Provenance Analyses of Lower Cretaceous Strata in the Liupanshan Basin: From Paleocurrents Indicators, Conglomerate Clast Compositions, and Zircon U-Pb Geochronology

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ABSTRACT: The Liupanshan Basin constitutes a major portion of the northern North-South tectonic belt. The Lower Cretaceous strata in the Liupanshan Basin recorded the tectono-sedimentary evolution processes of this area and are pivotal for understanding the original sedimentary appearance of the Liupanshan Basin. In this work, we present a study of provenance and tectono-sedimentary evolution of the Liupanshan Basin during the Early Cretaceous. Integrated-paleocurrent directions, gravel clast compositions, and detrital zircon U-Pb isotopic analysis of the Lower Cretaceous Sanqiao and Heshangpu formations were applied to determine the provenance. The gravel clast compositions of Sanqiao Formation conglomerates (mainly including magmatic rocks, metamorphic rocks and limestones) display various features in different places, revealing different rock components of source areas. The paleocurrent directions of the Sanqiao and Heshangpu formations suggest that the sediments were transported from the basin margin to the center. Detrital zircons of two samples from the Huoshizhai Section (northeastern Liupanshan Basin) yield a dominant unimodal distribution from 420 to 500 Ma, suggesting a single-sourced provenance. Based on the above analyses, comparing to the magmatic records in the Qilian-Qinling orogenic belt, the detritus of the Sanqiao and Heshangpu formations were mainly from the proximal metamorphic and magmatic rocks of the Qilian-Qinling orogenic belt and the limestones of the archaic uplift. Combined with sedimentary characteristics, we concluded that the Liupanshan Basin experienced multi-stage evolution history: (1) the early rifting extension stage (Sanqiao Period), (2) the middle spanning and depression stage (Heshangpu–Early Najiajie Period), and (3) the late extinction stage (Late Najiajie Period). The evolution of Liupanshan Basin is closely related to that of Ordos Basin and it is further associated with tectonic transition of the northern North-South tectonic belt.

KEY WORDS: provenance analyses, tectono-sedimentary evolution, Liupanshan Basin, Lower Cretaceous, North-South tectonic belt.

0 INTRODUCTION

The North-South tectonic belt (NSTB), also known as the Helan-Chuanbian tectonic belt, runs through the whole Chinese mainland and formed the cross structure of continental China together with the Central China Orogen. The NSTB is a significant boundary of the East and West China’s continental tectonics and has a comprehensive boundary from deep to shallow geology, geophysics, and surface systems (Zhao et al., 2018; Jiang et al., 2014; Ma et al., 2003; Xu et al., 2003; Zhang et al., 2001; Burchfiel et al., 1991). It has long been focused by many geologists due to its importance for understanding continental growth, geodynamics, geophysics, earthquake hazards, and metallogeny (e.g., He and Santosh, 2017; Wang et al., 2015; Wu et al., 2015; Jiang et al., 2014; Zhang et al., 2013). Despite the existence of different opinions on the mechanism for the formation and evolution of the NSTB, there has been consensus that the NSTB has obvious characteristics of segmentation and it can be divided into northern, middle and southern segments (Wang et al., 2015). Each segment needs to be studied in detail. The northern NSTB is adjacent to the Ordos Basin (Fig. 1a),...
and numerous studies have been carried out for the tectonic deformation (Huang et al., 2015; Wang et al., 2014; Liu et al., 2005), fault characteristics (Shi et al., 2015; Wang et al., 2014; Li et al., 2013; Cavalié et al., 2008), uplift history (Zhao et al., 2016a; Lin et al., 2010, 2009; Zheng et al., 2006), provenance analysis (Xie, 2016; Zhao et al., 2006) and geophysical characteristics (Wang et al., 2015; Jiang et al., 2014; Li and Li, 2012). These studies have enhanced our understanding of the intraplate evolution processes of the northern NSTB. However, the details of sedimentary filling and tectonic evolution of the northern NSTB during the Early Cretaceous have not yet to be established.

In the northern NSTB, there are many Mesozoic and Cenozoic sedimentary basins (e.g., Liupanshan Basin, Yinchuan Basin, Hetao Basin, etc.) (Fig. 1b), which are essential for understanding the evolution of the northern NSTB. The Early Cretaceous Liupanshan Basin is located at a key position with various structure features and complicated evolution processes (Fig. 1b; Bai et al., 2006; Zhao et al., 2006; Liu et al., 2005), which provides an ideal window for studying the Early Cretaceous evolution of the northern NSTB. However, previous studies have mainly focused on the arcuate thrust-fold belt (Lei et al., 2016; Li et al., 2016, 2013; Duvall et al., 2013) and source rock evaluation of the Liupanshan Basin (Han et al., 2019; Zhao et al., 2013; Liu and Tang, 2007). Furthermore, this area underwent extensive multi-stage uplift and deformation events, making it difficult to identify the provenance and original sedimentary extent of the Liupanshan Basin. Fortunately, the widespread Lower Cretaceous of the Liupanshan Basin (Liupanshan Group) can provide significant clues to decipher the tectono-sedimentary evolution during the Early Cretaceous (Fig. 2).

Clastic sedimentation plays a crucial role on the constraint of the source region and the composition, age, and successions of clastic sediments are also related to the tectonic evolution of the orogens from where the sediments are sourced (Zhou et al., 2016; Li et al., 2005; Taylor and McLennan, 1985). In this study, paleocurrent characteristics, conglomerate clast compositions, and detrital zircon U-Pb geochronology of the Lower Cretaceous from the Liupanshan Basin were analyzed together in order to identify the provenance of the detritus. In combination with regional geological setting, these new insights are used to decipher Early Cretaceous tectono-sedimentary evolution of the Liupanshan Basin, as well as the tectonic implications for the northern NSTB.

Figure 1. (a) Regional tectonic map (modified after Liu et al., 2005); (b) distribution of sedimentary basin in the Northern North-South tectonic belt and adjacent areas (modified after Liu et al., 2019, 2005); (c) simplified geological map of the study area (modified after Zhang et al., 2012 and GBSP, 1967). F1. Western Liupanshan fault; F2. Haiyuan fault; F3. Qingshuihe fault; F4. Yantongshan-Yaoshan fault; F5. Qingtongxia-Guyuan fault; F6. Qinglongshan-Pingliang fault.
1 GEOLOGICAL SETTING

Liupanshan Basin is situated in the northern NSTB, which is bounded by the Ordos Block, the Alxa Block, the Hexi Corridor belt, and the Qinling-Qilian orogenic belt (Fig. 1a). During the Paleozoic, this area experienced complex tectonic evolution, which is closely related with the development of the paleo-Qilian Ocean (Zhao et al., 2016b). In the Early Mesozoic, the study area and its neighboring region transformed to an intraplate setting (Darby and Ritts, 2002) and belonged to the Ordos Basin, where a large, uniform sediment dispersal system developed (Bai et al., 2006; Liu et al., 2006; Zhao et al., 2006). When it comes to the Late Jurassic, strong tectonic events happened and led to the separation of Liupanshan Basin and the Ordos Basin (Bai et al., 2006). The Liupanshan Basin entered into a relatively independent development stage since then. After the latest Early Cretaceous, the Liupanshan Basin began to shrink and eventually disappear. In the Cenozoic, although the strong compression of the Qinghai-Tibet Plateau, the study area experienced another stage of strong folding, which led to the formation of Liupanshan arcuate thrust-fold belt (Li et al., 2013). In addition, during the Late Cenozoic (~10 Ma), rapid cooling and erosion initiated in the Liupanshan Mountain, which is supported by low-temperature thermochronology from apatite fission-tracks and an estimate of the timing of sediment accumulation in the Sikouzi Basin (Lin et al., 2009; Zheng et al., 2006).

Lower Cretaceous strata (Liupanshan Group) is widely distributed in the study area and is divided into Sanqiao Formation, Heshangpu Formation, Liwaxia Formation, Madongshan Formation, and Naijiahe Formation (Yang et al., 1992) (Figs. 1c and 2). Sanqiao Formation is mainly composed of conglomerate, breccia and pebbly coarse sandstone (Figs. 3a and 3b). The gravel composition and thickness are distinguishing in different areas, suggesting a typical piedmont facies sedimentation. Heshangpu Formation mainly consists of conglomerate, breccia and pebbly coarse sandstone (Figs. 3a and 3b). The shallow lacustrine deposits are dominantly purple-red and gray-green sand-mudstone (Figs. 3d and 3e). The Madongshan Formation is mainly composed of mudstone, shale, and limestone (Figs. 3f and 3g). The

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**Figure 2.** Stratigraphic column of the Lower Cretaceous from the Liupanshan Basin, showing lithology and sample sites (modified after BGMRNHar, 2004). The tectonic stress fields of the Liupanshan Basin are referenced from Shi et al. (2006).
Naijiahe Formation is generally composed of mudstone, shale and limestone with gypsum (Figs. 3h and 3i). In general, from bottom to top, the Lower Cretaceous sequence in the Liupanshan Basin underwent the transformation process from piedmont-river facies to lake-saline lacustrine facies (Fig. 2). The Upper Cretaceous was absent in the Liupanshan Basin.

2 ANALYTICAL METHOD AND SAMPLE DESCRIPTION

Paleocurrent measurements help to establish paleoslope and paleotransport directions, which, in turn, reveal the provenance area of the sedimentary basin (Zhang et al., 2017). Paleocurrent measurements were taken following the method proposed by DeCelles et al. (1983). In this study, the paleocurrent measurements were based on gravel imbrication and cross-bededdings of the Sanqiao and Heshangpu formations at eight locations in the field (Fig. 4). All measurements have been corrected for declination using the Stereonet Program. These new data, compiled together with previous published data (e.g., Liu, 2010), were used to identify the paleocurrent directions during the Early Cretaceous.

Considering the Lower Cretaceous strata in the Liupanshan Basin contain thick conglomerate layers, we conducted gravel clastic component statistics on twelve well-preserved outcrops. The gravel compositions were measured at the bottom of the conglomerate sections so as to ensure that the analyzed conglomerates are synchronous in different sections. All gravel grains restricted in the plane of ~1×1 m² were identified and about 150 gravels were randomly selected and counted per investigation site. Typical exposures and pie charts of gravel composition are shown in Figs. 3 and 5.

Zircon grains were separated by conventional heavy liquid and magnetic techniques at the Langfang Regional Geological Survey, Hebei Province, China. Handpicked zircons, showing transparency, homogeneous color, homogeneity and absence of inclusions, were mounted in epoxy resin and polished until the centers of zircon grains were exposed. Transmitted and reflected light images were used to characterize external morphology of the zircon grains. Cathodoluminescence (CL) images were taken to identify internal structure of the zircons and to determine potential target sites for U-Pb isotopic analyses. The U-Pb dating was carried out using an Agilent 7500a ICP-MS instrument at the state Key Laboratory of the Continental Dynamics in Northwest University, Xi’an, China. The analytical procedures follow those described in Liu et al. (2007) and Yuan et al. (2004). The NIST 610 standard was used for element calculation, and zircon standard 91500 was used for isotope fractionation correction. 207Pb/206Pb, 206Pb/238U, 207Pb/235U and 208Pb/232Th ratios were calculated using the GLITTER 4.0 program. Concordia diagrams and weighted mean U-Pb ages were processed using ISOPLOT 2.49 (Ludwig, 2003).

Two representative samples of Sanqiao and Heshangpu formations from Huoshizhai Section were collected for detrital zircon dating (Fig. 1c). Sample NX-16-31 is purplish-red coarse sandstone from the Sanqiao Formation, and sample NX-16-32 is gray-purplish red, medium grained feldspar sandstone from the Heshangpu Formation.
3 RESULTS

3.1 Paleocurrent Directions

The paleocurrent measurements were taken at 8 sites in the Sanqiao and Heshangpu formations. For the Sanqiao Formation, the strata from different areas in Liupanshan Basin display various flow directions. To be more specific, in northern Longxian area, flow directions are mainly southwestward and westward; in southern Longxian area, flow directions are mainly northeastward and northwestward; in Anguo-Pingliang area, flow directions are mainly westward, southwestward, and northwestward; in Sanqiao area, flow directions are mainly northeastward; in Huoshizhai area, dominant flow directions point to the eastward, northeastward and southeastward (Fig. 4a).

The paleocurrent of Heshangpu Formation show similar characteristics with that of Sanqiao Formation. In Longxian area, flow directions are mainly northwestward; in Sanqiao area, flow directions are northeastward and southeastward; in Huoshizhai area, dominant flow directions point to the southward, southeastward and southwestward (Fig. 4b). In addition, in Pingliang area, the flow directions show the different feature of eastward paleocurrent direction (Fig. 4b).

3.2 Gravel Clastic Component

Conglomerate facies of the Sanqiao Formation are widely distributed along the margin of Liupanshan Basin (Fig. 1c). Six types of clasts with diverse originations were distinguished, and classified as limestone, sandstone, mudstone, quartzite, intermediate-acid magmatic rock, and metamorphic rock. Conglomerates from Sanqiao Formation in Liupanshan Basin are massive or grain-supported, which are composed prevailingly of poorly sorted, poorly to moderately rounded gravels (Figs. 3a and b). Generally, from the bottom to the up, the size of conglomerate changes from coarse to fine, the thickness of conglomerate layer gradually decreases, and the contents of conglomerate-bearing sandstone and sandstone layer increase. Gravels from conglomerates of the Sanqiao Formation are mainly intermediate-acid magmatic rocks, metamorphic rocks and inherited authigenic sedimentary rocks, with a small amount of recycled terrigenous clastic rocks. The gravel compositions display an obvious various feature in different sections (Fig. 5). For instance, the conglomerate components in the Longshan and Huoshizhai areas predominantly consist of intermediate-acid magmatic rocks and metamorphic rocks. In comparison, the conglomerate components in the eastern Liupanshan Basin (e.g., Pengyang, Tanshan, etc.) are mainly limestones (Fig. 5).

3.3 U-Pb Geochronology of Detrital Zircon

Two outcrop samples NX-16-31 and NX-16-32 from the Sanqiao Formation and Heshangpu Formation, respectively. They were selected and analyzed to provide significant constraints on sediment provenance (Figs. 1c and 2). Zircons grains from samples NX-16-31 and NX-16-32 show similar morphological features, and are mostly colorless and prismatic to
sub-prismatic (Fig. 6). The crystal sizes range from 80 to 300 μm, with the length/width ratios ranging from 1 : 1 to 3 : 1 (Fig. 6). According to CL images, most zircons of these two samples display clear oscillatory zoning or platy structures (Fig. 6), which tends to indicate a magmatic origin (Corfu et al., 2003; Hanchar and Rundnick, 1995). Additionally, Th/U ratios of oscillatory grains range from 0.16 to 1.39 (Table S1), also indicating a magmatic origin (Su et al., 2018; Corfu et al., 2003; Belousova et al., 2002). But a few zircons are black in CL images, which may be due to high Pb contents (Li et al., 2014).

Ninety-six zircon grains in NX-16-31 and 84 zircon grains in NX-16-32 were randomly dated of selected targets avoided inclusions and fractures. Ninety-six concordant ages were obtained from NX-16-31, with ages ranging from 411 to 1,518 Ma. Only one age cluster was identified, i.e., 420–500 Ma with the age peak of 447 Ma (Fig. 7). Eighty concordant ages were obtained from NX-16-32, ranging from 417 to 1,154 Ma. Similar to sample NX-16-31, one age cluster was identified from NX-16-32, which is 420–500 Ma with the age peak of 444 Ma (Fig. 7). The zircon structures and age distributions of these two samples from the Sanqiao Formation and Heshangpu Formation are similar, suggesting a homogenous sediment source terrane.

4 DISCUSSION

4.1 Provenance of the Sanqiao-Heshangpu Formations in the Liupanshan Basin

4.1.1 Conglomerate component and paleocurrent

The conglomerate components in the southeastern Longxian area consist abundant limestones, followed by granites and metamorphic rocks (Fig. 5). Due to the weak weathering resistance, the limestone gravels are generally preserved in near-source and fast-accumulating clastic rocks (Han et al., 2014; Wang et al., 2011). In the northwestern and southeastern Longxian area, a large number of Early Paleozoic limestones were exposed (Fig. 1c), and the paleocurrent directions also indicate that the gravels were probably from these Early Paleozoic...
limestones (Fig. 4). In comparison, the conglomerate components in Badu and Tiefosi areas are mainly composed of granites and metamorphic rocks without limestone (Fig. 5). The Longshan Mountain area to the southwest has a wide outcrop distribution of Proterozoic biotite quartz schist, phyllite, two-mica schist gneiss, quartzite and Variscan quartz diorite, biotite granite and amphibole granite (Huo, 1989), which is consistent in components with the Sanqiao conglomerate. Meanwhile, the paleocurrent direction is also support this understanding. The gravel components of the Sanqiao Formation in the Yueliangshan Mountain-Huoshizhai area mainly include granitoids and metamorphic rocks (Fig. 5), and the directions of paleocurrent
are eastward, northeastward and southeastward. Although the western Yueliangshan Mountain is widely covered Cenozoic strata, drilling data show that abundant old strata such as metamorphic rocks of the Proterozoic Haiyuan Group distributed under the Cenozoic strata. Furthermore, by comparing the stratigraphic features at the two sides of western Yueliangshan fault, we suggest that the structural inversion occurred in this area (Fig. 8). Therefore, the Sanqiao Formation in the Yueliangshan Mountain-Huoshizhai area was probably derived from the granitoids and metamorphic rocks under the Cenozoic in the western Yueliangshan area. In Pengyang-Tandonggou area, there is a large number of limestone gravels in the Sanqiao Formation, followed by sand and mudstone gravels (Fig. 5). The most prominent feature of this area is the existence of a Proterozoic–Early Paleozoic limestone, siliceous limestone, dolomite and quartz sandstone distributed as north-south direction, which is the so-called the archaic uplift. The extensive development of limestone gravels in the Sanqiao Formation in this area indicates that the archaic uplift has been a source region for the surrounding area during the period.

The Heshangpu Formation mainly includes sandstone and siltstone, thus, the reconstructed paleocurrent directions based on a large amount of measurement results are shown in Fig. 4b. The paleocurrent directions of the southeast part in the Liupanshan Basin are mainly northward and southwestward; in the southwest part of the basin, the paleocurrent directions are mainly southward, southwestward and southeastward. As indicated above, the paleocurrent features during Heshangpu Period basically inherited those of the Sanqiao Period. It also suggests that the tectonic environment of the Liupanshan Basin was relatively stable during the Sanqiao and Heshangpu formations deposition.

4.1.2 Detrital zircon U-Pb ages

Detrital zircon geochronology has been widely used to identify the source of sedimentary rocks, due to its stable physicochemical properties (Wang et al., 2016; Gehrels, 2014). The age structure of detrital zircons is unaffected by deposition, cycling, and fractionation processes, and even the ages of recycled zircons correspond with regional tectonic-magmatic events (Geslin et al., 1999; Drewery et al., 1987). Therefore, the age spectrum of detrital zircons can be used to reflect the age composition of the provenance region.

Based on lithological characteristics and strata distribution, this study selected two samples from Sanqiao Formation and Heshangpu Formation in Huoshizhai Section (northwestern Liupanshan Basin) for detrital zircon analysis (Fig. 1c). The

![Figure 8. Sketch model showing the tectonic evolution of Yueliangshan Mountain area.](image)
U-Pb age spectra of samples NX-16-31 and NX-16-32 display similar characteristic. To be more specific, the zircon ages of two samples (NX-16-31, NX-16-32) show a dominant unimodal distribution range from 420 to 500 Ma with the age peaks of 447 and 444 Ma, suggesting a single-sourced provenance (Fig. 7).

The Early Paleozoic ages are widely recorded in the Qilian-Qinling orogenic belt and Alxa Block (Fig. 9). Previous researches show that the Caledonian is a significant tectonic evolution stage of the Qilian-Qinling orogenic belt (Xu et al., 2008; Zhang et al., 2001; Xia et al., 1996), which is reflected by widespread igneous rocks. For instance, in eastern Qilian orogenic belt, zircon U-Pb ages of 440.2±0.92, 441±10, 440.5±4.4, 430–457, and 431–451 Ma were obtained from Yanjiadian diorite, Huangmenchuan granodiorite, adakitic granitoids in Quwushan area and Nanhuashan granodiorite, respectively (Yu et al., 2015; Meng et al., 2012; Wei et al., 2012; Pei et al., 2007). And in western Qinling, Caledonian ages are also common (Fig. 9), such as Dangehuai granites (438±3 Ma, Wang et al., 2008) and Tangzang quartz diorite pluton (454.7±1.9 Ma, Chen et al., 2008). Furthermore, the Caledonian ages are recorded in Alxa Block as well (Fig. 9) (Zhang et al., 2016; Geng et al., 2007).

However, the Early Paleozoic detrital zircons of the Sanqiao Formation and Heshangpu Formation in Huoshizhai area display the features of proximal sediments, which were ought to be controlled by an adjacent single source. Reasons are as follows: (1) the age spectra show paucity of zircon grains of Neoproterozoic, which implies that Neoproterozoic basements of the Qilian-Qinling orogenic belt and Alxa Block were not the provenance; (2) the sedimentary characteristics (e.g., poor sorting and rounded) and detrital zircon crystals (mainly prismatic) suggest they were proximal sediments. Thus, the provenance of Huoshizhai area has a close relationship with the adjacent Early Paleozoic igneous and metamorphic rocks in the Qilian-Qinling orogenic belt. However, due to the structural inversion in the later stage, these old rocks are not exposed on a large scale now.

Taking into account of the paleocurrent directions, gravel clastic components, and detrital zircon ages, the provenance of the Sanqiao Formation and Heshangpu Formations should be the highlands on the margin of the basin. To be more specific, sediments in western region (including Badu, Tiefosi, and Huoshizhai areas) were primarily derived from the proximal metamorphic and magmatic rocks of the Qilian-Qinling orogenic belt; those in eastern region were mainly originated from the limestones of the archaic uplift.

4.2 Early Cretaceous Tectono-Sedimentary Evolution of the Liupanshan Basin

Previous studies have shown that the North China Block was dominated by multi-direction convergent tectonic system during the Late Jurassic (Dong et al., 2008; Zhang et al., 2008), and a strong tectonic uplift was caused in the study area (Zhao, 2017; Liu et al., 2006, 2005; Yang et al., 1992). After the intense compression in the Late Jurassic, the Liupanshan area entered a stage of stress relaxation and developed a series of contemporaneous normal faults (Fig. 10). Furthermore, plenty of scientific researches also indicate the whole East China
Continent was under the tectonic setting of crustal extension and lithospheric thinning during the Early Cretaceous, resulting in widespread formation of rift basins and volcanic activities (Zhai et al., 2004; Zhang et al., 2004; Shao et al., 2003). The restoration of the regional paleo-stress field indicated that the Liupanshan Basin was rifted and deposited thick fluvial-lacustrine sediments of Liupanshan Group under the near-E-W direction tension stress in the Early Cretaceous (Shi et al., 2006). In addition, the paleomagnetic study also shows that the Liupanshan Basin has different magnitude of horizontal rotation during the sedimentation process, indicating that it also has obvious strike-slip properties (Liu, 2010). In the Sanqiao Period, a large amount of coarse clastic deposits with huge thickness were distributed along the margin of the basin characterized by poor sorting and rounding features (Figs. 3a and 3b). Additionally, our results indicate that the gravel components vary obviously with narrow sedimentary facies distribution, which were controlled by the highlands on the margin of the basin. In the western part of the basin, the Sanqiao Formation conglomerate is distributed along the western Liupanshan fault and the Guguan-Badu fault, which indicates that these faults control the sedimentation of the Liupanshan Basin as the boundary fault during the Sanqiao Period. In the northern part of the basin, the alluvial facies of the Sanqiao Formation are mainly distributed the Xingrenbao, Mahuangggou, Shangliushui and Yaoshan areas (Yang et al., 1992). In the eastern part of the Liupanshan Basin (e.g., the Shixianzi-Tanshan area), the Sanqiao Formation conglomerate is basically composed of limestones (Fig. 5) with poor rounding and sorting features. These features indicate that the archaic uplift has been uplifted and controlled the sedimentation at this time (Fig. 11a).

During the Heshangpu-Liwaxia Period, as the basin continued to subside and expand, the grain size of sediments gradually became finer. In plane, fluvial-delta facies and shore-shallow lake facies appeared successively from the periphery to the interior of the basin (Fig. 11a). In the Madongshan to Early Naijiahe Period, the basin entered its prosperous stage, which was also the main oil generation period of the Liupanshan Basin (Han et al., 2019; Liu and Tang, 2007; Yang et al., 1992). The Sikouzi area might be the depocenter at that time, characterized by the largest thickness and finest grain size (Fig. 11b). Most of the rest areas were characterized by shallow lacustrine facies. During this period, the sediments in the Liupanshan Basin can be compared with the Ordos Basin to the east,
indicating that the archaic uplift probably has been flattened and these two basins were connected again (Bai et al., 2006) (Fig. 11b). It is worth noting that the lake basin began to be salted, with the evidences by a large number of gypsum rocks and cadisfly case fossils in the Madongshan-Naijiahe Formation (He et al., 2015, 2014). In addition, the paleontological evidences suggest that the climate has gradually turned to arid and hot during the Naijiahe deposition (Du et al., 2018; Yang et al., 1992), such as the oncolites in the Naijiahe Formation (Zhong et al., 2010).

In the late of Naijiahe Period, the Liupanshan Basin was gradually uplifted due to the NW-SE compression (Liu, 2010; Shi et al., 2006), which lead to the final extinction of the Liupanshan Basin. This episode of tectonic uplifting was also recorded by the fission-track ages (Zhao et al., 2016; Liu et al., 2006).

To sum up, the Liupanshan Basin was a rift basin which underwent multi-stage evolution during the Early Cretaceous: the early rifting extension stage (Sanqiao Period), the middle spanning and depression stage (Heshangpu–Early Naijiahe Period), and the late extinction stage (Late Naijiahe Period). The formation of the Liupanshan Basin is probably the response to the lithospheric mantle detachment and lithospheric thinning in the East Asia Continent.

4.3 Implications for the Archaic Uplift in the Northern NSTB

In the northern NSTB, there are a series of mountains composed of Mesoproterozoic, Cambrian and Ordovician limestones and clastic rocks, which are distributed in north-south direction (e.g., Luoshan Mountain, Qinglongshan Mountain, etc.) (Fig. 1c). Therefore, it is generally believed that an archaic uplift with north-south distribution existed in this area (Han et al., 2014; Bai et al., 2006; Yang, 2002; Huo, 1989; Peng, 1955).

Different opinions about the evolution history of the archaic uplift have been proposed based on field observation and laboratory analyses (Han et al., 2014; Bai et al., 2006; Tang He et al., 2006; Zhao et al., 2006; Yang, 2002; Tang X Y et al., 1992; Peng, 1955).

Results of this study suggest that the archaic uplift was a significant source area to the eastern margin of Liupanshan Basin during the Sanqiao Formation deposition. Moreover, the variation of strata thickness, distribution of marginal facies, and the obvious provenance difference in eastern and western Liupanshan Basin also support the interpretation that the archaic uplift was a significant paleogeographic boundary during the Early Cretaceous (Fig. 11a). Hence, a north-south archaic uplift has been existed between the Liupanshan Basin and the Ordos Basin during the Early Cretaceous, and was probably resulted from the intensive tectonic event in the Late Jurassic. This uplift event played an important role in controlling the sedimentation of the Liupanshan Basin, and caused widespread high-angle unconformity contact between the Jurassic and Cretaceous and massive coarse debris deposition. However, during the late Early Cretaceous, the archaic uplift was leveled to the ground and the Liupanshan Basin connected with Ordos Basin.
again (Fig. 11b). In fact, the archaic uplift experienced multi-stage of uplift and planation. The steep ancient strata and angle unconformity between different strata were widely distributed in the study area. In addition, the obvious difference in sedimentary and detrital components between the Lower Yanchang Formation (Chang 8-10) and Upper Yanchang Formation (Chang 1-7) in the study area (Han et al., 2014; Deng et al., 2008) also suggest the archaic uplift was significantly uplifted by the indosinian movement at the end of Chang 8. The fission track ages further reflect that the northern NSTB experienced multiple periods of uplift during the Meso–Cenozoic (Zhao et al., 2018). Similarly, previous researches also indicate that the archaic uplift has been uplifted in the Carboniferous (Guo et al., 2015) and Late Triassic (Han et al., 2014), and then has been leveled to the ground in the Latest Carboniferous–Earliest Permian (Taiyuan Formation deposition) (Guo et al., 2015) and Middle Jurassic (Yan’an Formation deposition) (Guo, 2015), respectively. Therefore, the evolution of the archaic uplift probably displays a dynamic process of uplift-planation-re-uplift, which is closely related to the multi-stage tectonic events in the northern NSTB.

5 CONCLUSIONS
Integrating the regional geological, petrographic, geochemical and geochronological data in this study and the available studies in recent years, we have reached the following conclusions.

(1) Paleocurrent directions of the Sanqiao Formation and Heshangpu Formation suggest that the provenance of the Lower Cretaceous (Sanqiao and Heshangpu formations) should be the highlands on the margin of the Liupanshan Basin.

(2) Gravel clastic components and detrital zircon ages demonstrate that the sediments of the Sanqiao and Heshangpu formations were mostly derived from the proximal metamorphic and magmatic rocks of the Qilian-Qinling orogenic belt and the limestones of the archaic uplift.

(3) Source-to-sink relation reveals that the Liupanshan Basin was situated in a relative independent intra-continental subsidence depositional system during the Sanqiao and Heshangpu formations deposition. Then, the tectonic activity gradually weakened and the sedimentary area expanded, leading to the connection of the study area and Ordos Basin.

(4) Tectono-sedimentary evolution characteristics of the Liupanshan Basin indicate the archaic uplift experienced the early stage of uplift and the late stage of planation. Combining with previous research, we conclude that the archaic uplift experienced a dynamic evolution history, i.e., the process of uplift-planation-re-uplift.

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