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Is the Jurassic (Yanshanian) intraplate tectonics of North China due to westward indentation of the North China Block?

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ABSTRACT The northern mountains of Beijing are the type locality of the Mesozoic Yanshanian orogen. Our structural study emphasizes the importance of dextral strike-slip for the formation of this intracontinental belt. The South- and North-directed thrusts are positive flower structures rooted in strike-slip faults. This transpressional tectonics developed from Late Triassic to Late Jurassic-Early Cretaceous through three deformation phases coeval with syntectonic sedimentation, separated by two transtensional episodes coeval with magmatism. The Late Jurassic–Early Cretaceous tectonic event is also recognized in several places of North China. Strike-slip faulting controls the deformation of the northern border of the North China block in the Yanshan-Yinshan belt. Simultaneously, East-directed thrusts and folds develop along N-S elongated ranges in Helanshan, Shanxi highlands and Taihangshan. The Jurassic tectonics of the North China Block is interpreted in a unitary way as the result of the westward underthrusting of the North China block below the Alashan block.

Introduction

The mechanisms of intracontinental orogeny have long been discussed, since intraplate mountain belts cannot be ascribed to the plate margin interaction paradigm that assumes that the interior of a continent is rigid and hard to deform. It is well accepted that the deformation of the continental crust can be a far-field consequence of subduction or collision, as exemplified by

the North American Laramide belt or Indian collision (e.g. Avouac et al, 1993; English and Johnston, 2004).

From studies in the Yanshan range north of Beijing, Wong (1927) defined the Mesozoic “Yanshanian movement”. Subsequently, the term “Yanshanian” was used to account for the Mesozoic deformations in the entire China (e.g. Wong, 1929; Huang, 1978, Yang et al., 1986). Since nearly 80 years, “Yanshanian” depicts the Jurassic-Cretaceous time interval, rather than a specific tectonic event developed in the North China Block (NCB). This loose use led to confusion since contemporaneous events are not necessarily related to the same geodynamic cause.

The Yanshanian movement corresponded initially to a set of Jurassic-Cretaceous tectonic phases (Wong, 1929). It is now acknowledged that a major break took place in early Cretaceous (ca 136 Ma). Since this time, the NCB experienced a widespread NW-SE extension recorded by brittle and ductile normal faults, synsedimentary half grabens filled by continental red beds, and synkinematic plutons (e.g. Zheng et al., 1988; Davis et al., 1996; 2002; Meng, 2003; Liu et al., 2005; Lin and Wang, 2006, Lin et al., 2007, 2008; Charles et al., 2010). Although the timing and modalities of extension are well acknowledged in East Asia, the geodynamic mechanisms are still disputed. Post-orogenic collapse, roll-back of the subducting Palaeopacific slab, mantle lithosphere foundering or delamination due to asthenospheric convection are the most invoked processes (see Lin and Wang, 2006 for a discussion of these models). The pre-136 Ma tectonics, or Yanshanian tectonics *stricto sensu*, remains poorly understood. Most of authors acknowledge an intracontinental evolution accommodated by N-S contraction (e.g. Zhao, 1990; Zheng et al., 1998; He et al., 1999; Davis et al., 2001; Hu et al., 2010). However, the architecture, kinematics, timing, and geodynamics of the Yanshan orogeny are not well explained yet. This paper presents the architecture of the Yanshan range northeast of Beijing (Figs. 1, 2). The analysis of Jurassic deformations in other areas of the NCB allows us to propose a new tectonic interpretation of the Yanshan orogeny driven by westward indentation of the NCB below the Alashan block.

Polyphase Tectonics of the Yanshan area

The Yanshan range that develops NE of Beijing is a part of the 1000 km long, E-W striking, Yanshan-Yinshan belt. Numerous geological studies provide a general lithostratigraphic and tectonic outline of the Yanshan area. The Archean basement shaped up by a Paleoproterozoic orogeny (HBGMR, 1989; Kusky and Li, 2003; Kusky et al., 2007; Zhao et al., 2005; Faure et al., 2007; Trap et al., 2007; in press) was overlain by a thick Meso to Neoproterozoic sedimentary cover of terrigenous and carbonates rocks. The Cambrian-Ordovician platform carbonate rocks were partly eroded during the Devonian emersion (Wang et al., 2010). Since the Late Palaeozoic, continental deposits are dominant. The Triassic, Jurassic, and Cretaceous formations consist of sandstone, siltstone and conglomerate. This detrital sedimentation, represented by chaotic deposits with disrupted and slumped layers, and olistoliths, argues for a syn-tectonic setting. Due to the scarcity of fossils, the stratigraphic record is imprecise, but radiometric dating of interbedded lava flows provides some time constraints. The Zhangjiakou and Tiaojishan formations are now dated at 133 ± 3 Ma, and 156 ± 3 Ma, respectively (Liu et al., 2006, Fig. 3).

The Palaeoproterozoic Fengning-Longhua fault, which is the northern boundary of the Yanshan belt is reworked as a brittle dextral fault along which Mesoproterozoic rocks are placed to vertical (Fig. 4A). In the study area, the main Yanshanian deformations are concentrated between Chengde and Banbishan (Fig. 1). Along a North-South profile, the Chengdeshi, Pingquan-Gubeikou, Gubeikou, Xinglong, and Banbishan thrusts are the most important structures, but several second order faults are also mapped (HBGMR, 1989; Zhao 1990, Chen, 1998; Davis et al., 1998, 2001; Fig. 1).

The section from Chengdeshi to Kuancheng is analyzed below as an example of the architecture of the Yanshan belt (Fig. 2A). A “Chengde thrust” has been proposed as a large allochthonous nappe displaced from South to North for more than 40km, and rooted in the Xinglong thrust (Davis et al., 1998, 2001). This interpretation is disputed (He and Niu, 2004;

Liu et al., 2007). Our observations also do not support the view of a large overthrust, as in the footwall of the inferred nappe neither the Proterozoic sandstone nor the Jurassic volcanic and sedimentary rocks are deformed. For instance, sedimentary features are perfectly preserved in the Proterozoic sandstone (Fig. 5A). Furthermore, the geological map (HBGMR, 1989), and our field survey shows that Archean metamorphic rocks would belong to this speculated nappe. Such a structure is unlikely for a thin-skinned allochthon. A north-directed high-angle fault, called here Chengdeshi thrust (in order to avoid confusion), is a more realistic geometry than a large thin-skinned nappe. The Chengdeshi high-angle thrust is reworked by a Cretaceous normal fault that controls the sedimentation in the Chengde basin.

South of Chengde, Late Triassic sandstone and siltstone are folded and cleaved along the South-directed Pingquan-Gubeikou thrust (Zhao, 1990, Davis et al., 2001; Fig. 6D). In the thrust footwall, Palaeozoic rocks are deformed in a brittle way. Open folds, tension gashes and cracks are widespread, and still indicate a southward displacement. To the South, the brittle, high-angle Gubeikou thrust superposes Neoproterozoic rocks above Late Jurassic red beds (Fig. 4B). Lastly, SE of Kuancheng, a series of SE-directed thrusts merge into a single dextral strike-slip fault exposed between Xinglong and Banbishan (Fig. 1). The Banbishan thrust (Chen, 1998) appears as a combination of thrusting and folding, corresponding to a positive flower structure (Zhang et al., 2001; Fig. 7A, B, C). Between Banbishan and Kuancheng, km-scale, SE-verging recumbent folds are well developed (Fig. 5B, C). The SE-vergent folds exhibit an axial planar slaty cleavage (Fig. 6C). A western cross-section (Fig. 2B) shows the extension of the Gubeikou thrust, and documents the north-directed Xinglong thrust (Chen, 1998) that becomes vertical southward, and roots into a dextral strike-slip fault (Zhang et al., 1998; Fig. 8C).

The deep domain of the Yanshan belt is exposed to the west of the study area (Fig. 1). Due to the SE displacement along the Shuiyu extensional shear zone, the footwall exposes Mesozoic granitoids and metamorphic rocks. The S-directed Shihetang thrust involves the synkinematic Yunmengshan granodiorite (Davis et al., 1996; Wang et al., 2011; Figs. 2C; 7D).

To the north, a vertical fault separates the Archean basement from a Jurassic continental basin. Along the fault, drag-folds, with subvertical axes, and asymmetric lenses indicate a dextral strike-slip movement (Figs. 6A, B; 8A).

In summary, the structure of the Yanshan belt is characterized by a network of moderate to high-angle thrusts connected with dextral strike-slip faults. Although rarely recognized in the previous works (Zhang et al., 1998; 2001), fault planes with subhorizontal striae, sigmoidal lenses, and drag folds with vertical axes are widespread. Conversely to a classical fold-and-thrust belt, in the Yanshan area, the thrusts are not organized with a clear polarity as both north and south directed thrusts are recognized. The importance of belt-parallel strike-slip faults has been underestimated in the previous structural studies (Zhang et al., 2001).

Time Constraints

Five tectonic, magmatic and sedimentary events (D_0 to D_4 , Fig. 3) are recognized in the Yanshan area. The peraluminous Dushan granite, emplaced at 223 ± 2 Ma (Luo et al., 2003), results of a post-orogenic crustal melting. Thus a Middle Triassic D_0 event is inferred but its tectonic setting is not understood yet. Late Triassic South-verging folds along the Pingquan-Gubeikou thrust document a D_1 event (Zhao, 1990; Davis et al., 2001). The Triassic clastic rocks are syntectonic deposits supplied by a rising and eroding relief located to the north. The D_1 structures are unconformably covered by Early Jurassic (196-184 Ma) conglomerate, sandstone, basalt and andesitic volcanic rocks (HBGMR, 1989) that represent the post- D_1 molasse. Several granitic intrusions dated at ca. 175-172 Ma (Luo et al., 2001) post-date the D_1 event that occurred in Late Triassic.

The D_2 event is characterized by the N-NW directed Chengdeshi and Xinglong thrusts. The 165-155 Ma volcanic and terrigenous rocks (Tiaojishan formation) that unconformably cover these north-directed thrusts represent the D_2 molasse. Several dioritic and granodioritic plutons, emplaced at ca 160-150 Ma, post-date the D_2 event.

The D₃ event is the most developed one. South of Chengde, the Gubeikou and Banbishan strike-slip-thrust systems formed in superficial conditions. To the east, NW of Miyun, top-to-the south ductile shearing is developed in metamorphosed country rocks. The D₃ Shihetang shear zone is dated at 143±3 Ma by the syntectonic Yunmengshan granodiorite (Davis et al., 1996, Wang et al., 2011).

After 136 Ma, in late Early Cretaceous, the syntectonic deposition of the terrigenous Zhangjiakou formation in half grabens, such as the Luanping or Chengde basins, represents the D₄ event. The D₄ ductile and brittle normal faults developed in an area wider than the Yanshan belt, as Mongolia, S. Siberia, and South China are also involved (e.g. Meng, 2003; Donskaya et al., 2008, Lin et al., 2008; Daoudene et al., 2009). The D₄ extensional tectonics is not a direct consequence of the Jurassic Yanshan orogeny. Conversely, the D₁, D₂, and D₃ events described here are representative tectonic phases for the evolution of the Yanshan orogeny. Among these events, D₃ is the most widespread one, responsible for the main structures of the Yanshan belt.

Jurassic Tectonics in the North China Block

Mesozoic deformations distribute in narrow belts around or within the NCB (Fig. 9). In the *Yinshan area*, N-NW directed Middle and Late Jurassic thrusts with an estimated displacement of ca 30km are exposed in the Daqingshan (Zheng et al., 1998; Darby et al., 2001; Darby and Ritts, 2007). To the West of Baotou, along the southern margin of the Yinshan belt, S-directed Late Jurassic high-angle thrusts are recognized (Liu et al., 2004). The Daqingshan and S. Yinshan nappes can be correlated to the D₂ and D₃ events, respectively. An early Jurassic synsedimentary extension (Ritts et al., 2001) predates the D₂ event. In *Western Ordos*, km-scale Late Jurassic East-directed imbricated thrusts and folds are exposed in the Helanshan and surrounding ranges (Teilhard de Chardin and Licent, 1924; Wong, 1929; Zheng et al., 1998; Liu et al., 2000; Darby and Ritts, 2002; Zhang et al., 2007; Fig. 4C). A decollement layer separates the folded and thrustured Palaeozoic series from the underlying Ordos basement (Zhang et al., 2007). The N-S trending *Shanxi highlands* and *Taihangshan ranges* that bound the Ordos

basin from the North China Plain are characterized by thin-skin tectonics. The Late Jurassic East-directed thrusting and folding is accommodated at depth by a decollement layer (Zhang et al., 2008).

The *Qinling-Dabie belt* represents the southern margin of the NCB. In the northern side of the chain, NE-SW striking folds deform the Palaeozoic rocks, and locally metamorphic rocks overthrust to the North the Middle Jurassic formations (Zhang et al., 2008). This structure complies with a Late Jurassic NW-SE shortening. The age of this deformation is not settled yet as the thrusting occurred in upper crustal level, and most of the Mesozoic formations are buried beneath the Cenozoic deposits. Along the *Tan-Lu fault* (TLF), hornblende and phengite $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 198-181 Ma, 162-155 Ma, 143-139 Ma (Zhu et al., 2005, 2009; Wang, 2006) argue for several thermal episodes close in time to the D₁, D₂, and D₃ events, respectively. Strike-slip faulting was completed before Late Triassic (Zhu et al., 2009). During the Jurassic extensional and compressional phases are recognized in the Hefei basin (Zhao et al., 2000). A Jurassic N150E maximum principal stress (σ_1) direction has been computed from fault analysis (Vergely et al., 2007; Mercier et al., 2007). This NW-SE shortening is similar to the one inferred from dextral faulting in the Yanshan area. East of the TLF, in Shandong peninsula, a NW-SE stretching, coeval with the emplacement of the Late Jurassic Linglong pluton dated at 160-150 Ma (Charles et al., 2010), supports an extensional regime for the TLF before the D₃ event.

Discussion and Conclusion

In the Yanshan-Yinshan belt, northwestward or southeastward thrusts are rooted into E-W striking dextral strike-slip faults. These thrust sheets can be interpreted as positive flower structures resulting of several transpressional phases (D₁, D₂, D₃) separated by transtensional episodes during which sedimentation and volcanism developed in narrow East-West elongated basins. An along strike dextral strike-slip shearing accounts well for this structural pattern.

The eastward displacement along the western border of the Ordos basin, the Shanxi highlands and Taihangshan is coeval with the dextral strike-slip recorded in the Yanshan-Yinshan belt. Conversely to other places of North China, the Late Jurassic tectonics of eastern Shandong is extensional, but still controlled by an E-W to NW-SE stretching direction.

Although apparently unrelated, all these contemporaneous tectonic features can be interpreted in a unitary way. In terms of finite strain, the E-W to NW-SE direction appears to control the Jurassic structural evolution of NCB. Along the Yanshan-Yinshan belt, dextral shearing accommodated the deformation, whereas in Helanshan, and central part of NCB, east directed folding and thrusting are coeval with the E-W shortening. The basal decollement that separates the deformed sedimentary cover from the Precambrian basement implies that the NCB was underthrust to the West below the Alashan block (Fig. 10). During this displacement, the NCB did not behave as a rigid block. Compression occurred in Shanxi highlands, and Taihangshan, and extension in eastern Shandong. Ancient faults nearly perpendicular to the maximum stretching, (e.g. Tan-Lu fault), were reworked with a normal component. It is worth to note that the Shanxi highlands, and Taihangshan are located in areas where Palaeoproterozoic deformation is important (e.g. Zhao et al., 2005; Faure et al., 2007; Trap et al., 2011). These inherited structures might have played a role in localizing the Jurassic deformation. Modeling of the Late Jurassic stress field of the NCB indicates a NW-SE strike of σ_1 that complies with our interpretation (Hou et al., 2010).

The Jurassic tectonics in the Yanshan-Yinshan belt was interpreted as a far-field effect of the Mongol-Okhotsk collision (He et al., 1998; Davis et al., 2001; Darby et al., 2002). Alternatively, a far-field effect of the collision of the Lhasa block with Asia was considered as the cause of the deformation in Ordos area (Dong et al., 2008; Zhang et al., 2008). The deformation in eastern NCB has been viewed as a consequence of the Palaeopacific subduction (Zhu et al., 2005, 2009). All these three geodynamic causes are possible, but detail structural and chronological constraints are too rare to settle a definite conclusion.

In spite of an apparent heterogeneity, the Jurassic, i.e. Yanshanian, deformations of the NCB can be interpreted in their entirety as a consequence of the westward underthrusting of the NCB below the Alashan block. At the lithosphere scale, the geodynamic cause of the Yanshan orogeny of North China remains an open question. Nevertheless, this Jurassic tectonics is unrelated to the late Early Cretaceous extension widespread in eastern Eurasia.

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Figure Captions

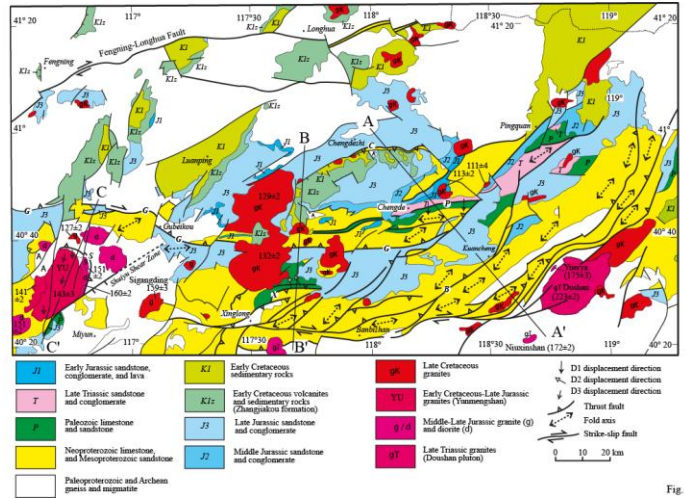


Fig. 1

Figure 1. Structural map of the Yanshan belt, north of Beijing. C: Chengdeshi thrust, P: Pingquan-Gubeikou thrust, G: Gubeikou thrust, X: Xinglong thrust, B: Banbishan thrust, Shihetang thrust. YU: Yunmengshan pluton. Figures in plutons correspond to available zircon U-Pb ages.

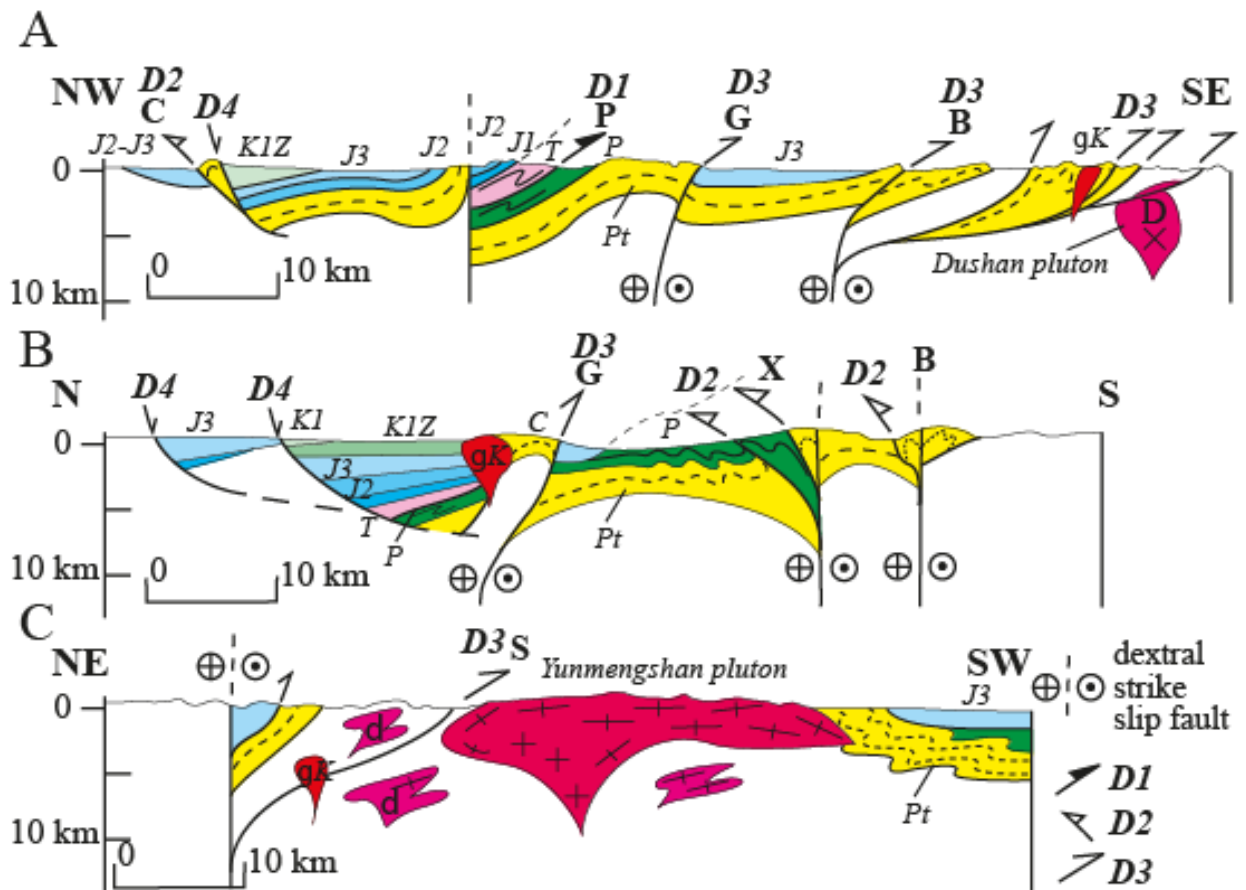


Fig. 2

Figure 2. Representative cross-sections through the Yanshan belt, (located in fig. 1), illustrating the structural style of the Mesozoic (Yanshanian) tectonics. D1, D2, D4, D4 refer to the deformation phases described in the text, see also Fig. 3 for the deformation age. C: Chengdeshi thrust, P: Pingquan-Gubeikou thrust, G: Gubeikou thrust, X: Xinglong thrust, B: Banbishan thrust. YU: Yunmengshan pluton. Note the contrasted, northeastward and southeastward senses of motion along the thrust faults, and the lack of general polarity. Patterns and symbols are the same as for Fig. 1

		Formation	Volcanism	Plutonism	Sedimentary record	Tectonics
100Ma	Albian					
110Ma	K1	Aptian				D4 event NW-SE Extension
120Ma		Barremian		<i>Dahaituo</i>		
130Ma	Hauterivian	Zhangjiakou K1z	trachytes andesites	<i>Wulingshan</i> <i>Fangshan</i> <i>Xuejiaoshiling</i>	m3 molasse	
140Ma	Valanginian	Baiqi				D3 event S-directed thrusting + strike-slip Shihetang T Gubeikou T
	Berriasian			<i>Yimengshan</i>		
150Ma	Tithonian	Houcheng				Extension or Transension
	J3	Kimmeridgian	trachytes andesites rhyolites	<i>Changyuan diorite</i>	m2 molasse	
160Ma		Oxfordian	Tiaojishan		<i>Siguangding</i>	
170Ma	J2	Jiulongshan		<i>Beishicheng diorite</i>	synclastic deposits?	D2 event N-directed thrusting strike-slip Xinglong T Chengde T
	Bathonian					
	Bajocian			<i>Niuxinshan</i>		
	Aalenian			<i>Yuerya</i>		
180Ma	Toarcian	Xiahnayan			m1 molasse	Extension or Transension
	J1	Pliensbachien	basalts			
190Ma		Sinemurian	Nandaling	andesites		
		Hettangian				
200Ma	Rhaetian	Xinshikou			synclastic deposits	D1 event S-directed thrusting Pingquan- Gubeikou thrust
210Ma	T3	Norian				D0 event
220Ma		Carnian		<i>Doushan</i>		
230Ma	Ladinian (T2)					undocumented

Fig. 3

Figure 3. Synoptic table of the Mesozoic volcanic, plutonic, sedimentary and tectonic events in the Yanshan area showing the timing of the five tectonic events, D₀ to D₄ described in the text.

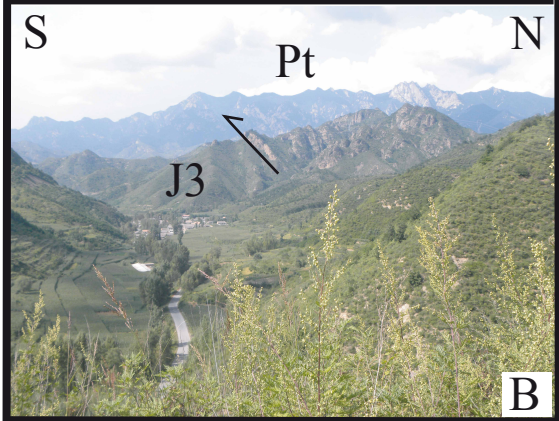


Figure 4. Field pictures of the Jurassic deformation in the North China block.

A: Verticalized Proterozoic quartzite along the Fenging-Longhua dextral strike-slip fault;

B: Gubeikou thrust, S. of Chengde. Proterozoic sedimentary rocks (Changcheng group) (Pt) overthrust to the South Jurassic red beds (J3).

C: Plurimeter-scale East-verging folds in Late Paleozoic limestone-coal formation in the Helanshan (D_3 event North of Yinchuan).

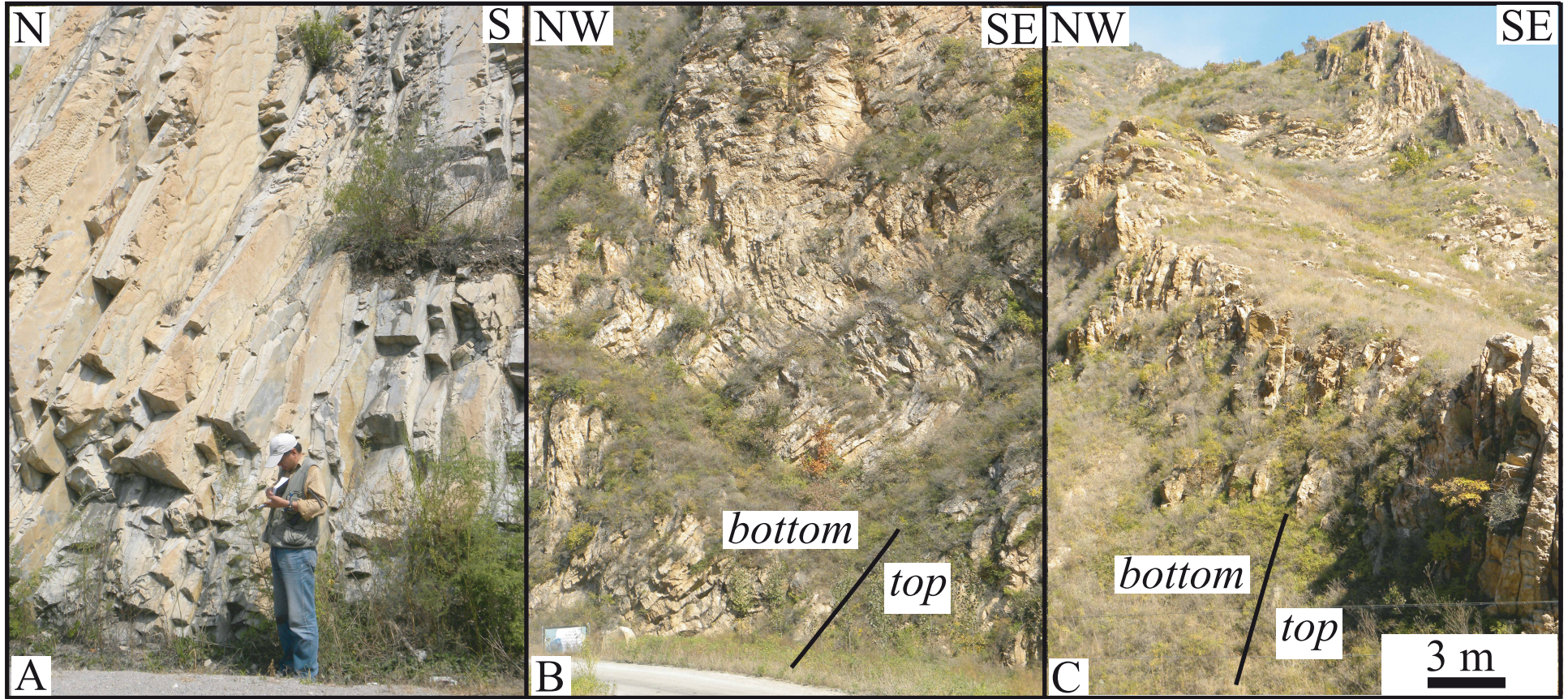


Figure 5. A: Load cast in verticalized but not ductilely deformed Proterozoic sandstone (Changcheng group, Northeast of Chengde).

B, C: South or Southeast overturned folds in Proterozoic sandstone (SE of Kuancheng), the beds are locally overturned.

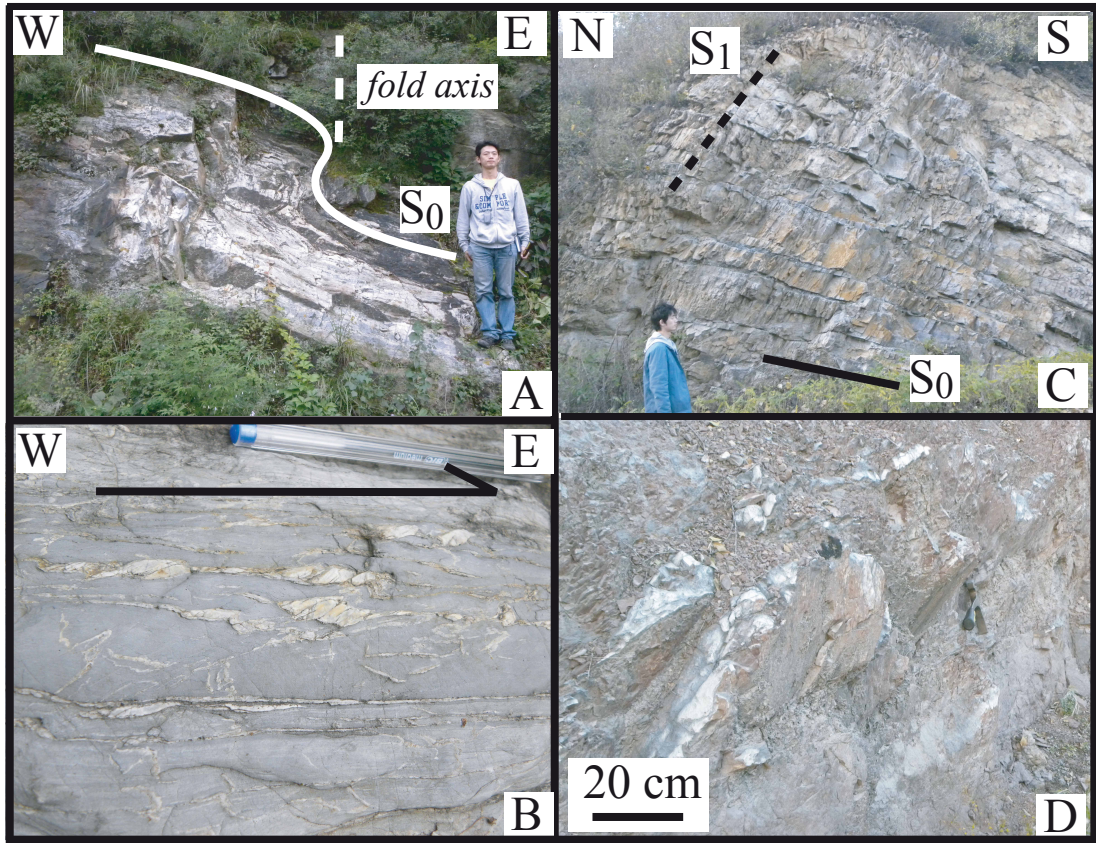


Figure 6A: Asymmetric fold with vertical axis in Proterozoic limestone (Jixian group), indicating a dextral shearing (D_3 event, North of Yunmengshan pluton).

B: Asymmetric dolomite boudins in Proterozoic limestone indicating a dextral ductile shearing (D_3 event, North of Yunmengshan pluton).

C: South-verging fold with axial planar cleavage in Proterozoic sandstone (SE of Kuancheng).

D: Schistose Triassic sandstone and siltstone along the Pingquan-Gubeikoi thrust (East of Chengde).

Figure 7A: Southeastward-verging fold in Proterozoic sandstone (East of Banbishan).

B: South-directed high-angle thrust in Proterozoic sandstone (SE of Kuancheng).

C: East-verging fold in Proterozoic sandstone (North of Dushan pluton).

D: Top-to-the-South asymmetric granite boudins in the Proterozoic country rocks of the Yunmengshan pluton, close to the Shihetang thrust.

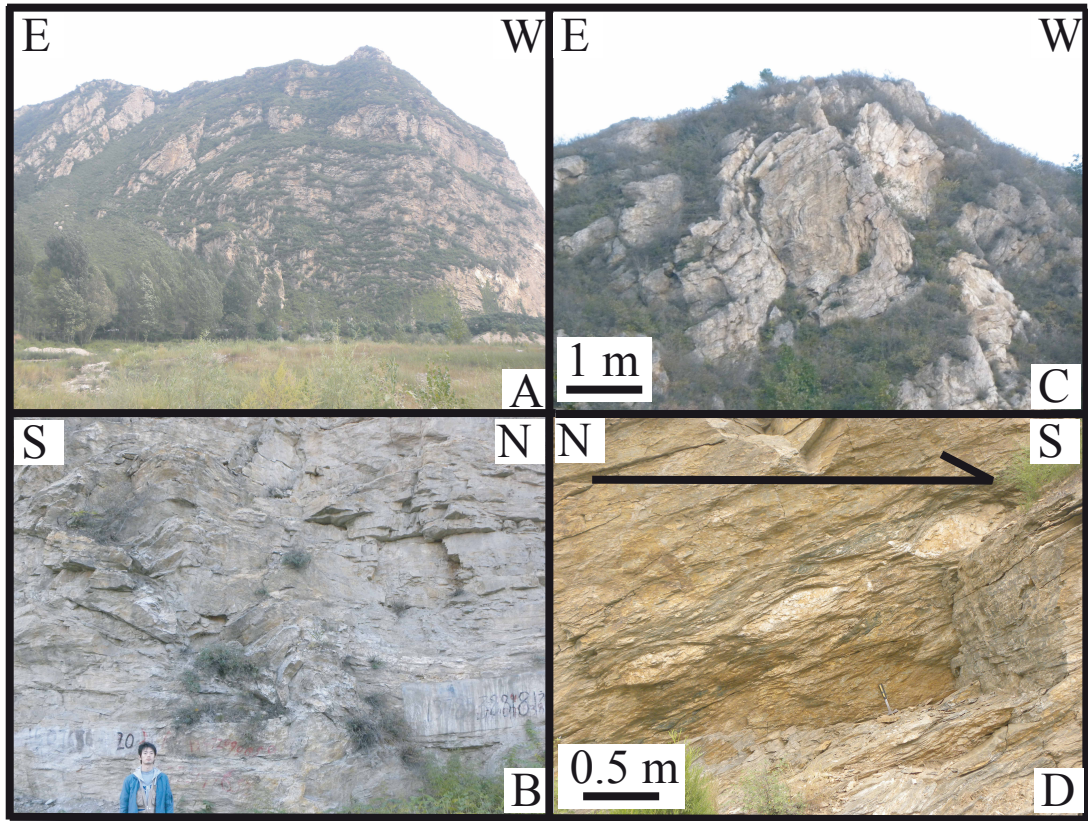




Figure 8A: Fold with vertical axis in Proterozoic limestone(Jixian group) associated with strike-slip faulting along the Gubeikou thrust (North of Yunmengshan pluton).

B: Vertical section perpendicular to the D₃ dextral strike-slip fault, east of Banbishan showing sigmoidal lenses developed in Neoproterozoic (Changcheng) sandstone.

C: Horizontal slickenlines and calcite steps indicating a dextral strike-slip motion along the Banbishan “thrust” (East of Banbisahan).

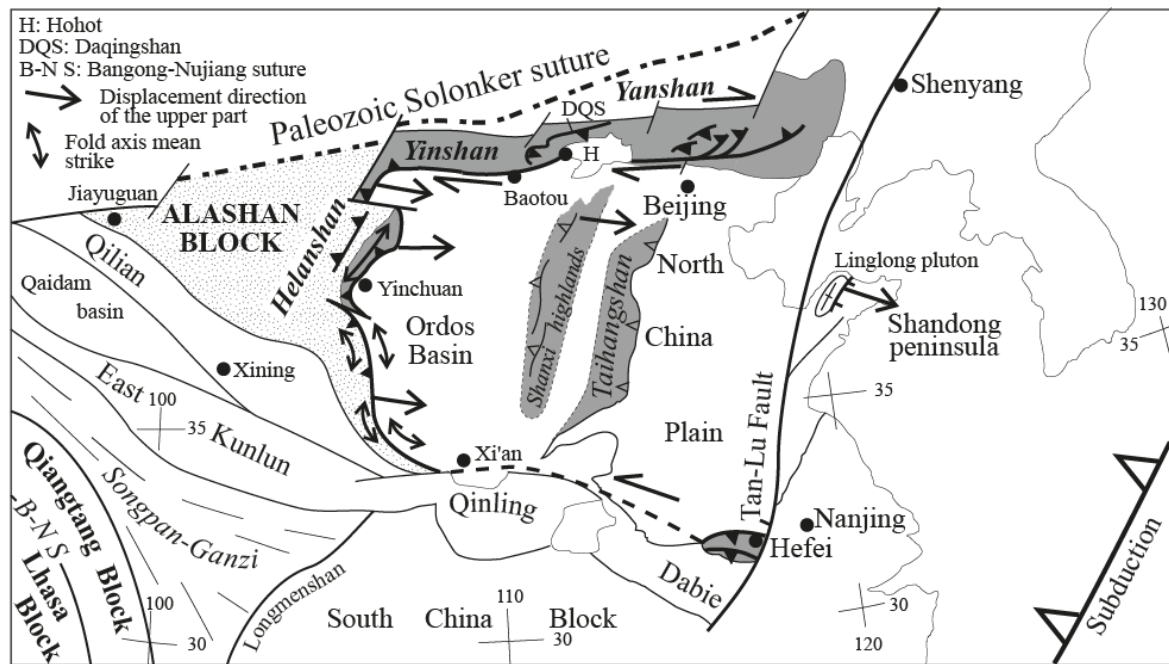


Fig.9

Figure 9: Interpretative structural map of the Jurassic tectonics of the North China Block (NCB). Grey pattern highlights fold-and-thrust belts. The E-W Yanshan-Yinshan belt developed as a dextral strike-slip along which North and South directed thrusts represent positive flower structures. This belt connects to the SW with the Helanshan belt characterized by East-directed folds and thrusts. To the South, left-lateral strike-slip develops along the northern margin of the Qinling-Dabie belt. To the East, sinistral wrenching and NW-SE normal faulting are recognized along the Tan-Lu fault and in the Shantung peninsula. Between the Ordos basin and the North China plain, the Shanxi highlands and the Taihangshan are east-directed fold-and thrust belts formed by thin-skin tectonics. As a whole, the NCB underthrusts to the West below the Alashan Block.

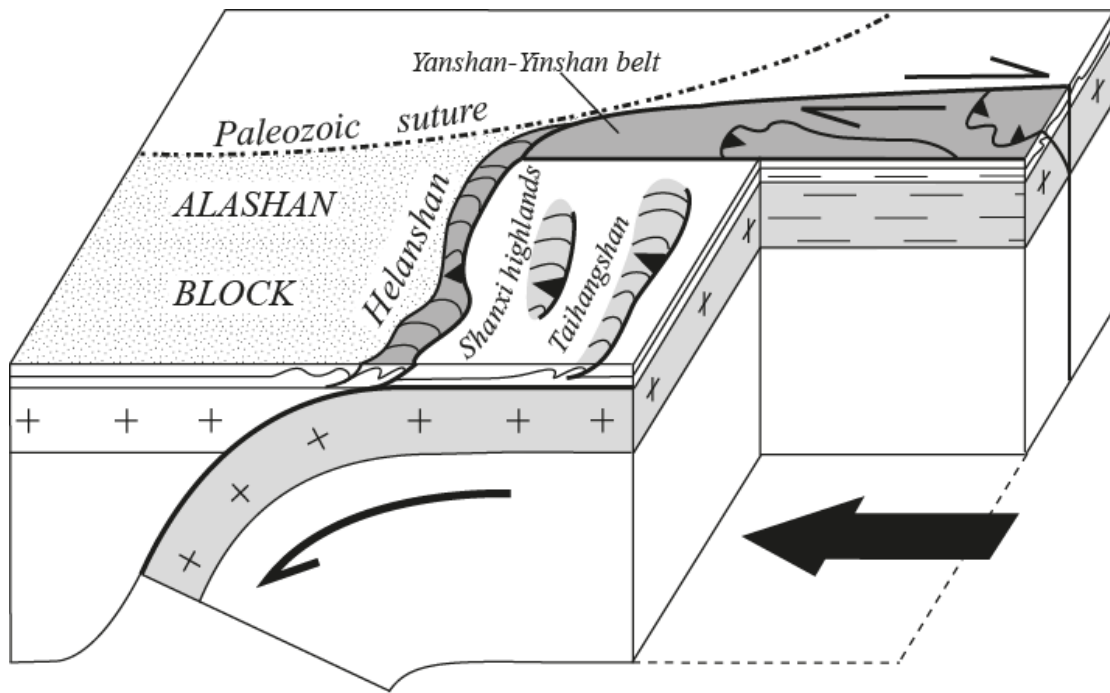


Fig. 10

Figure 10: Schematic block-diagram showing the continental subduction of the North China Block below the Alashan block. The main decollement is located in the Helanshan area. Subordinate fold-and-thrust belts develop in the Shanxi highlands and Taihangshan. The intracontinental Yanshan-Yinshan belt is interpreted as a transpressional orogen formed along an East-West striking strike-slip system.