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Wei Lin, Michel Faure, Qingchen Wang, Dominique Panis, Patrick Monié. Triassic polyphase deformation in the Feidong-Zhangbaling Massif (eastern China) and its place in the collision between the North China and South China blocks. *International Journal of Earth Sciences*, 2005, 25 (1), pp.121-136. 10.1016/j.jseas.2004.01.014 . hal-00091018

**HAL Id: hal-00091018**

**<https://insu.hal.science/hal-00091018>**

Submitted on 22 Nov 2007

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Triassic polyphase deformation in the Feidong-Zhangbaling Massif (eastern China) and its place in the collision between the North China and South China blocks

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## **Abstract**

The Feidong-Zhangbaling Massif is located between the Dabieshan and Sulu areas along the Tan-Lu fault in eastern China. Five tectonic-metamorphic events are distinguished there. The earliest deformation (D1) corresponds to a southward compression that occurred during subduction of the South China Block below the North China Block. Top-to-the-south shearing is coeval with Late Permian-Early Triassic blueschist facies metamorphism, and possibly with the development of south-verging recumbent folds in the Neoproterozoic-Paleozoic sedimentary cover of the South China foreland. The main ductile deformation (D2) is an extensional one, characterized by top-to-the-north shearing, coeval with the early stage of exhumation of the high-pressure rocks. A top-to-the-NW ductile shearing, and microfolds overturned to the northwest, belong to a second deformational phase of exhumation (D3) which is distinct from the main event (D2). Previous <sup>40</sup>Ar–<sup>39</sup>Ar mica dates ranging between 245 and 212 Ma suggest Late Permian-Early Triassic ages for the D1 to D3 events. The D4 event produced NE–SW trending folds in the sedimentary cover interpreted as gravity collapse structures. A Late Cretaceous brittle extensional event (D5) controls the opening and infill of continental half-grabens. In the study area, the Tan-Lu fault is a Cretaceous brittle normal fault. The lack of ductile deformation presented along the Tan-Lu fault suggests that it did not play a significant role in the exhumation of high-pressure metamorphic rocks.

**Author Keywords:** Structural analysis; Ductile deformation; Qinling-Dabie orogen; Permian-Triassic tectonics; Eastern China

## 1. Introduction

In eastern China, the Qinling-Dabie Belt formed during collision between the North China Block (NCB) and South China Block (SCB). The age of collision suggested as Neoproterozoic (Ernst et al., 1991), Pre-Devonian followed by Triassic intracontinental deformation (Mattauer et al., 1985), or Late Triassic (Xu et al., 1992). The eastern part of the Dabieshan Massif is truncated by the Tan-Lu fault. East of this fault, metamorphic rocks similar to those found in the Dabieshan crop out about 530 km to the north in the Sulu area (Fig. 1; e.g. Mattauer et al., 1985; Okay et al., 1993 and Cong, 1996). The Dabieshan and Sulu areas are famous worldwide for the occurrence of ultra high-pressure (UHP) coesite-bearing eclogite facies metamorphic rocks (e.g. Wang et al., 1992; Okay et al., 1993; Liou et al., 1996 and Cong, 1996). Abundant petrologic and geochemical data related to the UHP metamorphism have been published. However, structural data necessary for constraining any geodynamic evolution scenario are still rare. In the Dabieshan area, recent work recognized a main deformation phase coeval with amphibolite facies metamorphism, characterized by NW–SE trending mineral and stretching lineation associated with top-to-the-NW shearing (e.g. Hacker et al., 1995; Hacker et al., 2000 and Faure et al., 1999). Similar structures and kinematics are observed in the Sulu area (Faure et al., 2001 and Faure et al., 2003a).

Between the Dabieshan and Sulu UHP domains, the high-pressure (HP) Feidong-Zhangbaling Massif crops out on the eastern side of the Tan-Lu Fault (Fig. 1). The structural knowledge of this massif is key to understanding the relationships between the Dabieshan and Sulu massifs, as well as the role of the Tan-Lu fault. This paper presents the results of structural analysis of metamorphic rocks and their sedimentary cover in the Feidong-Zhangbaling Massif, with emphasis placed on polyphase deformation and kinematics. Together with available radiometric ages, our new structural data allow us to compare the tectonic evolution of the Feidong-Zhangbaling Massif with the Dabieshan and Sulu areas and to evaluate the significance of the Tan-Lu fault in the exhumation scenario following collision between the North China and South China Blocks.

## 2. Geological setting

Northwest of Nanjing City and east of the Tan-Lu fault, the Feidong-Zhangbaling Massif (nearly 1100 km<sup>2</sup> in area) bridges the Dabieshan and Sulu areas (Fig. 1). The massif contains three stratigraphic units from bottom to top, (1) the Feidong group, (2) the Zhangbaling group, and (3) the Late Proterozoic (Sinian) to Early Mesozoic sedimentary cover of SCB (e.g. ABGMR (Anhui Bureau of Geology and Mineral Resources), 1982 and Zhang and Huang, 1998).

The Feidong group, which crops out only in the Feidong area (Fig. 2), consists of quartzofeldspathic gneiss and biotite schist with minor quartzite, amphibolite and marble metamorphosed under upper greenschist to amphibolite facies conditions (Tong and Xu, 2000). In spite of a pervasive foliation, migmatitic features are well preserved, and thus the Feidong gneiss represents foliated migmatites.

The Zhangbaling group (Fig. 3) is mainly composed of metamorphosed volcanic rocks, micaschist, quartz-sericite phyllite, quartzite and sandstone that experienced Low Temperature-High Pressure metamorphism (300–400 °C and 0.6–0.7 GPa) (ABGMR (Anhui Bureau of Geology and Mineral Resources), 1982 and Xu et al., 1994). The HP mineral assemblages that include phengite, glaucophane, jadeite and piemontite are still preserved in

some mafic protoliths, although most rocks have been retrogressed to upper greenschist facies with mineral assemblages of chlorite, actinolite and epidote ( ABGMR (Anhui Bureau of Geology and Mineral Resources), 1982; Zhou, 1995 and Cong, 1996). Due to the presence of these HP rocks, and acidic volcanoclastic rocks, the Zhangbaling group is correlated with the Susong and Haizhou groups in the Dabieshan and Sulu areas, respectively (e.g. Cong, 1996 and Jing et al., 1996).

The metamorphic rocks are overlain by a sedimentary cover more than 8000 m thick ranging in age from Neoproterozoic (Sinian), through Early Paleozoic (Cambrian-Ordovician) to Middle Triassic (ABGMR, 1982). Sandstone, mudstone and limestone are the main rock types in the sedimentary cover of the SCB. Presently, no evidence of UHP metamorphism has been reported in the study area.

### **3. Structural analysis in the Feidong-Zhangbaling Massif**

#### **3.1. Bulk structure**

The deformation in the Zhangbaling area has been variously interpreted by previous workers either as southeastward decollement faulting of the Paleozoic cover from its metamorphic basement (Xu, 1987), or as thrusting of the metamorphic series over the foreland sedimentary cover of the SCB (e.g. Xu and Chen, 1987; Dong et al., 1995; Dong et al., 1996 and Zhang and Huang, 1998). However, polyphase deformation is not taken into account, thus these models are over simplistic. On the basis of radiometric dating and stratigraphy, there is a general agreement that syn-metamorphic deformation occurred before Late Triassic time.

From our field observations, the bulk architecture of the Feidong-Zhangbaling massif is dominated by a NNE–SSW trending antiform that records a partly syn-metamorphic polyphase evolution (Fig. 2, Fig. 3 and Fig. 4). In the Feidong area, the gneissic migmatite forms the core of the antiform. The gneissic Feidong group is heterogeneously deformed with a weakly foliated core and mylonitic shear zones on the limbs (Fig. 5A and B). The boundary between the lower gneissic Feidong group and the upper weakly metamorphosed Zhangbaling group is a low-angle ductile normal fault (Fig. 4A and B). In the Zhangbaling area, foliation in the metamorphic rocks is nearly subhorizontal, whereas bedding in the sedimentary sequence is deformed by southeastward verging folds ( Fig. 3 and Fig. 4). Five superimposed deformation events, called D1 to D5, are recognized in the Feidong-Zhangbaling Massif. Their characteristics are described below in chronological order ( Table 1).

#### **3.2. Evidence for an earlier ductile compressional deformation event (D1)**

The main deformation (D2, cf. below) observed in the Feidong-Zhangbaling Massif is not the first one. Relicts of earlier top-to-the-south ductile shearing coeval with the HP metamorphism have also been locally observed. In the field, rare top-to-the-south shear sense indicators (Fig. 5C) are preferentially developed in some domains such as northwest of Zhangbaling city where evidence of HP metamorphism is still preserved. In HP feldspathic phyllite (sample SL 21, Fig. 6) quartz ribbons exhibit microstructures such as undulose extinction and subgrain boundaries at high angle to the foliation typical of low temperature plastic strain. Quartz  $\langle 10\bar{1}4 \rangle$  axis, which lies at  $17^\circ$  to the  $\langle c \rangle$  axis and  $\langle a \rangle$  axis sub-fabrics, have been measured by X-ray texture goniometry. The  $\langle a \rangle$  axes define a great circle close to the stretching lineation, and  $\langle c \rangle$  axes are arranged in a girdle oblique to the foliation pole. Such a lattice preferred orientation (LPO) suggests that basal  $\langle a \rangle$  and prismatic  $\langle a \rangle$  are the

dominant slip systems. Their activation under medium temperature or high strain rate (ca. 350–400 °C, e.g. Law, 1990) is consistent with the metamorphic conditions. From the kinematic point of view, the fabric asymmetry showing top-to-the-south shearing is in good agreement with shear indicators, such as sigma-type porphyroclast systems observed in thin section.

In the study area, the Paleozoic series are deformed by kilometer-scale recumbent folds. The bedding-axial planar cleavage relationships indicate a southeastward overturning of these folds. The kilometer-scale of the inverted limbs is hardly compatible with their formation during gravity-driven D4 extensional tectonics (cf. below in Section 3.5). In the following section, this south-directed recumbent folding is considered as the result of the D1 event in the sedimentary cover, coeval with HP metamorphism at depth. D1 is related to an early compressional event ( Table 1).

### **3.3. Main ductile extensional deformation event (D2)**

In the Feidong and Zhangbaling groups, the regional subhorizontal foliation exhibits a conspicuous mineral and stretching lineation with a dominantly N–S to NNE–SSW trend (Table 1, Fig. 2, Fig. 3 and Fig. 5). Mylonite and ultramylonite with intrafolial folds are commonly developed ( Fig. 5E). A top-to-the-north (northeast) shearing is well indicated by quartz pressure shadows around feldspar or quartz clasts or sigma-type porphyroclast systems in metavolcanic rocks (Zhangbaling group, Fig. 5F) and phyllite (Sinian, Fig. 5G). Similar kinematics are deduced from quartz LPO ( Fig. 6). In the central part of the Zhangbaling area, mylonitic quartzite (sample SL 28) exhibits a weak quartz lattice preferred orientation of  $\langle 10\bar{1}4 \rangle$  (Cf. before) and  $\langle 1020 \rangle$  (or  $a$ -axis) determined by X-ray texture goniometry.

The poorly defined  $\langle c \rangle$  and  $\langle a \rangle$  axis patterns are partly due to de-focusing of the X-ray beam. Nevertheless, the fabric diagram asymmetry is consistent with top-to-the-north shearing inferred from other shear criteria. Both the  $\langle c \rangle$  and  $\langle a \rangle$  axis patterns show that quartz lattice preferred orientation with a maximum close to the center of the diagram is mainly controlled by the activation of a prismatic  $\langle a \rangle$  glide system under intermediate to high temperature conditions (i.e. in upper greenschist to lower amphibolite facies metamorphic conditions) higher than during the D1 event (e.g. Law, 1990).

In the Sinian sandstone, metamorphism is absent or very weak (with slight recrystallization of sericite or chlorite in the pelitic layers. However, those rocks exhibit a N–S to NNE–SSW stretching lineation marked by elongated and recrystallised quartz grains (Fig. 3). Along this lineation, asymmetric pressure shadows indicate a top-to-the-NNE shearing. Thus, ductile deformation in the sedimentary cover is related to the same D2 event as in the metamorphic rocks ( Table 1).

### **3.4. The ductile extensional deformation with NW–SE direction stretching lineation (D3)**

In the northern part of the Zhangbaling area, ribboned ultramylonite develops at the expense of metavolcanic rocks of the Zhangbaling group (Fig. 7A). A conspicuous NW–SE trending stretching and mineral lineation is preserved on the flat-lying foliation (Table 1, Fig. 2 and Fig. 3). This deformation event is coeval with greenschist facies metamorphism that overprints the blueschist facies metamorphism during exhumation. Asymmetric criteria such as quartz lenses, pressure shadows, and shear bands indicate a top-to-the-northwest shearing (

Fig. 7B and C). Quartz ribbons in ultramylonite, (e.g. sample SL 36, Fig. 6) exhibit a well-developed quartz lattice preferred orientation of  $\langle 10\bar{1}4 \rangle$  (near  $c$ -axis) and  $\langle 1020 \rangle$  ( $a$ -axis). The fabric asymmetry supports top-to-the-northwest shearing inferred from other shear criteria. In the Feidong area, NW–SE trending lineations that can be attributed to the D3 deformation event are almost lacking (Fig. 2).

It might be argued that D2 and D3 deformations belong to the same extensional tectonic event with different shearing directions, possibly due to local strain heterogeneities. However, several lines of evidence suggest that the NNE and NW directed shearing events likely occurred as two distinct stages during the exhumation of the HP metamorphic rocks. First, D3 shear bands deform the main D2 foliation. Secondly, D3 took place under temperature conditions lower than D2, suggesting that D2 and D3 occurred successively during cooling (Dong et al., 1995). Moreover, as discussed in the next section, the distinction between D2 and D3 is also supported by regional tectonics on the scale of the Dabieshan-Sulu Orogenic Belt (Faure et al., 2003a and Faure et al., 2003b).

The main foliation (D2) of the Feidong-Zhangbaling Massif is also deformed at the centimeter to meter scale by crenulation wrinkles and asymmetric microfolds associated with an axial planar crenulation cleavage marked by the concentration of white micas and opaque minerals (Fig. 7D). The fold axes and crenulation lineations dominantly trend ENE–WSW. On a regional scale, the crenulation cleavage is folded by a NE–SW trending antiform (Fig. 8). The development of these micro-scale folds overturned to the NW corresponds to a late increment of top-to-the-NW D3 shearing (Fig. 4A).

### **3.5. Gravity collapse folding and brittle detachment (D4)**

Another late deformation corresponds to folding of the early microstructures such as the D2 and D3 foliation and stretching lineation. In the southeastern part of the Zhangbaling area, the weakly metamorphosed Neoproterozoic (Sinian) pelitic limestone and non-metamorphosed Paleozoic rocks are deformed by southeast verging drag folds (Fig. 7E and F). These folds exhibit a ‘collapse style’ characterized by subhorizontal or southeastward dipping axial planes and downward vergence. They are related to the southward displacement of the Sinian-Paleozoic sequence above the metamorphic rocks. Indeed, the contacts between the metamorphic rocks and Sinian rocks and Sinian-Paleozoic series are SE dipping brittle faults. In the southeast part of the Feidong area, the unmetamorphosed Sinian and Paleozoic rocks are also deformed by south-southeast verging collapse folds (Fig. 4B). Similar structures are observed in the northwestern part of the Feidong-Zhangbaling Massif. Therefore, at the scale of the whole massif, the post-folial folds in the metamorphic rocks and some of the recumbent folds in the sedimentary cover are overturned to the southeast in the southeast part of the massif, and to the northwest in the northwestern part, respectively. As a result, the metavolcanic rocks of the central part of the Feidong-Zhangbaling Massif underwent an upward motion with respect to the Neoproterozoic-Paleozoic rocks (Table 1).

Due to the lack of superimposed structures that would have constrained the relative timing of the deformations, the large-scale folds observed in the Neoproterozoic-Paleozoic sedimentary cover might be related either to D1 compression or to a D4 gravity driven extensional collapse event. As discussed in Section 3.2, at the outcrop-scale, the distinction between D1 and D4 folds is almost impossible. Nevertheless, the kilometer-scale of these folds suggests that they formed during the D1 event.

### **3.6. Cretaceous brittle normal faulting (D5)**

The last significant deformation in the Feidong-Zhangbaling Massif is characterized by high angle brittle normal faulting. Normal faults are mainly located along the western boundary of the massif where they control the opening and sedimentary infill of half-grabens containing Late Cretaceous terrestrial red sandstone and conglomerate. It is worth noting that the nearby Early Cretaceous granites are deformed into cataclasite and gouge without any ductile deformation. Moreover, in granites and red sandstones, slickenlines show dominantly a down-dip attitude. Subhorizontal striation that would have supported a strike-slip motion is lacking the study area.

These five deformational events, along with their related kinematics, ages and tectonic significance, are summarized in Table 1 and synthesized in Fig. 9 for the Zhangbaling area.

## **4. Discussion and conclusion**

### **4.1. Chronological constraints**

In the study area, radiometric ages are rare.  $^{40}\text{Ar}/^{39}\text{Ar}$  mineral ages on phengite from blueschist facies metamorphic volcanic rocks yield  $245.1\pm0.5$  and  $244.2\pm0.5$  Ma (Zhang et al., 1989 and Li et al., 1993), whereas muscovite from quartz micaschist gives a  $212.6\pm0.4$  Ma age (Chen et al., 2000). The ca. 245 Ma (Early Triassic) date is considered the age of the HP event in agreement with available U/Pb and Sm/Nd ages on UHP rocks from the Dabieshan and Sulu areas (e.g. Mattauer et al., 1985; Chen et al., 1992; Ames et al., 1993; Eide et al., 1994; Hacker et al., 2000; Li et al., 1994 and Jahn, 1999). These radiometric dates are consistent with stratigraphy, since south of the study area, Middle Triassic limestone is involved in the recumbent folding but Late Triassic sandstone is undeformed (Liu et al., 2001). However, neither UHP metamorphic rocks nor ophiolites are preserved. Therefore the Triassic age of the collision between NCB and SCB cannot be substantiated in the Feidong-Zhangbaling area.

### **4.2. Regional significance of polyphase deformation**

The Feidong-Zhangbaling Massif is a structurally complex area which experienced several superimposed deformations events. In summary, the earliest event (D1), coeval with blueschist facies metamorphism, corresponds to top-to-the-south shearing associated with crustal stacking. In the whole Dabieshan-Sulu Belt, D1 is poorly constrained since tectonic superposition of thrust sheets is not documented by field geology but only by seismic profiles (e.g. Yang, 2002). In the southern foreland of the Dabieshan-Sulu Belt, recumbent folds involving the Neoproterozoic (Sinian)-Paleozoic-Middle Triassic sedimentary sequence are also attributed to D1 compression (e.g. Faure et al., 1998; Lin et al., 2000; Lin et al., 2001 and Liu et al., 2001). The D2 top-to-the-north (north-northeast) and D3 top-to-the-northwest ductile shearing events are related to exhumation stages of the HP rocks. As discussed above, the reality of a single extensional event with a progressive rotation of stretching lineation from north-northeast to northwest directions instead of two distinct events has not yet been proved. Thus two events are distinguished here. During the D3 event, northwest verging folds and associated crenulation developed as a late increment of the same deformation.

The deformation succession of the Feidong-Zhangbaling Massif can be compared with that described in the Dabieshan Massif (Faure et al., 1999 and Faure et al., 2003b). There, an early

top-to-the-north exhumation stage (similar to the D2 event described here) is followed by a conspicuous top-to-the-northwest shearing that can be correlated with the D3 event in the Feidong-Zhangbaling Massif. Thus the hypothesis of two distinct events is preferred.

The D4 event produced collapse folds related to detachment faulting. Therefore, in contrast to other areas, the Feidong-Zhangbaling Massif cannot be interpreted as a simple extensional gneiss dome cored by migmatites, but rather as a foliated antiform which experienced several deformation phases. Since undeformed Jurassic terrestrial and volcanoclastic rocks unconformably cover the Neoproterozoic to Paleozoic series, the D2 to D4 events must have occurred in Late Paleozoic to Early Mesozoic time. This relative timing is consistent with the acknowledged Early Triassic age of the main deformation inferred from the regional Late Triassic unconformity south of the Dabieshan Massif (e.g. ABGMR (Anhui Bureau of Geology and Mineral Resources), 1982 and Faure et al., 1998).

Lastly, the D5 Cretaceous extensional event is already well known since Early Cretaceous syn-kinematic plutons are coeval with ductile normal faulting and Late Cretaceous half-grabens are widespread throughout eastern China (Faure et al., 1996; Faure et al., 1999; Lin et al., 2000 and Ren et al., 2002). A general discussion of such a continental-scale phenomenon is beyond the scope of this paper. The polyphase deformation leading to the final bulk geometry of the Feidong-Zhangbaling Massif is summarized in Fig. 10.

### **4.3. The significance of the Tan-Lu Fault**

The Tan-Lu Fault is a major but controversial structure in eastern China (Xu et al., 1987; Xu et al., 1994; Mattauer et al., 1991; Yin and Nie, 1993; Zhu et al., 1995; Wang et al., 1996; Gilder et al., 1999 and Ratsbacher et al., 2000 and enclosed references). Several tectonic models suggest displacements of several hundreds of kilometers along the fault with timing ranging from the Precambrian to Cenozoic (cf. review in Xu, 1994). In the Feidong area, the Tan-Lu fault was thought to pass through the center of the massif and to be a left-lateral ductile shear zone ( Xu et al., 1994 and Tong and Xu, 2000). Our own fieldwork shows that the Feidong migmatitic gneiss is a NNE–SSW trending antiform with a brittle normal fault corresponding to the Tan-Lu fault located along the western margin of the antiform. Locally, subvertical gneissic foliation with a subhorizontal stretching lineation is observed. However, a detailed survey shows that this present geometric pattern is due to folding that rotated to vertical the early ductile planar fabric originally formed with a flat-lying attitude.

In the Feidong-Zhangbaling area, we did not observe any ductile deformation associated with strike-slip movements. In the present state of knowledge, the Tan-Lu fault appears only as a Late Cretaceous brittle normal fault. This result supports the observations in the Dabieshan area (e.g. Mattauer et al., 1991; Faure et al., 1999 and Ratsbacher et al., 2000). Of course, this conclusion does not preclude that the Tan-Lu fault originated in Early Mesozoic times or even earlier in the tectonic evolution of eastern Asia with different kinematics. However, at the continental-scale, the exact significance of the Tan-Lu fault either as an early transform fault or as a late normal structure still remains an unresolved problem. Moreover, the available structural data clearly show that the Tan-Lu fault did not play a significant role in the exhumation of the HP/UHP rocks.



## Acknowledgements

Field and laboratory expenses have been supported by Chinese National 973 Project (G1999075506), NSFC (40202021), JSPS (02060) and a French CNRS Intérieur de la Terre project and by a Franco-Chinese Cooperation Foundation (AFCRST-PRA T03). A post-doc grant for W. Lin from the Conseil Régional du Centre (France) is also acknowledged. Constructive comments by Sh. Chen and C. Burchfiel on an early draft of this manuscript are deeply acknowledged. Helpful reviews by T. Kusky and P. Vergely are also warmly acknowledged.

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## Figures

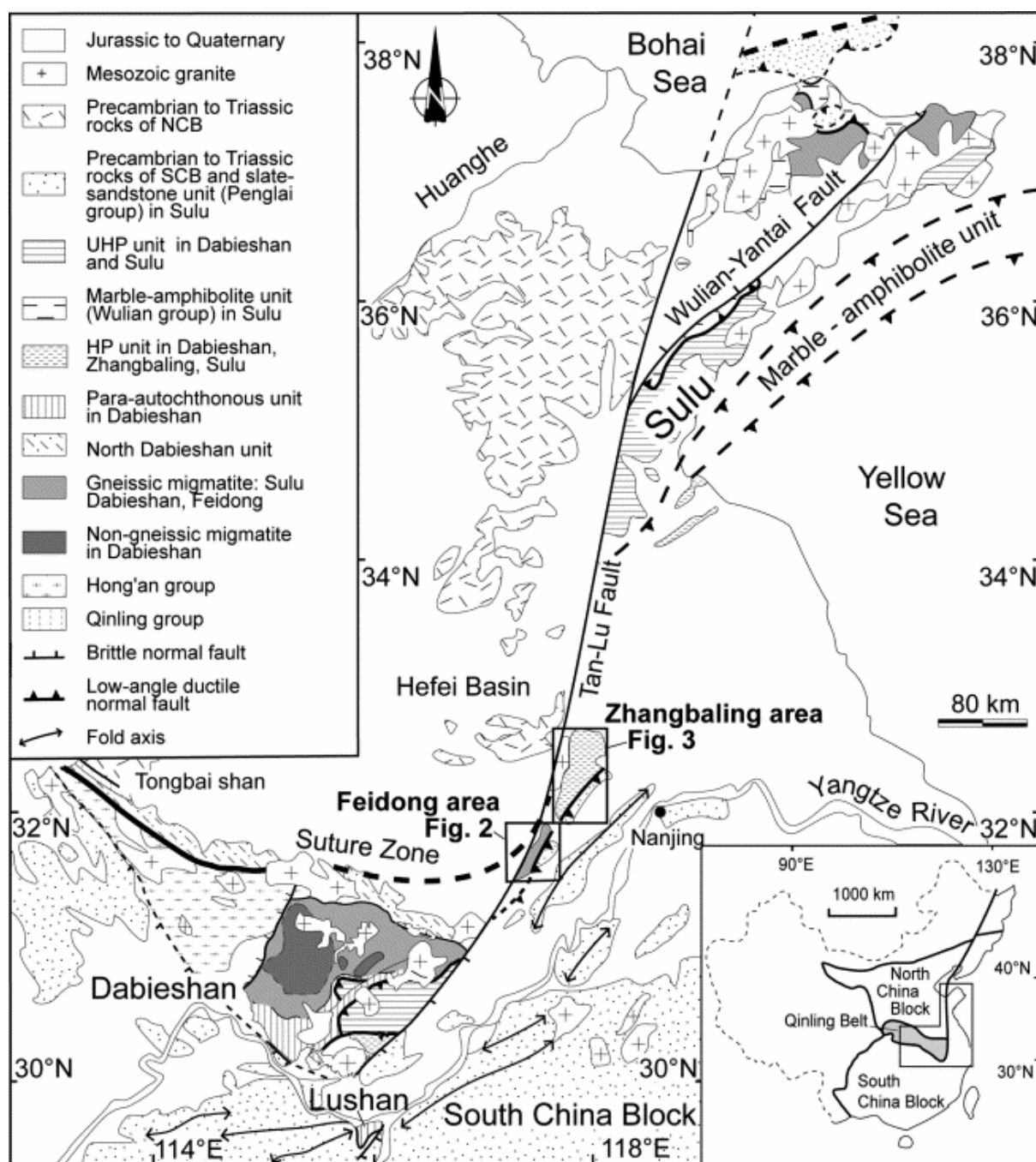


Fig. 1. Location map of the Feidong-Zhangbaling Massif within the Dabieshan-Sulu Belt.

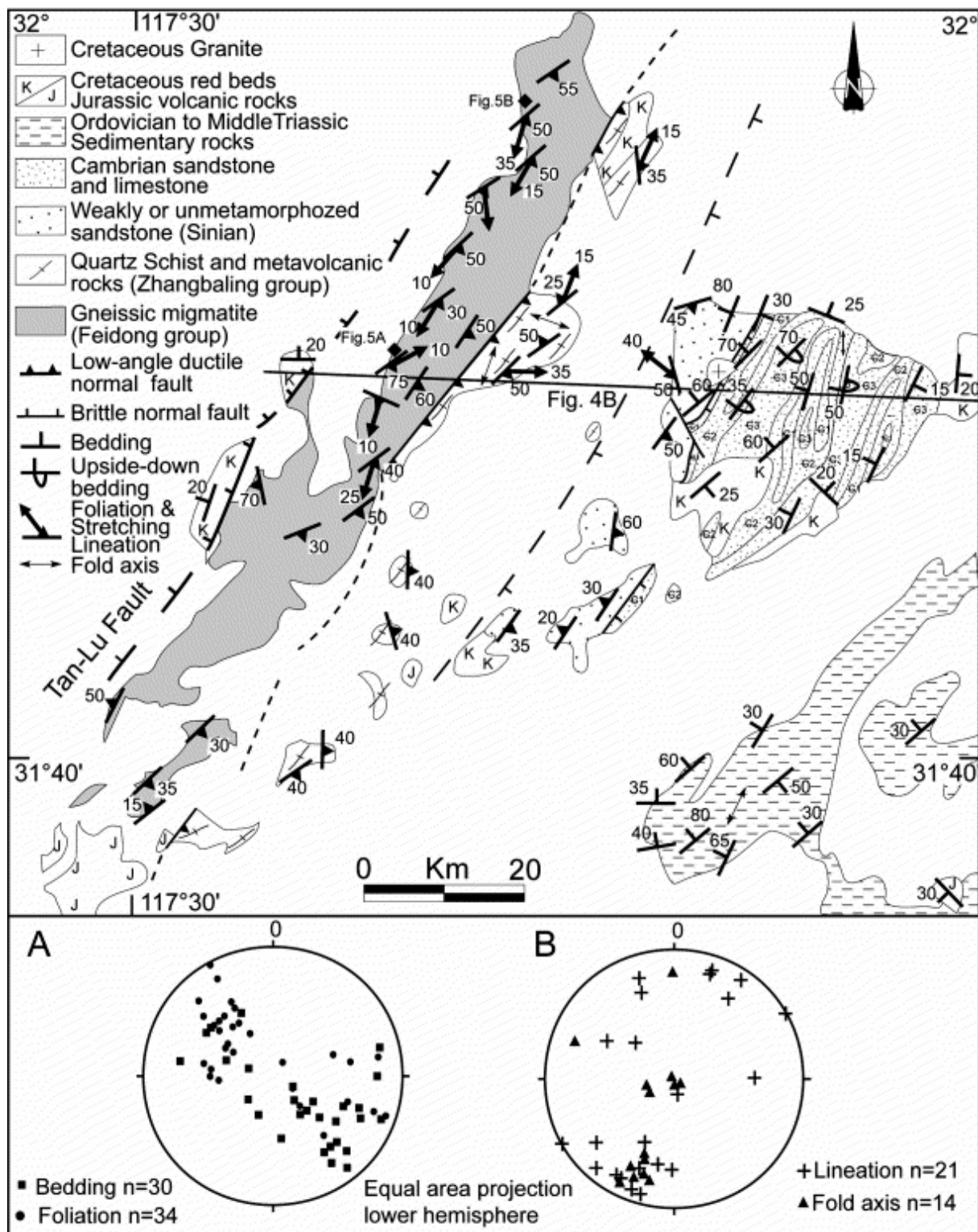


Fig. 2. Structural map of the Feidong area with stereoplots of structural elements, (A) foliation and bedding poles, (B) stretching and mineral lineations and fold axis.

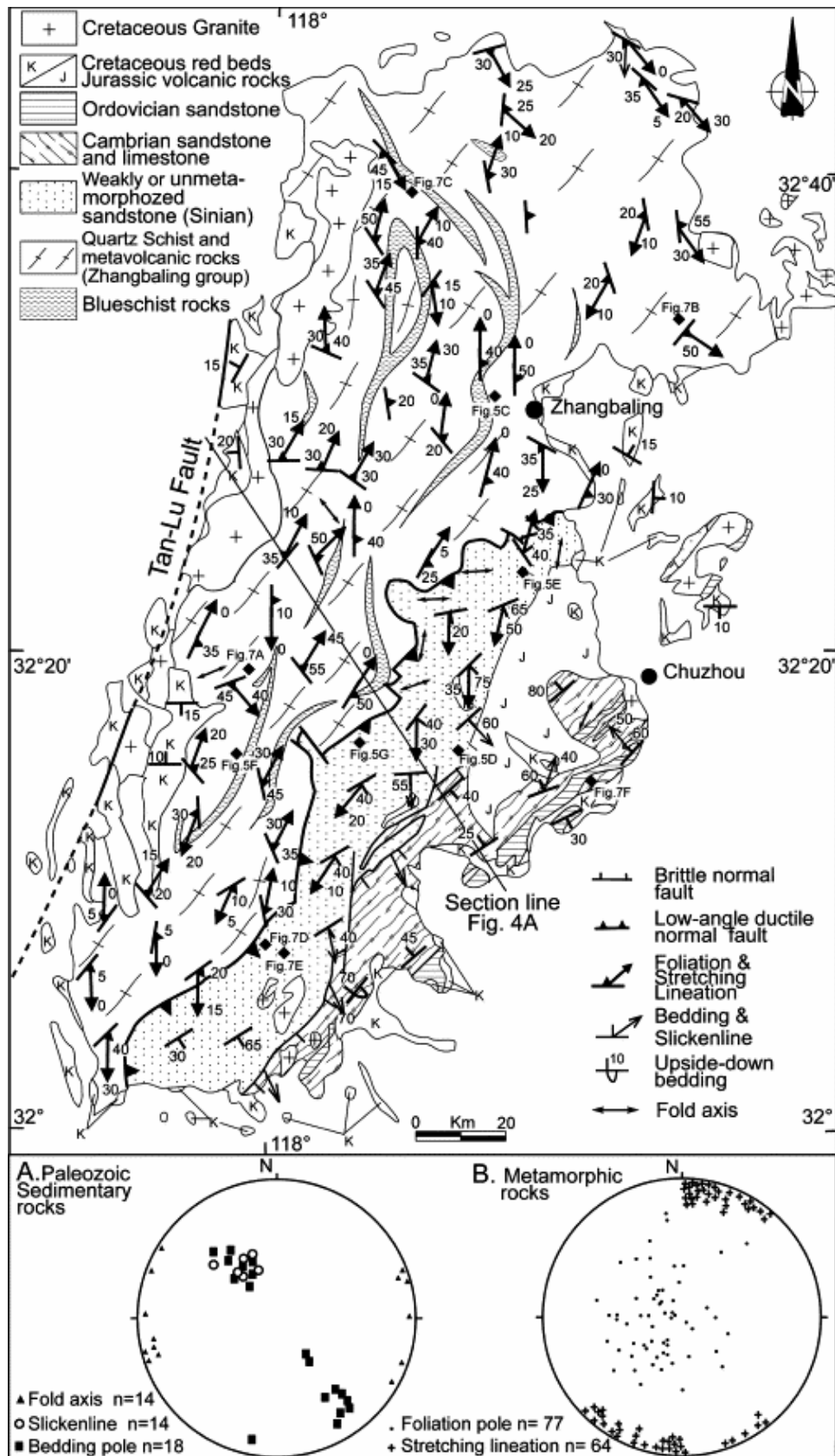


Fig. 3. Structural map of the Zhangbaling area with stereoplots of structural elements. (A) Bedding poles, slickenlines and fold axis in the Paleozoic sedimentary rocks; (B) foliation pole, stretching and mineral lineation in the metamorphic rocks.

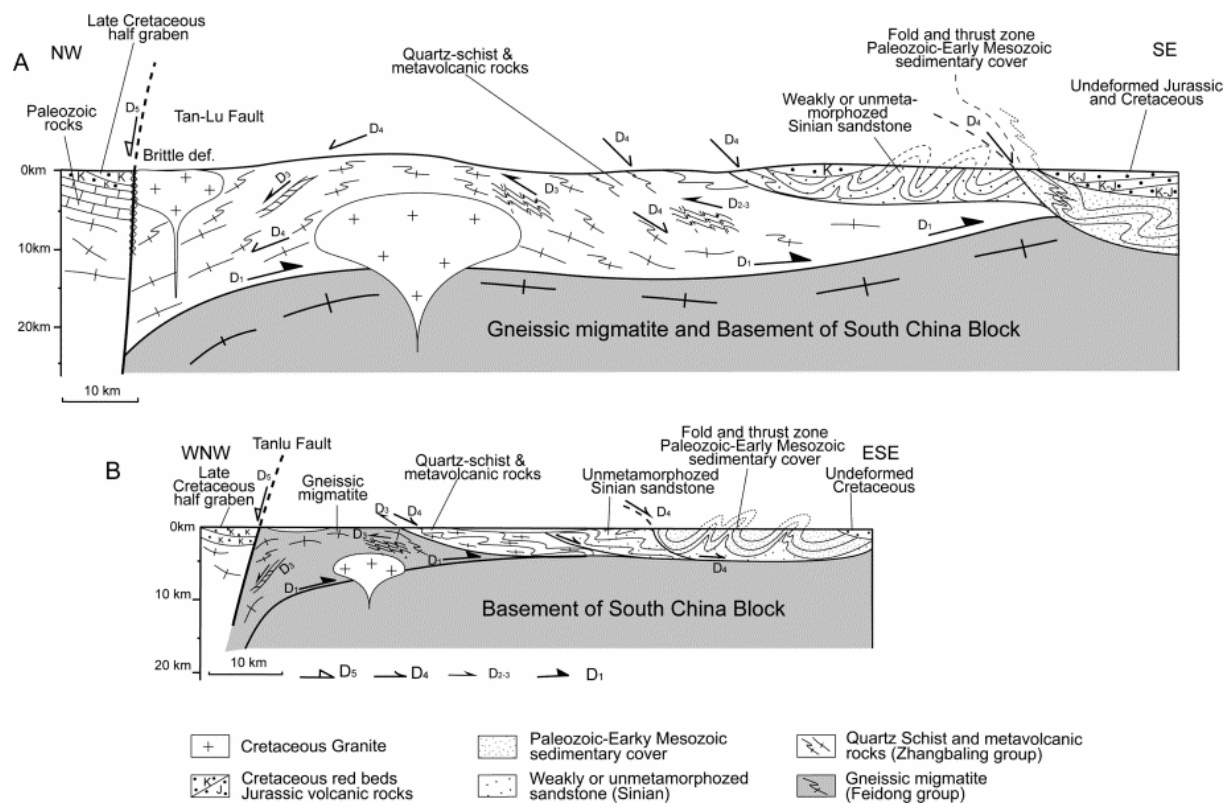


Fig. 4. Cross-sections throughout the study area showing the bulk geometry and polyphase deformation. (A) Zhangbaling area (see Fig. 3 for location). (B) Feidong area (see Fig. 2 for location).



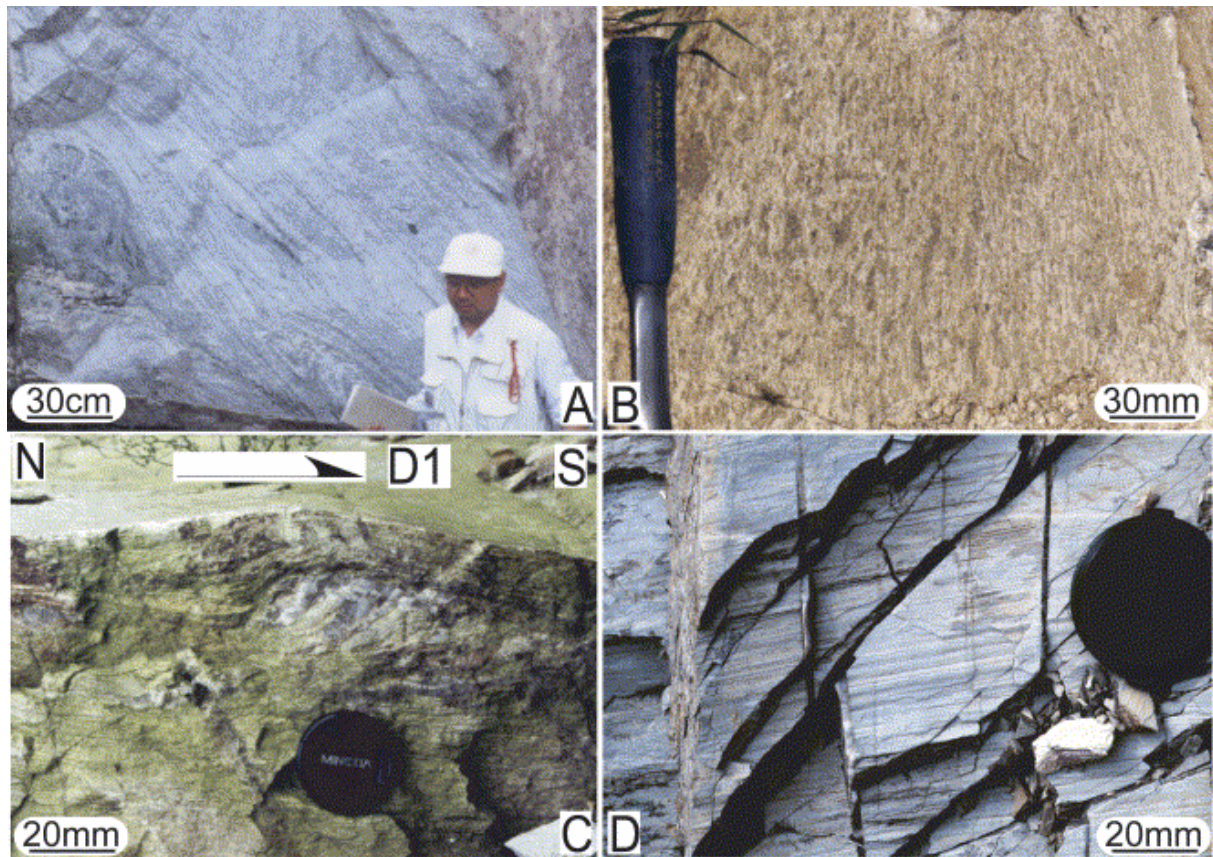


Fig. 5. (A) Gneissic migmatite in the Feidong group (Core of Feidong antiform); (B) mylonitic gneiss in the Feidong group (eastern flank of the Feidong antiform); (C) Asymmetric quartz clast showing top-to-the-south shearing related to D1 event in phyllitic sandstone (south of Zhangbaling); (D) Ultramylonite with conspicuous stretching lineation in metavolcanic rocks of the Zhangbaling group (related to D2 deformation); (E) Intrafolial folds with fold axes parallel with the N–S trending D2 regional stretching lineation; (F) Delta type porphyroclast system around quartz clasts in metavolcanic rocks related to D2 deformation (Zhangbaling group); (G) Top-to-the-NNE asymmetric pressure shadow around a quartz clast in phyllite (Sinian) (D2 deformation) (Location of the photos shown in Fig. 2 and Fig. 3).

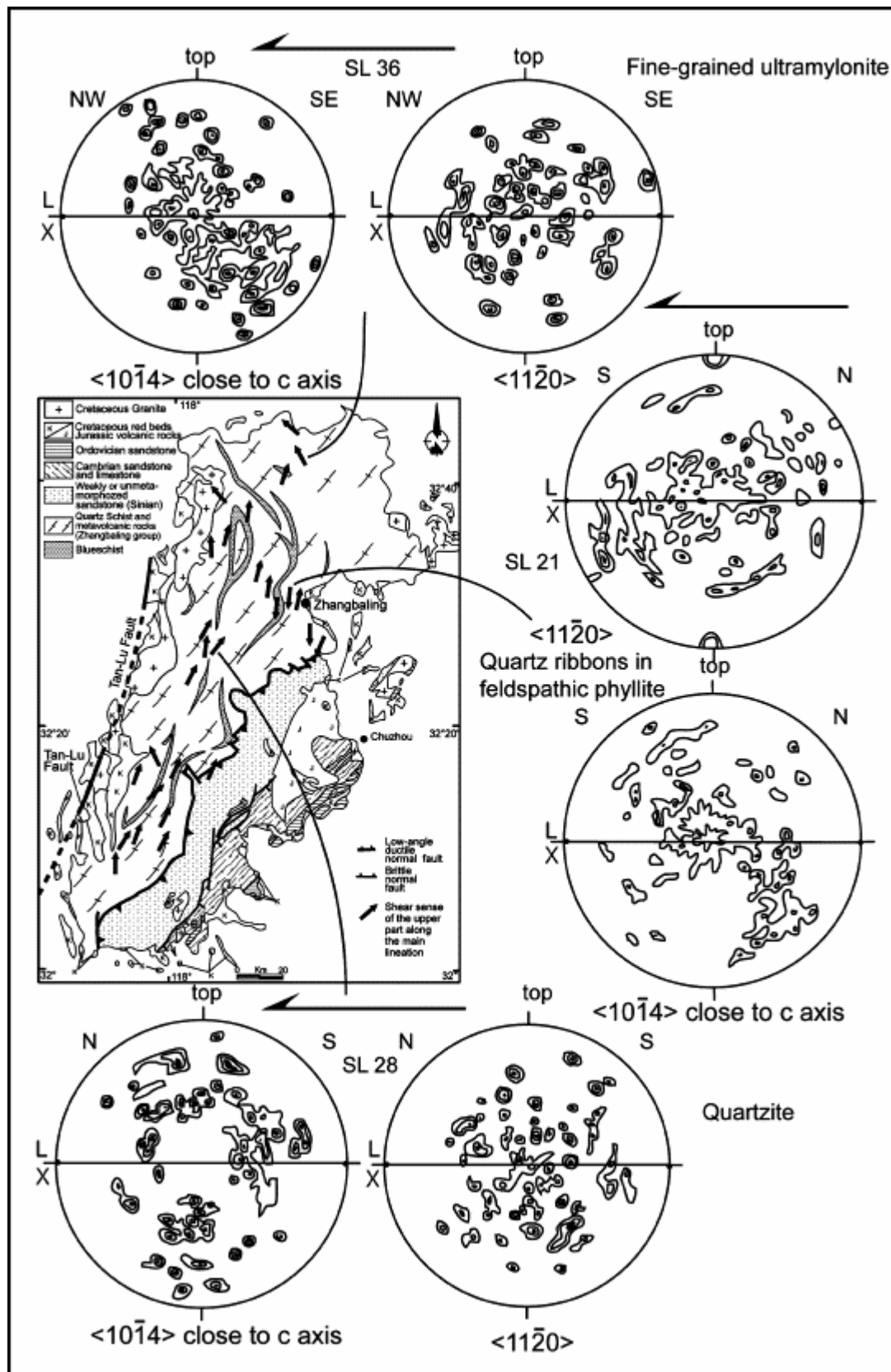


Fig. 6. Examples of quartz lattice preferred orientation of  $\langle 10\bar{1}4 \rangle$  and  $\langle 10\bar{2}0 \rangle$  subfabrics determined by X-ray texture analysis. Sample SL 21 is taken from a ribboned quartz-feldspar phyllite in which the early top-to-the-south shearing is preserved. Sample SL 28 from a quartzite shows top-to-the-north high temperature shearing. Sample SL 36, from a fine grain



ultramylonitic quartzite, is characterized by top-to-the-NW low temperature shearing. All diagrams are plotted on a lower hemisphere Schmidt net drawn in the XZ section of the bulk strain ellipsoid (i.e. perpendicular to foliation and parallel to lineation). Contour intervals are 1.5, 3 and maximum 5% multiple of random distribution.

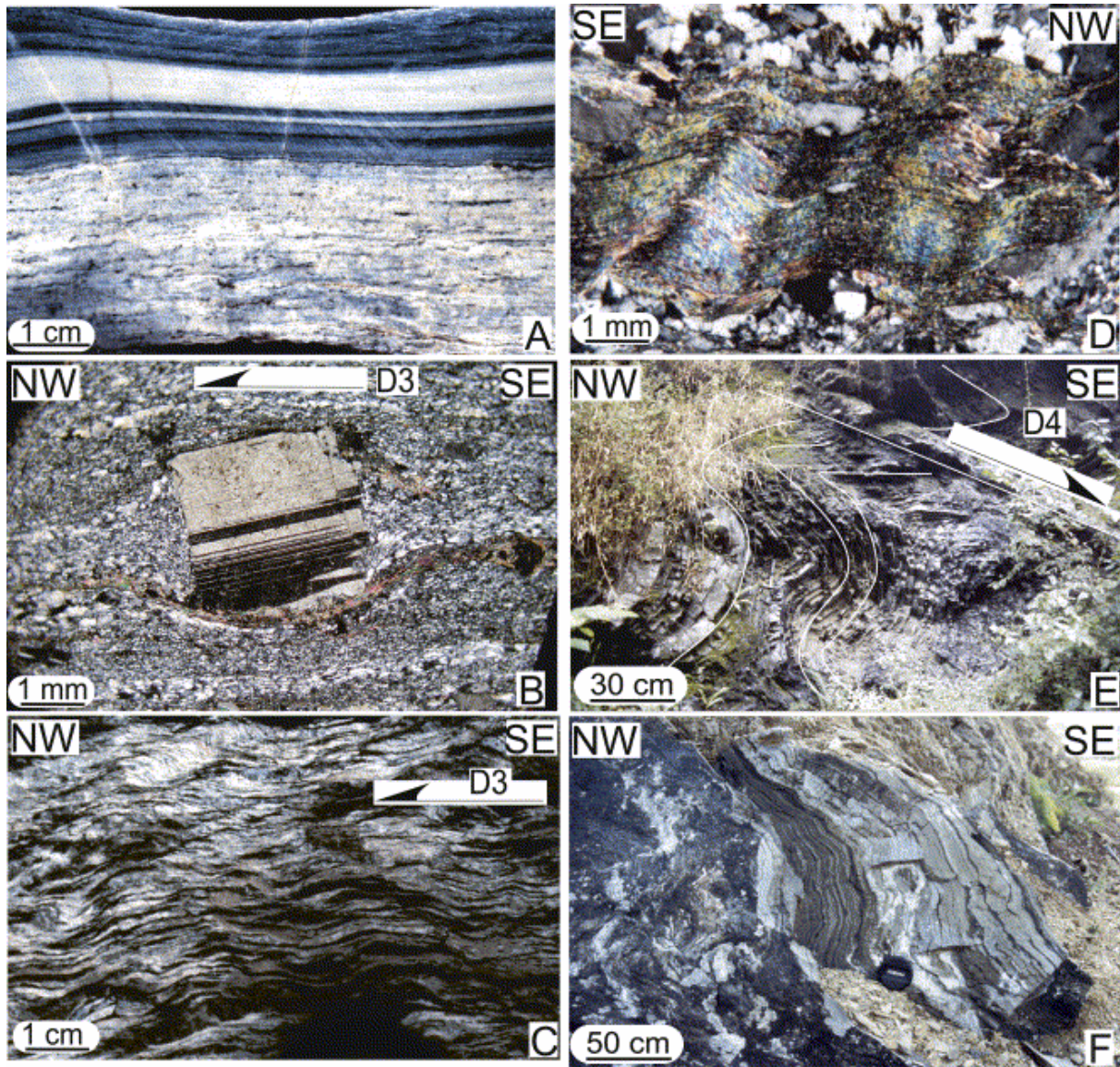


Fig. 7. (A) Ultramylonite in metavolcanic rocks of the Zhangbaling group (related with D3 deformation); (B) Quartz pressure shadows around plagioclase with a top-to-the-northwest shearing in metavolcanic rocks of the Zhangbaling group (D3 deformation); (C) Top-to-the-NW shear band in phyllite rock of the Zhangbaling group related to D3 deformation; (D) Oblique crenulation cleavage associated with asymmetric folds overturned to the NW related to the late increment of D3, (Zhangbaling group); (E) Meter-scale fold overturned to the southeast in Sinian pelitic limestone related to D4 deformation (Southeast of Zhangbaling massif); (F) Meter-scale fold overturned to the SE in thin-bedded Paleozoic (Cambrian) limestone (related to D4 deformation) (Location of the photos shown in Fig. 3).

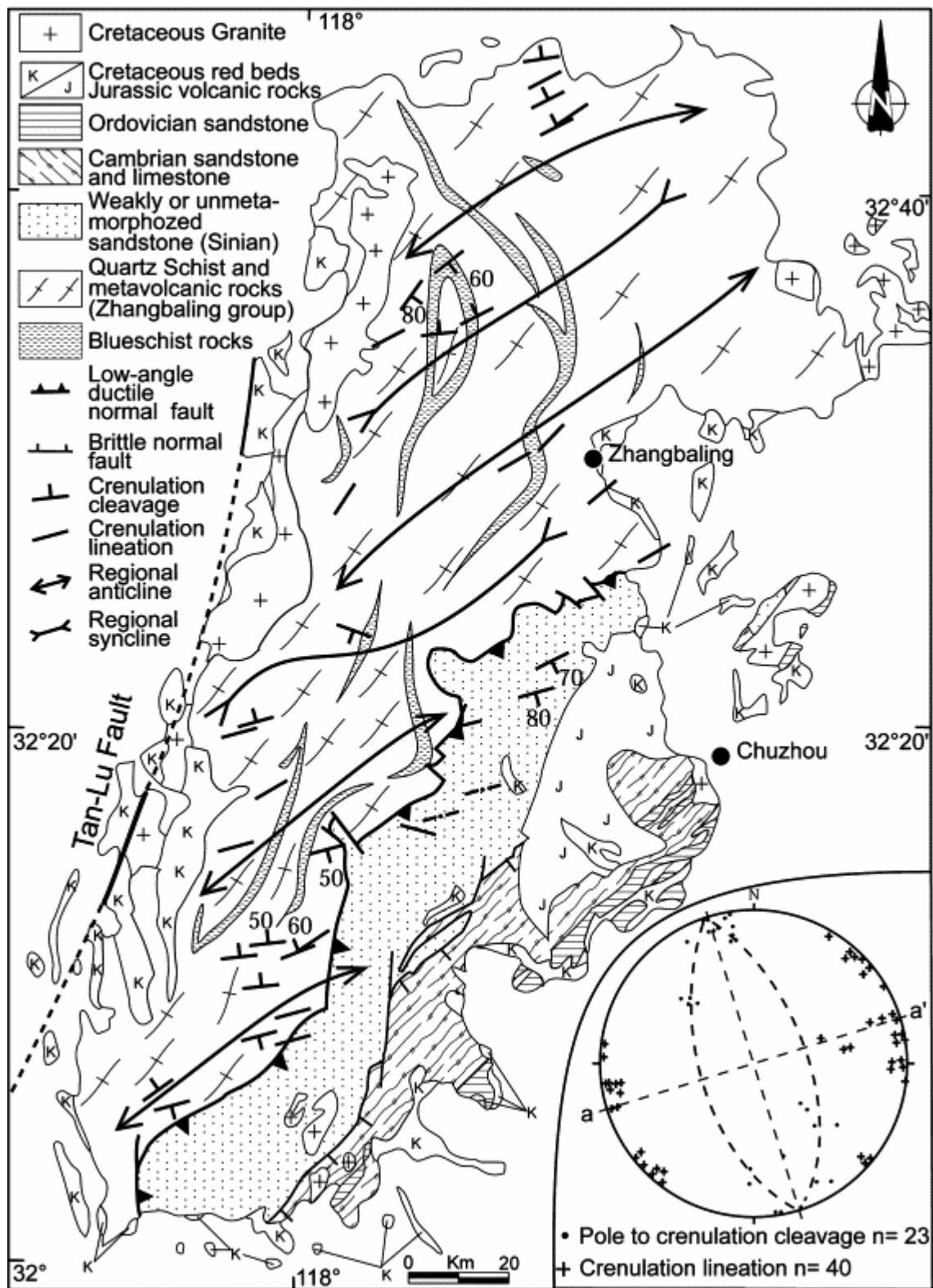


Fig. 8. Structural map and stereoplots of crenulation cleavage and crenulation lineation related to upright folds. In the stereogram, poles of the crenulation cleavage are displaced along two great circles with poles defining the axis of regional folds (a-a'). Note that the crenulation lineation plots near a-a'.

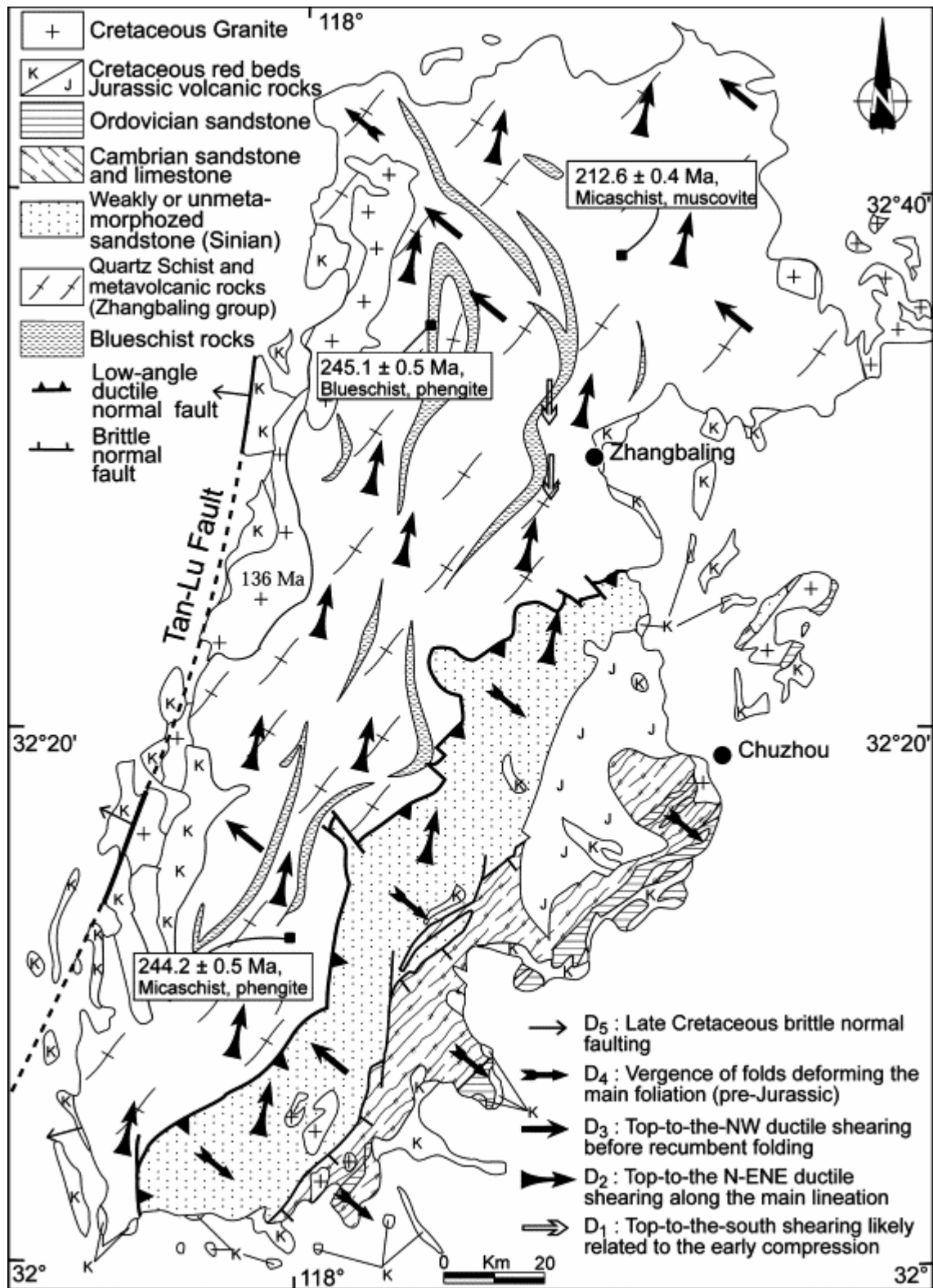


Fig. 9. Kinematic map for different tectonic events in the Zhangbaling area. Arrows point to the sense of shear of the upper layer over the lower layer. Available  $^{40}\text{Ar}/^{39}\text{Ar}$  dates on phengite and muscovite (see text for details).



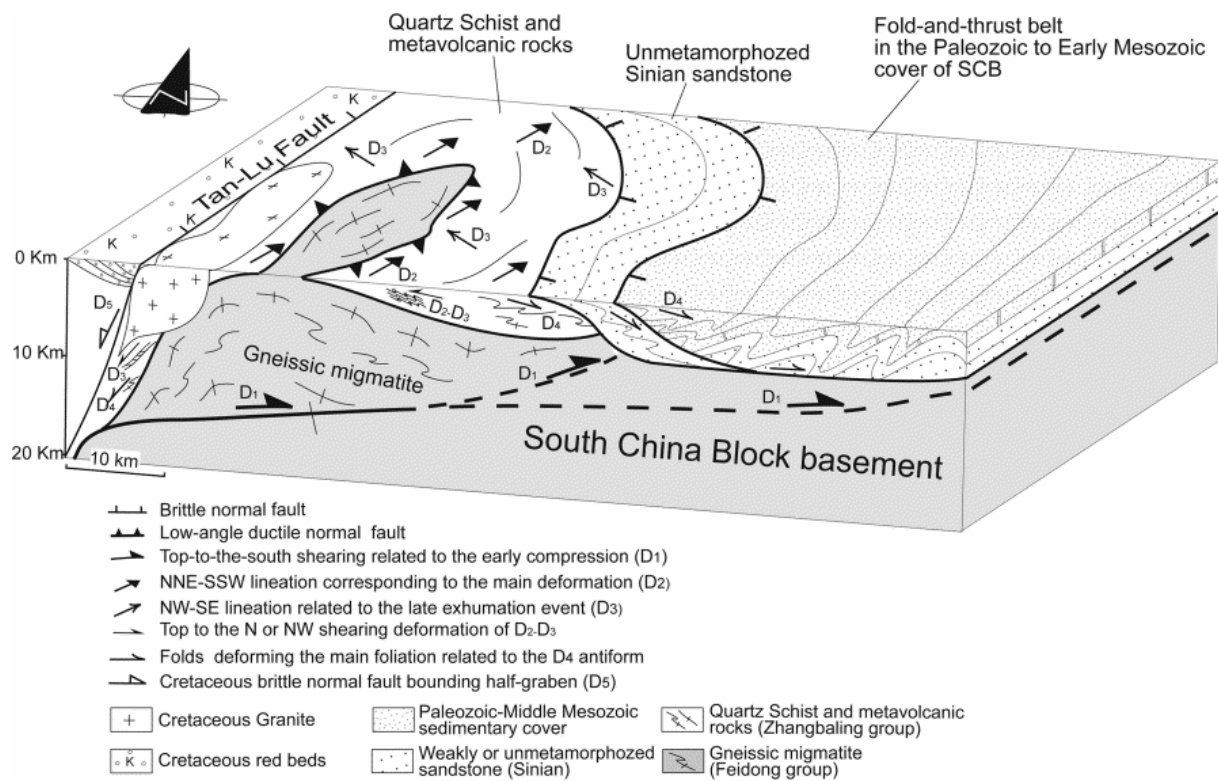


Fig. 10. Synthetic block diagram of the Feidong-Zhangbaling massif showing the bulk geometry and polyphase deformation.

## Tables

Table 1. Syn-optic table showing the characteristic features of the five deformation events recognized in the Feidong-Zhangbaling massif

Deformation event	Tectonic style	Trend of the linear structure	Kinematics	Coeval metamorphism	Age
D5	Brittle Extension	W or NW Down-dip slickenline	West side of the Tan-Lu fault moving downward	Absent	Late Cretaceous To early Eocene
<i>Late Triassic Unconformity</i>					
D4	Decollement Recumbent folding	NW–SE slickenline	NW and SE verging folds	Absent	Early Triassic
D3	Ductile extension	NW–SE mineral and stretching lineation	Top-to-the-Northwest	LP/LT Greenschist facies	
D2	Ductile extension	NNE–SSW mineral and stretching lineation	Top-to-the-North	LP/LT Greenschist facies	
D1	Ductile compression in the basement and recumbent folds in the cover	N–S mineral and Stretching lineation	Top-to-the-South	HP/LT Blueschist facies	Ca 245 Ma Late Permian–Early Triassic