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RESEARCH ARTICLE

Morpho-Sedimentary evidence of the Huoshan Fault's late Cenozoic right-lateral movement in the Linfen Graben, Shanxi Graben System, North China

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Abstract The Huoshan Fault, being of NEN strike, is one of the most important faults in the Shanxi Graben System of North China; it is the location of the 1303 A.D. Hongtong earthquake ($M_S = 8.0$). The late Pleistocene and Holocene offset of some gullies that cross the fault and some fault scratches have proved its right lateral movement during the late Quaternary; however, until now, geological evidence to support the movement in the Neogene and early Quaternary was scarce. Our work provides further crucial evidence that supports both its movement in the late Cenozoic and the total right-lateral displacement since the Pliocene. The difference in the outcrop heights of the Pliocene sediment along the fault, the difference in the geomorphological development along the fault, the inconsistency in the lithological composition of the Pliocene proluvial gravels with the rock types within the catchments of the current upper stream, and the offset of the Pliocene alluvial gravels all completely indicate that the fault has always moved right-laterally since the Pliocene. Additionally, this evidence indicates that the accumulative displacement is up to 12.5 km. Based on the horizontal and vertical displacement of the fault since the Pliocene, the time-averaged horizontal slip rate of the fault is estimated to be about 3.5 mm/a, while the ratio of the horizontal to vertical offsets is about 3.8; these data are roughly close to the results that were acquired from the Holocene and the present movement of the fault. This similarity in the tectonic movement parameters may imply that the intensity as well as the configuration of the regional stress field has remained constant, and that no significant changes have taken place since the Pliocene.

Keywords Huoshan Fault, Shanxi Graben System, right-lateral movement, geomorphological and sedimentary evidence

1 Introduction

North China is topographically composed of two parts (the east and the west) that are bounded by the Taihang Mountain Range. The eastern part is the North China Plain, while the western part is the Shanxi Plateau (Fig. 1). North China has been a tectonically active area in the Cenozoic era (Tian et al., 1992; Gao et al., 1995; Pavlides et al., 1999; Zhang et al., 2003). Since the Paleogene, due to the subduction of the Pacific Plate underneath the Eurasia Plate, the regional stress field had been characterized by a NW-SE extension that had produced a number of NEN-striking grabens and horsts in the eastern part; the western part had remained a plateau, which is known as the Shanxi Plateau, and had been eroded (Ma and Wu, 1987; Ye et al., 1987; Rodnikov et al., 1992). Since the Pliocene, the compressive force that has resulted from the collision of the Indian Plate with the Eurasia Plate has gradually become dominant, and the regional stress field has changed into an ENE-WSW compression as well as a NW-SE extension (Teng et al., 1979; Wang, 1983; Li et al., 1985). Under such a stress regime, the eastern part sunk wholly with a sediment thickness of several thousands of meters to form a depositional plain, which is the North China Plain. In the western part, the Shanxi Graben System extends from NEN to SWS and consists of the Huailai, Datong, Xinzhou, Taiyuan and Linfen Grabens; the Shanxi Graben System has developed on the Shanxi Plateau, along which the Late Cenozoic sediment, which is more than 2000 m thick, was deposited (Wang et al., 1996).

The Shanxi Graben System is primarily bounded by two

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groups of normal faults: one strikes NEN or NE, and the other strikes approximately EW. Most of the NEN or NE normal faults developed along the traces of the Mesozoic reversed faults (Meng and Yu, 1986; Research Group of State Seismic Bureau, 1988). Under the regime of the Late Cenozoic regional stress field, these faults changed to normal faults. The Late Pleistocene and Holocene deflection of the gullies that cross these faults, the faults' scratches and the modern crust movements during earthquakes (Xu et al., 1986; Xu and Deng, 1990; Wang et al., 1996) have all proved that in addition to the dip-slip dimension, the NEN or NE striking faults also slip right-laterally, while the approximate EW-striking faults slip left-laterally. Thus, these faults are essentially oblique-slip normal faults. However, until now, insufficient evidence has been acquired to indicate such movement in the Neogene and the Early Quaternary; the total displacement of these faults since their formation in the Pliocene is unknown.

The Linfen Graben is a graben in the Shanxi Graben System; the Huoshan Fault is located in its northeastern region and serves as a boundary fault (Fig. 1). This fault is

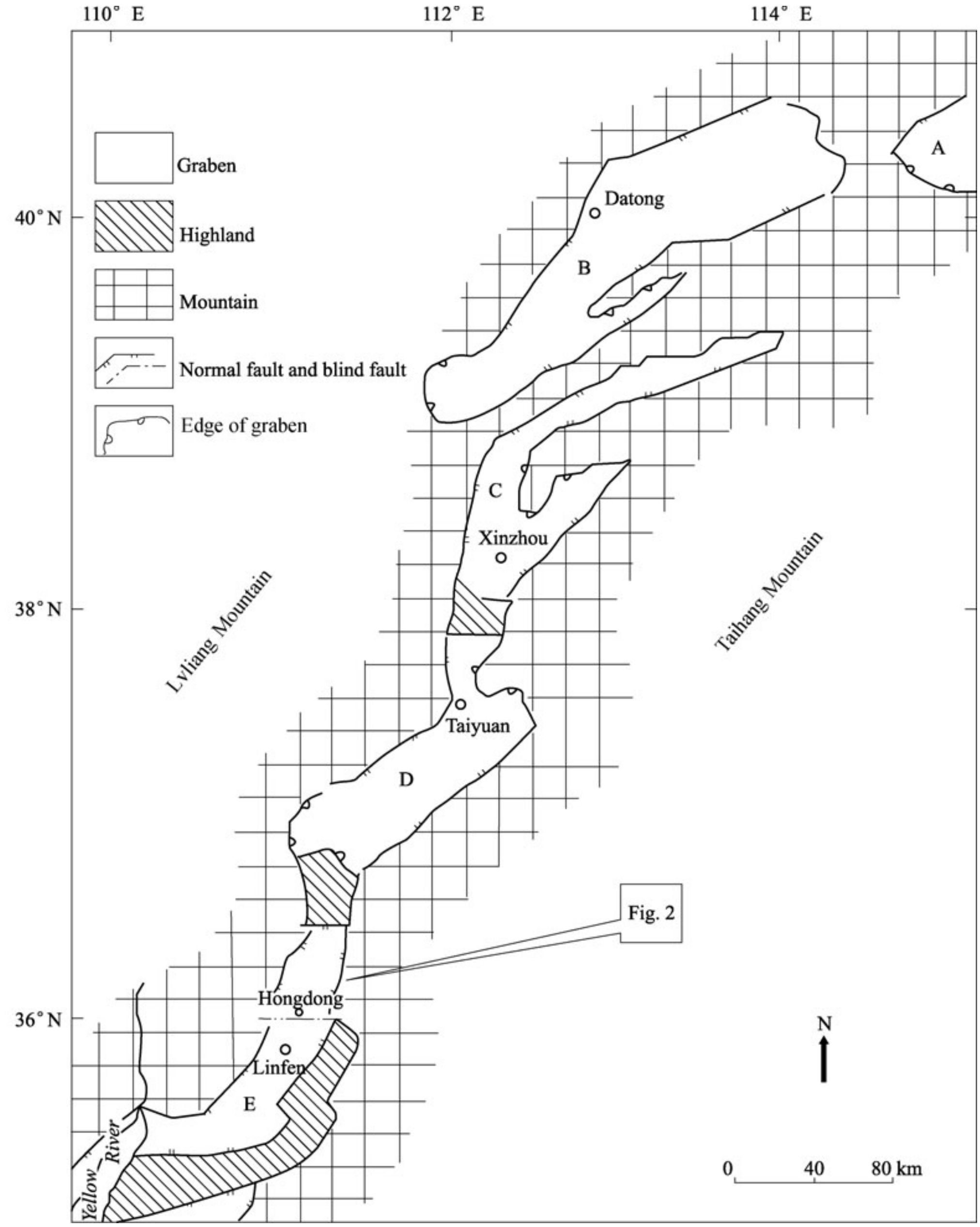

Fig. 1 Map sketching the geological structure of the Shanxi Graben System and the tectonic geomorphic characteristics of North China (A. Huailai Graben, B. Datong Graben, C. Xinzhou Graben, D. Taiyuan Graben, E. Linfen Graben)

one of the most important faults in the Shanxi Graben System and is responsible for the Hongtong earthquake in 1303 A.D. (Ms = 8.0) (Meng et al., 1985). Due to its continuous right-lateral movement since the Pliocene, it has produced a great deal of special landform deformations and sediment variations along the faults. In this paper, we will present some geomorphological and sedimentary evidence that is related to this kind of movement, and determine the total displacement since the Pliocene to improve our understanding of the neotectonic characteristics of such right-lateral faults in North China.

2 Regional geological and topographical characteristics around the Huoshan Fault

The Huoshan Fault extends about 60 km, strikes at 15°N–20°E and dips toward NW (Fig. 2) with a dip angle of about 55°–65° in the southern section and about 70°–80° in the northern section. It is only one segment of the eastern boundary fault of the Linfen Graben. The fault, which was displaced by the Supu Sinistral Normal Fault that has a nearly E-W strike in its southernmost part, distributes in en echelon with the Dayang Fault in the south. In the northernmost region, its geologic structure has been affected by the Shilin Sinistral Normal Fault that has an E-W strike; the trace gradually becomes blind (Research Group of State Seismic Bureau, 1988).

Previous studies have revealed that the fault has not only a dip-slip movement, but also a right-lateral slip. The eastern block, which acts as a footwall, uplifted to form Mt. Huoshan (its summit is 2396 m a.s.l.), and the western block, which is a hanging wall, subsided to form a graben. More than 200-m-thick Neogene and 800-m-thick Quaternary sediments were deposited in the graben; among the sediments, the oldest is from the Pliocene, which indicates the time of the graben's formation (Research Group of State Seimic Bureau, 1988; Wang et al., 1996). The height difference between the rocks at Mt. Huoshan's summit and the bedrocks that lie under the graben reaches about 3300 m, which indicates that the fault's vertical offset has grown by more than 3300 m since the Pliocene. Xu and Deng's studies (1990) showed that the fault has experienced right-lateral movement since the late Pleistocene, and that the horizontal offset of the fault was larger than the vertical one. Moreover, some geological evidence, such as gouges that developed at different ages and horizontally displaced gullies with different offset extents, also indicates the fault's many intensive oblique-slips since the late Quaternary.

Geologically, Mt. Huoshan is composed of the south-eastern limb of a SWS plunging anticline, while the northwestern limb has subsided underneath the Linfen Graben. The core rock of the anticline is Archaeozoic gneiss, while the eastern slope of the mountain contains Archaeozoic gneiss, Cambrian and Ordovician limestone, Carboniferous sandstone, gray-black shale that is intercalated with a coal seam, and amaranthine Permian sandy shale.

Topographically, the western slope of Mt. Huoshan, where many short and steep gullies developed, is steeper than the eastern one. The northern segment of the mountain is higher than the southern one and has a relief that decreases gradually southward. To the east of the mountain, a 150-km-long river developed (the Honganjian River), which also drains the eastern slope of Mt. Huoshan. The river flows from the northeast to the southwest and cuts across the bedrock to enter the graben in the mountain's southernmost region.

In addition, in the middle section of the Huoshan Fault, there exists a low hill on the graben block (Fig. 2). The hill is geologically a small NW-SE asymmetric anticline. The stratum in the core of the anticline is Cambrian limestone. In the northeastern limb, the stratum is Ordovician limestone with a dip angle of about 30°; the strata in the southwestern limb are Ordovician limestone, Carboniferous sandstone and gray-black shale, and Permian sandy shale with a dip angle of about 16°, which forms a structural drag. To the east, the anticline is bounded by the Huoshan Fault. The strata sequence in the anticline is consistent with the southern section of the eastern block near the fault; even the layers of coal in the Carboniferous sandstone and the grey-black shale in both of the sites can be well correlated, which implies that they were dextrally displaced.

3 Research method and new evidence that shows the right-lateral movement of the Huoshan Fault since the Pliocene

3.1 Method

Horizontal movement of a fault will offset all of the geomorphological and sedimentary bodies that cross the fault. For example, if there is a river flowing across an active fault, the lateral movement of the fault will displace the upper section of the river relative to the lower one and make the river turn left or right where it meets the fault. The displaced geomorphological and sedimentary bodies are the first-order consequences of the fault's lateral movement and provide direct evidence of the fault's lateral movement.

Under the action of a horizontal stress field, a set of conjugate strike-slip faults will develop. The lateral movements of the conjugate strike-slip faults can produce a local tectonic stress field along the fault, in which some parts are in compression while the others are in extension. According to Yang and Li (2006), in such a faults' pattern (Fig. 3), the continuous movement of the blocks will cause the A and A' areas to be in a compressive state and to uplift relatively; in contrast, the B and B' areas are under tensile

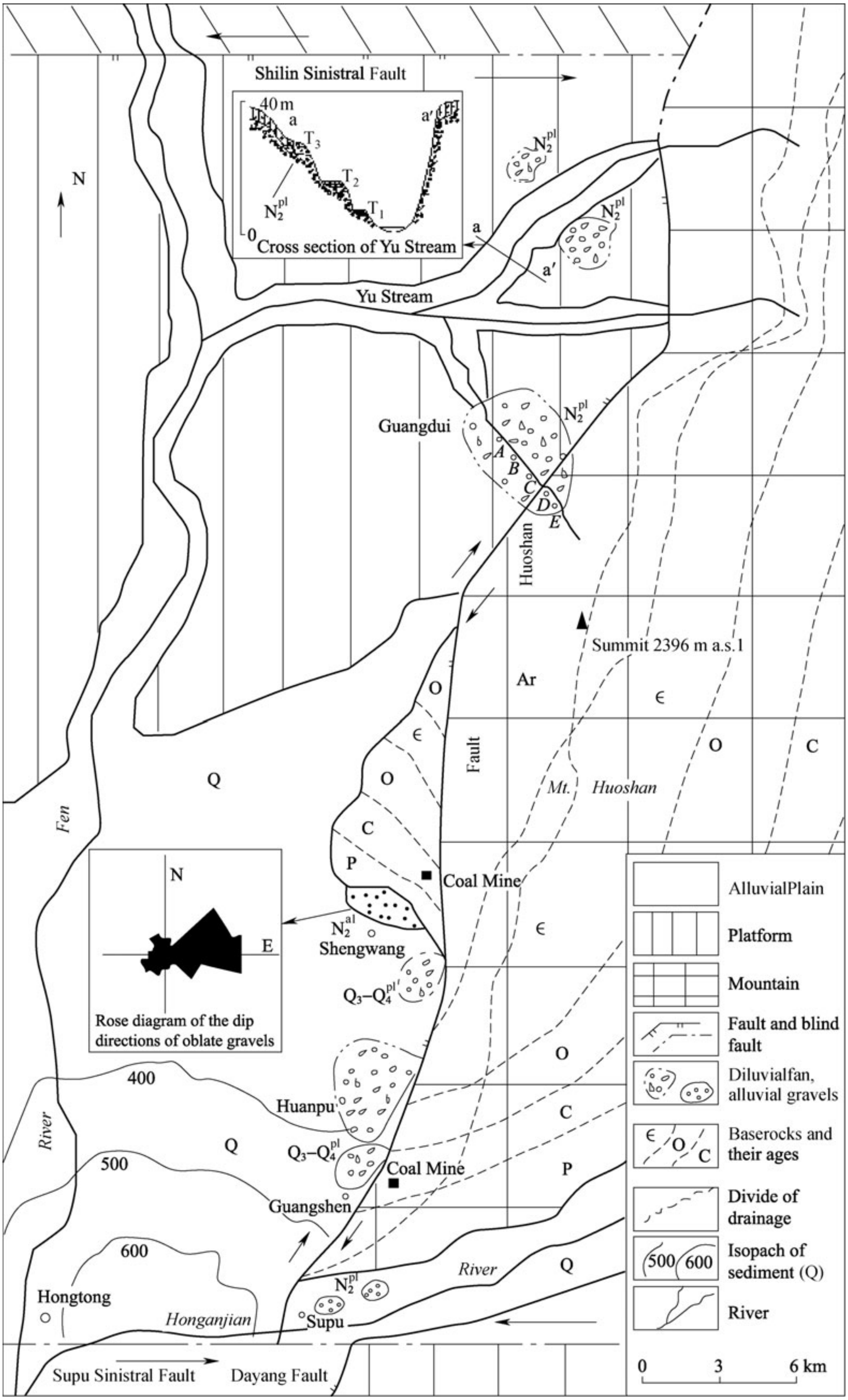

Fig. 2 Map sketching the geomorphological and geological characteristics around the Huoshan Fault (Partly modified after The Geologic Map by The Geologic Survey Bureau of China, 2004 and Wang et al., 1996)

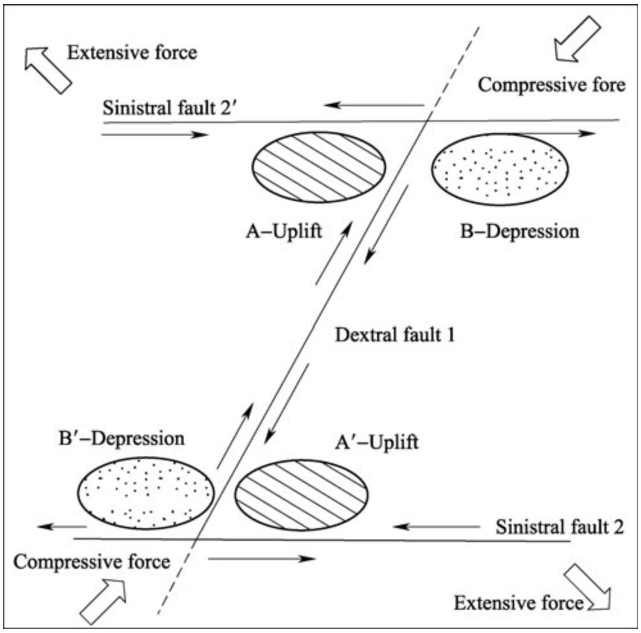

Fig. 3 Double uplifts and depressions that result from the lateral movement of a set of conjugate strike-slip faults

stress and sink relatively. Such movements of the conjugate strike-slip faults eventually develop a special neotectonic geomorphological phenomenon: double uplifts and double depressions on both sides of the fault. This kind of tectonic landform exists in several places in north and northwest China (Yang, 1983). These double uplifts and double depressions are the second-order consequences of the fault's lateral movement and can also provide some essential evidence of the fault's lateral movement.

3.2 New evidence

3.2.1 The difference in the outcrop heights of the Pliocene sediment and the difference in the geomorphological development along the fault

Red Clay is a kind of distinct aeolian sediment that formed during the Pliocene (N_2) in North China (Sun et al., 1997). In the graben side near the fault, the Pliocene sediments (the mixture of Red Clay with the proluvial gravels) distribute at different heights in different parts, but they are all deposited in the graben.

In the northern part of the graben close to the fault, the mixture of both the Pliocene Red Clay and the proluvial gravels is widely distributed; in addition, it partly crops out and is usually capped by 25- to 40-m-thick aeolian loess or redeposited loess with an alluvial origin. The height of its top is about 1000 m a.s.l. The sediment with the same age in the southern part of the graben near the fault is now deeply buried by Quaternary deposition. Hongtong City was one of the depocenters in the Linfen Graben during the Quaternary. The drilling data for the basin show that the depocenter is situated between Hongtong City and Guangshen Village (Fig. 2) and that the successive Quaternary sediment is about 600 m thick (Research Group of State Seimic Bureau, 1988; Wang et al., 1996). The height of the top of the underlying Pliocene sediment is estimated to be about 50 m a.s.l. This measurement shows that a great height difference exists in the Pliocene sediment's top between the northern and southern parts of the graben. The height difference reaches 950 m.

Along the southern section of the fault, many proluvial fans developed on the graben side. They are the result of sediment accumulation in the mouth of the gullies from the western slope of Mt. Huoshan. These proluvial fans are mostly 3–4 km^2 in area, and the largest one is about 10 km^2 near Huanpu Village. In the edges of these fans, some unearthed sections show that, overlying the fans' surfaces, there is a layer of loess that is 2 to 3 m thick, and that no paleosols have developed there. Loess is a kind of Aeolian sediment from the Quaternary in North China. Not only does it record the Quaternary paleoclimatic changes in eastern Asia, but it has also been used as a dating method to determine the age of other Quaternary sediments (Porter et al., 1992; Hu et al., 2005). No paleosols in the loess overlying the fans indicates that the loess was deposited in the late Pleistocene or the Holocene.

Besides these younger proluvial fans on the earth's surface, drilling data (Wang et al., 1996) and some exposed sediment sections reveal that much coarser proluvial sediment in the underlying Quaternary fills was deposited, and that many older proluvial fans exist, which are buried at a great depth.

In contrast, along the northern section of the fault, the geomorphological characteristics in the graben are the high platforms that are made of Pliocene Red Clay and proluvial gravel sediment, with some steep gullies incising them. No Quaternary proluvial fans formed along the piedmont of this section. Yu Stream is one of the largest gullies in this section; three bedrock-seated terraces developed there with Pliocene sediment as the baserock (the ages of the three terraces are probably in the Quaternary) (Fig. 2). This observation indicates that the local neotectonic uplifted relative to the southern part of the graben near the fault.

3.2.2 The lithological characteristics of the Pliocene proluvial gravels near Guangdui Village

Guangdui Village is situated in the northern part of the graben close to the fault; in this region, there is a platform with an area of nearly 20 km^2 and an accumulation of thick Pliocene proluvial sediment. Some gullies from the western slope of Mt. Huoshan have deeply incised into the platform; the exposed sections show that the sediment's thickness is more than 200 m. The gravels in the proluvial sediment are subangular, partly cemented and mixed with the Red Clay. Along a gully that incises into this platform, we have investigated the lithological composition of the gravels in the sediment. The gully is about 5 km long. Five sites (A, B, C, D and E) were selected for this investigation from its mouth to the headwater (Fig. 2). The field survey found that the Huoshan Fault extends across the Pliocene sediment. Sites A, B and C are located on the western block of the fault, while sites D and E are on the eastern block, which is very close to the gully's headwater. For the field investigation, we randomly took 100 gravels from the sediment as a sample unit and calculated the proportion of every type of rock in the sample. The investigative results are listed in Table 1.

The statistics show that the aposandstone, gneiss, limestone and sandstone all appear in sites A, B and C and retain a similar proportion of rock types. However, in sites D and E, only aposandstone and gneiss are present without limestone and sandstone.

3.2.3 Comparison of the sedimentary characteristics of the alluvial gravels on both sides of the fault

In the southernmost part of Mt. Huoshan, the Honganjian River flows from east to west and enters the graben in Supu Village. About 500 m to the east of Supu Village, several alluvial terraces developed on the north slope of the river; the highest terrace, which is a bedrock-seated terrace, is about 75 m above the river bed. The alluvial sand and gravels in this terrace are partly cemented and contain several thin layers of Pliocene Red Clay, which implies that the age of the terrace is Pliocene. Another bedrock-seated terrace that is about 21 m above the river bed is overlain by a layer of loess/paleosol, which is about 21 m thick; in this layer, the oldest aeolian unit is S_5, which indicates that the terrace's age is middle-Pleistocene (Q_2). We have surveyed the sedimentary characteristics of the two terrace gravels. The results are shown in Table 2.

Shengwang Village is to the north of Supu Village by about 12.5 km; however, it is located on the graben side of the fault and very near to the low hill in the middle section of the fault (Fig. 2). At the hill's foot, a gully, which originated on the western slope of Mt. Huoshan, incised through both the Quaternary and Pliocene sediment and into the baserock. The exposed profile shows that the Pliocene sediment at this location is a kind of partly-cemented-to-cemented sand and gravel, which also contain several layers of Red Clay. We have surveyed its lithological composition, sedimentary features and the occurrence of oblate gravels. The gravels in the sediment are highly rounded, which indicates that, in the past, they were transported over a long distance by a river. The precipitated calcium carbonate layers in the Red Clay, which originally occurred horizontally, are now inclined and dip 201°SW with a dip angle of 24°; thus, the layers of Pliocene sand and gravels have deformed since its formation. By using a Wulff Net (stereographic projection net) to correct the deformed occurrence of the oblate gravels to their original, we find that the prevailing dip directions of the oblate gravels are among 75°ENE to

Table 1 The lithological statistics of the Pliocene gravels from different sites near Guangdui Village

type of rocks	site A	site B	site C	site D	site E
aposandstone	4	10	8	36	30
gneiss	22	24	18	64	70
limestone	64	51	54	0	0
sandstone	10	15	20	0	0

Table 2 Comparison of the gravels' characteristics for different locations and different ages

sedimentary characteristics		site near Supu Village		site near Shengwang Village			
		(N_2)	(Q_2)	(N_2)	(Q_1)	(Q_2)	present riverbed
lithology	aposandstone	0	0	0	4	22	18
	gneiss	5	12	6	23	48	44
	limestone	62	53	68	51	17	22
	sandstone	33	35	26	22	13	13
	conglomerate	0	0	0	0	0	3
average gravel size/cm[a)]		4.5	3.6	4.7	6.1	6.8	5.7
average gravel oblateness[b)]		3.01	2.76	2.82			
average gravel roundness[c)]		2.36	2.21	2.29	1.24	1.06	1.13

a) The gravel size is equal to $(a+b+c)/3$, where a, b and c are the lengths of the maximum, intermediate and minimum axes of the oblate gravel, respectively. b) The gravel oblateness is equal to $(a+b)/2c$. c) The gravel roundness is divided into five grades: angular (0), sub-angular (1), rounded (2), sub-rounded (3) and very rounded (4). The average gravel roundness is equal to $(n_1\times 0+n_2\times 1+n_3\times 2+n_4\times 3+n_5\times 4)/100$, where n_1, n_2, n_3, n_4 and n_5 are the numbers of gravels with different roundness grades

105°ESE (Fig. 2), which implies that the flow direction of the river transporting the gravels was nearly from east to west.

About 5 to 6 m above the top of the Pliocene sediment, another layer of partly cemented gravels exists that is nearly 2.3 m thick. The overlying sediment on it is loess or redeposited loess with a thickness of more than 20 m; many gravels are distributed separately in it, and its age is estimated to be early Quaternary (Q_1). In addition, in the lower reach of the gully, the exposed profile also shows several younger layers of deposited gravels, which are overlain by loess/paleosols with different thicknesses and successions. Among them, a main layer of gravel, which is about 4 m thick, is capped by a successive 15-m-thick loess/paleosol; the oldest aeolian unit in it is S_4, which indicates that the age of the gravels is within the middle Quaternary (Q_2).

Both the Q_1 and Q_2 gravels are the most sub-angular, and their roundness is distinctly poorer than that of the Pliocene gravels. In the field, we have also done statistics on their lithological composition, size, oblateness and roundness. The same statistics were done on the present riverbed's gravels. The statistical results are listed in Table 2.

According to the statistics data in Table 2, it is very obvious that the Pliocene gravels near Shengwang Village are similar to the Pliocene-age gravels in Supu village with respect to the lithological composition, average size, average oblateness and average roundness. However, the sedimentary characteristics of these gravels are different from those of Q_1, Q_2 and the present riverbed.

4 Interpretation of the morpho-sedimentary phenomena

Lateral movements of a set of conjugate strike-slip faults can cause double uplifts and double depressions along the faults (Yang and Li, 2006). For the Huoshan Fault, the geomorphological display on the graben side of the fault is consistent with such tectonic geomorphological models. The high outcrop of Pliocene sediment and the lack of proluvial fans in the northern part indicate that this area has been in compression and uplifted relative to the southern part since the Pliocene. In contrast, the southern part has been in extension and has sunk; this sinking has resulted in a Quaternary depocenter and has also made it easy for proluvial fans to continuously develop in the piedmont. Thus, it is most probable that the right-lateral movement of the Huoshan Fault in combination with the left-lateral movement of both the Supu Fault and the Shilin Fault since the Pliocene caused such stress field redistribution and resulted in such topographical differences.

In the northern section of Mt. Huoshan, the western slope is drained by the westward gullies; however, the western slope is now completely covered by Archaeozoic gneiss and contains no limestone or sandstone in the drainage area. The survey results in Table 1 show that 66 to 74% of the Pliocene gravels on the graben (in Sites A, B and C) are limestone and sandstone, with only aposandstone and gneiss on the eastern side (in Sites D and E). The lack of limestone and sandstone in Sites D and E indicates that the western slope of the mountain has never had limestone and sandstone cover. Thus, What is the source of the limestone and sandstone gravels in the graben?

In the middle and southern sections of the mountain, the drainage area of the gullies on the western slope is partly occupied by Archaeozoic gneiss, Cambrian and Ordovician limestone, Carboniferous sandstone and Permian sandy shale. The gravel accumulation in the pediment and in the present gullies' beds is a mixture of gneiss, limestone and sandstone. Based on this fact, it can be reasonably speculated that the limestone and sandstone in the Pliocene gravels in the northern part of the graben near the fault were from the western slope of the middle section of Mt. Huoshan when the sediment originally accumulated in this area's pediment during the Pliocene period. Thereafter, the right-lateral movement of the fault had intermittently made the sediment move northward to the present location.

In Shengwang Village, the high roundness and the original dip directions of the majority of oblate gravels of the Pliocene from the east indicate that the N_2 gravels were from the deposition of a large and long river that flowed from east to west, which originated in the eastern mountainous area. However, the upper streams of the gullies from the western slope of Mt. Huoshan are all normally less than 4 km in length; in addition, it is impossible for them to transport angular gravel and to smooth the gravel to such roundness. There was probably another large and long river that can account for the formation of these Pliocene gravels.

Table 2 shows that the Pliocene gravels' characteristics in Supu Village are nearly consistent with those of the same age in Shengwang Village. Between the two locations, no large rivers exist, but many small gullies from the western slope of the mountain do. Thus, it is most likely that the alluvial gravels from the Pliocene period in Shengwang Village are also from the deposition of the Honganjian River during the Pliocene period. Due to the dextral displacement of the Huoshan Fault afterward, the gravels on the graben side were moved to the present location.

This interpretation can be further proved by three other facts. First, in the gullies near Shengwang Village, the gravels of Q_1, Q_2 and the present riverbed are greatly different from those of the Pliocene period with respect to the sedimentary characteristics (particularly the average gravel size and roundness). When extensive dextral offset took place along the fault, locales that formerly received deposition of alluvial gravels from the Honganjian River would only accumulate the coarse and angular gravels, which were carried by some short gullies from the western slope of Mt. Huoshan. Second, if we move the graben block back southward and let the gravels of N_2 in Shengwang Village parallel those in Supu Village, the sequence of rock layers in the small anticline in the middle section of the fault in the graben will fit with that in the eastern block. Third, after moving the graben block back southward and letting the gravels of N_2 in Shengwang Village parallel to those in Supu Village, the N_2 proluvial gravels around Guangdui Village will also move back nearly the same distance. This move will restore the location of the gravels to the middle section of the fault, where the western slope of Mt. Huoshan is partly covered by limestone and sandstone from the Cambrian, Ordovician and Carboniferous periods. This restoration will account for the existence of the components of limestone and sandstone in the Pliocene proluvial gravels in Guangdui Village.

5 Conclusions and discussion

The geomorphological changes and sedimentary variations have been two main resources from which researchers draw information about the regional neotectonic movement (Enzel et al., 2000; Burbank and Anderson, 2001; Zhang et al., 2004; Luis et al., 2006; He and Oguchi, 2008; Srivastava and Misra, 2008). In accordance with the analysis of the morpho-sedimentary phenomenon along the Huoshan Fault, it is revealed that the fault has dextrally moved since the Pliocene and that the space between the Pliocene alluvial gravels in Supu Village and Shengwang Village is the accumulated offsets of right-lateral movement of the fault since the Pliocene. Thus, it is believable that the total right-lateral displacement of the fault has been about 12.5 km since the Pliocene.

Li et al.'s study (1996) on the uplifts of the Tibet Plateau during the late Cenozoic indicates that there was an extensively intense tectonic uplift in 3.6 Ma BP (Pliocene epoch), which had profound effects on both landform development in the northwestern part of China and the paleoclimatic changes of eastern Asia. This intense tectonic movement may have also influenced northern China, resulted in the formation of the Shanxi Graben and promoted the right-lateral movement of NEN strike faults in this region. If the time when the Huoshan Fault started to move is taken as 3.6 Ma BP, then the estimated average horizontal slip rate of the fault is about 3.5 mm/a (12.5×10^6 mm/3600000 a), and the ratio of the horizontal offset to the vertical offset is about 3.8 (12.5×10^3 m/3300 m) for the late Cenozoic era.

Xu et al.'s (1986) and Xu & Deng's (1990) extensive field surveys found that the average horizontal slip rate of some primary NEN or NE strike faults in the Shanxi Graben System during the late Quaternary and the Holocene is about 4.9–6.4 mm/a. By analyzing GPS data that recorded intraplate tectonic block movement, Wu et al.'s research (2001) showed that the NEN striking Front Taihang Mountain fault currently has a horizontal slip of 5 ± 2 mm/a.

The slip rates of these NEN or NE strike faults during the Late Quaternary and Holocene and at the present time are roughly similar to that of the Huoshan Fault during the late Cenozoic era.

Moreover, based on an analysis of the focal mechanisms of the earthquakes, researchers (Zhang et al., 1979; Wang, 1983; Ma and Wu, 1987) found that the dip angle of the principal compressive stress in the ENE-WSW direction in North China is gentle and less than 25°; in addition, the horizontal dimension of the stress is more than the vertical one. Guo's survey (1977) of the NEN striking fault that caused the Tangshan earthquake (M_S = 7.8) in 1976 showed that the horizontal displacement of the fault is 2.3–5 times more than the vertical one. Thus, as for the present stress field and fault movement in North China, the ratio of the horizontal stress dimension to the vertical one and the ratio of the horizontal displacement to the vertical one in some active fault movements are also roughly similar to that displayed by the Huoshan Fault in the late Cenozoic era.

This similarity in the tectonic movement parameters of the NEN or NE striking faults in northern China, which were measured at different time scales, may imply that the intensity and configuration of the local stress field have remained constant and that no significant changes have taken place since the Pliocene. This speculation is in agreement with Teng et al.'s research results (1979).

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