Early Mesozoic basin development in North China: Indications of cratonic deformation

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A B S T R A C T

We integrated a systematic sedimentary data into a regional Early Mesozoic stratigraphic framework which demonstrated a detailed picture of spatiotemporal variations in basin deposition and formation in the North China Craton. The Early Mesozoic basin sedimentary evolution is utilized to interpret polyphase tectonism and to unravel the craton deformation. The Late Triassic, nearly WNW-trending, giant intracratonic Ordos basin was widely distributed across most of North China Craton, with a southern wedge-top depozone along the northern East Qilian–Qinling orogenic belt and a northwestern rift depozone along the Helanshan. The continuous subsidence and deposition within the basin were dominantly related to the thrust load of the East Qilian–Qinling belt and inferred mantle flow effects associated with paleotethys plate subduction, and the rift in the northwestern Ordos was driven by nearly north-vergent compression of the eastern North Qilian–North Qinling active margins with the stable North China Craton. This intracratonic Ordos basin formation initiated the deformation of the North China Craton. Formation of the Jurassic NNE-trending walled intracratonic Ordos basin and the broken flexural basins indicate the North China Craton underwent the second, even more abroad nearly NNE trending crustal deformation, with lithosphere thickening in the eastern part of the North China Craton, and dynamic subduction in the west, which may have been driven by nearly northward subduction of the Iazangi plate and the eastward extrusion and underthrusting of the western North China Craton crustal basement.

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1. Introduction

The North China Craton (NCC) is one of the oldest continental nuclei in the world (Jahn et al., 1987; Zheng et al., 2004). Early Paleozoic emplacement of diamond-bearing kimberlites within the craton indicates that a thick (ca. 200 km) and cold ancient lithosphere was already developed by the mid-Ordovician (Zheng and Lu, 1999). In contrast, basalts erupted at 674 Ma contain peridotite xenoliths and show that this same lithosphere was then as much thinner (<90 km), hot and compositionally heterogeneous (Xu et al., 1995; Zheng et al., 1998, 2001). Consequently, more than 100 km of cratonic lithosphere must have been removed or been strongly modified between the mid-Paleozoic and late Mesozoic (Fan and Menzies, 1992; Griffin et al., 1998; Menzies et al., 1993; Zheng, 1999; Gao et al., 2002; Zhang et al., 2007; Zhu et al., 2011). Regional extensional tectonics may be expected to have accompanied such a significant lithospheric thinning. The most likely phase of extension, documented across the North China region, reached a peak in the Early Cretaceous (ca. 125 Ma) (Zheng et al., 1999; Wu et al., 2006; Zhu et al., 2011). However, whether the deformation of the craton was initiated in the earlier Mesozoic (Late Triassic and Jurassic) (Xu et al., 2004a,b; Wu et al., 2006; Yang and Wu, 2009) is unclear. Observational constraints of the crustal tectonic process and the deformation mechanism of the NCC in this initial stage and its association with the Early Cretaceous extension are still limited. From the Permian to the Jurassic, the NCC and its adjacent regions underwent a series of tectonic events. The closure of the central Asian Ocean, the collision between North China and South China, and the initial subduction of the Paleo-Pacific plates acted on the northern, southern and eastern margins of the North China block, respectively, resulted in intraplate deformation (Davis et al., 2001; Darby and Ritts, 2002; Liu et al., 2007; Zhu et al., 2011; Zhang et al., 2011). Investigating these tectonic episodes helps to reveal the initial deformation (or modification) of the NCC. Basin studies of the relatively complete upper Paleozoic–Mesozoic section of North China, dominantly in the Ordos basin, provide
insights into the regional tectonics of the North China and clues to how and when the NCC began to deform. Based on our new sedimentary data and well-documented regional Mesozoic stratigraphic framework, this paper presents a detailed analysis of the temporal and spatial variations of sedimentation, depocenter migration and isolation, and the linkage between the Early Mesozoic basin evolution and coeval basin-margin tectonics. These new data provide further constraints on the mechanism of initial NCC modification.

2. Regional setting

The NCC, within the North China block (NCB), is bound on the north and south by orogenic belts and on its eastern margin by a subduction zone (Fig. 1). The Qinling–Dabie orogenic belt on the south experienced a protracted tectonic history (Liu and Zhang, 1999; Zhang et al., 2001; Dong et al., 2011), and underwent a two-phase collision along two suture zones, the Shangdan suture in the north and the Mainline suture in the south, in late Paleozoic and Triassic times, respectively. The Qinling–Dabie orogenic belt is divided into the North Qinling and the South Qinling belts by the Shangdan suture which represents the major suture separating the North China and South China blocks. The Shangdan ocean was finally closed prior to Middle Devonian (Dong et al., 2011). The Mainline suture zone is a composite tectonic zone formed on the basis of the Qinling–Dabie subduction–collision suture and superimposed by the Mesozoic and Cenozoic intracontinental structure (Zhang et al., 2001). There are ophiolites, oceanic island and island-arc volcanic rocks exposed along the Mainline zone stretching 1500 km from east to west (Dong et al., 2011). The Mainline suture represents the Mainland ocean which separates the South Qinling from the South China block in Devonian to Mid Triassic times (Liu and Zhang, 1999). After the closure of the Mainland ocean, the South Qinling belt was emplaced onto the Yangtze Block along the Middle Triassic Mainline suture zone and the North Qinling was thrust onto the North China block (NCB) along the Luan-nan–Luanchuan fault in Late Triassic–Jurassic times (Figs. 1 and 2a; Liu and Zhang, 1999; Zhang et al., 2001; Dong et al., 2011). To the east, the Qinling–Dabie orogenic belt is separated from its eastern part, the Euyangzi orogenic belt, by the NE-striking Tanlu fault zone. Along the Qinling–Dabie–Euyangzi orogenic belt crops out the world's largest terrane composed of ultrahigh-pressure metamorphic rocks, which originally formed at ca. 220–240 Ma by radiometric studies (Li et al., 1993; Ames et al., 1993; Hacker et al., 1998; Liu et al., 2004b). These ages indicated the timing of the final collision. The occurrence of coesite- and diamond-bearing, ultrahigh-pressure metamorphic rocks indicates that crustal rocks of the South China block were subducted to depths of >100 km under the North China block (Liu et al., 2006; Hacker et al., 2006).

The central Asian orogenic belt was located to the north of the NCC (Fig. 1). Within this belt, the Solonker suture separated the northeastern China–Mongolia arc complexes (NECM) from the NCB. Further north, the Mesozoic Mongol-Okhotsk suture belt is developed between the NECM and Siberia plate (Zorin et al., 1995; Zorin, 1999). The Solonker suture separates a northern accretionary belt that had consolidated by the Permian, when it developed into an Andean-type continental margin above a north-dipping subduction zone, from a southern accretionary belt that had consolidated by the Carboniferous–Permian when it...
evolved into an Andean-type continental margin above a south-dipping subduction zone (Xiao et al., 2003; Windley et al., 2007). With final subduction of the intervening ocean, these two opposing active continental margins collided to give rise to the Solonker suture (Xiao et al., 2003; De Jong et al., 2006). There are some controversies over the collision age, but confirmation of the middle or late Permian age of the collision is provided by a widespread terrigenous facies sedimentation from the Early–Middle Carboniferous to the Early Triassic (Zhu et al., 2011). Closure of the central Asian Ocean (Solonker suture) in the north margin, closure between the North and South China in the south, and potentially initial subduction of the Paleo-Pacific plate acted on the margins and interiors of the NCC (Liu et al., 2007; Zhu et al., 2011). The Late Triassic–Jurassic stratigraphy in the NCC and its adjacent mountains (Fig. 3) records these tectonic processes.

3.1. Stratigraphy in Ordos basin and its marginal mountains

Upper Triassic strata unconformably rest on the Middle Triassic in the Ordos basin and are dominated by thick, coarse to median sandbodies, interbedded with thin mudstone layers of the Yangchao Formation. These sequences are continuous southward in the North Qinling belt, but a dramatic facies change into Triassic–Jurassic sandstones interbedded with mudstone deposits (Fig. 3). Lower–Middle Jurassic strata are composed of mostly median to fine-grained sandstone and mudstone of the Yanan, Zhiluo, and Anding Formations in the Ordos basin, which extend to the western Taihangshan. But the Upper Jurassic Fenfanghe Formation is composed of unconformity-bound, coarse-grained clastic wedges, confined along the southwestern and northwestern Ordos basins (Fig. 3). Along the Yinshan fold-thrust belt, the Lower Jurassic Shiguai Formation, in the Shiguai basin (Fig. 1), for example, consists of boulder conglomerates and fluvial and deltaic sandstones and mudstones (Ritts et al., 2001). The Middle–Upper Jurassic Changhangou and Daqingshan Formations were dominantly composed of sandstone interbedded with conglomerate and conglomerate, respectively (Fig. 3). Jurassic rocks were deposited in the Hefei basin along the northern margin of the Qinling–Dabie orogenic belt, characterized by a general coarsening-upward clastic sequence, as represented by the early Jurassic Fanghushan.
Formation, Middle Jurassic Sanjianpu Formation and Upper Jurassic Fenghuangtai Formation (Fig. 3).

3.2. Stratigraphy in Yanshan orogenic belt

Late Triassic and Jurassic strata in the Yanshan fold-thrust belt are composed of Xingshikou, Nandaling, Xiahuayuan, Jiulongshan, Tiaojishan, and Tuchengzi Formations (and the other equivalent formations) (Fig. 3). Correlation of these strata in the Yanshan fold-thrust belt remain controversial. The deformed Xingshikou Formation, mostly composed of conglomerate, unconformably overlies the Early–Middle Triassic (Liu et al., 2007). U–Pb ages of detrital zircons within the formation include subsidiary peaks occurring at 198 ± 5 Ma (Liu et al., 2012) and /C24205 Ma (Yang et al., 2006), indicating a Late Triassic maximum depositional age. The Nandaling Formation, overlying the Xingshikou Formation, consists of basalts and associated clastic rocks, with a40Ar–39Ar biotite age of 180 ± 2 Ma (Davis et al., 2001) and a minimum U–Pb zircon age of 174 ± 8 Ma (Zhao et al., 2006) for the basalts. Therefore, most of the Nandaling Formation is Early Jurassic.

The Xiahuayuan Formation mostly conformably rest on the Nandaling Formation, and is predominantly sandstone and conglomerate, mudstone, and sandstone interbedded with mudstones. Jiulongshan Formation comprises fine-grained mudstone interbedded with thin coarse-grained sandstone and conglomerate. The Tiaojishan Formation (or Lanqi Formation), covering the Jiulongshan, mainly comprises andesitic and basaltic breccia, conglomerate, and tuff, interbedded with some sedimentary layers. Collectively, Ar/Ar and U–Pb ages span ca. 175–148 Ma for the Tiaojishan (the Lanqi) Formation (Davis et al. 2001; Zhao et al. 2004; Davis, 2005; Liu et al., 2007; Hu et al., 2010). The Tuchengzi (or Houcheng) Formation unconformably rests on the Xiahuayuan, Tiaojishan Formation, and Archean metamorphic rocks, and is overlain by the Zhangjiakou Formation. The Tuchengzi Formation consists of thick, massive, or horizontally stratified conglomerate intercalated with massive or laminated mudstone and thin layers of pebbly sandstone. Published K–Ar, Ar–Ar, and U–Pb ages from the Tuchengzi and Zhangjiakou Formations are ca. 156–139 Ma (Davis, 2005; Davis et al., 2001; Shao et al., 2003; Zhang et al., 2002) and ca. 147–127 Ma (Li et al., 2000; Swisher et al., 2002; Niu et al., 2003; Zhao et al., 2004; Zhang et al., 2005), respectively. These ages of the Tiaojishan, Tuchengzi, and Zhangjiakou Formations indicate that there is considerable diachroneity in the timing of volcanism and sedimentation. Based on geochronology and stratigraphic relations, the Xiahuayuan and Jiulongshan Formations are thought to be dominantly Middle Jurassic, Tiaojishan Formation to be Late Jurassic, Tuchengzi Formation to be Late Jurassic, and finally Zhangjiakou Formation to be Early Cretaceous (Fig. 3).

3.3. Regional stratigraphic correlation

The geochronology, the well-exposed unconformities, and the basin fill characterize the Early Mesozoic stratigraphy as three unconformity-bound phases within the basin, from oldest to
youngest: an Upper Triassic, Lower–Middle Jurassic, and Upper Jurassic phases (Fig. 3). The deformed Xinshikou Formation in the Yanshan belt is constrained to between 205 and 198 Ma (Yang et al., 2006; Liu et al., 2012), and corresponds to the uppermost part of the Upper Triassic basin phase filling the Ordos basin and the intermontane basin in the North Qinling belt. The Xiahuayuan and Jiulongshan Formations, covered by the Tiaojishan volcanic and volcanoclastic rocks, are correlated with the Yanan, Zhiluo, and Anding Formations in the Ordos basin, and both of the Xiahuayuan and Yanan Formations are coal-bearing sequences. All these formations constitute the Lower–Middle Jurassic basin phase. The Upper Jurassic basin phase is characterized by localized basin deposits, constrained to the western margin of the Ordos basin, the central Yanshan and Yinchuan basins, and the north of the Dabie, including the Fenfanghe, Tuchengzi, Daqingshan, and Fenghuangtai Formations, respectively.

4. Sedimentology

Depositional systems are especially sensitive to tectonics, and clearly reflect the basin marginal tectonic control at the margins of the basins (Liu and Yang, 2000). For NCC basin evolution their margins had different structural configuration during different stages. Through the temporal and spatial variation of the basin depositional systems, the tectonic evolution of the NCC is revealed.

4.1. Upper Triassic basin phase

Upper Triassic basin phase was largely distributed over the entire NNC, including the Ordos basin, the intermontane basins in the North Qinling and Yanshan fold-thrust belts.

4.1.1. Ordos basin

The Late Triassic Ordos basin was filled by a 3000 m thick succession of clastics, the Yanchang Formation, which was derived from the emerging North Qilian and North Qinling thrust belt to the southwest and south, the Alxa block to the northwest, and the Yinchuan Mountains to the north. With different structural controls, the stratigraphic succession has various depositional systems.

The northwestern Ordos subbasin is mostly located in the Helanshan Mountains, and spatially lined with the Alxa Massif. The lower part of the Yanchang Group deposited in this subbasin consists of alluvial fan conglomerates distributed only in the narrow western flank of Helanshan (Fig. 4) and up to 900 m thick, braid-plain coarse-grained sandstones deposited in the axis of the subbasin (Schumm, 1977; Liu and Yang, 2000) (Fig. 4). The alluvial fan-braid plain system represents the first tectonosedimentary facies configuration in the lower Yanchang Group in the northwestern Ordos subbasin (Liu and Yang, 2000). Palaeocurrent indicators demonstrate that the braided channels were oriented nearly parallel to or at a sharp angle to the basin axis (Liu and Yang, 2000). The Upper part of the Yanchang Group consists of several upward-coarsening successions, with both gravel deposits, which are restricted to a narrow band (<10 km) along the western Helanshan (Fig. 4B), and sandstone deposits covering almost the entire subbasin (Fig. 4C). All the gravel and sandy deposits are made up of fan deltaic and lacustrine systems (McPherson et al., 1987; Ritts et al., 2004), and represent the second tectonosedimentary facies configuration in the upper Yanchang Group (Fig. 4) (Liu and Yang, 2000). Palaeocurrent indicators show that the fan deltas issued from the western uplifting Alxa block, and flowed transversely to the basin axis (Liu and Yang, 2000; Ritts et al., 2004). The facies belts are oriented in a nearly N–S direction, controlled by the orientation of the western Helanshan structures.

In the southwestern Ordos, the Upper Triassic succession mostly consists of thick, vertically stacked, tabular, proximal sandbodies (40–150 m in thickness) interbedded with units of thin mudstone (<25 m in thickness) of overall coarsening-upward
appearance (Liu and Yang, 2000). Further out in the subbasin, deposition is primarily fine-grained sediment. In the basin margin, deposits are characterized by coarse gravels with massive, imbricated, and parallel beddings. Pebbly, silty sandstone forms small tongues between conglomerate lithosomes (Liu and Yang, 2000). These strata mainly comprise braided delta and alluvial fan systems (Liu and Yang, 2000; McPherson et al., 1987). The facies belts of the braided delta and lacustrine in the southwestern Ordos subbasin are orientated NW–SE, parallel to the marginal North Qilian fold-thrust belt to the southwest, and continuously extend eastward, parallel to the North Qinling fold-thrust belt.

The Upper Triassic succession in the northeastern present-day Ordos basin and Ningwu basin (Figs. 1 and 5) is composed of more than 500 m of coarse to fine-grained sandbodies interbedded with mudstone and lens-shaped pebble conglomerates. The whole succession, with a fining-upward appearance, are interpreted as meandering and braid channel deposits (Schumm, 1977) with a dominantly southern-flow direction (Fig. 5), sourced from the Yinshan Mountains in the north, but further south, they are changed into lacustrine delta deposits (Li et al., 1997).

### 4.1.2. Intermontane basins within the North Qinling fold-thrust belt

The Upper Triassic strata are locally distributed between the Luonan-Luanchuan fault and Shangdan suture within the North Qinling fold-thrust belt (Fig. 1). The stratigraphy was deformed. The measured section in Nanzhao county, more than 1000 m thick, consists of three parts (Fig. 6). The lowest part, ca. 70 m thick, comprises vertically stacked, upward fining, lens-shaped pebble conglomerate and coarse to fine-grained sandbodies interbedded with thin coaly shale and coal seams. Its depositional configuration is suggestive of a braided channel (e.g., Miall, 1978). The middle part, ca. 200 m thick, consists of three or more coarsening-upward successions with lower dark mudstone interstratified with thin, massive or ripple bedding, fine-grained sandstone layers, and massive, tabular or trough cross-bedding, coarse-median grained sandbodies, capped by massive and tabular coarse to median grained sandstones with plant fossils interbedded with thin coal layers. Deposition in this part is interpreted to be a braided delta (e.g. McPherson et al., 1987). The upper part, more than 750 m thick, consists of fine-grained mudstones with lacustrine fauna interbedded with thickening and coarsening upward, coarse–fine grained sandstone layers in which subaqueous slide structures, flute marks, massive or parallel beddings are developed indicative of a deep lacustrine and turbidite deposit (Liu et al., 1999). These depositional systems occur in the whole area of the North Qinling belt but the grain size and thickness increase southwards. The sections along the southern margin of the belt, more than 1500 m thick, are capped with thick fluvial plain sandbodies and alluvial fan cobble-boulder conglomerate sourced from the south, bounded by northward-vergent thrust fault suggesting that the intermontane basin was a thrust-controlled flexural depression.

### 4.1.3. Intermontane basins within the Yanshan fold-and-thrust belt

The Upper Triassic succession crops out in two E–W–trending zones, the northern and southern outcrop zones, in the Yanshan belt (Fig. 1). The Upper Triassic Xingshikou Formation in the northern zone includes two depositional sequences. One, ca. 320 m in thickness, consists mainly of grain-supported, imbricated, partly massive braided channel conglomerate (Liu et al., 2007); Imbricated clast orientations indicate southward flow (Liu et al., 2012). The other, ca. 40 m in thickness, is composed of poorly sorted, unstratified, clast-supported, and subangular or angular cobble and boulder debris flow conglomerates (Liu and Yang, 2000; Liu et al., 2007) (Fig. 7A); This conglomerate unconformably overlies Archean basement.

Upper Triassic strata in the southern outcrop zone, 15–20 m in thickness, consist of a granule conglomerate with some sandstone intervals (Fig. 7B). The whole section of the Xingshikou Formation
is divided into four fining- or coarsening-upward depositional cycles that consist of conglomerate, sandstone, and siltstone with massive bedding or cross-stratification, interpreted as gravelly, meandering channel deposits (Liu et al., 2007). Paleocurrent indicators (cross-stratification) suggest flow was to the west and southwest (Liu et al., 2007).

4.2. Lower and Middle Jurassic basin phase

The early and middle Jurassic strata were mostly deposited in the Ordos basin and its marginal intermontane basins. Here we only describe the Lower and Middle Jurassic basin phase in the Ordos basin and intermontane basins in the Yanshan belt.

4.2.1. Ordos basin

The pre-Jurassic unconformity is a basin-wide erosional surface. Lower Jurassic Fuxian Formation was deposited in local depressions developed on the pre-Jurassic erosional surface (Song, 1989). The lens-shaped, fining-upward, incised meandering channel sandbodies were deposited on the undulating topography (Liu and Yang, 2000). Deposition of the middle Jurassic Yanan Formation over the present-day Ordos basin (Fig. 1; Figs. 8H–K) and separated Ningwu (Fig. 8F) and Datong (Fig. 8L) basins (Fig. 1) commenced with the deposition of coarse-grained sandbodies and a few small poorly-sorted or oriented conglomerate. The middle part of the Yanan Formation is mainly composed of multiple coarsening-upward successions from mudstone with lacustrine fauna interbedded with fine to median grained sandstone layers. At its upper part, the Ordos lake was infilled with several coal-bearing parasequences consisting of fine-grained mudstone with horizontal beddings, fine-grained sandstone layers with tabular cross-beddings, and lens-shaped fine to median grained sandbodies with tabular and trough cross-beddings. The depositional characteristics indicates that the Yanan Formation was deposited with lowstand fluvial, transgressive lacustrine, and highstand deltaic systems (Liu and Yang, 2000).

The Zhiluo Formation of the Middle Jurassic is characterized by lateral extended, coarse to median grained sandbodies with trough...
cross-bedding interbedded with thin mudstones and fine grained sandstones, and is interpreted to be braid channel and flood plain deposits (Miall, 1978). Its large fluvial channels flowing from west to east produced the sub-Zhiluo erosional surface, and formed palaeovalleys in the underlying Yanan strata (Li et al., 1995). The Anding Formation at the upper part of the Middle Jurassic consists of purple-red, variegated strata presumably deposited in a semi-arid climate (Li et al., 1995). It includes mudstone interbedded with fine-grained sandstone, representing deposits of deltaic and lacustrine systems (Liu and Yang, 2000).

4.2.2. Intermontane basins within the Yanshan fold-thrust belt

A series of intermontane basins of the Early–Middle Jurassic were developed in the Yanshan belt (12, 13, 14, 15, 16, and 17, Fig. 9B). The Middle Jurassic Xihuayuan Formation is characterized by a coal-bearing succession, ca. 100 m in thickness in the Luanping–Chengde basin (16, Fig. 9B). At the base of the formation, a fining-upward sequence of conglomerates and fine sandstones, 10 m in thickness, is developed (Liu et al., 2004a). High upward in the sequence three coarsening-upward depositional sequences are developed, which are composed of horizontal laminated shale or very fine-grained shale and thin, massive coarse-grained and pebbly sandstones and conglomerates. At the top of these sequences there are ca. 25 m thick, laminated conglomerates with scoured surfaces and lens-shaped sandstone interlayers. The three depositional sequences are interpreted to be meandering channel, lacustrine and turbidite depositional systems with gravel braided channel deposits at their top (Liu et al., 2004a). In the Chicheng and western Beijing basins (14 and 15, Fig. 9B), the thick, dark lacustrine mudstone (Fig. 7C), and lacustrine mudstone interbedded with massive-bedding mouth bar deposits (Fig. 7D) are developed at the Xihuayuan Formation.

The Jiulongshan Formation, in concomitance with overlying volcanic and pyroclastic rocks of the Tiaojishan Formation, is mostly distributed along the synclines in the Yanshan belt. The Jiulongshan Formation within Luanping–Chengde basin (16, Fig. 9B), 160 m thick, mostly consists of red shale, silty shale and coarse-grained sandstone and conglomerate intervals. The sandstone,
gravel sandstone and conglomerate are in the shape of lens, in which massive and cross-beddings are developed, and horizontal lamination is developed in mudstones. The whole section forms 6 small coarsening upward cycles, which are interpreted to be fan delta depositional systems with subaqueous distributary channel deposits at the top of cycles and debris flow intervals within lacustrine shale (McPherson et al., 1987; Liu et al., 2004a).

4.3. Upper Jurassic basin phase

During the Late Jurassic, the NCC underwent a regional uplift, and the sedimentary basins became confined to marginal fold and thrust belts. The western Ordos basin and the intermontane basins in the central Yanshan belt are typical examples.

4.3.1. Western Ordos basin

The Upper Jurassic Fenfenghe Formation is composed of unconformity-bounded, coarse-grained clastic wedges along the southwestern and the northwestern Ordos subbasins (Fig. 9C). The northwestern Upper Jurassic clastic wedge tapering to the east is distinct on seismic reflection sections (Liu and Yang, 2000), and the southwestern clastic wedge tapering to the northeast is well exposed in the Fenfenghe district (Fig. 9C). These molasse wedges in the southwestern Ordos subbasin are predominantly composed of more than 1000 m of vertically stacked, imbricated (Fig. 7E) or poorly-sorted, cobble-boulder conglomerates, which are interpreted to be from alluvial fans (Liu and Yang, 2000). Palaeocurrent indicators obtained from clast imbrication indicate that the fans were built by runoff that flowed toward the north, north-east–north, and north-west–north. Conglomerate composition is dominantly granite gneiss, schist, and marble with a smaller amount of quartzite and dolomite clasts, and their lithology is similar to the Proterozoic Kuaping high-grade metamorphic rocks in the North Qinling belt. This indicates that the Fenfenghe Formation was sourced from the North Qinling belt to the south, and the molasse wedges were the depositional response to the rejuvenation of thrusting along the western margin of the Ordos basin. The molasse wedges in the northwestern Ordos subbasin are bounded by the Tiekesumiao thrust fault (Liu and Yang, 2000), and are composed of more than 2000 m thick of alluvial fan conglomerate at the thrust front, sourced from the west. These deposits are interpreted to be the response to the east-vergent progradating thrust of the Helanshan belt.

4.3.2. Intermontane basins within the Yanshan fold and thrust belt

Late Jurassic intermontane basins in the Yanshan belt are located along the thrust faults (Fig. 9C). The Upper Jurassic Tuchengzi Formation is characterized by thick, massive, or horizontally stratified conglomerate (Fig. 7F) intercalated with one or two parts of massive or laminated mudstone and thin layers of pebbly sandstone or conglomerate in the middle of the conglomerate (Liu et al., 2007). The Tuchengzi Formation has dramatic lateral changes in maximum clast size, which reach their largest size at the margins of the basins near the basin bounding thrust systems.

5. Basin evolution

5.1. Intracratonic basin (Late Triassic)

The Late Triassic intracratonic basin, the Ordos basin, in NCC, with ~several thousand km in lateral dimension and thick accumulations, was developed on rigid lithosphere and associated with the formation of a parallel-extended megasuture (Specht et al.,
Fig. 9. Tectono-paleogeographic maps of Upper Triassic (A), Middle Jurassic (B), and Upper Jurassic (C) in the North China Craton. The map (B) dominantly shows the early Middle Jurassic paleogeographic framework of the Yanan (in Ordos basin) and Xihuaquan (in Yanshan Mountains) formations in which 12, 13, 14, 15, 16, and 17 represent the Shangyi, Xuanhua, Chicheng, western Beijing, Luanping–Chengde, and Beipiao basins. The map (C) dominantly shows the paleogeographic framework of the Tuchengzi Formation in the Yanshan Mountains, in which 18, 19, 20, 21, and 22 represent Fenfanghe, Jinlingsi–Yangshan, Jianchang, Pingquan, Dazhangzi–Xincheng basins, respectively. F1: Shangyi–Pingquan thrust; F2: Linyuan–Dongguanyingzi thrust; F3: Miyun–Xifengkou thrust. The data of depositional facies in the Late Triassic and Middle Jurassic Ordos basin are partly modified from Li et al. (1997), and the data in the Yanshan Mountains modified from Liu et al., 2004a; 2007, and the data in the Bohai Bay basin area modified from Qi et al. (2003).
Prototype basin reconstruction shows that the Late Triassic Ordos basin was larger than the present-day basin, and extended eastward across the Taihangshan Mountains. The Upper Triassic stratigraphy in the Ningwu, Jinchong, Linfen, and Yima basins within the Taihangshan Mountains (1, 3, 4, and 5, Fig. 1; Fig. 9A) has been correlated with the Yanchang Formation in the Ordos basin (Sun and Liu, 1985; Li et al., 1997; Liu and Zhang, 1999). Isochaps from Sun and Liu (1985), and Li et al. (1995) shows a NWW–SEE orientated depocentre in front of the northern margin of East Qinlan–Qinling fold-thrust belt, crossing the Taihangshan Mountains to the Zhengzhou City, and a NNE–SSW elongate trough along its northwestern rift sub-basin in Helanshan.

The Late Triassic is the final collisional stage of the North China and South China plates along the Qinling–Dabie orogenic belt. The South China plate was thrust under, presumably by northward facing subduction, the Qinling–Dabie micro-plate along the Mianlue suture in the south, and the Qinling–Dabie micro-plate was under-thrust the North China plate along the Shangdan fault in the north (Zhang et al., 2001). The North Qinling belt (including the East Qinlan belt) formed a retro-arc foreland fold-thrust belt. Through a retro-arc thrust, a wedge-top basin was formed within the North Qinling thrust belt, filling the basin with turbidite, lacustrine, braided delta, and alluvial fan deposits (Figs. 6G and 9A). This subbasin belt pinched out westward, and was replaced by the southwestern Ordos subbasin, which was filled with alluvial fan and braided delta systems, forming a wedge, thick near the thrust belt and thinning towards the north-east, and sourced from the southwestern thrust belt. This subbasin is interpreted to be a North Qinlan thrust-controlled foredeep depozone (Liu and Yang, 2000). To the north of the North Qinling wedge-top basin, the southern Ordos subbasin extended nearly east–westward adjacent to the uplift of the southern margin of NCC, and filled with ca. 2500 m of lacustrine delta and deep lacustrine deposits from the Tongchuan to Zhengzhou districts (Li et al., 1997; Liu and Zhang, 2008), which represents a foredeep depozone (Fig. 9A). Therefore, the North Qinling wedge-top depozone and the southern Ordos foredeep depozone constitute a foreland basin system (DeCelles and Giles, 1996), which was related to the Late Triassic Qinling–Dabieshan orogeny (Liu and Zhang, 2008; Liu and Zhang, 1999; Liu et al., 1999). The forebulge and backbulge depozones in this foreland basin system cannot be uniquely differentiated, primarily because we suspect that the foredeep depozone may have been the subsidence center of the whole basin.

The northwestern Ordos subbasin was bounded by the Aba massif, and extended nearly north–east/northward. The stratigraphy in the subbasin was strongly asymmetric (Fig. 4); alluvial fan strata were restricted to the extreme western margin of the subbasin and interfingered with axial fluvial deposits low in the section and deep lacustrine and fan delta depositional systems high in the section (Liu and Yang, 2000; Ritts et al., 2004). Much of the eastern part of the subbasin is dominated by west flowing meandering river and lacustrine deltaic systems (Ritts et al., 2004). In the western and central Helanshan, Triassic normal faults were identified, and volcanic rocks and dykes (229 ± 15 Ma) were documented (Liu 1998; Ritts et al., 2004). These characteristics support an extensional origin for the northwestern Ordos margin. The subbasin is interpreted to have been a half graben, bound along its western margin by an east-dipping normal fault (Figs. 4 and 9A; Liu and Yang, 2000; Ritts et al., 2004).

The northern margin of the Ordos basin was linked by the Yinshan fold and thrust belt. The stratigraphy was between 500 and 1300 m thick, increasing to the south. The sequences of the Upper Triassic Yanchang Formation are well correlated among the eastern margin of the present-day Ordos basin (Fig. 5E) and the isolated Ningwu (Fig. 5F) and Jinchong basins, which indicates they formed the northern margin of a united Late Triassic basin. This part of the basin is dominated by south-flowing or southwest-flowing meandering fluvial and lacustrine delta facies with a gentle slope compared with the southern margin (Fig. 9A) (Yang et al., 1992; Ritts et al., 2009).

To the northeast of the northern Ordos basin, a satellite basin was developed in the Yanshan area, which was comprised by the northern and southern basin zones based on correlative stratigraphy, facies proximity, grain-size trends, and provenance linkages (Fig. 9A). Paleocurrents in both basin zones were mostly south-directed, suggesting that the two outcrop zones were not segmented during the Triassic. In the northern part of the basin, fanglomerates were developed; these systems passed into coarse-grained fluvial systems in the southern part, with the grain size of the conglomerate continuously decreasing from the northern part to the southern part (Liu et al., 2007).

5.2. Walled intracratonic basin (Jurassic)

5.2.1. The Early–Middle Jurassic

The Early–Middle Jurassic Ordos basin was different from the Late Triassic basin in basin deposition, structures of the bounding mountains, and crustal contraction direction. The basin was nearly N–S trending with contraction mountain margins both in the west and east (Fig. 9B) and bound by thrust belts in the north and south. The western Ordos basin formed a unified depressed margin without Late Triassic structural differences of rift and foreland in the northwestern Ordos belt from Late Triassic extension to Early Jurassic shortening and eastward tilting (Fig. 9B) (Liu and Yang, 2000; Ritts et al., 2009).

The eastern margin of the Early–Middle Jurassic Ordos basin shrank eastward relative to that in the Late Triassic (but eastward extended relative to the present-day Ordos basin), and was located along the Datong, Ningwu, Jinchong, Linfen, and Yima intermontane basins (2, 1, 3, 4, and 5, Fig. 9B). The Lower and Middle Jurassic strata in the Datong, Ningwu, Jinchong, and Linfen basins are well correlated with those in the present-day Ordos basin. The Middle Jurassic Yayan Formation in the Yanan, Hengshan, Shenmu, and Dongsheng sections of the present-day Ordos basin and the Ningwu and Datong intermontane basins are all divided into three units which represent facies change trends from the marginal fluvial in the north and northeast to deltaic and lake in the central (H–L, Fig. 8; Fig. 9B; Li et al., 1997; Cheng et al., 1997). From structural investigations, U–Pb dating, and 40Ar/39Ar chronological analyses, the Taihangshan Mountains initially uplifted and formed fold-thrust structures at 175–150 Ma. The extensive WNW-vergent thrust faults and folds formed in Middle–Late Jurassic indicate WNW-oriented contraction (Wang and Li, 2008). Therefore, Taihangshan fold-thrust belt deformed the eastern part of the Triassic Ordos basin, and controlled the deposition in the eastern margin of the Early–Middle Jurassic Ordos basin.

In the Yinshan belt, the north of the Ordos basin, deformation began with right-lateral strike-slip faulting and basin development along east-striking structures in the Early Jurassic (8, Fig. 1; Ritts
et al., 2001; Darby et al., 2001). This structure was kept until the earliest Middle Jurassic, and then changed into the contractile foreland-style basin formation (Hendrix et al., 1996; Darby et al., 2001). South of the Ordos basin, the North Qinling belt thrust and expanded northwards and deformed the late Triassic wedge-top basin strata. This thrust activity controlled the deposits in the southern and southwestern margins of the Middle Jurassic Ordos basin. Dabie Mountains was a doubly vergent thrust system in Jurassic with its northern thrusts controlling the deposition of the Hefei foreland basin (Liu et al., 2003; Liu et al., 2010).

Therefore, the Early–Middle Jurassic Ordos basin formed a walled intracratonic basin surrounded by orogenic uplifts (geomorphic walls) which was related to dominantly WNW–ESE and N–S-directed intraplate contraction (Carroll et al., 2010). Within this walled basin, Lower Jurassic strata are only locally preserved, and are generally characterized by proximal alluvial deposits in the west that grade into fine-grained lacustrine deposits basinward in the east, with a NEN trend. During the Middle Jurassic, lacustrine environments expanded to their fullest extent with the increased basin subsidence, covering most of the southern and eastern part of the Ordos basin (Fig. 9B; Li et al., 1997; Ritts et al., 2009). Coarse-grained clastics filled the lake mainly from west to east and from north to south during the Middle Jurassic. The subsidence centers were located along the western and eastern margins based on the isopachs from Li et al. (1997). This indicates that the basin forming in the Jurassic was related to uplift of the Alxa massif, Taihangshan, Yinshan, and Qinling mountains.

5.2.2. Late Jurassic
By the Late Jurassic, the Ordos basin greatly shrink with its margins involved with the fold-thrust deformation and uplift (Fig. 9C). East-vergent deformation in the western Ordos propagated into the Helanshan as low-angle thrust faults, east-dipping reverse faults and large folds that involve Archean through Upper Jurassic rocks (Liu 1998; Darby and Ritts, 2002). The frontal deformation of the western Ordos fold-thrust belt was in the eastern Helanshan during the Late Jurassic–earliest Cretaceous, and consisted of a major basement-cored fault propagation fold (Darby and Ritts, 2002) involving Upper Jurassic–Lower Cretaceous synorogenic proximal foreland basin conglomerates on the extreme western margin of the Ordos platform. The Upper Jurassic Fenfanghe Formation formed an unconformity-bound, coarse-grained molasse wedge along the southern margin of the Ordos basin. This molasse wedge was controlled by thrust in the North Qinling belt (Fig. 9C) (Liu, 1998). Meanwhile, the coarse-grained alluvial fan deposits of the Fenghuangtai Formation in the Hefei foreland basin were the response to the north-vergent thrust of the Dabie Mountains (Liu et al., 2003, 2010), which suggest that the whole North Qinling and northern Dabie kept N–S contraction and north-vergent thrusting. The Yinshan belt, to the north of the Ordos basin, underwent Late Jurassic–Early Cretaceous N–S shortening, south-vergent displacements on both low-angle and steeply dipping thrust faults, and development of an associated foreland basin (Darby and Ritts, 2007). Besides the marginal mountain thrust, the eastern part of the Ordos basin shows no evidence of deposition. The locally-distributed foredeep deposits in the western, southern, and the northern Ordos basin indicate that the walled basin was dismembered after its lateral expansion during the Early–Middle Jurassic.

5.3. Intermontane (broken) flexural basins (Jurassic)
In contrast to the large scale walled basin developed in the western part of the NCC, locally-distributed broken flexural basins formed in the Yanshan Mountains and the basement of the Bohai Bay basin in the eastern NCC (Liu et al., 2004a; Qi et al., 2003).

5.3.1. Early–Middle Jurassic
In the Yanshan belt, the early Middle Jurassic Xiahuayuan Formation overlying the early Jurassic volcanic rocks was scattered over large areas. The recovered proto-basins filled with Xiahuayuan Formation included the Shangyi, Xuanhua, Chicheng, western Beijing, Luanping–Chengde, and Beipiao basins from west to east (12–17, Fig. 9B). In general, the protobasins were distributed in nearly ENE trending, in which meandering channel with swamp deposits were filled in basin margins and lacustrine in the centers (Fig. 9B). In comparison with the early Middle Jurassic basin distribution, the late Middle Jurassic basins migrated from sides to center, and were dominantly located along the core of a syncline within the center of the Yanshan belt. The late Middle Jurassic Jiulongshan Formation consisting of clastic rocks was mostly covered with the Tiaojishan Formation. The composition of sediment lithic fragments changed from the fragments of Palaeozoic and upper Proterozoic carbonate in the early Middle Jurassic to the deep granite in the late Middle Jurassic (Liu et al., 2004a), which suggest gradually uplift and exhumation of the basin margins located at the synclinal limbs with time. We infer that these basins were an intermontane flexural basin, and were controlled by tectonism of regional folding in the late Middle Jurassic.

5.3.2. Late Jurassic
The Late Jurassic basins filled with Tuchengzi Formation northward migrated to the margins of Jining–Longhua, Shangyi–Pingquan and Lingyuan–Dongguanyaingzi thrust belts (Fig. 9C). The Pingquan, Beipiao, Jiningshi–Yangshan, and Jiangbang basins (21, 17, 19, 20, Fig. 9C) in the eastern Yanshan belt, NNE trending, developed with western dipping and eastern thrusting Lingyuan–Dongguaingzi (F2) and Miyun–Xifengkou (F3) faults, and the Shangyi, Chicheng, Luanping–Chengde, and Dazhangzhi–Xincheng basins (12, 14, 16, 22, Fig. 9C) in the western Yanshan belt, EW trending, developed with northern dipping and southern thrusting Jining–Longhua and Shangyi–Pingquan (F1) thrust faults (its northern branch was dipping to the south and thrust to the north). The basins in the Yanshan Mountains were filled with gravel braided channel and braided channel delta depositional systems, and the fan conglomerates were dominantly distributed along the thrust-controlled margins of the basins (Fig. 9C). Their sediment source, the hangingwalls of the thrust faults, is constrained by strong directional paleocurrent trends from the hangingwalls of the thrust, a fining lithology away from the thrust fronts, and distinct and recognizable clast types. High-grade metamorphic rocks in the source areas of the basins were multi-uplifted and unroofed. With thrusting and uplifting, the volcanic cover rocks above the hanging wall of thrust in basin margins were gradually eroded, and the underlying basement rocks were unroofed (Liu et al., 2004a). The Tuchengzi Formation was thickened toward the thrust front due to the thrust belt loading and footwall tilting (Liu et al., 2007). Therefore, we infer that the Late Jurassic basins in the Yanshan Mountains were intermontane broken flexural basins controlled by regional thrusting. Thus, the basin evolution in Jurassic suggests that the Yanshan Mountains underwent an intermontane deformation from regional folding to thrusting.

6. Implications for initial deformation of North China Craton
The NCC remained a stable block covered by thick, continuous, undeformed shallow marine–nonmarine deposits through the end of the Palaeozoic. Collision of the central Asian ocean (Solonker suture) in the north and Paleo-Tethys (Mianlue suture) in the south disturbed the stable tectonic setting, and drove the initial modification of the NCC.
6.1. Collision-induced rifting and foreland subsidence, and regional dynamic subsidence driven by oceanic plate subduction in the Late Triassic

The Late Triassic intracratonic basin was formed between the Yinshan in the north and the Qinling–Dabie in the south, widely distributed across most of the NCC. Within this intracratonic basin, nearly WNW–ESE trending depositional and subsidence centers were located in its southern part, with a relatively narrow, steep slope in the south and a wide, gentle slope in the north. The wedge-top depozone in the North Qinling and the rift depozone in the Helanshan were parallel and perpendicular to the East Qilian–Qinling suture belt, respectively (Figs. 9A and 10A). This indicates that basin formation is related to the Late Triassic final collisional orogeny in the East Qilian–Qinling–Dabie belt. During the Middle–Late Triassic, the South China plate was obliquely subducting beneath the Qinling–Dabie (Gilder et al., 1999; Liu et al., 2005). Beneath the southeastern portion of NCC, in the eastern half of the Qinling–Dabie region, continental crust of the South China plate deeply subducted (Zheng et al., 2009). Replacement of normal mantle with less-dense continent and delamination of the deeply subducted oceanic plate may have induced tectonic uplift within southeastern NCC. The western part of the South China oceanic plate subducted beneath the southern margin of the NCC along the Mianlue subduction zone. We propose that the overall negative buoyancy of the subducting oceanic plate caused the surface of the NCC to subside dynamically over a long-wavelength while being overprinted by thrust loaded short-wavelength subsidence (Fig. 10A), in a fashion similar to that which occurred during the Cretaceous in western North America (Liu and Nummedal, 2004; Liu et al., 2011). Therefore, we propose that the continuous subsidence and deposition in the NCC in the Triassic were dominantly related to mantle flow effects associated with plate subduction, which initiated the deformation of the NCC. Since there was roughly subduction of oceanic plates to the north and to the south of the NCC, conditions favoring broadscale dynamic subsidence perhaps in a manner akin to the present subsidence of Indonesia and Sunda land in the Cenozoic which is effected by both subduction of the Indian and Pacific oceans (Lithgow-Bertelloni and Gurnis, 1997).

Besides thrust faults developed in the North Qinling and southernmost margin of the NCB, a north-trending half graben formed at the northwestern Ordos subbasin (Helanshan) which locally deformed the NCC lithosphere. Liu (1998) put forward a deformation mechanism for the unconstrained lateral extrusion, in which the local extension was driven by the indentation of the eastern North Qilian–North Qinling active margins with the stable NCC and the lateral escape of the Ordos block. Therefore, this extensional subbasin was akin to passive rifting, e.g. an impactogen. The distribution of the half-graben appears to correspond to a crustal weak zone between the Alxa and Ordos blocks. Therefore, heterogeneity in basement strength may have served to weaken the western margin of the Ordos block relative to the undeformed part (Fig. 10A).

Fig. 10. Models for Early Mesozoic tectonic evolution of the NCC and its link to adjacent structural belts and plate subduction. (A) Late Triassic intracratonic basin formation and North China Craton rift and subsidence, and their link to adjacent East Qilian–Qinling–Dabie orogeny, Yinshan shortening deformation, and the South China plate oblique subduction. I–I′: Section from the Songpan to intracratonic basin and Yinshan fold and thrust belt; II–II′: Section across intracratonic basin from east to west. (B) Jurassic Walled intracratonic basin and broken flexural basin formation and North China Craton thickening and deformation, and their link to adjacent East Qilian–Qinling–Dabie orogeny, Yinshan shortening deformation, and Izańagi plate subduction. III–III′: Section from the Izańagi plate to the walled basin; IV–IV′: Section across Qinling–Dabie orogenic belt, walled basin, and Yinshan fold and thrust belt. See text for discussion.
6.2. Jurassic crustal deformation, lithosphere thickening, and dynamic subsidence dominantly driven by slab subduction

Tectonic setting was transformed, and the basin/mountain framework was rearranged from the Late Triassic to the Jurassic. Formation of the walled intracratonic basin and the broken flexural basins (Figs. 9B and C and 10B) indicates the NCC underwent the second, even more extensive modification, characterized by NEN trending crustal deformation. Compared to the Late Triassic basin development, the Jurassic Ordos basin was walled by bounding mountains. The western Helanshan fold and thrust belt propagated eastward, and the eastern Taihangshan deformed and uplifted. This structural change may be related to the westward subduction of the Paleo-Pacific plate. As initially advanced by Liu (1998), the western Ordos basin was changed into constrained lateral extrusion during the Jurassic, and the constrained margin was induced by plate subduction (Fig. 10B).

To the east of the Ordos walled basin, the eastern part of the NCC is characterized by basement-involved thrust tectonics, basement-cored buckling anticlines and dextral thrust, nappe tectonics and broken flexural basins, which are in the nearly NE, EW, WNW, and NEN trending (Zhang et al., 2011). The Yanshan and Taihangshan constituted a broad scale NNE–SSW-trending fold-thrust belts (Liu et al., 2007). The basins in the Yanshan belt behaved as regional folding-control in the Middle Jurassic and thrusting-control in the Late Jurassic. The deformation style consisted of N–S and NW–SE directed thrust faulting during the syndepositional stage of the Tuchengzi Formation. The crustal thickness increased due to the contraction deformation was expected to be around 47–50 km (Zhang et al., 2011), which lead to surface uplift with an increase of the Moho depth (Fig. 10B). Calc–alkaline volcanism was developed in the northeastern China, which suggests that the Paleo-Pacific subduction zone may be formed along the eastern Asia (Liu et al., 1994). But no evidence of Jurassic arc magmatism has been found in the eastern margin of the NCC.

The driving mechanism for Jurassic intracratonic deformation in the NCC may be related with both of regional plate tectonics and deep crustal and mantle activities. During Jurassic time, the Izanagi plate subducted northwestern, which imparted NW–SE-oriented compressive stress to the NCB, and caused folding and thrusting along the eastern continental margin of the eastern Asia (Fig. 10B). The Jurassic intracontinental shortening along the Qinling–Dabie suture zone, associated with clockwise rotation of the South China plate relative to the North China plate (Liu et al., 2005), also possibly driven by the subduction of the Izanagi plate, produced northward shortening in the NCC and northward propagating thrusting along the northern margin of the North Qinling–Dabie. The Mongol–Okhotsk suture lies ~1000 km north of the NCC. Crustal shortening prevailed in the China–Mongolia border during Middle to early Late Jurassic time in response to the continental collision along the Mongol–Okhotsk suture (Graham et al., 1996). Therefore, it appears likely that the Jurassic shortening in the NCC was driven by multiple far-field dynamic forces: northward subduction of Pacific plate, collision of the amalgamated blocks of China with those of Siberia along the Mongo–Okhotsk suture zone, and the post-collisional shortening along the Qinling–Dabie belt (Fig. 10B; Liu et al., 2007). The west or northwestern subduction of the Izanagi plate produced a dominant driver for the crustal deformation and thickening in the eastern NCC and the Ordos basin subsidence in response to mantle flow associated with the dynamic pull of the sinking slab, with some similarities to the western interior basin of Cretaceous North America (Liu and Nummedal, 2004; Liu et al., 2011). The northward indentation from the Qinling–Dabie orogenic belt and southeastern compression from the Mongol–Okhotsk suture zone lead to eastward extrusion and underthrusting of the crustal basement in the western NCC, which supplied large volumes of continental lower crust in the eastern NCC (Fig. 10B). This tectonism not only further increased the thickness of crust, but also fuel arc flare-ups after a lag-time of 10–20 Mys.

7. Conclusions

The NCC is bounded by the East Qinlian–Qinling–Dabie orogenic belt in the south, the Yinshan fold and thrust belt in the north, and the Paleo-Pacific subduction zone in the east. The Late Triassic–Jurassic stratigraphy in the NCC records the detailed tectonic processes that might represent the initial stage of the NCC modification.

1. In the Late Triassic, a large intracratonic Ordos basin developed on the rigid NCC, and was bound by east–west orogenic belts on the northern and southern margins of the NCC. It comprised a WNW–ESE orientated depocenter in the foreland of the East Qinlian–Qinling–Dabie fold-thrust belt crossing the Taihangshan Mountains, a NEN–SWS elongate rift sub-basin along the Helanshan, a wedge-top subbasin within the North Qinling belt, and an east–west foreland basin draining the Yanshan belt.

2. During the Jurassic, the North China basin framework was changed in depositional style and paleogeography, surrounding structures, and crustal strain orientations. The Early–Middle Jurassic Ordos basin was nearly N–S trending with contractional margins. This basin behaved as a walled intracratonic basin with surrounded orogenic uplifts (acting as large scale geomorphic walls), and was related to dominantly WNW–ESE and N–S–directed intraplate contraction. In the Late Jurassic, the Ordos basin diminished with its western margin involved in continued fold and thrust deformation and the eastern margin uplifted. The Upper Jurassic stratigraphy formed an unconformity-bound, synorogenic, coarse-grained molasse wedge along the northwestern and southwestern margins of the Ordos basin. In the eastern NCC, locally-distributed, Jurassic broken flexural basins were formed in the Yanshan Mountains and the basement of the Bohai Bay basin.

3. The continuous subsidence and deposition from the Late Paleozoic to the Early Mesozoic in the giant intracratonic basins were related to orogeny of the East Qinlian–Qinling–Dabie belt and mantle flow effects associated with plate subduction, and rifting in the northwestern Ordos was driven by the compression of the eastern North Qinlian–North Qinling active margins with the stable NCC, which initiated the deformation of the NCC.

4. The second, even more broad modification of the NCC in the Jurassic was characterized by nearly NE–SW trending crustal deformation and lithosphere thickening in the eastern part of the NCC, and dynamic subsidence in the west, which was driven by nearly northwestward subduction of the Izanagi plate and the eastward extrusion and underthrusting of the western NCC crustal basement. The changing tectonic styles from the Late Triassic to Jurassic reflect the underlying activities of the NCC transformed from downward viscous dragging caused by the sinking Paleo-Tethys slab to lithosphere thickening driven by contraction and underthrusting due to the Izanagi plate subduction. This tectonic behavior of NCC lithosphere in the Jurassic was the precursor of widely thinning in the Early Cretaceous.

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