Study on the Deformation Zone of Tianzhuang Fault in Taiyuan, China

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December 3, 2022

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The buried depth of modern urban lifeline engineering, subway engineering construction and super high-rise building foundation can be up to 30m or even deeper. Therefore, for the buried fault with buried depth less than 60m, it is necessary to judge its seismicity and study its paleoearthquake recurrence cycle, which is of great significance for engineering earthquake resistance and fault avoidance.

Tianzhuang fault is an important concealed fault with obvious activity in late Pleistocene in Taiyuan Basin, Shanxi Province, China. Through the analysis of regional geological tectonic background, the tectonic process of Yanshan movement and Xishan movement of Tianzhuang fault is analyzed: the temporal and spatial activity characteristics of multi-stage faults are analyzed by processing and interpreting the shallow seismic profile of Tianzhuang fault; Based on the ground deformation survey and the analysis of the characteristics of the borehole joint section, the details of the recently displaced strata of the main section are displayed; Assist the verification of fault gas anomaly zone of concealed fault, verify the range of deformation zone of Tianzhuang fault since late Pleistocene, and finally realize the dynamic display of the location change of main fault and the formation and expansion of fault zone in Jiaocheng fault zone.

Key words:Tectonic history; Shallow earthquake; Borehole joint profile; Fault gas; Deformation zone

1 Failure process of North China Craton

The caprock of North China block is mainly composed of Mesoproterozoic shallow metamorphic rocks, Cambrian Ordovician deep-sea facies sedimentary rock series, Carboniferous Permian sea land interactive rock series, and volcanic facies and terrigenous clastic facies sedimentary rock series since Mesozoic and Cenozoic. There are generally no upper Ordovician, Silurian, Devonian and Cenozoic Paleocene, and underlying Archean and Paleoproterozoic deep metamorphic rock series basemen（Zhu r et al.2019）.

According to the research results of structural geology and chronology, the age of the A-episode of the Yanshan movement was about 165 Ma. The most significant sign is the angular unconformity event widely developed in the North China Craton in the late Jurassic. The corresponding tectonic environment is in a compressive state, with a duration of about 5 Ma, resulting in the translation of the a-episode of the Yanshan movement and the Tanlu fault on the surface of the active continental margin; The crustal shortening, folding and stratigraphic angular unconformity events widely developed in the North China Craton around 138Ma marked the occurrence of the B-episode of the Yanshan movement. At this time, Eastern China was represented by a compression event, and the Tan Lu fault zone shifted leftward again, the basin reversed and the short-term regional uplift; The geodynamic mechanism causing the B-episode of Yanshan movement is that the subduction angle of the Western Pacific plate gradually decreases(Xu l et al.2013).

The nearly north-south trending high angle normal faults developed in the front of Taihang

Fund Project: general nature fund project of Shanxi Provihcial Department of science and Technology (No.: 201901d111462); Supported by the national field scientific observation and research station of continental rift dynamics in Taiyuan, Shanxi Province (Project No. norsty20-06); About the author: Han Xiaofei (1981 -), male, Taiyuan, senior engineer, mainly engaged in seismic geology and geophysics. E-mail: 38094048@qq.com

Mountain and along the southern segment of Tanlu fault zone in North China were formed in 75 ~ 65 Ma. These faults are also the products of marginal faults or initial rifts in North China Basin. With these deformations, a large number of volcanic activities developed along the southern segment of the Tan Lu fault zone. The formation of the Cenozoic North China basin is based on this(Wang y et al.2018).

Shortly after the initial India Asia collision (10-20 Ma), the upper crust of the Himalayas was thickened to the lower crust of > 35 km and produced anatexis. This earliest crustal thickening event was completely coupled with the era of residual epicontinental regression events recorded in foreland sub basins such as subathu in northwest India and Tansen in Nepal, which was the inducement of the initial uplift of the Himalayas. In other words, the Himalayas initially rose above sea level by crustal thickening at about 44-38 Ma(Huang F.2021).

The research results of thermochronology and fission track in recent years show that the initial plateau experienced the initial uplift of 24-17 Ma and the denudation, planarization and peneplanarization of 17-3.6 Ma during the Neogene, forming the main planation plane of the plateau; At 3.6Ma, the main planation surface of the plateau disintegrated, the terrain around the plateau changed sharply, the conglomerate of Xiyu formation with a thickness of 2000-3000m in the southern margin of the Himalayas, and the conglomerate of Dayi formation (Q_1) of lower Pleistocene in front of Longmen Mountain showed a large and rapid uplift in the hinterland of the plateau from late Pliocene (about 4-3.6Ma) to late Early Pleistocene (0.9-0.8Ma) (corresponding to the third episode of Himalayan), Today's Qinghai Tibet Plateau and its peripheral plateaus finally formed(Ge xiaohong et al.2010).

The sedimentary strata also prove that the Himalayan orogeny at the end of Paleogene (24Ma ±) caused major turning changes in China and even the Asian continent, and a series of fault basins in eastern China entered the overall depression stage(Huang l et al.2012).

To sum up, according to the direction and sequence of subduction and retreat of the Pacific plate, the tension pattern of the Jiaocheng fault in the Fenwei Rift was formed 75~65 Ma earlier. The first retreat of the Pacific plate started at 130 Ma in the Early Cretaceous and began to shape the embryonic form of the Taiyuan basin.

2 Understanding of Tianzhuang fault

The regional stress field changed in Cenozoic, and the thrust faults formed in Mesozoic were reversed by north-south dextral shear. Firstly, the thrust fault on the Zhongtiaoshan Wanrong anticline was faulted, and Oligocene and Miocene sediments were deposited, which are Yuncheng sag and Houma sag. Subsequently, in Pliocene, the Jiaocheng reverse fault on the northwest wing of Taiyueshan anticline, the Huoshan-Luoyunshan fault on the West Wing of Huoshan Matoushan anticline and its longitudinal and transverse fractures, as well as the western end of the conjugate fracture on Taiyueshan anticline also took place, gradually forming Taiyuan fault basin and Linfen fault basin(Xie x. et al.1996).

The thrust section of Jiaocheng fault formed by Yanshan movement basically tilts southeast. Its dip angle ranges from high angle to low angle. All the old rock series on the east side are pushed over the new rock series to the West. In the Himalayan period or Neogene Period, the block on the original east side of the upper wall fell down along the east foot of the Xishan mountains or roughly parallel to the original thrust fault line; However, the block on the lower wall of the original west side rises relatively, so the neotectonic movement begins. The east side receives new sediments and alluvium to become a plain, and the west side rises to form a platform.

This differentiation movement is still mainly carried out intermittently, which is the main factor that makes the east foot of the West Mountain steep(Pan g.1957).

Jiaocheng fault generally strikes NE, starting from Fenyang,Wenshui, Jiaocheng and Qingxu in the south to the west of Yuci (from Qingxu to the west of Yuci, also known as Tianzhuang fault). One branch cuts straight to the north, the fault line extends wavily, the section tends to SE, the fault dip is relatively steep, the footwall rises and the hanging wall falls, which is a tensile growth fault.From the seismic reflection profile and drilling results, it is found that the Taiyuan Basin receives the upper Neocene unified lower Pleistocene sedimentation. The sediment tilts slowly from east to west, and the thickness increases gradually. The thickness is the largest near the Jiaocheng fault, forming the sedimentary center. The deposition is wedge-shaped on the profile, indicating that the basin is controlled by the Jiaocheng fault. In the hanging wall of the fault, there are nearly parallel small faults with low sequence and same direction(Yang c. et al.1999;Zhang m. et al.1996;Zhang l. et al.2020).

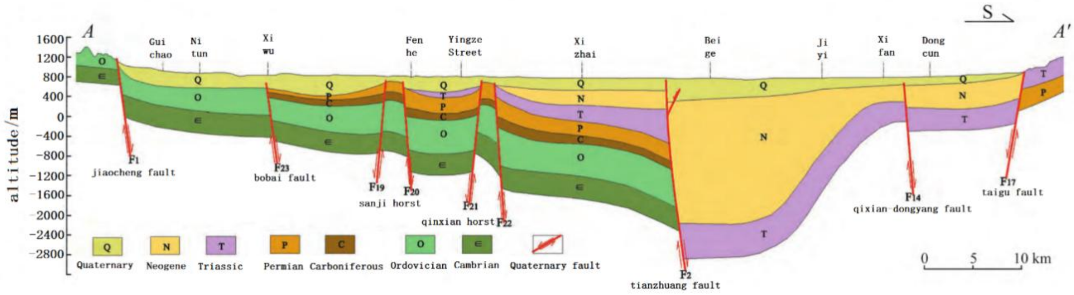

Fig .1 SN geological section of Taiyuan Basin (Quoted from Zhang Longfei,2020)

According to the velocity structure and seismic location, it is also proved that Jiaocheng fault, as the main fault controlling the western edge of Taiyuan Basin, is a typical plow type fault with steep upper attitude and slow shovel lower attitude. Most of the earthquakes occurred near the fault(Wang c. et al.2014).

3 Location change of main section of Tianzhuang fault and determination of deformation zone

3.1 Shallow seismic exploration reveals

In September 2012, Shanxi Institute of seismic engineering survey entrusted the Geophysical Exploration Center of China Seismological Bureau to carry out shallow seismic exploration of Tianzhuang fault. Wjb-xbg survey line starts from the highway intersection under construction in the north of Wenjiabao village in the north, passes through Songhuan village and Liujian village in the south, passes through ErGuang expressway, and ends in the field in the north of Xiaobeige village.See Fig. 2 for the location of measuring line and section position.

It can be seen from Figure 3 that the time profile of this survey line has a high signal-to-noise ratio, and a clear reflected wave group can still be seen at 1750ms of two-way travel time. There are abundant reflection wave groups in the section, which explains 11 strong reflection wave groups from top to bottom, and there are also abundant weak reflection wave groups between each wave group, which can be tracked continuously. The reflection interface characteristics revealed by each strong reflection wave group generally have the buried depth shape of deep in the South and shallow in the north. In the south of the section, there are abundant reflection wave groups, and each interface is distributed in nearly horizontal layers. The T_{Q+N} interface at the bottom continues to rise northward, and the T_{10} and T_{09} interfaces pinch out successively with the rise of

T_{Q+N} interface. In the middle of the section, the T_{Q+N} interface basically tends to be horizontal layered. On both sides of section stake No.790m, there is obvious depth difference at T_{Q+N} interface, and the drop difference is about 700m; To the north of 790m, T_{Q+N} interface is distributed in clear horizontal layers, and the interface is continuous. Combined with the

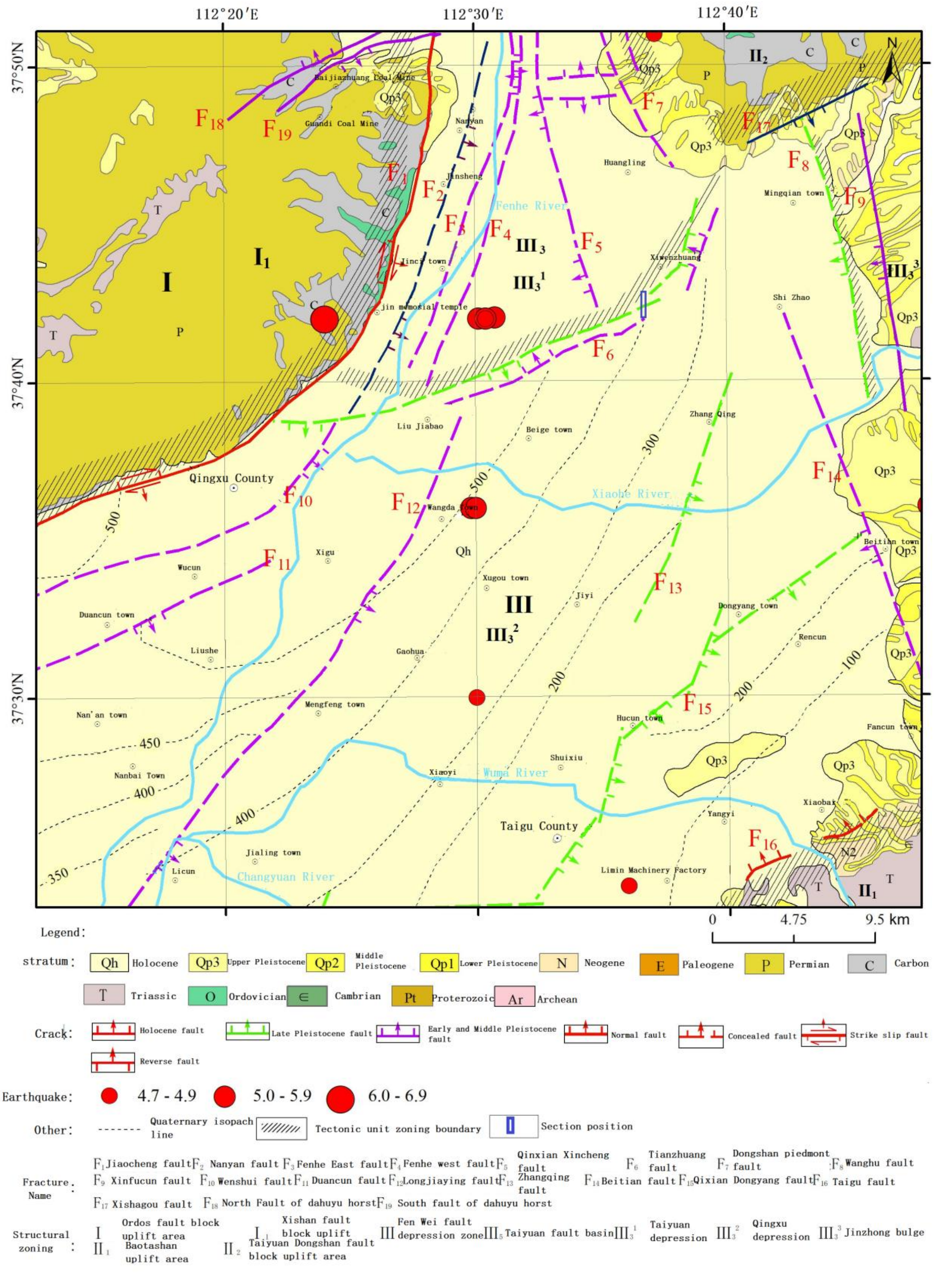

Fig.2 Location of survey line and section and Seismotectonic background

characteristics of other shallow interfaces, it is considered that there is a phase of $F_{1\text{-}Qp3}$ and $F_{2\text{-}Qh}$ normal fault activity with apparent dip to the south at section stake 790m in the north section of the section. Combined with the tectonic activity history of the basin, it corresponds to the significant fault depression activity from the early late Pleistocene to now. Due to the difference in the identification of fault surface position caused by section interpretation, the distance between the two sections is about 300m, In the Middle Pleistocene before the normal fault activity, thrust

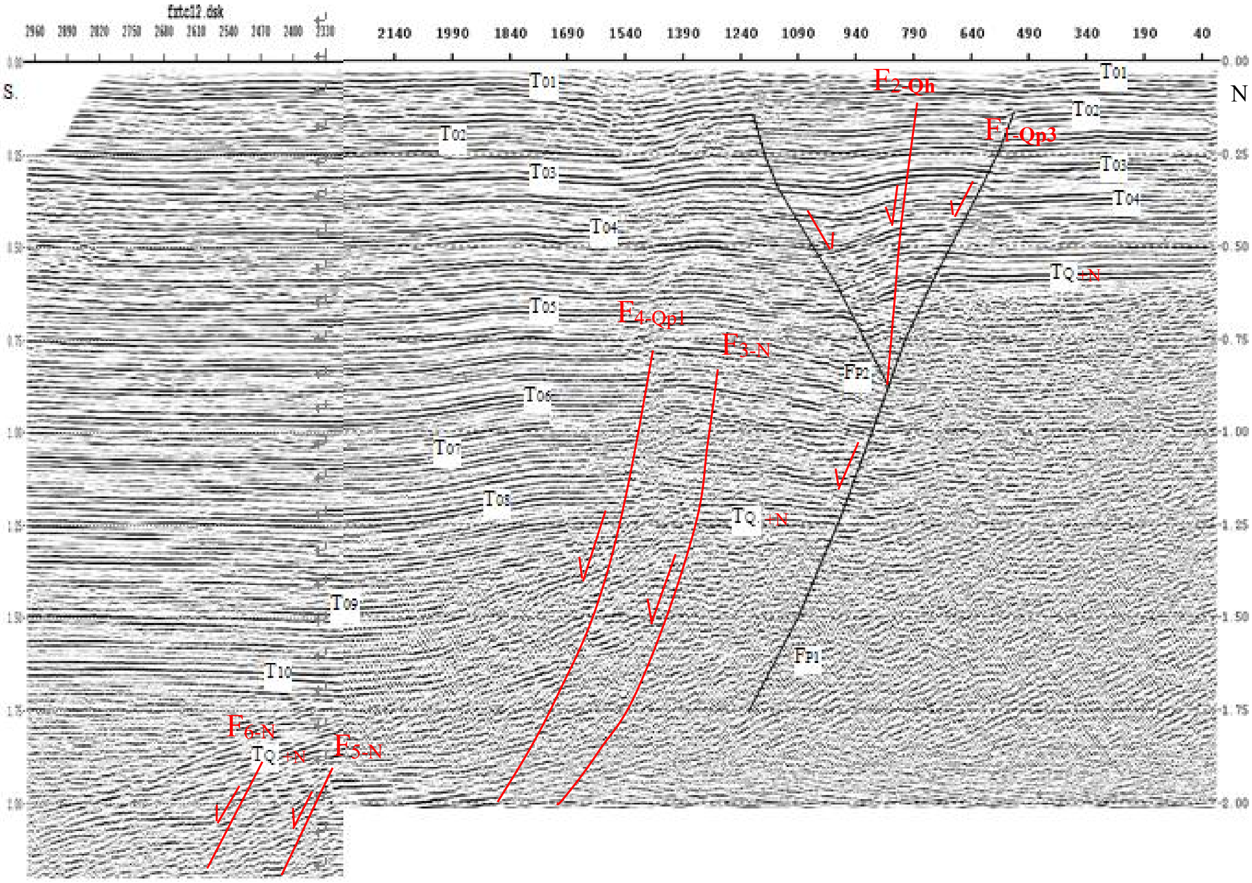

Fig.3 Shallow seismic reflection time profile of Tianzhuang fault wjb-xbg survey line

was the main activity, the basin uplifted and the denudation surface increased. The thrust activity in the Middle Pleistocene and the fault depression activity since the late Pleistocene formed a rolling anticline between section stake 640-940m; At 1500m of the section stake, there is also a period of strong fault subsidence activity, which corresponds to the third episode of Himalayan movement from Late Neogene to late Early Pleistocene of F_{3-N} and F_{4-Qp1}. The fault subsidence amplitude is estimated to be 1900m. This area also experienced compressive tectonic activity from middle Neogene to Late Neogene, resulting in uplift of bedrock near the section; At 2400m of the section stake, there are two sections formed by the fault subsidence activities of faults F_{6-N} and F_{5-N} in the early and middle Neogene. Because the bottom boundary of the hanging wall can not be seen, it is impossible to estimate the fault subsidence amplitude.

MLYL survey line is to further find out the structural characteristics of Tianzhuang fault at the bend.

From the section features(Fig. 4), the fault features are obvious, marked as F_{2-Qh} and F_{1-Qp3}. There are regular faults at all interfaces interpreted on the section. The two-way travel time of 1000ms can be recognized for the abundant reflection wave group in the south of F_{1-Qp3}, and only 360ms TN interface can be recognized in the north of F_{1-Qp3}. The sedimentary characteristics of the strata on both sides of the breakpoint are obviously different, which is a normal fault inclined to the south. The upper breakpoint is located at stake 690m, the buried depth of the distinguishable upper breakpoint is about 50 ~ 55m, and the vertical fault distance is about 3 ~ 4m. Combined with the tectonic activity history of the basin, it corresponds to the significant fault depression activity from the early Late Pleistocene to now. Due to different activity periods, rolling anticlines are also formed between the two sections. This feature is very similar to the fault in this period in Fig 1, and has also become the identification mark for the fault zone to track the fault in the same period in the basin. The distance between the breakpoints on the two sections is about 400m.

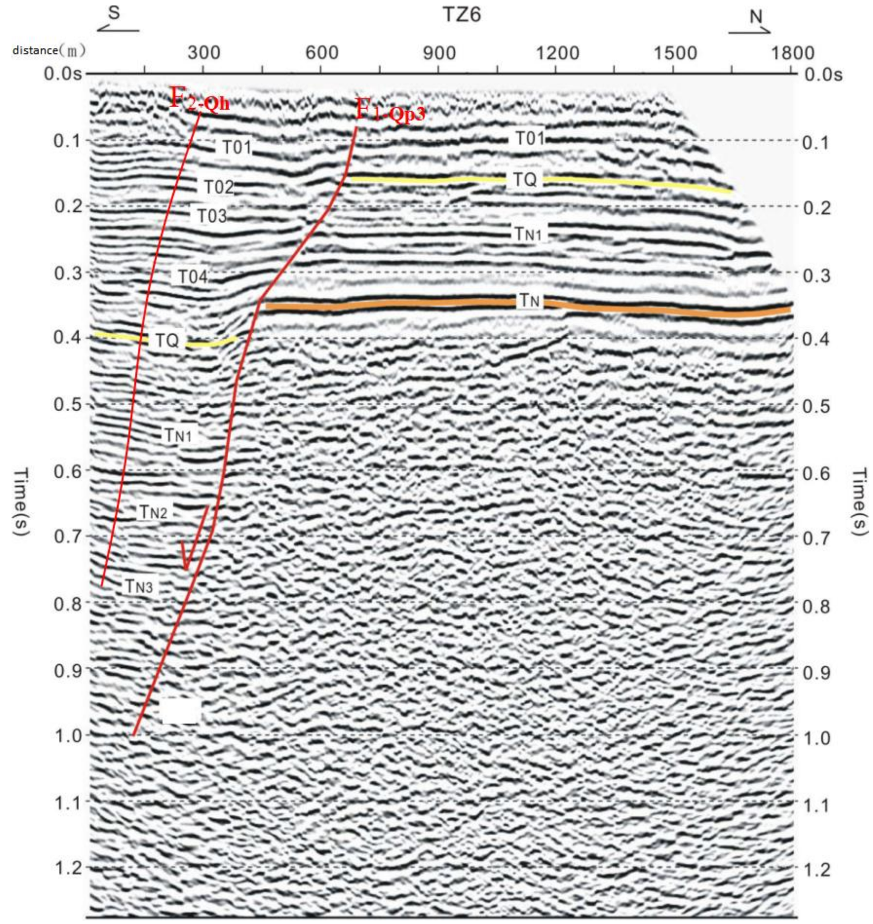

Fig. 4 Reflection seismic time profile of mlyl (malianying Road) survey line of Tianzhuang fault

5.2 Verification of fault gas on the latest active main section

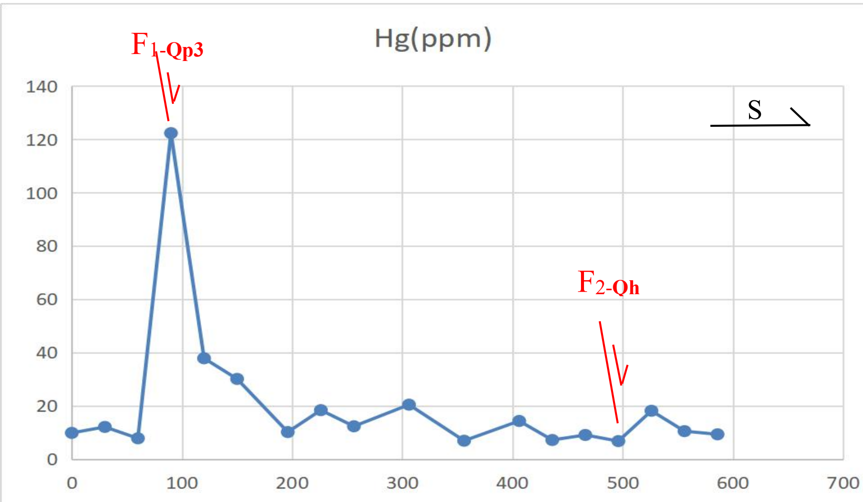

Fig.5 Fault gas Hg survey line of Tianzhuang fault MLYL (malianying Road)

According to the latest research results (Han x. et al.2017), the most active part of Tianzhuang fault can be divided into the main front section $F_{2\text{-}Qh}$ and the main rear section $F_{1\text{-}Qp3}$, with a spacing of about 400m. The deep part is the same main section, and the main front section $F_{2\text{-}Qh}$ and the main rear section $F_{1\text{-}Qp3}$ form an obvious stratigraphic arch area rolling anticline. See Figure 5-7 for fault gas detection results for details,see Figure 2.

From the malianying fault gas detection results, it can be seen that H_2 and CO_2 reflect the $F_{2\text{-}Qh}$ of the main front section accurately, and the anomaly of Hg corresponding to $F_{2\text{-}Qh}$ of the main front section is a little south, but Hg reflects the $F_{1\text{-}Qp3}$ of the main rear section accurately, with the highest value of 120ppm, while H_2 and CO_2 reflect the $F_{1\text{-}Qp3}$ of the main rear section, H_2 is backward and CO_2 is forward. Based on the detection results of Hg, H_2 and CO_2 fault gases on the main front section $F_{2\text{-}Qh}$ and the main rear section $F_{1\text{-}Qp3}$ of Tianzhuang fault, this is basically consistent with the distance between the two sections formed by the fault depression activity of Tianzhuang fault since the early Late Pleistocene revealed by shallow seismic exploration, both of which are 400m left and right. The $F_{1\text{-}Qp3}$ activity time of the main section at the rear edge is old, but the formed fracture zone is large, and the fault gas is easier to escape. While the $F_{2\text{-}Qh}$ activity time of the main section at the front edge is new, but the formed fracture zone is relatively small, and the hanging wall is still in the state of upward compression, so the fault gas is not easy to escape, resulting in small abnormal amplitude.

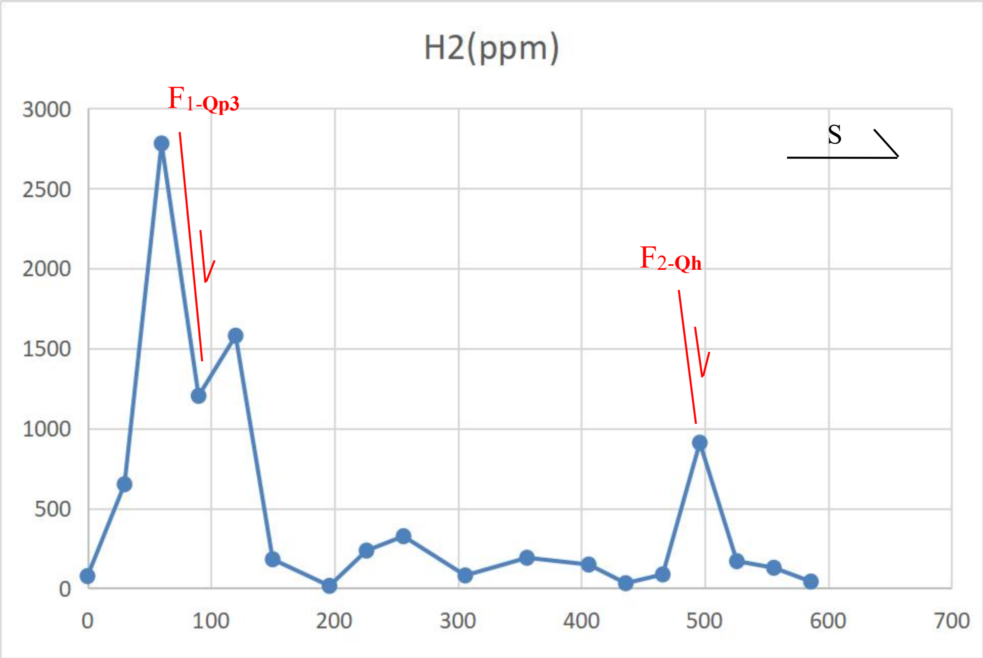

Fig.6 H_2 measuring line of mlyl (malianying Road) fault gas in Tianzhuang fault

5.3 Disclosure of $F_{1\text{-}Qp3}$ details of main section by combined borehole profile

According to the strata revealed by this cross-section borehole exploration (see Fig. 8), layer ⑤ is the bottom of Holocene, which is a set of basically continuous brown yellow fine sand, locally brownish red silty sand or dark brown silty soil. All boreholes are exposed, and the depth fluctuates slightly up and down. It is fluvial facies deposition. Considering that the sampling rate of sand layers in each borehole is inconsistent, it is considered that Tianzhuang fault has not broken the Holocene stratum.

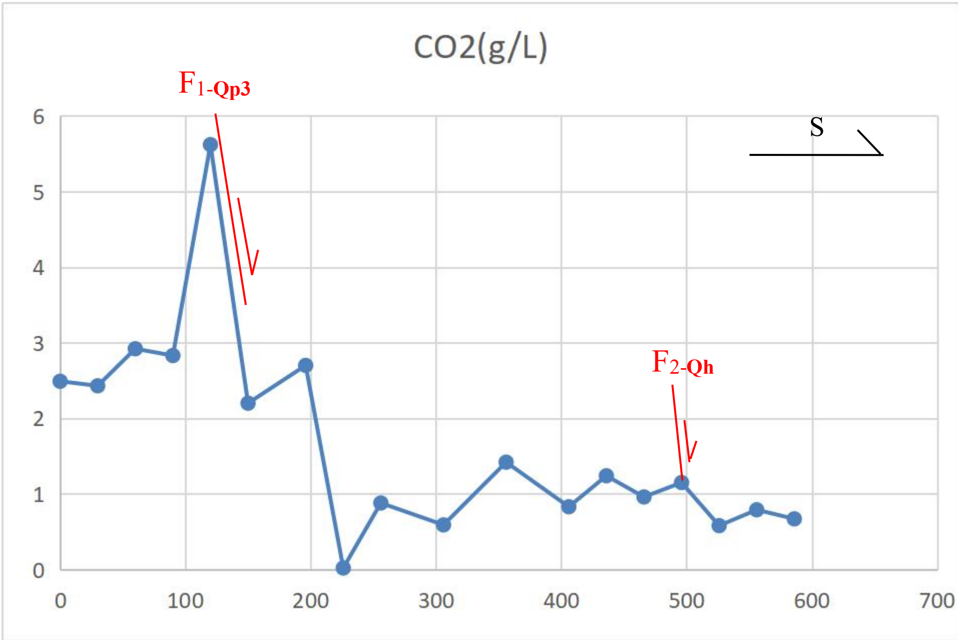

Fig.7 Fault gas CO_2 survey line of Tianzhuang fault mlyl (malianying Road)

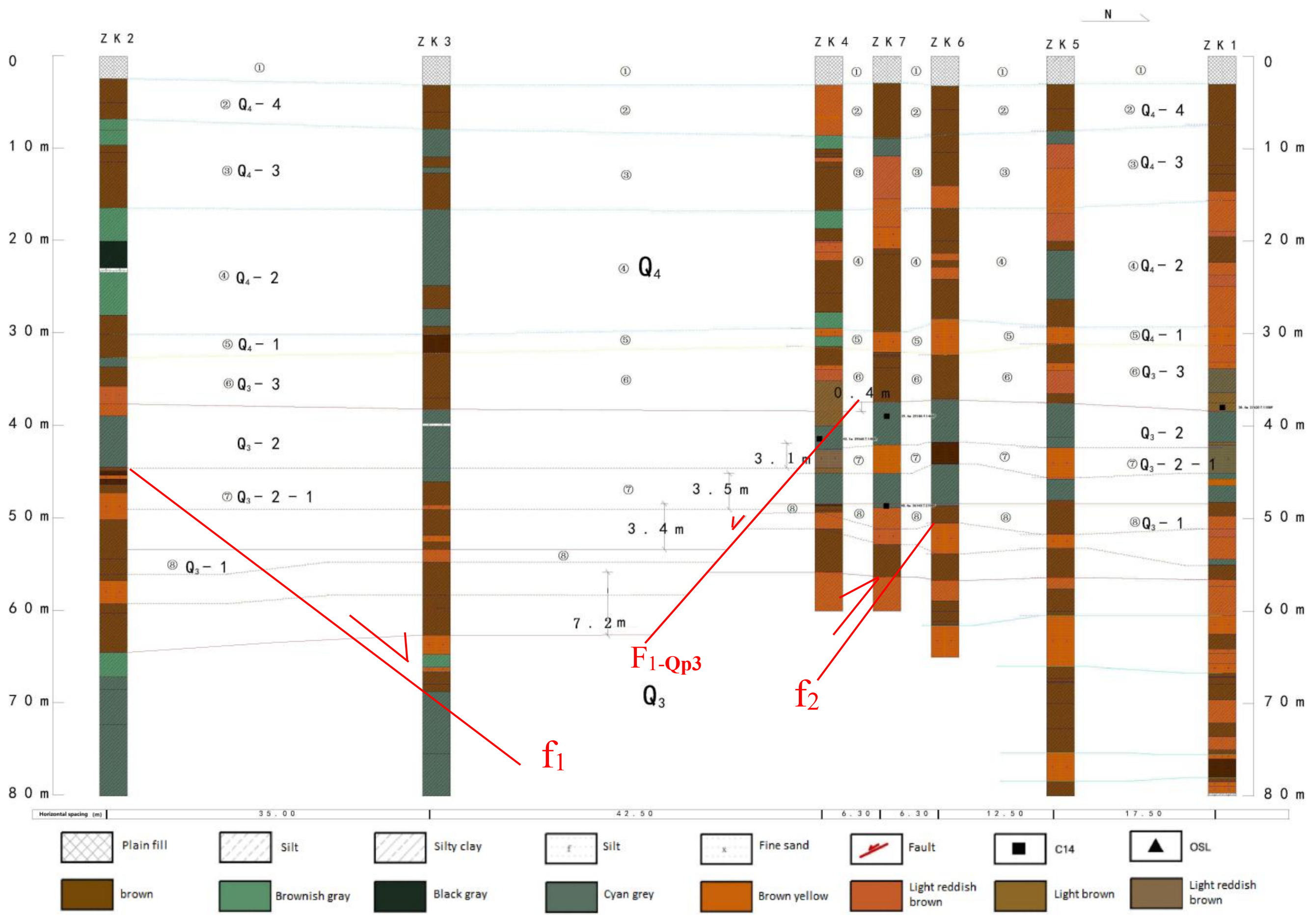

Fig.8 Borehole joint section

Layer ⑥ is dominated by Brown silty clay and silt as a whole and mixed with brown yellow silty sand locally. Rust yellow fine lines and gray spots can be seen. It is a swamp facies deposit. The basis for the dislocation of this set of strata is first based on the shallow seismic exploration interpretation section, which shows that the reflected wave in-phase axis is obviously misplaced at the depth of 30 ~ 40m, and the joint drilling section shows that there is slight dislocation in the stratum at the bottom of layer ⑥, The dislocation of $F_{1\text{-}Qp3}$ of the main section is about 0.4m.

Layer ⑦ shows three distinct sets of strata. The upper strata are staggered by the main section $F_{1\text{-}Qp3}$ for 3.1m, and the middle and lower strata are staggered by the main section $F_{1\text{-}Qp3}$ for about 3.5m: the upper strata of layer ⑦ are cyan, grayish cyan, black cyan and grayish brown muddy marker layers, which are mainly fluvial facies deposits. This set of strata can be tracked and identified in the upper and lower walls from lithology, particle size Color and sedimentary facies are compared. The upper part of the stratum corresponding to borehole ZK4 is brown silt and the lower part is cyan gray silt, which shows obvious differences from the adjacent strata of the upper and lower walls, indicating the change of fault activity on the normal sedimentary environment of the stratum in this section; The middle of layer ⑦ is a continuous and traceable silty sand layer, mainly light reddish brown and brownish yellow silty sand, and brownish yellow silty soil can be seen locally. This set of strata can also be used as a marker layer, mainly fluvial facies deposition; The hanging wall of the lower part of layer ⑦ is dominated by Brown silty clay and silt, and brown yellow silty sand can be seen locally, with embroidered yellow and calcareous nodules visible. The footwall is dominated by cyan gray silty clay, with embroidered yellow and calcareous nodules visible locally. The strata of the upper and lower walls of the lower fault of layer ⑦ show obvious differences in sedimentary environment, and the hanging wall is fluvial facies or swamp facies, It shows that the hanging wall can not always be in the underwater environment, and the water level should be shallow. The footwall is swamp facies, the water level is deep and basically maintains the underwater sedimentary environment. The two sedimentary environments provide good evidence of fault dislocation.

Layer ⑧ can also be divided into three sets of strata: the upper stratum is mainly brown and brown yellow silt and silty clay, mainly swamp facies deposits; The middle part is dominated by continuous and traceable brown yellow silt and silt. This layer can also be used as a marker layer, which is fluvial facies deposition; The lower stratum is brown silty clay, and the $F_{1\text{-}Qp3}$ staggered stratum of the main section is 7.2m, mainly swamp facies.

According to the fault characteristics revealed by the combined borehole profile, it is considered that the target fault is not faulted at the middle and upper part of $Q_{p3\text{-}3}$ (layer ⑥), and the main section $F_{1\text{-}Qp3}$ fault $Q_{p3\text{-}2}$ (layer ⑦), $Q_{p3\text{-}2\text{-}1}$ (middle of layer ⑦) and $Q_{p3\text{-}1}$ stratum can be identified (see Table 4).

Based on the stratigraphic characteristics of the combined borehole profile, it is concluded that the sedimentary thickness of the faulted strata in the descending wall is greater than that of the same layer in the ascending wall, which is consistent with the sedimentary characteristics of the normal fault faulted wall; The staggered distance is about 3m twice within the exposed depth of the borehole.The coseismic displacement can judge that two main dislocation events occurred in the identification layer, which provides reliable geological evidence for analyzing the seismic risk of Tianzhuang fault; The main section $F_{1\text{-}Qp3}$ of Tianzhuang fault is not faulted with Holocene strata in this site. The faulted strata are three sets of late Pleistocene strata. From top to bottom, the offset of faulted strata gradually increases, which is 0.4m, 3.5m and 7.2m in turn.

There are two associated faults f_1 and f_2 on both sides of the main section $F_{1\text{-}Qp3}$. f_1 is the reverse associated normal fault of the main section $F_{1\text{-}Qp3}$. It can be seen from ZK2 and ZK3 that the stratum has staggered, while f_2 is the co directional associated reverse fault of the main section

F_{1-Qp3}. It can be seen from ZK4, zk7 and ZK6 that the stratum has obviously staggered. From the section, the horizontal distance from ZK2 to ZK6 is 90m, so it can be seen that the influence range of the deformation zone on both sides of the main section F_{1-Qp3} of the late Pleistocene can reach 90m, of which the influence range of the hanging wall deformation zone is about 55m, the influence range of the footwall deformation zone is about 35m, and the range of the hanging wall deformation zone of the normal fault is larger than that of the footwall deformation zone. At the same time, the F_{2-Qh} activity of the main section of Tianzhuang fault is new, but the fracture zone is weaker than the F_{1-Qp3} of the main section. Therefore, it can be judged that the activity became weaker in the Holocene. The total deformation zone of F_{2-Qh} of the main section dominated by creep will not be greater than 90m, and the unilateral deformation zone will not be greater than 55m.

6 Analysis on formation mechanism of Tianzhuang fault deformation zone

Tianzhuang fault belongs to the Northeast Branch of Jiaocheng fault. Its formation is the same as that of Jiaocheng fault. With the Mesozoic Yanshan movement, Qinshui Basin thrust northwestward. The northwest corner of Qinshui Basin, that is, the area where Taiyuan basin is located, the west boundary of the area (the predecessor of Jiaocheng fault) thrust to Luliang Uplift, and the north boundary (the predecessor of branch fault Tianzhuang fault) thrust to Wutai complex anticline. With the beginning of the Cenozoic Himalayan movement, the compression in the southeast northwest direction turned to tension. During the three episodes of Himalayan activity, the thrust faults on the West and North boundaries of Taiyuan Basin revived in the form of normal fault strike slip. The middle and Late Neogene was the first episode, and the early and inter episodes were dominated by compressive strike slip uplift, which led to the jb-xbg survey line of Tianzhuang fault (Wenjiabao-xiaobeige) The shallow seismic reflection time profile shows a stepped fault depression. The deepest fault depression corresponds to the second act of Xishan, the sub deep fault depression corresponds to the fault depression in the initial section of the third act of Xishan, followed by the relative compression uplift in the Middle Pleistocene, the shallowest fault depression corresponds to the fault depression activity since the late Pleistocene, and the shallowest fault depression activity belongs to the third act of Xishan as a whole.

According to the characteristics of Himalayan movement, it is an alternating movement of compression uplift and tension fault depression. Compression will make the section retreat relative to the initial compression section, and tension will make the section move forward relative to the initial tension section. Therefore, under the action of the overall compression uplift in the previous stage and the continuous tension fault depression in the later stage, due to the migration of the section, a rolling anticline is formed between the section groups in a tension stage, This also provides a geological basis for determining the range of the whole fault deformation zone in this period, but combined with the details of the borehole joint section, the significant influence deformation range of the main section can be limited, which has engineering guiding significance for deep buildings.

7 conclusion

In conclusion, the Xishan Sanmu movement has caused many fault subsidence activities in Tianzhuang fault, especially the latest and shallowest fault subsidence activity, which has a great impact on surface and underground works. According to the investigation along the fault, it is found that there has been ground fracture activity and house tension fracture. Combined with the drilling joint section, the details of the deformation zone are revealed. Therefore, it is determined that the extension of the main section $F_{2\text{-}Qh}$ of the front edge is 55m to the south, The rear edge main section $F_{1\text{-}Qp3}$ extends 35m to the north, the spacing between the two main sections is determined to be 400m, and the total deformation zone width is 490m. Considering the specific needs of seismic fortification of the project, the limit range on both sides of the two main sections should be 55m.

Reference：

Zhu Rixiang, Xu Yigang(2019).Western Pacific plate subduction and North China Craton destruction. Chinese Science: geoscience, 49 (0): 1346-1356

Xu Liqing(2013). Characteristics of active fault system in the central part of North China block and preliminary study on post earthquake risk［D］. Qingdao: China Ocean University.

Wang Yu, Sun Lixin, Zhou Liyun, et al(2018). Discussion on the relationship between the Yanshan movement and the destruction of the North China Craton. Chinese Science: geoscience, 48 (5): 521-535.

Huang F., Rooney T. O., Xu J., Zeng Y(2021). Magmatic record of continuous Neo-Tethyan subduction after initial India-Asia collision in the central part of southern Tibet. GSA Bulletin, 133(7-8):1600-1612.

Ge Xiaohong, Wang minpei, Liu Junlai(2010). Redefining the era and background of the "Sichuan movement" and the initial uplift of the Qinghai Tibet Plateau: Enlightenment from the formation of Huangling anticline. Geoscience front, 17 (4): 206-217.

Huang Lei, Zhou Xinhuai, Liu Chiyang, et al(2012). Important turning period of Cenozoic basin evolution in Bohai Sea - evidence and regional dynamics analysis. Chinese Science: geoscience, 42 (6): 893-904.

Gong Mingquan(2010). Study on the uplift process of the southern Taihang Mountain in Cenozoic［D］. Beijing: Chinese Academy of Geological Sciences.

Wu Chen(2001). On tourism landscape and geomorphic resources in Taihang mountain area. Geography and land research, 17 (4): 6-10.

Zhang Bin(2014). Study on CBM enrichment law in Zhengzhuang block, Qinshui Basin［D］. Beijing: China University of Geosciences (Beijing).

Lin Yuxiang, Liu Hu, Guo Fengxia, et al(2014). Study on stratigraphic denudation in Qinshui Basin. Geology and exploration, 50 (1): 114-121

Xie Xinsheng, Xiao Zhenmin, Wang Weixiang(,1996). Study on Mesozoic Cenozoic tectonic evolution of Jinzhong South fault basin and current tectonic stress field in Linfen Basin [C]. Beijing: Institute of crustal stress, China Seismological Bureau, (S1)

Pan Guang. Large structure of Datong coalfield, Shanxi. Science Bulletin, 1957, 2 (20): 633

Yang Chengxian, Wang Wenqing(1999). Yanlie fault zone and Yanqiao structure of Cenozoic rift system in central and southern Shanxi - reanalysis of Cenozoic rift system structure in central and southern Shanxi according to geophysical data [C]. Beijing: Institute of crustal stress, China Seismological Bureau.

Zhang Minhou, Yang Chengxian(1996,). On truncated faults and earthquakes - Taking Three NE trending faults in North China as an example. China earthquake, 12 (2): 163-172

Wang Changzai, Wu Jianping, Yang ting(2018). Double difference tomography in Taiyuan Basin and its surrounding areas. Journal of Geophysics, 61 (3): 963-974

Han Xiaofei, Li Bin, Dong Bin, et al(2017). Study on the activity of the middle section of Tianzhuang fault [J]. Advances in geophysics, 33 (5): 1789-1795.