Features and mechanism of neotectonic deformation of the Xishan fault system west of Urumqi *

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Abstract We have made careful field investigation and trench exploration to the Xishan fault system in west of Urumqi, and an integrated analysis in conjunction with data of deep seismic sounding. Our result suggests that under the SN-oriented compressive stress, the Xishan block moves steadily toward the Tianshan Mountains in south, resulting in southward thrust-slip and crustal shortening, particularly the southward thrust of the Xishan fault which serves as the main boundary in south. North of the Xishan fault are the Wangjiagou fault and Jiujiawan fault which are the secondary faults associated with the Xishan fault in generation. Both faults have slippage along horizons during the uplift of the Xishan block, and the Jiujiawan fault has also a component of normal faulting due to the influence of the Bogeda nappe structure. These two faults accommodate the fold deformation of the hanging wall of the Xishan fault, thus the Xishan fault-bounded swell is characterized by monocline. All secondary faults of the Xishan fault system constitute a common seismogenic structural system, so that their seismic hazards should be considered in an equal manner.

Key words: Urumqi, Xishan fault system, neotectonic deformation, deformation mechanism

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1 Introduction

The Xishan fault system west of Urumqi refers to a series faults in the Xishan block in the west of the Urumqi city. This fault system lies at the transform site between the range-front fault-fold system of the North Tianshan and Bogeda nappe structural system (Deng et al, 2000). It comprises nine secondary faults of lengths from several thousands meters to 30 km or more with different motion features, including the Xishan fault, Wangjiagou fault and Jiujiawan fault in narrow sense. Many moderate earthquakes have been recorded around this fault system, such as the Urumqi $M5\frac{1}{2}$ of 1863, Urumqi $M5\frac{1}{2}$ of 1864 and Urumqi $M5$ of 1903. And a prominent paleoearthquake deformation zone was found on the fault (Ran et al, 2007; Shen and Song, 2008). Thus it is a significant seismogenic tectonic zone in the Urumqi area. However, since a long time, no systematic investigation has been made along this fault system. So there is no adequate evidence for the features of neotectonic deformation of this fault system, which limits understanding of mechanism of major earthquakes in this

area. During the period of 2004–2006, a project of active fault exploration and assessment of seismic hazard was implemented in the Urumqi city. Through detailed field investigation and trench exploration, in conjunction with data analysis of deep sounding, a new and more definite knowledge is obtained to the features and mechanism of neotectonic deformation of this fault system, which provides the assessment of seismic hazard of this area with scientific basis.

2 Features of neotectonic activity of Xishan fault system

The Xishan fault system in the west of Urumqi consists of nine branches, totally 35 km long, distributes in a belt of 7 km north-south width, of general trending ENE–NE (Figure 1). Among them, the Wangjiagou fault set (F_{1-1} , F_{1-2} , F_{1-3} , F_{1-4}) and Xishan fault is N-dipping thrust, while the Jiujiawan fault set (F_{2-1} , F_{2-2} , F_{2-3} , F_{2-4}) is NW-dipping normal one. The features of neotectonic activity of each fault are described below.

2.1 Wangjiagou fault set

The Wangjiagou fault set begins from the east bank of the Toutun River in west, extending eastward by Wangjiagou, and terminates nearby Muxugou. It spreads on the N-dipping pluvial gravel platform of the middle

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Pleistocene at the northern foothill of Xishan, consisting of 4 subparallel equal spacing secondary faults of ENE-striking, with lengths 8.7 km, 9 km, 10.8 km and 12.7 km from north to south, respectively. All members of this fault set are N-vergent thrusts, which dislocated the gravel platform of the middle Pleistocene and the III-grade terrace of the Wangjiagou east bank, generating apparent fault scarps of opposite-slope direction on the surface with clear geomorphic traces.

On the Wangjiagou east bank, the fault F_{1-1} dislocates the III-grade terrace of the river, resulting in fault scarps of 0.4–1.5 m height on the surface. The exploratory trench reveals F_{1-1} is thrust and offsets the dammed pond deposits of the early Holocene (Figure 2), sug-

gesting it is an active fault of the Holocene. Meanwhile, the faults F_{1-2} and F_{1-3} also dislocates the III-grade terrace of Wangjiagou, with similar geomorphic phenomena as the fault F_{1-1} . Both are active fault in the Holocene as shown by trench exploration and dating results. Scarps of the fault F_{1-4} at the southernmost of the Wangjiagou fault set are relatively gentle. As indicated by the trench, it did not dislocate the gravel beds of TL age (31.1 ± 3.2 ka B.P.) (Figure 3), implying weak activity since the late Pleistocene.

2.2 Jiujiawan fault set

The Jiujiawan fault set is composed of four NE-trending and NW-dipping normal faults arranged

Figure 1 Geological structure of the Xishan fault system west of Urumqi. 1. Holocene; 2. Upper Pleistocene; 3. Middle Pleistocene; 4. Tertiary; 5. Basement rock mountain; 6. Active fault in Holocene; 7. Active fault in late Pleistocene; 8. Inferred fault; 9. Reverse fault; 10. Normal fault.

Figure 2 Geomorphic offset by fault F_{1-1} and trench cross section on the Wangjiagou east bank. 1. silt bed; 2. sandy gravel; 3. fine sand; 4. scarp; 5. trench location; 6. measurement site at trench; 7. TL sampling site.

Figure 3 Trench cross section of fault F_{1-4} east of Wangjiagou. 1. silt bed; 2. gravel bed; 3. fine sand; 4. gypsum; 5. TL sampling site; 6. fault.

parallelly, the lengths of faults are 3.2, 4.2, 6.8 and 4.5 km from north to south, respectively. This fault set spreads on a pluvial platform of the middle Pleistocene east of Muxugou and west of Heitoushan. The fault dislocates the surface, generating fault troughs and other clear traces of deformation.

The trench across the fault reveals that the Jiujiawan fault set contains many normal faults with opposite dip directions, which exhibit an asymmetric Y-style graben on the cross section. In the south of the graben, the primary faults dip to NW at angles 50° – 70° . And in the north the secondary faults dip to SE at angles 50° – 60° . Between them, there are further secondary normal faults. Comparison of freshness of the fault

troughs shows that the surface traces of the three faults in the north are complete and continuous. The dating result indicates that they have dislocated the strata of TL age (8.4 ± 1.2) ka B.P. (Figure 4), implying active faults of the Holocene (Shen and Song, 2008). The offset landform by the southernmost fault F_{2-4} can only be identified on the air photos and satellite images. While the field investigations claim that the traces of fault deformation are very blurred, and almost no offset appears in the loess cover. This phenomenon resembles the fault F_{1-4} of the Wangjiagou fault set very much. Thus the fault branch F_{2-4} is considered to be active in the late Pleistocene.

Figure 4 Cross section of fault F_{2-3} west of Ergong railway station. ① Light-yellow loess surface bed; ② Red-brown sandy gravel bed; ③ Grey gravel bed.

2.3 Features of neotectonic activity of the Xishan fault

The Xishan fault is the main dominated fault along the southern boundary of the Xishan fault-bounded swell. In west it begins from nearby the Yongguang coal mine northwest of Liuhuanguo, extending eastward by the Toutunhe reservoir, Xishan coal mine, factory of construction material and ceramics, and 104 regiment, and splits into two branches at the factory of refractory material. The northern branch tends in NE, extending by the factory of caustic soda and Agricultural University of Xinjiang, and links the Wanyaogou fault. Roughly parallel to the Xishan road, the southern branch stretches eastward and ends nearby the communication station of the city. The fault is totally 35 km long, dipping to north at angles mostly greater than 40° , exhibiting thrust mo-

tion to south. The most obvious geomorphic indicator of this fault is that the gravel platform of the middle Pleistocene has been dislocated into escarpments of monocline ridges with throws more than 100 m between the two walls. The exploratory trench near Sidaocha in Xishan shows that the fault has only dislocated the middle and lower portions of the middle Pleistocene strata, while the upper offset is covered by the strata of TL age (37.9 ± 3.8) ka B.P. (Figure 5), implying that this fault was not active since the late Pleistocene.

The paleoearthquake study (Ran et al, 2007) suggests that the late Quaternary activities of the Wangjiagou fault set and Xishan fault are characterized by grouping and combined ruptures. Among them, F_3 and F_{1-4} are of one group, for which the last surface rupture

event occurred at 30 ka B.P. And F_{1-1} and F_{1-3} are another group which experienced 2–3 rupture events since 40 ka B.P. It means that the same event had produced combined ruptures on these four branch faults. Besides, the latest result of the project of active fault exploration and seismic hazard assessment indicates that the Wangjiagou fault set and Jiujiawan fault set have similar magnitudes, times and recurrence intervals of paleoearthquake events, though their motion manners are

different. Thus it is inferred that both the fault sets ruptures at the same times and produced different patterns of surface ruptures (Shen and Song, 2008). From this analysis, it is suggested that the faults F_{1-4} , F_{2-4} and F_3 of the Xishan fault system were all active in the late Pleistocene, and not active at present any more. Their new activities have migrated to other faults in the north, in other words the northward migration (to the basin) of the neotectonic activity characterizes this fault system.

Figure 5 Cross section of fault F_3 near Sidaocha. ① Soil-bearing gravel bed; ② Colluvial wedge; ③ Pebble bed; ④ Jurassic coal bed.

3 Features and mechanism of tectonic deformation of the Xishan fault system

3.1 Features of tectonic deformation

Since the late Quaternary, under the nearly NS-oriented tectonic stress field (Gao and Qu, 1998; Zhang et al, 2006; Long et al, 2007), the Xishan block west of Urumqi has moved steadily toward the Tianshan Mountains in south. Its overall consequence is southward thrust-slip and crustal shortening. Due to compression of the basement detachment, motions of thrust and block tilting generated apparent ENE-trending fault-bounded block monocline, i.e., the Xishan fault-bounded swell. The field investigation show that the rock beds of the Xishan mountains dip to north, its southern slope is short and steep and the northern slope broad and gentle. No obvious fold deformation appears in the hanging wall of the faults. The main boundary fault in the south, i.e., the Xishan fault, has prominent

neotectonic activity of southward thrust.

While the Xishan fault-bounded swell continues to tilt and rise, its northern flank is compressed steadily, producing a series of secondary faults, such as the Wangjiagou fault set which is of reverse faults with bedding slip (Liu et al, 2007; Shen et al, 2007). The Jiujiawan fault set lies in the east side of the Xishan block, where the nearly EW-trending Xishan fault system conjoins the NE-striking west flank of the Bogeda structural system. Because of different motion rates between these two systems, an extensional component is generated at the conjunction to form the Jiujiawan fault set which is of normal fault nature.

3.2 Beginning time of fault activity

The analysis of strata offset, sediment facies and tectonic geomorphology shows that the Xishan fault system formed after the middle Pleistocene. As found by geological mapping on a scale of 1:10,000, although all fault branches of this system have different motion am-

plitudes and activity times, they have apparently dislocated the gravel platform of the middle Pleistocene. On the both sides of the Xishan swell, there are widely distributed high platforms covered by gravel of the middle Pleistocene, which terminate abruptly nearby the fault, apparently isolated by the fault. Meanwhile, we have found it's the distribution of this gravel set at the low section of the Xishan ridge. Thus we can conclude that this fault system formed on the basis of upwarping range-front fluvial and ice-water deposit platforms of the middle Pleistocene.

Geological evidence suggests that the gravel platforms of the middle Pleistocene nearby Xishan were generated by glaciers, ice-water erosion and gravel accumulation associated with ice-water and alluvial-pluvial effects during the Dadonggou glacial period of the middle Pleistocene (200–300 ka B.P.) (Qiao, 1981; Han and Ye, 1985; Zhang et al, 1995). These gravel platforms spread widely with distinct characters and are comparable well. Our TL dating of the sample from the eastern bank of the Urumqi River shows that this set of gravel platforms is of age 200 ka, roughly consistent with the TL dating result 260 ka (Gao and Liu, 1990). Thus, it can be estimated that the Xishan fault system was generated by rapid upwarping since the time 200–300 ka B.P.

3.3 Mechanism of tectonic deformation

The stacked profile of deep seismic reflection displays clearly the subsurface structure of this fault system (Figure 6). South of Xishan, there is a low-angle

south-dipping detachment in the sediments of upper crust (R_A), which is the controlling fault of the range-front thin-skin nappe structure and does not reach and exposes on the surface near Xishan. Instead it plunges to the base of the Xishan block where the northward push from the Tianshan Mountains is hindered. In front of the Xishan block, a triangle compressive area was produced, of which the base is a wedge body bounded by a bottom thrust fault (detachment R_A) and a top passive thrust fault (F_6) (Liu et al, 2007; Shen et al, 2007). The structural analysis of strata shows that this area has experienced strong fold deformation, with low-angle reverse faults (such as F_5) and thrust sheets as well as imbricate stacks. Other features are considerable crustal thickening, swell structures and tilting uplift of the Xishan block.

Due to the north-oriented push from the Tianshan, the principal compressive stress field around the Xishan block is in NS direction, almost normal to the strike of the main fault in this area, resulting in dominant thrust deformation. Consequently, in the southern margin and north slope of the Xishan fault-bounded swell, there are a series of thrust faults, such as the Xishan fault and Wangjiagou fault set, which spread from south to north in a imbricate manner.

We suggest that the Jiujiawan normal fault set was generated by a local extensional stress which is associated with differential motions between tectonic systems. In the Urumqi area, there are two major tectonic systems: the Bogeda arcuate nappe tectonic system and North

Figure 6 Deep seismic sounding profile and geological interpretation in Urumqi area (Shen et al, 2007).

R_A : Detachment; R_B : Upper and lower crustal interface; R_C : Crust-mantle transitional zone.

Tianshan range-front nappe tectonic system (Shen et al, 2007). In tectonic setting, the Jiujiawan fault set lies at the conjunction site of these two systems. Because these two tectonic systems are moving northward at different rates, local tensile stress is generated at the Jiujiawan area, producing a series of NE trending normal faults and small grabens which constitute the Jiujiawan fault set.

The surface investigation and deep seismic sounding profiles indicate that the Xishan fault-bounded swell is a typical monocline structure, where the hanging wall of the fault has no apparent fold deformation. The Wangjiagou fault set and Jiujiawan fault set on the north slope of the Xishan swell are all N-vergent bedding slip faults. Under the NS compression, the Xishan fault-bounded swell continues to rise while no folding occurs on the fault hanging wall. The reason for this phenomenon is likely that the folding deformation of the hanging wall has been absorbed by the two fault sets mentioned above, and transformed into slippage along faults.

4 Conclusions

Since the late Quaternary, under the nearly NS-orientated compressive stress, the Xishan block west of Urumqi moves steadily southward to the Tianshan, resulting in thrust slip to south and crustal shortening as a general tectonic deformation. While the motion of its base detachment is characterized by thrust and tilting, as expressed by apparent ENE trending monocline mountains in landform, i.e., the Xishan fault-bounded swell. On its southern side, the new expression of activity of the main controlling fault-Xishan fault is also southward thrust.

On the northern side of the Xishan fault, there exist the Wangjiagou and Jiujiawan fault sets which are subsidiary faults associated with the Xishan fault in generation. The Wangjiagou fault set is of reverse faults and bedding slip which are generated by tilting of the north wall of the Xishan fault. While the Jiujiawan fault set is of normal faults under local extensional stress associated with the influence of the Bogeda nappe structure. Under the NS compression, the Xishan fault-bounded swell continues to rise while its fault hanging wall does not fold. It is likely because that the fold deformation of the Xishan fault hanging wall has been accommodated by the faults mentioned above and transformed into slippage along faults.

Although the Wangjiagou fault set and Jiujiawan

fault set on the northern slope of the Xishan swell have different motions, they are subsidiary faults generated by tilting and upwarping of the Xishan swell, and attributed to the same seismotectonic system as the Xishan fault. Therefore these faults should be taken into account equally in assessment of earthquake hazard.

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