16th World Conference on Earthquake Engineering, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 1378

Registration Code: S-Z1463098375

Study on the Late Quaternary Activity of Chenghai Fault Zone

FT. Tang(1), HJ. Ma(2), J. Song(3)

(1) Institute of Geophysics, China Earthquake Administration, Beijing 100036，China, fttang@sina.com
(2) National Earthquake Infrastructure Service, Beijing 100045，China, hjma@neis.cn
(3) Institute of Geophysics, China Earthquake Administration, Beijing 100036, songjian04@163.com

Abstract

The Chenghai fault zone with north-east trending is located on the west-south boundaries of the rhombus block in Sichuan and Yunnan. We study the late Quaternary activity of the Chenghai fault zone by the image data, field investigation, trenching and radiocarbon dating of charcoal samples. The results achieved by the authors show that the Chenghai fault zone can be divided into 3 segments. The first segment is located on the north end of the Chenghai fault zone, from JingGuan Basin to Northern Qina Basin, its length is about 50km. The Yongsheng earthquake with Ms 7.75 took place on this segment in 1515. There are many ancient seismic phenomena in the Yongsheng earthquake area, including surface ruptures, steep fault ridges, ground fissures, landslide wedges, ground collapses and landslips, etc. The surface rupture located on the right bank of Lingyuan River is about 600m long and 8m wide. Its vertical displacement is about 1.5m. The Lingyuan River was left-lateral strike-slip dislocated about 450m. The fault scarp located on the east bank of the Chenghai Lake is about 100m long and 3m high formed before 4000 years. Its vertical displacement is about 1.5m. The trench at Songguan village revealed that the first terrace of Qina River was dislocated 1.5m by the fault and it is dated to be 2330±30cal.a BP. The second segment is from southern Qina Basin to northern Binchun Basin, its length is about 60km. On October 27,2001, a earthquake with Ms6.0 occurred on this segment. The Jingsha River was left-lateral strike-slip dislocated about 3km. The third segment is located on the south end of the Chenghai fault zone, from the southern Binchun Basin to Midu Basin, ending at the Red River fault zone, its length is about 60km. On this segment, the Midu earthquake with Ms 6.25 took place in 1623 and the Bingchuan earthquake with Ms 6.25 took place in 1803. The trench at Housuo village revealed that the second terrace of Naxi River was dislocated about 2.0m by fault and it is dated to be 15000±600a. Two ravines located at the south of Yongfushao village were all left-lateral strike-slip dislocated about 200-280m. The geological profile at Maolipo village revealed that the upper clay was dislocated about 2.0m by fault and it is dated to be 4390±30cal.a BP.. All these data suggest that the Chenghai fault zone are active since the Holocene, it has both normal and left-lateral strike-slip features and the active intensity was gradually weakened from north to the South.

Keywords: Chenghai Fault zone; late Quaternary activity; left-lateral strike-slip; normal

1. Regional tectonic background

The Chenghai fault zone is located in the southwest boundary of the Sichuan-Yunnan rhombic block. It is a most striking late Quaternary fault in east part of Northwest Yunnan Province. In 1515, a Ms 7.75 earthquake occurred in Yongsheng County located in the northern part of Chenghai fault zone. The fault zone is nearly north-south, tilts towards the west and has a total length of 200km. Several parallel nearly NS trending faults are located in the fault zone from the east to the West and scatter from the north to the south. These faults control the basin boundary of Jingong, Yongsheng, Chenghai,Qina, Binchuan, Midu (Fig.1).

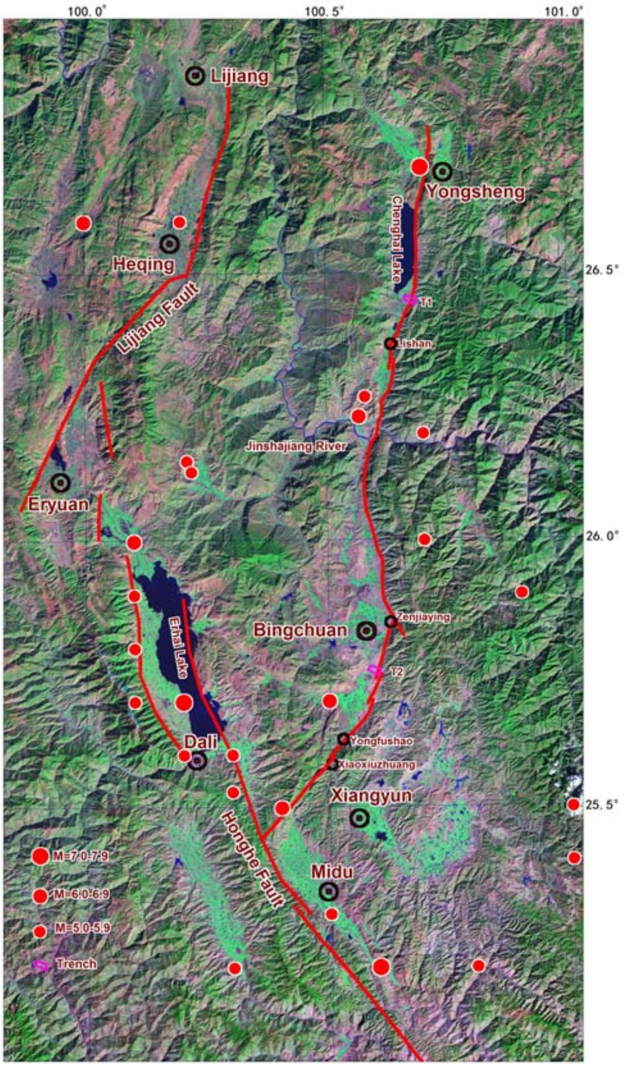


Figure 1 – Plane distribution of the Chenghai fault zone

2. Geological and landform evidence of fault activity

The Chenghai fault has significant SN - NE - NNE direction changes from north to south. Considering these direction changes, it is divided into three sections: Xiaochang ping-Chenghai-Lishan section, Lishan-Zengjiaying section and Zengjiaying-Yongfushao-Midu section.

2.1 Xiaochangping-Chenghai-Lishan section

This section is NNE, from Xiaochangping in the north to the Lishan village of Qina basin in the south, with a total length of about 50 km. This section consists of three oblique faults, Xiaochangping-Hongshiya fault, Hongshiya-Chenghai fault and Chenghai-Lishan fault. The Yongsheng Ms 7.75 earthquake occurred here in 1515.

The earthquake deformation belt is about 8 km wide and about 43km long. This belt has earthquake surface rupture zone, fault Quaternary strata, fault trench, scarps and landslide etc. There are many serious extrusions and scratches in this fracture zone which indicates many movements have occurred and most are oblique thrust. A strong extrusion movement has happened in the early stage. However recently, normal movement is the dominant, and the sinistral strike-slip movement is secondary. The main geological and geomorphic evidences for fault activity include:

An earthquake surface rupture develops in Devonian limestone located in the west hillside of Hongshiya and along the north side of Lingyuan River. The rupture is 7.8m wide, about 4m deep, about 200m long. Its direction is 20°. The height of east wall is about 7.5m and the west wall is about 3m. Subtracting the slope of the terrain, the vertical drop of two walls is about 1.5m（Fig. 2）.

In the south of Haiyao village in eastern Chenghai Lake, late Quaternary fluvial deposits are cut by the Hongshiya-Chenghai fault which is a normal fault. The fault profile is a scarp with the height nearly 3m. And there is 1.5m altitude difference between two fault sides. The occurrence of fault surface with 300 °∠20°can reach the earth surface (Fig.3).

Figure 2 –The landscape of earthquake surface rupture zone(face to north)

Figure 3– Faults and scarp in the Holocene fluvial deposits at Haiyao village(face to south)

In summary, the Xiaochangping- Chenghai-Lishan section is an active fault in the Holocene epoch. The fault structure is complex, which has the characteristics of multi-period activities. In the early stage, the fault was dominated by the thrusting movement. However since the Holocence, the fault has been dominant by left lateral-normal fault movement.

2.2 Liujiacun-Jinshajiang-Zengjiaying section

This section is from Liujiacun in Qina basin in the north to the southeast Zengjiaying in eastern Binchuan basin in the south, through Huangjin wan, Jinshajiang and Maliping. It consists of three oblique faults, Qina, Jinshajiang and Xiaoshuoluo—Zengjiaying. The fault length is about 63km.The fault direction has changed from near NS on the north of Binchuan basin to NNW in Binchuan basin. The main geological and topographic features of the fault activity are as follows:

At the groove in the south of Sandaohe village, the lacustrine strata were cut by the Qina fault. The west strata of the fault is near vertical, but the east strata of the fault is inclined to east with deformation bending indicating left strike. With the strike in 10°，the fault plane is near vertical. The ditch is turned left 10m (Fig.4).

To the south of Taoyuanhong brickfield, the gray white strata at purple red Jurassic strata in steep terrain is not a continuous strip descend westward affected by the Jinshajiang fault. Jinshajiang river is turned southward about 3km by Jinshajiang fault (Fig.5).

Figure 4–The fault and groove in the lacustrine strata at Sandaohe village(face to south)

Figure 5–The fault in Jurassic strata at Taoyuanhong brickfield and Jinshajiang river along the fault (face to south)

In the north of the Shanjiao village, a near 15m tall scarp was formed in the alluvial fan by the Xiaoshuoluo-Zengjiaying fault. Pale gray clay distributes near the fault. Brown sand and gravel distributes at both sides. Some arrangement phenomena of gravel are visible in the fault zone. The occurrence of fault plane is near W ∠60~70°.

In summary, the Liujia village-Jinshajiang-Zengjiaying section is an active Holocene fault. The fault structure is complex, which has the characteristics of multi-period activities. In the early stage, the fault was dominated by the thrusting movement. However since the Holocene, the fault has been dominant by left lateral-normal fault movement.

2.3 Zengjiaying-Yongfushao-Midu section

This section starts from south Zengjiaying village in eastern Binchuan Basin, ends in Red River fault, crosses through Guishan, Housuo, Yongfushao, Maolipo. This fault is composed of four oblique faults, Zengjiaying-Liuzhiao, Lilou-Housuo, Haojia village-Yongfushao and Xiaoxiu village-Midu. The fault length is about 60km. The fault direction is NNE. The main geological and topographic features of the fault activity are as follows:

To the east of the reservoir in northeast Guishan, quaternary sediments were cut by the Zengjiaying-Liuzhiao fault. The east side of the strata occurred steep inclination deformation influenced by the fault. Overlying late Quaternary brown strata was not affected. The fault occurrence close to the steep inclination deformation is 110°∠44°.

On the east side of the Housuo road, many faults including left-strike and normal faults were developed in quaternary Sheshan group. The occurrence of left-strike fault is 120°∠76°, and scratch occurrence is 30°∠11°.The occurrence of normal fault is 310°∠60°, with the maximum separation about 5m. The left-strike fault is located at the west side of the normal fault, close to the inner side of the basin. The left-strike fault acts at newer times. A scarp with height of about 7m can be observed at the location (Fig.6).

At Yongfu-Saocun village, this section developed obvious scarp landform and more gullies with left-hand bend (Fig.7).

Figure6–The fault (left)(face to NEE)and the scratch(right) (face to east) in quaternary strata at Housuo village

A large groove was formed by this section in the north of Maolipo village, which was 1800m long, about 35m wide and NNE. At the south end of the groove, the fault offset the quaternary weathered crust, brownish red clay with a c14 date of 4390 +/- 30 BP, and yellow clay soil (Fig.8).

In summary, Xiaoxiu village-Midu section is a Holocene active fault. The fracture structure is complex, which has the characteristics of multi-period activities, and the early stage was dominated by the thrusting movement. Since the Holocene, it has been transformed to the left lateral movement.

Figure 7– The fault landform in the vicinity of Yongfu-Shaocun (face to North East)

Figure 8–The quaternary fault profile at Maolipo village

3. The movement rate of the fault

3.1 Xiaochangping-Chenghai-Lishan section

Jinguan Basin and Yongshen Basin are located on each side of the fault and connected by Lingyuan River. The relative altitude between two basins is more than 500m. According to the geological data, lacustrine sediments of both basins in Pleistocene were gray clay with sand and gravel layer. Based on this, the height of both basins may be very close. However, there is significant difference since late Pleistocene. Jinguan Basin is still the same. But Yongshen Basin is lacustrine deposition of silt, clay and peat interbed. Since the late Pleistocene, the height difference is bigger and bigger due to rapid uplift of the fault, which results in obvious difference changes of the sedimentary environment. Therefore, the vertical movement rate of the Chenghai fault zone can be calculated as 4mm/a.

A sharp turn about 430m was formed on Lingyuan River by the fault. Based on the above analysis, Lingyuan River may be formed in the late Pleistocene. Therefore, the strike slip rate of the Chenghai fault can be about 4 mm / a. since late Pleistocene.

Many fault scarps, fault terraces and quaternary steep dips were developed in the quaternary alluvial and lacustrine terrace on the east bank of Chenghai. Near the village of Haizi, the fault has offset the quaternary sand and gravel layer of a terrace at an altitude of 1542m, which formed a near 3m scarp and also caused sinistral displacement of about 17m in a small gully. The terrace contains a large number of fossil shells. The formation times by ^{14}C measurement in the upper is 4910±115 BP, and lower is 6970 ± 30 BP. Thus, the formation age of the terrace takes the small value of 5000 years, and small gully takes the value of 7000 years. In addition, a lake erosion scarp in the North Chenghai was formed because the footwall limestone had been eroded by water for a long time. The height of the scarp is 4-6m and the elevation of its lower corrosion surface is around 1530m. On the basis of inference, the altitude of the old Chenghai Lake should be up about 1530. That is to say, the altitude of the sandy clay layer where the shells was located on the upper wall of the fault in the Banhaizi village should be around 1530m. Considering the formation age of the terrace at altitude around 1542m in the upper wall of the fault, the vertical movement rate of the Chenghai fault zone is about 3 mm/a since Holocene and the horizontal rate is about 2.5mm/a.

3.2 Liujiacun-Jinshajiang-Zengjiaying section

The drilling holes to the west of the Qina town show that the upper Holocene and late Pleistocene are alluvial sand, gravel and silty clay, and Middle Pleistocene series are lake silt and silty clay. The depth of lake sediments is 136m, however the lake sediments have exposed at the edge of the basin. The height of the lake sediments is 5-8m and the elevation difference is estimated about 145m. Therefore, the vertical movement rate of this section since the late Pleistocene is about 1.5mm/a.

From the satellite images, an about 2.9km left turn of Jinsha River is located along the Chenghai fault. On the south end of the turn, three large landslides were developed on the right (east) bank of the Jinsha River. No.1 and No.2 landslides have formed landslide dam on the bank of the Jinsha River, which have dammed Jinsha River , formed barrier lakes and accumulated very thick lake facies silty sand and fine sand in the Taoyuan area(Fig.9). The accumulation times of the lake phase layer at South Taoyuan Town is 37 ±3 ka BP (Li Qiankun, 2011), at Yongsheng sugar mill is 54.7±15 ka BP (Li Guangrong, 1990). The age of calcite on the slip surface of No.2 landslide is 60.3±9 ka BP (Li Qiankun, 2011). Therefore, the age of the landslide accumulation dam is 47-60 ka BP.

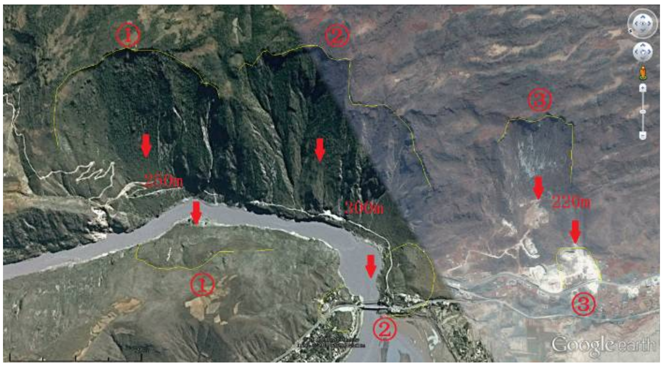


Figure9–The landslide images in the Zhaizi village along the Jinsha River

From the satellite images, some left lateral displacement between the accumulation center and the geometric center of landslides can be obtained. Respectively, from north to south, No.1 landslide is 250m; No. 2 landslide is 300m; No.3 landslide is 220m. Considering the age of the landslide accumulation dam is 47-60 kaBP, the horizontal movement speed is 4.0-6.0mm/a since late Pleistocene.

3.3 Zengjiaying-Yongfushao-Midu section

Fault landform, fault trench, and landslides are developed in this section, which indicates strong extrusion structural movement resulting in inclination deformation of early Quaternary sediments has occurred in early stage of the fault. The latest moment is normal with left lateral slip characteristics. In the Binchuan Basin, it is difficult to find the ideal fault geomorphology because of the artificial modification.

The fault profile in Housuo has revealed that the fault move vertically in early stage and then move horizontally. The elevation difference of fault scarp is about 22m, including vertical 5m displacement caused by fault cut the early-middle Pleistocene strata in early stage. The late Pleistocene deposits of alluvial sand and gravel layer cover above the early-middle Pleistocene strata. Because the late Pleistocene alluvial sand and gravel can be seen in the youngest fault zone, its vertical displacement is mainly formed since late pleistocene. Drill holes in Housuo reveal that the depth of late Pleistocene alluvial sand and gravel layer is about 50m. It can be obtained that vertical elevation of late Pleistocene gravel layer is about 72m in vicinity of Housuo. The vertical movement rate was about 0.6mm/a since the late Pleistocene.

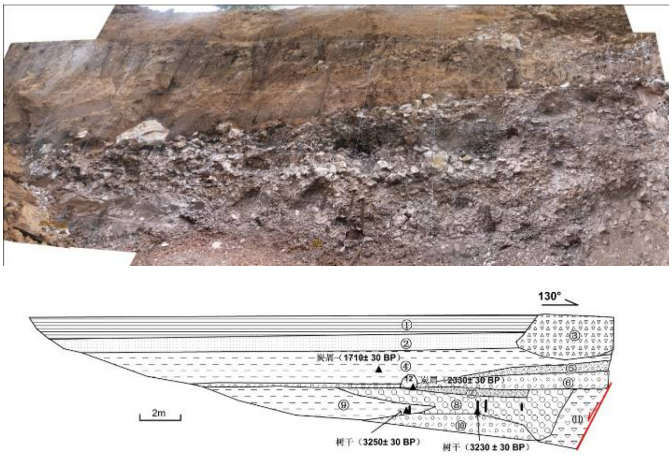
Some scarps and left turning gullies were found from Xinzhuang village to Yongfushao village. From the north to the south, the left lateral displacement projected onto the fault of 6 gullies are 200m, 260m, 200m, 240m, 280m and 260m. The fault around the corner of gullies in the vicinity of YongfuShao village developed a platform of late Pleistocene alluvial sand and sandy clay layer on both sides. The vertical displacement in platform is 22-24m and the horizontal displacement is about half (Fig.14). The age of alluvium sample is 25.0±0.9kaBP. Since the late Pleistocene, the vertical movement rate was about 1.0mm/a, and the horizontal movement rate was about 3.5-5.0mm/a.

4. Paleoseismic research

4.1 Songguan trench in southern Chenghai Basin

The Songguan trench is located in southern Chenghai Basin and below the southern boundary of a large landslide. A scarp about 3m high was developed here. The trench begins from the scarp edge, with length of 28m, width of 2-3m, depth of 5m. The trench reveals the structure of the fault zone (Fig.10) near this scarp.

The trench revealed that No.8 gravel layer with standing tree and No.11 motley gravel layer were rapid accumulation colluvial wedge by earthquake. This indicates that a paleoseismic event happened when No.8 layer was accumulated, and the time should be 3230±30 BP.



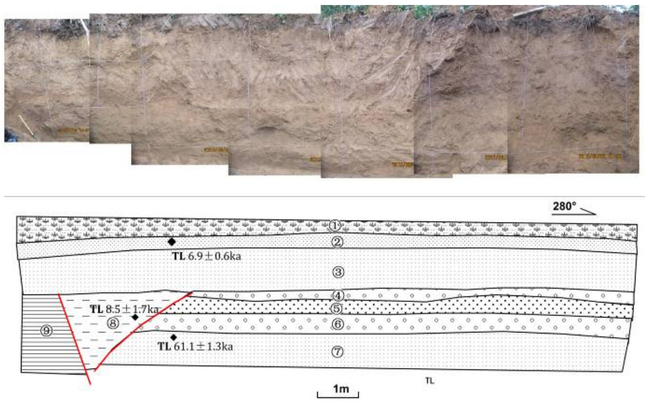
①pale yellow clay, ②gray clay, ③gravel layer, ④brown yellow clay, ⑤white gravel, ⑥black gravel with carbonaceous,⑦grey white gravel; ⑧gravel layer with standing tree; ⑨brown grey clay, ⑩brown red gravel, ⑾motley gravel, ⑿large gravel

Figure 10–The profile of north wall of the Songguan trench

4.2 The Housuo trench in Binchuan Basin

The Housuo trench is located in the Housuo village in southern Binchuan Basin. From satellite image, there are obvious scarps and left turning gullies near the scarps. Quaternary sediments profiles can be observed around the scarp. The trench is arranged in the river terrace of the southern scarp. The height of scarp here is about 4m.

The Housuo trench starts from begins from the scarp edge, with length of 28m, width of 2-3m, depth of 5m (Fig.11). The trench reveals that a paleo seismic event occurred before accumulation of No.2 brown yellow silty sand layer and after No.8 brown mottled clay layer. The time should be between 6.9±0.6ka and 8.5±1.7ka.



①gray-black farming soil, ②brown yellow silt and sand layer, ③light brown sand layer with little gravel, ④light brown gravel layer, ⑤tawny coarse sand layer with gravel, ⑥brown yellow sand and gravel layer,⑦brown sand layer, ⑧brown and motley clay; ⑨black clay

Figure 11–The profile of north wall of the Songguan trench

4.3 Features of fault segment motion and earthquake recurrence interval

Above analysis from the paleo seismic events revealed by trenches and profiles, the movement characteristics and earthquake recurrence interval are different at different section in the Chenghai fault zone.

As the northern section of the Chenghai fault, the activity period of Xiaochangping- Chenghai-Lishan section is Holocene and the nature of fault activity is left lateral-normal movement. Since the Holocene, the horizontal movement rate has been 2.5-5.0mm/a, and the vertical movement rate has been 2.5-4.0mm/a. Movement rate of northern Jinguan Basin is greater than the southern Chenghai Basin. A magnitude 7.75 earthquake occurred in 1515 in this section. Trenches revealed that there was one paleoseismic event in this section, and the magnitude 7 earthquake |recurrence interval was about 2700 years.

As the middle section of the Chenghai fault, the activity period of Liujia village-Jinshajiang-Zengjiaying section is Holocene. The nature of fault activity is left lateral-normal movement. Since the Holocene, the horizontal movement rate has been 2.0-2.6mm/a, and the vertical movement rate has been 1.0-2.0mm/a. The horizontal velocity at middle is larger than at both ends. That is to say, the velocity in the hill ground is larger than in the basin. However, the vertical velocity at middle is smaller than at both ends. That is to say, the velocity in the hill ground is smaller than in the basins. In this section, a magnitude 6 earthquake occurred in 2001. Field profiles revealed that there had been many paleoseismic events in the late Pleistocene. However, no direct evidence of paleoseismic events in Holocene has been found to determine the recurrence interval of earthquakes of magnitude 7.0.

As the southern section of the Chenghai fault, the activity period of Zengjiaying- Yongfushao-Midu section is Holocene. The nature of fault activity is left lateral-normal movement. Since the Holocene, the horizontal movement rate has been 2.0-4.5mm/a, and the vertical movement rate has been 1.0mm/a. Horizontal rate increases towards the south. In this section, two 6.25 earthquakes occurred in 1623 and 1803, respectively. Trench revealed one paleoseismic event in this area. The age of this event is about 6.9±0.6ka to 8.5±1.7ka. Also, profile revealed one paleoseismic event in this area occurred about 3000 years ago. The recurrence interval of magnitude 7 above earthquakes is about 3000 years.

5. Conclusions

By field geological, geomorphological survey and trench excavation of the Chenghai fault zone, the following main conclusions and understandings about the late Quaternary motion characteristics can be obtained:

As a whole fault zone in the NNE direction, the Chenghai fault zone control the formation and development of Jinguan basin, Chenghai basin, Qina basin, Binchuan basin and Midu basin. According to its geometric structure and movement characteristics, it can be divided into three section: Xiaochangping-Chenghai-Lishan section, Liujia village-Jinshajiang-Zengjiaying section, Zeng jiaying-Yongfushao-Midu section.

The Chenghai fault zone is a holocene active fault. Xiaochangping-Chenghai-Lishan section is the seismogenic structure of the Yongsheng 7.75 earthquake occurred in 1515. The faults have multi-period movements. In the early period, the movement of the faults was mainly dominated by compressional-thrust movement. Since the late Quaternary, the left lateral strike slip movement is the dominant, and the normal movement is secondary.

The structure of Chenghai fault zone is complex. Tectonic landform has been developed. In the inner of basins vertical motion is obvious, and in the join part of basins strike slip is obvious .Usually the vertical movement rate in basin is greater than in join part, but the horizontal movement rate is opposite.

By measuring and dating the faulted geological or geomorphological units, the vertical movement rate of Xiaochangping-Chenghai-Lishan section is 1.0-4.0mm/a since Holocene, and the horizontal movement rate is 2.5-5.0mm/a. The vertical movement rate of Liujia village-Jinshajiang-Zengjiaying section is 1.0-2.0mm/a in late Pleistocene, and the horizontal movement rate is 2.5-6.0mm/a. The vertical movement rate of Zengjiaying-Yongfushao-Midu section is 0.6-1.0mm/a in late Pleistocene, and the horizontal movement rate is 3.5-5.0mm/a.

In Xiaochangping-Chenghai-Lishan section, trench revealed one paleo seismic event which determines the earthquake recurrence interval of more than magnitude 7 is about 2700 years. In Liujia village-Jinshajiang-Zengjiaying section, many paleo seismic events happened in the late Pleistocene. However, there was no direct evidence in Holocene to determine the magnitude 7 earthquake recurrence interval. In Zengjiaying-Yongfushao-Midu section, both trench and profile revealed one paleo seismic event respectively. The time are about 6.9±0.6ka to 8.5±1.7ka and 3ka respectively. The magnitude 7 earthquake recurrence interval is about 3000 years.

Generally in the Chenghai fault zone, the activity intensity of the northern and southern sections has been large since the Holocene epoch. In the northern part, the vertical and horizontal movement rate are relatively large. In the southern part, the horizontal movement rate is large, and the vertical movement rate is small. The activity intensity of Jinguan basin and Chenghai basin is greater than Qina basin, Binchuan basin and Midu basin. The Binchuan basin has minimum movement rate. The rate of join part of basins is similar, generally 4.0-5.0 mm/a.

6. Acknowledgements

We thank all the field crews and Laboratory staffs for collecting the high-quality data that we used for this paper. This work has been supported by National Science Foundation of China (project No. 41274101, 41472199), Special Research Funds of Ministry of Finance of China for earthquake Administration(project No. 201108001).

7. References

[1] Guo SM, Zhang J, Li XG, Xiang HF, Chen TN, Zhang GW (1984): Fault displacement and recurrence intervals of earthquakes at the northern segment of the Hong he fault zone, *Yunnan province,Seismology and Geology*, **6**(1) , 1-6.

[2] Guo SM, Xiang HF, Zhang J, Hu RQ, Zhang GW (1988): Discussion on the deformation band and magnitude of the 1515 Yongsheng earthquake in Yunnan province. *Journal of Seismological Research*, **11**(2) , 153-162.

[3] Guo SM, Xiang HF, Ji FJ, Zhang WX (1996): A study on the relation between Quaternary right-lateral slip and tip extension along the Hong he fault. *Seismology and Geology*, **18**(4), 301-309.

[4] Peng G, Jiao WQ (1986): The radiocarbon dates of late quaternary sediments of Yong sheng and Jinguan basins and their geological significances. *Seismology and Geology*, **8**(3) , 10-10.

[5] Xiang HF, Guo SM, Xu XW (2000): Active block division and present-day motion features of the south region of Sichuan-Yunnan province. *Seismology and Geology*,**22**(3) , 253-264.

[6] Li QK, Xu ZM (2011): The ancient landslide and dammed lake found in the Jinsha river near Zhaizicun, Yongshen, Yunnan, China. *Journal of Mountain Scienc*e, **33**(5), 729-737.

[7] Li QK (2012): The Zhaizicun landslide in Jinsha River and its deposites of landslide-damed lake. *Master thesis of Kunming university of science and technology*.

[8] Xu ZM (2011): Deposits of Zhai zicun landslide-dammed lake along Jin sha river and its implication for the Genesis of Xigeda formation. *Geological Review*, **57**(5), 675-686.

[9] Li GR, Jin DS(1990): Neoid activity on the Chenghai fault. *Yunnan Geology*, **9**(1), 1-24.