Discovery of deep-level foreland thrust-fold structures in Taihang Mt. and its implication for early tectonic evolution of North China*

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Received July 16, 2004; revised Sepetember 3, 2004

Abstract Delineation and correlation of Dragon Spring Shear Zone with its deep-level structures at foreland have been studied by field work. This paper reports our new findings of thrust-fold structures within Taihang Neoarchean basement, which include flat thrusts, large-scale recumbent folds, subhorizontal foliation patterns, etc. It reveals that early tectonic evolution of North China clearly involves the horizontal contraction on a large scale, comparable to those of foreland of classical collisional orogenic belts. The vertical variation of structural patterns with foreland fold-thrust belt from shallow to deep levels has been documented for Taihang Mt. by structural correlation, which is associated with tectonic transposition and imbrication of basement complex with supracrustal sequences in the Neoarchean.

Keywords: recumbent fold, shear zone, crustal thickening, collisional tectonics, foreland, Neoarchean.

Archean plate tectonic processes involve spreading to subduction of oceanic basins, and final continental collision, etc. Hence, identification of ancient ophiolites, high-pressure granulites, and horizontal shortening tectonics is crucial for Precambrian geology[1—5]. Early Precambrian thrust tectonics have been documented from many cratons, including thrusting sheets, shear zones, and recumbent folds of large scale, which have been attested by the seismic reflection data with deep crustal level[6—8]. These researches conducted so far demonstrate that horizontal thrusting tectonics and crustal shortening are widespread in the continental basements. Thus, it is believed that plate tectonic regime began to operate in the Archean[9,10].

Precambrian tectonic evolution of North China has been investigated by many authors in the last decade, involving the genetic model of granite-greenstone belts, the tectonic setting of high-pressure granulites, timing and modeling for tectonic assembly among different blocks, etc.[3,11—16], which has greatly enhanced our understanding of its tectonic and geological evolution.

From consideration of regional geology, identification and documentation of crustal shortening tectonics may provide further and direct structural evidence and information on horizontal tectonic processes with North China Craton (NCC). The thrusting structures of Wutai-Taihang Mts., central part of NCC, are well exposed and eroded, revealing information for understanding the deep-level tectonics of early Precambrian[5,17—19]. This paper will focus on such topics.

1 Geological setting

The Taihang Mt. is situated in the foreland of Central Orogenic Belt (COB) across the North China, which separates the Western and Eastern Blocks[4,20]. It is a well-studied metamorphic terrain, consisting mainly of passive continental margin sedimentary sequences, granites and basement complex. The transition from Wutai to Taihang Mts. in the east, with topographic relief of more than 3000 meters, becomes ideal locations to document vertical variation of structural patterns of foreland fold and thrust belt from the shallow to deep levels. Moreover, the Dragon Spring Shear Zone (DSSZ), more than 100 km long, in the western part of Taihang Mt., represents one of the largest thrusting shear zones of North China[16,21,22]. However, whether DSSZ played an important role in the regional tectonic

* Supported by National Natural Science Foundation of China (Grant Nos. 40472097, 40172066 and 40242014)
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evolution in early Precambrian is unknown. It is also very important now to document its structural variation and kinematic history both along and across DSSZ. In addition, the tectonic correlation of DSSZ with its adjacent tectonic units may provide important constraint for the regional tectonic framework and geological evolution history of North China[23].

Based on field mapping and observation in the Taihang to Wutai Mts. area, evidence for crustal shortening and thickening has been revealed. The purpose of this paper is to report new discoveries of thrusting structures of deep level and updated understanding on basement tectonics of Taihang Mt. The large-scale thrust sheets, shear zones and many recumbent folds, identified at different elevation of Taihang Mt., are comparable with those of the typical collision tectonics[24]. So the research on the kinematics of foreland fold-thrust belt and its reworked basement will provide insights into collision tectonics in the early Precambrian times.

2 Regional and tectonic correlation of Dragon Spring Shear Zone(DSSZ)

The Dragon Spring Shear Zone(DSSZ) is dominated by augen gneiss and mylonite[16], and is located in the junction area between Wutai Mt. and Taihang Mt., outcropping for 4—8 km wide and about 100 km long, with elevation of about 1500 to 2000 m. It also represents one of the major tectonic discontinuities of COB at deep level. Because of higher topographic relief with DSSZ, early investigations have been mainly focused on its central section along highways, and no detailed work on its regional distribution, tectonic correlation and kinematics is conducted.

The hanging wall of DSSZ in the southeastern part of Wutai Mt. consists of Neoarchean diorite, TTG-granitic gneisses and Wutai greenstone belts. Both DSSZ and its hanging wall are onlapped by foreland basin sedimentary sequences (Douchun Group), and intruded by syntectonic granites (2.50 Ga)[14]. Its footwall consists mainly of Wanzi Group and Fuping complex. From its footwall toward the interior of DSSZ, complicated fold patterns are gradually transposed into flat and parallel foliation, accompanied by development of rootless folds, tectonic boudins, and finally, mylonitic gneiss and mylonite. Furthermore, DSSZ mainly shows flat west-dipping foliation with NW-plunging mineral elongation lineation. Asymmetric folds and feldspar porphyclasts indicate SW-directed tectonic transport with the main phase of shearing deformation (D1) of DSSZ[16].

Structural correlations among several geological sections indicate that DSSZ is actually a flat-dipping composite shear zone, which can be further subdivided into different structural domains with contrasting strain. High-strain subzones mainly consist of mylonite, mylonitic gneiss, augen gneiss and straight gneiss. Whereas, the weakly deformed domains preserve complicated fold patterns. With the increasing of the strain toward the centre of DSSZ, early folds are gradually transposed by the penetrative foliations, leading to the formation of rootless folds and asymmetric boudins (Fig. 3(a), (b)). Kinematic indicators (asymmetric folds, tectonic boudins and feldspar porphyroclasts) suggest southeast-directed thrusting along DSSZ. In addition, A-type folds of small- to medium scale (Fig. 3(b)), with shallow NW plunging axes, are also very common within DSSZ. The mylonitic gneiss and mylonite from DSSZ display NW plunging mineral elongation lineation (Fig. 3(c)). The structural measurement and statistics with structural fabrics suggest that at least two sets of mineral elongation lineation have been documented with DSSZ, including D1 flat NW-plunging lineation, and D2 lineation plunging SW (Fig. 2(a)).

Detailed observation has been carried out along the Changchengling-Longquanguan transect across DSSZ, and several late discrete steep-dipping high strain zones with meso-scale sheath folds, overprinted DSSZ, are identified (Fig. 3(d)). These sheath folds show characteristic closed fold patterns at outcrops, and their elongation is parallel to the plunging fold axis, with diameter of 2—3 m on cross-section. They occur within felsic mylonite, ultramylonite and intensely strained biotite schist, with SW flat-plunging mineral stretching lineation and fold axis. These sheath folds show closure toward top, indicative of northeast-directed dextral strike-slipping transport.

Along the northern extension of DSSZ, in Kouquan to Dachuan area, its exposed width becomes narrow, and numerous ultramafic structural lenses are distributed with intense shearing along their margin, which are interpreted to be oceanic crustal relicts[3,15]. Along the western part of DSSZ, quartzites and marbles of foreland basin sequences (Doucun Group) occur as dismembered recumbent folds of large size (Fig. 4(a), (b)), which are tectonically stacked by flat thrusts. These folds show northwest-

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shallow dipping axial planes. Because the width of shear zone turns to narrow with the increase of sedimentary components involved along strike to the north, it is suggested that more shallow level of DSSZ is exposed there. Furthermore, along the southern sector of DSSZ, DSSZ overturned to recumbent folds and tectonic slices of quartzite thrusted onto augen gneiss[17], which indicates intensely horizontal shortening with thrusting imbrication.

DSSZ characterized by sheared granitic to TTG gneiss tectonically reworked the supracrustal sequences distributed on its eastern side (Fig. 1). As a result, the complicated structural patterns with TTG complex and supracrustal sequences are uniformly transposed into flat parallel fabrics.

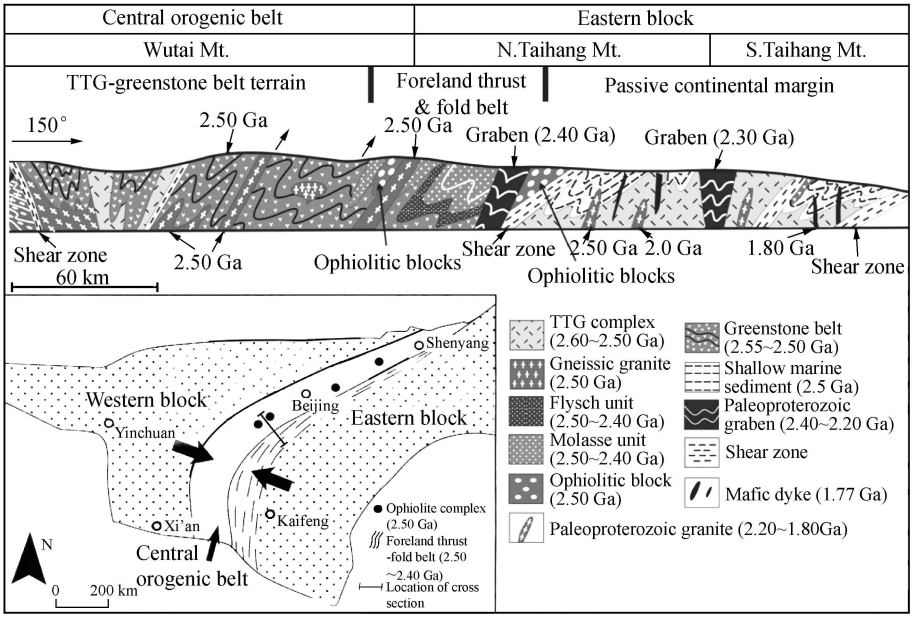


Fig. 1. Cross section of the Wutai-Taihang metamorphic terrains, inset showing tectonic division of NCC basement and location of the section.

3 Deep-level thrusting structures in Taihang Mt.

DSSZ represents an important tectonic boundary in the foreland area. Consequently, its correlation across foreland area may provide insight into the tectonic process of deep-level. The metamorphic terrain underlying DSSZ is significantly involved in relevant thrusting deformation. The recumbent folds, thrust and flat foliation pattern are widely developed there, associated with SE-directed thrusting deformation (D1). In the southern part of Fuping area, small- to medium- scale recumbent folds with E-W axes and flat foliation are very commonly outcropped. As their fold axes are parallel to mineral elongation lineation, they may be interpreted to be A-type folds (Fig. 4(c)), with presence of typical sheath folds[18,19]. At several localities, large-scale folds outlined by marbles have been recognized, up to tens of meters wide. Both fold axes and mineral lineation are subhorizontal, and kinematic indicators suggest tectonic thickening along the east to west section. In the Pingshan area, several large thrust sheets have been identified with supracrustal sequences characterized by the presence of marbles and calc-silicates. They are related to the structural imbrication between supracrustal sequence and crystalline basement complex, the thrust sheets clearly transpose the structures of underlying gneiss, with the formation of large-scale flat-ramp (Fig. 4(c)), up to several hundred meters wide. In addition, thrusting can result in the formation of subhorizontal foliation and pervasive interleaving, in contrast to the complicated fold patterns preserved in the weakly-deformed domains.

Nearly E-W-trending folds widely occurred in North Taihang Mt. area, as a fan-like array diverging to west. Further west near DSSZ, circular to closed fold interference patterns from outcrop to regional scale are distributed[25], which are traceable by marble or amphibolite marker layers. These folds are

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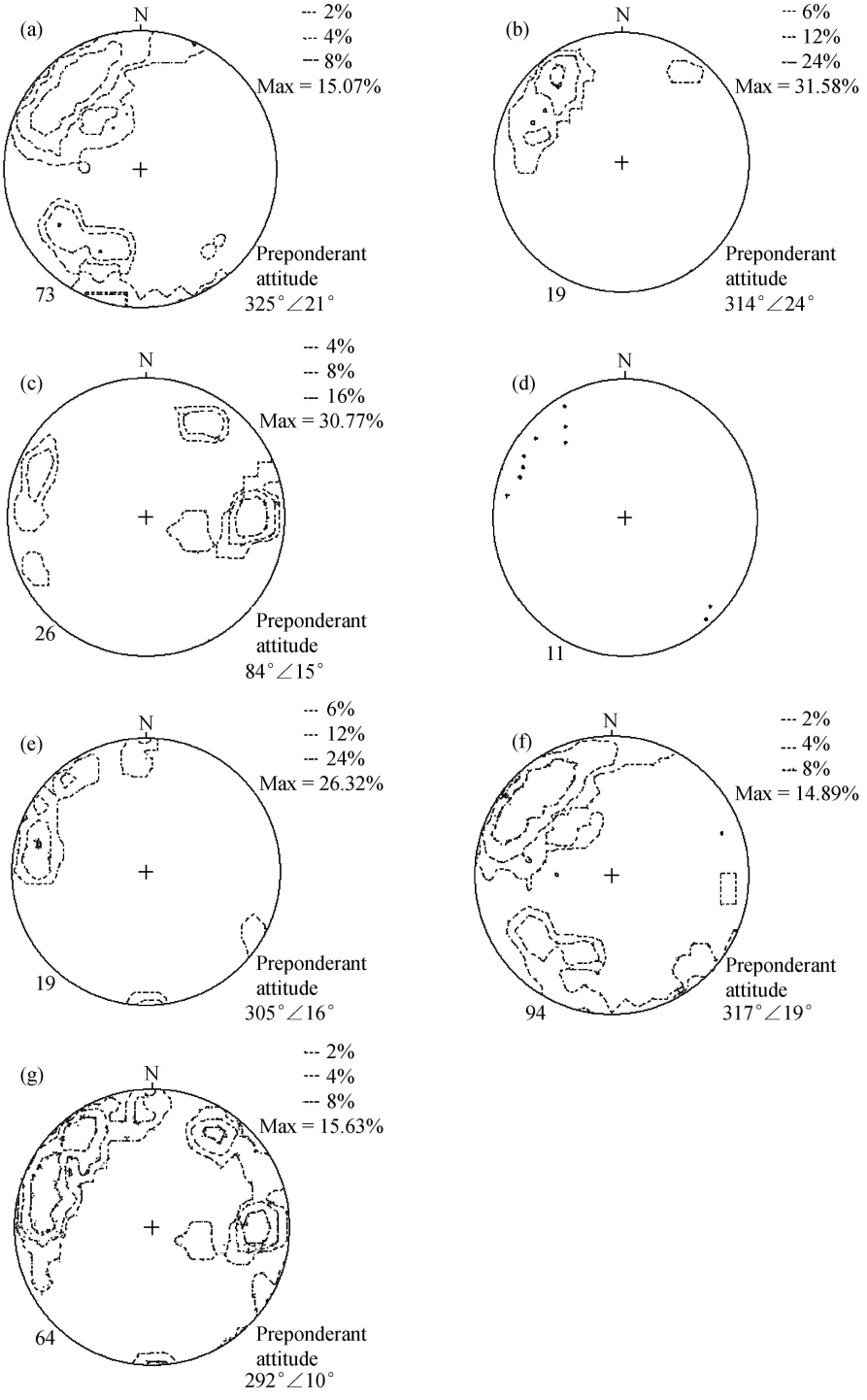


Fig. 2. Equal-area stereograph plots of structural fabric elements of Taihang metamorphic terrain. (a) Lineations of northern sector of DSSZ; (b) fold axes of northern sector of DSSZ; (c) fold axes of Xibaipo-Chengnanzhuang area; (d) lineations of South Taihang, Neiqiu-Yanghe area; (e) fold axes of South Taihang, Neiqiu-Yanghe area; (f) lineations of North Taihang; (g) fold axes of North Taihang.

dismembered and become branched with formation of structural noses, which implies increasing strain by transposing. To the west, these folds are gradually transposed into recumbent folds with flat west-dipping foliation through increasing intensity of shearing. Hence, the structural evidence can be explained by regional thrust-fold deformation in the foreland area[26].

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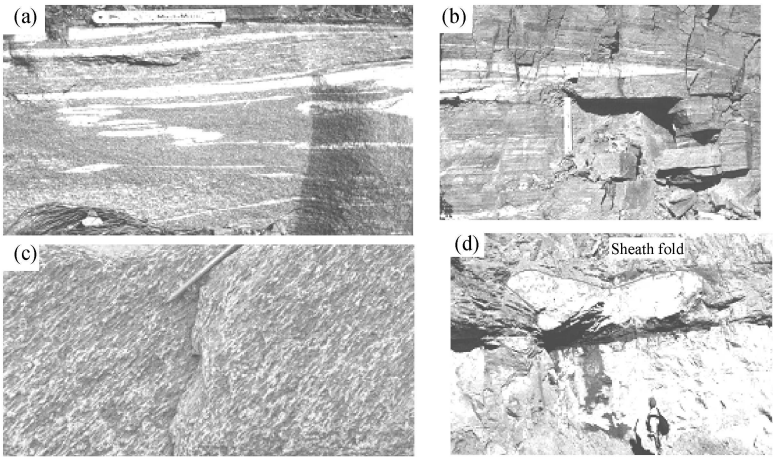


Fig. 3. Meso-scale structures within Dragon Spring shear zone (DSSZ). (a) Isoclinally folded felsic veins and boudins within mylonitic gneiss; (b) tight folds associated with felsic mylonite; (c) mylonitic gneiss showing shallow NW-plunging mineral elongation lineation; (d) large-scale sheath folds occurred with D2 high-strain zone, indicating NE-directed dextral shearing.

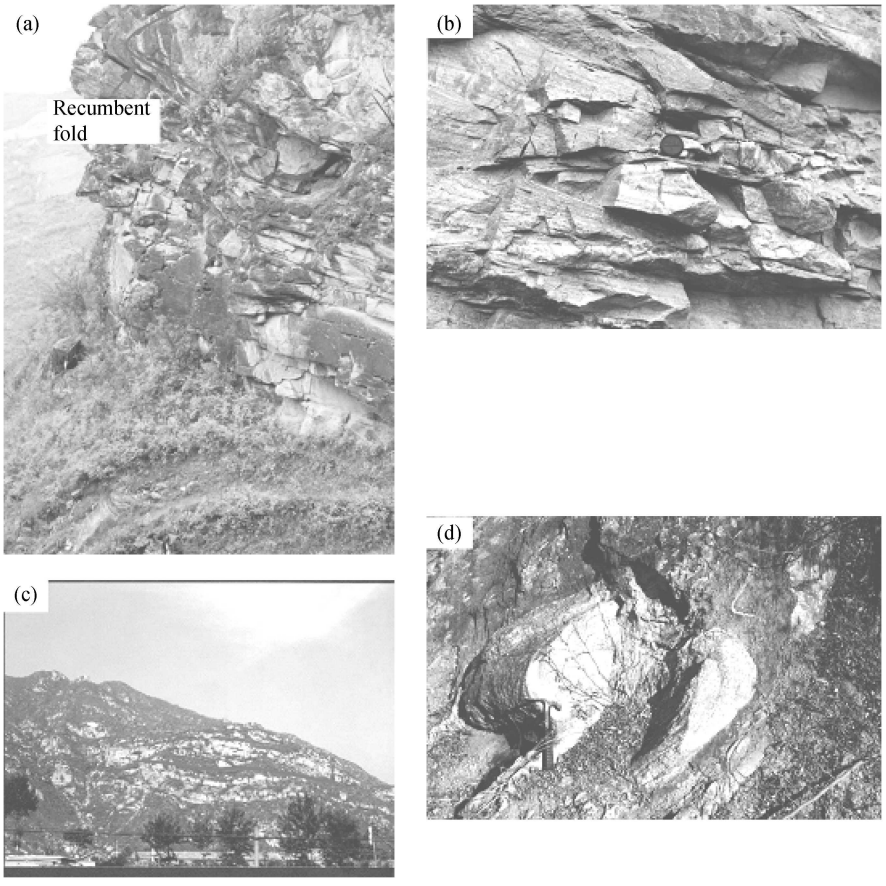


Fig. 4. Recumbent folds and thrusts in the complex of North Taihang Mt. (a), (b) Large-scale recumbent folds (as indicated by heavy line) within quartzite sequences of Doucun Group. Both the axial planes and fold axes dip NW, at Kouquan; (c) marble layers formed recumbent folds, with fold axes parallel to west-plunging mineral elongation lineation; (d) the flat-dipping shear zones resulted in interleaving of supracrustal sequences, with east-directed transport, at Xibaipo.

Similar large-scale folds and thrust sheets have been also very common in South Taihang Mt. In the western part of Beiqiu area, in the supracrustal sequences recumbent folds, nappe-style folds and refolded folds of various scales widely develope, and both fold axes and mineral elongation lineation show

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shallow NW plunges (Fig. 2(c), (d), Fig. 5(a), (b)). At some cliffs with high elevation, east-directed thrusts and recumbent folds tens of meters wide can be traced by marble layers (Fig. 5(c)), suggesting stratigraphic repetitions by intensely crustal shortening. Thrust sheets of supracrustal sequences are very common, with development of underlying shear zone with flat orientation (Fig. 5(d)). Moreover, many massive sulfide and epidote-amphibolite boudins hosted by mafic volcanics are tectonically emplaced onto marble sequences by eastward transport, with development of shallow west-dipping foliation and west-plunging mineral elongation lineation. It can be interpreted by the subhorizontal tectonic imbrication of supracrustal sequences in the foreland area.

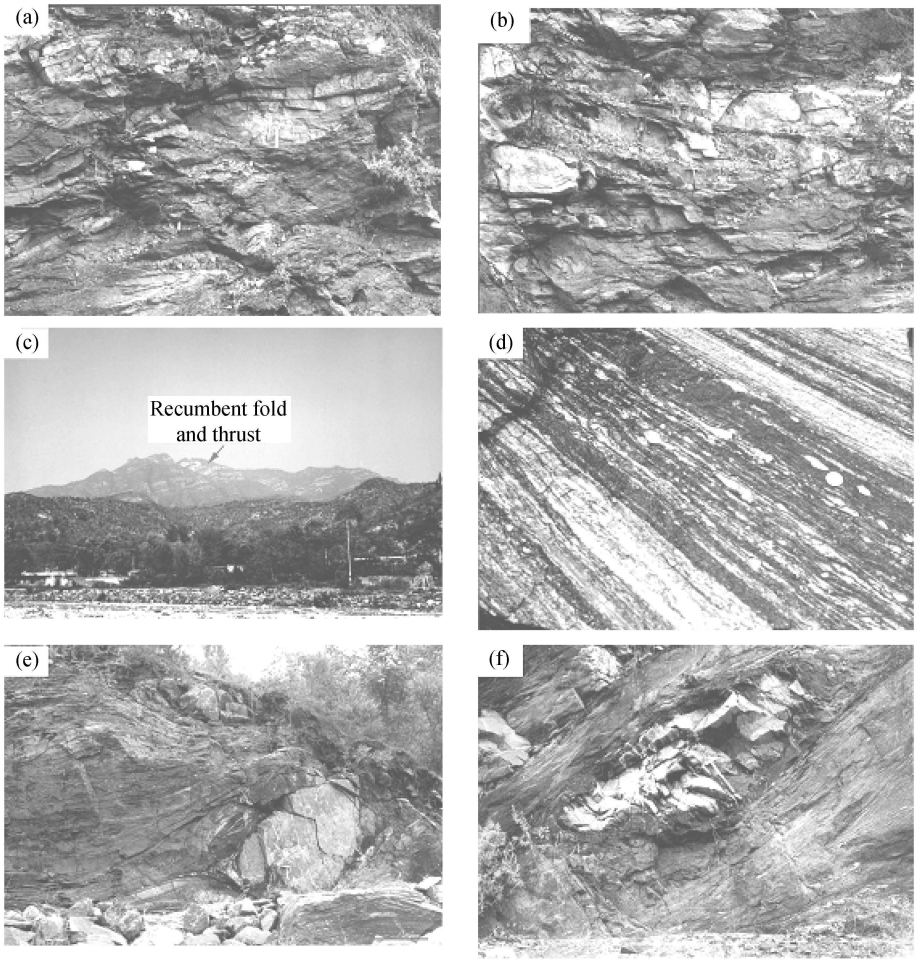


Fig. 5. Recumbent folds and thrusts in the Archean complex of South Taihang Mt. (a) Refolded recumbent folds outlined by marble, with flat NW-plunging axes, at Neiqiu; (b) vertical stacks of marble recumbent folds, with NW-plunging axes, at Neiqiu; (c) large asymmetric recumbent folds and thrusts outlined by marble layers on top of Mountain, indicating East-directed transport, southwest of Neiqiu; (d) strongly sheared augen gneiss and mylonite with TTG complex; (e) gneiss characterized with intense transposition, mafic boudins rotated with early foliation pattern preserved; (f) transposed boudins within gneiss, which preserved early foliation in their core parts, suggesting polyphase deformation.

The crystalline basement gneisses exposed in the area with low-elevation, South Taihang Mt., are characterized by the penetrative flat foliation, tectonic boudins of mafic and TTG rocks occurred within the completely transposed gneiss(Fig. 5(e)). Toward the interior of tectonic boudins, the early folds with complicated foliation pattern have been preserved, whereas they are intensely sheared along their margins (Fig. 5(f)). Mafic intrusions are widely sheared to form tectonic boudins surrounded by foliation. This is also a common structural pattern of intensely strained basement complex in the area. So, it is suggested that the thrusting is responsible for the regional crustal shortening.

From Wutai to Taihang Mt., a transition from

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shallow- to deep-level thrusting tectonics has been well exposed, which involves intense shearing and tectonic imbrication of different lithologies. From west to east, sub-greenschist-, greenschist- to upper amphibolite-facies, are distributed with increasing metamorphic grade and intrusions of syn-tectonic granites (2.50 Ga). Statistics on DSSZ's lineation suggest that the early mineral elongation lineation (D1) is subhorizontal and has a well-defined northwest trend (Fig. 2(f)), which attributes to the SE-directed thrusting. Thrusting deformation reworked rock units of a large area of Taihang Mt. D2 lineation plunges SE, associated with D2 folding and subsequent strike-lip shearing. The statistics of fold axes show three preferred orientations (Fig. 2(g)), i.e. shallow NW-, east-, and NNE (or SSW) ones, respectively. Shallow east-plunging folds are distributed mainly in the Fuping to Pingshan areas, central sector of Taihang Mt, which result from D1 folding with Fuping complex. Moreover, folds with shallow northwest-plunging axes are very common across the whole Taihang Mt. area. They are of mesoscopic to small-sizes, closely related to the regional thrusting deformation. Whereas, nearly north-south trending folds are formed by subsequent D2 deformation.

In summary, tectonic patterns of different lithologies can be suggested here by structural analysis. The thrusting deformation with supracrustal sequences mainly produced various fold types, such as recumbent fold, refolded fold, A-type fold, and non-cylindrical to sheath folds. In contrast, the reworking with crystalline basement is characterized by the foliation transposition and development of shallow-dipping shear zones. The comparable structural styles have been extensively documented in many other high-grade metamorphic terrains of North China, such as northwestern Hebei, Hengshan, and eastern Hebei[18,27,28]. Through correlations among them, it is possible to constrain the deformation mechanism of deep crustal level.

4 The age constraint for deep-level thrusting deformation of Taihang metamorphic terrain

The timing of deformation events associated with DSSZ and relevant thrusting structures can be constrained from a lot of geological evidence and age datings. Both in the northern and southern Taihang Mt., the metamorphic basements are unconformably overlain by the unmetamorposed cover, such as Changcheng System (<1.85 Ga, deposited in continental graben). Thrust sheets and recumbent folds are widely cut by the unmetamorphic NW-trending mafic dyke swarms, which yield a U-Pb zircon age of 1769 ± 2.5 Ma, and an Ar-Ar age of 1800 Ma[4,28—31]. Pegmatite veins commonly distributed in the working area are dated to be 1782 ± 4 Ma by SHRIMP method[14]. So, the upper limit of regional thrusting deformation must be older than ca. 1.80 Ga. Moreover, the Taihang metamorphic terrain is also unconformably overlain by the Paleoproterozoic sequences, such as Gantaohe Group (ca. 2.30 Ga) deposited in graben settings[25], which suggests that the thrusting deformation may be of Neoarchean age. Regionally, it can be seen that Dongye Group (2.40—1.90 Ga) onlaps overlying the DSSZ and its hanging wall[16,17,27,32]. Thus, the geological relationships discussed above suggest that DSSZ and the relevant fold and thrust belt formed in Neoarchean.

The western part of DSSZ is widely reprinted by late low-temperature strike-slip shear zones (with Ar-Ar isochron ages of 1952 Ma)[22]. Moreover, the Lanzishan granite emplaced within the hanging wall of DSSZ yields U-Pb ages of zircon, 2537 ± 10 Ma, 2553 ± 8 Ma, and zircon xenolith crystal age of 2702 ± 14 Ma[14]. Field observation suggests that Lanzishan granite displays a zonation of composite intrusion, and its eastern margin is characterized by mylonitic granite with pervasive fabric, and transitional to DSSZ. Toward DSSZ in the east, numerous granitic sheets of small scale can be recognized, associated with syntectonic emplacement. Augen gneisses from DSSZ have been dated at 2540 ± 18 Ma, 2543 ± 7 Ma, and 2541 ± 4 Ma, by zircon U-Pb method (SHRIMP), interpreted to be emplacement age of granitoids[33]. They are essentially coeval with that of the Lanzishan granite. Augen gneisses that closely merge with the anastomosing mylonite zones are generated under high-temperature condition (upper amphibolite-facies) as indicated by their metamorphic assemblages[16]. Consequently, it suggests here that the intrusions of anatectic granite are generated by and closely associated with shearing. From the datings of these granites, it can be inferred that the main deformation phase of DSSZ occurred at circa 2.54 Ga.

The foreland basin sediments overlapped DSSZ and Wutai greenstone belt. The tuffes from foreland flysch sequences (Gaofan Group) yields a U-Pb zircon age (SHRIMP) 2528 ± 6 Ma[14], which also supports

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that the main phase of deformation (D1) took place at the end of Neoarchean.

Although extensive geochronologic studies reveal that both 2.50 Ga and 1.80 Ga tectonothermal episodes are crucial to understanding of the early tectonic evolution of NCC[5,14,28,30,34,35], it has been argued whether they belong to a single tectonic cycle or represent separate tectonothermal episodes, which owes much to the lack of understanding of the regional geology and tectonics[36]. As indicated by structural analysis and geological mapping[20,28,34,35], the working area underwent polyphase deformations ca.2.50—1.80 Ga, associated with several different tectonothermal episodes. The tectonic episode ca.2.50 Ga was closely related to subduction to collision processes along COB, including emplacement of granite from different settings (ca.2.50 Ga), the thrusting along DSSZ and subsequent development of a foreland basin. At ca. 2.40—2.0 Ga, it was dominated by extensional regime, followed by the emplacement of mafic intrusions, and the deposition of volcano-sedimentary sequences (Gantaohe and Dongye Groups) in the continental rifts. At ca.1.95—1.85 Ga, the working area underwent extensive reworking (strike-slip shearing and emplacement of granites), related to accretional orogeny along the northern margin of NCC[20], and finally deposited Guojiazhai molasses (1.9 Ga) in the Wutai Mt. At ca.1.80 Ga the whole North China craton widely underwent extension and breakup, with development sedimentary cover in the aulacogen-rift systems, onset of uplifting and retrograde metamorphism of basement, and emplacement of mafic dyke swarms (ca.1.77—1.80 Ga)[31].

5 Discussion and conclusions: structural style of deep crustal level and its implication for early Precambrian collisional tectonics

As the topographic elevation of Taihang Mt. rapidly decreased from west to east, deformed units of deep level were well exposed to the east. Based on observation of structural patterns along several east to west-trending sections across Taihang Mt., it is now possible to postulate an overall variation of structural styles from middle to deep crustal levels of foreland area. By synthesizing the structural data from the working area, a general model for thrusting structures from shallow to deep level can be postulated here (Fig.6), and five deformation domains can be vertically divided.

(1) In the greenstone belts and overlying molasses in the eastern part of Wutai Mt. the tight to closed folds and brittle thrust faults mainly develop. (2) Foreland basin sequences are characterized by the development of recumbent folds, outlined by quartzite beds, and accompanied with tectonic emplacement of numerous mafic to ultramafic boudins. (3) DSSZ mainly involves ductile shearing of granitic to TTG gneiss, and syntectonic emplacement of anatectic granites, both of which thrusted over and reworked Wanzi Group. (4) In Wanzi Group recumbent folds, refolded folds and thrust sheets develop by tectonic interleaving with gneiss complex. Many folds belong to A-type folds with NW-dipping axial planes. (5) The basement complex of Taihang is characterized by the formation of flat-lying foliation, rotation and shearing of mafic to TTG boudins through tectonic interleaving and transposition at deep level.

DSSZ and related thrust structures can be traced across a large area of Taihang foreland, which proves that DSSZ played an important role in the regional tectonic framework and deformation of deep crustal level. The horizontal tectonic stacking caused by DSSZ at ca. 2.50 Ga can result in a significant crustal shortening and thickening, in connection with collisional processes along COB. Furthermore, occurrences of Neoarchean ophiolitic complex from Wutai Mt., Taihang Mt., eastern Hebei and western Liaoning[3,4,20,37] also support explanation of accretion to collision orogeny at 2.50 Ga. Hence, the tectonic style of Archean crustal deformation in Taihang Mt. may provide important information on how ancient plate collision worked from its foreland deformation.

Finally, the large-scale recumbent folds and widespread foliation transposing are clearly associated with the detachments between supracrustal sequences and underlying complex. It is suggested that the development of thrust sheets and related folds are probably controlled by ramp-flat structures. Therefore, the horizontal structural imbrication and tectonic transport may provide evidence for operation of plate tectonics in the Archean period.

In contrast with the Wutai greenstone belt characterized by composite folds and thrusts, the Taihang high-grade terrain is dominated by subhorizontal shear zones and dome-like structures of deeper level. The tectonic style of Taihang Mt. is also very com-

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mon to other metamorphic terrains worldwide[28]. For example, the subhorizontal shear zones have been also proved in the Abitibi greenstone belt of Superior by geophysical exploration[6]. As flat structural patterns are closely associated with anatexis of deep level, it is believed that the thermally induced anisotropy may be favorable to the regional subhorizontal translations and ductile deformation. In addition, lithological contrast is also very important to the development of thrusting structures, as they are commonly outlined by layering structures of supracrustal sequences or sheet-like intrusions from middle to deep levels.

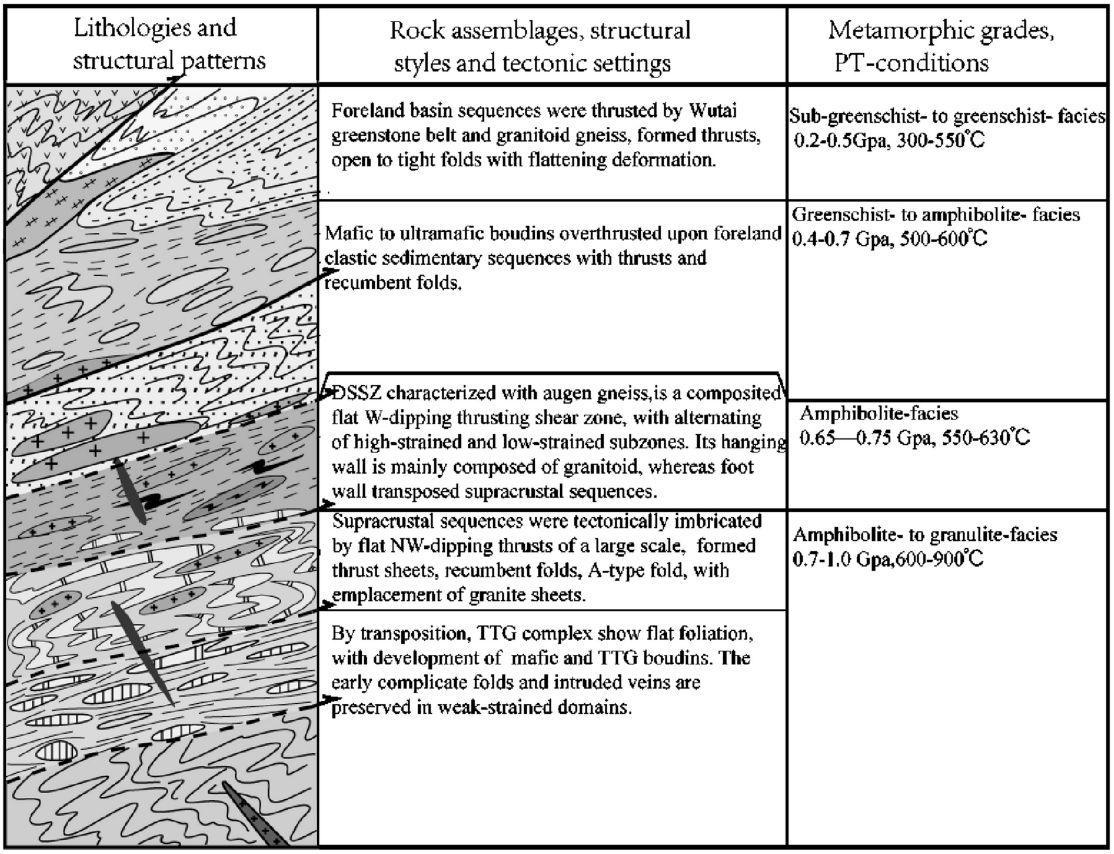


Fig. 6. Schematic diagram of vertical variation of structural patterns with Taihang foreland based on field observation (P-T conditions and metamorphic grades are cited from references [12, 13, 16, 27, 30]).

Acknowledgements The authors would like to thank Professors Tian Yongqing, Wang Kaiyi, Zhai Mingguo, Guo Jinghui, Liu Shuwen, A. Kroner, and S. Wilde, and those who participated in the field work during the last decade for their help to this paper.

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万方数据

万方数据 WANFANG DATA 文献链接

Discovery of deep-level foreland thrust-fold structures in Taihang Mt. and its implication for early tectonic evolution of North China

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刊名： 自然科学进展（英文版） SCI

英文刊名： PROGRESS IN NATURAL SCIENCE

年，卷(期)： 2005,15(3)

被引用次数： 3次

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