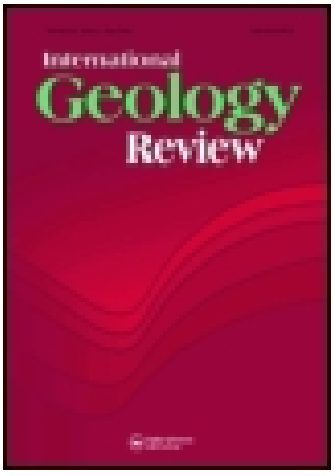
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Early Mesozoic Basin Development and Its Response to Thrusting in the Yanshan Fold-and-Thrust Belt, China

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Early Mesozoic Basin Development and Its Response to Thrusting in the Yanshan Fold-and-Thrust Belt, China

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Abstract

Mesozoic basins in the Yanshan belt of northern China record two episodes of shortening during the Late Triassic and Late Jurassic that span the transition from retroarc deformation and basin formation to continental intraplate deformation. Gravel braided river depositional systems in the Upper Triassic Xingshikou Formation show provenance from the north and become relatively more distal southward onto the North China Block. These relationships are interpreted as a foreland basin system, southward of a retro-arc, and later collisional, fold-thrust belt. The Triassic basin shows widely correlative stratigraphy, simple proximal-to-distal relationships, and uniformly south-directed paleocurrents that suggest a simple integrated foreland basin. In contrast, the Upper Jurassic Tuchengzi Formation is characterized by coarse conglomerates with rapid facies changes, lateral non-uniformity, and local provenance, which argues for deposition in a broken foreland setting, with local high-gradient depositional systems dominant.

Introduction

THE YANSHAN fold-thrust belt marks a zone of shortening along the northern margin of the North China Block that has a polyphase Mesozoic history of deformation and basin formation (Davis et al., 1998). The Yanshan fold and thrust belt is connected with the Yinshan belt along strike to the west, and previous studies have suggested that the Yinshan belt has both similarities to, and differences from, the Yanshan belt (e.g., Darby et al., 2001; Davis et al., 2001) (Fig. 1). North of the Yinshan and Yanshan belts, the late Paleozoic Suolon suture separates the North China plate in the south from the northeastern China–Mongolia complexes (NCMC) in the north (Wang and Liu, 1986; Enkin et al., 1992; Wang and Mo, 1995). Far north of the Yanshan belt, the Mesozoic Mongol-Okhotsk suture belt is developed between the NCMC and Siberia (Zorin et al., 1995). Northward subduction of the Mongol–Okhotsk Ocean eventually led to collision of the NCMC and Siberia during the later Jurassic (Zorin et al., 1995; Yin and Nie, 1996; Zorin, 1999). On the southern margin of the North China block, the Middle–Late Triassic Qinling-Dabie suture separates North China from the South China Block (Hacker et al., 2000; Ratschbacher et al., 2003; Zhang et al., 2001; Liu et al., 2005).

Although the nearly E-W trend of the Yanshan belt is at a high angle to the Pacific plate margin, suggesting considerable tectonic independence of the belt from Pacific-Eurasian plate interactions, the regional geometry of structures in eastern China may indicate otherwise (Cope, 2003). Northeasterly tectonic trends of Mesozoic age are found in the Taihang Shan and in the eastern Yanshan in western Liaoning Province (Fig. 1). These may be related to northwestward subduction of a paleo-Pacific plate

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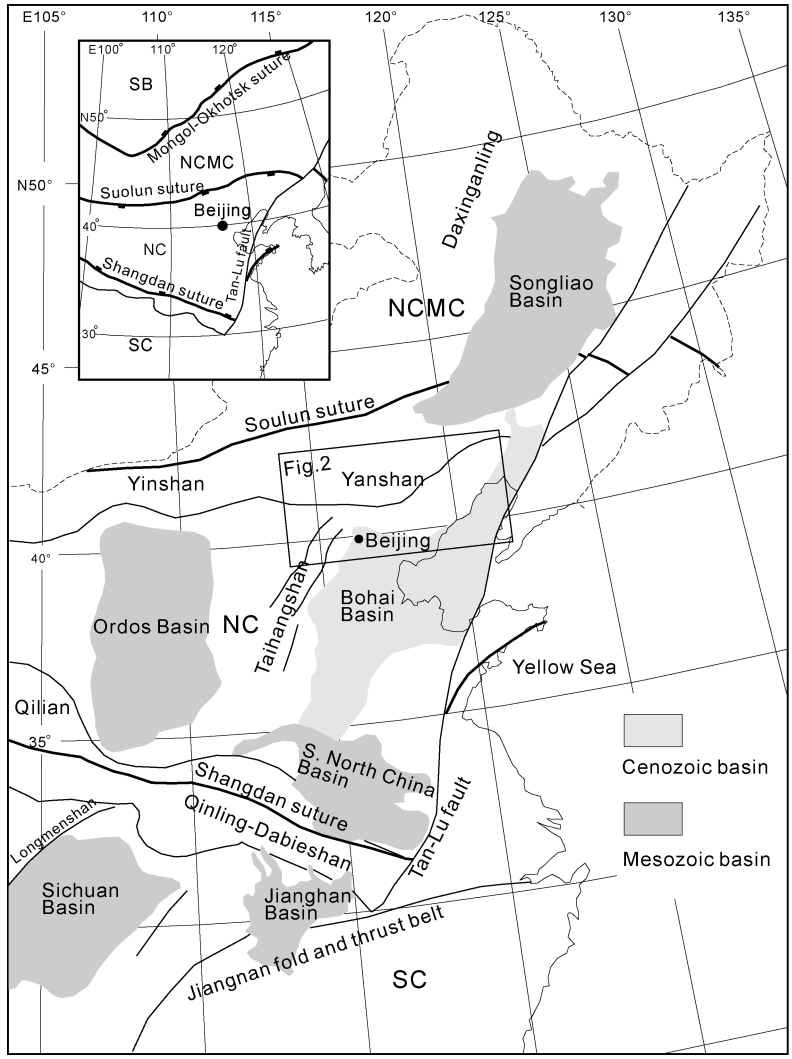


FIG. 1. Tectonic map showing distribution of major structural belts and basins in northeastern part of China. Abbreviations: SB = Siberia; NCMC = northeastern China–Mongolia complexes; NC = North China; SC = South China. Refer to inset map for regional tectonic framework.

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(Izanagi plate) beneath eastern Asia (e.g., Deng et al., 1999). Under the far-field effects of Jurassic tectonism from these surrounding plate margins, the Yanshan belt developed as a polycyclic belt of shortening structures and associated superposed basins. Investigations of the sedimentary response to thrust faulting and the origin of the intracontinental basin and mountain systems, such as we present herein for the Yanshan orogenic belt, help elucidate to the tectonic setting of East Asia and the mechanics of ancient intracontinental deformation.

Major Triassic–Jurassic Thrust Structures

The Yanshan belt is characterized along its length by reverse faults and folds that shorten rocks ranging from Archean crystalline basement to a variety of Upper Jurassic synorogenic sedimentary units. Structures in western parts of the Yanshan

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belt west of Beijing have predominantly ENE to NE trends, whereas easterly trends characterize middle parts of the Yanshan and NE to NNE trends characterize more easterly parts of the Yanshan. The Yanshan is onlapped by the Cenozoic Bohai Basin to the south, and is cut by the Tanlu fault on its eastern margin. Parts of structures in the western part of the belt are connected with the Taihang Shan fold-and-thrust belt and the Yinshan belt to the west (Fig. 1).

Davis et al. (2001) described several major thrust structures within the E-W–trending segment of the Yanshan belt near Chengde and provided timing constraints based on cross-cutting relationships and newly reported radiometric dates. Below we discuss the major framework structures that served as a Mesozoic basin marginal fault in the Yanshan system.

Chengde thrust and the "unnamed thrust"

Davis et al. (1998, 2001) discovered the NNW-directed Chengde thrust in northern Hebei Province (Figs. 2 and 3). The fault places Proterozoic sedimentary rocks atop Jurassic volcanic and clastic strata. Following its emplacement, the Chengde thrust plate was folded in a major E- to ENE-trending asymmetric synform with a very steep to overturned southern limb (Fig. 4). The synform is intruded to the west by granitic plutons with U/Pb ages ranging from 128.8 ± 1.5 Ma to 131.7 ± 1.5 Ma (Davis et al., 2001). Analysis of the deposition of the Tuchengzi Formation in the Chengde Basin and its relation with marginal thrusts (Cope, 2003; Liu et al., 2004b; Davis, 2005) suggests that the Chengde thrust was activated after deposition of the Tuchengzi Formation (discussed below), and has a considerably smaller displacement than that proposed by Davis et al. (2001).

The "unnamed thrust," first discovered by Zhao (1990), is distributed along Gubeikou and Chengde County (Fig. 4). The large-scale S-directed overthrusting of the hanging wall resulted in the complete denudation of the cover and extensive exposure of crystalline basement in the northern part of the Yanshan belt (Zhao, 1990). Thick Triassic syntectonic footwall deposits of conglomerate exposed in a syncline between Chengde County and Pingquan to the east are strongly overturned beneath the "unnamed thrust" (Davis et al., 2001). Moreover, the thrust fault was also covered by the Chengde County thrust (discussed below). So we think the "unnamed thrust" was mainly formed during the Triassic time. Davis et al. (2001) interpreted that the fault as pre-180 Ma based upon syntectonic Triassic deposits and age of strata that unconformably overlie the footwall conglomerates.

Shangyi-Pingquan thrust

The Shangyi-Pingquan thrust, is E-W trending and extends from Shangyi in the west to Pingquan in the east. In the western part near Shangyi and Chicheng, the fault probably followed the earlier "unnamed thrust" and placed an Archean hanging wall over the Jurassic Xiahuayuan and Tuchengzi formations.

The eastern part of the Shangyi-Pingquan thrust in the Chengde area of the middle Yanshan is divided into two branch faults—the northern Chengde County thrust and the southern Gubeikou thrust. The Chengde County thrust is a N-vergent thrust fault that places Proterozoic and Paleozoic strata atop overturned Triassic and Jurassic strata, and cuts the southern limb of the Chengde synform. It is in turn cut by plutonic rocks with U/Ph ages of 129 and 132 Ma, and cuts a 161 Ma footwall unit. So the Chengde County thrust was active post-161 Ma and pre-129 Ma.

The Gubeikou thrust, which dips to the north and strikes E-W, places Proterozoic carbonate and clastic rocks over Middle-Upper Jurassic Tiaojishan volcanic rocks and the Tuchengzi conglomerates. The fault extends along strike for over 100 km before becoming obscured by other structure (Cope, 2003). The age of the Gubeikou thrust is constrained by an U/Pb age of 132 Ma on plutons that intrude the fault, and by a 148 Ma hornblende age on volcanic rocks at the base of the footwall Tiaojishan Formation section (Davis et al., 2001).

These geological relations show that the thrusting of the Shangyi-Pingquan thrust took place before the Early Cretaceous but after deposition of the Middle–Upper Jurassic Tiaojishan Formation. The Shangyi-Pingquan thrust is connected with the Lingyuan-Dongguanyingzi thrust beyond Pingquan toward the east, and the latter places Archean or Proterozoic crystalline rocks over Jurassic strata.

In summary, the structural sequence in the Yanshan belt (Davis et al., 2001) consists of (1) emplacement of the southward-directed "unnamed thrust" before 180 Ma, probably mainly in the Triassic; (2) thrust faulting on the Chegde County and Gubeikou thrust faults (as well as most other thrust faults in the Yanshan belt), synchronous with deposition of the Upper Jurassic Tuchengzi Formation during 161–129 Ma and 148–132 Ma, respectively;

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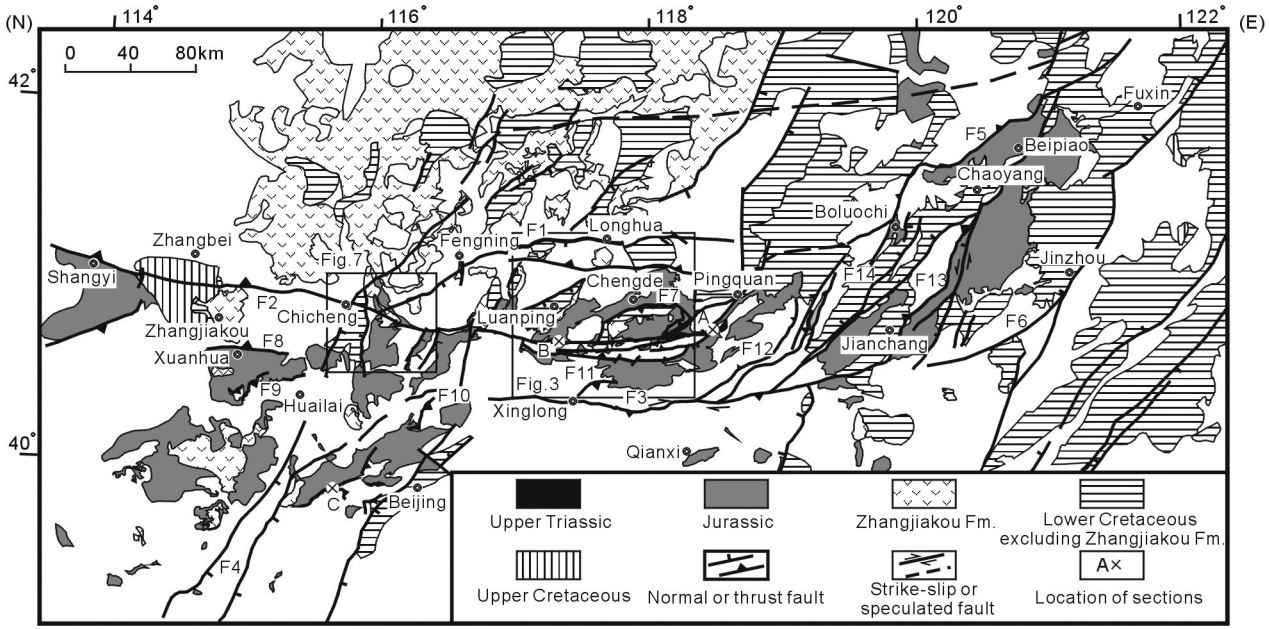


FIG. 2. Structural framework of Yanshan belt (modified from Liu et al. (2004a). Abbreviations: F1 = Fengning-Longhua thrust; F2 = Shangyi-Pingquan thrust; F3 = Miyun-Xifengkou thrust; F4 = Zijingguan fault; F5 = Linyuan-Dongguanyingzi thrust; F6 = Datun-Jinzhou fault; F7 = Chengde thrust; F8 = Xuanhua thrust; F9 = Xiahuayuan thrust; F10 = Shisanling thrust; F11 = Xinglong thrust; F12 = Yangzhangzi-Wafangdian thrust; F13 = Jianchang-Chaoyang thrust; F14 = Zhongsanjia thrust. A, B, and C represent measured stratigraphic sections of southern Pingquan, southern Luanping, western Beijing, respectively, shown in Figure 6. Refer to Figure 1 for location of map.

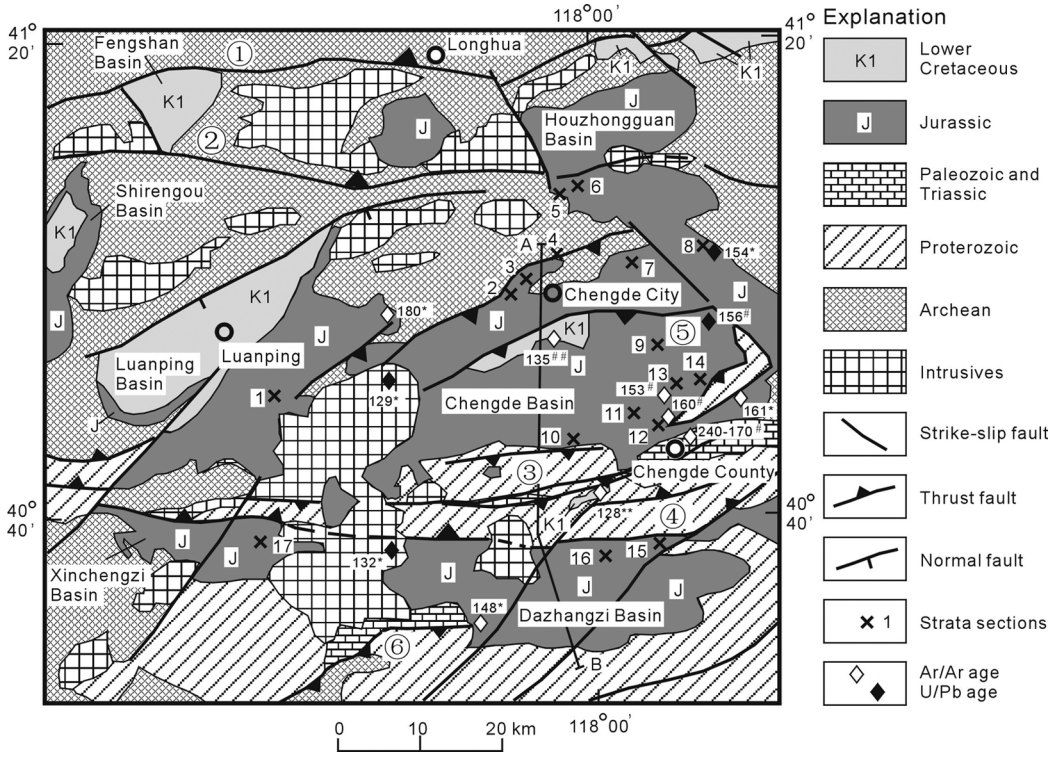


FIG. 3. Sketch of structural framework in Chengde and its adjacent regions. Circled numbers: 1 = Fengning-Longhua thrust; 2 = Damiao-Niangniangmiao thrust; 3 = Panjiadian-Chengde County thrust (Chengde County thrust in short); 4 = Gubeikou-Dazhangzi thrust (Gubeikou thrust in short); 5 = Chengde thrust; 6 = Xinglong thrust. Names of measured stratigraphic sections: 1 = Changshanyu; 2 = Sancha; 3 = Shuangjing-Pingdingshan; 4 = Shuangfengshi; 5 = Lanjiagou; 6 = Dianzi; 7 = Cangzi; 8 = Ergoucun; 9 = Luotoushan; 10 = Shuangmiao; 11 = Guozhangzi; 12 = Jiyuqing; 13 = Biandanliang; 14 = Maozhangzi; 15 = Chehekou-Dazhangzi; 16 = Chehebao; 17 = Yaoqiaoyu. $^{40}Ar/^{39}Ar$ and U/Pb ages from Davis et al., 2001(*); Davis, 2003 (**); Cope, 2003 (#); Niu et al., 2003 (##). A–B represents location of cross-section in Figure 4. Refer to Figure 2 for location of map.

(3) movement on the Chengde thrust after deposition of the Upper Jurassic Tuchengzi Formation; (4) extensional reactivation of the Chengde thrust and intiation of other normal faults throughout the Yanshan belt in the Early Cretaceous (Davis et al., 2001).

Basin-Filling Sequence

The Yanshan belt extends across the northern margin of the North China craton; the latter is composed of 3.9–2.5 Ga crystalline basement and widespread Proterozoic shallow-water marine strata (~1850–800 Ma) (Li and Qian, 1996; Zhao et al., 2001). Uppermost Proterozoic strata (~800–615 Ma) are missing (Chen et al., 1997). Phanerozoic strata on the craton are represented by (1) Cambrian through Middle Ordovician shallow-marine carbonates; (2) regressive Upper Carboniferous through Lower Permian marine-to-terrestrial megasequences characterized by carbonates, marine sandstones, and coal-bearing clastics; (3) Upper Permian and Triassic redbeds and conglomerates; and (4) Jurassic and Cretaceous terrestrial volcanic and clastic strata (Yang et al., 1992; Chen et al., 1997). Early Jurassic to Early Cretaceous mafic to intermediate volcanism was widespread across the Yanshan belt, and reached its maximum intensity in the Late Jurassic and Early Cretaceous (Xu, 1990). Strata intercalated with Jurassic and Lower Cretaceous volcanic rocks include coal, conglomerate, sandstone, and volcaniclastic rocks. The combina-

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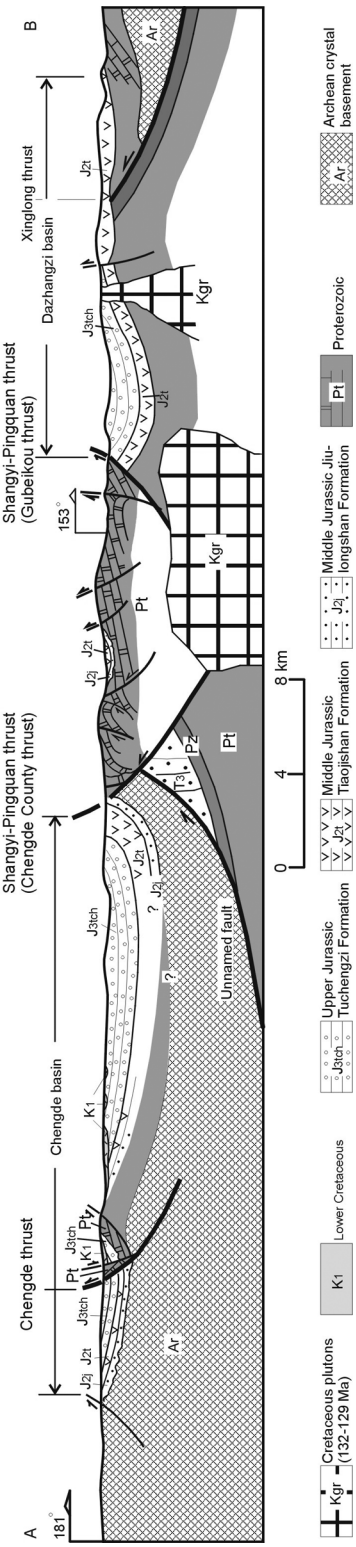


FIG. 4. Cross-section of Shangyi-Pingquan thrust and its adjacent basins. Refer to Figure 3 for location of section.

tion of volcanic strata and abundant organic-rich units results in good age control for the Jurassic and Cretaceous (Table 1). Formation names and ages of lower Mesozoic strata, as inferred from reported radiometric dating and the summary by Davis (2005), are illustrated in Figure 5. Here we only introduce the depositional characteristics of the Triassic and Upper Jurassic related to episodic thrust events.

Deformed Triassic basins

The oldest Mesozoic sedimentary rocks in the Yanshan belt are Triassic; they are highly deformed, and crop out in two E-W–trending belts. One belt stretches from Luanping to Pingquan (the northern outcrop belt), and the other is located in western Beijing (the southern outcrop belt) (Figs. 2 and 3). The measured Triassic section in southern Pingquan in the northern belt contains two parts: the lower part is the Ermaying Formation, and the upper part is the Xingshikou Formation (Figs. 2 and 6A). The Ermaying Formation contains massive or cross-stratified coarse sandstone and pebbly conglomerate, and massive red mudstone. Individual conglomerate and sandstone beds are lenticular over 50-100 m laterally, fine upwards, and are interpreted to be gravel meandering channel deposits. Interbedded mudstone beds are interpreted as floodplain deposits (see also Allen, 1978 for analogous deposits). The overlying Xingshikou Formation is 320 m thick, and consists mainly of grain-supported, imbricated, and partly massive conglomerate with internal scour surfaces. Clasts are round and generally 10–25 cm in diameter, although clast size ranges from 5 to 40 cm. Imbricated clast orientations indicate southward paleoflow. The Xingshikou conglomerate is interpreted to be gravel braided channel deposits (Miall, 1978; Liu et al., 2003). Forty meters of Triassic Xingshikou Formation conglomerate was also measured in southern Luanping, and is composed of poorly sorted, unstratified, clast-supported, and subangular or angular cobble and boulder conglomerates (some gravels about 1 m in diameter) (Figs. 2 and 6B). This conglomerate unconformably overlies Archean basement and is interpreted as a debris flow deposit based on the coarse, unorganized character (Liu and Yang, 2000).

Triassic strata in western Beijing (the southern belt) can be divided clearly into the Middle and Upper Triassic along an unconformity. The overlying Upper Triassic Xingshikou Formation is 15–20 m thick and consists of granule conglomerate with

TABLE 1. Geochronology of Yanshan Volcanic Rocks ($T–J_3/K_1$)[1]

Age, Ma	(Rock) dating method	Location	Reference
	"Xinshikou" age determinations (post-241 Ma and pre-180 Ma)		
241.1 ± 0.8	(Volcanic cobble) b; $^{40}Ar/^{39}Ar$	Chengde County, Hebei	Cope, 2003
166.3 ± 1.2	(Dike cutting the unit) b; $^{40}Ar/^{39}Ar$	Chengde County, Hebei	Cope, 2003
	"Nandaling" age determinations (178–180 Ma)		
177.5 Ma	(A) whole-rock; K-Ar	Western hills, west of Beijing	Chen, 1996
180.2 ± 1.8	(ST) b; $^{40}Ar/^{39}Arw$	West of Chengde, Hebei	Ren et al., 1996
	"Tiaojishan" and "Lanqi" age determinations (174–147 Ma)		
174.7 ± 1.4	(A) whole rock; $^{40}Ar/^{39}Ar$	North of Qian'an, Hebei	Zhang et al., 2004
174 ± 1.8, 173±1.6	(A) p; $^{40}Ar/^{39}Ar$	West of Jianchang, Liaoning	Davis et al., 2001
161.1 ± 1.9	(A) h; $^{40}Ar/^{39}Ar$	Shisanling, Beijing	Davis et al., 2001
160.7 ± 0.8	(ST) b; $^{40}Ar/^{39}Ar$	North of Chengde County, Hebei	Davis et al., 2001
158 ± 1	(ST) U-Pb; zircon	Xingzhangzi, Lingyuan, Liaoning	Zhao et al., 2004a, 2004b
147.6 ± 2.6	(A) h; $^{40}Ar/^{39}Ar$	Huantuliang, Hebei Province	Davis et al., 2001
	"Tuchengzi" age determinations		
≤ 156~152	(ST) U-Pb; zircon, basal tuff (ST) Kspar; $^{40}Ar/^{39}Ar$, basal tuff	Chengde basin, Hebei	Cope, 2003
144.7 ± 2.8	(B) K-Ar; whole rock	Xuanhue-Pangjiafang, Hebei	Shao et al., 2003
139.4 ± 0.19	(ST) s; $^{40}Ar/^{39}Ar$	Near Sihetun, Liaoning	Swisher et al., 2002
	"Zhangjiakou" and "Donglintai" age determinations (Zhangjiakou unless noted)		
122.5 ± 5.5	(TI) Kspar; $^{40}Ar/^{39}Ar$	Chengde, Hebei	Davis et al., 2001
147.3 ± 0.6	(T) Ar/Ar; whole rock	Shangdijiagou, Beipiao, Liaoning	Li et al., 2001
140.4 ± 0.4	(TA) Ar/Ar; whole rock	Shangdijiagou, Beipiao, Liaoning	Li et al., 2001
140	(—) Nd-Sm	Western Hills, "Donglingtai," Beijing	Li et al., 2000
136.3 ± 3.4	(R) U-Pb; zircon	Base of fm., Luanping basin, Hebei	Niu et al., 2003
135.8 ± 3.1	(R) U-Pb; zircon	Luotuo Shan, Chengde basin, Hebei	Niu et al., 2003
135 ± 1	(R) U-Pb; zircon	Jiquan Shan, Chengde basin, Hebei	Zhao et al., 2004a, 2004b
127.2 ± 1.5	(ST) s; Ar/Ar	Daijiagou, Luanping basin, Hebei	Davis et al., 2001

[1]Rock types: A = andesite; Ab = andesite breccia; B = basalt; D = dacite; R = rhyolite; ST = silicic tuff; T = trachyte; TA = trachyandesite; TI = trachyitic ignimbrite. Minerals dated: b = biotite; h = hornblende; p = plagioclase; s = sanidine.
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some sandstone intervals (Figs. 2 and 6C). Clasts in the conglomerate are subrounded and imbricated. 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. Paleocurrent indicators (cross-stratification) suggest paleoflow was to the west and southwest.

Late Jurassic sedimentary basins

Late Jurassic sedimentary basins are distributed along the Shangyi-Pingquan and Lingyuan-Dongguanyingzi thrusts (Fig. 2). The Tuchengzi Formation is characterized by thick, massive, or

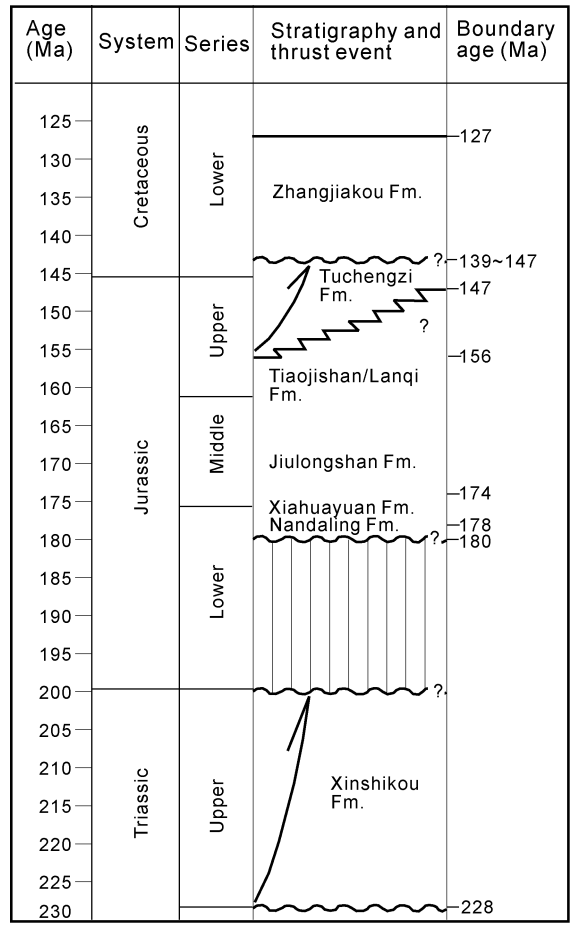


FIG. 5. Stratigraphy of Yanshan belt, mostly showing units discussed in text (compiled mainly from Davis's summary of the geochronology of Yanshan volcanic rocks). Unconformities shown by wiggle line, major thrusting events shown. Age control comprises $^{40}Ar/^{39}Ar$ ages and U/Pb ages from Davis et al., 1998, 2001; Li et al., 2000; Li et al., 2001; Cope, 2003; Niu et al., 2003; Shao et al., 2003; Zhao et al., 2004a, 2004b; Davis, 2005.

horizontally stratified conglomerate intercalated with one or two parts of massive or laminated mudstone and thin layers of pebbly sandstone or conglomerate in the middle. The former is typically composed of vertically amalgamated, mostly fining-upward conglomerate layers with sharp scour surfaces at their bases, and the latter composed of multiple coarsening-upward depositional cycles. The Tuchengzi Formation has dramatic lateral changes in maximum clast size, reaching maxima at the present margins of the basins near the basin-bounding thrust systems (Figs. 7, 8, and 9). We describe the Luanping-Chengde and Dazhangzi-Xinchengzi basins as representative of the Upper Jurassic stratigraphy.

Luanping and Chengde basins. The Luanping and Chengde basins are now separated by a Cretaceous pluton (129 Ma, U/Pb; Davis et al., 2001), but they were filled with very similar Upper Jurassic sedimentary rocks and were a contiguous basin prior to pluton emplacement. The Tuchengzi Formation measured at Changshanyu (Fig. 8A) comprises about 330 m of pebble to cobble conglomerate with some boulders >1 m in diameter at its base. Clasts that were mostly derived from the underlying Tiaojishan andesite. The conglomerates are not sorted, and clasts are not oriented except for those in

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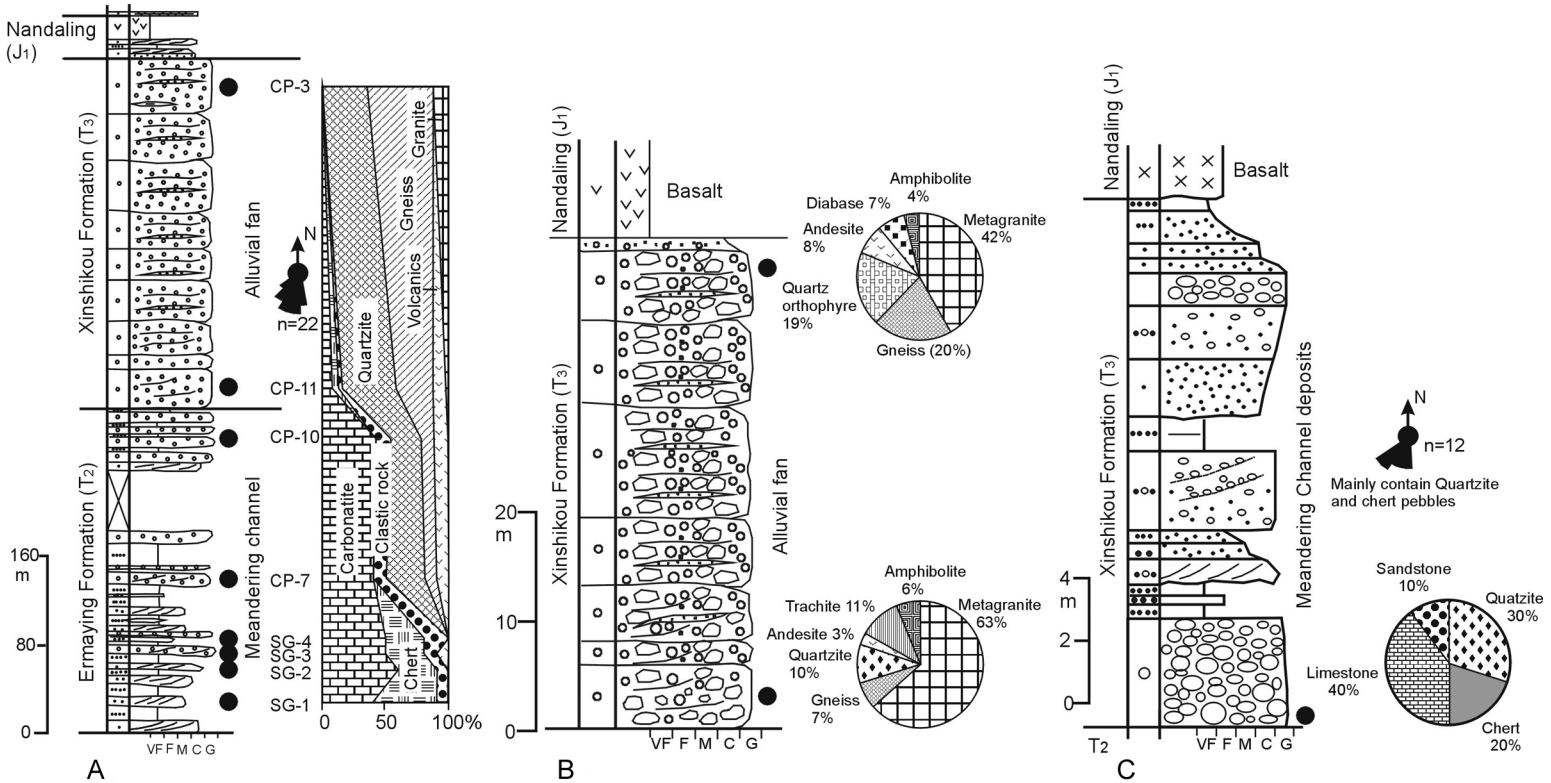


FIG. 6. Stratigraphic sections and gravel composition of Upper Triassic in Yanshan belt. Solid circles next to stratigraphic column show location of samples for gravel counts. Vertical change of lithic petrofacies contents is shown in Figure A. Abbreviations: VF = very fine sandstone; F = fine sandstone; M = median sandstone; C = coarse sandstone; G = conglomerate. Refer to Figure 2 for location of sections.

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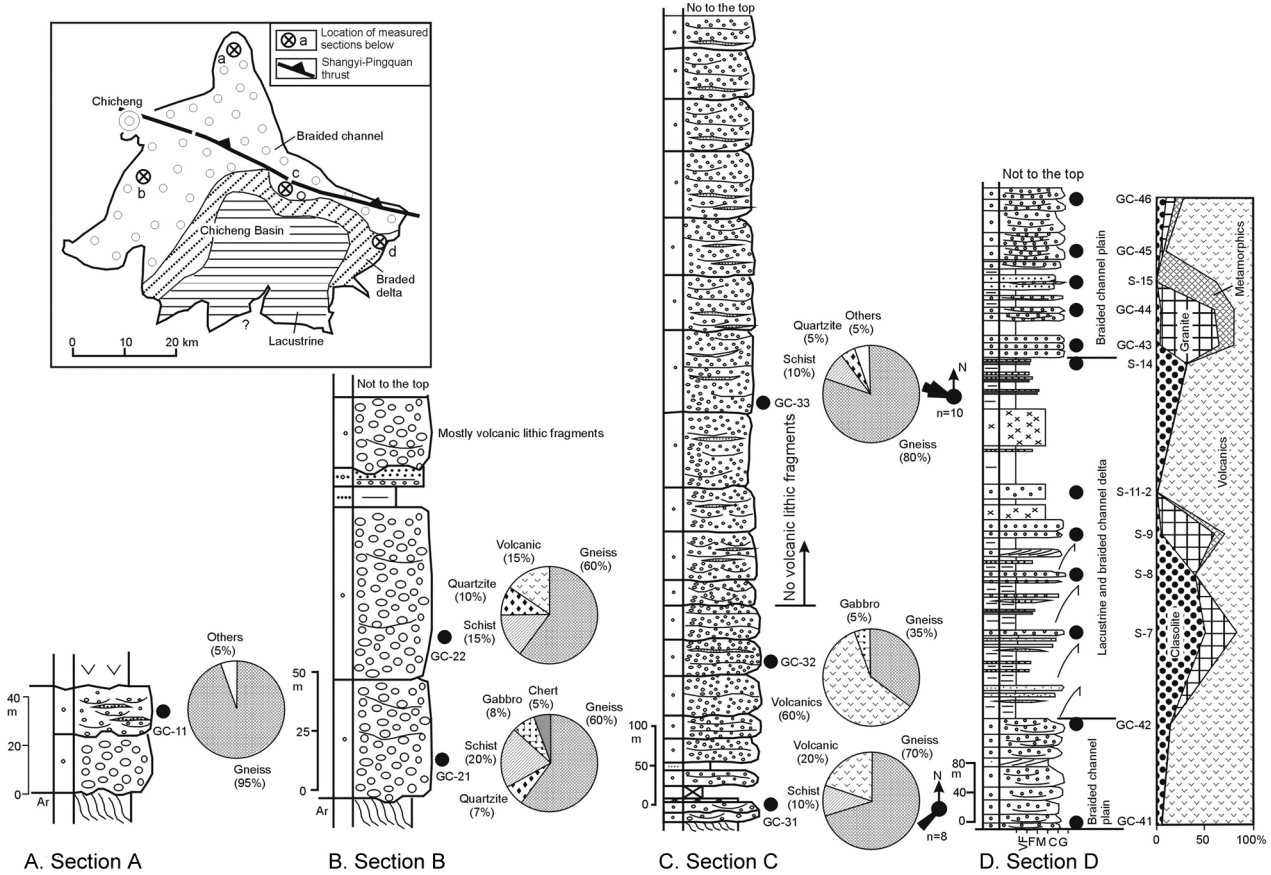


FIG. 7. Stratigraphic sections and gravel or lithic fragment composition of the Tuchengzi Formation in the Chicheng Basin. Refer to inset map for location of sections. Solid circles next to stratigraphic column show location of samples for thin-section or gravel counts. Sites of gravel counting are numbered using "GC", and samples for thin sections numbered using other words. Inset map shows distribution of depositional systems of the Tuchengzi Formation in recovered prototype Chicheng Basin and location of measured stratigraphic sections. Names of sections: A = Dongwanchang; B = Tunjunbao; C = Wanquansi; D = Qianjiadian. Refer to Figure 2 for location of inset map. See explanation in Figure 6.

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the upper part of the section. We interpret these conglomerates as debris flow and braided channel deposits in an alluvial fan depositional system (see Liu and Yang, 2000 for analogous deposits). Overlying the alluvial fan conglomerate is silty mudstone, coarse sandstone, and pebble conglomerate, which form several coarsening-upward cycles. Mudstone and siltstone beds are typically laminated to massive; sandstone and interbedded conglomerate beds are massive, graded, plane-bedded, and planar cross-stratified. We interpret the mudstones in the lower portion to have been deposited in lacustrine systems and the sandstone and conglomerate deposited in a variety of lacustrine deltaic systems, including prodelta turbidites, subaquous debris flows, and distributary channels (McPherson et al., 1987). Each delta cycle is 30–50 m thick and the whole delta sequence is about 250 m thick. Volcanic rocks are present at the base of the lacustrine deltaic section.

The 825 m thick upper part of the Tuchengzi Formation mostly consists of vertically amalgamated conglomerate beds. Each bed is typically massive, roughly tabular and cross-stratified from the bottom to the top, and has an erosive base. Clasts are mostly 1–10 cm and rarely up to 50 cm in diameter, and are typically imbricated. These conglomerates are interpreted as braided channel deposits (Miall, 1978). The paleocurrents measured from imbricated clasts and cross-stratification are mainly toward the SSE or SE. Intervals of 10–50 cm thick massive and graded sandstone beds with sharp bases, which occur within dark laminated mudstone, are also found. These are interpreted to be lacustrine turbidity current deposits that are the components of a braided channel delta system (McPherson et al., 1987). Two lacustrine flooding surfaces occur in the Tuchengzi Formation, and three basin phases are divided by these maximum flooding surfaces. Phase 1 consists of alluvial fan systems, and phases 2 and 3 consist of braided channel delta and braided channel plain systems, respectively (Fig. 8A).

The Tuchengzi Formation in the Chengde Basin has similar depositional characteristics to that in the Luanping Basin described above. There are some depositional differences for the measured sections in different place of the Chengde Basin. Measured section 3 of the Tuchengzi Formation in the northern margin of the Chengde Basin (refer to Fig. 3 for its location) maintains the two lacustrine units, but the upper Tuchengzi Formation was eroded (Fig. 8B). Phase 1 in the section consists of 400 m of alluvial fan conglomerate; the lower part of phase 2, interrupted with several volcanic layers, is mudstone and interbedded pebbly sandstone, which represents the first lacustrine unit; the base of phase 3 consists of laminated, fining-upward, coarse- or medium-grained sandstone, and thin beds of massive conglomerate, interrupted with volcanic layers. It is interpreted to be sandy fluvial or floodplain deposits (see Liu et al., 2005 for analogous deposits) that probably correspond to the sediments of the second lacustrine flooding event. The top of phase 3 is missing due to erosion. Measured sections 5 and 6 in the northernmost margin of the Chengde Basin (Fig. 3) still have sedimentary rocks of the three basin phases, but they become coarser and are composed of sandy fluvial plain and gravel braided channel deposits.

The Tuchengzi sequence in the southern margin of the Chengde Basin is different from the northern margin and the Luanping Basin, but the two lacustrine flooding surfaces are also found there. The base and middle of the Tuchengzi Formation in measured section 10 (refer to Fig. 3 for its location) has two sets of conglomerate and pebbly sandstone, within which each bed, separated by clear scour surfaces, is fining-upward and with massive or massive and indistinct cross-bedding from the lower to upper parts. They are interpreted to be gravel braided channel deposits (Miall, 1978) (Fig. 8C). The dark mudstones and interbedded massive sandstones and pebbly conglomerates with sharp bases, which constitute several coarsening-upward sequences, overlie the two conglomerates, and represent lacustrine and braided channel delta depositional systems (McPherson et al., 1987). Compared with the deposits in the northern margin of Chengde and Luanping basins, the gravel braided channel deposits in the upper part of phase 3 are missing in southern Chengde Basin. Toward the eastern part of the southern Chengde Basin, grain size becomes coarser, the entire Tuchengzi Formation is composed of gravel and sandy braided channel systems, but three basin phases can be distinguished by grain size change.

A summary of the Tuchengzi deposition is as follows: (1) two lacustrine flooding events occurred synchronously in both basins, demonstrating that they were connected; (2) the depositional facies of the Tuchengzi Formation are very similar, and volcanic layers are developed within the parts of lacustrine deposits in the northern Chengde Basin and the Luanping Basin; (3) the top of phase 3 is

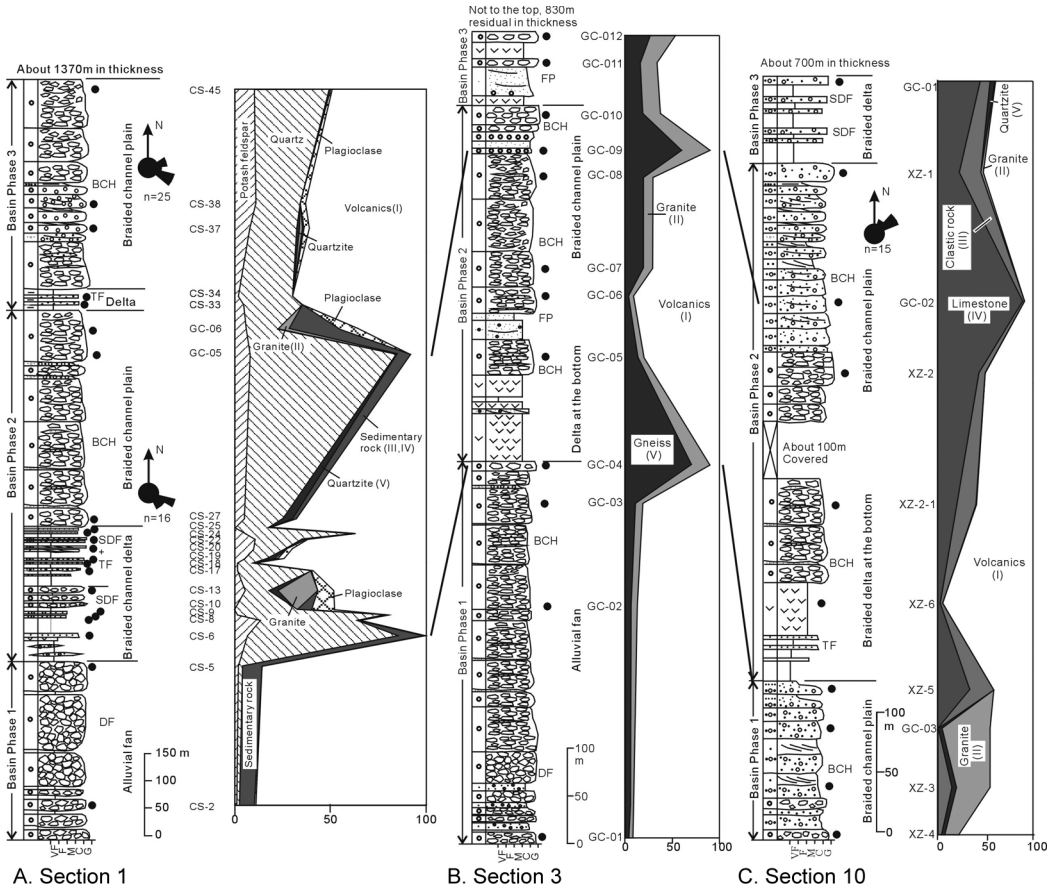


FIG. 8. Stratigraphic sequences of the Tuchengzi Formation and the vertical change of clastic fragment content in the Luanping-Chengde Basin (modified from Liu et al., 2004b). Refer to Figure 3 for location of sections. Abbreviations: DF = debris flow; SDF = subaqueous debris flow; TF = turbid flow deposits; BCH = braided channel deposits; FP = floodplain deposits. I, II, III, IV, and V represent types of lithic petrofacies. See explanation in Figure 6 and 7.

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eroded in the southern, but preserved in the northern Chengde Basin; (4) mudstone and thin sandstone, representing lacustrine and delta deposits, are mostly developed between Luotoushan and Biandanliang (Fig. 3), close to the depositional center of the basin.

Dazhangzi and Xinchengzi basins. The Dazhangzi and Xinchengzi basins, distributed south of the Shangyi-Pingquan thrust, are separated by a pluton (132 Ma, U/Pb; Davis et al., 2001) (Figs. 2 and 3). Both basins have a similar depositional facies as the Tuchengzi Formation in the Chengde Basin. The Tuchengzi Formation in measured section 15 in the Dazhangzi basin (Fig. 3) is divisible into three basin phases (Fig. 9). The lower part of phase 1 contains several fining-upward cycles with basal scour surfaces, which consist of massive or poorly imbricated conglomerates and massive siltstone. The upper part of phase 1 is mainly composed of conglomerate in which clasts are imbricated, and lenticular depositional bodies with basal scour surfaces are vertically superposed. We interpret phase 1 as gravel braided channel deposits (Miall, 1978). Phase 2 is composed of dark mudstone or silty fine sandstone with plane bedding and interbedded coarse sandstone and pebbly conglomerate with massive and graded tabular to lenticular bedding and sharp basal contacts. The former is interpreted to be lacustrine deposits

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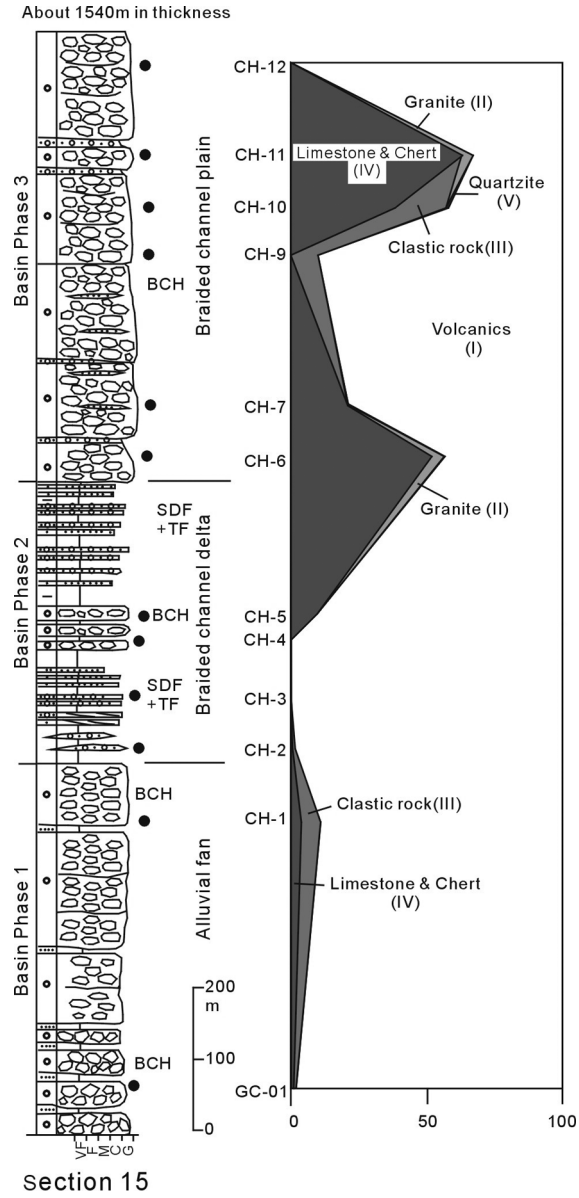


FIG. 9. Stratigraphic sequences of the Tuchengzi Formation and the vertical change of lithic fragment content in the Chehekou-Dazhangzi section in the Dazhangzi-Xinchengzi Basin. See explanation in Figures 6, 7, and 8. Refer to Figure 3 for location of section.

and the latter, to be turbidity current and debris flow deposits (McPherson et al., 1987). The lacustrine mudstones and turbidity current and debris flow sandstones and conglomerates constitute several upward-coarsening depositional cycles. Braided channel conglomerates are developed at the top of each cycle. Phase 2 represents lacustrine and braided channel delta deposits. Phase 3 has a similar depositional character to Phase 1, and is interpreted as braided channel conglomerates.

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Basin Depositional Provenance and Unroofing of Source Areas

Methodology

The composition of conglomerate and sandstone contains information about the uplift and unroofing of adjacent mountains (e.g., Hendrix et al., 1996; Hendrix, 2000). Basins in the Yanshan belt are dominated by sandstones and gravels; therefore different techniques were used to identify composition of these different grain sizes. In order to link rock fragments to specific protoliths, we determined sandstone composition by the traditional point-counting method (e.g., Indiana method), in which all grains are counted as their respective rock type, even if coarsely crystalline (e.g., sand-sized monocrystals within a rock fragment are counted as that rock fragment). Thin sections were made and more than 300 to 310 framework grains were counted per slide. We calculated the contents of different fragments, and also showed the results for rock fragment composition, which typically represents more than 15% of all the grains counted. We collected conglomerate clast data in the field. In each case nearly every clast in an area of 2 m^2 was identified, typically more than 50 to 80 clasts.

In order to determine compositional contents and the change of different grains through time, we plotted grain composition vs. stratigraphic position for some sections (Figs. 6, 7, 8, and 9). The composition results are shown as petrofacies: volcanic rocks, intrusive rocks, clastic rocks, carbonates and cherts, and metamorphic rocks (quartzite, gneiss) and so on, consisting of groups of lithologies that are found together in different source regions, thus defining distinctive provenances. Volcanic petrofacies contain andesite, dacite, trachyandesite, rhyolite, tuff, and trachyte clasts. Intrusive rock petrofacies contain granite, granite porphyry, diorite, and anorthosite in the Chengde Basin, and gabbro in the Chicheng Basin. Clastic rock petrofacies include sandstone, siltstone, mudstone and shale. Carbonate and chert petrofacies include limestone, dolomite, chert and minor vein calcite. Metamorphic rock petrofacies contain gneiss, granite gneiss, quartzite, schist, slate, and minor mylonite.

Provenance Analyses of Triassic Basins

Results for composition of lithic and gravel grains are shown in Figures 6A–6C for the Middle and Upper Triassic sections in southern Pingquan, southern Luanping, and western Beijing, respectively. The gravel clasts and sandstone rock fragments contained in the Middle and Upper Triassic in southern Pingquan include carbonates, cherts, clastic rocks, quartzites, gneiss, volcanic rocks, and granites (Fig. 6A). Comparison of the rock fragments with source area strata suggests that the provenance of the Middle and Upper Triassic includes Archean, Middle, and Upper Proterozoic and Paleozoic, and the provenance strata underwent an unroofing process. The rock fragment petrofacies in the lower Ermaying Formation of the Middle Triassic include carbonates, cherts, and clastic rocks, and their corresponding provenance strata are the Middle–Upper Proterozoic Jixian and Qingbaikou formations and Paleozoic stratigraphy mainly containing carbonates, cherts, and clastic rocks. The petrofacies in the upper Ermaying Formation include carbonates, quartzites, clastic rocks, gneiss, and volcanic rocks, which suggest that the lower Proterozoic Changcheng System, mostly containing quartzite, was largely eroded (aside from the Jixian System), and the Archean, mostly containing gneiss, began to be unroofed. Percentages of quartzite, gneiss, and granite increase and carbonatite, chert, and clastic rocks decrease in content in the Upper Triassic Xingshikou Formation, which represents the erosion of the Archean and Changcheng System and unroofing of granite. Upper Triassic conglomerate in southern Luanping unconformably overlies the Archean, and gravels within it mainly include gneiss, amphibolite, granite, quartzite, and volcanic rocks (Fig. 6B). Their provenances are the Archean and Changcheng systems. The composition of the Upper Triassic rock fragments and conglomerate clasts in western Beijing includes quartzite, clastic rocks, carbonate, chert, and volcanic rock (Fig. 6C), and their provenances are probably the Proterozoic Changcheng and Jixian systems; however, the Archean basement rocks apparently were not exposed. In sum, the northern Yanshan was deeply eroded, but the southern part experienced relatively shallow unroofing in the Late Triassic.

Provenance Analyses of Jurassic Basins

The provenance of the Upper Jurassic Tuchengzi Formation is complicated, and is related to basin marginal thrusting. Here we introduce the distribution of its lithic fragments in different basins.

Chicheng Basin. The provenance characteristics of the Tuchengzi Formation have some differences in different parts of the Chicheng Basin. Through field clast-counts in Sections a, b, and c (Figs. 7A,

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7B, and 7C), we found that about 80 to 95% of gneiss and schist clasts and a few volcanic, quartzite, and gabbro clasts are contained in the lower parts of the sections, which are derived from the Archean distributed to north of the Shangyi-Pingquan thrust. In addition, volcanic fragments are increased upward. The petrofacies of more gneiss fragments and less volcanic fragments reappear in the upper part of Section c. The paleoflow, based on imbricated gravels and cross-sets, was to the west and southwest (Fig. 7C).

The petrofacies in the eastern part of the basin are different. The composition of rock fragments and conglomerate clasts in Section d, for example, includes volcanic and clastic rocks, metamorphic rocks (quartzite and schist), and granites (Fig. 7D). The contents of volcanic rock fragments show three upward decreasing cycles across the whole section. Clearly, the provenance for volcanic fragments was predeveloped or syndepositional volcanic rocks, and the provenances for other fragments were the Lower Proterozoic Changcheng System, Archean metamorphic rocks, and intrusives. The rock fragment cycles in the Tuchengzi Formation suggest that the source areas covered by volcanic rocks were unroofed and eroded three times, or three-time syndepositional volcanism.

Luanping, Chengde, Dazhangzi and Xinchengzi basins. The Late Jurassic Luanping, Chengde, Dazhangzi, and Xinchengzi basins are located in the middle part of the Yanshan belt, and are located in different thrust sheets within the Shangyi-Pingquan thrust system. Rock fragment analysis of sandstones in these basins supplies more evidence of synchroneity between basin subsidence and basin-margin thrust faulting. Figure 8A shows the content of plagioclase and volcanic rock (I), granite (II), sedimentary rocks (including limestone [IV] and sandstone, mudstone, and claystone [III]), potassium feldspar, quartz, and quartzite (V) of the Tuchengzi Formation in Section 1 in the Luanping Basin (refer to Fig. 3 for its location). The fragments of quartz and potassium feldspar were probably derived from granite gneisses, quartzite and granite and granite porphyry in source areas, and plagioclase fragments mostly from volcanic rocks (I) such as andesite and rhyolite, and some from anorthosite (II) and gneiss (V). There is an inverse relationship between quartz-potassium feldspar and volcanic rock contents in Figure 8A. The quartz-potassium feldspar fragments that are the representative of metamorphic petrofacies (V) are organized in three cycles from low to high contents in the section, along with the volcanic (and plagioclase) fragments as three cycles from high to low contents. The low contents of the volcanic fragments appear at the base and upper parts of the phase 2 and the top of the phase 3 that are the locations of the relatively high contents of fragments of potassium feldspar and quartz. The volcanic fragments are the products of unroofing and erosion of volcanic rocks, and the others are due to unroofing and erosion of Proterozoic and Paleozoic intrusive and metamorphic rocks.

The Tuchengzi Formation in the northern Chengde Basin does not contain any carbonate or chert rock fragments; instead its composition is dominated by basement metamorphic and intrusive clasts. Some sections contain anorthosite lithic fragments or gravels that were derived from the anorthosite intrusives to the north of the Chengde basin. The types of rock fragments in measured section 3, for example, mainly include volcanic rock (I), granite (II), and gneiss (V) (Fig. 8B; refer to Fig. 3). A growth and decline relationship between the contents of granite-gneiss and volcanic rock fragments exists in the section, and the volcanic fragment contents form three cycles from high abundance to low abundance vertically. The low contents of the volcanic fragments are located at the top of phase 1 and the upper part of phase 2. The volcanic fragment content decreases in phase 3, but its top is missing. The lower contents of the volcanic fragments are the depositional response to unroofing of basement metamorphic rocks and granites. In Section 8 of the northern Chengde Basin (refer to Fig. 3 for location), the content of granite fragments is about 20%, and gneiss and granite gneiss fragments about 17%, clastic rock fragments about 4%, and volcanic fragments about 60%; detrital carbonate fragments are lacking. In Section 9 of the middle Chengde Basin (Fig. 3), the content of granite and anorthosite fragments is about 15–50%, and gneiss and quartzite fragments about 5–19%. The volcanic fragments (I) are lower in content at the upper parts of phase 1 and 2, and forms two cycles in which their contents decrease upwards. This petrofacies cycle is not clear in phase 3. In sum, not only are depositional facies and sequences similar between the Luanping and northern Chengde basins, but they also have almost the same rock fragment types and petrofacies cycles, suggesting the same provenance. Additionally, the southeastward and southward paleoflows in southeastern Luanping (measured section 1 in Fig. 3) (Fig. 8A) and eastern Chengde

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City (Section 8 in Fig. 3), respectively, measured from the imbricated gravels, also support the conclusion that they share the same source terrane (Fig. 11).

Sandstone rock fragment components of the southern Chengde Basin are quite different from those of the northern margin. Gneiss and granite fragments occur in lower abundances, but carbonate, chert, and sandstone fragments are more abundant. The rock fragment components in measured section 10 (refer to Fig. 3), for example, include volcanic grains of andesite, rhyolite, and tuff (I); chert and carbonate rocks of limestone and dolomite (IV); and clastic rocks (III) of sandstone, siltstone, and mudstone (Fig. 8C). The contents of the former petrofacies and the latter two petrofacies represent a growth and decline relationship. The lower contents of the volcanic petrofacies appear at the top of the phase 1 and the upper part of the phase 2, and show two high-low cycles and an incomplete third cycle, because the top of the section is eroded. The lower contents of the volcanic petrofacies are located at a similar place to those in the northern Chengde and Luanping basins. But the carbonate (IV) and chert petrofacies (III) in the southern Chengde Basin replace the metamorphic petrofacies (V) in the northern basin. Other sections in the southern basin have similar petrofacies characteristics to Section 10. Section 12 in the southeastern Chengde Basin (Fig. 3) contains 45% carbonate rock fragment, 52% volcanic rock fragments, 2% clastic rock fragments, and 1% metamorphic rock fragments, based on 3175 gravel counts in the two spots. The detrital carbonate component of Sections 13 ad 14 (Fig. 3) decreases to 5–20%, but clastic fragments increase to about 30%. Volcanic fragments maintain a higher abundance (50–90%) and metamorphic and intrusive fragments a much lower content.

Therefore we conclude the following: (1) The provenance of the northern Chengde and Luanping basins was mainly from the Archean basement metamorphic rocks along the northern margin of the Luanping-Chengde Basin, but the provenance of the southern Chengde Basin was mainly from Proterozoic and Paleozoic carbonate, clastic, and banded chert rocks along the southern margin, both including volcanic rocks. (2) The provenance along the northern and southern margins of the basin underwent at least three periods of unroofing, and the increase of volcanic fragments in the basins was probably caused by syndepositional volcanism or erosion of early-formed volcanic rocks.

Sandstone in the Dazhangzi and Xinchengzi basins includes more than 95% andesite, rhyolite, limestone and chert, and sandstone, siltstone, mudstone, claystone, and granite, and less than 5% quartzite clasts in their rock fragment fraction. A growth and decline relationship between the contents of the limestone and chert fragments (IV) and volcanic fragments (I) exists in Section 15 in the Dazhangzi Basin (Fig. 9). The contents of limestone and chert fragments constitute three upward-increased cycles, and their higher contents (6%, 52%, and 62%) are placed at the top of phase 1, and the bottom and top of phase 3, respectively. Section 17 in the Xinchengzi Basin (Fig. 3) shows the same characteristics as the former. The components and dispersal styles of lithic fragments in the Dazhangzi and Xinchengzi basins show that the provenance of the basins was Proterozoic and Paleozoic strata distributed within the Shangyi-Pingquan thrust, but the location of the petrofacies cycles is clearly different from the sections in the northern Chengde Basin.

The Tuchengzi Formation in the northern margins of the Shangyi and Beipiao basins (Fig. 10) contains abundant rock fragments and clasts of gneiss, amphogranite, and granite, but the Xuanhua, southeastern Pingquan, and Boluochi basins contain a large proportion of limestone and dolomite, which are related to thrust uplift and unroofing of different basement rocks (BGMRHP, 1989; BGMRLP, 1989). Typically the provenance from the northern side of the Shangyi-Pingquan, Fengning-Longhua, and Linyuan-Dongguanyingzi thrusts is mostly Archean basement metamorphic rocks, but the provenance from the southern side of the thrusts consists mostly of Proterozoic and Paleozoic carbonate rocks.

Paleogeography and Tectonics of Basins and Their Marginal Thrusting

The Mesozoic basins in the Yanshan belt underwent syn- or post-depositional structural modification and were broken into small basins. In order to reconstruct this evolving paleogeography, we correlated stratigraphic sections, analyzed grain size trends, measured paleocurrent indicator orientations, and determined provenance of rock fragments in sandstone and conglomerate clasts. We then related these results to structures.

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Late Triassic

The northern and southern belts of Late Triassic basins previously comprised a continuous basin based on correlative stratigraphy, facies proximality, grain-size trends, and provenance linkages. Paleocurrents in both basin belts were mostly south-directed, suggesting that the southern belt is a more distal equivalent of Triassic strata to the north, and that the two outcrop belts were not segmented during the Triassic. In the northern part of the basin gravel alluvial fan and gravel braided plain depositional systems were developed; these systems passed into coarse-grained fluvial systems, with better developed overbank facies in the southern part of the region. Similarly, the grain size of the conglomerate continuously decreases from the northern part of the northern outcrop belt to the southern outcrop belt.

The present northern extent of the northern outcrops, bound by the "unnamed fault" (Zhao, 1990; Davis et al., 1998), roughly defines the Triassic basin margin. Based on clast compositions in the conglomerates, we interpret Triassic conglomerate to have been derived from the active hanging wall of the "unnamed fault." These conglomerates and the southern coarse-grained fluvial systems filled a thrust-related foreland basin system related to south-directed thrusting on the "unnamed " fault to the north.

Late Jurassic

Late Jurassic basins, represented by the Tuchengzi Formation, migrated northward to the margins of the Fengning-Longhua, Shangyi-Pingquan, and Lingyuan-Dongguanyingzi thrusts (Fig. 10) relative to Middle Jurassic basins (Liu et al., 2004b). The Shangyi, Chicheng, Xinchengzi, Dazhangzi, Luanping, and Chengde basins are distributed along the Shangyi-Pingquan and Fengning-Longhua thrusts, and the NNE-trending Boluochi, Beipiao, and Jinlingshi-Yangshan basins in Jianchang and Chaoyang (Fig. 10) developed synchronously with western dipping and eastern thrusting faults. An excellent example of this type of polycyclic deformation and basin development is found in the Chengde area and is introduced below as a case study.

South of the Shangyi-Pingquan thrust are the Xinchengzi and Dazhangzi basins, which are partitioned by a 132 Ma intrusive body. To the north are the Shirengou, Luanping, and Chengde basins, the Shirengou and Luanping basins being partitioned by a basement uplift and the Luanping and Chengde basins partitioned by a 129 Ma intrusion (Fig. 3). Sedimentary and provenance study shows that there are clear depositional facies belts in the Luanping-Chengde Basin. The Tuchengzi Formation in Sections 2, 3, 4, 6, 7, and 8 in Figure 3 at the northern margin of the basin consists of a braided channel plain, alluvial fan at the base, and two interbedded braided channel delta systems. Across the Chengde thrust fault, the grain size of sediments in Section 9 is greatly decreased, and depositional systems are composed of distal fluvial plain and interbedded delta and lacustrine systems. The southern narrow depositional margin of the Luanping-Chengde Basin, distributed along Sections 10, 11, 12, 13, and 14, develops coarse braided channel plain and interbedded two delta depositional systems. Lacustrine, delta, and distal fluvial plain systems are developed in E-W–trending basin centers. The provenance of the basin to the north of the depositional center is mostly from the Fengning-Longhua and Damiao-Niangniangmiao thrusts, and the sediments contain abundant basement metamorphic conglomerate clasts and sand-sized rock fragments. However, the provenance of the basin to the south of the depositional center is from the Shangyi-Pingquan thrust, and voluminous Proterozoic and Paleozoic carbonate, chert, and clastic gravels and fragments are developed in the sediments (Fig. 11).

Measurement of imbricated cobble to boulder conglomerate and cross-stratification shows that the paleocurrents of the Luanping-Chengde Basin are from the northern and southern margins toward the basin center, and to the east or ESE at the basin center (Fig. 11). The sediments of the Tuchengzi Formation at Chengde City, measured sections 7 and 9 (Fig. 3) in the northern margin of the basin, contain pebbles and rock fragments of anorthosite that must have been derived from the north where the anorthosite intrusions are located along the Fengning-Longhua and Damiao-Niangniangmiao thrusts, and the distributional scope of anorthosite fragments cross the Chengde thrust (Fig. 11). These geological relationships show that the Chengde thrust did not destroy the basin architecture, and had no long-distance displacement.

The Luanping and northern Chengde basins are divided by a younger igneous instrusion, but they are filled with almost the same depositional systems and clastic components. The paleocurrent indicator orientations measured from imbricated gravels and cross-bedding are toward the ESE along the eastern

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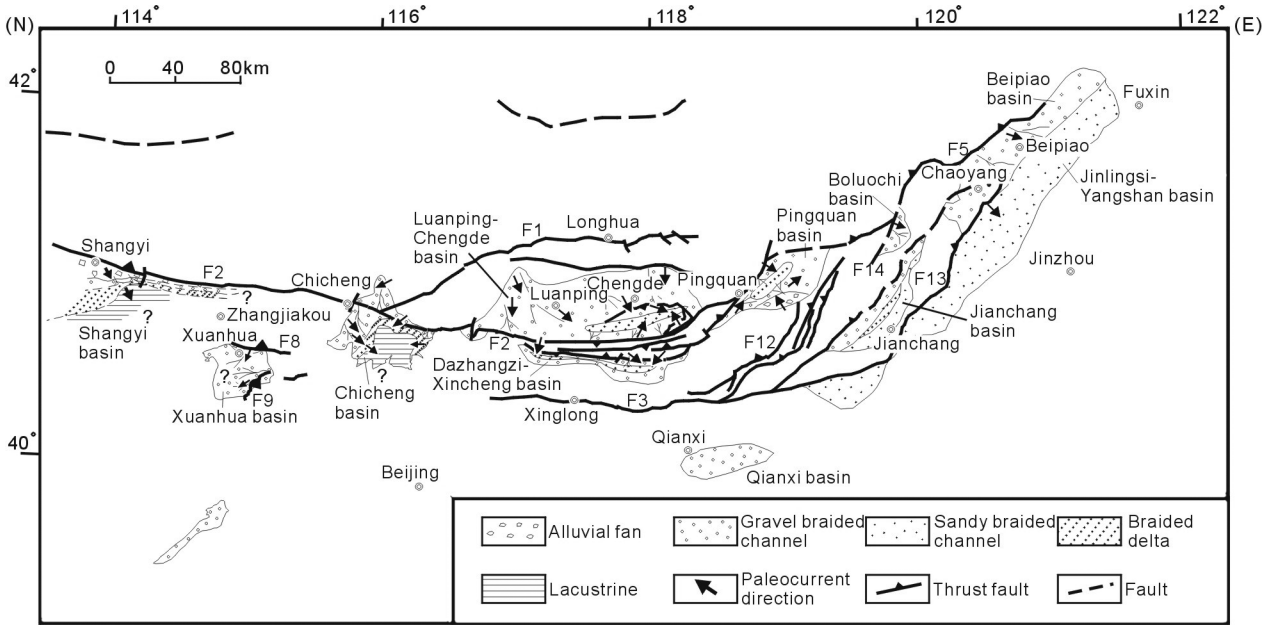


FIG. 10. Late Jurassic protobasins and their paleogeography in Yanshan belt (modified from Liu et al. 2004a). See explanation in Figure 2.

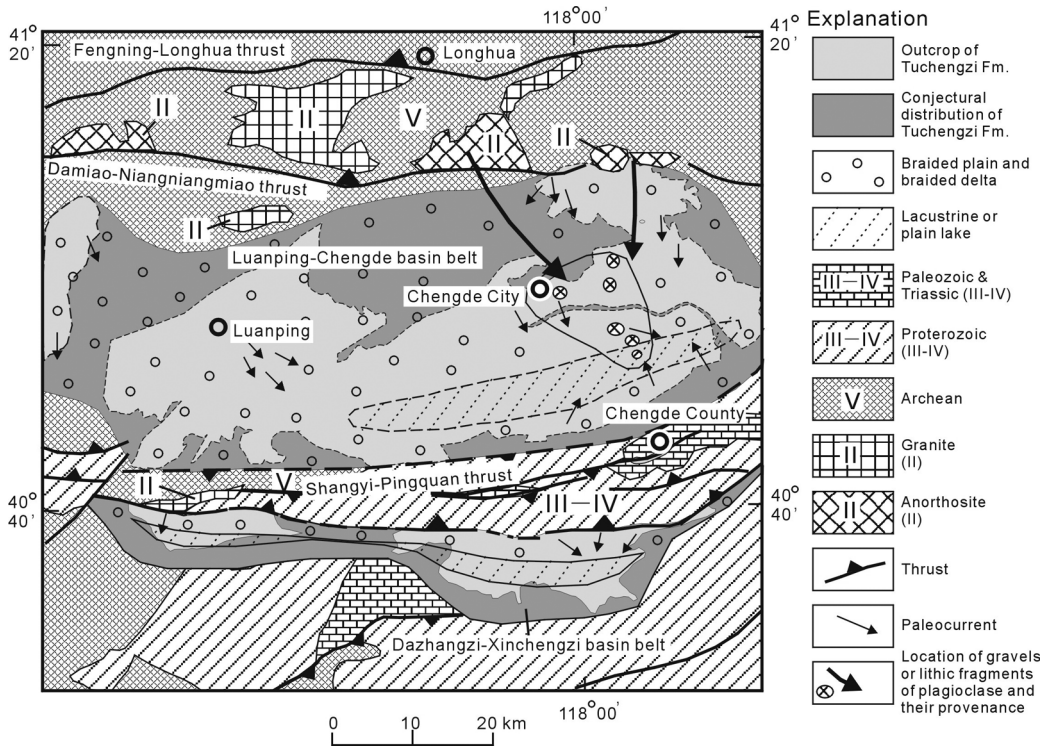


FIG. 11. Reconstruction of the Late Jurassic Tuchengzi Formation basins, paleocurrent directions, and provenance in Chengde and its adjacent regions (modified from Liu et al., 2004b). Area is identical to that shown in Figure 3.

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margin of the Luanping Basin. The Shirengou Basin is divided from the Luanping Basin by basement uplift, but its similar depositional constitution to the latter basin and its southward and SSE paleocurrent indicators demonstrate that the two basins were connected at the syndepositional stage (Fig. 11). Thus we can conclude that the Chengde, Luanping, and Shirengou basins represent the Luanping-Chengde protobasin located between the Damiao-Niangniangmiao and Shangyi-Pingquan thrusts, and the Luanping Basin occupies the northern margin of the protobasin. Because of erosion and structural deformation, it is difficult to restore basin subsidence, but in general the stratigraphic thickness of the Tuchengzi Formation in the northern and southern margins of the basin (measured section 1 in the northern margin, 1370 m, measured section 14 in the southern margin, 1690 m) is greater than that at the basin center (section 9, 800 m). The Dazhangzi and Xinchengzi basins, divided by an igneous intrusion, belong to the Dazhangzi-Xinchengzi protobasin with the same depositional constitution and southward paleocurrents, distributed to the south of the Shangyi-Pingquan thrust.

The Luanping-Chengde and Dazhangzi-Xinchengzi basins are linked with the Damiao-Niangniangmiao and Shangyi-Pingquan thrusts, and their formation is related to shortening of the two thrust belts. The provenance of the northern Luanping–Chengde Basin is mostly from the Archean basement metamorphic rocks and volcanic rocks, and its paleocurrent directions are mainly southward, which demonstrates that the Fengning-Longhua and Damiao-Niangniangmiao thrusts uplifted and underwent erosion during deposition. In contrast, Davis (2005) doubted that there was syndepositional thrust faulting along the Fengning-Longhua thrust, inasmuch as the initial geometry of this steep fault, its kinematics, and its age remain highly controversial, suggesting that further work may be required to establish this relationship.

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The northern branch of the Shangyi-Pingquan thrust is the Chengde County thrust, and the southern branch is the Gubeikou thrust (Fig. 4). Backthrusting led to uplift and unroofing of the Proterozoic and Paleozoic limestone, chert, and clastic rocks, which supplied sediment to the Chengde Basin and the Dazhangzi-Xinchengzi Basin. Davis et al. (1998, 2001) thought that the hanging wall of the Chengde thrust, which consists of Proterozoic and Jurassic sedimentary rocks, was an allochthon that came from a long distance southwards. From their view, the northern and southern parts of the Chengde Basin should belong to different basins, and depositional components filled in the two parts should have a clear diversity. But the provenance of Section 9 located to the south of the Chengde thrust (Fig. 3) was still from the northern margin of the basin, and the anorthosite-bearing gravels, transported from the northern side, were distributed across the entire Chengde thrust (Fig. 11). As a result, we conclude that the Chengde long-distance thrusting, if it exists, post-dated Tiaojishan deposition, but pre-dated depositon of the Tuchengzi Formation. Therefore, there does not appear to be enough time between deposition of the Tiaojishan and Tuchengzi formations for major displacement of the Chengde thrust sheet, its subsequent erosion, and the deposition of Upper Jurassic Tuchengzi strata across the thrust trace (Davis, 2005). Furthermore, the Tiaojishan-Tuchengzi contact in the Chengde-Luanping basin area is generally concordant and may be conformable (Cope, 2003; Liu et al., 2004a; Davis, 2005). According to these structural and depositional data, we infer that the Chengde thrust was post-Tuchengzi (in age), limited displacement, and basement-involved thrust fault, which was reactivated as a normal fault during the Early Cretaceous (BGMRHP, 1989; Davis, 2005) (Fig. 4). According to the structural relationship between the Chengde and Shangyi-Pingquan thrusts, the northern and southern branches of the Shangyi-Pingquan thrust fault thrust northward and southward before the Chengde thrust, and controlled the Late Jurassic deposition in the southern Luanping-Chengde and Dazhangzi-Xinchengzi basins (Figs. 4 and, 11).

Generally, shortening on the basin margin was concomitant with the change in basin provenance (Liu et al., 2003). A systematic stacking of sandstone petrofacies is evident in the Luanping-Chengde and Dazhangzi-Xinchengzi basins, characterized by upward-increasing cycles of basement metamorphic lithic fragments in the northern Luanping-Chengde Basin and carbonate and clastic fragments in the southern Luanping-Chengde and Dazhangzi-Xinchengzi basins. This systematic stratigraphic ordering of petrofacies is recognized repetitively in the stratigraphy (Figs. 8 and 9). The rock fragment petrofacies cycles almost fit with basin phase cycles, but some high percentage values of lithic petrofacies V (gneiss) or III (clastic rocks) and IV (limestone and dolomite) are located at slightly higher positions than those of basin phase margins. The contents of volcanic grains in the sandstones of the two basin belts are high, but decrease upward (Figs. 8 and 9). All these characteristics of the petrofacies were controlled by structural uplift in source areas. At the beginning stage of basin subsidence and deposition, abundant Middle Jurassic volcanic rocks (Jiulongshan and Tiaojishan formations) were distributed in the source areas of the basins. 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. Archean metamorphic rocks were exposed within the Fengning-Longhua and Damiao-Niangniangmiao thrusts, and the Proterozoic, Paleozoic, and Mesozoic carbonate and clastic rocks crop out within the Shangyi-Pingquan thrust. The three petrofacies cycles are the depositional response to three episodes of thrusting and unroofing of basement rocks along the basin margins. With erosion of volcanic rocks on the surface, the abundance volcanic lithic fragments in sediments gradually decreased.

Geodynamics of Basin/Mountain Systems—Discussion

The Yanshan belt lies along the northern margin of the Archean-floored North China craton, but during Jurassic and Cretaceous time it lay within an amalgamated Mesozoic NCMC and North China plate (Zhao et al., 1990; Enkin et al., 1992; Davis et al., 2001). The timing and style of amalgamation of the two elements of the Mesozoic North China and NCMC along the Suolon suture is controversial. Some authors (e.g., Robinson et al., 1999) favor northward subduction of North China beneath successively accreting arc fragments, whereas others (e.g., Wang and Liu, 1986; Nie et al., 1990) argue for S-dipping subduction beneath the North China block. Southward Permian–Triassic subduction beneath the Archean craton is supported by the

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widespread occurrence of numerous plutons ranging in age from 285 to 217 Ma south of the suture (e.g., Cui and Wu, 1997), causing a strong southward compression and thrusting. Responding to subduction and, ultimately, collision along the Suolun suture between North China and NCMC from Late Permian to Middle Triassic, the retro-arc foreland basin south of the Yinshan-Yanshan belt and on the North China Block was filled with mostly nonmarine sandstone, mudstone, and minor conglomerate (Zhou, 2002; Cope et al., 2005; Ritts et al., 2004, 2006). Upper Triassic conglomerate south of Luanping-Chengde was deposited in response to the southward thrusting of an "unnamed fault," which represents the last stage of deposition in the retro-arc foreland basin. Sediment composition records thrust uplift and unroofing of Paleozoic, Proterozoic, to Archean soure terranes north of the Shangyi-Pingquan thrust. The deposition of gravel molasse distributed in the West Beijing syncline was also related to thrust uplift of basin margins. Thus, Late Triassic sediments were the products of the later stages of the ongoing orogeny along the retro-arc belt in the Yinshan-Yanshan, south of the Suolon suture. This continued shortening was probably caused by both post-collisional convergence on the Suolon suture as well as the North China–South China plate collision along the Qinling-Dabie suture to the south during the Middle and Late Triassic (Zhang et al., 2001; Liu et al., 2005).

The Yanshan belt underwent an important tectonic transformation from a retroarc orogenic belt to intracontinental deformation during the Jurassic. This transition coincided with shallow intermontane basins in the area of the Yanshan (Liu et al., 2004a) and initiation of extension, interpreted to indicate either orogenic collapse or strike-slip deformation, in the nearby Daqing Shan segment of the along-strike Yinshan belt (Darby et al., 2001; Ritts et al., 2001). Shortening was apparently re-activated during the Middle Jurassic, and resulted in uplifts and synclinal basins from about 180 Ma to 147 Ma (Liu et al., 2004a). This shortening was accompanied by a change from mostly N-S shortening to NW-SE shortening. This change in shortening direction correlates to the beginning of northwestward subduction of paleo-Pacific plate (Liu and Ke, 1996).

The Late Jurassic shortening event took place during between 156 and 139 Ma, continuing earlier Jurassic N-S shortening. In the Late Jurassic, the deformation style consisted of N- and S-directed thrust faulting during the syndepositional stage of the Tuchengzi Formation. This faulting controlled the formation of the Late Jurassic broken foreland basins (Fig. 10). The Shangyi and Chicheng basins were mainly controlled by the western part of Shangyi-Pingquan thrust, and the Xuanhua basin controlled by the Xiahuayuan thrust in the south and Xuanhua thrust in the north. The Luanping-Chengde Basin was controlled by the northern branch of Shangyi-Pingquan thrust in the south and Fengning-Longhua thrust in the north, and the Dazhangzi-Xincheng Basin was controlled by the southern branch of Shangyi-Pingquan thrust. The NNE-trending basins in West Liaoning were mainly controlled by thrusts west of the basins, and were located between Lingyuan-Dongguanyingzi and Miyun-Xifengkou thrusts in diagonal style, which suggests that the basins were formed by clockwise rotation transpression. Controlled by regional thrusting, the broken foreland basins in the Yanshan belt were filled with gravel braided channel and braided channel delta depositional systems, and the basement rocks in the source areas of the basins were uplifted multiple times and unroofed. Cross-cutting relationships and geochronologic data clearly indicate that these S- and N-directed thrusts were activated at the syndepositional stage of the Tuchengzi Formation. The Chengde County thrust and the Gubeikou thrust, for example, were emplaced during 152–129 Ma and 148–132 Ma, respectively.

In summary, active N-S shortening during the Triassic was related to retro-arc and collisional deformation related to plate margin tectonics along the Suolon suture. This deformation and related foreland basin formation is very similar in timing and style to structural and stratigraphic relationships seen along strike to the west in the Yinshan belt. Following a period of relative quiescence, marked by development of localized intermontane basins in the Yanshan and extensional basins in the Yinshan, during the Late Triassic and Early Jurassic shortening initiated in the Yinshan again during the Middle Jurassic, with intense N-S and NW-SE shortening in the Late Jurassic.

The driving mechanism for Jurassic intraplate deformation in the Yanshan belt is important. There are three major collisional accretional events in eastern Asia during Jurassic time: northwestward subduction of Pacific plate; the post-collisional shortening along the Qinling-Dabie suture zone; and collision of the amalgamated blocks of China with those of Siberia along the Mongol-Okhotsk suture

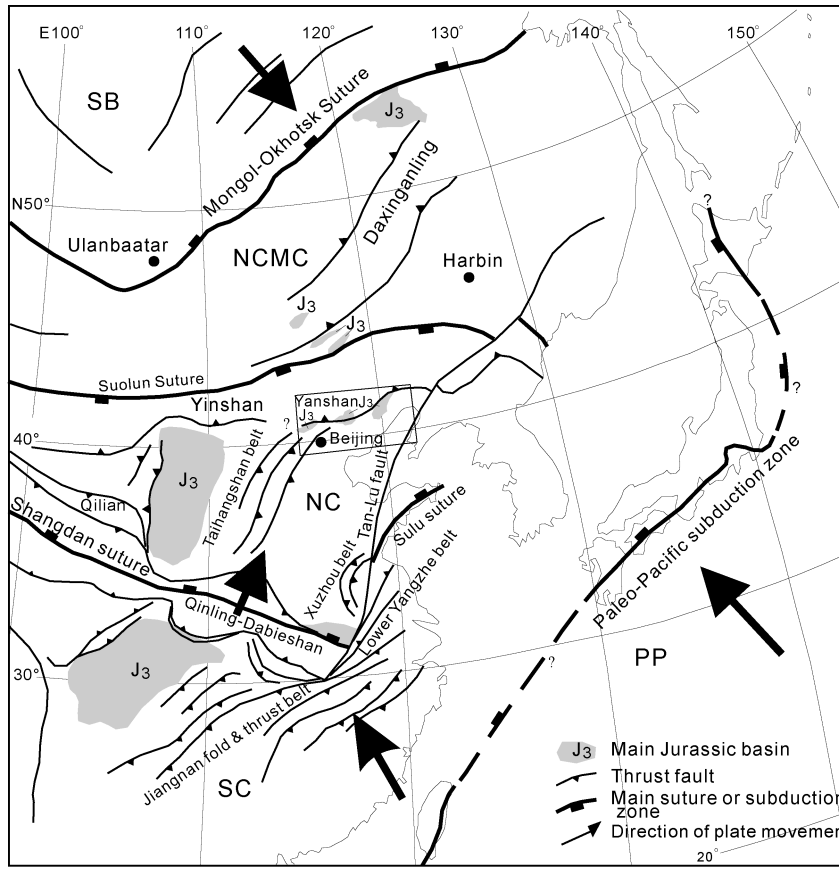


FIG. 12. Regional tectonic background and geodynamics of Yanshan belt. Abbreviations: SB = Siberia plate; PP = Paleo-Pacific ocean plate. See explanation in Figure 1.

zone (Fig. 12). After the Early–Middle Jurassic, the Izanagi plate subducted northwestward, which could have imparted NW-SE–oriented stresses to the NCB, and caused very strong thrusting along the eastern continental margin of China, the Taihang-Yanshan thrust belt, and the southern Tanlu fault–Lower Yangzhe–Xuzhou–Sulu thrust belt (Zhang, 1997). The two belts constitute giant NNE-SSW–trending and anti-"S"–shaped thrust belts.

The Qinling-Dabie suture zone closed from east to west, and achieved complete oceanic closure in the Middle Jurassic time. During the Late Jurassic through Early Cretaceous, the intracontinental shortening 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, could have produced northwestward shortening in the Yanshan fold-thrust belt.

The Mongol-Okhotsk suture lies ~1000 km north of the Yanshan belt, twice as far as the Qinling-Dabie suture zone. The collision along the suture began in the west and progressed to the east, ending at the end of the Jurassic time (Nie et al., 1994; Zorin, 1999). Crustal shortening prevailed in the China-Mongilia border during Middle to early Late Jurassic time in response to the continental collision along the Mongol-Okhotsk suture (Graham et al., 1996). From the above analyses of regional tectonism, it appears likely that the Jurassic shortening represented by fold and thrust was driven by multiple far-field dynamic forces: northwestward subduction of Pacific plate and collision of the amalgamated blocks of China with those of Siberia along the Mongolo-Okhotsk suture zone. The

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regional tectonic setting resulted in episodic Jurassic thrusting after the Late Triassic to the south of the Suolun suture along the northern margin of the North China plate (Yanshan belt). The far-field driving forces from the south and north caused southward and northward thrusting in the Yanshan belt, which controlled the broken foreland basin development.

Conclusions

1. In response to two thrusting events during the Late Triassic and Late Jurassic, gravel braided channel depositional systems in the Xingshikou Formation and gravel alluvial fan, braided channel plain, and braided delta systems in the Tuchengzi Formation were deposited in front of thrust belts in the Yanshan belt.

2. Sediment provenance of Middle and Upper Triassic strata suggests that Archean and Proterozoic rocks in the source areas were uplifted and unroofed. Composition of lithic fragments and gravels shows that the cover strata gradually eroded away, and granites were continuously unroofed. The provenance of the Upper Jurassic sedimentary rocks shows multiple episodes of unroofing of pyroclastic cover and incision of underlying basement rocks.

3. The long-term evolution of the basin system was from a Late Triassic foreland basin, through uplift and erosion of the region, to an evolving Jurassic basin system that transitioned from earlier intermontane basins, through distributed folding, to a broken foreland system by the Late Jurassic.

4. The evolution of Early Mesozoic basin-mountain systems in Yanshan was driven by deformation along the retro-arc belt of the Suolon suture in the Triassic, and regional transmission of far-field stresses, northwestward subduction of the Pacific plate, and collision of the amalgamated blocks of China with those of Siberia along the Mongolo-Okhotsk suture zone in the Late Jurassic.

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