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Research Article

The Dabie Extensional Tectonic System: Structural Framework

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A previous study of the Dabie area has been supposed that a strong extensional event happened between the Yangtze and North China blocks. The entire extensional system is divided into the Northern Dabie metamorphic complex belt and the south extensional tectonic System according to geological and geochemical characteristics in our study. The Xiaotian-Mozitan shear zone in the north boundary of the north system is a thrust detachment, showing upper block sliding to the NNE, with a displacement of more than 56 km. However, in the south system, the shearing direction along the Shuihou-Wuhe and Taihu-Mamiao shear zones is tending towards SSE, whereas that along the Susong-Qingshuihe shear zone tending towards SW, with a displacement of about 12 km. Flinn index results of both the north and south extensional systems indicate that there is a shear mechanism transition from pure to simple, implying that the extensional event in the south tectonic system could be related to a magma intrusion in the Northern Dabie metamorphic complex belt. Two ^{40}Ar-^{39}Ar ages of mylonite rocks in the above mentioned shear zones yielded, separately, ~190 Ma and ~124 Ma, referring to a cooling age of ultrahigh-pressure rocks and an extensional era later.

1. Introduction

Dabie area is well known of owning one largest area of ultrahigh-pressure metamorphic belt (UHPB) in the world, located, as a tectonic zone, between the North China Block and Yangtze Block (Figure 1).

The Dabie area experienced a complicated tectonic evolution during the Mesozoic and resulted in thrust-nappe, extensional detachment, and strike-slip structures [1, 2]. Much attention has been paid to the tectonic evolution of the Dabie Mountains, with most tectonic models proposing although compressional tectonism for the formation of the orogen. However, Mesozoic extensional structures in the Dabie Mountains are also obvious and important for understanding the Mesozoic tectonic regime inversion from compression to extension occurred throughout the Dabie Mountains and even in the eastern North China Block [3].

The purpose of this paper is to figure out the structural framework of the Dabie Late Mesozoic extensional detachment system by analyzing deformation, tectonic styles, and physical conditions, to constrain the time of the extensional tectonics, and finally to discuss the tectonic implications.

2. Tectonic Background

The general geology of the Dabie area has been described in multiple publications [5–13]. Briefly, from north to south, the Dabie Mountains can be divided into four major tectonic units: (1) the North Huaiyang Flysch belt (NHMB) mainly composed of the Foziling Group (Pt_2); (2) the Northern Dabie metamorphic complex belt (NDMCB), composed dominantly of granitic gneisses of TTG composition, with the Xiaotian-Mozitan and the Shuihou-Wuhe shear zones defining the northern and southern boundaries, respectively; (3) the ultrahigh-pressure metamorphic belt (UHPB) refers to the Central Dabie ultrahigh pressure metamorphic complex and is bounded in the south by the Taihu-Mamiao shear zone; (4) the high-pressure belt (HPB) refers to the Southern Dabie high-pressure blueschist/greenschist terrane [10],

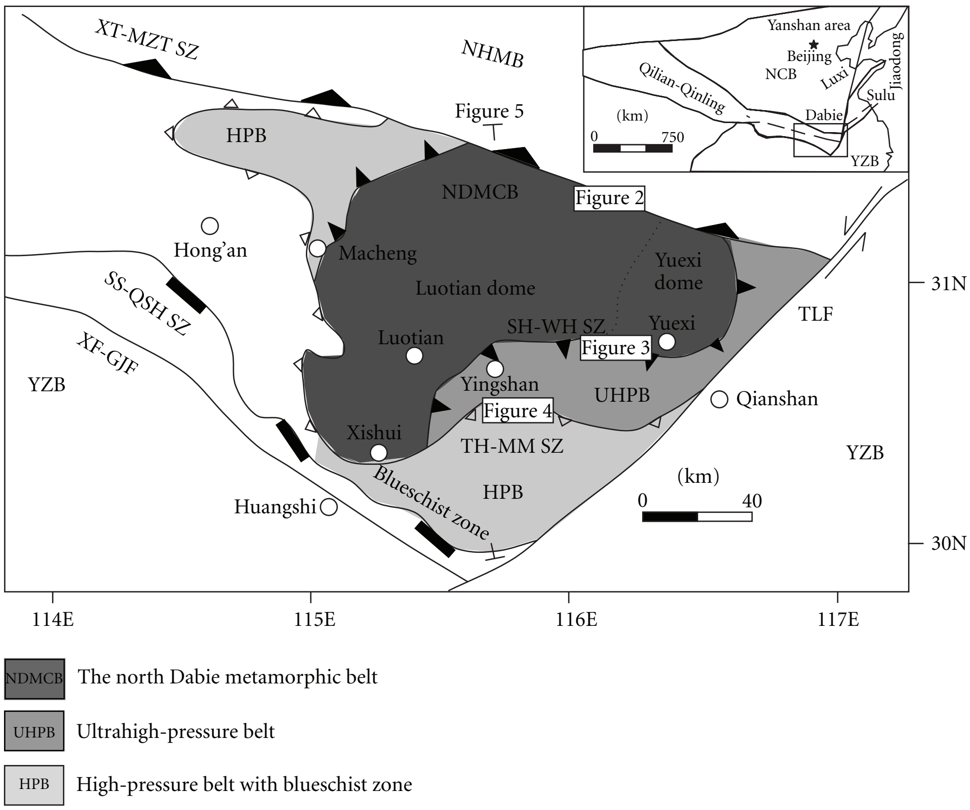


Figure 1: Simplified map of late Mesozoic main shear zones in eastern Dabie Mountain, Central China (after Suo et al., 2000 [4]). NCC: Northern China Block; YZC: Yangzi Block; NHMB: North Huaiyang metamorphic belt; NDMCD: North Dabie metamorphic complex belt; UHPB: Ultrahigh-pressure metamorphic belt; HPB: high-pressure metamorphic belt; SH-WH SZ: Shuihou-Wuhe shear zone; TH-MM SZ: Taihu-Mamiao shear zone; SS-QSH SZ: Susong-Qingshuihe shear zone; XT-MZT SZ: Xiaotian-Mozitan shear zone; TLF: Tancheng-Lujiang Fault (Tanlu Fault); XF-GJF: Xiangfan-Guangji Fault.

whose southern margin is defined by the Susong-Qingshuihe shear zone (Figure 1).

Several contrasting tectonic models have been proposed for the Dabie orogenic belt. Suo et al. [4, 14] identified extensional tectonism in the Dabie orogen during the middle-late Mesozoic. Song [15] defined extensional structures in metamorphic rocks with different ages that formed prior to the continental collision that produced the Qinling-Dabie orogen. Based on geochemical analyses of the Wangmuguan pluton in Xinxian, Zhang et al. [16] proposed that the pluton formed within extensional conditions after the formation of the orogen and was related to lithosphere detachment. A two-stage extension model proposed by Jin et al. [17] describes extension during the early Caledonian period, which resulted in the local sea and the beginnings of the Dabie-Qinling metamorphic core complex; extension during the Yanshan period coincided with the formation of the core complex and the intrusion of granite. Wang and Yang [18] investigated the extensional domes in the Dabie Mountains. Li [19] studied the late Mesozoic extension in the eastern part of the Dabie Mountains. Among these studies, there is a hot debate about the timing of the onset of extension, its direction, and tectonic styles. In this paper, we describe the results of our field observations and geochemical analysis, which provide some new insights into understanding the evolution of the late Mesozoic extensional detachment zones in the Dabie area.

3. Deformation History of Extensional Detachment Zones

The NDMCB is the crystalline core of the late Mesozoic extensional structures. These features can be divided into two tectonic systems, the north extensional tectonic system and the south extensional tectonic system (Figure 1).

3.1. The North Extensional Tectonic System. The principal detachment shear zone is the XT-MZT SZ, which is located between the NHMB and the NDMCB. To the east (i.e., along the Huoshan-Zhujiapu Road), the brittle-ductile extensional shear zone dips to the NE (60°) at an angle of 30°–40° to the horizontal. To the west (i.e., in the Jinzhai-Qingshan area), the shear zone dips towards the NNE-NE (30°–50°). From south to the north, the dip angle changes from steep (about 70°) to gentle. Hence, it is shaped like a shovel and is locally sinuate (orientation 220° and dip 20°). The displacement orientation on the shear zone is to the NE or NNE. Noticeably, the extensional shear zone locally in the

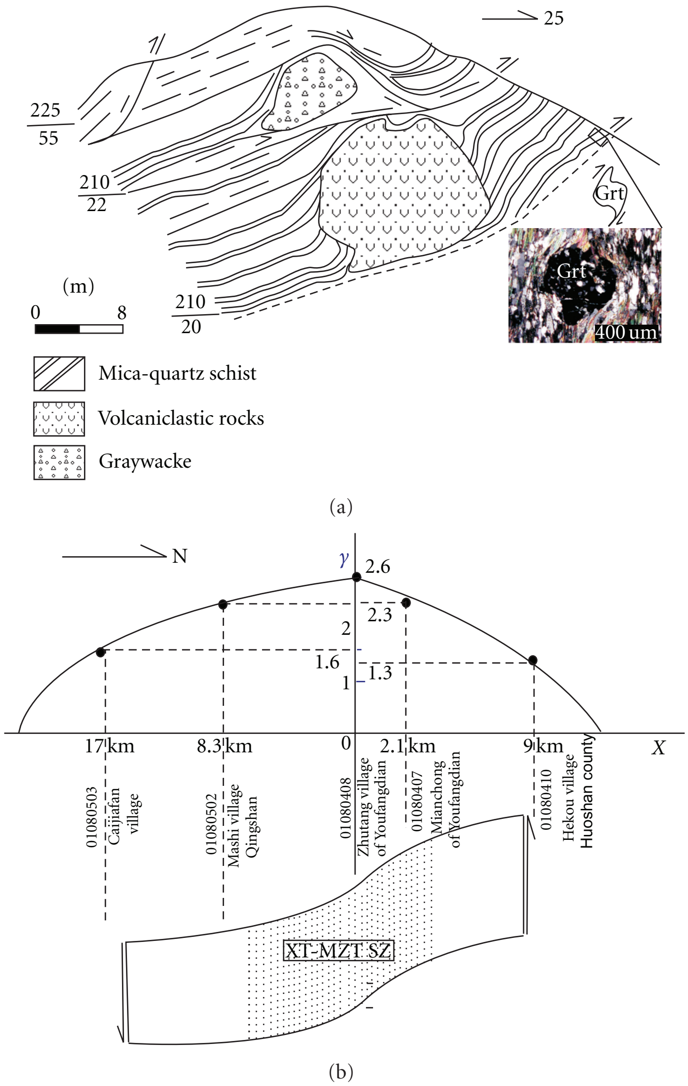


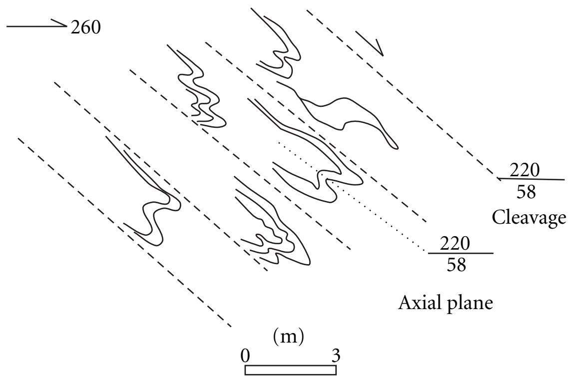
FIGURE 2: (a) The north extensional detachment zone suggests extension shearing after late Jurassic from the XT-MZT SZ. Late Jurassic volcaniclastic tectonite blocks are hosted by mica-quartz schist (Pt_2). The photo right below shows snow ball structure observed by microscopy. (b) The shear length of the XT-MZT SZ is more than 56 km.

NHMB has developed into an inconsecutive extensional crenulation cleavage (C′, the same as S_3 in some places) with NE-dip. The extensional crenulation cleavage is an important character of the north extensional tectonic system. The foliations (S_1 or S_2) dipping SW in quartz schist (Pt_2) may represent earlier overshear deformation in the NHMB. Asymmetric augen in amphibole gneiss in the Huoshan area indicates shearing towards the NE. Using the optical microscope, garnet in quartz schist has a "snowball" texture and also confirms that NE-directed shearing (Figure 2(a)).

According to a systematical strain-measurement analysis of the snowball textures in garnet and deformed quartz grains, the shear strain (γ) in the central part of the north detachment zone is up to 2.6 and gradually decreases outward. Measurements of a rock finite strain in the detachment zone indicated that the shear displacement is at least 56 km.

3.2. The South Extensional Tectonic System. The south extensional tectonic system is composed mainly of one deep ductile shear zone and ltwo brittle-ductile shear zones.

3.2.1. One Deep Ductile Shear Zone (Shuihou-Wuhe). The Shuihou-Wuhe ductile shear zone (SH-WH SZ) consists of feldspar mylonite and formed under lower crustal conditions; the shear zone was named the "first southern detachment zone" by Zhong et al. [20]. The shear zone dips towards the S, SSW, and SSE at an angle of 40–60°. The S-C shear fabrics, sheath folds, and shear folds in the shear zone consistently dip towards the south (Figures 3(a) and 3(b)). Much of these extensional shear deformations superpose on earlier thrust-shearing deformation and strike-slip deformation. The shear strain (γ) in the zone is up to 5, such as observations in the north of Yingshan (Figure 3(a)).



(a) Zhangzui

(b) Yazhangshu

Figure 3: Quartz bands in gneiss in the Shuihou-Wuhe shear zone, the shear zone dips SSW; (a) and (b) are, respectively, from places the Zhangzui village and the Yazhangshu primary school of the Yingshan County.

Based on strain-measurement analysis, the strain ellipsoid of the shear zone displays the Flinn parameter (K) range of 0.01–0.1, corresponding with pancake-shape flattening and reflecting intense compression and pure shear deformation.

According to the fabric analysis of deformed quartz, the small-circle belt at the east segment of the SH-WH SZ reflects high-temperature deformations conditions (>700°C) and relatively slow strain-rate velocity ($10^{-7}s^{-1}$). The middle segment was asymmetric with point belonging to a rhomb slide system, which reflects middle-high-temperature deformational conditions (650–700°C). The quartz fabric analysis also shows that the principal stress direction was oriented NE-SW, which is consistent with the principal stress direction determined from the preferred orientation of amphibole long axes. The paleodifferential stress was calculated at about 92 Mpa based on quartz dislocation density.

3.2.2. Two Brittle-Ductile Shear Zones (Taihu-Mamiao, Susong-Qingshuihe)

(a) The Taihu-Mamiao Shear Zone. The Taihu-Mamiao shear zone (TH-MM SZ) lies to the south of the SH-WH SZ and is bounded by the southern Dabie and Susong metamorphic zones in the north and south, respectively (Figure 1). The TH-MM SZ dips mainly towards the S or SSE; the dip angle changes from steep to gentle with increasing depth. A series of recumbent folds, S-C shear fabrics, asymmetric augen, extensional lineations in some profiles indicate that extension was to the SSE (Figures 4(a) and 4(b)). Based on strain-measurement analysis, the Flinn parameter for the shear zone is about 1, indicating a planar strain.

(b) The Susong-Qingshuihe Shear Zone. The Susong-Qingshuihe shear zone (SS-QSH SZ) lies to the south of the TH-MM SZ and to the north of the Xiangfan-Guangji fault (XF-GJ F.). The SS-QSH SZ marks the interface between high-pressure eclogite and blueschist units (Figure 1). The stretch lineation of monzogranitic mylonite in Qingshuihe plunges towards the SSW. According to strain-measurement analysis, the Flinn parameter of the shear zone is more than 7, which suggests cigar-shaped, extensional deformation. The shear displacement along the detachment zone is more than 12 km based on strain measurement analysis. Deformed quartz displays asymmetic point coarctation, belonging to a rhomb slide system, and suggesting middle-to-high temperatures during deformation. Based on the dislocation density of quartz, we calculated the paleodifferential stress 70–84 Mpa, which is smaller than that of the SH-WH SZ.

Based on the structural analysis above, the three shear zones in the south extensional tectonic system probably represent deeper, middle, and upper detachment systems, ranging from north to south, respectively. Deformation temperatures and differential stresses decrease from the northern Dabie complex to the south. Remarkably, strain changes from north to south; from flattened (i.e., $K \ll 1$) in the northern the SH-WH SZ, to planar (i.e., $K \approx 1$), and then to extensional strain (i.e., $K \gg 1$) in the southern SS-QSH SZ. This transition of strain reflects the influence of magmatic intrusion during the extensional detachment.

4. Chronological Constraints on the Extensional Detachment

$^{40}Ar/^{39}Ar$ dating of biotite and hornblende from the four extensional detachment zones in Dabie area are shown in Table 1. The data can be divided into two groups, ca. 124 Ma and ca. 190 Ma, respectively. The north extensional tectonic system and the SS-QSH SZ were active at ca. 124 Ma, representing the time of extensional detachment to this period. In contrast, the SH-WH and TH-MM SZs, on the north and south sides of ultrahigh-pressure metamorphic zone, respectively, have ages of ca. 190 Ma, representing the time of exhumation of ultrahigh-pressure metamorphic rocks.

5. Discussion

The north extensional detachment zone hosts a shear zone that cuts the Late Proterozoic Xinyang Group (Pt_2n) mica-quartz schist. The shear zone contains allochthonous blocks

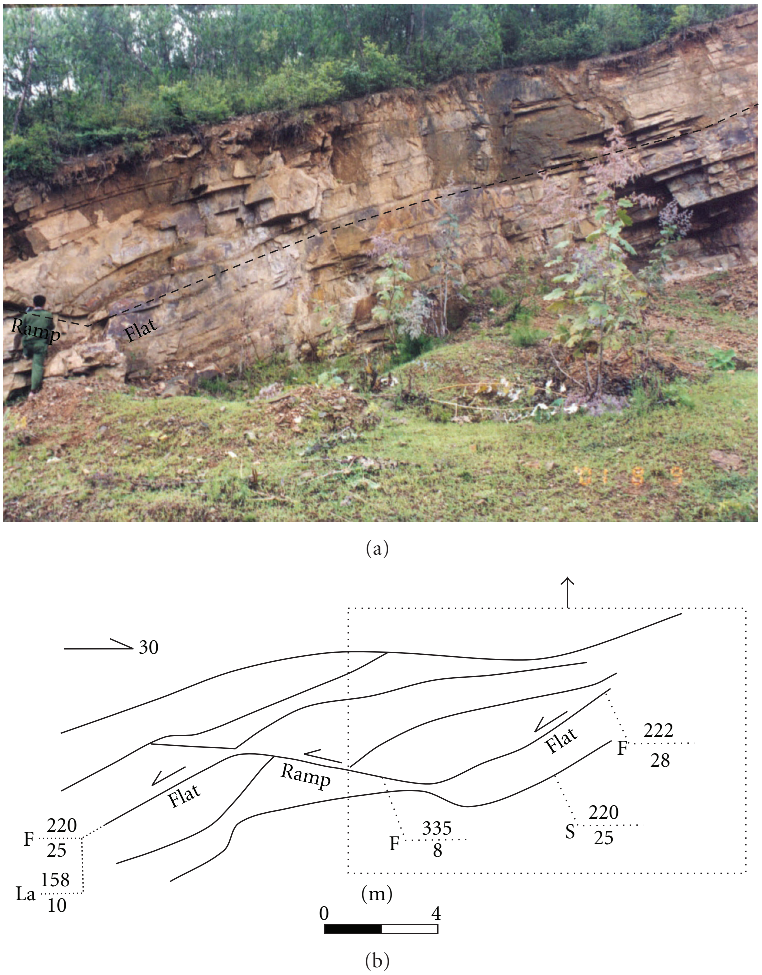


Figure 4: Extensional flat-ramp structure in the Taihu-Mamiao shear zone, indicating S-extension (near Luoxi village along the road between Liuyang and Hualiangting in the Taihu County). The occurrences of gneiss cleavage, flat and ramp, and extensional lineation are marked.

Table 1: Summary of mineral ^{40}Ar-^{39}Ar data in the main shear zone of eastern Dabie Mountains.

Shear zone	Sample locations	Mineral	Weighted mean plateau age (Ma)
XT-MZT SZ	Qingshan town	Biotite	124.17 ± 0.25
	Zhangchong village	Biotite	126.91 ± 0.30
SH-WH SZ	Shuihou village	Biotite	190.59 ± 0.42
TH-MM SZ	Luoxi village	Hornblende	197.41 ± 0.46
	Luoxi village	Biotite	189.42 ± 0.29
SS-QSH SZ	Qingshuihe village	Biotite	124.87 ± 0.21
	Chenhan village	White mica	194.01 ± 0.36
	Qingshuihe village	Biotite	127.96 ± 0.30

of Late Jurassic volcaniclastic rocks and tuff that are up to several meters in size (Figure 2).

Large-scale, harmonic, recumbent folds also occur in the Late Jurassic volcaniclastic rocks and the Late Proterozoic mica schist. In the south extensional detachment system, the Hong'an Group (Pt) and Yanshanian granite (J_3—K_1) experienced extensional shear deformation at the same time. These features suggest that the extensional detachment of both the south and north detachment systems took place after the Late Jurassic.

The age group ~200 Ma is coincide with the U-Pb ages, Sm-Nd ages, and Rb-Sr ages of UHP rocks [22–26], which reflect protracted cooling or partial resetting by Jurassic or Cretaceous magmatism.

In addition, massive granitic intrusions and numerous ultrabasic plutons were emplaced in the NDMCB during

Table 2: The comparison of deformation ages from southern Dabie belt of China.

Age groups	Data of XT-MZT SZ [21]		Our data from other shear zones
~200 Ma			229.8 ± 70.97
			219.52 ± 1.57
150~190 Ma	156.7 ± 1.5		197.41 ± 0.46
			194.01 ± 0.36
			190.59 ± 0.42
			189.42 ± 0.29
			156.5 ± 7.15
145~110 Ma	136.5 ± 1.3	132.0 ± 0.8	
	129.8 ± 0.6	141.9 ± 1.2	
	129.2 ± 1.0	127.1 ± 0.7	127.96 ± 0.30
	133.1 ± 0.9	128.3 ± 0.9	124.87 ± 0.21
	134.1 ± 0.9	127.0 ± 0.8	124.56 ± 2.4
	136.8 ± 1.1	122.5 ± 0.6	
	130.7 ± 1.0	120.7 ± 0.7	

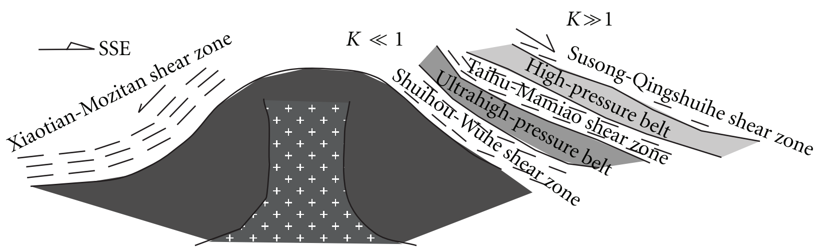


Figure 5: Extensional detachment model for the late Mesozoic in the Dabie Mountains.

the extensional phase at about 120 Ma. The Ar-Ar and Rb-Sr isotopic analyses of rocks in the Dabie group also record this time at about 110–145 Ma (Table 2). All these lines of evidence suggest that they were closely related to extensional detachment. The Cretaceous lacustrine, fluvial, and piedmont facies (several kilometers thick in the Hefei basin) also reflect a regional extensional setting and intense mountain-basin movement. Therefore, voluminous magmatic emplacement and lithosphere delamination during the early Cretaceous induced the rapid uprising of the North Dabie central area, with extensional detachment on both sides. The intense denudation resulted in the thick sediment deposits in the Hefei basin. The high- and ultrahigh-pressure eclogites were probably emplaced during this event (Figure 5). Large-scale extension in the Dabie Mountains during the late Mesozoic is representative of the tectonic regime inversion that affects the eastern North China Block.

Lastly, the deposition of platinum group elements (PGEs) in ultramafic and/or mafic rocks with two ages, ca. 120 Ma and ca. 230 Ma, in the North Dabie complex core suggests that their source region was the upper mantle. The PGE data indicate that the late Mesozoic upper mantle (ca. 120 Ma) enriched in PGE, whereas depleted PGE before 120 Ma. The late Mesozoic upper mantle with PGE enrichment in the Dabie region is contaminated with about 8% Earth core materials, as the PGE contents in the Earth's core are much higher than in the upper mantle [27, 28]. If this is correct, then the PGE mantle enrichment must be related to the late Mesozoic extensional detachment in the Dabie area.

6. Conclusions

(1) The main shear zones in the Dabie area are characterized by extensional detachment during late Mesozoic era. The XT-MZT SZ is detached to the NNE, the SH-WH SZ, and the TH-MM SZ are displaced to the SSE, while the SS-QSH SZ is displaced to the SW.

(2) The shear length of the XT-MZT SZ is more than 56 km and that of the SS-QSH SZ is more than 12 km. The Flinn parameter of the Shuihou-Wuhe shear zone is much smaller than 1 (i.e., 0.01–0.1), which suggests that the shear zone was flattened when it formed. The Flinn parameter of the Taihu-Mamiao shear zone is about 1 (i.e., 1.1), whereas the Susong-Qingshuihe shear zone is much more than 1 (i.e., 7.6), which suggests that they were formed during extension. From north to south in the south extensional tectonic system, these Flinn parameter values display the transition from pure shear to simple shear, possibly reflecting the active intrusion of magma during the extensional detachment.

(3) Two deformation ages, ~190 Ma and ~124 Ma based on mineral ^{40}Ar-^{39}Ar data, are concluded from the main shear zones in the Dabie area. The early age (~190 Ma) could be related to the UHP cooling and reversion during orogenesis, whereas the later one (~124 Ma) could represent

the extensional detachment age after the formation of the orogeny.

(4) The strain analysis, chronology, and the mantle enrichment in platinum group elements suggests that magmatic intrusion in the north Dabie complex core is the main cause for extensional detachment structures during the late Mesozoic.

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