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Jurassic Tectonics of North China: A Synthetic View

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Abstract: This paper gives a synthetic view on the Jurassic tectonics of North China, with an attempt to propose a framework for the stepwise tectonic evolution history. Jurassic sedimentation, deformation and magmatism in North China have been divided into three stages. The earliest Jurassic is marked by a period of magmatism quiescence (in 205–190 Ma) and regional uplift, which are considered to be the continuation of the "Indosinian movement" characterized by continent-continent collision between the North and South China blocks. The Early to Middle Jurassic (in 190–170 Ma) was predominated by weak lithospheric extension expressed by mantle-derived plutonism and volcanism along the Yanshan belt and alongside the Tan-Lu fault zone, normal faulting and graben formation along the Yinshan-Yanshan tectonic belt, depression and resuming of coal-bearing sedimentation in vast regions of the North China block (NCB). The Middle to Late Jurassic stage started at 165±5 Ma and ended up before 136 Ma; it was dominated by intensive intraplate deformation resulting from multi-directional compressions. Two major deformation events have been identified. One is marked by stratigraphic unconformity beneath the thick Upper Jurassic molasic series in the foreland zones of the western Ordos thrust-fold belt and along the Yinshan-Yanshan belt; it was predated 160 Ma. The other one is indicated by stratigraphic unconformity at the base of the Lower Cretaceous and predated 135 Ma. During this last stage, two latitudinal tectonic belts, the Yinshan-Yanshan belt in the north and the Qinling-Dabie belt in the south, and the western margin of the Ordos basin were all activated by thrusting; the NCB itself was deformed by the NE to NNE-trending structural system involving thrusting, associated folding and sinistral strike-slip faulting, which were spatially partitioned. Foliated S-type granitic plutons aged 160–150 Ma were massively emplaced in the Jiao-Liao massif east of the Tan-Lu fault zone and indicate important crustal thickening in this part of the NCB. The Jurassic deformation patterns, different tectonic systems and multi-directional contractions in North China recorded far-field effects of synchronous convergences, toward the East Asian continent, of three different plates, the Siberian plate in the north, the paleo-Pacific oceanic plate in the east and the Lhasa block in the southwest. This Middle to Late Jurassic intraplate orogenesis and pervasive shortening deformation preceded lithospheric attenuation and thinning in East China, which most possibly started by the Early Cretaceous around 135 Ma.

Key words: Jurassic tectonics, intraplate deformation, North China, multi-directional compression

1 Introduction

North China is a vast region composed of different physiographic units. The Yinshan-Yanshan Ranges and the Qinling-Dabie Ranges stand respectively to north and south; the western margin follows Langshan-Helanshan-Liupanshan; the Tan-Lu fault zone, a huge lithospheric discontinuity, slices its eastern part. The broad interior of North China consists of five morphostructural domains, which, from west to east, are the Ordos basin, Shanxi highland, northern North China Plain (NNCP) (also called the Great Bohaiwan basin), southern North China Plain (SNCP) (also called the Hehuai basin), the Jiaolai-Liaodong (Jiao-Liao) massif located east of the Tan-Lu fault zone. The boundaries between these morphostructural domains are sharp or distinct (Fig. 1).

Geotectonically, the North China block (NCB) belongs to part of the Sino-Korea craton, whose crystalline basement was cratonized successively through the Fuping movement

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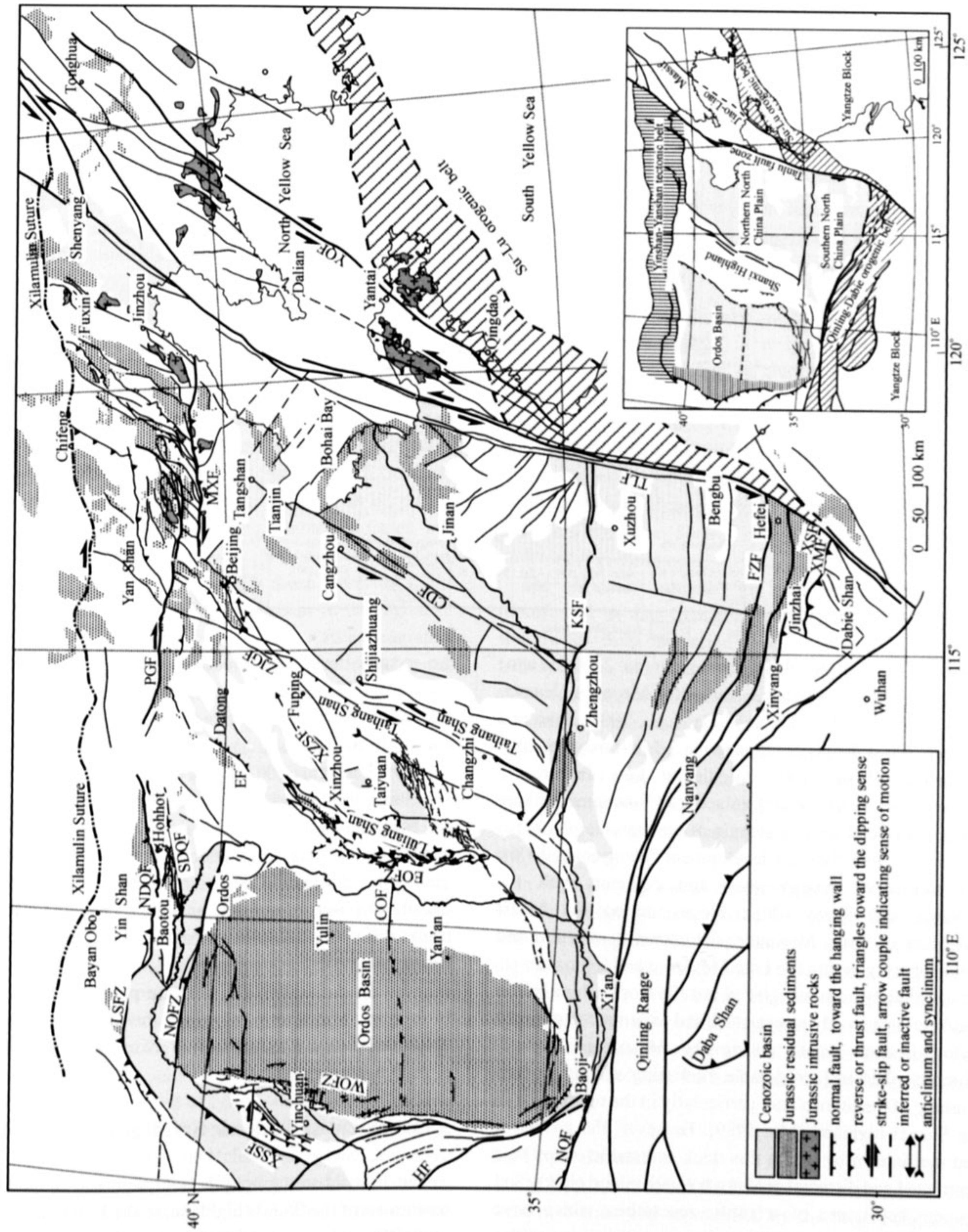
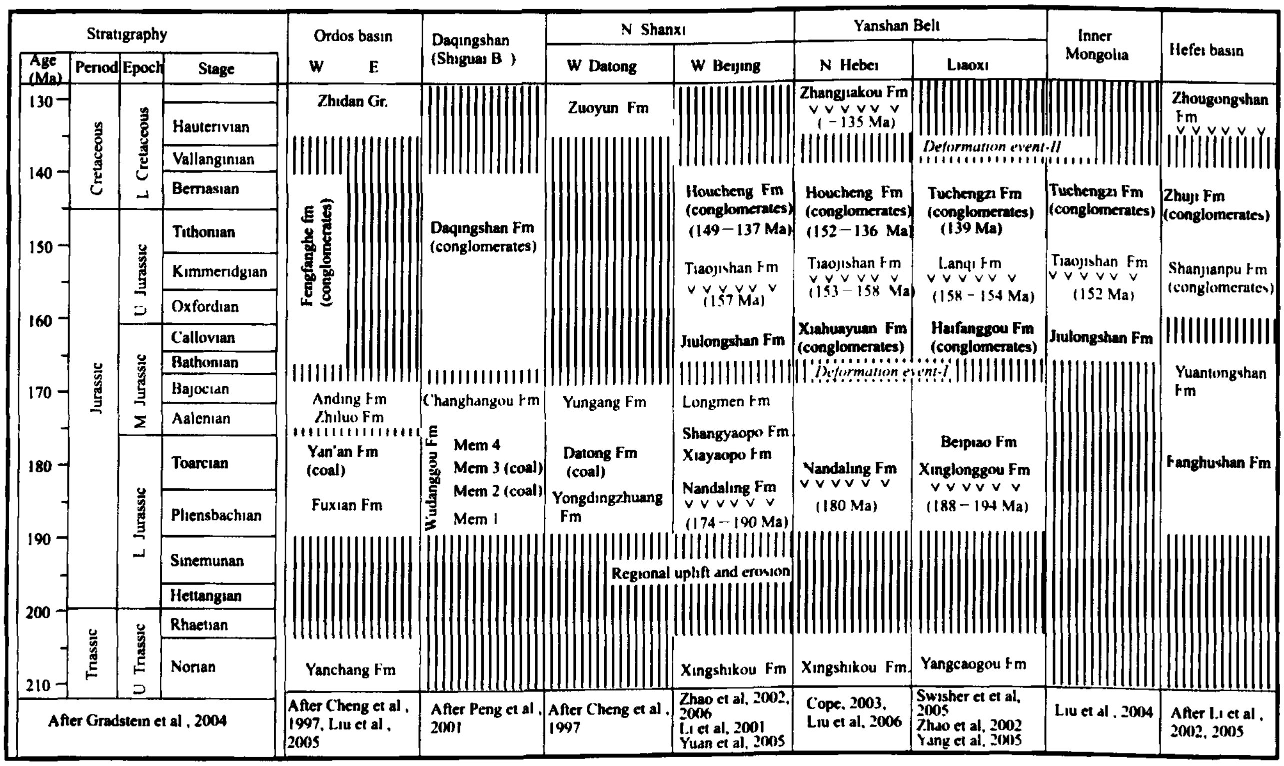


Fig. 1. Outline of the Jurassic tectonics of North China.

Compiled from Zhang et al. (2007) for Ordos basin, Zhang et al. (2001, 2002) for Yanshan belt, Zhu et al. (2006) for the Hefei basin, Qi et al. (2003, 2004) for northern North China Plain. Inset at lower right corner presents main physiographic units of North China.

Main fault zones: TLF – Tan-Lu fault zone; YQF – Yalvjiang-Qingdao fault zone; PGF – Pingquan-Chengde fault zone; MXF – Miyun-Xifengkou fault zone; ZJGF – Zijinguan fault zone; CDF – Cangdong fault zone; EF – Emaokou fault; EOFZ – Eastern Ordos fault zone; XZSF – Xizhoushan fault zone; COD – Central Ordos fault; SDQF – southern Daqingshan fault zone; NDQF – northern Daqingshan fault zone; NOFZ – northern Ordos fault zone; LSFZ – Langshan fault zone; XSSF – Xiaosongshan fault zone; KSF – Kaifeng-Shangqiu fault zone; HF – Haiyuan fault zone; NQF – northern Qinling fault zone; FZF – Feizhong fault; XSF – Xinyang-Shucheng fault zone; XMF – Xiaotian-Mozitan fault zone.

Table 1 Correlation of Jurassic Formations in North China



Stratigraphy				Ordos basin	Daqingshan (Shiguai B)	N Shanxi		Yanshan Belt		Inner Mongolia	Hefei basin
Age (Ma)	Period	Epoch	Stage	W E		W Datong	W Beijing	N Hebei	Liaoxi		
130	Cretaceous	L Cretaceous		Zhidan Gr.	▥	Zuoyun Fm	▥	Zhangjiakou Fm v v v v v v (~135 Ma)	▥	▥	Zhougongshan Fm v v v v v v
			Hauterivian		▥		▥		▥	▥	
140			Vallanginian	▥	▥	▥	▥	▥	Deformation event-II		▥
			Berriasian	Fengfanghe fm (conglomerates) ▥		▥	Houcheng Fm (conglomerates) (149−137 Ma)	Houcheng Fm (conglomerates) (152−136 Ma)	Tuchengzi Fm (conglomerates) (139 Ma)	Tuchengzi Fm (conglomerates)	Zhuji Fm (conglomerates)
150	Jurassic	U Jurassic	Tithonian		Daqingshan Fm (conglomerates)	▥					
			Kimmeridgian			▥	Tiaojishan Fm v v v v v v (157 Ma)	Tiaojishan Fm v v v v v v (153−158 Ma)	Lanqi Fm v v v v v v (158 − 154 Ma)	Tiaojishan Fm v v v v v v (152 Ma)	Shanjianpu Fm (conglomerates)
160			Oxfordian			▥					
		M Jurassic	Callovian			▥	Jiulongshan Fm	Xiahuayuan Fm (conglomerates)	Haifanggou Fm (conglomerates)	Jiulongshan Fm	▥
			Bathonian	▥	▥	▥	▥	Deformation event-I	▥	▥	Yuantongshan Fm
170			Bajocian	Anding Fm	Changhangou Fm	Yungang Fm	Longmen Fm			▥	
			Aalenian	Zhiluo Fm						▥	
180		L Jurassic	Toarcian	Yan'an Fm (coal)	Wudanggou Fm Mem 4 Mem 3 (coal)	Datong Fm (coal)	Shangyaopo Fm Xiayaopo Fm	Nandaling Fm v v v v v v	Beipiao Fm Xinglonggou Fm v v v v v v	▥	Fanghushan Fm
			Pliensbachian	Fuxian Fm	Mem 2 (coal) Mem 1	Yongdingzhuang Fm	Nandaling Fm v v v v v v (174 − 190 Ma)	(180 Ma)	(188 − 194 Ma)	▥	
190			Sinemurian	▥	▥	▥ Regional uplift and erosion	▥	▥	▥	▥	▥
			Hettangian	▥	▥	▥	▥	▥	▥	▥	▥
200	Triassic	U Triassic	Rhaetian	▥	▥	▥	▥	▥	▥	▥	▥
210			Norian	Yanchang Fm	▥	▥	Xingshikou Fm	Xingshikou Fm	Yangcaogou Fm	▥	▥
After Gradstein et al , 2004				After Cheng et al , 1997, Liu et al , 2005	After Peng et al , 2001	After Cheng et al , 1997	Zhao et al, 2002, 2006 Li et al, 2001 Yuan et al, 2005	Cope, 2003, Liu et al, 2006	Swisher et et al, 2005 Zhao et al, 2002 Yang et al, 2005	Liu et al , 2004	After Li et al , 2002, 2005

▥ Hiatus v v v Vocanic layers ☐ Syntectonic deposits

(ca. 2500 Ma ago), the Wutai movement (ca. 2300 Ma ago) and the Lvliang movement (ca. 1800 Ma ago) (Huang, 1954; Wang and Mo, 1995; Wilde et al., 2004; Zhao and Kröner, 2007). Its platform experienced four mega periods of tectonic history: (1) Middle to Late Proterozoic intracontinental rifting and aulacogen development along the northern and western margin of the cratonic block; (2) Paleozoic stable platform development (Wang et al., 2006); (3) successive amalgamation and collision with the Siberian and South China blocks during the Latest Paleozoic to Early Mesozoic; (4) craton destruction and dismembering during the Late Mesozoic and Cenozoic.

It has already been recognized that the North China craton had been intensively rejuvenated and experienced periodic tectonothermal events during the Mesozoic-Cenozoic, which resulted in considerable thickening and subsequent thinning of the lithosphere, particularly in the region east of the Shanxi highland (Ma, 1989). However, the processes and mechanism by which this thick and stable craton was destructed and dismembered are not understood clearly and become key issues of scientific researches, which have attracted a lot of attention from geosciences' communities in the would. The Jurassic is an important era for the development of intraplate deformation in East Asia in general, and has been exclusively investigated in North China in particular. The term "Yanshan movement", originally named by Wong (1927, 1929), specifically referred to Jurassic tectonic events in China and becomes the tectonic term most frequently cited in the Chinese literatures of geosciences. The sense of this notion had been enlarged and includes all tectonothermal events occurred during the Jurassic and Cretaceous (Huang, 1954; Ren et al., 1990; Cui et al., 2002; Dong et al., 2000, 2008).

In this paper, Jurassic stratigraphy, tectonic deformation and magmatism in North China are synthesized based on integration and data compilation from published literatures. This is possible duo to intensive investigation and a large amount of observational and analytical data accumulation from different disciplines (sedimentology, petrology, structural geology, geochronology, seismic tomography, etc.) during the last two decades. The purpose of this paper is to give a synthetic view on the Jurassic intraplate deformation and magmatisms of North China and their plate dynamic setting.

2 Overview of Jurassic Stratigraphy

The Jurassic stratigraphy is best preserved in the Ordos basin west of the Shanxi highland, in the Hefei basin south of SNCP and in extensional basins along the Yinshan-Yanshan belt. It is also drilled beneath NNCP but poorly constrained in stratigraphic age (Qi et al., 2003, 2004). A tentative correlation of locally named Jurassic Formations in North China has been made on the basis of stratigraphic contacts, sequence analysis and isotopic dating results and summarized in Table 1. Volcanic rock layers are interbedded in the Jurassic sequences developed along the Yanshan-Liaoxi belt and in West Beijing, and have been dated using ^{40}Ar-^{39}Ar and zircon U-Pb SHRIMP methods. The results form the basis for a best chronology of Jurassic stratigraphy in North China. Overall, the Jurassic stratigraphy consists of three mega sequences that can be correlated with the Lower, Middle and Upper Jurassic. The stratigraphic contact relationships between them are in either erosion or angular unconformities, which recorded a stepwise evolution history of Jurassic tectonics in North China.

2.1 Lower Jurassic

In the Ordos basin, Lower Jurassic consists of the Fuxian and Yan'an Formations. The lowermost Jurassic is absent duo to regional uplift and erosion following the Triassic collision between the NCB and the SCB (Liu et al., 2005, 2006a). The Fuxian Formation corresponds to a fluvial to lacustrine facies sedimentary series; the Yan'an Formation is a series of coal-rich deposits, stable in facies and thickness distribution, with a total thickness of 250–400 m. These series can be correlated with those preserved in the Datong and Ningwu synclinorium basins in the region of North Shanxi (Cheng et al., 1997). Paleogeography reconstruction showed that the overall Lower Jurassic coal-bearing prograding sequence was deposited in a huge depression, which covered the whole Ordos basin and Shanxi highland and may possibly extend eastward to the NNCP (Wang and Zhang, 1999).

The Lower Jurassic in the Daqingshan basin is represented by the Wudanggou Formation. 200–300 m-thick conglomerates developed along the footwall of the boundary fault zone and are overlapped by a prograding sequence composed of fluvial to lacustrine and deltaic facies sandstones, siltstones and mudstones (Peng et al., 2001). This sedimentary sequence was deposited in an extensional basin controlled by N-dipping master normal faults in the south (Ritts et al., 2001).

In the Hefei basin, the Lower Jurassic outcropped along its southern margin and was named the Fanghushan Formation; it is composed of coarse sandstones, siltstones and mudstones, about 1000 m thick (Li et al., 2002, 2005). It was encountered within the Hefei basin by well Ancan-1, about 230 m, composed mainly of thick-bedded mudstone and muddy siltstone (Xu et al., 2002). This sequence was deposited under a semi-deep water lacustrine environment.

The Lower Jurassic in West Beijing and along the Yan-Liao belt is characterized by eruptive to flow volcanic rocks, represented by the Nandaling Formation in West Beijing and West Yanshan and by the Xinglonggou or Shuiquangou Formation in the Liaoxi region. The volcanic beds have been dated in the range of 180–194 Ma (Zhao et al., 2002, 2006; Xu et al., 2005). This volcanic rock series is overlain by coal-bearing clastic deposits of the Yaopo Formation in West Beijing and of the Beipiao Formation in Liaoxi, which can be correlated with the Lower Jurassic Yan'an Formation in the Ordos basin.

2.2 Middle Jurassic

The sedimentary environment had changed during the Middle Jurassic. In the Ordos basin, lake water was progressively deepened to form a huge lacustrine facies depression (Chen et al., 1997; Liu et al., 2006a). The Middle Jurassic was divided into two formations. The Zhiluo Formation below is a lacustrine facies series composed of intercalation of thick bedding sandstones, siltstones and marlstone, without coal beds, 200–300 m thick; its base is marked by an erosional surface indicating uplift of the basin between Early and Middle Jurassic. The Anding Formation above consists of interbedded mudstone and calcaceous siltstones intercalated with marlstone and dolomitic marlstone, 50–400 m thick, which was deposited under a dry environment.

The Middle Jurassic in the Daqingshan basin, represented by the Changhangou formation, is made of shallow to deep lacustrine facies sediments, composed mainly of grey to greenish siltstones, fine grain sandstones, calcaceous siltstones, marlstone and carbonates, upgrading to conglomeratic sandstones and conglomerates.

In the Hefei basin, the Middle Jurassic encountered by well Ancan-1 is in continuation with Upper Jurassic, with a total thickness of 2407 m (Xu et al., 2002). This thick sedimentary series consists of intercalation of mudstones and sandstones.

In West Beijing and along the Yanshan-Liaoxi belt, the Middle Jurassic is characterized by a prograding sequence with thick conglomeratic deposits and coarse sandstones at the base upgraded to sandstones and siltstones, comparable with those in the Ordos basin. Volcanic rocks are scarce in this series. The base of the Longmen Formation in West Beijing is marked by an erosional surface, indicating fast uplift in time between the Early and Middle Jurassic (Zhao et al., 2002).

2.3 Upper Jurassic

The Upper Jurassic in the Ordos basin is restricted to its western margin and represented by the thick Fengfanghe conglomeratic formation (Zhang, 1989, Table1). This conglomeratic series outcrops along the Fengfanghe river valley south of the western margin of the Ordos basin and is expressed on seismic profiles as a wedge-shaped body, thick in south and thinning northwards (Liu et al., 2006a). It sits in angular unconformity on the Early to Middle Jurassic and other older rock series and is overlain unconformably by Lower Cretaceous conglomeratic sediments. The components of pebbles are mixed, consisting mostly of metamorphic rocks, carbonates, sandstones, which represent syntectonic growth strata accompanying the development of the western Ordos thrust and fold belt (see section 3.1).

Upper Jurassic in the Shiguai basin along the Daqingshan range corresponds to the Daqingshan Formation. It consists of a thick series of conglomeratic tracts with four coarse to fine grained subsequences. The total thickness is about 332 m (Peng et al., 2003). This conglomeratic series, overlapping on old strata (Fig. 2b), represents syntectonic growth strata deposited in response to development of the Daqingshan thrust and nappe tectonic system in the Mid-Late Jurassic.

The Upper Jurassic along the Yanshan-Liaoxi belt developed in volcanic basins and was divided into two formations: the volcano-clastic Tiaojishan or Lanqi Formation below and the conglomeratic Houcheng or Tuchengzi Formation above. The ages of these two formations have been reviewed by Swisher et al. (2001), Cope (2003), Davis (2005), Liu et al. (2006b) and Sun et al. (2007). The volcanic rocks in the Tiaojishan or Lanqi formations are mainly intermediate to acid assemblage and interbeded clastic sediments, which contain the Yan-Liao biota (Ji et al., 2004). The volcanic rocks have been dated by zircon U-Pb SHRIMP method, in different basins, in the range of 165–153 Ma (Zhao et al., 2002; Gao et al., 2004; Liu et al., 2004b; Ji et al., 2004; Xu et al., 2005; Yuan et al., 2005; Zhang et al., 2005; Liu et al., 2006b; Sun et al., 2007). The thick conglomeratic Houcheng or Tuchengzi Formation was deposited under dry fluvial-lacustrine facies environment; it consists of three members: the lower one composed of purple siltstones, shale and sandstone intercalated with carbonates; the intermediate one with tuff sandstones and conglomerates; and the upper one with conglomerates and sandstones. The total thickness varies between 1000–3000 m (He et al., 1998). Interbeded acid volcanic rocks have been dated to 152–136 Ma in different basins (Liu et al., 2006b).

3 Jurassic Deformation Pattern and Structural Systems

Jurassic deformation is widespread in North China and has been intensively investigated by many researchers. It is not uniformly distributed but spatially partitioned. Typical Jurassic structures have been compiled and presented in Fig. 1. These include the Western Ordos thrust-fold belt (WOTFB), the Shanxi thrust-fold system (STFS), and the Tan-Lu strike-slip fault system. The two latitudinal orogenic belts, the Yinshan-Yanshan one in the north and the Qinling-Dabie Shan in the south, were also strongly rejuvenated by thrusting and folding.

3.1 The Western Ordos thrust-fold belt (WOTFB)

The WOTFB developed along the western margin of the Ordos basin and extends in N-S between the longitude 106° and 107°, about 600 km long and 30–80 km wide in total. It has been viewed as a typical intraplate deformation zone in central Asia by Darby and Ritts (2002). This structural belt has been intensively studied by numerous authors based on geophysical, drilling exploration data (Zhao and Liu, 1990; Yang, 2002) and field observations (Zhang, 1989; Zhang et al., 2006, 2007). Structurally, this zigzag extending belt can be divided into three segments, from north to south, the Zhuozishan and Hengshanpu segment, the central Majiatan segment and the south segment. The difference in structural features among these segments is distinct. The Zhuozishan segment involves pre-Cambrian basement rocks and consists of east verge, imbricate thrusts. The Zhuozishan fault dips to the west with a dipping angle of 60°–70° and a vertical offset of several hundreds to thousand of meters. The horizontal shortening across this segment has been estimated to 32%. The south segment corresponds to an imbricate thrust faults involving cover rocks, with the deep décollement zone being rooted westward to the Qingtongxia-Guyuan and Haiyuan-Liupanshan fault zones. Crustal shortening across this zone has been estimated to 33.6%–42.8%. The central segment shows a contrast structural style characterized by east verge thrusts with the maximum vertical offset of more than one thousand of meters, while the estimated shortening is only 10%. Because of the superimposition of the Cenozoic Yingchuan graben, the geometric and kinematics relationship between the central structural segment and the Helanshan fold and thrust belt remains unclear; different interpretation has been proposed. Most of the researchers considered that the W-E trending Zhengyiguan fault which bounds the Helanshan to the north prolonged eastward and connects with a transcurent fault south of the Zhuozishan thrust fault segment. However, Darby and Ritts (2002) interpreted that the Zhengyiguan fault might match with the fault that cuts the Zhuozishan thrust fault zone to the north. These authors inferred, based on this interpretation, that a left-lateral strike-slip offset of about 60 km should occur along a N-S striking fault zone, the Yellow river fault zone. According to the palinspastic reconstruction map, the northern segment of the WOTFB belongs to the foreland of the Helanshan orogenic belt. However, a problem remains for this interpretation because it is difficult to absorb such a huge sinistral strike-slip displacement on both sides of the N-S-striking Yellow river fault zone.

Several lines of evidence exist supporting that the

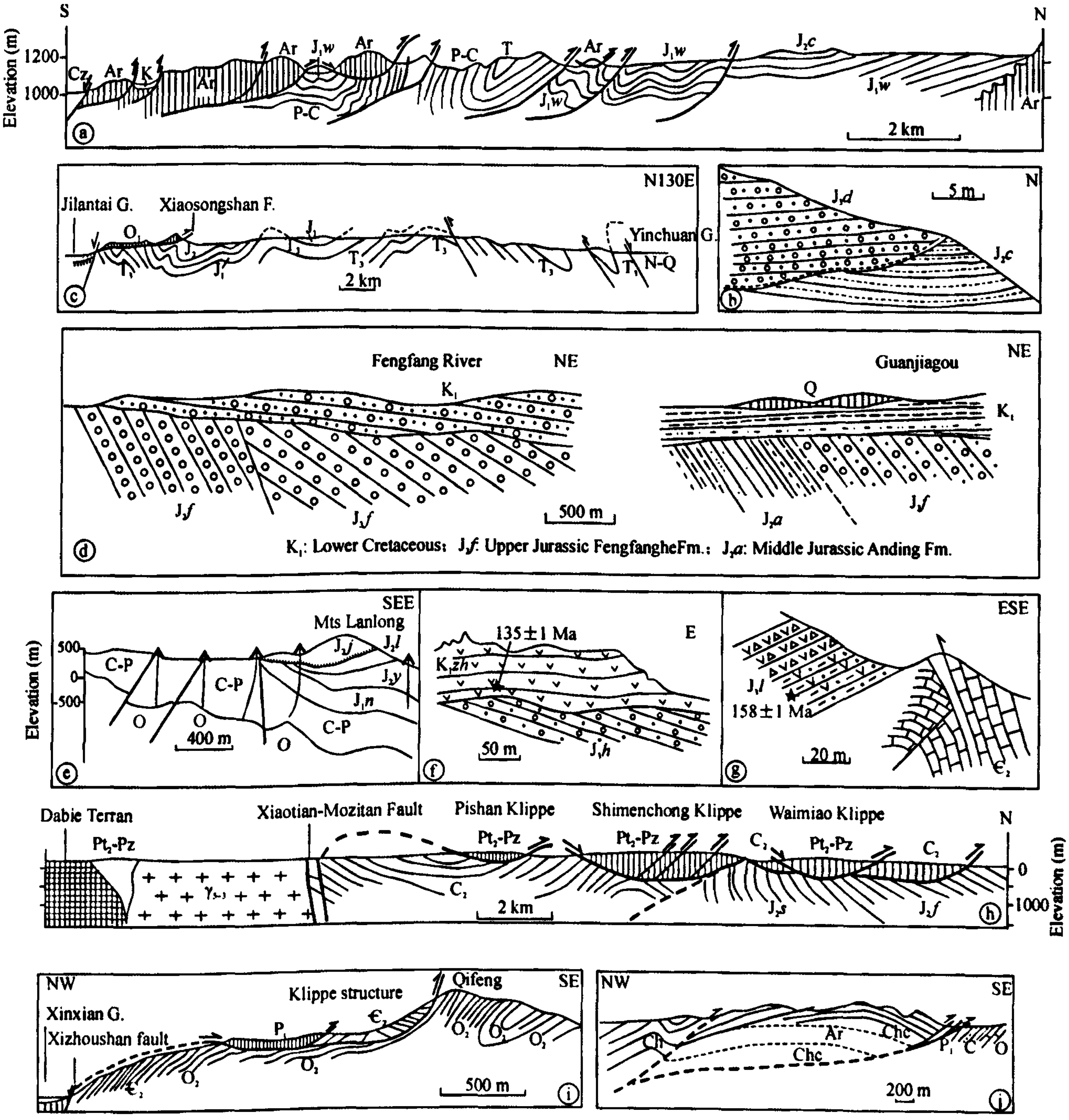


Fig. 2. Sketches showing the Jurassic deformation events and structural styles in North China.

a: Simplified N-S structural section across the Daqingshan belt (modified from Du et al., 2006). Cz – Cenozoic; K – Cretaceous, J_1w – Lower Jurassic Wudanggou Fm.; J_2c – Middle Jurassic Changhangou Fm.; P-C – Permo-Carboniferous; Ar – Archean. b: Sketch of the disconformity between Upper Jurassic Daqingshan Formation and Middle Jurassic Changhangou Formation at Erqinyao, Tumeteyouqi (after Peng et al , 2003) c: Simplified structural section across the E-W Helanshan (after Zhang, 1989). N-Q – Neogene-Quaternary; J_2 – Middle Jurassic; J_1 – Lower Jurassic; T_3 – Upper Triassic; O_1 – Lower Ordovician. d: Unconformity beneath the Upper Jurassic Fengfanghe Formation along the western margin of the Ordos basin (after Zhang, 1989). e, f, g: Stratigraphic unconformity beneath the Middle Jurassic Jiulongshan Formation in West Beijing (e), beneath the Upper Jurassic Lanqi Formation in the Lingyuan basin, Liaoxi (g), and beneath the Early Cretaceous Zhangjiakou Fm. in west Yanshan (f) (from Zhao et al., 2003, 2004). h: Simplified structural section across N-S northern Huaiyang belt, north of the Dabie belt (after Liu and Wang, 1999). J_2s – the Middle Jurassic Sanjianpu Formation; J_2f – the Middle Jurassic Fenghuangling Formation; C_2 – Middle carboniferous; Pt_2-Pz – Proterozoic to Paleozoic. i: Structural section of the Xizhoushan fault, north Shanxi (after Sun et al., 2004). j: Structural section of the Nandazhai thrust nappe in West Beijing (after Zhao and Shan, 1994)

WOTFB was initiated and developed by the time of the Late Jurassic. First, a thick series of Upper Jurassic conglomeratic deposits, 1200–3000 m-thick Fengfanghe Formation, developed along the foreland zone and has been considered to represent syntectonic deposits. The bedding of the conglomerates itself steeply dips to the east and is unconformably overlapped by Early Cretaceous sandstones and conglomerates. Second, provenance analysis of the Jurassic sedimentary series in the Helanshan area showed inversion of the Helanshan basin occurred after the Middle

Jurassic sedimentation. Last, one important observation made along the western edge of the Helan Mountains is that Ordovician carbonates were thrust eastward over Middle Jurassic sediments of the Zhiluo and Anding Formations (Fig. 2c, Zhang, 1989), indicating that the Helanshan fault-fold belt was rooted to the Xiaosongshan fault and that thrusting took place during the Late Jurassic.

3.2 The Shanxi thrust-fold system (STFS)

The STFS occupies the central part of the NCB. This tectonic system consists of NNE- to NE-striking reverse faults, thrusts and associated folds that are distributed in "S"-shaped pattern over the Shanxi highland. Reverse faults were observed along the most boundary zones of the Cenozoic Shanxi grabens. Taking the Xizhoushan fault as an example (XZSF in Fig. 1), this fault bounds the Xingxian graben to the east; thrusting was documented at its footwall and the minimum horizontal displacement was estimated to 5.8 km (Fig. 2i, Sun et al., 2004). The reverse faults in this region dip either westwards or eastwards (Zhao and Shan, 1994) and involved rocks from pre-Cambrian metamorphic basements to the youngest Middle Jurassic sedimentary covers. Cataclasis in fault zones indicate brittle deformation. Folds are mainly box-shaped in association with décollement in pre-Cambrian basement. The Middle Jurassic residuals are found in synclinorium basins, such as the Datong and Jingle synclinorium west of the Shanxi graben system, the Qingshui synclinorium in southern Mts. Taihang. Small-scale Early Cretaceous igneous rocks were emplaced into these structures but not affected by contractional deformation. Liao et al. (2007) and Zhang et al. (2007) inferred that the overall structural pattern of the Shanxi thrust-fold system can be interpreted as a westward propagating décollement system beneath the Shanxi highland. This interpretation was based on an analysis of structural styles along the western edge of the Shanxi highland, a particular boundary belt separating Mts. Lvliang from the Ordos basin. Detailed mapping and field survey show that this boundary is expressed by a set of W-dipping faults and hanging wall ramps, indicating that this boundary was dominated by backthrusts.

3.3 The Tan-Lu strike-slip fault system (TSFS)

The TSFS, also called the Tan-Lu wrench fault system (Xu et al., 1987), refers to faults or fault zones of different scales that slice the eastern Asia continent in the NNE-SSW direction, parallel or sub-parallel to the Tan-Lu fault zone. Except the Tan-Lu fault zone that apparently offsets the Dabie and Sulu UHP metamorphic belts, the Yalvjiang-Qingdao fault zone (YQF on Fig. 1) is another major crustal-scale fault cutting through the Jiao-Liao massif east of the Tan-Lu fault zone. The Tan-Lu fault zone itself was initiated as a transform fault zone during the Triassic collision between the NCB and SCB (Zhu et al., 2005, 2006). The Tan-Lu fault system behaved as a sinistral strike slip system active during the Late Jurassic to Early Cretaceous, although there is still problem concerning the amount of left-slip offset accumulated during this period. It is difficult to directly observe Jurassic deformation along the Tan-Lu fault zone because of heavy overprint of widespread Cretaceous extension and subsidence (Zhu et al., 2002; Zhang et al., 2003). However, fragments of sinistral ductile shear zones have been observed and documented along the eastern edge of Dabie Shan, in the Zhangbaling-Feidong massif exposed east of the Tan-Lu fault zone and along the western edge of the Sulu belt. ^{40}Ar/^{39}Ar dating of hornblende, phengite and muscovite from these ductile shear zones yielded plateau ages ranging from about 136 Ma to 143 Ma (Zhu et al., 2005) and from 162±1 Ma to 156±2 Ma (Wang, 2006), which might represent cooling events of these shear zones. In the Jiao-Liao massif, well developed Late Jurassic granitic plutons, aged 165–150 Ma (Miao et al., 1998; Guan et al., 1998; Guo et al., 2005), exhibit distinctive characteristics of foliation indicating ductile deformation during the Late Jurassic granite emplacement. Post-emplacement brittle deformation was also obvious in the northern uplift area of the Jiaodong peninsular, east Shandong Province, where NW-ward thrusting and left-slip faulting along the eastern edge of the Linglong granitic pluton occurred after the pluton emplacement and before Early Cretaceous extension, between 150 Ma and 135 Ma. Yang et al. (2004a), by using the laser alblation ^{40}Ar/^{39}Ar technique, dated deformation age of a late Jurassic pluton, the Heigou pluton, in the Liaodong region; their results show that ductile deformation occurred at ca.145 Ma before Early Cretaceous extension (ca. 128 Ma). Ye et al (1994) reported a ^{40}Ar/^{39}Ar dating result, about 154 Ma, of a vein crossite in glaucophane-schist outcropped along the Dunshan-Mihua fault zone in the Mudanjiang area, NE China, which indicates Late Jurassic strike-slip shear of the Tan-Lu fault zone in this region. All these observations and dating results indicate that the Tan-Lu fault system behaved as a sinistral strike-slip system during the Late Jurassic.

3.4 The Yinshan-Yanshan tectonic belt (YYTB)

This belt extends along the northern margin of the North China craton (NCC) and has experienced multi-stage tectonic history. The northern boundary corresponds to the Xar Moron (Solon) suture separating the NCC from the Xing-Meng orogenic belt. Jurassic contractional deformation was remarkable along the YYTB.

The Yanshan segment is the most intensively studied area for Mesozoic tectonics in China. The "Yanshan movement" includes three major deformation events named A, B, and an intermediate one in between, based on stratigraphic unconformities observed along this segment (Wong, 1927, 1929). According to geochronological investigation and isotopic dating of Jurassic volcano-clastic rocks (Zhao et al., 2002, 2006; Xu et al., 2005; Liu et al., 2006b), the event A, marked by angular unconformity at the base of the Tiaojishan volcanic rocks, is the most intensive phase of tectonic deformation dated prior to 160 Ma; the event B, indicated by angular unconformity at the base of the Early Cretaceous Zhangjiakou Formation, is characterized by strong S-ward thrusting dated prior to 135.8±3.1Ma (Niu et al., 2003, 2004); the intermediate one, represented by the Tiaojishan and Lanqi Formations, occurred in the time span from 160 to 139 Ma.

Davis et al. (1996, 1998, 2001), Davis (2003) and Zheng et al. (2000) have investigated in details the Yanshan structural belt and identified and dated several deformation phases. The earliest phase (Phase-I deformation) was marked by S-ward thrusting of the Pingquanguan-Gubeikou fault zone (PGF, Fig. 1), which predated 180 Ma, possibly occurred during the Triassic or Early Jurassic. Major compressional deformation along the Yanshan belt took place during the Late Jurassic (the Phase III deformation in Davis et al., 1996). Several thrust-nappe structures formed by this phase deformation have been identified and documented, including the north- to NW-thrusting Chengde thrust and nappe, dated 161–148 Ma, the Shisanling thrusting dated 161–141 Ma, the Yunmengshan folding and metamorphic event dated 141–143 Ma, the S-ward thrusting Sihetang and Gubeikou thrust and nappe structures dated prior to 148 and 143 Ma and lasted to 127 and 132 Ma.

After investigating the late Jurassic deposition along the Yinshan-Yanshan belt, He et al. (1998, 1999) postulated a 1200 km-long basin group which developed in a foredeep zone and was associated with S-directed thrusting of the Yinshan-Yanshan thrust system. This interpretation has been criticized by Davis (2005), who pointed out that Late Jurassic contraction of the basins occurred along both north- and south-dipping thrusts and reverse faults. After studying the geometry and inner structures of the two major W-E striking fault zones, the Gubeikou-Pingquan fault zone (PGF, Fig. 1) and the Miyun-Xifengkou fault zone (MXF, Fig. 1), in the central Yanshan segment, and the thrust-nappe structures in the Liaoxi area, Zhang et al. (2001, 2002) proposed a unified kinematics model to explain the complex structures in these areas. According to these authors, the east-west trending master fault zones slicing the central Yanshan belt behaved as a dextral strike-slip duplex, which relay eastward in the Liaoxi area with northeast-oriented contractional faults and related folds, they together forming a dextral strike-slip system that was active during the time between 148 Ma and 132 Ma. This fault kinematics model is consistent with dextral strike-slip motion observed along the Xar Moron (Solon) suture in the Chifeng area, Inner Mongolian, where Liu et al. (2003) reported a whole rock Rb-Sr isotopic dating result of 165 Ma, for the age of ductile shear deformation in this fault zone.

Large-scale thrust sheets have been mapped and documented in the Yinshan belt, between the northern and southern Daqingshan fault zones (NDQF, SDQSF, Fig. 1). The NDQF, which forms the southern boundary of the Inner Mongolian "geoaxis", was inferred to thrust southward, while the SDQSF thrust northward prior to Cenozoic normal faulting. The narrow area in between develops the Jurassic basins and large-scale thrust-nappe structures, which have been investigated by Chen et al. (2002), Liu et al. (2002) and Zheng et al. (1998). According to their research results of the geometry and kinematics of thrust sheets in east Daqingshan, the pre-Cambrian basement was overthrust northward to Early-Middle Jurassic sediments, forming klippe-and-window structures. The minimum displacement of thrust sheets was estimated to 25–30 km and rooted to the SDQSF. Du et al. (2006) have shown that, in west Daqingshan, a N-verge thrust system consists of three zones, which from south to north are: a thrust nappe sheet zone, inclined to overturned fold and thrust zone, and a fault-relate fold zone, with deformation being weakened northward. The sense of thrusting is from SSE to NNW and the minimum displacement reaches 10–20 km. This thrust system has been thought to occur during the Late Jurassic because Early to Middle Jurassic sedimentary series were involved in the thrust-fold zone. The north Ordos fault zone (NOFZ, Fig. 1), presently a N-dipping normal fault which bounds the Cenozoic Hetao graben system to south, forms the southernmost boundary of the Yinshan contractional belt. Detailed field survey of Liu et al. (2004c), made along the northern edge of the Ordos basin, found a small-scale pre-Cambrian metamorphic sheet that was thrust southwards over Permian sediments; the minimum horizontal displacement of this sheet from the root zone of the NOFZ is about 5 km. This indicates that the W-E elongate zone presently buried beneath the Cenozoic deposits of the Hetao graben was a tectonic high.

3.5 The Qinling-Dabie tectonic belt (QDTB)

The tectonic history of this globally W-E extending belt is rather complex, characterized by long evolution history of accretions and collisions along the southern margin of the NCC (Zhang et al., 1996, 1997; Ratschbacher et al., 2003). The Triassic collision between the NCB and the

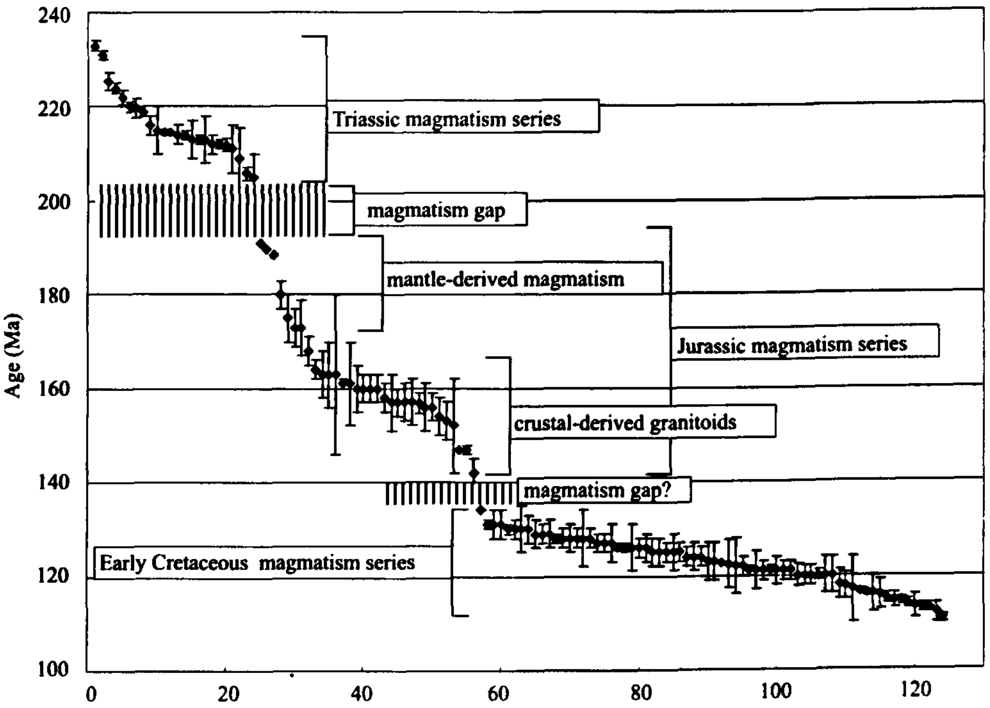


Fig. 3. Scatter plot of isotopic dating ages of Mesozoic intrusive rocks from the Jiao-Liao massif and Luxi-Xuhuai regions.

Data compiled from: Chen et al., 2003; Guo et al., 2005; Miao et al., 1998; Hu et al., 1987; Hu et al., 2004; Xu et al., 1997; Guan et al., 1998; Zhao et al., 1997, 1998; Zhou et al., 2003; Wu et al., 2005a, 2005b, 2006; Lin et al.,1996, 2000; Jin et al., 2003; Xu et al., 2004; 2005; Yang et al, 2005a, b, c.

SCB finally gave birth to this huge orogenic belt with UHP metamorphic rocks being exhumed in the Dabieshan and Sulu belts. Jurassic deformation is also important but poorly studied. The well documented Jurassic deformation has been found along the northern edge of Dabieshan, where different metamorphic rocks and Jurassic sediments were thrust northward on the Jurassic sedimentary series and overlain by Early Cretaceous volcanic rocks (Sun et al., 2004a, b). The most intensive shortening deformation occurred in a zone between the Xiaotian-Mozitan fault zone (XMF) and the Xingyang-Shucheng fault zone (XSF) (Fig. 2h, Liu and Wang, 1999). The trends of the major thrusts and reverse faults indicate NNE-SSW compression.

4 Jurassic Magmatisms

Jurassic intrusive rocks mainly outcropped in the Jiaolai-Liaodong massif east of the Tan-Lu fault zone, in the Bengbu uplift west of the Tan-Lu fault zone and along the Yanshan-Liaoxi belt. High resolution isotopic dating ages of intrusive rocks from these regions have been gathered and analyzed (see references in Figs. 3, 4) and age sequences of the Mesozoic magmatism series have been established by scatter plot (Figs. 3, 4).

Most foliated granitic plutons emplaced in the Jiao-Liao region and Bengbu uplift, once considered to be Proterozoic in age by regional geological survey, have been dated by the SHRIMP technique in the range of 150–160 Ma. Statistical analysis of reliable age data from the Jiao-Liao and Xu-Huai regions (Fig. 3) illustrates that the Jurassic magmatism series is distinctive from both Late Triassic and Early Cretaceous ones. There appears a magmatism gap in 205–190 Ma that separates the post-collisional intrusive rock series from the syn-collisional one. The tectonic significance of this magmatism quiescence stage is however not understood. The passage from Late Jurassic to Early Cretaceous magmatisms seems to be separated by a short gap in 143–135 Ma. Overall, Jurassic intrusive magmatism in these regions includes two rock groups: the Early Jurassic gabbro and diorite rocks and the late Jurassic S-type granitoids. The first one has been dated in the range from 190 Ma to 175 Ma; rock types and geochemistry indicate mantle-derived magma intruded under extensional tectonic setting. The late Jurassic plutonic rocks were mostly aged in the range of 160–150 Ma, some in 172–165 Ma and in 149–142 Ma. The rock types, geochemistry and field features indicate crustal-derived magma. The Early Cretaceous plutonism was predominated by crustal-mantle mixing, I-A magma type.

Jurassic magmatism along the Yanshan-Liaoxi belt seems to be mainly distributed in the Liaoxi area. The age plot diagram (Fig. 4) shows a magmatism gap in the time span between 210–195 Ma; it separates the Jurassic magmatism series from the Triassic one. The boundary between the Jurassic and Early Cretaceous magmatism series cannot be clearly separated. Overall, the Jurassic plutonic series can be grouped into three time spans: Early Jurassic (195–180 Ma) gabbro-diorite-quartz diorite-granite assemblage, Middle Jurassic (180–170 Ma) diorite-quartz diorite-granite assemblage, and Late Jurassic (165–138 Ma) granitoids. It seems that there is a short period of magmatism quiescence in 170–165 Ma. Along

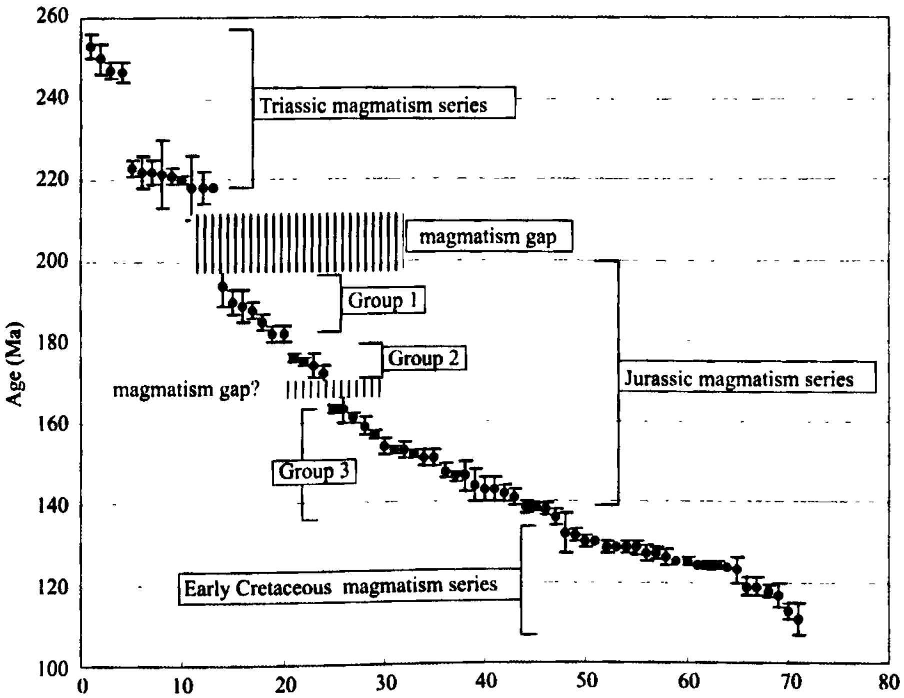


Fig. 4. Scatter plot of isotopic dating ages of Mesozoic intrusive rocks from the Yanshan-Liaoxi belt.

Data compiled from: Davis et al., 2001; Luo et al., 2001a, b, c, 2003, 2004; Mu et al., 2001; Han et al, 2004; Mao et al., 2003; Liu et al., 2004a; Li et al., 2003; Miao et al., 2003; Ren et al., 2004; Wu et al., 2006; Yan et al., 2000; Su et al., 2006.

the west Yanshan segment, Jurassic plutons are not well exposed; only some plutons outcropped in the Yunmengshan area have been dated to 160–141 Ma (Davis et al., 2001). This area contains two rock groups: one consisting of gabbro and diorite origin from mantle derived primitive magma; the other granodiorite origin from crustal-derived magma.

5 Stepwise Evolution of Jurassic Tectonics in North China

The above presentation shows that the Jurassic tectonics in North China developed episodically and is characterized by alternate compression-extension. By integrating the Jurassic stratigraphic sequences, magmatism and deformation events in North China, a chronology of three-stage evolution history of the Jurassic tectonics can be established and described in the following.

Stage I The earliest Jurassic stage (before ~190 Ma). This stage is marked by a magmatism gap in the Jiao-Liao and Xu-Huai areas and by regional uplift and erosion in North China as indicated by an erosional unconformity at the base of the Lower Jurassic in the Ordos and Hefei basins. Putonism only occurred scarcely in Liaoxi. The tectonic deformation pattern during this period has not been well recognized, although a pre-180 Ma compressional deformation phase was documented in the Yanshan belt (Zheng et al., 2000; Davis et al., 2001). It is likely that this stage might be predominated by the NCB/SCB collision along the Qinling-Dabie-Sulu belt and by the collision of the Siberian plate with the Mongolian-North China block (Chang, 1996; Yin and Nie, 1996).

Stage II The early to Middle Jurassic weak extension (190–170 Ma). This stage was tectonically relative quiescent and the continental lithosphere of North China was under weak extension manifested by (1) mantle-derived plutonism and mafic to acid volcanism active along the Yanshan-Liaoxi belt and alongside the Tan-Lu fault zone; (2) intensive normal faulting and sedimentation in extensional basins along the Yinshan-Yanshan belt; (3) resuming of subsidence and coal-bearing deposition over the areas of the Ordos basin, Shanxi highland and North China Plain. A vertical movement (different uplift and subsidence) governed sequential sedimentation of Early to Middle Jurassic stratigraphy. Normal faults inherited from W-E basement structures interior of NCB were observed to be active in and around the Ordos basin, indicating N-S to NNE-SSW extension (Zhang et al., 2006). Regionally, extensional deformation seems strong along the Yinshan-Yanshan belt and weak along the Qinling-Dabie belt. Geotectonically, Early-Middle Jurassic extension in North China might be considered as post-effect of the Triassic amalgamation collision between the NCB and the SCB and between the Siberian plate and the Mongolian-North China block.

Stage III Late Jurassic multi-directional contractions (from 165±5 Ma to 136 Ma). This stage is marked by intensive intraplate deformation involving thrusting and strike-slip faulting in North China, which resulted in dismembering of the unified Jurassic coal-bearing depression in North China. The present-day configuration of the Ordos basin was shaped. At least two major deformation events have been identified (see Table 1). The event I, marked by stratigraphic unconformity at the base of Upper Jurassic conglomeratic formations (the Fengfanghe Formation in west Ordos basin, the Daqingshan Formation

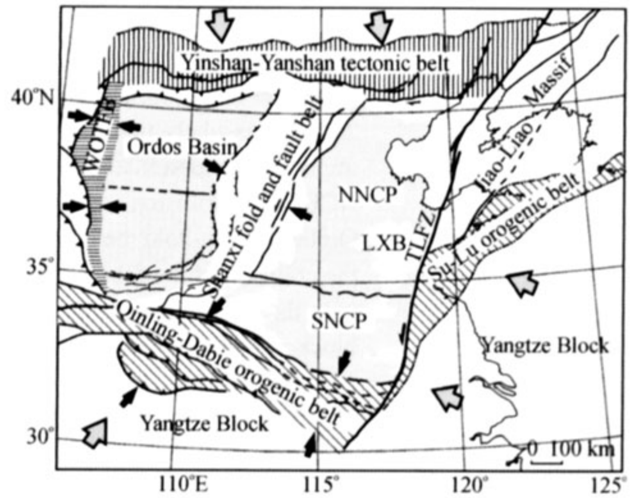


Fig. 5. Schematic map showing Late Jurassic multi-directional contractions.
WOTFB – western Ordos thrust-fold belt; NNCP – northern North China Plain; SNCP – southern North China Plain; LXB – Luxi block.

along the Yinshan range, the Houcheng Formation in West Beijing and the Tuchengzi Formation in Liaoxi); the Houcheng Formation has been dated to 152–136 Ma (Ji et al., 2004; Liu et al., 2006b; Sun et al., 2007). This shortening event should have started earlier but not predate 170 Ma. The fact that the 160–150 Ma period was marked by massif emplacement of syntectonic, foliated S-type granitoids along the Yanshan belt and in the Jiao-Liao massif and by mafic to acid volcanic activity in an area west of Beijing and along Yanshan-Liaoxi belt implies that the crust in the eastern part of North China was considerably thickened at the beginning of the Late Jurassic. Phase II, indicated by stratigraphic unconformity between the Lower Cretaceous above and the Upper Jurassic below, has been documented in the Ordos basin and along the Yinshan-Yanshan belt; it must predate 135±1 Ma (the base of the Zhangjiakou volcanic formation) and postdate 150 Ma. The short magmatism gap in the age range of 143–135 Ma, derived from the Jiao-Liao and Luxi-Xuhuai regions (Fig. 4), may coincide with this deformation event.

Tectonic deformation was characterized during this stage by multi-directional contractions which are summarized in Fig. 5. The Yinshan-Yanshan tectonic belt was activated by NNW-SSE compression, the Qinling-Dabie belt by NNE-SSW compression, the Western Ordos thrust-fold belt by nearly W-E compression, and the Shanxi highland was compressed in the NWW-SEE to NW-SE direction. The Tan-Lu fault zone slipped left-laterally and deformation in the Jiao-Liao region east of the Tan-Lu fault zone involves both thrusting and sinistral strike slip faulting, resulting from NW-SE to NWW-SEE compression.

6 Discussions

6.1 Middle to late Jurassic crustal thickening, tectonic style and strain partitioning

Several lines of evidence exist to infer that the crust and lithosphere of the eastern part of the North China block was considerably thickened by crustal shortening during the Middle to Late Jurassic. (1) Massif emplacement of late Jurassic S-type granitic plutons along the Jiao-Liao massif east of the Tan-Lu fault zone and in the Bengbu uplift west of the Tan-Lu fault zone, as well as along the Yan-Liao belt indicate important thickening of the crust near the end of the Middle Jurassic. (2) Geochemistry studies also suggested that the volcanic rocks of the Late Jurassic Tiaojishan or Lanqi Formation along the Yan-Liao belt represent the adakites occurred in a thickened crust (Li et al., 2001; Li and Li, 2004). Lu et al. (2006) estimated the crustal thickness in the Yanshan belt to be 40–45 km before the Tiaojishan volcanic activity. (3) Moreover, the Late Jurassic Fengfanghe conglomerates deposited along the western margin of the Ordos basin, the Tuchengzi or Houcheng conglomerates developed along the Yan-Liao belt and the Daqingshan conglomerates along the Daqing Shan belt, all represent syn-tectonic growth strata in response to crustal shortening deformation.

Jurassic contractional structures in North China show contrasting deformation styles. On one hand, thrusts, reverse faults and associated folds in the Shanxi highland have been related to a gently dipping décollement zone probably occurring in the middle crust, while the lower crust remained undeformed. This thin-skin tectonic style prevailed over the Shanxi highland and possibly along the two latitudinal tectonic belts west of the North-South Gravity Anomaly Gradient lineament. On the other hand, Late Jurassic deformation in the Jiao-Liao massif east of the Tan-Lu fault zone appears to be dominated by lower crust involvement thick-skin tectonic style, as indicted by massif emplacement of late Jurassic granitic plutons. Small-scale foliated granitic plutons documented in the Bengbu uplift west of the Tan-Lu fault zone also implies lower crust involvement in the North China Plain. The fact that there was no Jurassic plutonism in the Shanxi highland implies that the eastern edge of the Mts. Taihangshan, which corresponds to the North-South Gravity Anomaly Gradient lineament, could be a transition between lower-crust involved thick-skin deformation to the east and upper crust involved thin-skin deformation to the west.

The deformation style of the Jurassic rejuvenation along the two latitudinal tectonic belts (the Yinshan-Yanshan and Qinling-Dabie ranges) was also partitioned between the east and west segments. For instance, the lower crust was involved in the Jurassic shortening along the Yanshan-Liaoxi belt, where Jurassic magmatism was active; while no Jurassic magmatism occurred along the Yinshan belt indicating upper crust involved thin-skin deformation.

Accordingly, crustal deformation was temporally and spatially partitioned into thrusting and sinistral strike-slip faulting. A general interpretation is that crustal shortening duo to nearly N-S contraction was localized along the two latitudinal belts, while NW-SE contraction took place over a broad area of North China involving the Shanxi highland, NNCP and Jiao-Liao massif. Specifically, the Jiao-Liao massif was deformed by both thrusting and sinistral strike-slip faulting, the Shanxi mainly by thrusting and folding, and the region beneath North China Plain by strike-slip faulting with thrust component. This pattern of deformation partitioning indicates multi-directional compressions acting in North China in the Late Jurassic.

6.2 Plate dynamic settings of Jurassic multi-directional contractions in North China

The occurrence of Mid-Late Jurassic contractions in North China is of regional tectonic significance, which has been investigated and discussed for more than 80 years since Wong (1927, 1929). Zhao et al. (1994, 2004) have hold that Jurassic tectonothermal events identified in the areas of Yanshan, Liaoxi and west Beijing, recorded tectonic transition from the paleo-Asian and paleo-Tethyan systems to paleo-Pacific active margin system in eastern Asia, which began at ~170 Ma and ended up before 135±1 Ma. The thought of late Mesozoic tectonic regime transition in east China has become an issue of wide discussion in the Chinese literatures (e.g., Wu et al., 2000, 2004; Xu et al., 2004; Zhai et al., 2004a, b; Zhou, 2006). In these discussions, people focused on the question of lithosphere thinning and craton destruction, but ignored the fact that there was a considerable crustal thickening before lithosphere attenuation. We believe that there should have a causal link between the Jurassic contraction and crustal thickening in North China and subsequent Early Cretaceous extension and lithosphere thinning in east China (Dong et al., 2008).

In fact, the Late Jurassic is an important era of intraplate deformation and intracontinental orogenesis in East Asia, characterized by multi-directional contractions, formation and rejuvenation of different oriented tectonic systems. Plate boundaries active during the Mid-Late Jurassic include a paleo-Pacific subduction zone along the eastern margin of the continent, a subduction/collisional zone between the Qiangtang and Lhasa blocks in Tibet, and a subduction/collisional zone between the Siberian plate and Mongolia-North China block. The North China Craton seems to be located in the center of such active plate boundary systems. The appearance of an active and accreted margin duo to westward subduction of the Paleo-Pacific plate beneath the Asia continent played the key role in intraplate tectonics of North China. Synchronous convergences of three plates, the Siberian in the north, the paleo-Pacific in the east and the Lhasa block in the west, toward the East Asian continent governed the Middle to Late Jurassic multi-directed contractions and deformation partitioning in North China.

The Paleo Mongolia-Okhotsk ocean was finally closed around the Middle Jurassic (Parfenov and Natal'in, 1986; Zhao et al., 1990; Nie and Rowley, 1994; Zorin et al., 1995), and the collision between the Siberian plate and the Mongolia-North China block continued during the Late Jurassic, which rejuvenated old orogenic belts and resulted in intensive intraplate deformation along the Yinshan-Yanshan belt. Great Jurassic thrust sheets documented in the North Mountain-Gobi area (Zheng et al., 1996) are the best example for south-directed motion of the Mongolia-North China block located far from the plate boundary. To the west in the Tibetan Plateau, the Lhasa block collided with the Qiangtang terrain along the Bangong-Nujiang suture during the Late Jurassic (around 160 Ma), evidenced by stratigraphic unconformity between the Lower Cretaceous and the Jurassic (Jia et al., 2005). Liu et al. (2003) reported ^{40}Ar-^{39}Ar dating results, aged 178.4–137.5 Ma, of deformed granitic gneiss along the eastern segment of the Altyn Tag fault zone, which recorded these tectonothermal events. Wang et al. (2005) documented an important cooling event, 165–160 Ma, representing sinistral strike-slip shearing along the Altyn Tag fault in response to the closure and collision along the Bangong–Nujiang suture. This block collision caused the eastward broadened, wedge-shaped Alxa and Longxi blocks, north of the Haiyuan fault zone, to be extruded eastwards, as a consequence, resulting in activation of the basement weak zone along the western margin of the Ordos block (Zhang et al., 2007). To the east along the west Pacific margin, the Paleo Pacific plate started subducting under the Asian continent in the Middle Jurassic around 170 Ma (Isozaki and Nishimura, 1989; Isozaki, 1997; Maruyama et al., 1997). Isozaki et al. (1990) believed that the majority of the Japanese subduction-accretion complexes were formed during the subduction of plates up to 160 Ma old. Oblique flat subduction of the oceanic slab is inferred to occur during the Mid-Late Jurassic, and the oceanic lithosphere was underplated beneath the East Asian continent, which caused crustal thickening and strain partitioning between thrusting and sinistral strike-slip faulting in the eastern part of the North China block.

7 Concluding Remarks

The Jurassic was an important era for the development of intraplate tectonics in East Asia. It is characterized in North

China by three-stage evolution history. The Early to Middle Jurassic weak extension (190–170 Ma) identified in North China represents a period of transition from the early tectonic stage to the late tectonic stage. The early tectonic stage was dominated by continent-continent collisions between the NCB and the SCB along the Qinling-Dabie-Sulu orogenic belt and between the Siberian and Mongolian blocks, while the late tectonic stage (from 165±5 to ~136 Ma) was dominated by multi-directional contractions and strong intraplate deformations. This late tectonics stage evolved episodically; contractional deformation was partitioned spatially and was related to far-field effects produced by synchronous convergences toward the East Asian continent of three plates, the Siberian in the north, the Pacific in the east and the Lhasa block in the west. The North China block seems to be situated in the center of such plate convergence settings; the crust of its eastern part was thickened considerably, which became the triggering factor for subsequent Early Cretaceous lithospheric thinning in East China. It was during this stage that the Tan-Lu fault system developed on the eastern margin of the Asia continent.

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