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Palaeo-stress field and tectonic evolution of the Mazhan graben area in the Yi-Shu fault zone of the Tan-Lu fault belt, East China

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Abstract

The Mazhan graben is located in the Yi-Shu fault zone, which is the middle segment of the Tan-Lu fault belt, one of the oldest and famous large fault belt in China. As a result of the structural analyses on the change of stress field and basin formation, it is clarified that tectonic evolution of the Manzhan graben can be divided into three stages, namely the pre-graben first stage in Palaeozoic to middle Jurassic, the graben-forming second stage in Cretaceous and the post-graben third stage in post-Palaeogene.

Palaeo-stress field and tectonic movement have also changed from NW-SE compressive state resulted in thrusting with sinistral shear movement at the first stage, through NNE-SSW compressive state that formed "graben/horst/graben" as the final tectonic framework at the second stage, to NNW-SSE compression with sinistral shearing and rising of the area at the third stage.

The fundamental dynamics of these large scale fault movement in East China would be affected by Kular palaeo-plate, however its precise study is problem in the future.

Key words: Mazhan graben, Yi-Shu fault zone, Tan-Lu fault belt, stress field, East China

Introduction

The Yi-Shu fault (YSF) zone is the middle segment of the Tan-Lu fault (TLF) belt, or strictly speaking, the Tancheng-Lujiang fault belt. YSF is situated in valley areas of the rivers Yishui and the Shushui in central Shandong Province (Fig.1). TLF belt is the oldest and most famous large fault belt extending in the East China with NNE trend. There are considerable studies not only of geology, but also of the related fields of earth sciences because of its distinctive tectonic position

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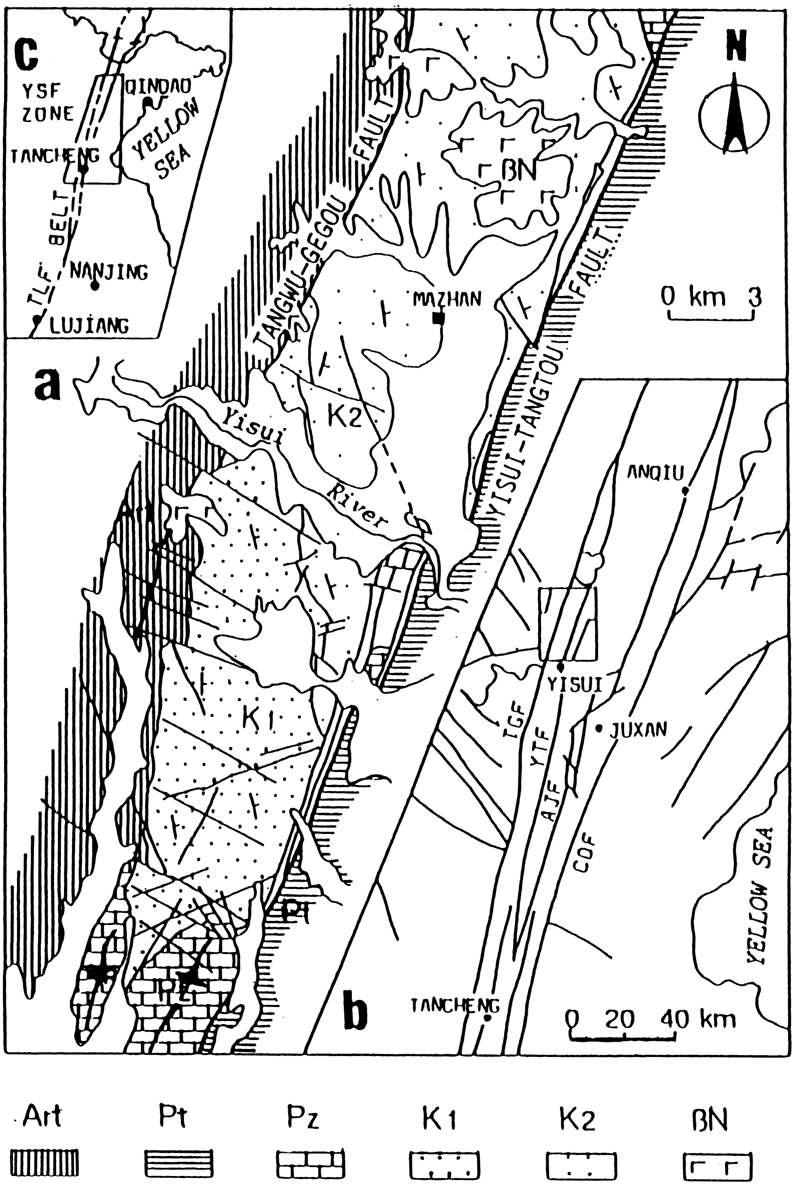

Fig.1. Map showing geology, tectonics and location of the Mazhan graben and its vicinity, central Shandong Province, East China.

a : geology of the Mazhan graben area. Art : Archaeozoic granite-gneiss. Pt : Proterozoic low-grade metamorphics. Pz : Palaeozoic limestone. K_1: Early Cretaceous volcanic rocks. K_2 : Late Cretaceous sandstone. β N : Neogene basalt.

b : tectonic sketch of the Yi-Shu fault (YSF) zone area.

c : location of the Tan-Lu fault (TLF) belt and YSF.

and complicated deformation history as well as the close relation with endogenesis of minerals, formation of fault basins and seismicity in adjacent areas during its development. Moreover, there are excellent outcrops in TLF belt areas that can be contributed to study. Many geologists in China and in foreign countries have been attracted with great interests in study of TLF, and relevant research results based on different academic ideas or by using various means have been achieved.

A number of conclusions have been carried out through those studies as follows in summary:

(1) TLF belt is one of the oldest fault zones in China, and it was probably formed in late Archaeozoic (or, pre-Sinian) mostly with vertical movement and weakly with transcurrent movement in its tectonic history (Huang, 1959; Li and Wang, 1980; Zhang, 1981).

(2) TLF belt is an important Neo-Cathaysian tectonic system in China (Li, 1974). Owing to NNE trending sinistral compresso-shearing since Mesozoic times, the horizontal displacement would be about 200-350km at most, or it could be more than 740km (Xu J.W., 1984) by virtue of obvious displacement of tectonic or lithologic boundary lines in both sides of TLF belt.

(3) Thick volcanic rocks including alkaline ones are widely distributed in TLF belt to suggest that there was a continental tension-valley in Cretaceous (Xu Zh.Q., 1980).

(4) TLF belt was thought to have been a suture line of palaeo-plate (Cheng, 1980).

YSF zone studied in this paper is composed of four normal faults which are named as the Tangwu-Gegou fault (TGF), the Yishui-Tangtou fault (YTF), the Anqiu-Jushan fault (AJF) and the Cangyi-Dadian fault (CDF) from west to east (Fig.1). General view of the tectonic framework suggests that the west-graben was formed by the former two faults and the east-graben by the latter two as well as a horst between them. Late Mesozoic (Cretaceous) thick volcanic and pyroclastic rocks (andesite, tuff and volcanic breccia) and sedimentary rocks (sandstone and mudstone) were accumulated in these grabens. The west-graben named as the Mazhan graben can provides an excellent opportunity to study the various deformed structures and microstructures and to comprehend the features and tectonic history of different stage and to analyse the tectonic stress fields related to YSF zone although they are limited to those about TLF belt during late Mesozoic (Cretaceous).

Geological setting

As stated above, YSF zone is extending through all area of the Shandong Province with pronounced NNE trend. It separates the Shandong block into the Lushi platform on the west and the Ludong shield on the east. In both parts, quite different rock types and deformation structures are distributed. The former consists of Archaeozoic granite-gneiss basement (2.4 Ga) and widely developed Palaeozoic sedimentary cover only with a little Mesozoic (mainly Jurassic) sediments locally accumulated in NW trending fault basins, but the later has Proterozoic basement of low grade metamorphic rocks (1.7-1.8 Ga), and the directly overlying Mesozoic (mainly Cretaceous) sediments with wide distribution, and there is lacking of Palaeozoic sediments. All the tectonic trend in the Ludong shield is NE, on the contrary in the Lushi platform, it is NW, and the apparent discordant relation between the sediments might be induced by the complicated tectonic evolution of YSF zone and/or TLF belt.

The Mazhan graben studied at present is a NNE trending Cretaceous graben with a length over than 80km and width of 5-8km (Fig.1-a) and is isolated by a Palaeozoic rise in the southern area. Cretaceous volcanic rocks (the lower Qingshan Group) and sedimentary rocks (the upper Wangshi Group) were best developed in the graben, where the structure of all of Cretaceous sequences can be observed as a homocline dipping to NE at less than 30°. Only in the vicinity of a boundary fault, small folds with wavelengths of some metres which were locally affected by YSF movement are

Table 1. Attitudes of a-b planes of tectonic lenses on the foliations of fault rocks along YSF zone in the Mazhan graben and inferred movement of YSF zone.

locality no.	attitude of YSF zone	a-b plane of tectonic lense	foliation in fault rock	inferred sense of YSF movement
Fg-1	300° ∠60°	100° ∠60° 130° ∠71°		dextral-thrusting sinistral-thrusting
Fy-2	300° ∠75°	140° ∠48° 150° ∠61°		sinistral-thrusting sinistral-thrusting
Fy-3	300° ∠75°	120° ∠35° 210° ∠45°		thrusting dextral-transcurrent
Ft-1	300° ∠85°	230° ∠76° 35° ∠78° 115° ∠49° 135° ∠58°		dextral-normal dextral-normal dextral-thrusting sinistral-thrusting
Ft-2	95° ∠66°	195° ∠67°		sinistral-normal
Ft-3	110° ∠70°	145° ∠76° 110° ∠79°	100° ∠63°	sinistral-thrusting sinistral-thrusting dextral-normal
Fy-4	295° ∠66°	345° ∠21°	310° ∠45°	sinistral-normal
Fy-5	315° ∠61°	295° ∠78° 326° ∠54°	290° ∠80°	dextral-thrusting sinistral-normal
Fy-6	115° ∠80°	170° ∠66°	120° ∠80°	sinistral-normal sinistral-thrusting
Fy-7	280° ∠30°	290° ∠67°	300° ∠66°	sinistral-thrusting
Ft-4	300° ∠85°	115° ∠66° 240° ∠78°		dextral-thrusting dextral-normal
Fy-8	297° ∠75°	285° ∠83° 97° ∠64° 297° ∠50° 310° ∠57°	127° ∠35°	dextral-thrusting dextral-thrusting sinistral-normal sinistral-normal sinistral-thrusting
Fy-9	115° ∠80°	40° ∠90°		sinistral-thrusting
Ft-5	100° ∠84°	255° ∠79° 290° ∠77°	110° ∠85°	dextral-thrusting sinistral-thrusting sinistral-thrusting
Fy-10	285° ∠75°	260° ∠20° 335° ∠20° 140° ∠11°		dextral-normal sinistral-normal sinistral-thrusting

developed. Cretaceous strata unconformably overlies deformed Palaeozoic formation folded in general even though partly destroyed. Some fault blocks, outlier sheets and klippes are distributed along the boundary fault,

Deformation characters of the Mazhan graben

Boundary faults

The development of any graben is always associated with that of a fault zone dividing the crust into various blocks (Zhang and Zhong, 1982). The origination, development and completion of the Mazhang graben as well as its spatial rule of distribution had been also controlled by YSF zone as a boundary faults, which had played an important rôle in all the history of deformation events and that of tectonic field of stress in the Mazhan graben. Although the boundary faults of graben have NNE trend in general, the west boundary TGF (Tangwu-Gegou fault) shows a step fault pattern as a whole, whereas the east boundary YTF (Yishui-Tangtou fault) forms rather low-grade graben/horst structure. Whatever the boundary fault zones are all composed of those formed at different stages, complicated fault tectonites such as breccias, buckles, tectonic lenses and corrugations are formed. Based on the geometrical relations of compressive planes to the attitudes of main faults, it could be inferred that YSF was originated as either sinistral or dextral strike-slip fault. Moreover the aggregate of fault rock and scratch as well as the feature of normal graben/horst or anti-graben structure display that YSF zone was formed by either tension or compression. Measurement of microstructures provides useful information for restoring the local stress field all over the boundary faults. The results indicating different movement of boundary faults are shown in Table 1 in detail.

The microscopic observations of deformed fault rocks reveal that there are other evidences of complicated active career and unsynchronizing tension cracks (tracing cracks or en échelon cracks), and that conjugate shear cracks are commonly developed in fault tectonites, especially some diabase veins in fault zone are crushed by compression and porphyroclasts are further flattened to form lenses. Some veinlets filled in cataclastic rocks are subsequently cut by shearing of fault together with matrix. Presice measurement of these relevant microstructures demonstrates that preferential compressive stress axis is NNW-SSE in direction.

Fold and folding

In Palaeozoic strata, there is a pronounced fold greatly differing from that of Cretaceous. In southern area of the Mazhan graben, there are several large folds composed of Cambrian bedded limestone and bedded marlite. Their hinges are parallel to boundary fault with NNE trend suggesting a result of NW-SE compressive stress pattern since Palaeozoic times. Although the east limb of the Shiguanzhuang anticline and west limb of the Nanzhangzhuang syncline are locally cut by boundary faults due to subsequent shearing, it is just explained that they were encountered different stress events. Hu (1980) draws that these folds would be a large regional drag structure due to dextral shearing of YSF after Palaeozoic times. In fact, field survey indicates that contact relation between remained limbs and YSF shows a sinistral rotating drag structure apparently. Other folds in Palaeozoic strata along the boundary fault are usually small-scale, and have not any integrated

Table 2. Stress states restored by Palaeozoic folds in the Mazhan graben.

	attitude of fold			restored stress axis		
	east-limb	west-limb	axial plane	σ_1	σ_2	σ_3
Manzhangzhuang syncline	330° ∠20°	100° ∠25°	301° ∠87°	120° ∠03°	351° ∠18°	234° ∠66°
Shiguanzhuang anticline	75° ∠70°	230° ∠20°	92° ∠61°	92° ∠28°	31° ∠18°	226° ∠29°
Lishan anticline	45° ∠15°	307° ∠31°	102° ∠79°	281° ∠11°	15° ∠13°	158° ∠71°
Dadingzhi syncline	276° ∠69°	110° ∠65°	103° ∠88°	283° ∠02°	193° ∠17°	18° ∠74°

Table 3. Movement sense of YSF zone inferred by attitudes of accompanied corrugations (low grade folds) and their orientation relation to YSF zone.

	fold attitude		attitude of YSF zone	angle of fold hinge trend to YSF trend	inferred sense of YSF movement
	axial plane	hinge			
Weijiahe anticline	316° ∠84°	44° ∠19°	300° ∠80°	14°	sinistral
Shengjiazhuang anticline	132° ∠84°	47° ∠35°	300° ∠70°	17°	sinistral
Daluguanzhuang syncline	123° ∠68°	41° ∠19°	292° ∠68°	19°	sinistral

forms due to fault destruction, but they could also provide usuful aditional informations of similar stress event (Table 2).

In case of Cretaceous strata, they show a broad homocline with the stable dips rarely exceeding 30° in question. And fold structure is not developed in the Mazhan graben area except for that developed in the vicinity of boundary faults, where some corrugations of plastic layers induced by YSF zone and those deformed corrugations are indicators of stress event of YSF according to the geometric orientation relation between them and main fault plane (Table 3).

Fault and faulting

Main fault systems in the Mazhan graben area have been clarified by interpretation of regional air-photos (1:24000 in scale) and remote sensing imagess (RITTIO EXP 4/5R, 5/6G, 6/7B) as well as field survey. They consists of four different trending fault sets as shown in Fig.2.

(1) 290°- 300°(NW) fault set

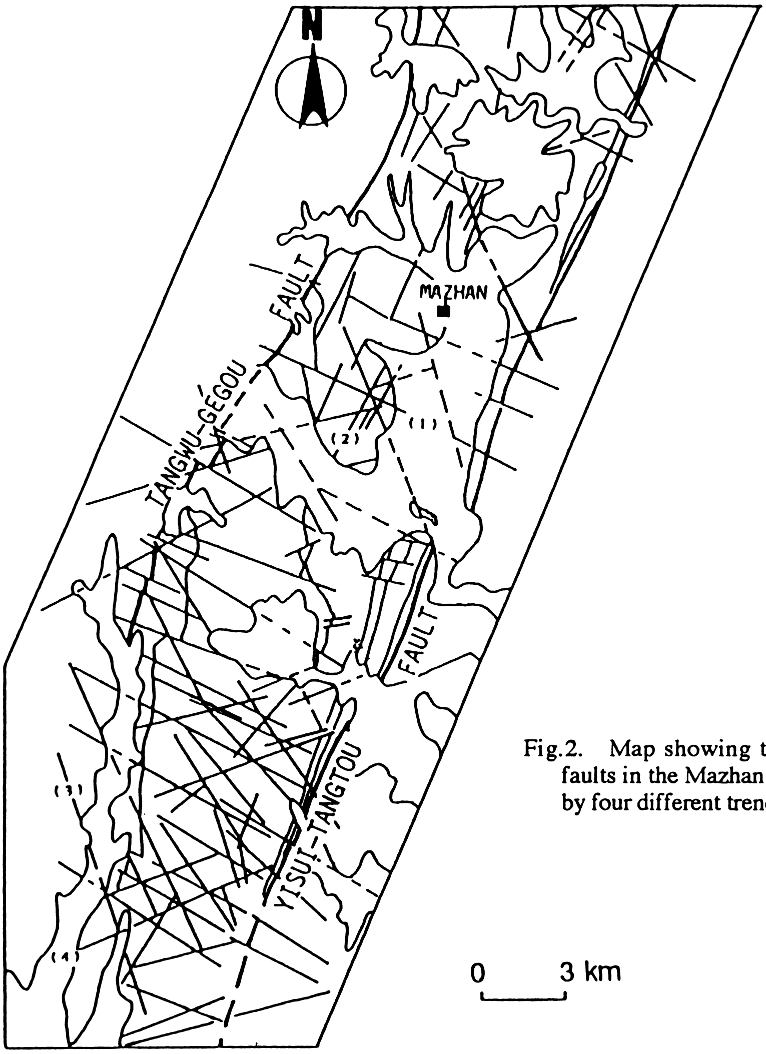

Fig.2. Map showing two systems of vertical faults in the Mazhan graben area constructed by four different trending fault sets.

This is best developed in graben. Most of them have metre-scale fault breccia zones which are often visible. They cut across whole the graben even YSF zone with maximum offset of 500 m, and the pattern of recent river valley like the Yishui and the Shushui rivers are obviously controlled by them.

(2) 15°-20°(NNE) fault set

This is commonly developed in graben area too, and distributed parallel to boundary fault. The sets of fault often has compresso-shear fault tectonite zone over than 10m in width. Within it, flattened gravel and corrugations are developed to indicate sinistral compresso-shearing faults.

(3) 320°-340°(NW) fault set

This set is also developed well in graben area. According to apparent tension breccia and clear slicken lines on fault surface it can be suggested that the set is of dextral normal shearing faults.

(4) 50°-70°(NE) fault set

This shows sinistral compresso-shearing feature. Some definite evidences of cutting relations are found when the faults intersect each other. Based on these evidences, following two fault sys-

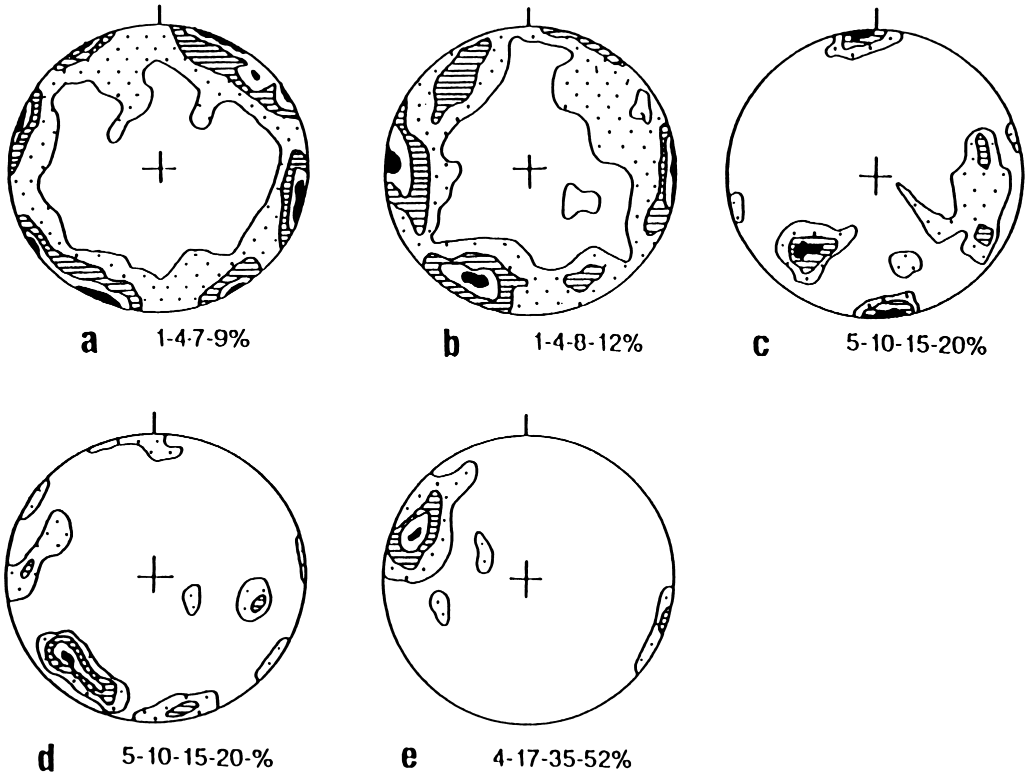

Fig.3. Equal area projections (lower hemiphere plot) of the tectonic joints and a-b planes of tectonic lenses from YSF zone. **a** : shear joints in Cretaceous strata. Four sets are apparently visible. **b** : three sets of shear joints in Archaeozoic strata. **c** : two sets of shear joints in Palaeozoic strata. **d** : tension joints in Palaeozoic strtata showing three or four sets en échelon apparently. **e** : preferred orientations of tectonic lenses on a-b planes in YSF zone.

tems can be defined :

The fault set of (1) - (2) belongs to the same system.

The fault set of (3) - (4) belongs to another same system.

Where, the trend of (1) - (2), and that of (3) - (4) are perpendicularly oriented, respectively. These relations provide useful informations for inducing two palaeo-stress events.

Joint and jointing

Measurement of tectonic joints in sedimentary rocks provides reliable information to restore the regional stress field over a wide area. Two kinds of tectonic joints are apparently found in the Mazhan graben area. One of them is shear joint extremely developed in upper Cretaceous sandstone or shale layers and also in lower Cretaceous pyroclastic rocks. Whereas, tension joints are dominantly developed in Palaeozoic limestone. Tectonic joints must have preferred orientation in response of tectonic stress field under which the joints could be formed commonly as the conjugate

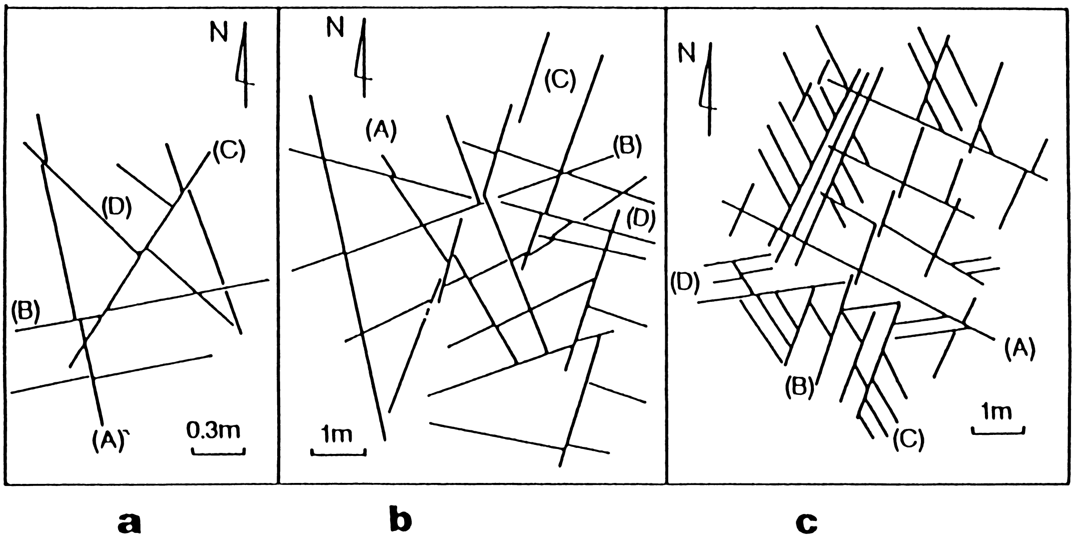

Fig.4. Field sketch showing the cutting and confining relation of shear joints on fracture planes at the outcrops of **a** : the Gaoqiao, **b** : the Qiaobeichun and **c** : the Shuanghechun, in the Manzhan graben area.

The cutting relation of shear joints is very obvious from **a**, **b** and **c** to show not only (A)-(B) sets or (C)-(D) sets cutting each other, but also (A)-(B) sets being cutting by (C)-(D) sets, namely (A)-(B) sets are earlier conjugate joint system and (C)-(D) sets are later one. The confining relation of shear joint is also visible from **c**, in which (C)-(D) sets are often confined by (A)-(B) sets. This clearly shows that (C)-(D) sets were formed later than (A)-(B) sets.

shear fractures or a set of tension fracture en échelon. They can be formed at the same tectonic position to that of the identical layer, however at least four sets of discordant shear joints and three sets of tension joints could be found in a gentle homocline of Cretaceous rocks and in Palaeozoic limestone, respectively. They would be undoubtedly induced by different field of stress events .

Measurements of 2658 shear joints at 64 joint domains on the Mazhan graben area illustrated in Fig.3. It is quite clear that four sets of shear joints and three sets of tension joints are dominant in Cretaceous layers and in Palaeozoic strata, respectively. The key is how to identify either shear joints or tension ones to divide into different joint system in accordance with stress field, respectively. Even though it is difficult and trouble matter to observe and confirm some certain evidences, it is requested to reveal the joints induced by different stress events. Some excellent evidences were found in somewhere in the Mazhan graben in terms of apparent cutting or confined relation among the joint systems (Fig.4). The result of study shows that in case of shear joint, (A) and (B) in Fig.4 are of a conjugate joint system related with the earlier stress event and, (C) and (D) are of that related with the later one. In addition to this, three systems of tension joints en échelon can be also confirmed, namely earlier, intermediate and later, and the formation time for the latter two systems might correspond with those of two systems of shear joints, respectively.

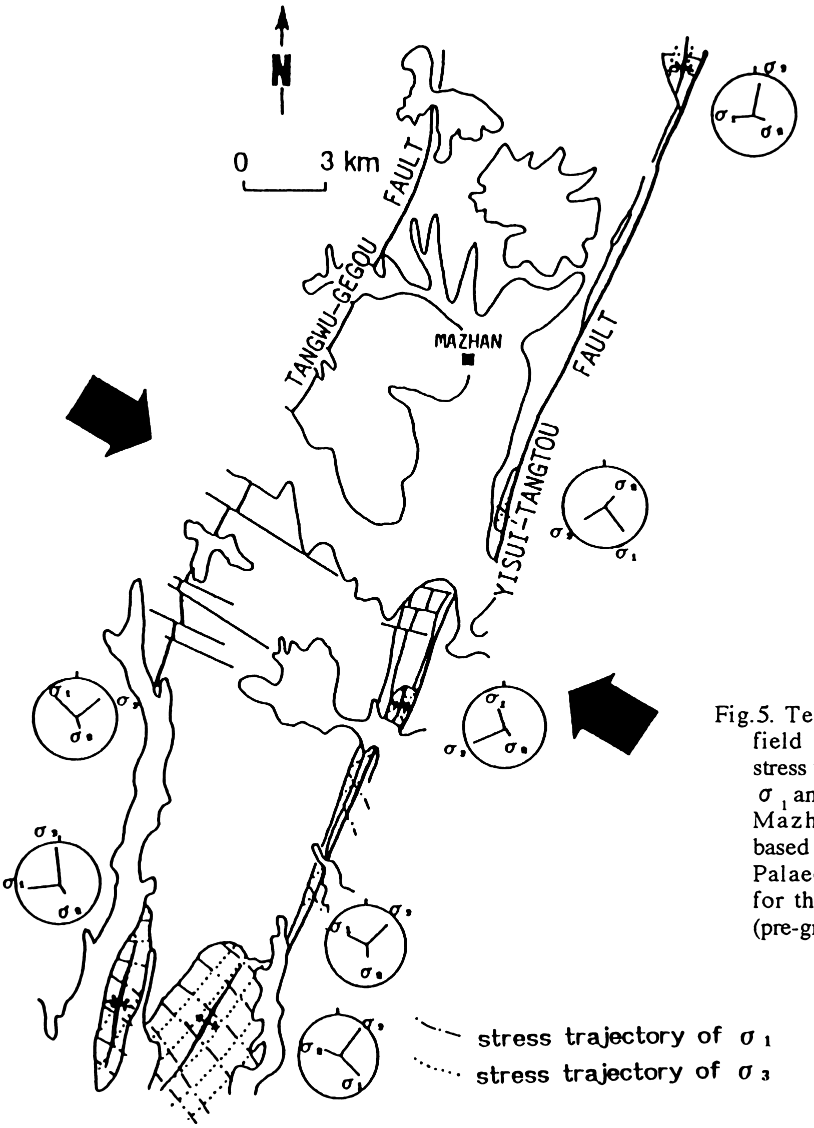

Fig.5. Tectonic stress field pattern with stress trajectories of σ_1 and σ_3 in the Mazhan graben based on data from Palaeozoic rocks for the first stage (pre-graben).

Analysis of tectonic stress field and the graben evolution

The studies of actual microstructures and regional geologic structures prove that at least three times of stress field transfers have apparently occurred in the Mazhan graben area since Mesozoic as follows:

The first stage (pre-graben)

Tectonic events at this stage can be confirmed by virtue of the followings:

(1) In Palaeozoic time, under NW-SE compression stress, NW trending regional faults were formed at the west side of YSF zone, which caused lateral extension of NE-SW direction to form

NW trending fault-angle basins, where upper Jurassic sediments were accumulated and subsequently, folds with 30°-65° (NE) trending hinges were formed.

(2) Wide Palaeozoic strata in Lushi area were tilted to NW, but in YSF zone Palaeozoic strata were folded strongly to form some fold structures with hinges apparently parallel to YSF zone, which are unconformably overlain by Cretaceous strata.

(3) NW trending tension joints en échelon are commonly developed in Palaeozoic strata and are cut by NE trending en échelon joints obviously. Consequently, NW-SE compressive stress field in YSF zone area occurred before the Cretaceous times (middle Jurassic), and analogously corelated to the middle Yanshanian movement of East China.

(4) According to the actual data of measurement (Fig.5), it is revealed that the maximum principal stress (σ_1) axis is plunging at about 20° to NW or SE, the minimum principal stress (σ_3) axis is plunging at about 17° to NE or SW, and the intermediate principal stress (σ_2) axis is approximately vertical. Under this stress field, thrusting with sinistral shear movement occurred in YSF zone area.

The second stage (graben formation)

Tectonic events at this stage can be confirmed by virtue of followings:

(1) As a result of tectonic extension of YSF zone, strong eruption of basic to intermediate magma occurred along YSF in early Cretaceous.

(2) As lateral spreading of YSF zone was still strong in late Cretaceous, thick sub-molasse formation was accumulated in YSF zone area. Finally the tectonic framework of "graben/horst/graben" was induced by inhomogeneous movement of YSF. Lushi area is lacking of upper Cretaceous, because the west fault (the Tangwu-Gegou fault) of YSF zone was more active than others.

(3) Early conjugate joint system in Cretaceous layers and NE trending tension joints (moderately en échelon) as well as early vertical fault system show that (σ_1) is NE-SW trend.

(4) In the above mentioned NW trending fault angle basins in west side of YSF zone, compresso-rising movement occurred in that time, so that upper Cretaceous was lost.

(5) Some a-b planes of flattened gravels in tectonite of YSF zone indicate NW-SE strikes suggesting NE-SW compressive stress event.

It is clearly shown that the tectonic stress field transferred to NE-SW compressive stress during Cretaceous, which is revealed by the orientation of stress axes that σ_1 is plunging to 10°-30°(NNE) at 15°, σ_3 is to 280°-300°(NW) at 14° and σ_2 is approximately vertical (Fig.6). Such a stress field, at which σ_3 (the maximum tensile stress) is perpendicular to YSF zone and σ_1 (the maximum compressive stress) is parallel to YSF zone, would lead to lateral spreading to complete the final tectonic framework of the Mszhan graben at the time during whole the Cretceous (about 60 Ma).

The third stage (post-graben)

Tectonic stress field at this stage shows the following features:

(1) After Cretaceous time the history of lateral spreading of YSF zone was finished, and there is lack of Palaeogene due to subsequent comprssso-rising in YSF zone area.

(2) Some folds of Early Neogene strata were formed with NE trending hinges in southern part of YSF zone.

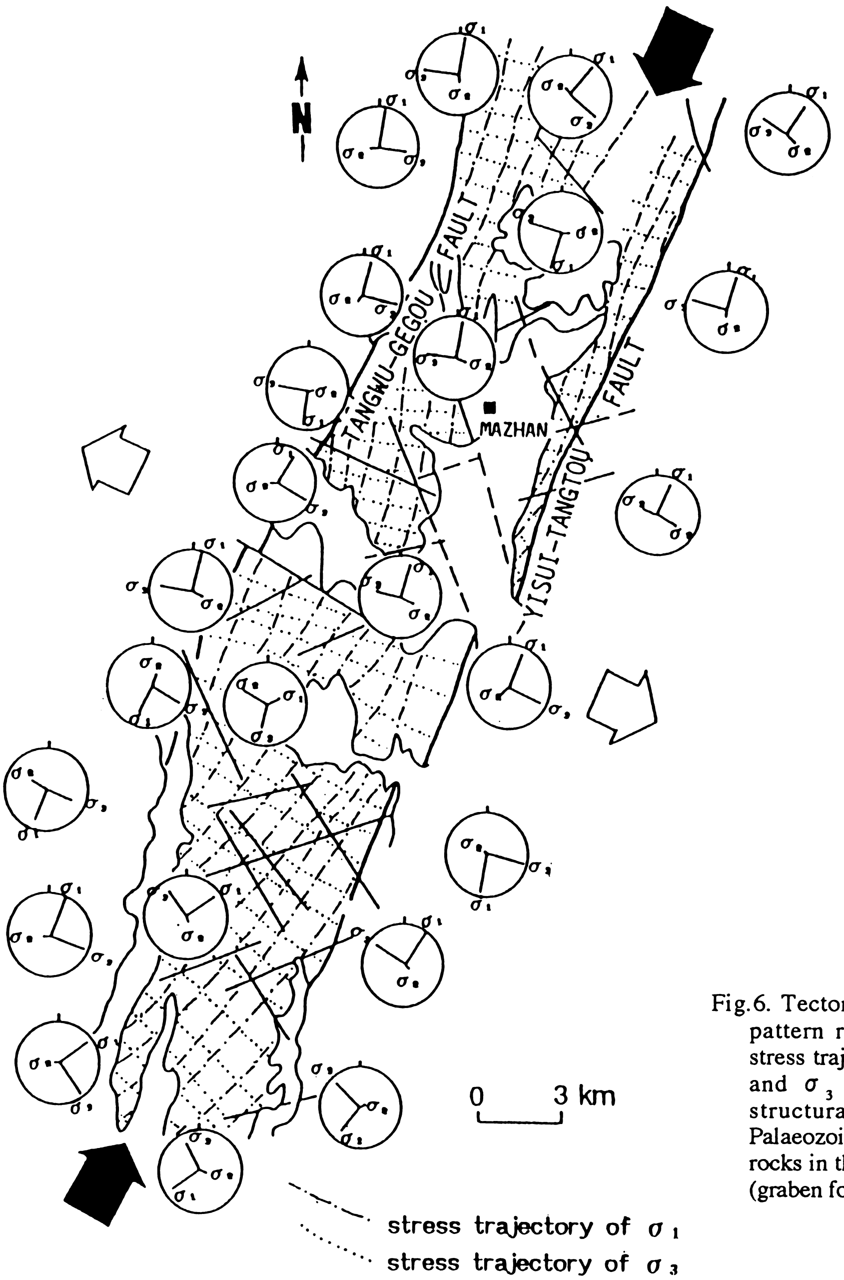

Fig.6. Tectonic stress field pattern represented by stress trajectories of σ_1 and σ_3 deduced from structural analyses of Palaeozoic to Cretaceous rocks in the second stage (graben formation).

(3) NW trending fault-angle basins of the west side of YSF zone were formed and extended in NE-SW direction again inducing accumulation of upper Palaeogene.

(4) Most of a-b planes of flattened gravels in Cretaceous rocks in YSF zone indicate NNE strikes preferably. A later system of conjugate joint in Cretaceous strata, that of tension joints en échelon and late vertical fault system in the Mazhan graben area shows the stress field at that time, namely σ_1 axis is plunging to 330°-345°(NNW) at 14°, σ_3 is to 60°-75°(NE) at 12° and σ_2 is approximately vertical (Fig.7).

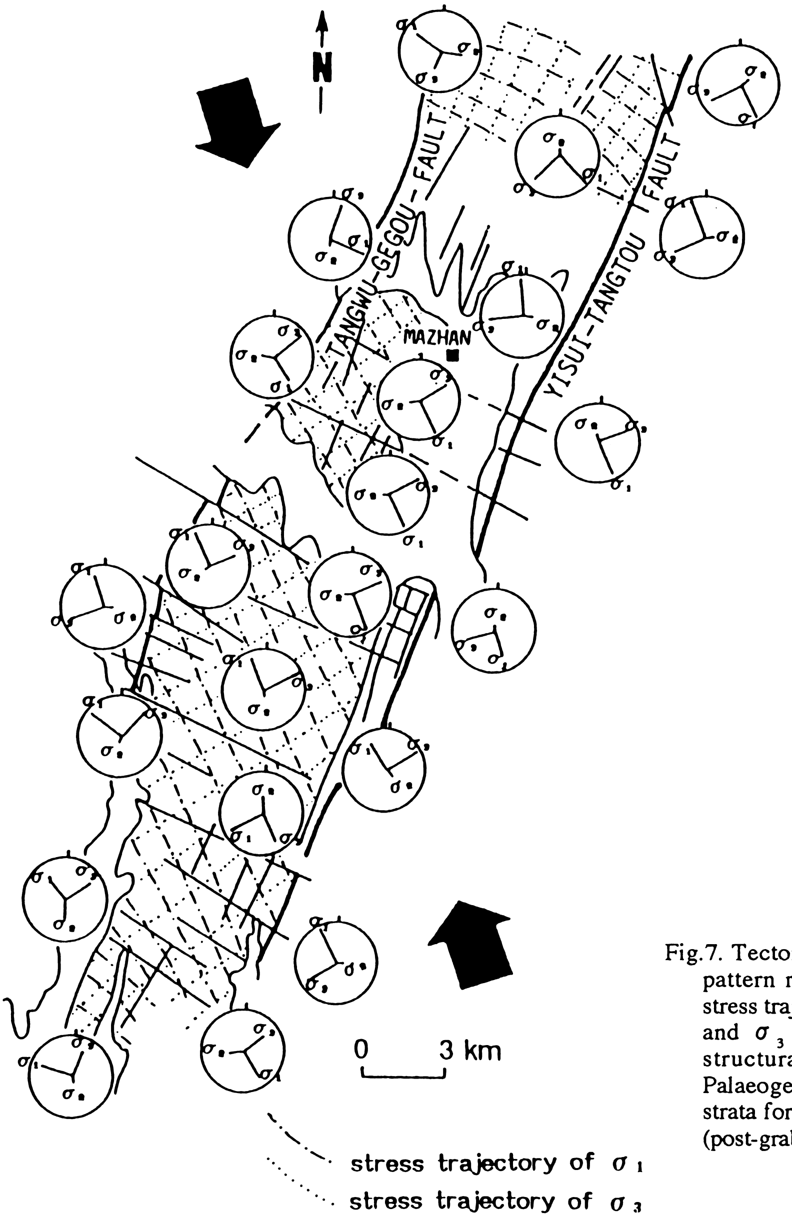

Fig.7. Tectonic stress field pattern represented by stress trajectories of σ_1 and σ_3 deduced from structural analyses of Palaeogene to Neogene strata for the third stage (post-graben).

Conclusion — evolution of the Mazhan graben —

East China in Jurassic was commonly under NW-SE trending compressive stress field, probably in response to the NNW-oriented Kular palaeo-plate motion, which induced the reactivation of YSF zone. In early Cretaceous, regional tectonic stress field was transferred to NNE-SSW, which made the maximum stress axes of compression and tension parallel and perpendicular to the trend of YSF zone, respectively. Consequently, deep-cutting tensional fracturing and eruption of basic magma were brought about. As a result of the inhomogeneous movement within YSF zone, the embryonic graben was formed in the Mazhan area. The most intense extension of YSF zone occurred in late Cretaceous, which did not transfer until the end of late Cretaceous. Since Palaeogene, NNW-SSE trending compressive stress became predominant to intensify again the compresso-shearing movement of YSF zone, which induced a rising of the area. Thus, the tectonic history of the Mazhan graben area is concluded as hitherto stated.

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References

Cheng J.T., 1980, Some geoseismological problems of Yi-Shu fault belt. *Abst. of Sci. Confer. on the Tan-Lu fault belt.* Organizing Committee of Sci. Confer. on the Tan-Lu fault belt, Geol. Bureau of Shandong Province, 67.*

Hu S.Y., 1981, Renewal understnding of the Tancheng-Lujiang fault zone from the study of inner structures of the Yi-Shu fault belt. *Shandong geology information*, 1, 1-27.*

Huang J.Q., 1959, New knowledge on tectonic division and characteristic of the east China. *Acta Geologica Sinica*, **39**, 116-119.*

Li S.G., 1974, The origin of the Neocathaysian sea. In Chinese Acad.Sci.,ed., *The analysis of tectonics*, Sci. Publ. House, Beijing, 49-58.*

Li X.T. and Wang, G.D.,1980, Structural evolution and crust activity of the Tancheng-Lujiang fault zone. *Abst. of Sci. Confer. on the Tan-Lu fault belt.* Organizing Committee of Sci. Confer. on the Tan-Lu fault belt, Geol.Bureau of Shandong Province, 20.*

Xu J.W., 1984, The Tancheng-Lujiang fault system. *Coll. Pap. on Structural Geology*, no.3, Publ. House of Geology, Beijing, 18-32.*

Xu Zh.Q., 1984, The outline of Tan-Lu rift valley system. *Coll. Pap. on Structural Geology*, no.3, Publ.House of Geology, Beijing, 39-46.*

Zhang W.Y., 1981, The formation mechanism of graben. *Scientica Geologica Sinica*,**16**, Chinese Acad.Sci., 31-34.*

Zhang W.Y. and Zhong, J.Y., 1982, The introduction of theory and practice on tectonic faults and massifs. In Chinese Acad. Sci., ed, *The progress of structural geology*, Publ. House of Geology, Beijing, 12-26.*

* In Chinese.