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Genesis of the Hongzhen metamorphic core complex and its tectonic implications

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The Hongzhen metamorphic core complex is situated in the Yangtze plate to the east of the Dabie orogenic belt. Its ductile detachment zone in the foot wall overprints on the metamorphic complex of the Proterozoic Dongling Group. The present profile of the ductile shear zone with consistent SW-dipping mineral elongation lineation shows antiform and reversed S-shape from northeast to southwest respectively. Exposure structures, microstructures and quartz *C*-axis fabric all indicate top-to-SW movement for the ductile shear zone. Recrystallisation types of quartz and feldspar in the mylonites demonstrate that the shear zone was developed under the amphibolite facies condition and at mid-crust levels. The metamorphic core complex formed in the Early Cretaceous with a muscovite plateau age of 124.8±1.2 Ma. Regional NE-SW extension along a SW-dipping, gentle detachment zone was responsible for formation of the core complex. Intrusion of the Hongzhen granite with a biotite plateau age of 124.8±1.2 Ma rendered the ductile shear zone curved, uplifted and final localization of the core complex. The Hongzhen metamorphic core complex suggests that the Early Cretaceous magmatism in this region took place under the condition of regional extension and the eastern Yangtze plate also experienced lithospheric thinning.

Yangtze plate, Hongzhen metamorphic core complex, ductile shear zone, lithospheric thinning

The Hongzhen metamorphic core complex is the only core complex in the Yangtze plate north of the Jiangnan uplift zone. Previous studies on the core complex concentrated in extensional structures in the cover. Lack of detailed studies on the ductile detachment zone of the foot wall in the basement caused a controversy over its genesis. Luo et al.[1] proposed that NW-SE extension in the earlier Indosinian movement resulted in development of the Hongzhen metamorphic core complex, and the core complex then suffered from NE-SW folding in the later Indosinian movement. Li[2] demonstrated that extensional detachment faulting at different levels between the basement and upper Triassic strata, related to doming in the Yanshanian movement, was responsible for formation of the core complex. Dong et al.[3] pointed out that the core complex formed after development of the Indosinian NE-SW Dongling anticline and was caused by diapir-related sliding due to a series of intrusion under the bubble expansion mechanism in the Yanshanian. Therefore, there exists an obvious controversy over formation time, mechanism and relation to the magmatism for the metamorphic core complex.

The lithospheric thinning issue is a hot topic of geodynamic researches in recent years. Shallow responses to the lithospheric thinning include extensional structures, volcanic eruption, surface elevating and so on. Metamorphic core complex as expression of the extensional structures and associated magmatism are good examples for researches of lithospheric thinning. Large-scale lithospheric thinning of the North China block (NCB) during late Mesozoic has been widely accepted[4−7]. The Dabie-Sulu orogenic belt also experienced intense

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extensional activities and deep unrooting during the Early Cretaceous[8,9]. However, it is under debate whether or not the Yangtze plate also experienced the lithospheric thinning as the NCB[10,11]. A series of metamorphic core complexes with consistent NW-SE extension direction were developed in the NCB during the lithospheric thinning of Early Cretaceous. The Yangtze plate was also subjected to extensional activities in late Mesozoic, but the starting time and extension direction remain controversial[13−16]. By means of fault slip measurement, Schmid et al.[13] and Ratsch-bacher et al.[8] proposed that NW-SE extension occurred in the Dabie belt and the Yangtze plate east of the Dabie belt during the Early Cretaceous time. However, Hou et al.[15] inferred using the same method that the lower Yangtze region experienced NNE- SSW extension from Late Jurassic to earliest Early Cretaceous, and NW-SE extension from latest Early to Late Cretaceous. After studies on the Lushan gneiss dome, Lin et al.[17] also pointed out that NE-SW extension appeared in the Yangtze plate during the Early Cretaceous (133—127 Ma). These important issues can be constrained by detailed studies on metamorphic core complex.

On the background of above issues, detailed, structural studies were conducted on the ductile foot-wall detachment zone of the Hongzhen metamorphic core complex. With the research results and relevant dating data, new understanding for the genesis of the core complex is proposed, and discussion on the relation between the development of the core complex and magmatism as well as the lithospheric thinning is performed in this paper.

1 Geological background

The Hongzhen metamorphic core complex is situated in the Hongzhen area between Anqing and Qianshang south of Anhui. The core complex occurs in the Yangtze plate east of the Dabie orogenic belt and north of the Jiangnan uplift zone (Figure 1). Sinian to Middle Triassic marine cover shows NE-trending antiform, so-called "Hongzhen anticline", around NE-trending metamorphic basement composed of the Dongling Group. The Qiangshan fault-bound basin of Cretaceous to Paleogene appears to the northwest of the antiform structure while Wangjiang fault-bound basin occurs to the southeast of the structure.

The Dongling Group, as exposed basement in the Yangtze plate in the lower Yangtze region, is composed of amphibolite facies rocks such as muscovite quartz schist, biotite plagioclase gneiss, granitoid gneiss and plagioclase amphibolite. Mylonitization widely overprints on the basement rocks (see the text). Exposures of the basement in the area are in a NE-tending belt as long as 15 km and as wide as 2 km. Three single zircon ages obtained by Grimmer et al.[18] from sillimanite, cordierite-bearing K-feldspar gneiss (locality: 116°49.20′, 30°33.80′) range from 2370±2 Ma to 2377±10 Ma while the other two zircon ages are 692±10 Ma and 783±7 Ma respectively. The former are interpreted as representing times of the protolith whereas the latter is considered as being times for the Jinling movement widely experienced by the basement of the Yangtze plate.

Marine cover on the basement in the area includes carbonate and clastic rocks of Sinian to Middle Triassic. Owing to fault contact between the cover and basement, the basement contacts with different cover strata such as Lower Sinian, Middle-Upper Cambrian, Lower and Upper Ordovician strata. These phenomena indicate that the contact is occupied by a fault, and the fault is oblique to the base plane of the cover so that different missing of the cover strata appears in the contact zone. The area is located in the foreland deformation region near the Dabie orogenic belt and was also subjected to NE folding and thrusting in the Indosinian movement. The NE-trending folds and parallel thrusts were produced by the Indosinian foreland deformation[19]. The thrusts dip SE and lead to repeated strata in many places (Figure 1). A series of NW-trending, normal faults perpendicular to the fold axes and dipping NE might be transverse normal faults related to the Indosinian folding.

The southern and northwestern areas are covered by the continental facies basins controlled by normal faulting. The basin south of the core complex, filled with red clastic rocks of the Lower Cretaceous Wanggongmiao Formation and controlled by a nearly EW-striking, S-dipping normal fault, is a part of the Wangjiang basin (Figure 1). The basin northwest of the core complex, filled with red beds of the Pukou and Chishan formations of Upper Cretaceous and bound by NE-striking, NW-dipping normal faults, is extension of the NE-trending Qiangshan basin.

Intrusions in the area include Hongzhen granite, Hailushan diorite, Jinshan diorite, Xiashi granite and

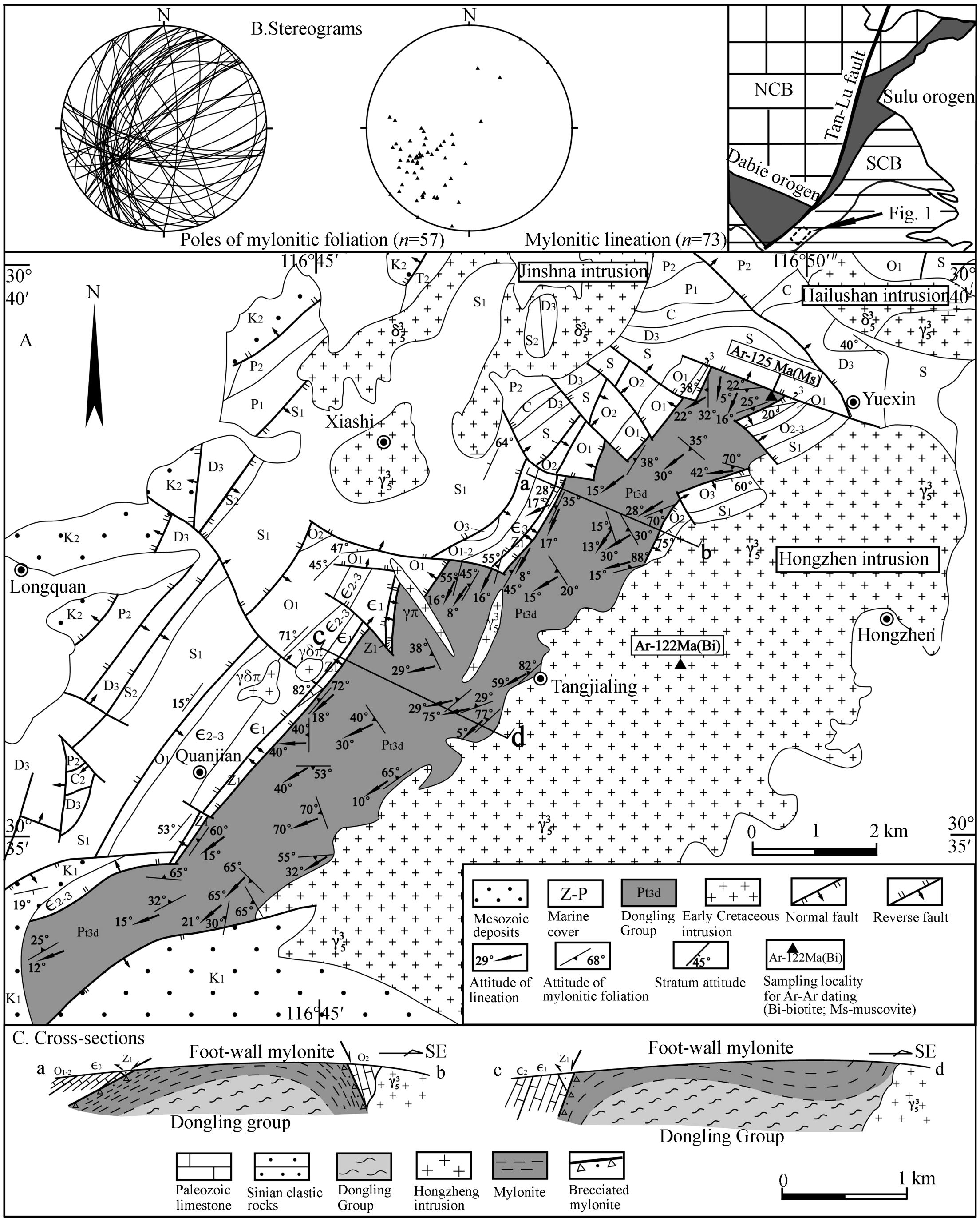

Figure 1 Structural map of the Hongzhen metamorphic core complex.

some small-scale porphyritic granodiorite and acid veins (Figure 1). The NE-trending Hongzhen granite body just appears to the southeast of the NE-trending Dongling metamorphic core complex. Biotite from the granite (see its locality in Figure 1) yields a $^{40}Ar/^{39}Ar$ plateau age of 121.7 Ma (Early Cretaceous) that represents its intrusion time[20]. The field-work found that the Hongzhen granite was not involved in ductile deformation, and caused contact metamorphism of surrounding limestone into marble. Flow lines and planes occur on the margin of the intrusion, but disappear in the interior. Microscopic observation reveals that the flow lines and planes are shown by partially oriented alignment of feldspar and biotite, and there is no phenomenon of ductile deformation such as undulatory extinction, sub-grains and dynamic recrystallisation. To prove this, the analysis of quartz *C*-axis fabric was conducted for an oriented granite sample (YS19), which exhibits random distribution (Figure 3) due to lack of ductile deformation. Widespread mylonitization of the Dongling Group in the contact zone with the intrusion body and its disappearance in the granite in the contact zone demonstrate that the mylonitization took place prior to the intrusion.

2 Features of the foot-wall ductile shear zone

In a typical metamorphic core complex, step normal faults are developed in a hanging wall while an extensional, ductile shear zone forms in a foot wall. A fault between the hanging and foot wall appears as chloritized breccia due to exhumation of the foot-wall ductile shear zone. Basement rocks of the Hongzhen metamorphic core complex contact the cover of different ages with faults, indicating that detachment faulting was developed in a low-angled plane oblique to the unconformity. The marine cover is characterized by development of inter-layer folds whereas brecciated mylonite as wide as 2 m occurs in the Dongling Gourp in the contact fault (Figure 2(a)). Owing to lack of ferromagnesian minerals in the previous mylonites, the chloritization phenomena did not appear in the contact mylonite zone. The brecciated mylonite transits into mylonites of the ductile shear zone downwards away from the contact zone.

Detailed field investigation and microscopic observation of 68 samples demonstrate that the Dongling Group was mylonitized into protomylonite, mylonite or ultramylonite (Figure 2(b)). It is suggested therefore that the Dongling Group was overprinted with a large-scale, ductile shear zone. Measurement of 73 mineral elongation lineation (Figure 1B) reveals that the mineral lineation in the shear zone mostly dips SW gently, and its predominant dip is parallel to extent direction of the exposed Dongling Group. However, attitudes of the mylonitic foliation changes from place to place (Figure 1B). In the northeast segment of the core complex (north of the a-b section in Figure 1), the mylonitic foliation dips NW in the northwestern part, SE in the southeastern part, SW in the middle part, generally showing an antiform gently plunging SW (see the a-b section of Figure 1). In the middle segment between the a-b section and Quanjian, the foliation dips NW both in northwestern and southeastern part, but SW gently in the middle part, with exception of local steep foliation due to later reworking, exhibiting reversed S-shaped profile of the shear zone (see c-d section in Figure 1). In the southwestern segment to the south of Quanjian, the ductile shear zone strikes NE and dips NW in the western part, strikes NW and dips SW in the eastern part, showing a left half part of the reversed S-shaped zone for the profile. In summary, the ductile shear zone appears as a gentle zone striking NW and dipping SW in the interior whereas its northwestern and southeastern flanks are steep. It is proposed that the former represents original attitudes while the latter are results of later reworking (see the details later).

3 Kinematics of the foot-wall ductile shear zone

Moving sense of a ductile shear zone can be determined from outcrop structures, microstructures of oriented thin-sections and analysis of quartz *C*-axis fabric. S-C fabric shown by schistose minerals or elongated quartz (Figure 2(c)), tails shown by pressure shadow of porphyroclastic feldspar or small-scale, asymmetry folds in the mylonites of the foot-wall ductile shear zone in the Dongling Group all indicate moving sense of top-to-SW (Figure 3).

On the basis of microscopic observation on 62 thin-sections of oriented mylonite samples, microstructures such as mica-fish, rotated tails of pressure shadow of porphyroclastic feldspar, feldspar “book-shelf” and so on also exhibit moving sense of top-to-SW.

To further determine the shear sense of the foot-wall ductile shear zone, measurement of quartz *C*-axes was conducted for 14 oriented thin-sections (XZ plane) perpendicular to foliation and parallel to lineation in this work. About 200 *C*-axes of recrystallized quartz in each thin-section was measured on a U-stage, and the *C*-axis stereogram on an equal-area net was made by using STEREONETT (Version 2.46) (Figure 3). The quartz *C*-axis stereogram can be used for determining important information such as deformation mechanism, shear sense, active slip systems and deformation temperatures[21]. Coaxial deformation normally caused clinosymmetry pattern in the *C*-axis stereogram whereas the non-coaxial deformation leads to development of monoclinic symmetry in the *C*-axis stereogram that can be used for determining shear sense. The *C*-axis patterns

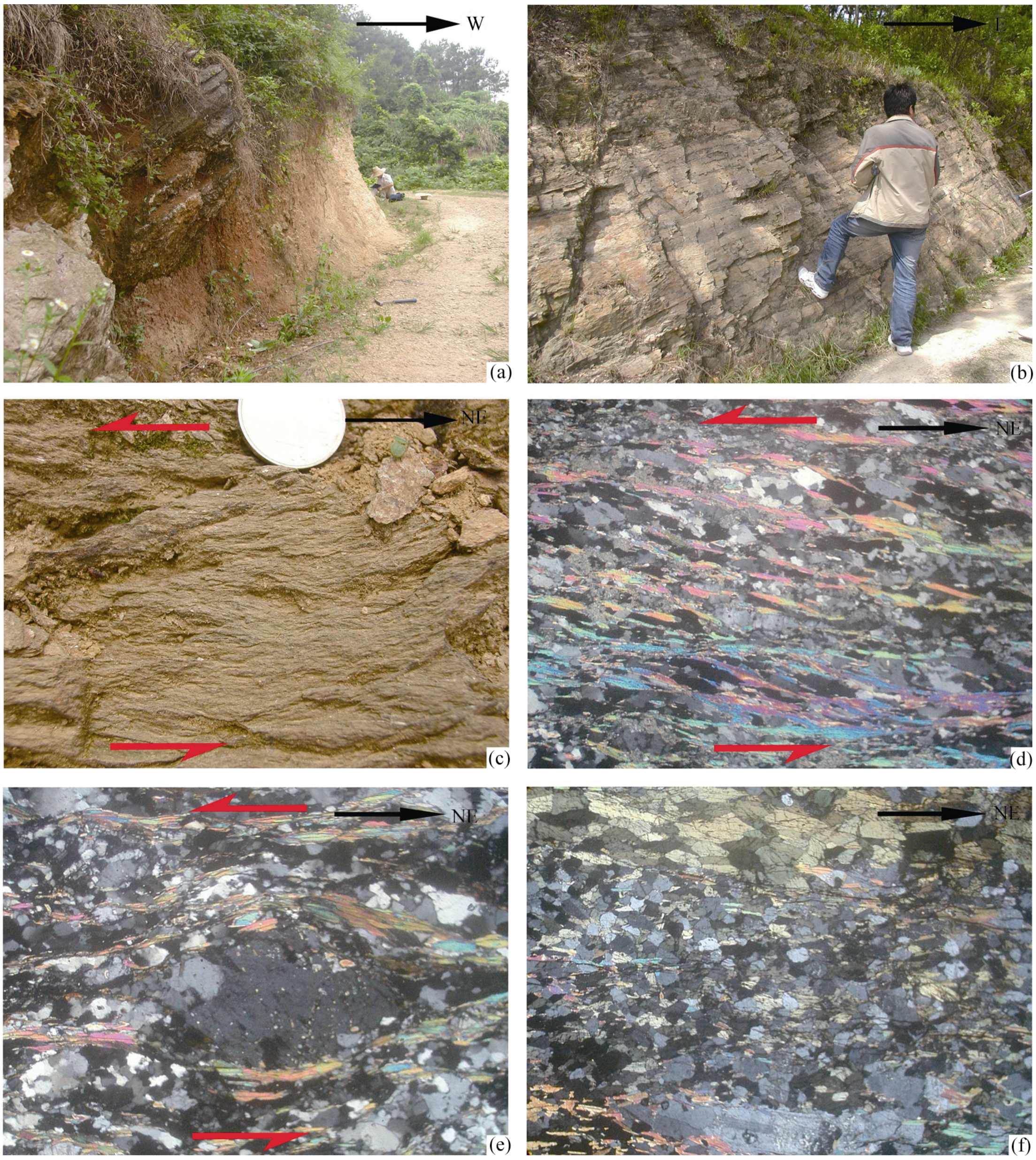

Figure 2 Exposure photos and photomicrographs of the Hongzhen metamorphic core complex. (a) Fault contact between the Lower Ordovician limestone (left) and Dongling Group (right) as well as the brecciated mylonite NE of Tangjialing (site YS46); (b) gentle, W-dipping ultramylonite belt in the west of the Dongling Group exposures at site YS3 (see Figure 3 for its locality); (c) S-C fabric indicating moving sense of top-to-SW in the muscovite-bearing mylonite in the Dongling Group at site YS14; (d) Muscovite S-C fabric in ultramylonite at site YS3 showing top-to-SW motion, and wide-spread dynamic recrystallisation of quartz and feldspar appearing. Crossed polarizers, width of view=4 mm; (e) tails of porphyroclastic feldspar in mylonite in the Dongling Group indicating top-to-SW motion at site DL8-3. Crossed polarizers, width of view=4 mm; (f) mylonite in the Dongling Group SW of Tangjialing, site YS36, showing porphyroclasts of hornblende (top) and feldspar (bottom) and matrix composed of recrystallised feldspar (BLG+SR type) and minor quartz (GBM type) as well as neoformed hornblende and biotite. Crossed polarizers, width of view=4 mm.

obtained from the protomylonite, mylonite and ultramylonite in the ductile shear zone (Figure 3) are characterized or dominated by the monoclinic symmetry. They indicate not only simple shear deformation or deformation dominated by simple shear, but also shear sense of top-to-SW. Samples DL20-1, DL21-1, YS16, YS3 show *C*-axis patterns mixed with clino- and monoclinic symmetry. The maxima related to the monoclinic symmetry as a result of simple shear deformation still reveals moving sense of top-to-SW. The clino-symmetry may be

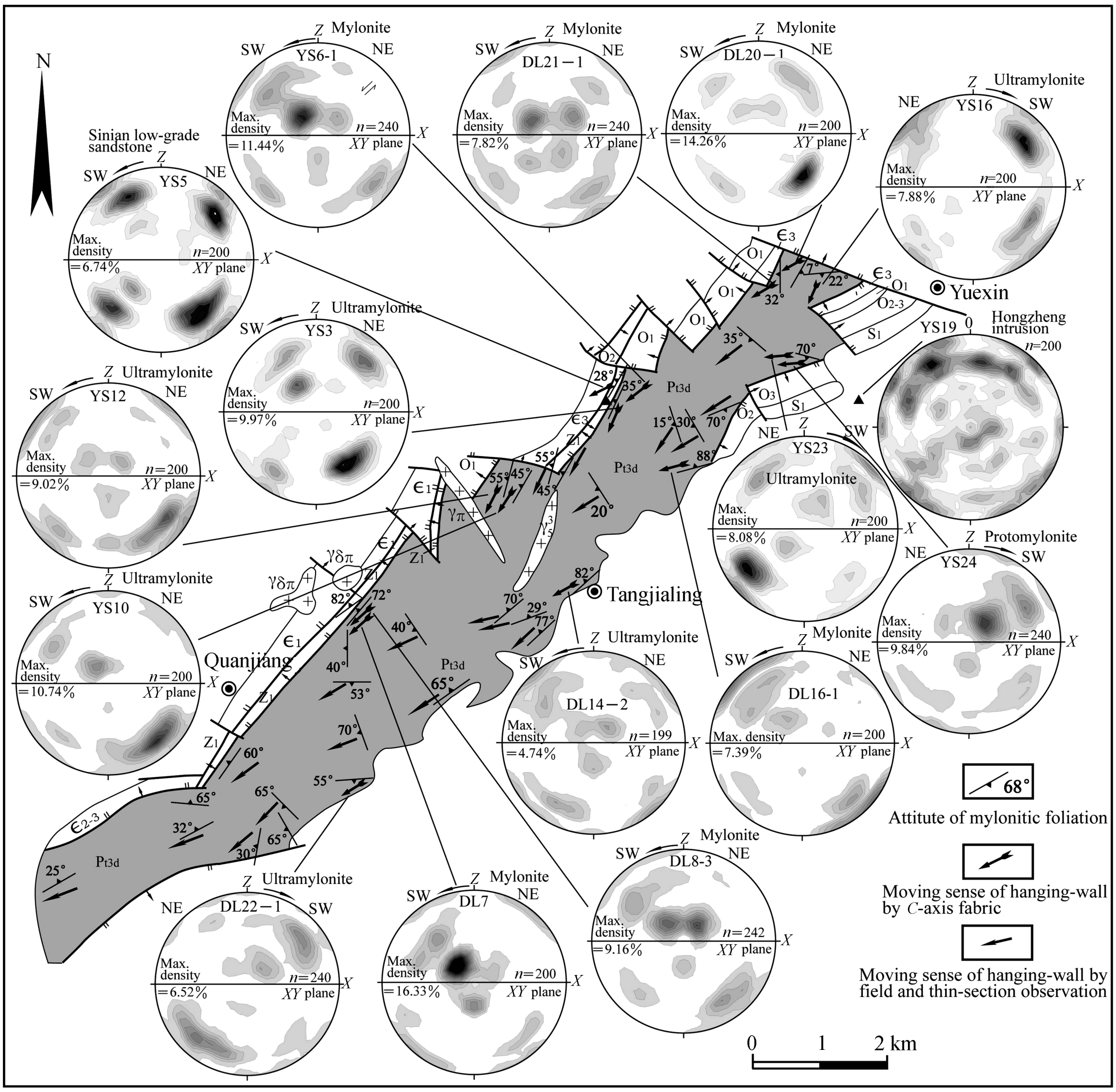

Figure 3 Quartz C-axis stereograms from the Hongzhen metamorphic core complex. Lower hemisphere projection; *n* denoting numbers of measured quartz grains; *X*,*Y*, *Z* indicating three principle strain directions.

related to coaxial deformation caused by overlying rock weights during the low-angled detachment faulting. One oriented sample was also collected from the Sinian low-grade sandstone, the Zhougang Formation, just on the ductile shear zone. Although its *C*-axis pattern mostly exhibits clino-symmetry related to coaxial deformation imposed by the overlying rock weights, it still shows overprinting by weak monoclinic symmetry that suggests moving sense of top-to-SW. It is demonstrated that the top-to-SW shearing along the main detachment zone also imposed weak influence on the overlying cover, and the phenomenon is also evidence for the moving sense of top-to-SW along the detachment.

4 Estimate for formation depths of the foot-wall shear zone

Deep formation depths for an exposed, foot-wall shear zone in metamorphic core complex reflect deep cutting depths and large motion scale. Formation depths of a ductile shear zone can be estimated indirectly from its deformation temperatures. The foot-wall ductile shear zone in the Hongzhen metamorphic core complex overprints on metamorphic rocks of the Dongling Group. Owing to lack of appropriate neoformed minerals for mineral-pair geothermometer in matrixes of the mylonites, the deformation temperatures for the shear zone cannot be determined by any geothermometer. It is found in this work that new hornblende was crystallized in matrixes of mylonite overprinting on plagioclase amphibolite, such as samples DL16-1, YS16, YS36 (Figure 2(f); Table 1), indicating amphibolite facies mylonitization.

Recent researches have demonstrated that types of dynamic recrystallisation for quartz and feldspar are closely related to deformation temperatures, and can be therefore used for estimating the deformation temperatures with errors of ca. 50℃. In naturally deformed rocks, dynamic recrystallisation of quartz starts at ca. 300℃. It shows bulging recrystallisation (BLG) at 300—400℃, sub-grain rotation recrystallisation (SR) at 400—500℃ and grain boundary migration recrystallisation (GBM) at temperatures exceeding 500℃. Feldspar behaves as brittle fracturing at temperatures less than 400℃, presents coexistence of micro-fracturing and plastic elongation at 400℃ to 500℃ and starts to be dynamically recrystallized at above ca. 500℃[21,22]. Feldspar exhibits BLG recrystallisation at 500—650℃, transition from BLG to SR recrystallisation at 650℃ to 700℃, SR recrystallisation at 700—800℃, transition from SR to GBM recrystallisation at 800—850℃ and GBM recrystallisation at above 850℃[23−26].

Microscopic observation on 62 oriented thin-sections shows that quartz in the protomylonite, mylonite or ultramylonite experienced widespread, dynamic recrystallisation of GBM type, suggesting deformation temperatures exceeding 500℃ and the amphibolite facies condition for the mylonitization. Feldspar, mostly appearing in matrixes of the mylonites, also exhibits widespread recrystallisation with the BLG type or mixtures of BLG and SR types (Table 1; Figure 2(f)), demonstrating deformation temperatures of ca. 600℃ or 650℃.

Quartz *C*-axis patterns can also indicate deformation temperatures for mylonites. Periphery maxima in a qartz

Table 1 Results of microscopic identification for some mylonites from the Hongzhen metamorphic core complex

Sample	Rock type	Mineral assemblage	Quartz recrystallization	Feldspar recrystallization	Estimated *T* (℃)
DL7	mylonite	P(35%): Qz+Fel M(65%): Qz+Fel+Ms	GBM	BLG+SR	650
DL8-3	mylonite	P(20%): Ms+Fel+Qz M(80%): Qz+Ms+Fel	GBM	BLG and sub-grains	600
DL14-2	ultramylonite	P(5%): Fel M(95%): Fel+ Qz+Bi	GBM	BLG+SR	650
DL16-1	mylonite	P(35%): Hb+Fel M(65%): Fel+Qz+Bi+Hb	GBM	BLG+SR	650
DL20-1	mylonite	P(15%): Qz+Fel+Ms M(85%): Qz+Fel+Ms+Bi	GBM	BLG	600
DL21-1	mylonite	P(25%): Fel+ Qz M(75%): Qz+Fel+Ms+Bi	GBM	BLG+SR	650
DL22-1	ultramylonite	P(10%): Fel+Ms M(90%): Qz+Ms+Fel+Bi	GBM	BLG	600
YS3	ultramylonite	P(5%): Fel+Qz M(95%): Qz+Fel +Ms	GBM	BLG+SR	650
YS6-1	mylonite	P(15%): Qz+Fel+Ms M(85%): Qz+Ms+Fel+Bi	GBM	BLG+SR	650
YS10	ultramylonite	P(5%): Fel+Ms+Qz M(95%): Qz+Ms+Fel+Bi	GBM	BLG and sub-grains	600
YS12	ultramylonite	P(5%): Fel+Ms M(95%): Fel+Ms+Qz+Bi	GBM	BLG	600
YS16	ultramylonite	P(10%): Hb+Fel M(90%): Fel+Bi+Hb+Qz	GBM	BLG+SR	650
YS23	ultramylonite	P(10%): Qz+Fel M(90%): Qz+Fel+Bi+Ms	GBM	BLG+SR	650
YS24	protomylonite	P(55%): Qz+Fel+Ms M(45%): Fel+Qz+Ms	GBM	BLG+SR	650
YS36	mylonite	P(15%): Hb+Fel M(85%): Fel+Hb+Bi+Qz	GBM	BLG+SR	650

P, Porphyroclast; M, matrix; Qz, quartz; Fel, feldspar; Bi, biotite; Ms, muscovite; Hb, hornblende; BLG, bulging; SR, sub-grain rotation; GBM, grain boundary migration.

C-axis stereogram are related to activity of basal slip system under conditions of deformation temperatures less than 400℃. A great girdle is caused by coeval activities of basal, rhomb and prism slip systems under simple shear at 400℃ to 500℃, whereas the central maximum around the *Y* axis is contributed by predominant activity of prism slip system at more than 500℃[21,22−26]. Except for sample DL7 indicating the amphibolite facies condition, the obtained *C*-axis patterns for the mylonites all suggest deformation temperatures from 400℃ to 500℃, obviously less than those indicated by quartz and feldspar deformation. As pointed out by Hongn and Hippertt[27] and Lebit et al.[28], the quartz *C*-axis fabric belongs to the sensitive fabric to strain, and often records the later state during progressive deformation. The mylonites developed in the extensional, ductile shear zone in the Hongzhen metamorphic core complex experienced tem- perature decline during its unroofing, and the later, lower temperature state was recorded by the *C*-axis fabric. In this case, the deformation temperatures suggested by the *C*-axis patterns are inconsistent with those indicated by the mineral deformation. The phenomena also reveal characteristics of the dip-slip motion for the ductile shear zone.

In summary, the foot-wall ductile shear zone in the Hongzhen metamorphic core complex was developed under the amphibolite facies condition with temperatures of 600－650℃. Using an average geothermal gradient of 30℃/km, formation depths of ca. 20 km can be estimated for the ductile shear zone. It is demonstrated therefore that the shear zone was developed at mid-crust levels originally, and then raised to the near-surface levels through large-scale extensional faulting. These suggest that deep cutting and large-scale movement was involved in the main detachment faulting during evolution of the metamorphic core complex.

5 Genesis of the core complex and its relation to lithoshperic thinning

As mentioned before, the study area is situated in the foreland deformation belt of the lower Yangtze region, and experienced the NE-SW folding and thrusting as the surrounding region. The NE-SW folds and thrusts in the marine cover on the metamorphic core complex are results of the foreland deformation (Figure 4A). A series of NW-SE, NE-dipping normal faults also appear in the cover. From the SW-dipping attitudes and top-to-SW moving sense for the main detachment zone of the core complex, it can be inferred that the transverse, NE-dipping normal faults was developed as transverse normal faults during the Indosinian folding (Figure 4A), rather than step normal faults of the core complex in the hanging wall, in which case the normal faults should dip SW.

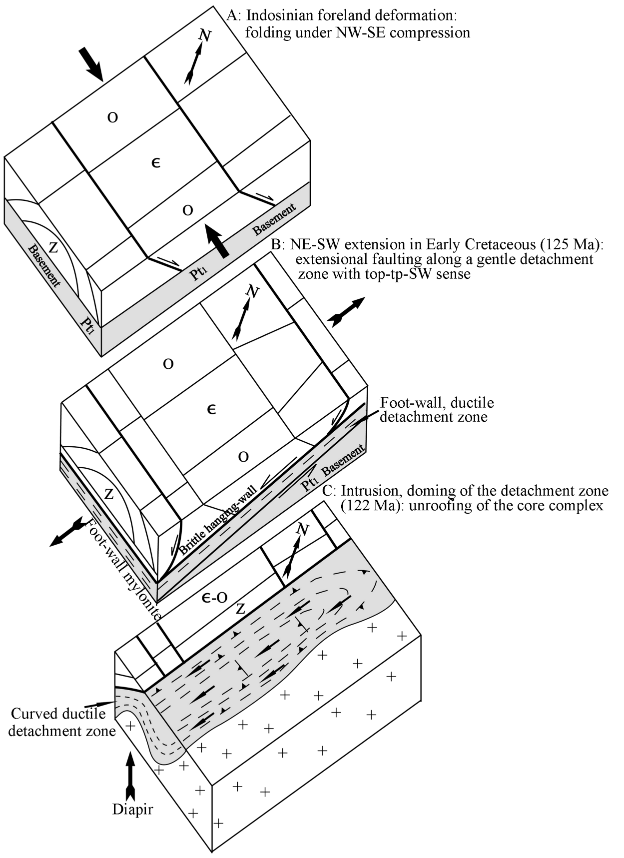

Figure 4 Structural evolution model for the Hongzhen metamorphic core complex.

The above structural investigation demonstrates that the metamorphic rocks of the Dongling Group in the Hongzhen area were overprinted by a large-scale ductile shear zone. In the northeastern segment of the exposed Dongling Group, the ductile shear zone presents an antiform in profile whereas in the mid-segment it exhibits a reversed S-shape in profile (Figure 1C). The shear zone in the middle part of the exposed Dongling Group from northeast to southwest strikes NW and dips SW gently. No matter how changeable are the mylonitic foliation in the shear zone, the mineral elongation lineation always dips SW gently, and the shear sense is always top-to-SW. These suggest that the detachment ductile shear zone of the metamorphic core complex was originally striking NW and dipping SW gently. The southward, extensional movement of the hanging wall resulted in elevation of the deep core complex to shallow crust levels (Figure 4B). An original, main detachment zone with a monoclinic attitude is a normal form for a metamorphic core complex[29]. The Early Cretaceous basin controlled by a EW-striking, S-dipping normal fault south of the Hongzhen metamorphic core complex (Figure 1) is a result of brittle normal faulting in the hanging wall. Grimmer et al.[18] obtained a 124.8±1.2 Ma (Early Cretaceous) $^{40}Ar/^{39}Ar$ age of muscovite from mylonite in the foot-wall ductile shear zone in the northeast of the metamorphic core complex (locality: 116°50.08′, 30°34.37′, see Figure 1) . The sample is the amphibolite facies mylonite in the Dongling Group with NE-SW mineral lineation and shear sense of top-to-SW. The dated muscovite is neoformed muscovite aligned along the mylonitc foliation[18]. The age indicates the cooling time of the extensional event due to the higher mylonitization temperature than the closure temperature of muscovite (350±50℃). The extensional event of the Early Cretaceous time is concordant with development of the extensional Qiangshan, Wangjiang basins filled with Lower Cretaceous, the oldest strata (Figure 1), with large-scale, Early Cretaceous magmatism trigged by regional extension[7,20], and with widespread extension of Early Cretaceous in East China[4-8,12,13,16,17].

The Hongzhen granite body appears to the southeast of the metamorphic core complex (Figure 1), and shows similar extent and scale as the core complex. Although the biotite $^{40}Ar/^{39}Ar$ age of 121.7 Ma from the Hongzhen granite is younger than the muscovite $^{40}Ar/^{39}Ar$ age of 124.8±1.2 Ma from the mylonite, the age difference cannot be used for determining time relation between the two events because the closure temperature of biotite (300±50℃) is lower than that of muscovite (350±50℃). As mentioned before, the field and microscopic observation and analysis of the quartz *C*-axis fabric all demonstrate that the foot-wall ductile shear zone of the core complex had not cut or affected the Hongzhen granite, indicating that the intrusion is post the detachment faulting of the core complex. However, the similar ages of the two events suggest that the intrusion just followed activity of the metamorphic core complex.

It is proposed that the intrusion of Hongzhen granite resulted in doming, elevating, unroofing and present localization of the Hongzhen metamorphic core complex (Figure 4C). The intrusion and diapir curved the foot-wall ductile shear zone, and the curved shape was controlled by the top boundary of the underlying granite body, leading to antiform of the shear zone in the northeastern segment and a reserved S-shape in the middle segment. The marine cover still remains west of the core complex whereas it is missing to the east where the granite body occupies (Figure 1), indicating more intensely elevation in the east. Similarly, remains of the marine cover to the northeast and its missing to the southwest demonstrate weaker elevation in the northeast. This implies that the S-dipping attitude of the shear zone in the middle part was not attributed to later, uneven elevation, but represents its original attitude. The NE-SW distribution of the Hongzhen core complex was caused by the intrusion of the NE-trending Hongzhen granite body. Another possibility for localization of the core complex is that curving of the foot-wall shear zone was related to later folding under NW-SE compression. However, the irregular profile shapes from antiform in the northeast to reversed S-shape in the middle do not support this later folding speculation. The irregular shapes of the shear zone also do not support genesis of the corrugation during the detachment faulting. Parallelism and similar extent between the core complex and granite body also suggest that the later exhumation of the core complex and curving of the ductile shear zone are results of the intrusion.

The new opinion on genesis of the Hongzhen metamorphic core complex has important implications for understanding the regional, lithospheric thinning. The formation process of the Hongzhen core complex reveals that the extension was associated with magmatism on one hand, and earlier than the intrusion in detail on the other hand. This suggests that the Early Cretaceous magmatism took place under the extensional background, and should be the result of the lithospheric thinning. The thinning of lithospheric mantle can happen by means of chemical replacement[4] or delamination into asthenosphere[5,6]. Both the cases can trigger magmatism, but the later case also result in lithospheric uplifting and shallow, extensional faulting due to gravitational isostasy in response to the delamination whereas the former case is usually not associated with the shallow, extensional faulting. The presence of the Hongzhen metamorphic core complex reveals that the shallow, extensional faulting took place during the lithospheric thinning, supporting the delamination proposal for the lithospheric thinning. Lithospheric state in the Yangtze plate remains unknown for the pre-Mesozoic times. However, the similar extensional faulting and magma activities in both the Yangtze plate and NCB [10] also indicate an obvious lithospheric thinning event in the Yangtze plate. By comparison with the NCB, the extensional faulting and magmatism in the Yangtze plate are not obviously weaker than those in the NCB, implying similar intensity of the lithospheric thinning for the two blocks in the Early Cretaceous. The phenomena are consistent with the proposal that the lithospheric thinning in East China in late Mesozoic is related to the oceanic plate motion in the Pacific Basin[10,14].

The Hongzhen core complex also reveals that the study area in the Yangtze plate was subjected to NE-SW extension in the Early Cretaceous time. The result is consistent with the Early Cretaceous extension direction obtained by Hou et al.[15] on the basis of the fault slip data, but do not supports the proposal by Schmid et al.[13] that the region experienced NW-SE extension in Early Cretaceous and then NE-SW extension in the latest Early Cretaceous. The Lushan gneiss dome in the lower Yangtze region in the south of the Yangtze plate also shows the NE-SW extension in Early Cretaceous[17]. These demonstrate that the eastern Yangtze plate might experience similar NE-SW extension in the Early Cretaceous time, which is different from the coeval NW-SE extension in the NCB and Dabie orogenic belt. The regional difference in the extensional direction may be attributed to deep, different processes during the lithospheric thinning. What is interesting is that the deep, extensional detachment faulting in the Lushan gneiss dome also indicates shear sense of top-to-SW[17], consistent with that of the Hongzhen metamorphic core complex. The consistent shear sense for the deep faulting implies the presence of a large-scale, detachment fault at a deep crust level. Studies of the Early Cretaceous metamorphic core complexes in the NCB also suggest the presence of a single extensional detachment zone at deep levels[30]. The phenomena of the extensional structures are very important for understanding the genesis of lithospheric thinning, but more detailed, comprehensive researches are needed.

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