault. This configuration at least indicates that there is no simple and direct relation between the shallow and deep-seated structures in North China extensional tectonic region. At present, however, it is unreasonable to absolutely deny the relationship between the two structures, and obviously a more detailed prospecting and further study are required. In Yanqing-Huailai basin, wide band seismic array sounding has discovered the existence of high temperature intrusive body at 10~20km depth, in addition to a similar deep-seated high angle fault. The foci of minor to moderate earthquakes frequently occurred in this basin are mostly located in the vicinity of the boundary of this intrusive body. At present, the prospecting and study of the shallow and deep-seated seismogenic structures in the epicentral area of 1679 Sanhe-Pinggu M=8 earthquake is still in progress. This earthquake produced a surface rupture zone and displacement along the Xiadian fault zone. Ultra-shallow (<200m), shallow (2km) and deep seismic sounding profile have been conducted across the fault. It is expected that the results of prospecting will reveal the geometric and kinematic evolution of seismogenic fault from shallow to depth.

In Northwest China compressive seismic region, seismologists have been puzzled by the inconsistency between the microscopic epicenter and the meizoseismal area. An important recognition has been gained from the research of the seismogenic structures of 1906 Manas M=7.7 earthquake since 1980's. This seismic region is an active fold-and-thrust belt developed since Quaternary time, where the folds belong to fault-propagating fold type, which are a by-product of a series of thrust faults exposed at the surface or buried at depth. All these faults terminated downward at a large scale detachment belt, which join the northern mountain-front fault of Tianshan Mountains. Several rows of fold-and-thrust belts at the mountain front of Tianshan Mountains become successively younger in age toward the Junggar Basin. The rates of crustal shortening and uplift of the fold from the second and third rows have been calculated according to the results of geologic investigation. In addition, surface scarps and minor uplift produced by the Manas earthquake were discovered during the investigation. A model of seismogenic structures of Manas earthquake has been formulated by integrating geologic, seismic and geophysical data. The focus of the

earthquake is located at the slope of upper-mid crust near the mountain front, while the seismic rupture extends along the gentle detachment belt for several tens kilometers and terminates at the second row of active fold-and-thrust belt to the north, resulting in a relatively small scale surface deformation. The seismogenic model of Manas earthquake is probably typical of seismic event in compressive convergence region.

Research of seismic source body and the origin of continental shallow earthquake

Fault-genarated pseudotachylyte has been considered earlier as fossil earthquake. It is the product of frictional melting of wall rocks along fault plane during rapid dislocation of the seismogenic fault. Therefore, pseudotachylyte along with its surrounding deformed rocks can be considered as paleo-seismic source body that is exposed at the surface due to uplift and erosion. Detailed mineralogical and experimental petrologic studies of fossil earthquake may provide a lot of information on the physical environment of seismic source. This is the so-called research of seismic source body.

Fossil earthquake exposed at the eastern foot of Dabieshan Mountains demonstrate a relatively complete seismic source body. Detailed investigation reveals that the origin of this fossil earthquake bore close relation to the transition of deformation behavior from ductile to brittle of feldspar-bearing adamellite massif in the ductile shear zone due to decreasing temperature during the ascending process. This transition of deformation behavior caused the occurrence of strain instability and local concentration of stress during sustained shear dislocation at low grade condition of upper-mid crust (10~15km depth), resulting in the formation of barrier preventing sustained dislocation and the occurrence of two-phase deformation.

In addition to the above-mentioned research fields, seismogeologists have made their contribution in various aspects, such as reservoir-induced seismicity, seismic hazard prediction, seismic zoning, long-term earthquake prediction, and seismic safety assessment of engineering site.

Looking forward to the future, we realize that to get more significant and rapid progress, seismo-geology must be combined and integrated with other relevant disciplines, and new, sophisticated technology must be widely applied.

The application of wide-band digital seismograph may provide static and dynamic information on deep crust. This powerful tool should be used in seismogeologic research to get better understanding of the deep-seated structures. Seismic network and seismic array must be set up in major seismic area to reveal the patterns of shallow and deep-seated seismogenic structures and their motion.

The major scientific project, "the monitoring network of crustal movement in China", initiated in 1998, is of great significant to geo-science cycles of China. We believe that with the accumulation of observation data obtained from this network, the mystery of the current lithospheric deformation in China will be discovered clearly, and thorough understanding of the intraplate lithospheric dynamics of China and its relation to the occurrence of strong earthquake can be obtained by integrating the results of deep sounding.

(References and Figures are omitted)