地学雑誌
Journal of Geography
112(4) 489-520 2003

Recent Progresses of Active Fault Research in China

Honglin HE* and Eikichi TSUKUDA*

Abstract

This paper provides a brief overview regarding the history and major advances in research on active faults in China. Active fault research in China has progressed through three periods. The initial period, covering the former half of last century, was characterized by descriptions of the relationship between faults and strong earthquakes. In the second period, reconnaissance surveys on active faults were carried out along major historically seismic zones during the 1960's to 1970's. The third period, characterized by quantitative studies on active faults, started in the early 1980's. Researches were focused on fault slip rates, earthquake surface rupture and coseismic displacements, paleoearthquakes and earthquake recurrence intervals, fault geometry and segmentation, and seismic hazard assessment on the basis of these quantitative data of active faults. Based on the characteristic tectonic differences in the Quaternary, the China continent is divided into 5 active tectonic provinces: Tibet (TTP), Xinjiang-Uygur (XUTP), Northeast China (NETP), North China (NTP), and South China (STP). Major progress in paleoseismology and fault segmentation in China include the application of new techniques and concepts as follows: large-scale and three-dimension trenches, paleoseismic rupture behavior and recurrence of large earthquakes along several major fault zones, regional paleoearthquake recurrence behavior, and the stability of segmentation and persistency of segment boundary, gradation of segmentation and multi-rupture.

Key words: China, active tectonic province, active fault research, paleoseismology, activity history, segmentation

I. Introduction

An active fault is generally defined as a fault activated in the Quaternary, or in the Late Pleistocene (100-120 Ka), and will activate in the future (*e.g.*, Wood, 1916; Willis, 1923; Research Group for Active Fault of Japan, 1991). Considering that the recurrence interval of an intra-continental earthquake usually exceeds thousands of years, it is more reasonable to take the Late Pleistocene (100-120 Ka) to present as the time scale of active faults (Deng, 1996). Although research on active faults is almost a century old with Lawson (1908) firstly proposing the concept of active fault, active fault research principally developed in the latter half of the last century as an independent discipline. The

* Active Fault Research Center, National Institute of Advanced Industrial Science and Technology (Site 7, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan)

mapping works of active faults in California (Jenning, 1975) and in Japan (Research Group for Active Fault of Japan, 1980) are two examples of the early research. Since the late 1970's and 1980's, the research of active faults has turned into a new period characterized by quantitative analysis. In this period, new study methods, techniques and concepts were developed, such as paleoseismology, fault segmentation, blind thrust earthquake, marine active fault, and probability analysis of seismic risk (*e.g.*, Wallace, 1970; Sieh, 1978; Yonekura, 1983; Schwartz and Coppersmith, 1984; Stein and King, 1984; Working Group on California Earthquake Probabilities, 1988). In addition, since the 1990's the research of active faults and paleoseismology has been brought into the ILP program, such as the World map of active fault (Trifonov, 1995) and Task Group II-5 of ILP Paleoseismology Section (Yeats, 1996).

Research on active faults in China, almost keeping step with international research, has gone through three periods: (1) description of the relationship between faults and strong earthquakes, (2) reconnaissance on active faults and (3) quantitative study. In this paper we intend to make a brief overview of the history and advances of active fault research in China, including characteristics of active faults in different active tectonic provinces, and progresses in paleoseismology and fault segmentation. We hope this paper can help researchers outside China to understand the status of active fault research in China.

II. History of Active Fault Research in China

The investigation of the surface rupture of the 1920 Haiyuan earthquake of *M* 8.1 conducted by Weng (1922) was the first study of active fault in China. From that time to the early 1960's, the initial period of active fault research in China occurred. During that time several large earthquakes and their relationship to faults were investigated. The field investigation of the 1923 *M* 7.3 Daofu earthquake on the Xianshuihe fault (XSHF) Conducted by a German scientist in 1930 is Well-known outside China (Heim, 1934). Chang (1938) and Chan (1938) Conducted an investigation of the 1933 *M* 7.5 Diexi earthquake in Sichuan and the 1936 *M* 6.7 Lingshan earthquake in Guangxi, respectively. In the first symposium on neotectonics, convened by the China Academy of Science in 1957, some theoretical problems of neotectonics and active fault were firstly discussed (Geosicence Division of China Academy of Science, 1957). Other important researches Concerning active faults and neotectonics in dam construction sites had also been done such as Sanxia in Sichuan Province, Danjiangkou in Hubei Province and Xinfengjiang in Guangdong Province (Li, P., 1994).

From the late 1960's to the 1970's, several large earthquakes occurred on the China continent, including the well-predicted 1975 *M* 7.4 Haicheng earthquake and the 1976 *M* 7.8 Tangshan earthquake that caused more than 240,000 deaths. Damage caused by these earthquakes forced China to pay more attention to earthquakes and associated disciplines. In this period, active fault research focused primarily on seismic prediction and seismic zonation; reconnaissance survey of many active faults in major seismic zones was carried out. One representative work is the reconnaissance survey of seismogeologic settings of large earthquakes in Southwest China led by Li (Survey Team of Seismic Intensity in Southwest China, 1977 and

1979). The "Map of Active Faults and Distribution of Strong Earthquakes in China (1:3,000,000)" (State Seismological Bureau, 1976), "Seismotectonic Map of China (1:4,000,000)" (Institute of Geology, State Seismological Bureau, 1979), and the first symposium on active faults and paleoearthquakes convened by Seismogeological Committee of Chinese Seismological Society (Seismogeological Committee of Chinese Seismological Society, 1982) are examples of active fault research in the second period.

The separation of the State Seismological Bureau as an independent institution from the Chinese Academy of Science in 1978 greatly promoted the research of active faults. Since 1980's, the quantitative research of active faults in China, such as slip rate, seismic recurrence interval based on historical and paleo-earthquake data, *etc*., has kept pace with other countries. Mapping and quantitative studies of major active faults in Western China began during this period. It was during period that Li and his research group made a comprehensive study of the Xianshuihe-Xiaojiang fault zone (KDF) from 1981 to 1988 (Li, P., 1993). The Seismological Bureau of Xinjiang Uygur Autonomous Region (1985) completed a synthetic study of the rupture of the 1931 *M* 8 Fuyun earthquake and Keketuohai-Ertai fault (KEF) in 1981. Institute of Geology, State Seismological Bureau and Seismological Bureau of Ningxia Hui Autonomous Region (1989 and 1990) carried out the study and mapping of Haiyuan fault from 1981 to 1987. In the time period from 1984 to 1986, a research group from the State Seismological Bureau chaired by Wang and Deng made a study of the active fault system around Ordos Massif (Research Group on "Active fault system around Ordos massif," State Seismological Bureau, 1988). From 1983 to 1987, Chinese scientists led by Ding took part in Project IGCP-206: Comparison of Major Active Faults in the World, and published the "Atlas of Active Fault in China," including 6 major active faults in China (Chinese Working Group of the Project IGCP-206, 1989). A working group in the State Seismological Bureau led by Deng conducted a project of similar synthetic studies on approximately 20 other major active faults in the China in 1990's. These major active faults include almost all of the well-known fault zones in China, such as the Altyn Tagh fault zone, the Red River fault zone, and the Xianshuihe fault zone.

As a result, several research monographs, bulletins and 1:50,000 maps of these faults were published (*e.g.*, Institute of Geology, State Seismological Bureau, 1992; Working Group of Altun (Altyn Tagh) Fault Zone of State Seismological Bureau, 1992; Seismological Bureau of Shaanxi Province, 1996; Li, T. *et al*., 1997; Song *et al*., 1998; Deng *et al*., 2000; Guo, 2001). Quantitative research on these major active fault zones covered almost all aspects of an active fault, usually including the geometry and structure of the fault zone, moving sense, slip rate in the Quaternary or in the Holocene, paleoseismology and the recurrence interval of large earthquakes, surface rupture and coseismic displacement, segmentation and rupture process, deformation mechanism and dynamics, and seismic risk analysis.

As a summary of the research results of active tectonics in the past 20 years, the "Active Tectonics Map of China (1:4,000,000)" and "An Introduction to Active Tectonics of China" have been compiled and will be published. In addition large earthquakes, active volcanoes, active folds, active basins and active blocks, more than 800 active faults and 80 earthquake surface ruptures are also delineated on the map. The map includes more than 400 slip rates for more than 200 active faults, and more than 150 coseismic displacements for more than 70 earthquake ruptures (Deng *et al.*, 2002). The active faults presented on the map are divided into five groups: (1) Late Pleistocene-Holocene (100–120 Ka) active faults with geomorphic and geologic evidence, and dating data; (2) Quaternary active faults that become active in the Quaternary with unclear activity in the Late Pleistocene, or lacking geomorphic and geologic evidence; (3) Active faults in the Qinghai-Tibetan Plateau interpreted mainly based on satellite imagery and regionally geologic and geomorphic data; (4) Active faults that lie under plains or basins; (5) Active faults in marine areas covered by a body of water. Earthquake ruptures identified on the map are placed in two categories, one caused by historical and contemporary earthquakes, and another caused by paleoearthquakes (Deng *et al.*, 2002). In China, earthquakes recorded in historical data are termed as historical earthquakes. The earliest earthquake recorded in China is the BC 1831 Taishan earthquake of M 7 near Mt. Taishan in Shandong Province.

In recent years, several large earthquakes occurred in major cities causing terrible catastrophes, such as the 1995 Kobe earthquake in Japan, the 1999 Jiji earthquake in Taiwan, China and the 1999 Izmit earthquake in Turkey. The movement along active faults under major cities is the main contributing factor in these disasters. Therefore, clearly identifying the distribution of active faults in urban areas is very important to earthquake hazard mitigation. According to the tenth five-year plan which started in 2002, new researches of active fault in urban areas are programed. Besides continuing the theoretical research on active faults, reconnaissance survey of active faults in urban areas is an important goal for Chinese scientists in the tenth five-year. Comprehensive works are to be carried out in more than 20 major cities in China.

III. Characteristics of Active Faults in Active Tectonic Provinces of China

The continental crust of China is highly active tectonic area located at the southeastern part of the Eurasian plate and surrounded by the Indian plate, Pacific plate and Philippine plate. It consists of several crustal blocks with different tectonic activities, such as Tarim massif, and Ordos massif. The relative movement of these massif blocks is the basic tectonic feature of the intra-plate of China. The active tectonics of China, thus, presents obviously provinces (Zhang, W., 1984; Ma, 1987; Ding, G., 1991; Deng *et al.*, 1994a; Zhang, P., 1999). Based on the characteristic differences in tectonic activities in the Quaternary, China can be divided into 5 active tectonic provinces: Tibet (TTP), Xinjiang-Uygur (XUTP), Northeast China (NETP), North China (NTP), and South China (STP) (high to low in gray scale, insets in Figs. 1 and 2: Xu and Yonekura, 1995; Deng *et al.*, 2002). We discuss the characteristics of active faults in and around these five tectonic provinces.

1) Tibet tectonic province (TTP)

The Tibet Tectonic Province covers all of the Tibetan Plateau (Fig. 1). The continuing northward indentation of the Indian plate into the inhomogeneous Tibetan crust after the collision between the Indian and Eurasian plates induced uplift and deformation of the Tibetan Plateau. Deformtion extends 1,600 km to the north reaching the northern margin of Mt. Qilianshan and the Hexi Corrider basin zone. This continuing northward indentation has also resulted in three types of tectonic deformation: convergence zones surrounding the plateau, strike-slip fault zones associated with the laterally extruding crustal blocks in the eastern plateau, and extensional basins in the southern plateau.

1. Convergence zones

Two types of convergence zones have been recognized around the plateau. The Himalayan and West Kunlun (WKT) convergence zones, which occur on the southern and northern margins of the plateau, respectively, are formed directly due to the indentation of India against Eurasia. They extend roughly perpendicular to the indenting direction. The Longmenshan (LMT), Liupanshan (LPT) and Qilianshan-Hexi Corridor (Q-HT) thrust zones along the northeastern margin of the plateau exemplify the second type of convergence zones. They are formed as a response to the eastward lateral extrusion of the Tibetan crust.

The Himalayan convergence zone on the southern flank of the Himalayan arc (Fig. 1) extends from the Lesser Himalayas to south of the Siwalik Hills, including the Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT) (Arita and Ganzawa, 1997). A convergence rate of about 20 ± 10 mm/yr has been reported for this zone (Armijo *et al*., 1986; Avouac and Tapponnier, 1993). The slip rate of the MFT in the Holocene is 15–18 mm/yr (Love and Avouac, 2000), while across the MBT and MFT, the slip rate has been inferred to be 10–13 mm/yr (Zhang, P. *et al*., 2002a), or 15 – 16 mm/yr (Bilham *et al*., 1997; Larson *et al*., 1999) based on GPS data. The West Kunlun thrust zone (WKT) develops between Mt. West Kunlun and Tarim massif. Mt. West Kunlun forms an east-west trending mountain range on the northwestern margin of the plateau. Tarim massif to the north of the plateau is currently a sedimentary basin with Cenozoic sediments measuring up to 10,000 m thick.

The Longmenshan thrust zone (LMT) mainly consists of three thrusts and associated fault-propagation folds, thrusting southeastward over the Sichuan rigid massif. This zone is approximately 60 km wide, and constitutes the topographic boundary between the eastern Tibetan Plateau and the Sichuan basin. The total vertical slip rate is about 1–2 mm/yr, and thus the convergence rate across the thrust zone is inferred to be 4–6 mm/yr (Deng *et al*., 1994b). This inferred convergence rate is consistent with 4–8 mm/yr (Zhang, P. *et al*., 2002b) or 6.7 ± 3.0 mm/yr (Wang, Q. *et al*., 2001) based on GPS data.

The Liupanshan thrust zone (LPT) is located on the northeastern margin of the Tibetan Plateau between the plateau and Ordos massif. This thrust zone absorbs a fraction of the eastward lateral slip along the Haiyuan fault (HYF), which changes its strike from NWW to NW and NS, and transforms to a fold-and-thrust structure. Based on the displacement of river terraces, the vertical slip rate in the Late Pleistocene (50–60 Ka) of the Liupanshan reverse fault has been estimated to be 0.5 – 0.6 mm/yr (Ikeda *et al*., 1998). The amount of convergence during the Quaternary has been estimated to be 11.4–15.4 km for this thrust zone based on the balanced geological cross-section method (Zhang, P. *et al*., 1991).

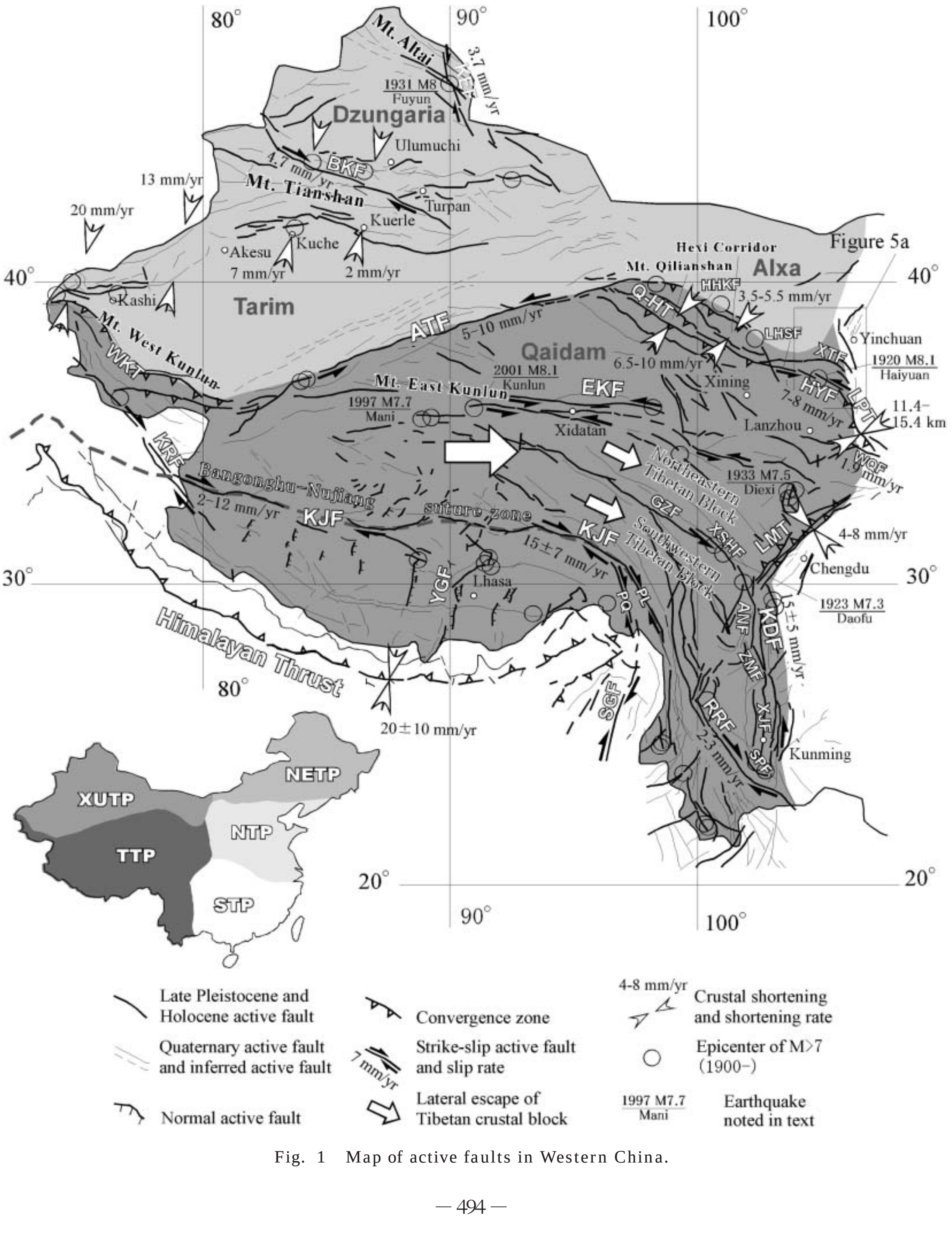

Fig. 1 Map of active faults in Western China.

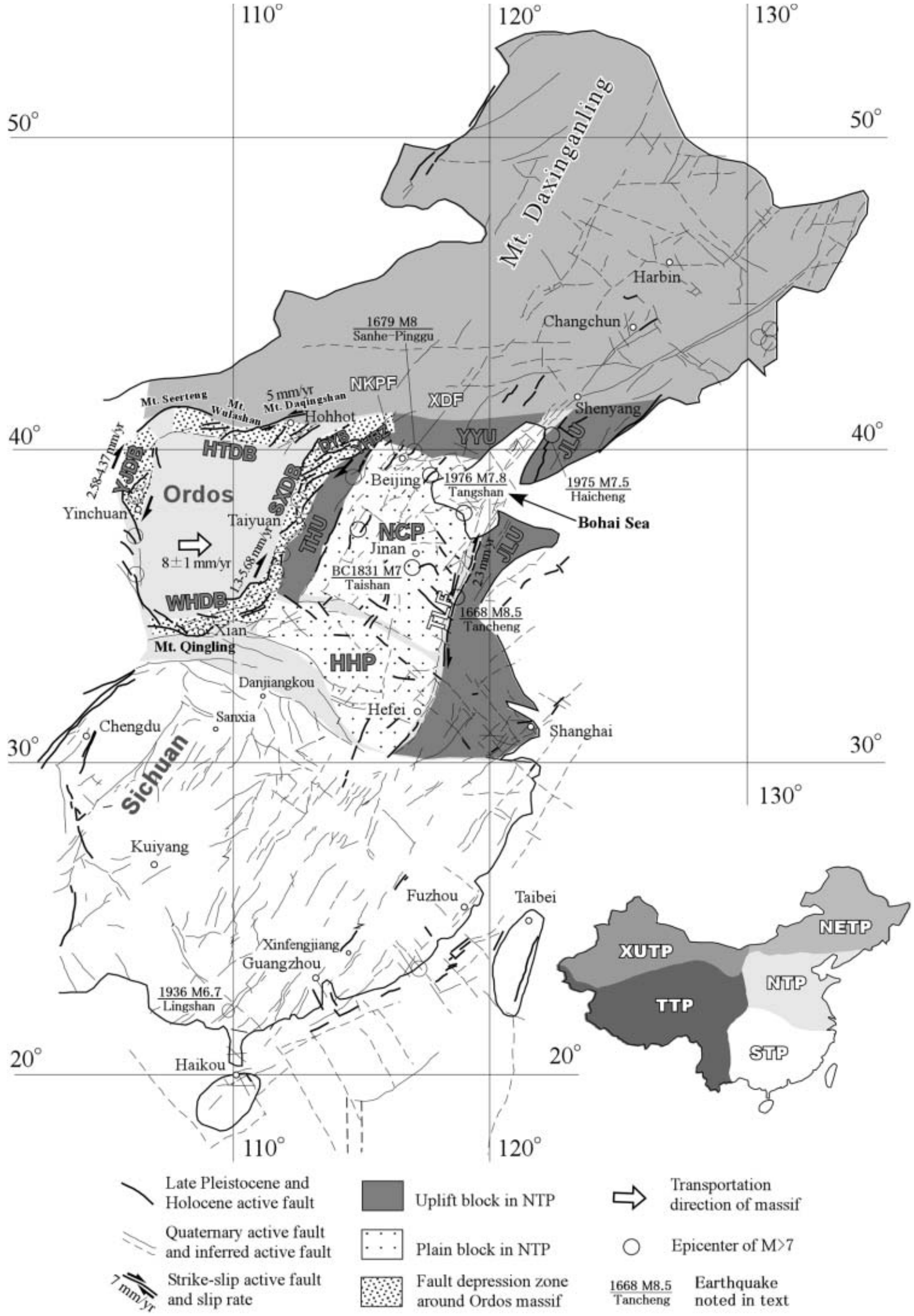

Fig. 2 Map of active faults in Eastern China.

The northwest trending Qilianshan-Hexi Corridor thrust zone (Q-HT) extends along the northeast boundary of the plateau between the plateau and Alxa massif. It consists of alternately distributed parallel mountain chains and valleys, and has a total width of 200–300 km (Institute of Geology and Lanzhou Seismological Institute, State Seismological Bureau, 1993). By reconstructing the volume of sediments deposited in the Qaidam and Hexi Corridor basins since ~35 Ma, Metivier *et al*. (1998) claimed that this thrust zone resulted from the northeastward migration of over-thrusting and uplift south of the NE termination of the Altyn Tagh fault. The rate of horizontal convergence on major faults is estimated to be 4 – 5 mm/yr, while the convergence rate across the entire zone is estimated to be 15 mm/yr (Avouac and Tapponnier, 1993). However, based on GPS data, Zhang, P. *et al*.(2002a) proposed that the convergence rates across Mt. Qilainshan and Hexi Corridor basin in the orientation of N30°E are 6.5–10 mm/yr and 3.5–5.5 mm/yr, respectively. Moreover, the horizontal slip rate and vertical slip rate along the north marginal fault of Mt. Qilianshan in the Holocene are estimated to be 2.0 mm/yr and 0.8 – 2.1 mm/yr, respectively (Institute of Geology and Lanzhou Institute of Seismology, State Seismological Bureau, 1993).

2. Extensional basins

Seven NS-trending normal fault zones (indicated by thick lines with teeth in Fig. 1) and associated graben basins have been documented in southern Tibet, situated approximately south of the Bangonghu-Nujiang suture zone (indicated by a gray dashed line in Fig. 1: Han, 1987; Institute of Geology, State Seismological Bureau, 1992). Although no field investigation on most of these normal fault zones and associated basins has been occurred, the horizontal and vertical slip rates of the Yadong-Gulu fault (YGF) and faulted basin zone have been estimated to be 3.5 – 7.5 mm/yr and 1 – 3.5 mm/yr, respectively (Institute of Geology, State Seismological Bureau, 1992). The Quaternary extension rate, is approximately 1% Ma^{-1} along an 1,100-km-long ESE traverse across southern Tibet as estimated by Armijo *et al*. (1986), while approximately 18 ± 9 mm/yr as deduced from contemporary earthquake records by Molnar and Lyon-Caen (1989). The newest estimation of the extension rate across southern Tibet is 21.28 ± 1.5 mm/yr based on GPS data (Zhang, P. *et al*., 2002b), which is similar to that deduced from contemporary earthquake records. Moreover, southern Tibet is significantly different from northern Tibet in terms of the thermal state of their crust; the crust is hotter in the south and colder in the north. Southern Tibet is characterized by a high terrestrial heat flow and a high geothermal gradient (Shen, X. *et al*., 1990). The high geothermal anomaly in the crust could be closely related to the east-west extension in southern Tibet.

3. Strike-slip fault zones

The strike-slip faults in the Tibetan Plateau can be classified into two categories. The first category, consists of the left-slip Altyn Tagh fault zone (ATF) and the right-slip Karakorum-Jiali fault zone (KJF). These fault zones are usually considered to be boundaries for the eastward extrusion of the entire northern Tibetan crust. The strike-slip faults in the second category occur within eastern Tibet, such as the East Kunlun fault zone (EKF) and the Kangding fault zone (KDF). These faults divide the eastward extruding Tibetan Plateau into several sub-crustal blocks.

The Altyn Tagh fault zone (ATF) is one of the most prominent geological features attributed to the India-Eurasia collision (Molnar and Tapponnier, 1975). This fault zone is an active, predominantly left-slip fault system extending in a NEE direction for about 1,600 km from the Mt. West Kunlun to the Mt. Qilianshan. Although it has long been recognized that the Altyn Tagh fault has a very long history of geologic evolution, left-slip faulting could have initiated as late as the late Tertiary and is currently active today (Working Group of Altun (Altyn Tagh) Fault Zone of State Seismological Bureau, 1992). The left lateral slip rate and thrust rate on the Altyn Tagh fault in the Holocene are about 4.4 – 6.8 mm/yr and 0.7 – 1.8 mm/yr, respectively (Working Group of Altun (Altyn Tagh) Fault Zone of State Seismological Bureau, 1992). Although some other researches reported the slip rate of Altyn Tagh fault to be up to 20 mm/yr (Peltzer *et al.*, 1989) or 30 mm/yr (Avouac and Tapponnier, 1993), recent GPS observation supports the results of Chinese researchers. Based on GPS data, the left lateral slip rate along the Altyn Tagh fault has been inferred to be less than 10 mm/yr (Bendick *et al.*, 2000), 5.1 ± 2.0 or 9 ± 2 mm/yr (Shen, Z. *et al.*, 2001; Wang, Q. *et al.*, 2001). The sinistral rate of relative movement between Mt. Qilianshan and the Alxa massif of 7.5 ± 1.5 mm/yr is also based on GPS data (Zhang, P. *et al.*, 2002a).

Along the Bangonghu-Nujiang suture zone occurs a structure zone composed of active, *en echelon* right-slip faults, called the Karakorum-Jiali fault zone (KJF). This fault zone, first recognized and described in detail by Armijo *et al.* (1989), comprises the hypotenuse of the Himalayan arc and divides the Tibetan Plateau into northern and southern parts. It consists of three segments with a diverse history of evolution. In the west, the fault zone follows the northwest segment of the Karakorum right-slip fault (KRF), of which right-lateral slip rate reaches 30 mm/yr (Avouac *et al.*, 1993). The middle segment consists of several *en echelon* faults, in which Gelincuo, Bengcuo and Jiali faults dextrally slip varying between 2–12 mm/yr (Institute of Geology, State Seismological Bureau, 1992; Shen, J. *et al.*, 2000). Moreover, the slip rate on the Jiali fault has also been estimated to be 15 ± 7 mm/yr by Armijo *et al.* (1989). At the eastern end, the fault zone splays into the eastern and western branches along the Parlung river valley (PL) and the Po-Qu valley (PQ), respectively (Molnar and Tapponnier, 1978). To the south, the western branch is connected with the Sagaing fault (SGF), while several *en echelon* faults, extending across the steep gorges of the Nujiang and Lancangjiang rivers, bridge the ~100-km-wide gap between the eastern branch (Parlung fault) and the Red River fault (RRF).

The East Kunlun fault zone (EKF) extends about 2,000 km along the southern boundary of the Qaidam basin. It is an important left lateral slip fault in the eastern plateau, controlling eastward extrusion of crustal sub-blocks. The slip rate along the fault zone is relatively higher in the Tibetan Plateau, measures up to 8–10 mm/yr (Seismological Bureau of Qinghai Province and Institute of Crustal Dynamics, China Seismology Bureau, 1999). The Holocene slip rate of 10 mm/yr has been estimated on the basis of the offset of drainage along the Xidatan segment (Ren *et al.*, 1993). This fault zone has been divided into 7 segments based on the geometric features, distribution of slip rate, and ruptures of historical and pre-historical earthquakes. Four large earthquakes of $M \geq 7$ have occurred on the fault zone since the 1930's, including the 1997 Mani earthquake of M 7.7 and the 2001 Kunlun earthquake of M 8.1.

The Kangding fault zone (KDF) is another major left lateral slip fault zone in the eastern plateau. It extends about 1,400 km from southern Yunnan Province, through Sichuan Province, and into Qinghai Province. This fault zone consists of five major faults (the Ganzi (GZF), Xianshuihe (XSHF), Anninghe (ANF), Zemuhe (ZMF), and Xiaojiang (XJF) faults) connected to each other by large bends or *en echelon* steps. Each segment of the fault zone has been the locus of at least one major earthquake according to historic records. During the last century, six earthquakes of $M \geq 7$ had occurred along the fault system, and at least twenty-one such events have occurred since AD 624 (Gu, 1983). The Kangding fault zone divides the eastward-extruded Tibetan crust into two parts (Fig. 1). North of the fault zone, the eastward-extruded crustal block(the Northeastern Tibetan Block)encounters resistance from the Sichuan rigid massifs, which has led to the formation of the Longmenshan thrust zone on the leading edge of the extruding crustal block. South of the fault zone, the crustal block (the Southeastern Tibetan Block) extrudes eastward or southeastward at a faster rate than the Northeastern Tibetan Block (He and Ikeda, 2001). The sinistral strike-slip rates are about 6–10 mm/yr (Zhao, 1985) and 15 ± 5 mm/yr (Allen *et al.*, 1991) along the Xianshuihe fault, 6–10 mm/yr along the Anninghe fault, 5.8–8.5 mm/yr along the Zemuhe fault, and 13.0–16.5 mm/yr along the Xiaojiang fault (He, 2000), respectively.

The Red River fault (RRF) extends southeastward through Vietnam into the South China Sea. During the early-mid Tertiary it was a left-lateral shear zone (Tapponnier *et al.*, 1990), which converted to a right-slip fault in the late Tertiary (Briais *et al.*, 1993). The late Quaternary slip rate along this fault is 2–3 mm/yr(Allen *et al.*, 1984)or 2.6–4 mm/yr (Guo, 2001), much less than those of other strike-slip faults in eastern Tibet. Moreover, these estimated slip rates are all based on the data taken from the northwestern portion of the fault zone. Almost no sound evidence of activity in late Quaternary has been confirmed from the southeastern portion of the fault. An alternate explanation is that the activity on the southeastern portion of the fault zone has transferred to the Shiping-Jianshui fault zone (SPF), which extends southeasterly to the north of and parallel to the Red River fault zone. The dextral slip rate of the Shiping-Jianshui fault zone has been estimated to be 3–6 mm/yr (Han and Mao, 1993), and several earthquakes of $M \geq 6$ have been recorded for this fault zone.

In addition to the major strike-slip faults mentioned above, there are several other active faults within and around the Tibetan Plateau, such as the Haiyuan left-slip fault (HYF) and the West Qinling northern piedmont left-slip fault (WQF). The former has a slip rate of 7–8 mm/yr (Zhang, P. *et al.*, 1988; Institute of Geology, State Seismological Bureau and Seismological Bureau of Ningxia Hui Autonomous Region, 1990), and the latter has a slip rate of about 1.9 mm/yr (Teng *et al.*, 1991).

2) Xinjiang-Uygur tectonic province (XUTP)

The Xinjiang-Uygur tectonic province is a Cenozoic regenerated orogenic belt characterized by depressed basins, reverse faults, active folds, and large strike slip faults. The

Tarim and Dzungaria massifs are two uniform active blocks. Mt. Tianshan is a typical Cenozoic regenerated orogenic belt located between the two massifs. An active reverse fault-fold belt in the foreland basin, and the intermountane-depressed basin characterize the late Quaternary tectonic activities in the XUTP. The horizontal shortening rates across the reverse fault-fold belts in the foreland depression of Kuche and Ulumuchi are 10.4 mm/yr and 5.8 mm/yr, respectively, while the shortening rate of Turpan basin is 3.4 – 4.1 mm/yr. The total horizontal shortening rate of crust across Mt. Tianshan has been calculated using the balanced geological cross-section method: 15 mm/yr near Kuche, 10 mm/yr near Kuerle, and 7 mm/yr near Turpan (Deng *et al*., 2000). Using GPS data the horizontal shortening rate across Mt. Tianshan has been estimated 20 mm/yr for areas west of Kashi, 13 mm/yr for areas east of Kashi, 7 mm/yr near Kuche, and 2 mm/yr at Kuerle (Abdrakhmatov *et al*., 1996; Zhang, P. *et al*., 2002a). Both the results induced by the balanced geological cross-section method and GPS observation indicate that the shortening rate decreases eastward. In addition, in the area north of the Dzungaria massif the vertical slip rate across the frontal reverse fault of Mt. Altai is 1–2.3 mm/yr (Shen, J. *et al*., 1998a).

Furthermore, the faulting along the NW striking faults obliquely crossing Mt. Altai and Mt. Tianshan generally present right lateral strike slip. The Keketuohai-Ertai fault (KEF) is the seismogenic fault of the 1931 M 8 Fuyun earthquake (Seismological Bureau of Xinjiang Uygur Autonomous Region, 1985), and the lateral slip rate is 3.7 mm/yr (Bai *et al*., 1996). The lateral slip rate along the Boluokenu fault(BKF), which obliquely crosses Mt. Tianshan, is estimated to be 4.7 mm/yr (Yang and Shen, 2000).

3) North China tectonic province (NTP)

The North China tectonic province (Fig. 2, NTP) is an extensional province, mainly pieced together by normal faults, normal strike-slip faults, and graben or half-graben basins. The western part of the tectonic province consists of the stable Ordos massif, while the eastern part consists of several fault blocks.

In the Ordos massif there are no obvious active faults or relative movements. GPS data observed in the massif have shown that this massif moves eastward at an approximate uniform rate of 8 ± 1 mm/yr (Zhang, P. *et al*., 2002a). In contrast, strong tectonic activity occurs in the extensional shear belts around this massif (Research Group on "Active fault system around Ordos massif," State Seismological Bureau, 1988). East of the Ordos massif is Shaanxi fault depression belt (SXDB), an extensional dextral shear belt consisting of tens of down-faulted basins and associated normal faults, and normal strike-slip faults. In the middle section of this belt, NNE-trending faults of normal dextral slip develop with a horizontal slip rate of 1.3–5.68 mm/yr and a vertical slip rate of 0.15 – 0.69 mm/yr. In the northern and southern ends of the belt, extensional range-basin tectonic zones are controlled by ENE-trending normal faults with vertical slip rate of 0.12–1.48 mm/yr (Shentu *et al*., 1990; Xu and Deng, 1990; Liu *et al*., 1991; Ran *et al*., 1991; Deng *et al*., 1994c; Dou *et al*., 1995; Cheng and Yang, 1996). West of the Ordos massif is Yingchuan - Jilantai fault depression belt (YJDB). The horizontal and vertical slip rates on the NNE-trending normal dextral faults in this belt vary from 2.58 to 4.37 mm/yr and from 0.23 to 2.1 mm/yr, respectively (Research Group on "Active fault system around Ordos massif", State Seismological Bureau, 1988; Deng and Liao, 1996; Liao *et al*., 2000). To the south of the Ordos massif, the Weihe fault depression zone (WHDB) is controlled by a series of EW-trending normal sinistral faults. The normal slip component is usually larger for these controlling faults. The normal-slip rates on the range-front faults of Mt. Huashan and Mt. Qingling are 2–3 mm/yr and 1.5 – 2.2 mm/yr, respectively (Research Group on "Active fault system around Ordos massif", State Seismological Bureau, 1988; Li, Y., 1992; Seismological Bureau of Shaanxi Province, 1996). To the north of the Ordos massif extends the EW-trending Hetao fault depression zone (HTDB). The vertical slip rate along the controlling normal faults of the depression zone, the range-front faults of Mt. Daqingshan, Mt. Wulashan and Mt. Seerteng, vary from 2.2 to 6.47 mm/yr, while the sinistral slip rate along the range-front fault of Mt. Daqingshan is about 5 mm/yr (Research Group on "Active fault system around Ordos massif", State Seismological Bureau, 1988; Li, K. *et al*., 1994; Wu *et al*., 1996; Jiang *et al*., 2000). Moreover, in the four fault-depression belts mentioned above, three earthquakes of *M* 8 and 30 earthquakes of *M* 6–7.5 have occurred since the Christian era.

The eastern part of the tectonic province is more complex, consisting of several blocks. The North China Plain block (NCP) is the center block, surrounded by the Taihangshan uplift block (THU) to the west, the Yingshan-Yanshan uplift block (YYU) to the north, the Jiaoliao uplift block (JLU) to the east and Hehuai Plain block (HHP) to the south. Among these blocks, NW-trending sinistral strike-slip and NE-trending dextral strike-slip faults exist. Of these faults, The Tancheng-Lujiang fault zone (TLF) is one of well-known fault zones in China (Institute of Geology, State Seismological Bureau, 1987). It serves as the boundary between North China Plain and Jiaoliao uplift blocks, and has obvious segmentation. The northern segment is a normal dextral slip fault, while the southern segment shows reverse dextral slip with horizontal slip rate of 2.3 mm/yr. The 120 km long surface rupture and 7–9 m coseismic displacement of the 1668 *M* 8.5 Tancheng earthquake have been found along the southern segment (Li, J. *et al*., 1994). In the North China Plain, a group of conjugate faults of NNE-trending and NWW-trending developed. The 1976 *M* 7.8 Tangshan earthquake and 1679 *M* 8 Sanhe-Pinggu earthquake originated on the NNE-trending dextral faults, while the 1975 *M* 7.5 Haicheng earthquake occurred on one of the NWW-trending sinistral faults. The Bohai Sea in the east of the North China Plain may be an active pull-apart basin (Deng *et al*., 2001).

4) South China tectonic province (STP)

The South China tectonic province (Fig. 2: STP) is a province of less tectonic activity. Active faulting is mainly located in the middle and downstream basin areas of the Yangtze River and the southeastern coast regions. Even in the most active southeastern coast regions, the vertical slip rate along the NE-trending faults is 0.4–2.3 mm/yr, and horizontal and vertical slip rates on the NW-trending sinistral slip faults only vary from 1.1 to 3.2 mm/yr and from 0.4 to 1.7 mm/yr, respectively (Ding, X. *et al*., 1999; Wang, Y. *et al*., 2001). The distribution of velocity in this tectonic province based on GPS date presents no obvious change or gradient. This suggests that the tectonic deformation in the tectonic province is of a decreased magnitude (Zhang, P. *et al*., 2002a).

5) Northeast China tectonic province (NETP)

The tectonic activity and earthquakes of the Northeast China tectonic province (Fig. 2, NETP) are more subdued than that in other tectonic provinces. The deep-focus earthquake caused by subduction of the Pacific Plate under the Asian Plate is characteristic in this tectonic province. The activity of faults in this province is somewhat related to volcano activity.

IV. Paleoseismology and Fault Segmentation

Both paleoseismology and fault segmentation are very active frontiers in the field of active fault research. In order to make the advance of research of active faults in China well understood, it is necessary to introduce in more detail progresses in these two important aspects in China.

1) Paleoseismology

A paleoearthquake is a pre-historic event or historic event without clear historical record. Although paleoearthquake research is over a century old, the modern paleoseismology initiated in the 1970's, when researchers (Clark *et al*., 1972; Sieh, 1978) applied trenching and radiocarbon dating techniques to researching paleoearthquake fault. Paleoseismology in China started in the late 1970's when the understanding of paleoseismology began with paleo-landslide, paleo-liquefaction, and paleo-fissure evidence. Zhu *et al*. (1979) excavated the earliest trenches in China aiming at revealing the traces of paleoearthquakes, and began modern paleoseismology research in China.

Since the late of 1980's, the study of paleoseismology in China has progressed in an international arena. Using trenching to directly study the paleo-rupture events and the recurrence interval of paleoearthquakes has resulted in many achievements. Deng *et al*. (1984) first used the term "colluvial wedge" to recognize and divide the paleoearthquake sequences exposed by trenches in China. Wang and Li (1984) excavated and studied the seismogenic fault of the 1976 *M* 7.8 Tangshan earthquake, and concluded that the recurrence interval of events with the same magnitude is about 7,500 years. Ran *et al*. (1988) dated the paleoearthquakes on the Heihekou fault (HHKF), Hexi Corridor, using fault scarp morphology, soil-chronology, Radiocarbon-14, and thermoluminescence to reveal the periodicity of paleoearthquakes during late Quaternary.

Since the 1990's, paleoseismology research in China has made great progresses, mainly in increasing the accuracy of paleoearthquake location, filling in the paleoearthquake history, and applying paleoearthquake data to make mid- to long-term earthquake prediction and assess seismic hazard. Trenching technology is one of the main methods used in paleoseismology research. The application of large-scale trench group and the three-dimension trench has increased the accuracy of paleoearthquake parameters. The first application of the three-dimension trench not only revealed at least seven paleoearthquakes in the Holocene, but also measured coseismic horizontal displacements of five paleo-events at the trench on the Haiyuan fault (Fig. 3; Ran *et al*., 1997). Combined with information collected from 35 other trenches (Institute of Geology, State Seismological Bureau and Seismological Bureau of Ningxia Hui Autonomous Region, 1990; Min, 1998), more reliable

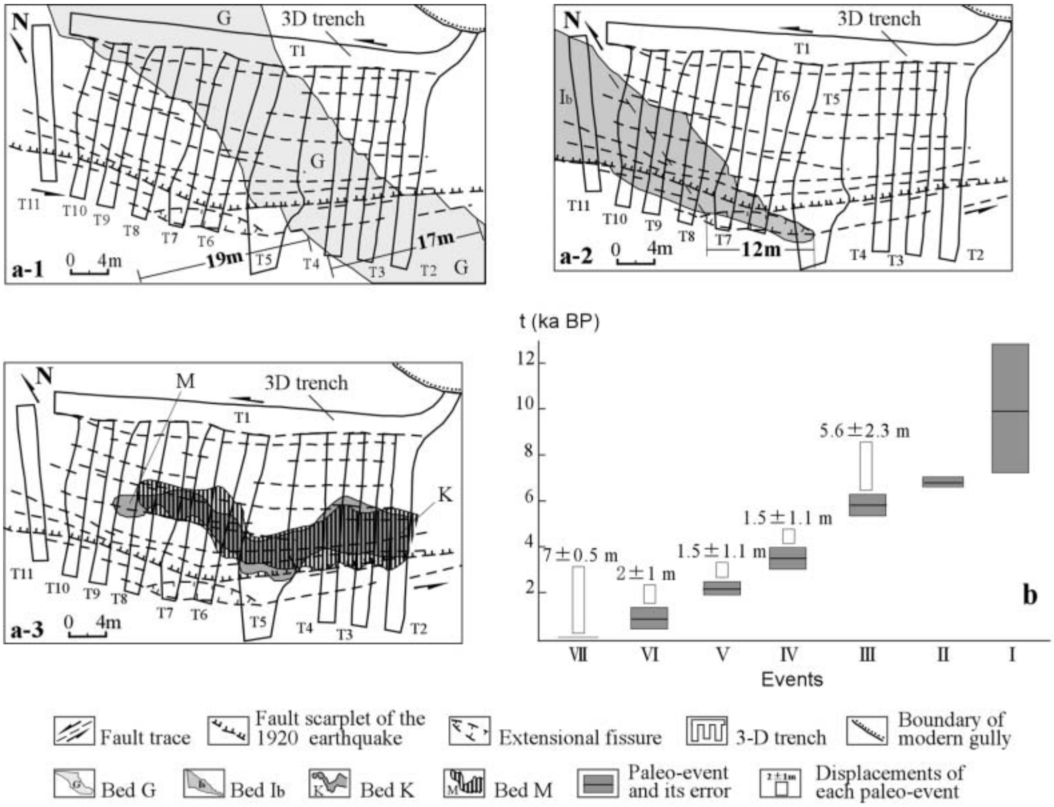

Fig. 3 a) 3-dimension trench excavation at Gaowanzi Village on the Haiyuan fault, northwestern China (see Fig. 7a for location: Ran *et al*., 1997); a-1, a-2 and a-3 indicate the present distribution and displacement of bed G, bed Ib and beds K and M in the trench. b) paleo-events found in the 3-dimension trench (Ran *et al*., 1997).

analysis of earthquake recurrence intervals and earthquake rupture patterns along the Haiyuan fault zone (HYF) is possible. A large-scale trench group has also been widely applied to paleoseismology instead of single small trench that was widely applied in the 1980's and the early 1990's. The Laohushan fault (LHSF), located at the eastern section of the northern piedmont fault zone of Mt. Qilianshan, is a Holocene strike-slip active fault. A group of twelve trenches were excavated across the fault, with measurement of twelve topographic profiles of fault scarps. It was revealed that the paleoseismology on the fault currently present was inhomogeneous in time and space: 7 paleoearthquakes of approximately *M* 7 with 1,000 years recurrence interval on the eastern segment and 3 paleo-events of approximately *M* 7 with 1,500 years recurrence interval on the western; a larger earthquake of *M* 7.5 caused the fault to rupture entirely (Yuan *et al*., 1994). The Yanhuai Basin zone (YHBZ), located northwest of Beijing, is a typical basin-range tectonic zone in the northeastern boundary of the Ordos massif. Thirty trenches revealed thirty-four paleoearthquakes with an 1,153 ± 990 years average recurrence interval and 1.2–

2.2 m coseismic displacement on four normal faults in this basin zone (Ran, 1997; Ran *et al*., 1998). The piedmont fault of Mt. Daqingshan is the northern boundary fault of the eastern part of Hetao basin, the northern boundary of the Ordos massif. A trench group, consisting of two trenches of 36 m and 25 m long, and 9 m and 5 m deep, revealed four paleoearthquakes with a recurrence interval of proximately 2 – 5 Ka (Wu *et al*., 1995).

Furthermore, many trenches excavated across different portions of a fault make it possible that more events may be revealed and complete history of earthquake activity of the fault may be discovered. However, it does not mean that the more trenches there are, the less the uncertainty of the information on paleoearthquake events is. Because of the dating uncertainty of paleoearthquake events, one paleoearthquake event may be interpreted as different events in different trenches. For example, a paleoearthquake which occurred on an active fault is revealed in two different trenches, but radiocarbon samples taken from the two trenches dated different ages for the same event. In cases where dating data are lacking, the same event is usually interpreted as two or more events. Mao and Zhang (1995) proposed use of the progressive constraining method to decrease this kind of uncertainty due to complicated trench data. For events revealed in any trench we can determine either its upper bound, or lower bound, or its time interval. When all of the events revealed in each trench along the same fault are plotted, it is possible to identify the same event revealed in different trenches by upper bound, lower bound and time interval constrains. If an event is discovered in more than two trenches, we can use different upper and lower bounds to constrain the occurrence time of paleoearthquake and to reduce the uncertainty associated with dating. Figure 4 shows how to determine paleoearthquakes based on data from several trenches using progressive constraining.

Besides the trenching technology, there are several other methods applied to recognizing paleoearthquake in recent years. Li, T. *et al*. (1994) made a research of 62 sag ponds along the Xianshuihe fault (XSHF), and found that 6 depositional cycles of these sag ponds represent 6 paleoearthquake events during past 20 Ka near Luhuo County. The Xiadian fault (XDF) is the seismogenic fault of the 1679 *M* 8 Sanhe-Pinggu earthquake. Comparison of two stratigraphic logs of drills on both sides of the fault showed different deposition on both sides of the fault in the last 26 Ka. By analyzing the offsets of sediments and stratigraphic marks, Xu *et al*.(2000) identified 11 paleoearthquakes. Moreover, microstructural observation on invisible or die-out faults can assist in the determination of the age and recurrence intervals of paleoearthquakes more accurately. Invisible faults or concealed faults often lead to complexity and uncertainties in paleoearthquake research. Confirming or negating the existence of concealed faults and tracing the terminated levels of die-out faults by microstructural observation can assist in recognizing paleoearthquakes more accurately. Chao *et al*. (2000) analyzed microstructures of original-state directional samples taken from several typical paleoearthquake trenches to conclude this knowledge.

The research of paleoseismology in the last 10 years has helped us understand paleoseismic rupture behavior, and recurrence behavior along several major fault zones or in an

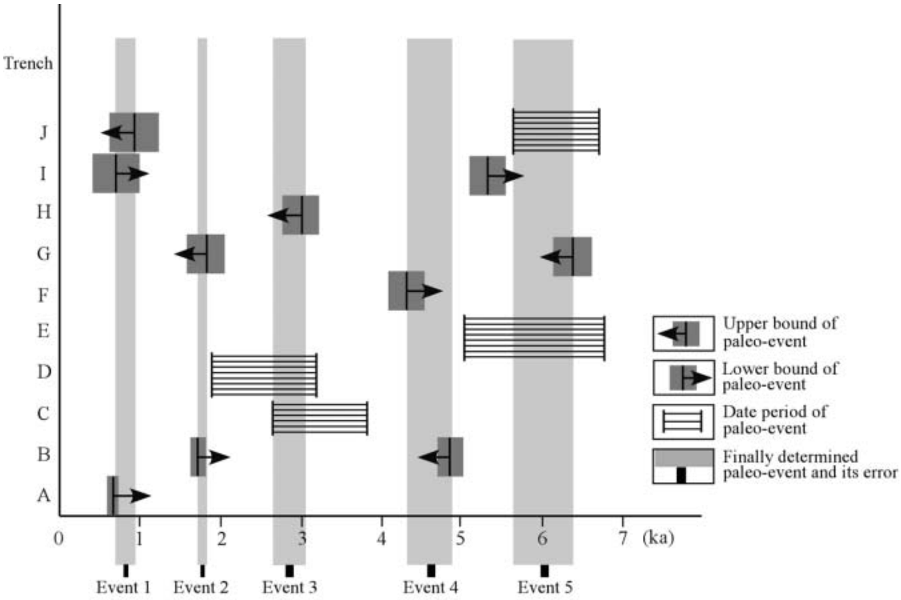

Fig. 4 Illustration diagram showing the progressive constraining method in paleoseismological studies (Mao and Zhang, 1995).

active region. A group of trenches, consisting of 3 main trenches and 3 auxiliary trenches, was excavated across the Hohhot segment of the piedmont fault of Mt. Daqingshan. A complete paleoseismological history of the fault during the period time since 19 Ka BP was revealed. The paleoseismic recurrence pattern shown by the complete paleoearthquake record follows a quasi-periodic recurrence model with an average recurrence interval of 2,375 ± 432 years (Ran *et al.*, 2002). Based on paleoearthquake data from a 3-D trench (Ran *et al.*, 1997) and 35 other trenches (Institute of Geology, State Seismological Bureau and Seismological Bureau of Ningxia Hui Autonomous Region, 1990; Min, 1998), we can identify two temporal clusters during the last 7 Ka paleoearthquake history: the first cluster occurs approximately 4.6 – 6.4 Ka and the second 1 – 2.8 Ka (Ran and Deng, 1998; Min *et al.*, 2001; Zhang, P. *et al.*, 2001). Furthermore, the ruptures affect each other in segments not only along an active fault zone but also in an active region. Between the northeastern margin of the Tibetan Plateau and the North China tectonic province, many active faults, including the Haiyuan fault zone and faults in the southern part of the YJDB exist (Fig. 5a). In addition to 5 large earthquakes of $M \geq 7$ in the last 400 years (1561, 1622, 1709, 1739 and 1920), there hane been 19 paleoearthquakes in this area (Min, 1998; Research Group on "Active fault system around Ordos massif", State Seismological Bureau, 1988; Wang, Y. *et al.*, 1990). Min *et al.* (2000) analyzed these earthquakes to conclude that: (1) the average recurrence interval along an individual fault is usually 1 – 2 Ka, and earthquakes along faults in the NTP seem to have quasi-periodic recurrence intervals, while those along faults in the northeastern margin of the Tibetan Plateau

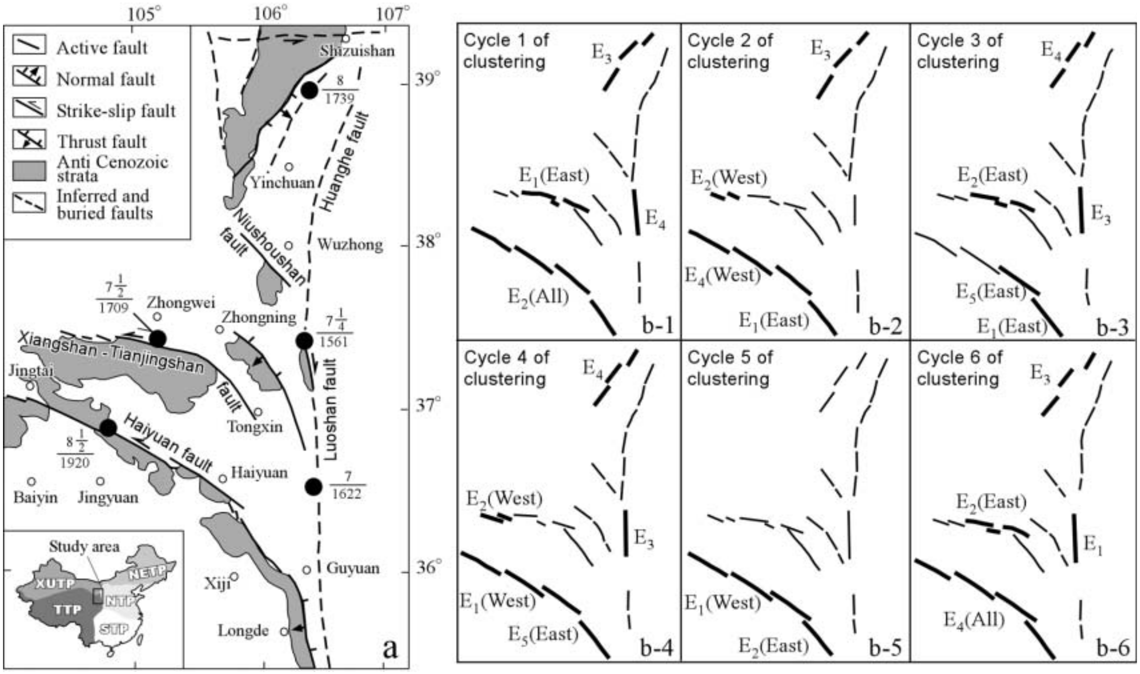

Fig. 5 Between the northeastern margin of the Tibetan Plateau and North China tectonic province (a), 24 paleoearthquakes and historic earthquakes have been recognized, which show temporal clustering pattern. Earthquakes within a cluster migrate according to a certain pattern, usually starting at south, then migrating to north and come back to south (b) (Min *et al*., 2000).

have no regular recurrence interval; (2) regional earthquakes clearly show a temporal clustering pattern, and the mitigation of earthquakes within a cluster follows a certain pattern, usually starting to the south, then migrating to north and back to south (Fig. 5). In addition, paleoseismological research along the Xiaojiang fault (XJF) shows that the recurrence interval of a characteristic earthquake based on paleoearthquake data is longer than that deduced from the average slip rate and maximum displacement of a major earthquake, even when subtracting 10% creep slip (Wallace *et al*., 1984). Shen, J. *et al*. (1998b) proposed the new concept of "relative creep", which means that the total displacement is caused by all earthquakes other than the characteristic earthquake, and determined a formula for calculating slip rate of "relative creep". Comparing the slip rate of relative creep and paleoearthquake data, we can obtain a more reliable recurrence interval for the characteristic earthquake.

2) Fault segmentation

Fault segmentation is a fundamental concept to earthquake research. The segmentation of many large faults on the basis of geometric, structural and active features has been known for decades. Allen (1967) described five zones of the San Andreas fault based on seismic activity, three strong active zones and two weak active or inactive zones, and divided this fault into four segments. Wallace (1970) divided the San Andreas fault into nine segments, and described their active features in detail. The contemporary fault segmentation theory with the concept of seismic rupture behavior, an important contribution of paleoseismology, only developed in the 1980's. On the basis of paleoseismological data for the Wasatch and San Andreas fault zones, Schwartz and Coppersmith (1984) proposed that a large fault zone is usually divided into several segments, and that each segment tends to generate essentially the same magnitude or characteristic earthquake having a relatively narrow range of magnitude near the maximum. In China, segmentation of a large fault zone based on geometric, structural and active features had been done for decades, while fault segmentation associated with earthquake rupture behavior and prediction of seismic risk has only started since the mid 1980's. Major research work has been done on the Xianshuihe fault (XSHF) in eastern Tibet (Wen, 1993; Wen *et al*., 2002), the Anninghe fault (ANF) in southwestern China (Tang *et al*., 1989; Wen, 2000), the Xiangshan-Tianjingshan fault (XTF) in north-central China (Wang, Y. *et al*., 1990), the Tancheng-Lujiang fault (TLF) in eastern China (Gao and Zheng, 1991), and the Haiyuan fault (HYF) in north-central China (Institute of Geology, State Seismological Bureau and Seismological Bureau of Ningxia Hui Autonomous Region, 1990; Zhang, P. *et al*., 2001), *etc*.

Generally, fault segmentation can be generated in four ways: 1) geometric segmentation, 2) structural segmentation, 3) active segmentation and 4) rupture segmentation. Of them, geometric and structural features are the basis of fault segmentation, while the distribution, process, and history of rupture are the essence of segmentation. Nevertheless, most of the completed segmentation research is usually based on the difference of active feature, associated with geometric and structural, because of the lack of paleoseismological data. After approximately ten years of fault segmentation research, some useful segmentation criteria and methods have been summarized (Ding, G., 1992; Ding, G. *et al*., 1993; Deng and Zhang, 1995). Based on the results of segmentation researches on three faults that have been regarded internationally as the most reliable for fault segmentation, Zhang, P. *et al*. (1998) summed up six segmentation methods (geotectonic, geophysical, geomorphologic, geometric, active characteristic, and paleoseismological), and thirty segmentation features.

The Nankou piedmont fault (NKPF) in west Beijing is one of the northeastern trending normal faults developing in the Beijing area (Huang *et al*., 1991). He and Fang (1995) divided this fault into four segments based on the differences in geometry, geomorphology and Quaternary activity. It was proposed that segmentation of the fault is caused by differential movement of the depressed blocks in the southeastern side of the fault rather than the discontinuities along the fault. The eastern piedmont fault of Mt. Liupanshan is an active reverse fault due to the eastward extrusion of the Tibetan crust. Based on the change of geometric features, active history and active characteristics, Xiang *et al*. (1998) divided this reverse fault into a north, middle and south segment. The faulting along the northern segment indicates mainly sinistral slip, while faulting in the middle and southern segments is principally reverse slip. The active period of the northern segment is younger than that of the southern segment, and the horizontal slip is greater in the north than in the south.

Cheng and Yang (1996) divided the southern marginal fault zone of Datong-Yangyuan basin

(DYB) located in the Shaanxi fault depression zone (SXDB) into northeast and southwest segments. This segmentation was based on the differences in tectonic geomorphology: (1) the height of the fault scarp along the northeastern segment is larger than that along the southwestern segment, and the height of the fault scarp is greatest in the center and deceases gradually toward two ends along both the segments; (2) 0.34 mm/yr slip rate, 0.9 m average coseismic displacement from an earthquake event, and 900–1,000 years recurrence interval along the southwestern segment, while 0.99 mm/yr, 3.1 m and 1,800 years along the northeastern segment.

In addition to such standard methods as geometry, geologic structure, geophysical field and active history, some other features have been developed for segmenting active faults. Preferred orientation and fabric of minerals have a close relationship to the mode of slip along a fault. The fabric analysis of gouge in the Xiangshan-Tianjingshan fault (XTF) by an X-ray method with a Textrete-Goniometer showed that this fault could be divided into three segments. The illite fabric in the middle segment has no orientation due to strike slip faulting, while the maximum density area in the eastern and western segments is caused by sinistral-shear creep (Zhang, B., 1997). The fabric feature of fault gouge shows that the eastern piedmont fault of Mt Liupanshan is composed of three segments as Xiang *et al.* (1998) divided based on change of geometric and active features (Zhang, B. *et al.*, 2000). The sinistral slip along the northern segment has made the local strong deformation, traction fold, Riedel shear angle of 11°—26°, P foliation and randomly preferred orientation of illite mineral developed within fault gouge. The creep slip and reverse slip along the middle and southern segments are identified by general deformation, a Riedel shear angle of 11°or less, banded fold, ptygmatic structure and polygemic preferred orientation of illite mineral developed within fault gouge (Zhang, B. *et al.*, 2000). The deep circulation of hot spring water can strongly weaken an active fault and its wall rock, and the weakening increases as the circulation depth increases. Based on observations of 14 hot springs along the northern section of the Red River fault zone, Lin (1993) segmented the northern section of the Red River fault zone into four segments: Jianchuan, Eryuan, Dali and Midu. The earthquake activity on the Eryuan segment is lower because of deeper circulation of hot spring water, while earthquake activity of the other segments is higher because of shallower circulation of hot spring water.

In recent years, the stability of segmentation, the persistence of a segment boundary, the gradation of segmentation, and the multirupture scenarios have received much focus in research. The extent of a segment is commonly used to estimate the potential earthquake size, and the segment boundary plays an important role in arresting earthquake rupture from event to event. The means to identify persistent discontinuities is very important to eliminate the uncertainties in fault segmentation and prediction of potential earthquake sizes. Studies of the geometric pattern of five well-documented historic earthquake ruptures in the Basin and Range Province revealed three important relationships between rupture termination and the size of structural discontinuities: (1) terminations of normal faulting earthquakes are associated with structural discontinuities; (2)

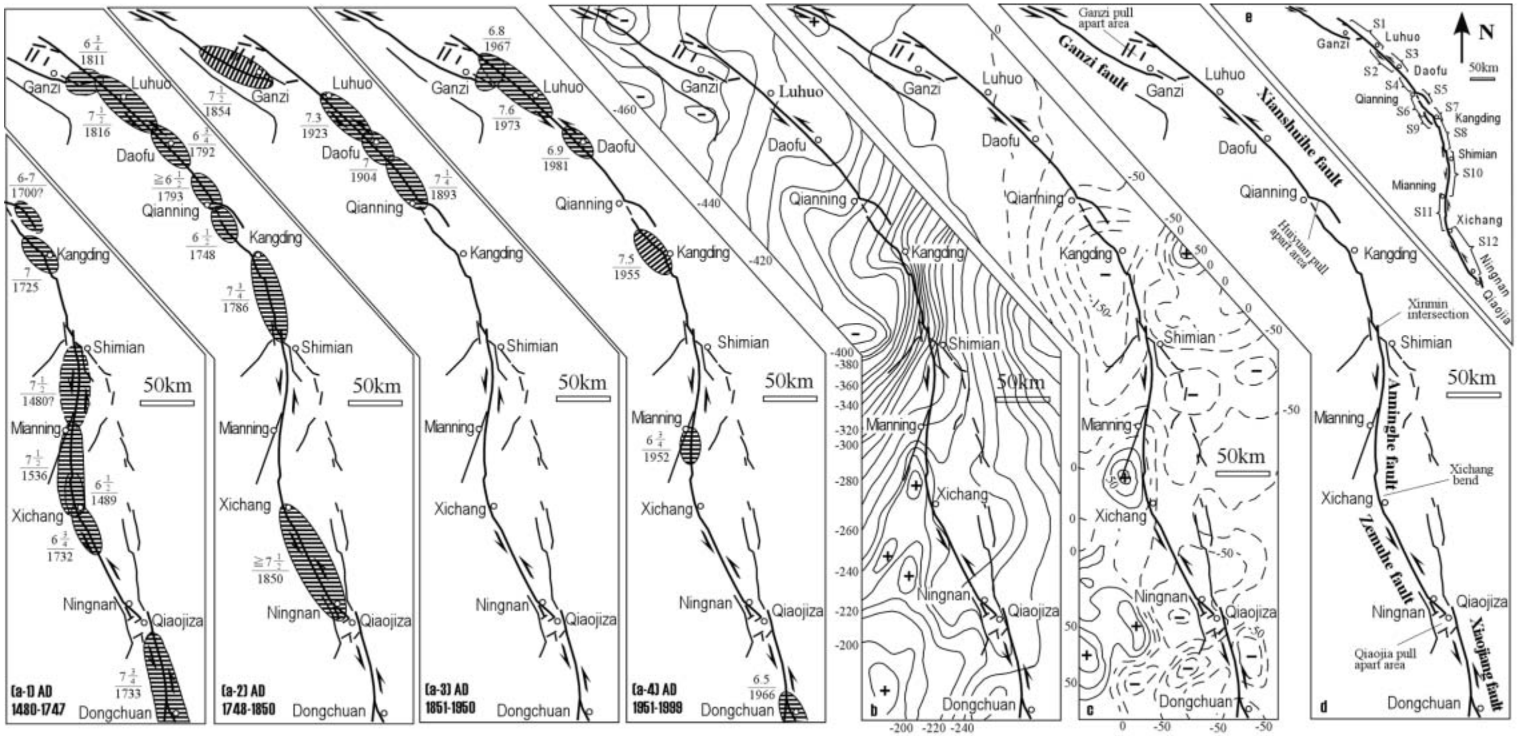

Fig. 6 Scheme of rupture segmentation for characteristic earthquakes of the Xianshuihe-Anninghe-Zemuhe fault zone (XSHF, ANF and ZMF in Fig. 1: Wen, 2000).

a) seismic sources for different periods, a-1: 1480 – 1747, a-2: 1748 – 1850, a-3: 1851 – 1950, a-4: 1951 – 1999); b) Bouguer anomaly; c) 10 km-upward aeromagnetic anomaly; d) fault geometry; e) scheme of rupture segmentation.

the sizes of inter-rupture discontinuities that significantly stop or impede the propagating rupture are larger than the intra-rupture discontinuities that have been ruptured through by the earthquake; (3) the sizes of inter-rupture discontinuities that stopped the earthquake rupture appear to scale with the length and displacement of the surface rupture(Zhang, P. *et al*., 1999). In spite of the lack of a quantitative relationship between discontinuity size and segment length, these three relations mentioned above are useful to identify persistent discontinuities.

The Xianshuihe-Anninghe-Zemuhe fault zone (XSHF-ANF-ZMF), located in the northern-central section of the Kangding fault zone (KDF), is one of the well-segmented faults in China. Wen (2000) delineated the fault zone into 12 rupture segments using geometric structure, active features, geophysical data, crustal deformation, historic earthquake data and research results of paleo-earthquakes(Fig. 6). The following knowledge of segmentation on strike-slip fault zone was also concluded. (1) The persistent and important boundaries are generally larger geometric discontinuities, structural barriers, and transition areas of Quaternary active behavior of faults, which terminate the propagation of earthquake ruptures by partly change in volume; (2) Approximately 50% of the historic earthquake ruptures terminated without obvious geometric discontinuities or structural barriers, suggesting that identifying such non-persistent boundaries on the strike-slip fault is as important as persistent boundaries; (3) The non-persistent boundaries can be identified by earthquake rupture and the recurrence behavior, spatial difference of current active behavior, composition of small geometric discontinuities, and release barriers.

The phenomenon of segment gradation or multi-rupture is an important finding on major faults as the San Andreas fault and the Haiyuan fault. As noted above, the Haiyuan fault is a left-slip fault zone, trending north-western along the northeastern margin of Tibetan Plateau. The fault consists of 11 sub-parallel fault strands separated by pull-apart basins of different sizes(Fig. 7a). The average strike of the Haiyuan fault is about N75 °W, while individual fault strands trend N60－65 °W. Based on the difference of active sense and fault strike, this fault was divided into eastern and western segments, taking the eastern piedmont of Mt. Nanhua as the boundary (Institute of Geology, State Seismological Bureau and Seismological Bureau of Ningxia Hui Autonomous Region, 1990). Recent research on paleoearthquakes along the fault suggested that the Haiyuan fault not only can be delineated by three segments but also presents multi-rupture segmentation. There are three kinds of earthquake rupture models proposed: rupture of one segment, cascade rupture of two segments, and rupture of entire fault (Ran and Deng, 1998; Min *et al*., 2001; Zhang, P. *et al*., 2001). Min *et al*. (2001) identified ten paleoearthquakes in the last 10 Ka along the Haiyuan fault through trenching research: the first and last events ruptured all of fault strands, three faults (third, sixth and eighth) ruptured in the western segment, two faults (fifth and seventh) ruptured in the middle segment, the other three faults (second, fourth and ninth) ruptured in the middle and eastern two segments, and no paleo-event ruptured independently in the eastern segment (Fig. 7b). Therefore, the rupture segmentation of the fault presents three grades: first, entire fault zone that produces larger size earthquake of

$M \geq 8$; second, two segments (middle and eastern) that produces smaller size earthquake of $M \geq 7$; third, one segment that also produces smaller size earthquake of $M \geq 7$.

Furthermore, because paleoseismology and fault segmentation are very useful to understand the rupture process of faulting and predict the place and magnitude of potential earthquake, the paleoseismology and fault segmentation have been applied to seismological engineering, analysis of seismic risk and seismic zonation (He and Zhou, 1993; Zhang,

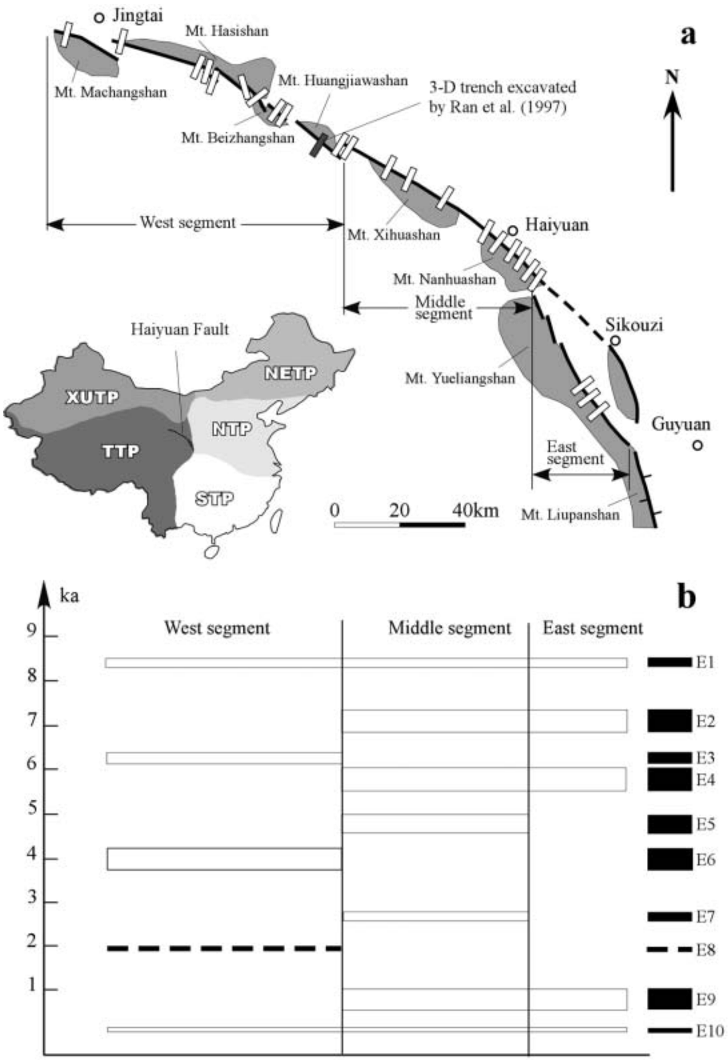

Fig. 7 Segmentation of the Haiyuan fault (Min *et al.*, 2001).
a) The geometric pattern of three segments of the Haiyuan fault, trench locations across the fault indicated by short bars; b) the history of large ruptures on the Haiyuan fault based upon paleoseismic data from trenches.

P. *et al*., 1998). When applying paleoseismology and fault segmentation, we should pay more attention to uncertainty and incompleteness of paleoseismology, and segment gradation or multi-rupture. Zhang, P. *et al*. (1998) suggested following points of view when fault segmentation is used in seismic safety assessment: (1) Sufficient and concrete evidence is necessary for fault segmentation; (2) uncertainties associated with fault segmentation require comprehensive segmentation features, (3) in order to increase reliability of fault segmentation, reliable features should be used as much as possible;(4)it is important to pay attention to the persistent nature of fault segmentation boundary.

V. Remarks

In this paper, we presented a brief review of active fault research in China on: (1) research history, (2) the characteristics of active faults in different active tectonic provinces, and (3) major progresses in paleoseismology and fault segmentation. Although many foreign researchers conducted research works in China, especially in the Tibetan Plateau, we focused on work done by Chinese researchers. Moreover, the Institute of Geology, China Seismological Bureau, independent from Chinese Academy of Science in 1978, is the major institution engaged in active fault research in China. There are other institutions and universities have engaged in active fault research, however, most of active fault research in China have been done by China Seismological Bureau and associated local seismological bureaus. This review paper is made principally based on the research work done by the Institute of Geology, China Seismological Bureau and associated local seismological bureaus. Since last year, China Seismological Bureau has begun a major five-year project to detect active faults under more than 20 selected major cities. The Institute of Geology and some local seismological bureaus will participate in this project. We are confident that this project will contribute to active fault research in China and throughout the world.

Acknowledgments

Thanks to Qidong DENG, Peizhen ZHANG, Rongkan RAN and Bengang ZHOU of Institute of Geology, China Seismological Bureau for their helpful suggestions and useful references. Thanks are also due to Eric CANNON from Colorado University, USA for his reviews that improved the English expression of this paper.

References

Abdrakhmatov, K.Y., Aldazhanov, S.A., Hager, B.H., Hamburger, M.W., Herring, T.A., Kalabaev, K.B., Kalabayev, K.B., Makarov, V.I., Molnar, P., Panasyuk, S.V., Prilepin, M.T., Relinger, R.E., Sadybakasov, I.S., Souter, B.J., Trapeznikov, Y.A., Tsurkov, V.Y. and Zubovich, A.V. (1996): Relatively recent construction of the Tianshan inferred from GPS measurements of present-day crustal deformation rates. *Nature*, **384**, 450–453.

Allen, C.R. (1967): The tectonic environment of seismically active and inactive areas along the San Andreas fault system. *Stanford Univ. Pubs. Geol. Science*, **11**, 70–82.

Allen, C.R., Han, Y., Sieh, K.E., Zhang, B. and Zhu, C. (1984): Red River and associated faults, Yunnan Province, China: Quaternary geology, slip rate, and seismic hazard. *Geol. Soc. Am. Bull*., **95**, 686–700.

Allen, C.R., Luo Z., Qian, H., Wen, X., Zhou, H. and Huang, W. (1991): Field study of a highly active fault zone: The Xianshuihe fault of southwestern China. *Geol. Sco. Am. Bull*., **103**, 1178–1199.

Arita, K. and Ganzawa, Y. (1997): Thrust tectonics and uplift process of the Nepal Himalaya revealed from fission-track ages. *J. Geography*, **106**, 156–167. (in Japanese)

Armijo, R., Tapponnier, P., Mercier, J.L. and Han T. (1986): Quaternary extension in Southern Tibet: Field observations and tectonic implications. *J. Geophys. Res*., **91(B14)**, 13803–13872.

Armijo, R., Tapponnier, P. and Han, T. (1989): Late

Cenozoic right-lateral strike-slip faulting in southern Tibet. *J. Geophys. Res.*, **94(B3)**, 2787–2838.

Avouac, J.P. and Tapponnier, P. (1993): Kinematic model of active deformation in central Asia. *Geophys. Res. Lett.*, **20**(10), 895–898.

Avouac, J.P., Tapponnier, P., Bai, M. and Wang, G. (1993): Active thrusting and folding along the northern Tian Shan and late Cenozoic rotation of the Tarim relative to Dzungeria and Kazakhstan. *J. Geophys. Res.*, **98**, 6755–6804.

Bai, M., Luo, F. and Yin, G. (1996): Keketuohai-Ertai active fault zone, Xinjiang. *Inland Earthquake*, **10**(4), 319–329. (in Chinese)

Bendick, R., Bilham, R., Freymuller, J.T., Larson, K. and Yin, G.(2000): Geodetic evidence for a low slip rate in the Altyn Tagh fault system. *Nature*, **404**, 69–72.

Bilham, R., Larson, K., Freymuller, J., Jouanne, F., Lefort, P., Leturmy, P., Mugnier, J., Gamond, J., Glot, J., Martinod, J., Chaudury, N., Chitrakar, G., Gautam, U., Koirala, B., Pandey, M., Ranabhat, R., Thakuri, M., Timilsina, U., Tiwari, D., Vidal, G., Vigny, C., Galy, A. and de Voogd, B. (1997): GPS measurement of present-day convergence across the Nepal Himalaya. *Nature*, **336**, 61–64.

Briais, A., Patriat, P. and Tapponnier, P. (1993): Updated interpretation of magnetic anomalies and seafloor spreading stages in the South China Sea: Implication for the Tertiary tectonics of Southeast Asia. *J. Geophys. Res.*, **98**(B4), 6299–6328.

Chan, Kuota (1938): Lingshan earthquake of April 1, 1936, in Guangxi province. *Geological Review*, **3** (4), 427–447. (in Chinese)

Chang, L.C. (1938): Investigation of Diexi earthquake in Sichuan Province. *Geological Review*, **3** (3), 251–292. (in Chinese)

Chao, H., Deng, Q., Li, J., Wang, Z. and Man, H. (2000): Characteristics of microstructures of the invisible faults in Quaternary unconsolidated sediments. *Seismology and Geology*, **22**(2), 147–154. (in Chinese with English abstract)

Cheng, S. and Yang, G. (1996): Late Quaternary segmentation and segmented variations in tectonic geomorphology of southern marginal fault zone of Datong-Yangyuan basin. *Seismology and Geology*, **18**(4), 289–300. (in Chinese with English abstract)

Chinese Working Group of the Project IGCP-206 (1989): *Atlas of Aactive Fault in China*. Seismological Press, Beijing, and Xi'an Cartographic Publishing House, Xi'an.

Clark, M.M., Grantz, A. and Rubin, M. (1972): Holocene activity of the Coyote Creek fault as recorded in sediments of Lake Cahuilla. *U.S. Geol. Surv. Prof. Pap.*, **787**, 112–130.

Deng, Q. (1996): Active tectonics in China. *Geological Review*, **42**(4), 295–299. (in Chinese with English abstract)

Deng, Q. and Liao, Y. (1996): Paleoseismology along the range-front fault of Helan Mountains, North Central China. *J. Geophys. Res.*, **101(B3)**, 5873–5893.

Deng, Q. and Zhang, P. (1995): Principles and methods of segmentation of active fault(1). *Researches on Contemporary Crustal Movement*, **6**, 196–207. (in Chinese)

Deng, Q., Wang, Y. and Liao, Y. (1984): Fault scarps, colluvial wedges on the frontal fault of Mt. Helan and its active history during Holocene. *Chinese Science Bull.*, **9**, 557. (in Chinese)

Deng, Q., Xu, X. and Yu, G. (1994a): Provincial characteristics of active faults in Chinese continent and its contributing factors. *In* State Seismological Bureau eds.: *Research of Active Fault in China*. Seismological Press, Beijing, 1–14. (in Chinese)

Deng, Q., Chen, S. and Zhao, X. (1994b): Tectonics, seismicity and dynamics of Longmenshan Mountains and its adjacent regions. *Seismology and Geology*, **16**(4), 387–403.(in Chinese with English abstract)

Deng, Q., Yonekura, N., Xu, X., Suzuki, Y., Wang, C., Takeuchi, A., Su, Z. and Wang, Y. (1994c): Study on the late Quaternary kinematics of the northern piedmont fault of the Liuleng Mountain. *Seismology and Geology*, **16**(4), 339–343. (in Chinese with English abstract)

Deng, Q., Feng, X., Zhang, P., Xu, X., Yang, X., Peng, S. and Li, J. (2000): *Active Tectonics in Tianshan Mountains*. Seismological Press, Beijing. (in Chinese with English abstract)

Deng, Q., Min, W. and Chao, H.(2001): Tectonics in the Cenozoic and seismicity in Bohai Sea region. *In* Lu, Y. (Chief-editor): *Neotectonics and Environment*. Seismological Press, Beijing, 218–233. (in Chinese)

Deng, Q., Zhang, P., Ran, Y., Yang, X., Min, W. and Chu, Q. (2002): Basic characteristics of active tectonics in China. *Science in China (D)*, **32**(12), 1020–1030. (in Chinese with English abstract)

Ding, G. (Chief-editor) (1991): *An Introduction on Lithospheric Dynamics of China*. Seismological Press, Beijing. (in Chinese)

Ding, G. (1992): Several problems regarding the segmentation of active fault. *Earthquake Research in China*, **8**(2), 1–10. (in Chinese with English abstract)

Ding, G., Tian, Q., Kong, F., Xie, X., Zhang, L. and Wang, L. (1993): *Segmentation of Active Fault - Principles, Methods and Application*. Seismological Press, Beijing. (in Chinese)

English abstract)
Ding, X., Wang, Y. and Ye, S. (1999): *Active Faults and Earthquakes in Southeastern Coast Region of Fujian Province*. Scientific Press of Fujian, Fuzhou. (in Chinese)
Dou, S., Yu, S., Liu, G., Xu, Y., Liang, H. and Yan, F. (1995): Geometric structure and activity of the Xizhoushan Mountain piedmont fault in Shanxi Province. *Research on Active Fault*, **4**, 104 – 115. (in Chinese with English abstract)
Gao, W. and Zheng, L. (1991): Active fault segmentation and the identification of potential seismic zones along the Tanlu fault. *Earthquake Research in China*, **7**(4), 87–91. (in Chinese with English abstract)
Geosicence Division of China Academy of Science (1957): *1st Symposium on Neotectonic Movement in China, China Academy of Science*. Scientific Press, Beijing. (in Chinese)
Gu, G. (1983): *Earthquake Catalog of China*. Scientific Press, Beijing. (in Chinese)
Guo, S. (Chief-editor) (2001): *Honghe (Red River) Active Fault Zone*. Ocean Press, Beijing. (in Chinese with English abstract)
Han, T. (1987): *Active Tectonics of Tibet*. Geological Memoirs of Ministry of Geology and Mineral Resources, People's Republic of China, Series 5: Structural Geology and Geomechanics, No.4, Geological Publishing House, Beijing. (in Chinese with English abstract)
Han, X. and Mao, Y. (1993): Seismic risk analysis to Shiping-Jianshui fault zone in the next 30 years. *J. Seismological Research*, **16**(1), 52–59. (in Chinese with English abstract)
He, H. (2000): *Quaternary Tectonic Deformation in the Southeastern Margin of the Tibetan Plateau*. Ph. D. Dissertation, Department of Geography, University of Tokyo.
He, H. and Fang, Z. (1995): Fault block movement and segmentation of active fault. *Seismology and Geology*, **17**(1), 1 – 6. (in Chinese with English abstract)
He, H. and Ikeda, Y. (2001): Strike-slip rate of the Kangding fault system: Implications of regional tectonic evolution of the Tibetan Plateau. *EOS. Trans. AGU, Fall Meet. Suppl.*, Abstract, T11E 0884.
He, H. and Zhou, B. (1993): Segmentation of seismo-active faults and the potential maximum earthquake magnitude on the segment. *Seismology and Geology*, **15**(4), 333–340.(in Chinese with English abstract)
Heim, A. (1934): Earthquake region of Daofu. *Geol. Sco. Am. Bull.*, **45**, 1057–1049.
Huang, X., Wang, L., Xu, J., Fang, Z., Zhang, F., Xiang, J. and Wang, H. (1991): Characteristics of neotectonic movement in Beijing area. *Seismology and Geology*, **13**(1), 43 – 51. (in Chinese with English abstract)
Ikeda, Y., He, H., Xiang, H., Guo, S., Zhang, W. and Zhang, B. (1998): Quaternary activity of the Liupanshan fault along the northeastern margin of the Tibetan Plateau. *J. Geography*, **107**, 542 – 548. (in Japanese)
Institute of Geology and Lanzhou Seismological Institute, State Seismological Bureau (1993): *The Qilian Mountain-Hexi Corridor Active Fault System*. Seismological Press, Beijing.(in Chinese)
Institute of Geology, State Seismological Bureau (1979): *Seismotectonic Map of China (1:4,000,000) and Its Summary Instruction*. Cartographic Publishing House, Beijing. (in Chinese with English abstract)
Institute of Geology, State Seismological Bureau (Chief-editor, Fang, Z.) (1987): *Tancheng-Lujiang Fault Zone*. Seismological Press, Beijing. (in Chinese)
Institute of Geology, State Seismological Bureau (Chief-editor, Wu, Z.) (1992): *Active Fault in the Central Tibet*. Seismological Press, Beijing. (in Chinese with English abstract)
Institute of Geology, State Seismological Bureau and Seismological Bureau of Ningxia Hui Autonomous Region (Chief-editor, Deng, Q.) (1989): *Geological Map of Haiyuan Active Fault (1:50,000)*. Seismological Press, Beijing. (in Chinese)
Institute of Geology, State Seismological Bureau and Seismological Bureau of Ningxia Hui Autonomous Region (Chief-editor, Deng, Q.) (1990): *Haiyuan Active Fault*. Seismological Press, Beijing. (in Chinese)
Jenning, C.W. (1975): *Fault Map of California with Locations of Volcanoes, Thermal Springs and Thermal Wells (1:750,000)*. California geologic data map series, California Division of Mine and Geology.
Jiang, W., Xiao, Z. and Wang, H. (2000): Sinistral strike-slip along western end of the piedmont active fault of Daqingshan Mountain, Inner Mongolia, China. *Earthquake Research in China*, **16**(3), 203 – 212. (in Chinese with English abstract)
Larson, K., Bürgmann, R., Bilham, R. and Freymueller, J. (1999): Kinematics of the India-Eurasia collision zone from GPS measurement. *J. Geophys., Res.*, **104**, 1077–1093.
Lawson, A.C. (1908): *The California Earthquake of April 18, 1906-Report of the State Earthquake Investigation Commission, 1. Parts 1, 2*. Carnegie Institution of Washington, Publication, 87.
Li, J., Chao, H., Cui, Z. and Zhao, Q. (1994): Segmentation of active fault along the Tancheng-Lujiang fault zone and evaluation of strong earthquake risk. *Seismology and Geology*, **16**(2),

121–126. (in Chinese with English abstract)

Li, K., Wu, W. and Yang, F. (1994): Segmentation research of piedmont active fault of Mt. Daqingshan. *In* State Seismological Bureau eds.: *Research of Active Fault in China*. Seismological Press, Beijing, 102–113. (in Chinese)

Li, P. (Chief editor) (1993): *Xianshuihe-Xiaojiang Fault Zone*. Seismological Press, Beijing. (in Chinese)

Li, P. (1994): *Research of Seismology in Sanxia and Danjiangkou Regions*. Seismological Press, Beijing. (in Chinese)

Li, T., Du, Q., Zhang, C. and You, Z. (1994): Study on paleoearthquakes based on sag ponds and associated sediment along the Xianshuihe fault zone. *Research on Active Fault*, **3**, 126 – 134. (in Chinese with English abstract)

Li, T., Du, Q., You, Z. and Zhang, C. (1997): *Xianshuihe Active Fault and Seismic Hazard Assessment*. Chengdu Cartographic Publishing House, Chengdu. (in Chinese)

Li, Y. (Chief-editor) (1992): *Study of Ground Fissures in Xi'an and Active Fault in Weihe Basin*. Seismological Press, Beijing. (in Chinese)

Liao, Y., Chai, Z., Zhang, W. and Xu, W. (2000): The active features and slip rate of Lingwu faults in late Quaternary. *Earthquake Research in China*, **16**(2), 158–165.

Lin, Y. (1993): A discussion on the relation of circulation depth of hot spring water to seismic activity on the northern segment of the Honghe fault zone. *Seismology and Geology*, **15**(3), 200 – 206.

Liu, G., Yu, S., Zhang, S., Dou, S., Xu, Y. and Fan, Z. (1991): The north Wutaishan piedmont fault zone in Shanxi. *Research on Active Fault*, **1**, 118 – 130. (in Chinese with English abstract)

Love, J. and Avouac, J.P. (2000): Active folding of fluvial terraces across the Sirvolike Hills, Himalayas of Central Nepal. *J. Geophys. Res.*, **105**, 5735–5770.

Ma, X. (Chief-editor) (1987): *Lithospheric Dynamics Atlas of China*. China Cartographic Publishing House, Beijing. (in Chinese)

Mao, F. and Zhang, P. (1995): Progressive constraining method in paleoseismic study and paleoearthquakes along the major active faults in Northern Xinjiang. *Research on Active Fault*, **4**, 153 – 164. (in Chinese with English abstract)

Metivier, F., Gaudemer, Y., Tapponnier, P. and Meyer, B. (1998): Northeastward growth of the Tibet plateau deduced from balanced reconstruction of two depositional areas: The Qaidam and Hexi Corridor basins, China. *Tectonics*, **17**, 823–842.

Min, W. (1998): *Study on Regional Paleoseismology*. Ph.D. Dissertation, Institute of Geology, China Seismological Bureau. (in Chinese with English abstract)

Min, W., Zhang, P. and Deng, Q. (2000): Primary study on regional paleoearthquake recurrence behavior. *Acta Seismologica Sinica*, **13**(2), 180 – 188.

Min, W., Zhang, P., Deng, Q. and Mao, F. (2001): Detailed study of Holocene paleoearthquakes of the Haiyuan active fault. *Geological Review*, **47** (1), 1–7. (in Chinese with English abstract)

Molnar, P. and Lyon-Caen, H. (1989): Fault plane solution of earthquakes and active tectonics of Tibetan Plateau and its margins. *Geophys. J. Int.*, **99**, 23–153.

Molnar, P. and Tapponnier, P. (1975): Cenozoic tectonics of Asia: Effects of a continental collision. *Science*, **189**, 419–426.

Molnar, P. and Tapponnier, P. (1978): Active tectonics of Tibet. *J. Geophys. Res.*, **83(B11)**, 5361–5375.

Peltzer, G., Tapponnier, P. and Armijo, R. (1989): Magnitude of late Quaternary left-lateral displacements along the north edge of Tibet. *Science*, **246**, 1285–1289.

Ran, Y. (1997): *Detailed Research of Paleoearthquakes at Several Typical Regions in China and Exploration of Recurrence Behavior of Large Earthquakes*. Ph.D. Dissertation, Institute of Geology, China Seismological Bureau. (in Chinese with English abstract)

Ran, Y. and Deng, Q. (1998): Paleoearthquakes along Haiyuan fault and discussion of grading on rupture of large earthquakes. *Quaternary Science*, **3**, 272 – 278. (in Chinese with English abstract)

Ran, Y., Li, Z., You, H. and Zhu, X. (1988): Research and dating of paleoearthquake along Heihekou fault in Hexi Corridor. *Seismology and Geology*, **10** (4), 118–126. (in Chinese with English abstract)

Ran, Y., Fang, Z., Li, Z., Wang, J. and Li, R. (1991): Characteristics of active faults around Huailai-Zhuolu basin. *Research on Active Fault*, **1**, 140 – 155. (in Chinese with English abstract)

Ran, Y., Duan, R. and Deng, Q. (1997): 3-D trench excavation and paleoseismology at Gaowanzi of the Haiyuan fault. *Seismology and Geology*, **19** (2), 97–107. (in Chinese with English abstract)

Ran, Y., Fang, Z., Duan, R., Li, Z., Wang, J., Yang, Z., Ji, F. and Li, J. (1998): Recurrence model of paleoearthquakes along Baying segment of the northern marginal fault of Fanshan basin in Hebei Province. *Earthquake Research in China*, **14**(1), 47–58. (in Chinese with English abstract)

Ran, Y., Zhang, P., Hu, B. and Guo, W. (2002): Paleoseismic activity on the Hohhot segment of Daqingshan piedmont fault in the late Quaternary history. *Earthquake Research in China*, **18**

(1), 15–27. (in Chinese with English abstract)
Ren, J., Wang, Y., Wu, Z. and Ye, J. (1993): Holocene earthquake deformation zones and their displacement and slip rates along the Xidatan-Dongdatan of Kusaihu-Maqu fault in northern Qinghai-Xizhang Plateau. *Seismology and Geology*, **15**(3), 285 – 288. (in Chinese with English abstract)
Research Group for *Active Fault of Japan* (1980): Active Faults in Japan. University of Tokyo Press, Tokyo. (in Japanese)
Research Group for Active Fault of Japan (1991): *Active Faults in Japan: Sheet Maps and Inventories(Revised Edition)*. University of Tokyo Press, Tokyo. (in Japanese)
Research Group on "Active fault system around Ordos massif", State Seismological Bureau(Chief-editor, Wang, Y. and Deng, Q.) (1988): *Active Fault System Around Ordos Massif*. Seismological Press, Beijing. (in Chinese)
Schwartz, D.P. and Coppersmith, K.J.(1984): Fault behavior and characteristic earthquake: Example from the Wasatch and San Andreas fault zones. *J. Geophys. Res.*, **89**(B7), 5681–5698.
Seismological Bureau of Qinghai Province, Institute of Crustal Dynamics, China Seismological Bureau (1999): *Eastern Kunlun Fault Zone*. Seismological Press, Beijing. (in Chinese)
Seismological Bureau of Shaanxi Province (1996): *Active Fault of the Northern Piedmont of Qingling Mountains*. Seismological Press, Beijing. (in Chinese)
Seismological Bureau of Xinjiang Uygur Autonomous Region (Chief-editor, Ding, G.) (1985): *The Fuyun Earthquake Fault Zone in Xijiang, China*. Seismological Press, Beijing. (in Chinese)
Seismogeological Committee of Chinese Seismological Society (1982): *Active Faults in China*. Seismological Press, Beijing. (in Chinese)
Shen, J., Wang, Y. and Li, M. (1998a): Preliminary study of active fault along the western Altai Mountains. *Research on Active Fault*, **6**, 109–120. (in Chinese with English abstract)
Shen, J., Wang, Y., Song, F. and Li, Y. (1998b): Relative creep rate and characteristic earthquake recurrence interval-Example from the Xiaojiang fault zone in Yunnan, China. *Seismology and Geology*, **20**(4), 328–331.(in Chinese with English abstract)
Shen, J., Ren, J. and Wang, Y. (2000): Study of right lateral slip on Jiali fault zone in late Quaternary. *Research on Active Fault*, **8**, 150–159. (in Chinese with English abstract)
Shen, X., Zhang, W., Yang, S., Guan, J. and Jin, X. (1990): Heat flow evidence for the differentiated crust-mantle thermal structures of the northern and southern terranes of the Qinghai-Xizang Plateau. *Bulletin of the Chinese Academy of Geological Science*, **21**, 203–214. (in Chinese)
Shen, Z., Wang, M., Li, Y., Jackson, D., Yin, A., Dong, D. and Fang, P. (2001): Crustal deformation along the Altyn Tagh fault system, western China, from GPS. *J. Geophys. Res.*, **106**, 30607 – 30621.
Shentu, B., Xu, Y. and Wang, Y.(1990): Preliminary study of active features and paleoearthquake relics on the Hancheng fault. *North China Earthquake Sciences*, **8**(1), 1–10.(in Chinese with English abstract)
Sieh, K.R. (1978): Pre-historic large earthquake produced by slip on the San Andreas fault at Pallett Creek, California. *J. Geophys. Res.*, **83**, 3909–3939.
Song, F., Wang, Y., Yu, W., Cao, Z., Shen, X. and Shen, J. (1998): *Xiaojiang Active Fault*. Seismological Press, Beijing. (in Chinese)
State Seismological Bureau (1976): *Map of Active Faults and Distribution of Strong Earthquakes in China(1:3,000,000)*. State Seismological Bureau, Beijing. (in Chinese)
Stein, R.S. and King, G.C.P. (1984): Seismic potential revealed by surface folding, 1983 Coalinga, California Earthquake. *Science*, **224**, 869–872.
Survey Team of Seismic Intensity in Southwest China (Chief-editor, Li, P.) (1977): *Studies of Seismogeology and Intensity Zonation in Southwest China*. Seismological Press, Beijing. (in Chinese)
Survey Team of Seismic Intensity in Southwest China (Chief-editor, Li, P.) (1979): *Bulletin of Seismogeologic Investigation of Large Earthquake Areas in Sichuan and Yunnan*. Seismological Press, Beijing. (in Chinese)
Tang, R., Huang, Z., Wen, D. and Xia, D. (1989): Study of segmentation and earthquake activity along the Anninghe fault. *J. Seismological Research*, **12**(4), 337–346. (in Chinese)
Tapponnier, P., Lacassin, R., Leloup, P.H., Scharer, U., Zhong, D., Wu, H., Liu, X., Ji, S., Zhang, L. and Zhong, I. (1990): The Ailaoshan/Red River metamorphic belt: Tertiary left-lateral shear between Indochina and South China. *Nature*, **343** (6257), 431–437.
Teng, R., Jin, Y., Li, X. and Su, X. (1991): Relation between episodes of faulting and recurrence of earthquakes along the Huangxianggou fault in the northern margin fault zone of the western Qiling. *Research on Active Fault*, **1**, 96 – 104. (in Chinese with English abstract)
Trifonov, V.G. (1995): World map of active faults (preliminary results of studies). *Quaternary International*, **25**, 3–12.
Wang, Q., Zhang, P., Niu, Z., Freymuller, J.T., Lai,

X., Li, Y., Zhu, W., Liu, J., Bilham, R. and Larson, K.M. (2001): Contemporary crustal movement and tectonic deformation in China continent. *Science in China (Series D)*, **31**(7), 529–536. (in Chinese)

Wang, T. and Li, J. (1984): Recurrence interval of large earthquakes in Tangshan, Heibei Province. *Seismology and Geology*, **6**(3), 76. (in Chinese with English abstract)

Wang, Y., Song, F., Li, Z., You, H. and An, P. (1990): Study on recurrence intervals of great earthquakes in Xiangshan-Tianjingshan faults in Ningxia. *Earthquake Research in China*, **6**(2), 15–24. (in Chinese with English abstract)

Wang, Y., Song, F., Huang, Q. and Chen, W. (2001): Geomorphic evidence for and rate of sinistral strike-slip movement along northwest-trending faults in Chaoshan Plain. *Earthquake Research in China*, **17**(1), 35–43. (in Chinese with English abstract)

Wallace, R.E. (1970): Earthquake recurrence intervals on the San Andreas fault. *Geol. Sco. Am. Bull.*, **5**, 190–205.

Wallace, R.E., Davis, J.F. and McNally K.C. (1984): Terms for expressing earthquake potential prediction and probability. *Bull. Seism. Soc. Am.*, **74**, 1819–1825.

Wen, X. (1993): Rupture segmentation and assessment of probabilities of seismic potential on the Xianshuihe fault zone. *Acta Seiemologia Sinica*, **6** (4), 993–1004. (in Chinese with English abstract)

Wen, X. (2000): Character of rupture segmentation of the Xianshuihe-Anninghe-Zemuhe fault zone, Western Sichuan. *Seismology and Geology*, **22**(3), 239–249. (in Chinese with English abstract)

Wen, X., Yi, G., Zhang, P. and Xu, X. (2002): Time-dependent seismic hazard assessment for the eastern-boundary fault zone of the Sichuan-Yunnan block, China. *Proceedings of the First China-Japan Workshop on Earthquake Disaster Mitigation, Sept., 2001, Beijing, China*, 141–154.

Weng, W. (1922): The earthquake of December 16, 1920, in Gansu Province. *Science*, **7**(2), 105 – 114. (in Chinese)

Willis, B. (1923): A fault map of California. *Seismol. Sco. Amer. Bull.*, **13**, 1–12.

Wood, H.O. (1916): The earthquake problem in the western United States. *Seismol. Sco. Amer. Bull.*, **6**, 181–217.

Working Group of Altun (Altyn Tagh) Fault Zone of State Seismological Bureau (1992): *The Altun (Altyn Tagh) Active Fault Zone*. Seismological Press, Beijing. (in Chinese)

Working Group on California Earthquake Probabilities (1988): Probabilities of large earthquakes occurring in California on the San Andreas fault. *U.S. Geological Survey Open-file Report*, 88–398.

Wu, W., Li, K., Ma, B., Yang, F. and Guo, W. (1995): Research on Holocene paleoearthquakes using large combinative trench along the piemont fault of Mt. Daqingshan, Inner Mongolia. *Research on Active Fault*, **4**, 123–132. (in Chinese with English abstract)

Wu, W., Nie, Z., Xu, G., Zhang, J, Jiang, W. and Yang, F. (1996): Research on the active fault of western segment of the piedmont fault of Mt. Seerteng. *Research on Active Fault*, **5**, 113 – 124. (in Chinese with English abstract)

Xiang, H., Guo, S., Zhang, B., Zhang, W., Ikeda, Y. and He, H. (1998): Active features of the eastern Liupanshan piedmont fault zone since late Quaternary. *Seismology and Geology*, **20**(4), 321 – 327. (in Chinese with English abstract)

Xu, X. and Deng, Q. (1990): The features of late Quaternary activity of the piedmont fault of Mt. Huoshan, Shaanxi Province and 1303 Hongdong earthquake (Ms=8). *Seismology and Geology*, **12** (1), 21–30. (in Chinese with English abstract)

Xu, X. and Yonekura, N. (1995): Geological setting for $M \geq 7$ historical earthquakes and future seismic risk areas in China. *J. Geodetic Society of Japan*, **41**(2), 139–160.

Xu, X., Ji, F., Yu, G., Chen, W. and Wang, F. (2000): Reconstruction of paleoearthquakes sequence using stratigraphic records from drill logs: A study at the Xiadian fault, Beijing. *Seismology and Geology*, **22**(1), 9–19. (in Chinese with English abstract)

Yang, X. and Shen, J. (2000): Late Quaternary activity of Jinghe-Alashankou section of the Boluokenu fault, interior Tianshan. *Seismology and Geology*, **22**(3), 305–315. (in Chinese with English abstract)

Yeats, R.S. (1996): Introduction of special section: Paleoseismology. *J. Geophy. Res.*, **101(B3)**, 5847–5853.

Yonekura, N. (1983): Active deformation of the continental margin along the Nankai and Suruga troughs, Southwest Japan. *Bull. Dept. Geogr. Univ. Tokyo*, **15**, 47–62.

Yuan, D., Liu, B., Lu, T., Liu, J., He, W. and Liu, X. (1994): Research on paleoearthquakes along the Laohushan active fault zone. *Research on Active Fault*, **3**, 160 – 169. (in Chinese with English abstract)

Zhang, B. (1997): Application of X-ray method with Textret-Goniometer to active fault studies. *Seismology and Geology*, **19** (1), 68 – 70. (in Chinese with English abstract)

Zhang, B., Xiang, H., Guo, S. and Zhang, W. (2000): The fabric of fault gouge from the eastern Liupanshan piedmont fault zone and their implication. *Seismology and Geology*, **22**(1), 47 – 52. (in Chinese with English abstract)

Zhang, P., Molnar, P., Burchfiel, B.C., Royden, L., Wang, Y., Deng, Q., Song, F., Zhang, W. and Jiao, D.(1988): Bounds on the Holocene slip rate of the Haiyuan fault, north Central China. *Quaternary Research*, **30**, 151–164.

Zhang, P., Burchfiel, B.C., Molnar, P., Zhang, W., Jiao, D., Deng, Q., Wang, Y., Royden, L. and Song, F. (1991): Amount and style of late Cenozoic deformation in the Liupanshan area, Ningxia Autonomous Region, China. *Tectonics*, **10**, 1111–1129.

Zhang, P., Mao F. and Chang, X. (1998): The criteria for active fault segmentation in seismic safety assessment of major engineering. *Seismology and Geology*, **20**(4), 289–301.(in Chinese with English abstract)

Zhang, P., Mao, F. and Slemmons, D.B. (1999): Rupture terminations and sizes of segment boundaries from historical earthquake ruptures in the Basin and Range Province. *Tectonophysics*, **308**, 37–52.

Zhang, P. (1999): Latest neotectonic deformation of continental lithosphere in China and earthquake disaster. *Quaternary Research*, **5**, 404–411.

Zhang, P., Min, W. and Mao, F.(2001): Paleoseismic rupture behavior and recurrence of great earthquakes along the Haiyuan fault, north-central China. *Report of "Study of Active Behavior of Fault, Paleoseismology and Recurrence Interval of Large Earthquakes", Institute of Geology, China Seismological Bureau, Project of United Seismological Fund*, 95087421.

Zhang, P., Wang, Q. and Ma, Z. (2002a): GPS velocity field of contemporary tectonic movement and active blocks in China continent. *Earth Science Frontiers*, **9**(2), 430–438. (in Chinese)

Zhang, P., Wang, Q. and Ma, Z.(2002b): Features of contemporary tectonic deformation and GPS velocity field in Qinghai-Tibetan Plateau. *Earth Science Frontiers*, **9**(2), 442–450. (in Chinese)

Zhang, W. (1984): *An Introduction of Fault-Block Tectonics*. Petroleum Industrial Press, Beijing.(in Chinese)

Zhao, X. (1985): Multiphase faulting along the Kangding fault. *In* Sichuan Seismological Bureau ed.: *Symposium of the Seismology on the Xianshuihe Fault.* Seismological Press, Beijing, 41-47. (in Chinese)

Zhu, H., Zhu, S., Wang, L. and Chen, J. (1979): An ancient earthquake profile in Zhongning County, Ningxia Hui Autonomous Region. *Seismology and Geology*, **1**(4), 26. (in Chinese)

(Received, November 12, 2002; Accepted, March 24, 2003)

Appendix: 地名の英漢対照表.

List of place name

Alxa	阿拉善	Huashan	華山	Shannxi	陝西
Baiyin	白銀	Hubei	湖北	Shanghai	上海
Beijing	北京	Jianchuan	劍川	Shenyang	沈陽
Bohai	渤海	Jiaoliao	胶遼	Shimian	石棉
Changchun	長春	Jinan	済南	Sichuan	四川
Chengdu	成都	Jingtai	景泰	Sikouzi	寺口子
Dali	大理	Jingyuan	靖遠	Taibei	台北
Danjiangkou	丹江口	Kangding	康定	Taishan	泰山
Daofu	道孚	Kashi	喀什	Taiyuan	太原
Datong	大同	Kuche	庫車	Tangshan	唐山
Diexi	迭溪	Kuerle	庫尔勒	Tarim	塔里木
Dongchuan	東川	Kunming	昆明	Tongxin	同心
Dzungaria	準葛尔	Lanzhou	蘭州	Turpan	吐魯番
Eryuan	洱源	Lhasa	拉薩	Ulumuchi	烏魯木斉
Fuyun	富蘊	Lingshan	靈山	Wuzhong	呉忠
Fuzhou	福州	Longde	隆徳	Xian	西安
Guangdong	広東	Luhuo	炉霍	Xichang	西昌
Guangsi	広西	Mani	瑪尼	Xidatan	西大灘
Guangzhou	広州	Mianning	冕寧	Xiji	西吉
Guiyang	貴陽	Midu	彌渡	Xinfengjiang	新豊江
Guyuan	固原	Ningnan	寧南	Xinjiang	新疆
Haicheng	海城	Ningxia	寧夏	Xining	西寧
Haikou	海口	Ordos	鄂尔多斯	Yangtze River	長江（揚子江）
Harbin	哈尔濱	Qaidam	柴達木	Yingchuan	銀川
Hehuai	河淮	Qianning	乾寧	Zhongning	中寧
Heifei	合肥	Qiaojia	巧家	Zhongwei	中衛
Hetao	河套	Qinghai	青海		
Hexi Corridor	河西走廊	Sanhe-Pinggu	三河-平谷		
Hohhot	呼和浩特	Sanxia	三峡		

List of Mountains

Mt. Altai	阿尔泰山	Mt. Qinling	秦嶺
Mt. Beizhangshan	北嶂山	Mt. Seerteng	色尔騰山
Mt. Daqingshan	大青山	Mt. Shizuishan	石嘴山
Mt. East Kunlun	東昆侖	Mt. Taihangshan	太行山
Mt. Hasishan	哈思山	Mt. Tianshan	天山
Mt. Huashan	華山	Mt. Wulashan	烏拉山
Mt. Huangjiawashan	黄家洼山	Mt. West Kunlun	西昆侖
Mt. Longmenshan	龍門山	Mt. Xihuashan	西華山
Mt. Machangshan	馬廠山	Mt. Yanshan	燕山
Mt. Nanhuashan	南華山	Mt. Yingshan	陰山
Mt. Qianlianshan	祁連山	Mt. Yueliangshan	月亮山

List of active faults and tectonic zones

Bangonghu-Nujiang suture zone	班公−怒江縫合線
Altyn Tagh（Altun） fault zone（ATF）	阿尔金断層
Anninghe fault（ANF）	安寧河断層
Boluokenu fault（BKF）	博羅可努断層
Datong-Yangyuan basin（DYB）	大同−陽原盆地帯
East Kunlun fault zone（EKF）	東昆侖断層帯
Ganzi fault（GZF）	甘孜断層
Haiyuan fault（HYF）	海原断層
Hehuai Plain block（HHP）	河淮平原地塊
Heihekou fault（HHKF）	黒河口断層
Hetao fault depression zone（HTDB）	河套断層沈降帯
Jiaoliao uplift block（JLU）	胶遼隆起地塊
Kangding fault zone（Xianshuihe-Xiaojiang fault zone）（KDF）	康定断層帯（鮮水河−小江断層帯）
Karakorum fault（KRF）	喀喇昆侖断層
Karakorum-Jiali fault zone（KJF）	喀喇昆侖−嘉黎断層帯
Keketuohai-Ertai fault（KEF）	可可托海−二台断層
Laohushan fault（LHSF）	老虎山断層
Liupanshan thrust zone（LPT）	六盤山衝上断層帯
Longmenshan thrust zone（LMT）	龍門山衝上断層帯
Nankou piedmont fault（NKPF）	南口山麓断層
Northeast China tectonic province（NETP）	東北活動構造区
North China Plain block（NCP）	華北平原地塊
North China tectonic province（NTP）	華北活動構造区
Qilianshan-Hexi Corridor thrust zone（Q-HT）	祁連山−河西走廊衝上断層帯
Red River fault zone（RRF）	紅河断層帯
Sagaing fault（SGF）	石階断層
Shaanxi fault depression belt（SXDB）	山西断層沈降帯
Shiping-Jianshui fault zone（SPF）	石屏−建水断層帯
South China tectonic province（STP）	華南活動構造区
Taihangshan uplift block（THU）	太江山隆起地塊
Tancheng-Lujiang fault zone（TLF）	郯城−芦江断層帯
Tibet tectonic province（TTP）	青蔵活動構造区
Weihe fault depression zone（WHDB）	渭河断層沈降帯
West Kunlun thrust zone（WKT）	西昆侖衝上断層帯
West Qinling northern piedmont fault（WQF）	西秦嶺北山麓断層
Xiadian fault（XDF）	夏甸断層
Xiangshan-Tianjingshan fault（XTF）	香山−天景山断層
Xianshuihe fault（XSHF）	鮮水河断層
Xinjiang-Uygur tectonic zone（XUTP）	新疆−維吾尔活動構造区
Xiaojiang fault（XJF）	小江断層
Yadong-Gulu fault（YGF）	亜東−谷露断層
Yanhuai Basin zone（YHBZ）	延懐盆地帯
Yingchuan-Jilantai fault depression belt（YJDB）	銀川−吉蘭泰断層沈降帯
Yingshan-Yanshan uplift block (YYU)	陰山−燕山隆起地塊
Zemuhe fault (ZMF)	則木河断層

近年の中国活断層研究の進展

何　宏　林*　佃　栄　吉*

本論文では中国における活断層研究の歴史及び近年の主な進展状況を簡潔にとりまとめた。中国の活断層研究の歴史は以下の三つの段階に分けられる：1）20 世紀前半の第一段階では，活断層研究は大地震と断層の関係の定性的な記述が中心；2）1960 年代から 1970 年代に至る第二段階では，重要な地震帯における活断層について全面的な調査を実施；3）1980 年代初期からの第三段階では，下記のような定量的な研究を実施：断層変位速度，地震断層と変位量分布，古地震調査と地震再来周期，断層幾何学とセグメンテーション，地震危険度の評価など。中国大陸は第四紀の構造運動の差異によって，五つの活構造区に分けられる。即ち，チベット活動構造区（TTP），新疆ウィグル活動構造区（XUTP），東北活動構造区（NETP），華北活動構造区（NTP），華南活動構造区（NTP）である。これらの各活動構造区内と境界に分布する活断層について本小論では主に議論した。また，最近大きく進展してきた古地震及び断層セグメンテーションを中心とする研究について検討した。即ち，大規模トレンチ調査や三次元トレンチ調査が適用され，主な断層帯に沿っての古地震の活動履歴，断層セグメントとセグメント境界の持続性，及び断層セグメンテーションの等級と断層の多重破壊との関係などに関する研究を紹介した。これらの資料は，中国大陸地震危険度の高精度化に役立てられると期待される。

キーワード：中国，活構造区，活断層研究，古地震，活動履歴，セグメンテーション

＊ 独立行政法人産業技術総合研究所・活断層研究センター