

Mesozoic basin evolution and tectonic mechanism in Yanshan, China

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Abstract The Mesozoic basins in Yanshan, China underwent several important tectonic transformations, including changes from a pre-Late Triassic marginal cratonic basin to a Late Triassic-Late Jurassic flexural basin and then to a late Late Jurassic-Early Cretaceous rift basin. In response to two violent intraplate deformation at Late Triassic and Late Jurassic, coarse fluvial depositional systems in Xingshikou and Tuchengzi Formations were deposited in front of thrust belts. Controlled by transform and extension faulting, fan deltas and lacustrine systems were deposited in Early Cretaceous basins. The composition of clastic debris in Late Triassic and Late Jurassic flexural basins respectively represents unroofing processes from Proterozoic to Archean and from early deposited, overlying pyroclastic rocks to basement rocks in provenance areas. Restored protobasins were gradually migrated toward nearly NEE to EW-trending from Early Jurassic to early Late Jurassic. The Early Cretaceous basins with a NNE-trending crossed over early-formed basins. The Early-Late Jurassic and Early Cretaceous basins were respectively controlled by different tectonic mechanisms.

Keywords: Yanshan, Mesozoic, depositional provenance of basin, unroofing of provenance, basin evolution, tectonic mechanism.

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The Yanshan belt is located in the northern North China block, close to the Late Paleozoic Suolun-Linxi suture in the north, and linking with the Late Mesozoic paleo-Pacific subduction belt in the east. It is an important, intraplate deformation belt that underwent a specific evolution^[1–5]. A Jurassic-Cretaceous collision of an amalgamated North China-Mongolian plate with the Siberian plate is widely believed to have accompanied closure of a Mongolo-Okhotsk sea from west to east, north of Yanshan, and Late Triassic-Early Cretaceous collision from east to west and accompanying

oblique compressing deformation along Mianlue suture in Qinling, separated the North China block from the Yangzhe block, took place south of Yanshan. Under this unbalance tectonism from surrounding blocks, the Yanshan belt underwent complicated intraplate structural deformation and tectonic transformation, and developed different stages of overlapped structures and basins. The basins, as a main structural unit, joined and recorded mountain building evolution. The shape of protobasins, distribution of syndepositional deformational belts, and their combination relationship

represent the direction, property of regional geodynamic process. The overlapping relation and history of protobasins in different stages indicate a regional tectonic evolution. Recently geologists began to pay attention to the control of southward thrusting of Shangyi-Pingquan thrust fault over the basins filled with the Tuchengzi Formation of Late Jurassic, Jurassic basin evolution and its structural significance in West Beijing, and have been doing the sediment trace research of tectonism^[6-8]. Especially the research Davis et al. have done on Chengde, Miyun Reservoir, Xinglong and Gubeikou thrust faults greatly helps us to confirm Late Jurassic-Early Cretaceous thrusting^[9,10]. But Mesozoic structural transformation process, tectonic mechanism and possible dynamic background in Yanshan still need to do further cooperation research of different subjects. Based on basin depositional analysis and its combination with structural research, this paper restored protobasins through detailed comparison research of remnant basin filling sequences, provenance and paleocurrents in different stages, and successfully confirmed the basin properties, overlap-

ping relationship and its tectonic transformation process and time limit, and probed into the relationship between basin development and basin margin tectonism and uplift and erosion, and further analyzed interaction of continental blocks and tectonic transformation.

1 Basic structural framework

The Fengning-Longhua fault is the northern margin of the Yanshan belt, and links it with the northern Hebei Archean basement uplift^[11]. The Yanshan belt links with the Bohai Bay basin to the south, and is cut by Tanlu fault in the east. The major structures are distributed in the direction of nearly NEE and NNE, and in a shape of anti-“S” (fig. 1). The Mesozoic structures have main characters below.

(1) According to general distribution of stratigraphy, the Yanshan belt is divided into Xuanhua, Chengde composite syncline in the north, Malanyu composite anticline in the middle and West Beijing composite syncline in the south with a direction of nearly NEE-SWW (fig. 1). The regional synclines

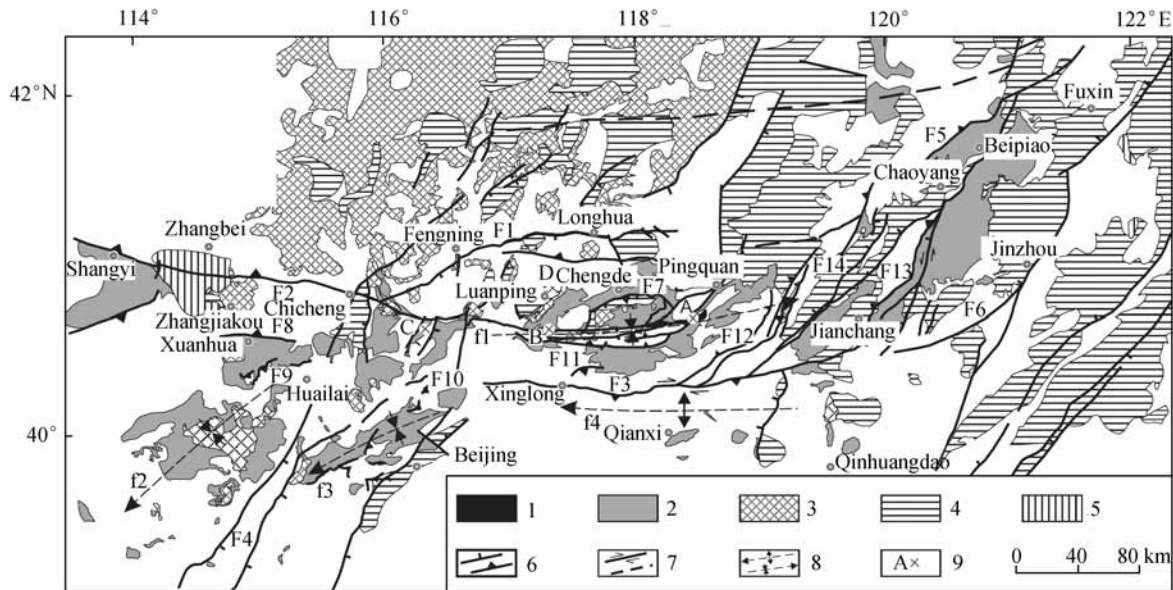


Fig. 1. Structural framework of the Yanshan belt. F1, Fengning-Longhua fault; F2, Shangyi-Pingquan fault; F3, Miyun-Xifengkou fault; F4, Zijing-guan fault; F5, Linyuan-Dongguanyingzi fault; F6, Datun-jinzhou fault; F7, Chengde fault; F8, Xuanhua fault; F9, Xiahuyuan fault; F10, Shisanling fault; F11, Xinglong fault; F12, Yangzhangzi-Wafangdian fault; F13, Jianchang-Chaoyang fault; F14, Zhongsanjia fault. f1, Chengde syncline; f2, Xuanhua syncline; f3, West Beijing syncline; f4, Malanyu anticline. A, B, C, D represent numbers of measurement stratigraphic sections. 1, Upper Triassic; 2, Lower-lower Upper Jurassic; 3, Zhangjiakou Formation of Upper Jurassic; 4, Lower Cretaceous; 5, Upper Cretaceous; 6, normal and thrust fault; 7, strike-slip fault and speculated fault; 8, anticline and syncline; 9, location of stratigraphic sections.

generally control the location of Mesozoic sedimentary basins, and are cut by NNE-trending faults.

(2) Faults in Yanshan are mostly distributed in the directions of nearly EW and NNE. The EW-trending faults include Fengning-Longhua and Shangyi-Pingquan faults and the like (fig. 1). The Fengning-Longhua fault has a different attitude on the earth's surface, but dips to the north and cut into about 10 km depth according to a geophysical section. The fault, connected with Shangyi-Pingquan fault at its west, was active in Mesozoic^[12], and acted as the northern margin of Jurassic basin.

The Shangyi-Pingquan fault, nearly EW trending, obliquely cut across the composite folds in the Yangshan belt. It is divided into two branch faults, the northern Panjiadian-Chengde fault and the southern Gubeikou-Dazhangzi fault, in the Chengde area of the middle Yanshan starting from Gubeikou at west, which constitute an anti-direction thrusting structure. The Panjiadian-Chengde fault behaves as thrust of Proterozoic strata over Paleozoic or Triassic, or Paleozoic over Triassic. The Gubeikou-Dazhangzi fault, dipping to the north, behaves as thrust of Proterozoic strata over Tuchengzi Formation of Upper Jurassic. According to the relationship between thrust fault and stratigraphy, the anti-direction thrusting of Shangyi-Pingquan fault took place in Late Jurassic, and controlled the deposition of Tuchengzi Formation at its both sides. The Early Jurassic basin is located in and beside the thrust belt, and was not controlled by the fault. There is unnamed, southward thrusting fault north of the Shangyi-Pingquan fault, under the hanging wall of the Panjiadian-Chengde fault. This fault, active during Indo-Chinese and Early Yanshanian epoch (>180 Ma)^[9,13], is located along the northern margin of the Late Triassic molasses conglomerate, and controlled its deposition. The Late Triassic basins in the Yanshan belt are only located to the south of the unnamed fault. The Shangyi-Pingquan fault is connected with the Lingyuan-Dongguanyingzi thrust fault beyond Pingquan and toward the east, and the latter behaves as thrust of Archean or Proterozoic over Mesozoic strata.

(3) The NNE trending faults are largely distributed in the Yanshan belt, but mainly concentrated in Fengning-Chicheng and Chaoyang-Jianchang. The eastward dipping normal faults are mainly located in Fengning-Chicheng, and the westward dipping normal faults in Chaoyang-Jianchang. Controlled by the NNE-trending faults, Late Jurassic-Early Cretaceous rift basins are scattered in all the Yangshan belt.

(4) The fact that the composite folds in Yanshan involved pre-Jurassic strata represents the folds mainly formed in early Mesozoic. The thrust faults, controlling the deposition of Tuchengzi Formation, covered by Upper Jurassic or Lower Cretaceous, were mainly developed in Late Jurassic. The NNE trending normal faults, controlling the distribution of Late Jurassic pyroclastic rocks of Zhangjiakou and Yixian Formations and Lower Cretaceous strata, mainly formed in Early Cretaceous.

2 Basin filling sequence

The Mesozoic broken basins in the Yangshan belt, controlled by almost the same tectonic and climate background, possess a similar depositional framework at different stages, and concurrent unconformities and their divided basin depositional cycles. The Mesozoic strata in Yanshan mainly include Upper Triassic Xingshikou Formation, Lower Jurassic Nandaling and Xiahuayuan Formations, Middle Jurassic Jiulongshan and Tiaojishan Formations, Upper Jurassic Tuchengzi and Zhangjiakou Formations, Lowest Cretaceous Yixian and Jiufotang Formations, etc.^[14,15], besides several volcanic and pyroclastic stratigraphic formations. Here we only introduce the filling sequences of depositional clastic rocks (fig. 2).

2.1 Upper Triassic Xingshikou Formation

Upper Triassic Xingshikou Formation is mainly distributed in the cores of both Chengde and West Beijing composite synclines, and the northern one westward extends to Chaoyang in West Liaoning. The Xingshikou Formation in Shanggu, Chengde County, distributed within the core of Chengde composite syncline, overlies on the Middle Triassic Ermaying Formation, which consists of gravel meandering deposi-

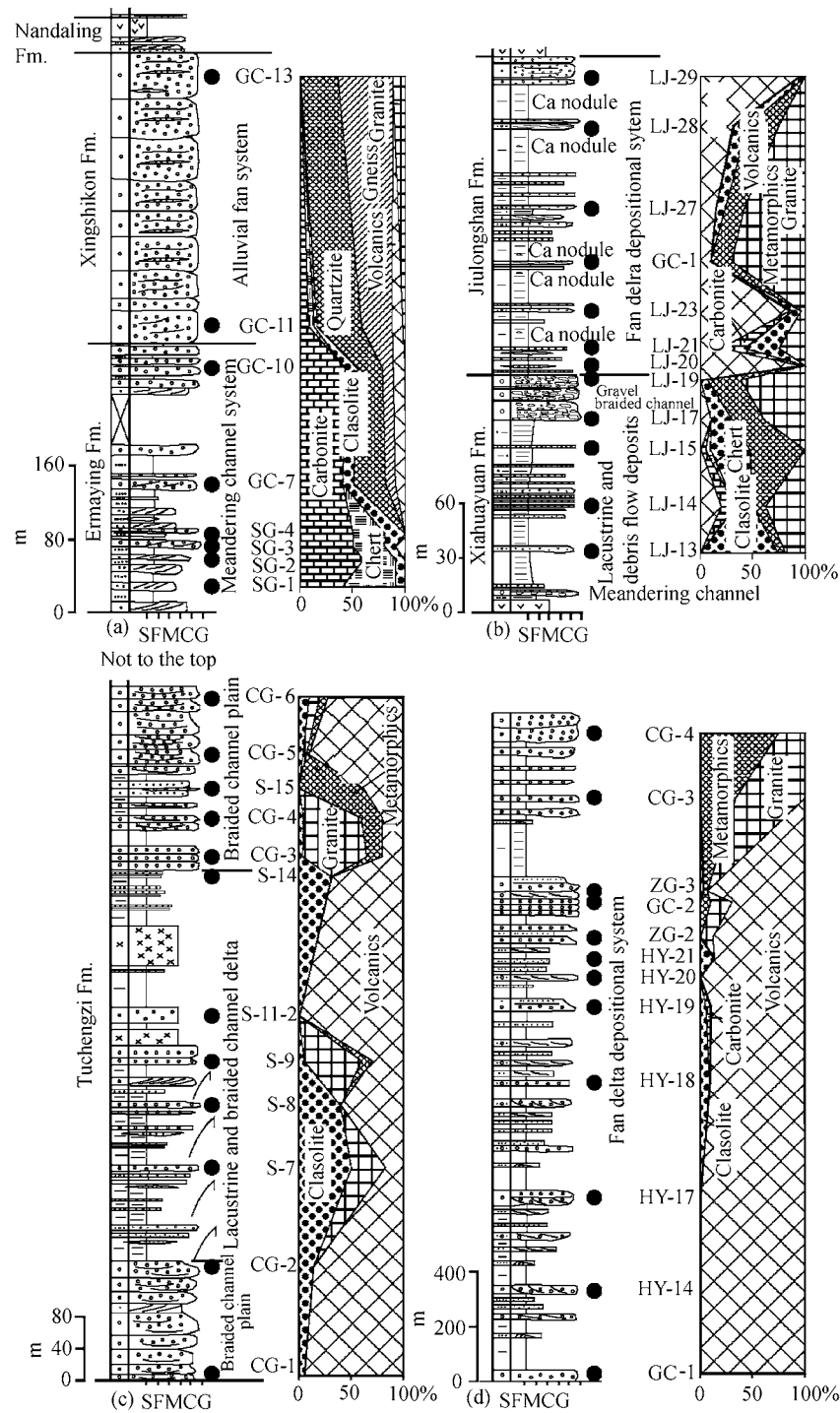


Fig. 2. Mesozoic stratigraphic successions and change of lithic fragment composition content in the Yanshan belt. (a) Triassic section in Shanggu; (b) Lower-Middle Jurassic section in Dashipeng; (c) Upper Jurassic section in Qianjiadian; (d) Lower Cretaceous section in Liying. Location of sections is shown in fig. 1. Solid circles next 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. S, silt; F, fine sandstone; M, median sandstone; C, coarse sandstone; G, conglomerate. Vertical change of lithic petrofacies contents is shown in this figure.

tional systems. But it is not clear that both are contacted unconformity or conformity (fig. 2(a)). The Xingshikou Formation, 320 m thick, consists of conglomerates. The gravels are round, and generally 10–25 cm in diameter, and bigger gravels are 40 cm and smaller 5 cm. The whole section is coarsening upwards, and gravels are arranged with slight direction. Paleocurrent indicators, from imbricated gravels, are toward the south, only a few to the north. The Xingshikou conglomerate is interpreted to be gravel braided channel deposits. The Xingshikou Formation in Dashipeng, Luanping, located in the northern margin of a basin, is composed of boulder conglomerate of debris flow origin.

The Xingshikou Formation in West Beijing syncline unconformably contacts with the Middle Triassic. The formation, 15–20 m thick, consists of a set of granule conglomerate with some sandstone intervals in Panjianzigou, Xishan, Beijing. Gravels are slightly round and orientated. The whole section of Xingshikou Formation is divided into 4 fining or coarsening upward depositional cycles that consist of conglomerate, sandstone and siltstone with massive or cross lamination. The formation is deposits of gravel meandering channel. Paleocurrent indicators (cross beds) suggest that paleoflow was to the west. As a whole, the Xingshikou Formation was the depositional response to thrust uplift in source area.

2.2 Lower Jurassic Xiahuayuan Formation

The Xiahuayuan Formation mostly overlies volcanic rocks of Nandaling Formation in the Yanshan belt. But in Shangyi, Chicheng and Qianan, it unconformably overlies Archean metamorphic rocks.

The Xiahuayuan Formation in the Yanshan belt, a set of coal measures strata, mostly consists of meandering channel, lacustrine and delta depositional systems. The formation within the Chengde composite syncline in Dashipeng, Luanping, about 100 m thick, develops a 10 m thick, fining upward depositional cycle at its base, which consists of conglomerates and fine sandstones, the former orientated and the latter with parallel and cross laminations. It is interpreted to be a meandering channel deposition. Upwards three

coarsening upward depositional cycles are developed, which are composed of horizontal laminated shale or silty shale and thin, massive coarse and gravel sandstones and conglomerates. At the top of the upper cycle, 25-m-thick conglomerates are developed, which are orientated, and contain lots of erosion surface and some lens-shaped sandbodies. The three depositional cycles are interpreted to be lacustrine and debris flow depositional systems with gravel braided channel deposits at their top (fig. 2(b)).

The Xiahuayuan Formation within West Beijing syncline in Panjianzigou, about 620 m thick, was divided into Upper and Lower Yaopo Formations and Longmen Formation in 1 : 50000 regional investigation data. The Lower Yaopo Formation is composed of 4 or 5 coarsening upward depositional cycles that contain shale, silty shale and median and fine sandstones, which are interpreted to be lacustrine and lacustrine delta parasequences. The paleocurrent determined from cross beds was to the east or south-east-east. The lower part of the Upper Yaopo Formation develops fining upward depositional cycles composed of median, fine sandstones and shale, which are interpreted to be meandering channel deposits. The upper part mostly contains horizontal laminated sandy shale with some massive and cross bedded, lens-shaped median and fine sandstone intervals, which are interpreted to be flooded plain deposits with some crevasse channels. Two sets of conglomerates are developed at the base of Longmen Formation, underlying strata were eroded with a very clear boundary. The conglomerates are composed of two fining upward cycles with massive bedding. The whole Longmen Formation is interpreted to be meandering channel depositional systems, and also represents a kind of coarser and bigger clastic channel depositional events at the top of the depositional cycle of Yaopo Formation. In general, the Xiahuayuan Formation in West Beijing constitutes a depositional cycle from lacustrine to fluvial. Comparing the Xiahuayuan Formation in Chengde, northern Hebei and West Beijing filled in different protobasins, we found the latter is thicker and represents more abundant sediment supply, and both develop fluvial conglomerates, corresponding to

“Longmen Formation”, with a character of close-source deposition. The depositional characters of Xiahuayuan Formation represent that the basin sediment supply rate was slow, but continually increased compared with the basin subsidence rate. The formation was absent of boulder conglomerate, and the fragments were rounded by long distance transportation, which show that it was in a kind of quiescent state tectonically.

2.3 Middle Jurassic Jiulongshan Formation

The Jiulongshan Formation, in concomitance with overlying volcanic and pyroclastic rocks of the Tiaojishan Formation, is distributed along Xuanhua and Chengde composite synclines, and West Beijing syncline. The Jiulongshan Formation within Chengde composite syncline in Dashipeng, Luanping, 160 m thick, mostly consists of red shale, silty shale and coarse 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 contains 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 (fig. 2(b)). The Jiulongshan Formation unconformably overlies the Xiahuayuan Formation.

The Jiulongshan Formation in West Beijing syncline consists of red, mignonette and gray lithic sandstones, fine tuff sandstones, siltstones, silty shales and several conglomerate intervals. Thick gravel coarse sandstones and fine sandstones are developed at the base of the formation, and are interpreted to be meandering channel deposits. At the upper part there are two depositional cycles composed of siltstones, interbedding siltstones and fine sandstones, median and coarse sandstones, gravel coarse sandstones and conglomerate, but the upper cycle misses coarse deposits. The two depositional cycles represent depositional successions of lacustrine, lacustrine delta and meandering channel plain systems. The distribution scope of the Jiulongshan Formation in West Beijing syncline migrated northwards relative to Xiahuayuan Forma-

tion, so some strata overlies Nandaling volcanic rocks and even Paleozoic strata. Regional correlation analysis found that the Jiulongshan Formation in West Beijing becomes coarser than and developed different depositional systems from that in Chengde, but the Jiulongshan Formation in western Liaoling becomes even coarser and is composed of gravel fluvial deposits. These characters represent different tectonism happened in different areas, and some areas tectonically uplifted.

2.4 Upper Jurassic Tuchengzi Formation

The Upper Jurassic Tuchengzi Formation is mainly distributed beside the Shangyi-Pingquan fault. The Tuchengzi Formation has different characters in the Chicheng basin. The formation developed in Qianjiadian, the middle-eastern part of the basin, about 800—1000 m thick, unconformably overlies the Xiahuayuan Formation, and the Middle Jurassic is absent. A set of alluvial fan conglomerates with massive bedding is developed in the lower part of the Tuchengzi Formation. The middle part contains 3—4 coarsening upward depositional cycles that are composed of mudstone at the lower part, upward coarsening, massive, parallel and cross laminated, fine, median and coarse sandstones and conglomerates at the middle, interpreted to be braided channel delta systems, and lens-shaped, massive, trough and cross laminated gravel sandstones and conglomerates at the top with lots of scour surfaces, interpreted to be braided channel plain systems. The Tuchengzi Formation in the northern margin of the basin covered on Archean basement metamorphic rocks, and consists of conglomerates and gravel sandstones with massive and roughly cross beddings that are interpreted to be braided plain depositional systems.

The Tuchengzi Formation in Huazhangqizi, eastern Chaoyang, West Liaoling, overlies on the Tiaojishan pyroclastic rocks with clear scour surface and thin weathered layer at its conglomerate base. As the attitude of strata beside the contact surface is unclear, the unconformable relation between the two strata is not easy to determine. The Tuchengzi Formation, about 2200 m thick, is composed of massive cobble and

boulder conglomerates at its lower part, red, ripple and horizontal laminated shale and muddy siltstones, and sandstone intervals at its middle part, and massive, parallel, trough and cross laminated median, coarse and gravel sandstones at its upper part, which are interpreted to be alluvial fan, lacustrine and braided delta, and braided channel plain depositional systems respectively. As a whole, the Tuchengzi Formation in Yanshan constitutes a complete depositional cycle mainly composed of coarse conglomerate which was the depositional record of another thrust event after Late Triassic thrusting.

2.5 Lower Cretaceous Jiufotang Formation

The volcanic and pyroclastic rocks of the Zhangjiakou Formation in the northern Chicheng basin and the Yixian Formation in Jianchang, West Liaoling, for example, unconformably overlies on the Tuchengzi Formation. The two sets of strata above and below the contact formed different landforms and altitudes. The Jiufotang Formation covers on the Zhangjiakou Formation in Hebei, or the Yixian Formation in West Liaoling. The formation is mostly distributed in Luanping, West Liaoling, and was not controlled by the composite folding. The measured section of this formation in Liying, Luanping, for example, about 2500—3000 m thick, is composed of 30—50 m thick, poor rounded and unsorting alluvial fan conglomerates at its base, and 5 upward coarsening fan delta depositional cycles in which shale, and lens-shaped, massive and cross laminated, subaqueous distributary channel or debris flow sandstone and conglomerate intervals that are upward multiplied are developed at its upper part. The coarse conglomerate was distributed along normal faults, which represents that the basin fill was controlled by rifting. The depositional constitution of the Jiufotang Formation is different with different location in basins.

3 Basin depositional provenance and its unroofing

3.1 Methodology

The information of composition recorded in basin gravels and sandstones supplies an important indicator

for uplift and erosion history of basin marginal mountains^[16,17]. Basins in the Yanshan belt are dominated by sandstones and gravels. Therefore different techniques were used to identify composition of these different grain sizes. Sandstone compositions were determined by the traditional method. Thin sections were made and 300 to 310 framework grains were counted per slide. We calculated the contents of different fragments, and also showed the results for lithic composition, which typically represents more than 15% of all the grains counted. We collected gravel clast data in the field. In each case nearly every grain in an area of 2 m² was identified, typically more than 30 to 80 clasts. As basin source areas in the Yanshan belt develop different rock outcrops, lithic and gravel composition of sedimentary rocks is an important indicator to determine their provenance.

In order to know compositional contents and their change of different grains through time, we compiled the vertical change figure (fig. 2) of lithic fragment composition of different sections. Percentages shown on fig. 2 are normalized percent of the total lithic content. The composition results are shown as petrofacies: volcanic rocks, granites, clastic rocks, carbonates (limestone), 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 provenance. Volcanic petrofacies contain andesite, dacite, trachyandesite, rhyolite, tuff and trachite clasts. Granite petrofacies contain granite and granite porphyry et al. Clastic rock petrofacies include more rock types, that is, median and fine sandstones, siltstones, mudstones, shale, etc. Carbonate petrofacies include limestone, dolomite and a few calcite veins. Chert petrofacies mainly contain chert rocks. Metamorphic rock petrofacies contain gneisses, granite gneisses, quartzites, schists, slates and a few mylonite and structural schist rocks.

3.2 Lithic composition change of sediments and their provenance

Results for composition of lithic and gravel grains are respectively shown in fig. 2 for the Middle and Upper Triassic sections in Shanggu, Xiahuayuan

and Jiulongshan Formations in Dashipeng, Tuchengzi Formation in Qianjiadian, Chicheng basin, and Jiufotang Formation in Liying, Luanping. The gravels and lithic fragments contained in the Middle and Upper Triassic sandstones include carbonates, cherts, clastic rocks, quartzites, gneiss, volcanic rocks and granites (fig. 2(a)). Comparison of the lithic fragments with source area strata represents that the provenance of the Middle and Upper Triassic includes Archean, Middle and Upper Proterozoic and Paleozoic, and the provenance strata underwent an inverse unroofing process. The lithic petrofacies in the lower Ermaying Formation of the Middle Triassic include carbonates, cherts and clastic rocks, and their corresponding provenance strata are the Middle Proterozoic Jixian Formation and Paleozoic mainly containing carbonates and cherts. The petrofacies in the upper Ermaying Formation include carbonates, quartzites, clastic rocks, gneiss and volcanic rocks, which represent that the lower Proterozoic Changcheng System mostly containing quartzite largely unroofed besides the Jixian System, and the Archean mostly containing gneiss began to be eroded. The lithic petrofacies of quartzite, gneiss and granite are increased and the others decreased in content in the Upper Triassic Xingshikou Formation, which represent the Archean and Changcheng System in provenance largely unroofed, and granite began to be eroded, but the Jixian System reduced. The Upper Triassic conglomerate in southern Luanping unconformably overlies on the Archean, and gravels within it mainly include gneiss, amphibolite, granite, quartzite, volcanic rocks, etc. Their provenances are the Archean and Changcheng System et al. The composition of the Upper Triassic lithic fragments and gravels in West Beijing includes quartzite, clastic rocks, carbonate, chert and volcanic rock, and their provenances are probably the Proterozoic Changcheng, Jixian Systems, etc., but the Archean basement rocks did not unroof. So generally the northern Yanshan deeply unroofed, but the southern part relatively shallow unroofing in Late Triassic.

The types of the lithic fragments and gravels in the Xiahuayuan Formation in Dashipeng, Chengde basin include more quartzite, clastic rock and granite,

less volcanic rock, limestone, dolomite and chert, which represent the variety of its provenances (fig. 2(b)), but the underlying Nandaling volcanic rocks did not largely unroof. The composition of lithic fragments and gravels of the Xiahuayuan Formation in Panjiazigou, West Beijing includes quartzite, clastic rock, limestone, volcanic rock and chert, which represent a similar provenance strata character to the Upper Triassic. The composition of the lithic fragments and gravels in the Jiulongshan Formation in Dashipeng contains more volcanic rocks and granites and less metamorphic rocks of quartzites and schists and clastic rocks, and a few carbonate rocks. The lithic fragments of volcanics are largely developed in the lower Jiulongshan Formation, and decreased in the middle, and increased again in the upper. Granite fragments are largely contained in the middle. The volcanic fragments were probably transported from syn-depositional volcanic source areas (fig. 2(b)). The distribution of petrofacies in the Jiulongshan Formation represents that the strata of carbonate and chert in source areas gradually eroded out, and the deeply located granites largely unroofed, and the quartzite strata gradually reduced.

The composition of lithic fragments and gravels in Qianjiadian, Chicheng basin includes volcanic rocks, clastic rocks, metamorphic rocks of quartzites and schists, and granites (fig. 2(c)). The contents of volcanic lithic fragments represent three upward decreasing cycles in the whole section. Clearly the provenance for volcanic fragments was the underlying Tiaojishan Formation or the syn-depositional volcanic rocks, and the provenances for other fragments were the Lower Proterozoic Changcheng System, Archean metamorphic rocks and intrusives. The lithic fragment cycles in the Tuchengzi Formation represent the source areas covered by volcanic rocks unroofed and eroded several times. The Tuchengzi Formations in Chengde and Beipiao contain similar lithic fragment cycles. Regional research shows that the Tuchengzi Formations in the northern margins of Shangyi, Chicheng, Chengde and Beipiao basins contain a lot of lithic fragments and gravels of gneiss, amphibolite and granite, but in the southern margin of Chengde

basin contain a large number of limestone and dolomite, which are related with thrust uplift and unroofing of different basement rocks.

The composition of lithic fragments and gravels in the Jiufotang Formation in Liying, Luanping basin, contains more volcanic rock, granite and gneiss, and less clastic rock and limestone (fig. 2(d)). As violent volcanism happened at and before syn-depositional stage of Jiufotang Formation, the lithic fragments of the middle and lower Jiufotang Formation mainly contain volcanic rocks. With erosion of volcanic rocks in source areas, the fragments of basement metamorphic rocks and granite rocks in the upper Jiufotang continually increase.

4 Protobasins and their evolution

The Mesozoic protobasins in the Yanshan belt underwent syn or post depositional structural modification and multistage basin overlapping and erosion, and were broken into small basins. In order to know paleogeography, basin evolution and its relation with tectonism, we recovered Late Triassic, late Early Jurassic, early Late Jurassic-early Early Cretaceous protobasins through observation and correlation of depositional sections, analysis of grain size change, measurement of paleocurrents and comparison of lithic fragment and gravel composition, and combination with structural study. The protobasins underwent evolution below.

4.1 Late Triassic

Although a few of outcrops of the Upper Triassic Xingshikou Formation, we presumed that the Late Triassic basins were mainly distributed along two zones: the northern branch of Shangyi-Pingquan fault to Chaoyang eastwards and the core of West Beijing composite syncline, south of Luanping and Chengde, with NNE trending. Typical gravel molasses were deposited in the two basin belts. Gravel alluvial fan and gravel braided plain depositional systems were developed in the northern basin belt with southward paleocurrent, and gravel meandering plain systems in the southern basin belt. Grain size of gravels is coarse in the northern belt and fine in the southern belt. The protobasins did not cross over Shangyi-Pingquan fault

northwards.

4.2 Early Jurassic

Early Early Jurassic, first violent volcanism in Mesozoic happened in the Yanshan belt, and the Nandaling volcanic rocks mainly composed of basalt were developed. The Xiahuayuan Formation overlying volcanic rocks is scattered on large areas. The Shangyi, Xuanhua, southwestern Xuanhua, Chicheng, West Beijing, Chengde and Beipiao protobasins filled with Xiahuayuan Formation were recovered from west to east (fig. 3). But because of a very few outcrops in the northern Yanshan, protobasins there are difficult to be recovered. In general, the extend of the protobasins is parallel to that of structural belts, but there is no banding distribution character. The basin deposition systems are distributed concentrically, and meandering channel with some swamp deposits in basin margins and lacustrine in the centers. The Shangyi-Pingquan faulting almost stopped because small coal basins were developed along it.

4.3 Middle Jurassic

The Middle Jurassic includes Jiulongshan and Tiaojishan Formations, and both were distributed at the same areas. In comparison with the Xiahuayuan Formation, the basins in Middle Jurassic migrated from sides to center, and were mainly located along Huailai-Chengde-Pingquan-Chaoyang in the core of composite syncline. To the north of Shangyi and Chicheng, the Middle Jurassic missed. The Jiulongshan and Tiaojishan Formations unconformably overlapped northwards in comparison with the Xiahuayuan Formation, which represents the Middle Jurassic basins migrated northwards. The Jiulongshan Formation consisting of clastic rocks was mostly covered with the Tiaojishan Formation. So it is impossible to restore paleogeography at the stage of Jiulongshan Formation. Fig. 4 represents the distribution of the Tiaojishan Formation that contains andesite, trachite, rhyolite and pyroclastics. Isotopic ages for the Tiaojishan volcanic rocks are almost the same in the whole Yanshan as Middle Jurassic (about 160 Ma)^[9,18]. The distribution of the Tiaojishan Formation may represent the Middle Jurassic basin framework.

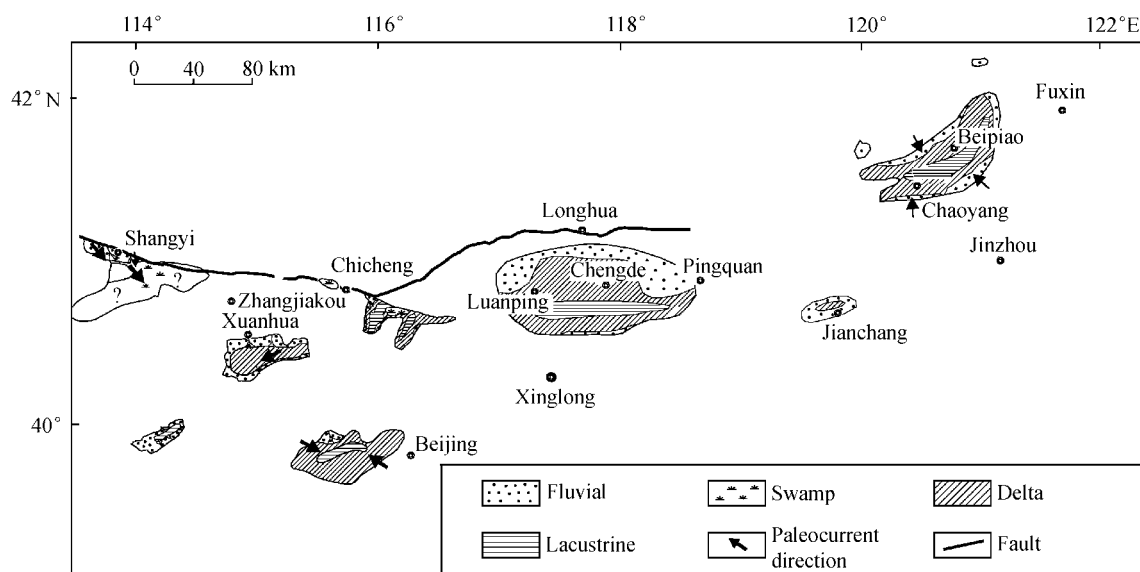


Fig. 3. Late Early Jurassic protobasins and paleogeography in Yanshan.

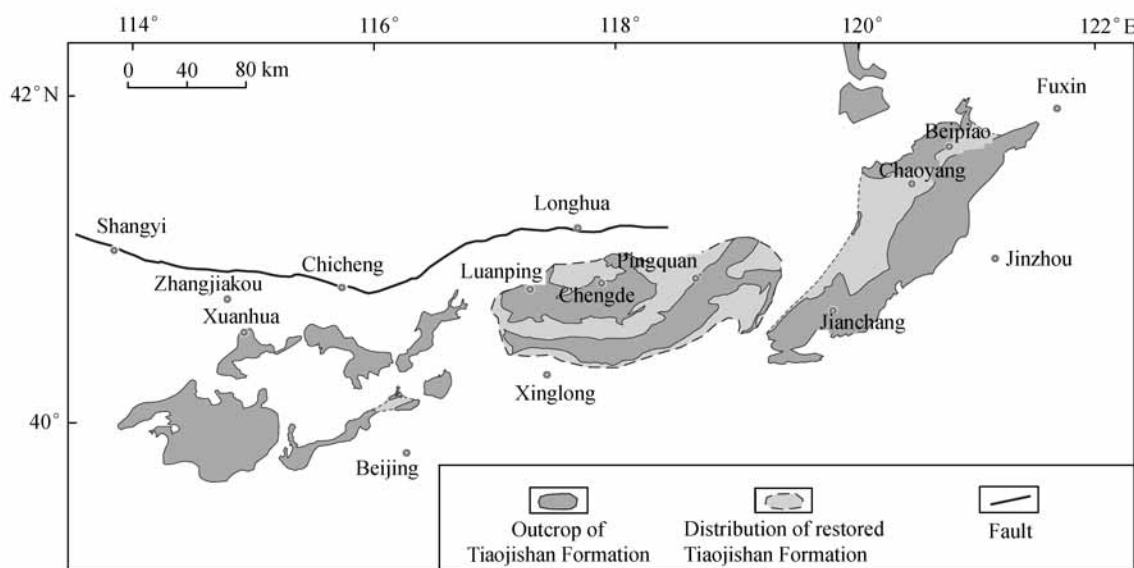


Fig. 4. The distribution of the Middle Jurassic Tiaojishan volcanic and pyroclastic rocks in Yanshan.

4.4 Early Late Jurassic

The protobasins in early Late Jurassic, the syn-depositional stage of Tuchengzi Formation, re-migrated northwards and toward thrust front, and are mainly located along Chongli-Longhua, Shangyi-Pingquan, Lingyuan-Dongguanyingzi, Xuanhua,

Xiahuayuan and Jianchang-Chaoyang thrust belts, which represent a thrusting control on basin development (fig. 5).

The Shangyi basin was clearly controlled by its northern thrust fault. Alluvial fan conglomerates were developed along its northern margin with 50—100 cm

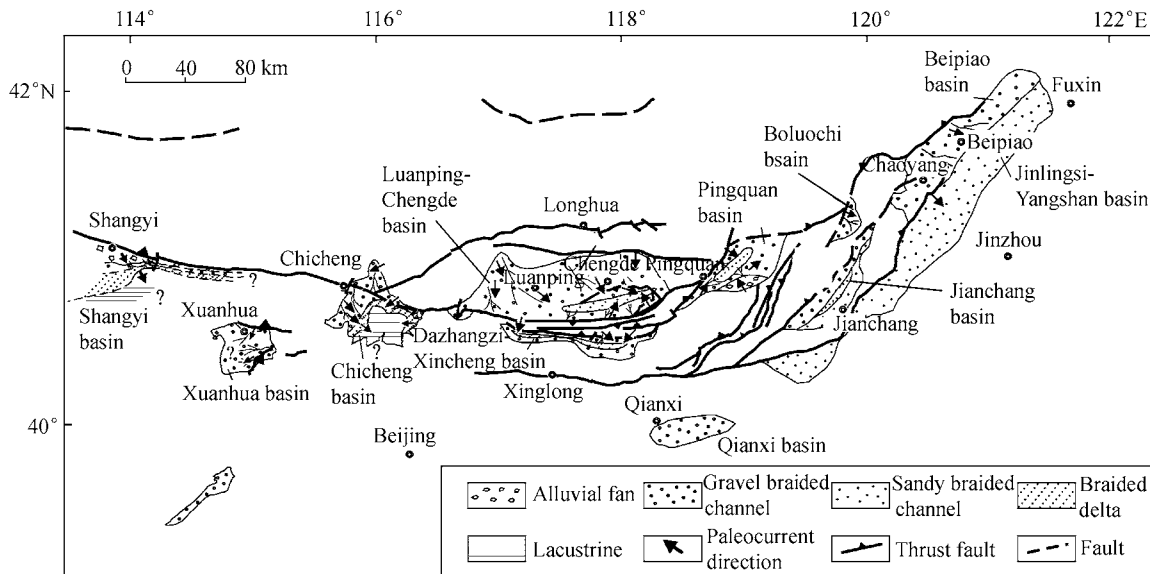


Fig. 5. Early Late Jurassic protobasins and their paleogeography in Yanshan.

grain-sized gravels that were transported from Archean basement metamorphic rocks, and delta and lacustrine systems in its southern margin with an un-recovered facies because of few outcrops. The paleocurrent of the basin was mainly southeastwards.

The Chicheng basin was still controlled by the Shangyi-Pingquan fault, but extended in the direction of NNE because of influence of Zhijinguan fault. Field study shows that gravel braided plain systems, thickening southwards (about 50–100 m), were deposited in the northern margin to the north of the thrust fault, unconformably covering on Archean metamorphic rocks and underlying below the volcanic rocks of the Upper Jurassic Zhangjiakou Formation. Across the thrust fault and at its margin, the Tuchengzi Formation is greatly increased to about 800 m, and consists of aggradational gravel braided plain depositional systems. At the eastern and western sides of the basin, marginal facies with different width are developed. Delta and lacustrine systems with a lot of mudstone are distributed in the middle and southern basin, and the grain size of sediments is clearly decreased. As no outcrop, the marginal facies in southern margin of the basin were not recovered. The paleocurrents in the basin were toward southwest and southeast.

Two protobasins, Luanping-Chengde basin in the north including present Luanping and Chengde basins and Dazhangzi-Xincheng basin in the south, are recovered in Chengde district. Gravel braided plain systems are developed in northern and southern margins of the two protobasins, and delta systems in the center of the basins. Sediment provenance analyses represent that the sediments in the northern Luanping-Chengde basin were mostly transported from the northern Archean basement metamorphic rocks besides volcanics, and in the southern Luanping-Chengde basin mainly from Middle Proterozoic carbonate in the southern Shangyi-Pingquan fault belt. The sediment provenance of the Dazhangzi-Xincheng basin was from the northern Middle Proterozoic carbonate, the same as that of the southern Luanping-Chengde basin. Two protobasins were clearly controlled by northern Fengning-Longhua southward thrusting and anti-directional thrusting of Shangyi-Pingquan thrust belt.

The NNE-trending basins in Jianchang and Chaoyang were in concomitance with western dipping and eastern thrusting faults. Bordered upon the Zhongsanjia thrust fault, Boluochi basin was filled with gravel braided channel and delta systems whose provenances were from western Archean limestone

and dolomite, and the paleocurrents were to the east. The Beipiao and Jinlingshi-Yangshan basins are respectively linked with western Lingyuan-Dongguan-yingzi and Jianchang-Chaoyang thrust faults. We are not sure that the two basins were connected or not, but we think they were divided up at the late stage of the Tuchengzi Formation, because gravels in the western basin were sourced from granite, granite gneiss, quartzite, volcanic rocks and mudstone, and in the eastern basin contain the Proterozoic limestone sourced from Jianchang-Chaoyang thrust belt, besides volcanic, granite and quartzite rocks. Braided channel systems were developed in the western Beipiao basin, but sandy braided channel, delta and lacustrine systems in the eastern basin.

4.5 Late Late Jurassic-Early Early Cretaceous

Basin framework underwent an important transformation after late Late Jurassic so that the basin distribution was changed from the early EW to NNE trending. The late Late Jurassic volcanic and pyroclastic rocks in Zhangjiakou Formation were distributed along Zijingguan fault in Huailai, Chicheng and Fengling (fig. 1). The Early Cretaceous basins, NNE trending, were largely developed in not only western

Liaoning but also Zijingguan fault (fig. 6). All the basins but volcanic ones were linked with normal faults and in the shape of half graben. The controlling normal faults are located at the western margins of the basins to the west of Pingquan, but at the eastern margins to the east, which represent a kind of basin and range structure rifting at both sides of Pingquan. The early Early Cretaceous stratigraphy mainly includes Yixian and Jiufotang Formation. The former mostly contains volcanic and pyroclastic rocks, and the latter mainly depositional clastic rocks. There are two different opinions about the age of the two strata. Some thought they formed at the same time, but the others thought the former formed early and the latter later^[14,15]. Fig. 6 represents the distribution of both of the volcanic rocks of the Yixian Formation in early Early Cretaceous and the depositional systems of the Jiufotang Formation that consists of fan delta, lacustrine and alluvial fan systems. The fan delta systems are usually developed along a normal faulting margin, and lacustrine system in basin center. Additionally fluvial, swamp and lacustrine depositional systems are distributed in Fuxin basin, and some basins mainly contain alluvial fan systems (fig. 6).

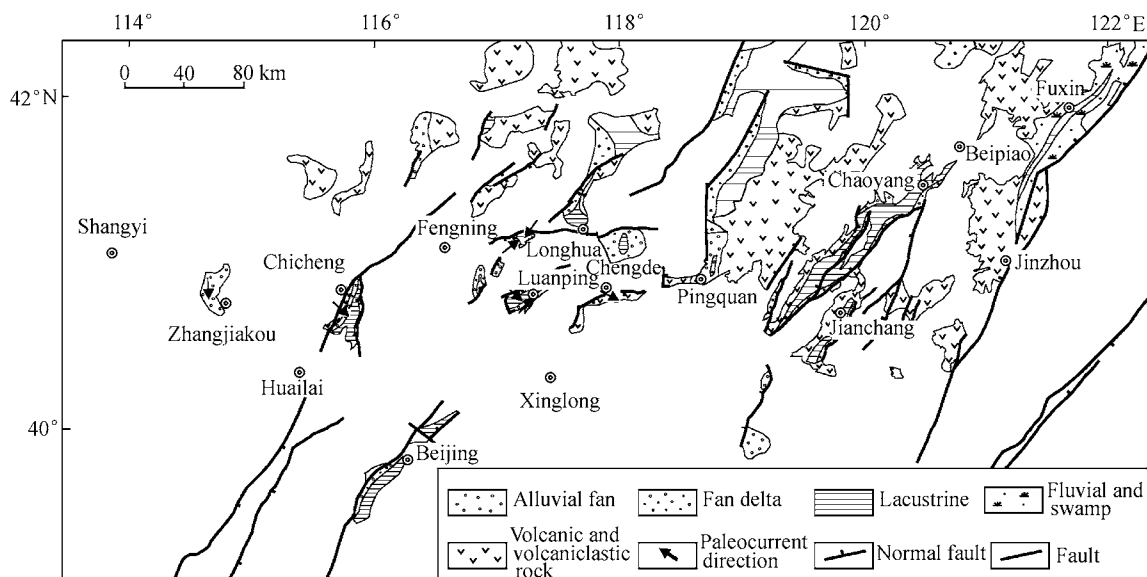


Fig. 6. Early Early Cretaceous protobasins and their paleogeography in Yanshan.

5 Structural mechanism

Yanshan is an intraplate deformation belt, and its tectonism and mechanism is one of important scientific topics. Basin sedimentary analysis and its combination study with structure is a new method for studying structural mechanism in Yanshan. The basins in Yanshan underwent a complicated evolution, and were filled with not only depositional sediments but also volcanic rocks that were distributed at almost the same areas, representing their genetic relation. According to the geological facts of structure, deposition, provenance and basin paleogeography above, we make some discussions about structural mechanism below.

(1) Yanshan was a component of the northern North China cratonic basin in late Paleozoic. Alternate Marine and nonmarine carbonate and coalseries clastic rocks were deposited in Late Carboniferous to Early Permian. Responding to thoroughly collisional orogeny along Suolun suture between North China and Mongolia from Late Permian to Middle Triassic, the cratonic basin was filled with sandstone, mudstone and conglomerate of fluvial plain origin^[19]. Yanshan in North China underwent a new intracontinental violent deformation stage after Late Triassic. The Late Triassic gravel molasses south of Luanping-Chengde were developed under thrusting hanging wall of Panjiadian-Chengde fault, the northern branch of Shangyi-Pingquan fault belt, and controlled by the southward thrusting of an unnamed fault^[9,13], which was the deposits of foreland flexural basin. The basin sediments recorded a thrust uplift and unroofing process from Paleozoic, Proterozoic to Archean in the north of Shangyi-Pingquan fault. The position of gravel molasses distributed in West Beijing syncline was also related with thrust uplift of basin margins. Clearly the Late Triassic was an intracontinental violent deformation stage in Yanshan after collision between North China and Mongolia plates.

(2) The Jurassic was another important intraplate deformation stage in Yanshan. The basin evolution in this stage recorded detailed deformation process. In Early Jurassic the Xiahuayuan Formation in the basin unconformably overlay on different basement strata, and even Shangyi-Pingquan fault belt. The Early Ju-

assic basin was filled with low energy, fine grain sized meandering channel, lacustrine delta and lacustrine systems, and the lithic composition of the basin strata has no clearly change. The Paleozoic and Proterozoic strata were largely developed in basin source areas. Tectonism in the syn-depositional stage was weak, and denudation and deposition process mainly behaved as truncating highland and filling up lowland. The basin was a kind of intracratonic sag basin. The Middle Jurassic basins were changed in their framework, and gradually migrated and centered on composite syncline in Xuanhua, Chengde and Chaoyang with NEE trending, which represent that the areas north of Zhangjiakou, Chicheng and Longhua, and south of Beijing and Xinglong, tectonically uplifted. The composition of sediment lithic fragments also clearly changed, and the fragments of Paleozoic and upper Proterozoic carbonate gradually disappear, and deep granite largely unroofed. So we interpreted that tectonism in Middle Jurassic mainly behaved as regional folding, and basins were distributed along the cores of synclines and were defined as a kind of flexural basin. The basin was a flexural basin. The early Late Jurassic basins filled with Tuchengzi Formation northward migrated to the margins of Fengning-Longhua, Shangyi-Pingquan and Lingyuan-Dongguanyingzi thrust belts, and were controlled by thrusting. The basin was a typical foreland flexural basin, and the faults controlling basin formation behaved as southward^[6] and northward^[9] thrust. The Shangyi and Chicheng basins were mainly controlled by the western part of Shangyi-Pingquan thrust fault, and the Xuanhua basin by Xiahuayuan in the south and Xuanhua in the north, the Luanping-Chengde basin by the northern branch of Shangyi-Pingquan fault in the south and Fengning-Longhua thrust fault in the north, and the Dazhangzi-Xincheng basin by the southern branch of Shangyi-Pingquan fault. The basins in West Liaoning, NNE trending, were mainly controlled by thrusts west of the basins, were located between Lingyuan-Dongguanyingzi and Miyun-Xifengkou faults in diagonal style, which represent that the basins were formed by right handed rotation transpression^[20]. Controlled by regional thrusting, the foreland flexural basins in Yanshan were filled with gravel braided

channel and braided channel delta depositional systems, and the basement rocks in the source areas of the basins were multi-uplifted and unroofed. Thus it can be seen that Yanshan in Jurassic underwent a violent intraplate deformation process from regional folding to thrusting.

(3) The late Late Jurassic is another important tectonic transformation stage in Yanshan, and the transforming boundary is the unconformity between Tuchengzi Formation and Zhangjiakou Formation (or Yixian Formation). The basin framework was thoroughly changed after late Late Jurassic, NNE-trending rift basins were formed and controlled by normal and transtensional faults. Small alluvial fan, fan delta depositional systems were developed along the rift basin margins. The formation of the NNE trending rift basins represent that Yanshan underwent a transformation from nearly N-S compression to E-W extension.

(4) The Mesozoic structural evolution and transformation of Yanshan were controlled by regional interplate interaction. Plates, especially North China and Yangtze plates, in China realized final collision in Middle and Late Triassic. East China was in the state of nearly S-N compression^[5]. Nearly E-W trending collisional orogeny in Qinling-Dabieshan happened, and the Suolun suture between North China and Mongolia was reactive. Nearly E-W trending violent folding and thrusting, the structural transforming event, happened in Yanshan. During Jurassic East China suffered from not only S-N trending but also northwestward compression. The latter resulted from a change from passive to active in the eastern continental margin of China since Early-Middle Jurassic, and northwestward subduction of the Izanagi plate^[21,22]. So East China in Jurassic was in the state of three-directional, unbalanced compression. North China block anticlockwise rotated which led to a nearly E-W, clockwise transpression in Yanshan. With strengthening of compression, the basin and mountain belts in Yanshan continually clockwise rotated and migrated, and violent thrusting finally took place along Shangyi-Pingquan and Lingyuan-Dongguanyingzi faults. During late Late Jurassic and Early Cretaceous, the Izanagi plate moved northwards, and a Mongolo-Okhotsk ocean

closed from west to east in late Mesozoic and northward subducted^[23]. The most major geodynamic force resulted from a collision across Bangonghu Nujiang suture in southwestern Tethys Domain^[24] and formed a huge, long-distance tectonic effect that resulted in reverse of structural stress field from Jurassic NW-SE-trending compression to late Late Jurassic-Early Cretaceous clockwise, strike-slip extension behaving as abroad volcanism, igneous intrusion and rifting in East China.

6 Conclusions

(1) The Mesozoic basins in Yanshan, China underwent two times of important tectonic transformations, including changes from a pre-Late Triassic marginal cratonic basin to a Late Triassic-Late Jurassic flexural basin and then to a late Late Jurassic-Early Cretaceous rift basin. In response to two violent intraplate thrusting events at Late Triassic and Late Jurassic, gravel braided channel depositional systems in Xingshikou, and gravel alluvial fan, braided channel plain and braided delta systems in Tuchengzi Formation were deposited in front of thrust belts. Controlled by folding flexure in Early-Middle Jurassic, lacustrine, lacustrine delta and fluvial depositional systems were developed. Controlled by normal faulting in Early Cretaceous, fan delta and lacustrine systems were deposited in Yanshan.

(2) Sediment provenance analysis made conclusions below. The fragment composition of Middle and Upper Triassic represents that the Archean and Proterozoic in the source areas were uplifted and unroofed in turn controlled by thrusting. The composition of lithic fragments and gravels shows that the several cover strata gradually eroded away, and the deep granites were continuously unroofed. The provenance types of the Upper Jurassic sediments indicate that the provenance covered with pyroclastic rocks were eroded and their underlying basement rocks were unroofed several times. The fragment composition of Lower Cretaceous represents that the basement metamorphite and granite covered with pyroclastic rocks were unroofed again.

(3) Through protobasin recovery we found that

the foreland flexural basins were distributed in two lines and filled with typical gravel molasse in Late Triassic. Restored protobasins were gradually migrated toward nearly NEE to EW-trending from Early Jurassic to early Late Jurassic. The scattered intracratonic sag basins were developed in Early Jurassic and were gradually changed into flexural basins controlled by folding in Middle Jurassic, and further into foreland flexural basins controlled by thrusting in Late Jurassic. Afterwards the basin framework got a fundamentally change, and the NNE trending rift basins in Early Cretaceous crossed over early-formed basins. The evolution of Mesozoic basins in Yanshan was controlled by the regional coaction among different plates.

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