Late Paleoproterozoic–Neoproterozoic (1800–541 Ma) Mafic Dyke Swarms and Rifts in North China

Peng Peng

Abstract The Late Paleoproterozoic–Neoproterozoic (1800–541 Ma) sedimentation, volcanism and igneous events, and rifting in the North China Craton can be categorized into different stages: (1) Stage 1 (1800–1730 Ma, Early Statherian): It is represented by the Taihang (1780–1770 Ma) and Miyun (~1730 Ma) dyke swarms, the Xiong'er volcanic province (~1780 Ma), and a little clastic sedimentation related to the evolution of the Xiong'er rift. (2) Stage 2 (1730–1600 Ma, Late Statherian): It is represented by the Damiao–Shachang anorthosite–rapakivi granite–dyke complexes (1710–1680 Ma), the Laiwu (~1680 Ma) and Taishan (~1620 Ma) dyke swarms, the Dahongyu lavas (~1620 Ma), and some clastic rocks and a little limestone related to the Yan-Liao rift, the Xiong'er rift, and probably the Bayan Obo rift. (3) Stage 3 (1600–1400 Ma, Calymmian/Jixian): It is represented by the dolomite-dominated strata in the Yan-Liao rift, the Xiong'er rift, and probably the Bayan Obo rift, with little volcanism and magmatism. (4) Stage 4 (1400–1200 Ma, Ectasian): It is represented by the ~1320 Ma dykes–sills–granites and ~1230 Ma Licheng dyke swarm, and the sedimentation dominated by clastic rocks with a little marlstone and limestone possibly limited in the Yan-Liao rift. (5) Stage 5 (1200–1000 Ma, Stenian): It is unclear whether there were any magmatism and deposition during this period. (6) Stage 6 (1000–800 Ma, Tonian): It is represented by the Dashigou (~925 Ma) and Qianlishan (~810 Ma) dyke swarms, the Sariwon (Dalian–Chulan–Zenghekou) sills (925–890 Ma), and clastic rocks/carbonate-dominated sediments within the Xuhuai rift. (7) Stage 7 (800–541 Ma, Cryogenian–Ediacaran): It is uncertain yet if there were any igneous events or sedimentation during this period, although some strata in Henan province are candidates. Multiple stages of rifting indicate a prolonged and stepwise rifting lasting for 1000 Ma, with the center of the rifts shifted from the south (the Xiong'er rift, 1780–1730 Ma) to the north (the Yan-Liao rift, 1730–1200 Ma) and to the southeast (the Xuhuai rift, 1000–800 Ma) of the North China Craton.

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It is well known that there was widespread metamorphism at 1950–1800 Ma in the North China Craton (e.g., Zhai et al. 1996; Zhao et al. 2001; Kusky and Li 2003; Guo et al. 2005, 2012; Liu et al. 2005; Kusky et al. 2007; Zhai and Peng 2007; Zhao 2014; Peng et al. 2014); and thus, ca. 1800 Ma was traditionally thought to be the timing between the Paleoproterozoic and the Mesoproterozoic in China; this is quite different from an international time framework (Fig. 1). There was a series of intra-continental rifts from 1800 Ma and intermittently continued to ca. 800 Ma (Fig. 2). In this chapter, the Late Paleoproterozoic to the Neoproterozoic (1800–541 Ma) strata, rift systems, and igneous events, mainly mafic dyke swarms, sills, and volcanic rocks in North China, will be summarized.

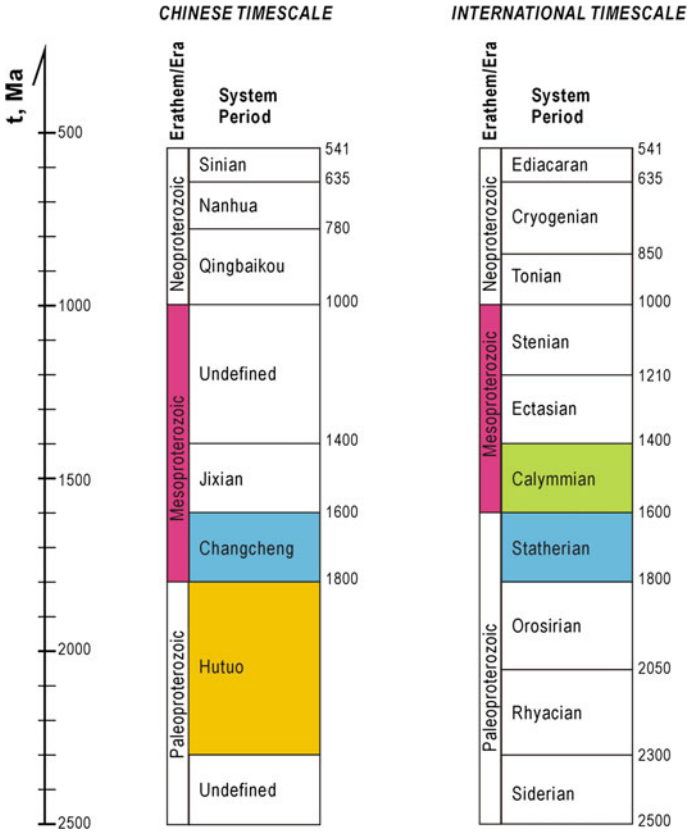
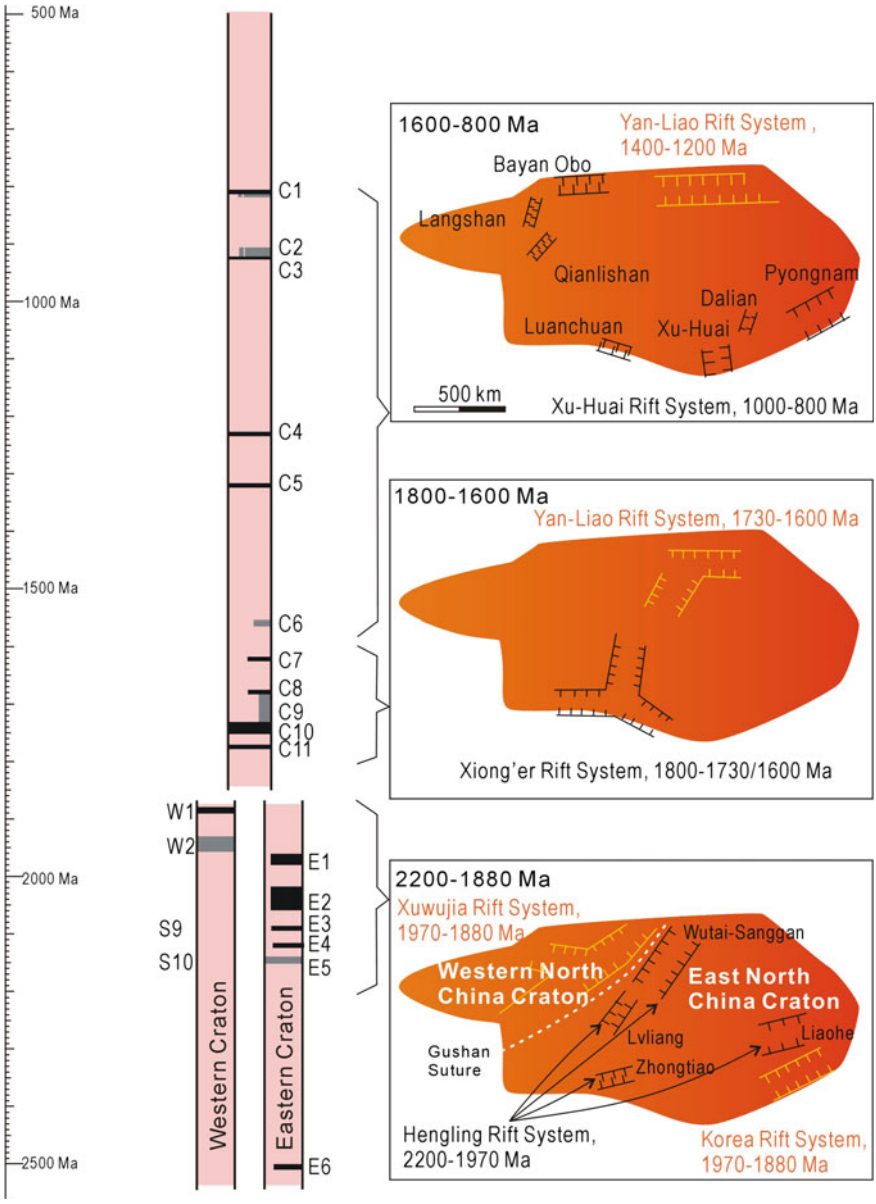


Fig. 1 Timescales of Proterozoic as released by the Chinese National Commission on Stratigraphy in 2009 and the International Commission on Stratigraphy in 2014


500 Ma
1000 Ma
1500 Ma
2000 Ma
2500 Ma
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
W1
W2
S9
S10
E1
E2
E3
E4
E5
E6
Western Craton
Eastern Craton
1600-800 Ma
Yan-Liao Rift System , 1400-1200 Ma
Bayan Obo
Langshan
Qianlishan
Pyongnam
Dalian
Luanchuan
Xu-Huai
500 km
Xu-Huai Rift System, 1000-800 Ma
1800-1600 Ma
Yan-Liao Rift System, 1730-1600 Ma
Xiong'er Rift System, 1800-1730/1600 Ma
2200-1880 Ma
Xuwujia Rift System, 1970-1880 Ma
Wutai-Sanggan
Western North China Craton
East North China Craton
Lvliang
Liaohe
Gushan Suture
Zhongtiao
Hengling Rift System, 2200-1970 Ma
Korea Rift System, 1970-1880 Ma

◀ **Fig. 2** The 2200–800 Ma major igneous events and rift systems in North China. Note that the shape of the craton was reconstructed back to the Precambrian (the strike slip movement along the Tan-Lu fault was reconstructed). *C1* Qianlishan dykes and Langshan volcanics; *C2* Sariwon, Chulan, Dalian, and Luanchuan sills; *C3* Dashigou dykes; *C4* Licheng dykes; *C5* Datong dykes, Chaoyang, Chengde, and Liaoyang sills; *C6* Gaoyuzhuang volcanics/sills; *C7* Taishan dykes; *C8* Laiwu dykes; *C9* Damiao anorthosites, Shachang rapakivi granites; *C10* Miyun dykes; *C11* Taihang dykes, Xiong'er volcanics. (8) Western North China Craton: *W1* Halaqin dykes/volcanics; *W2* Xuwujia dykes. (9) Eastern North China Craton: *E1* Xiwangshan dykes; *E2* Yixingzhai dykes; *E3* Zanhuang sills; *E4* Haicheng sills; *E5* Hengling dykes/sills; *E6* Huangbaiyu dykes. After Peng (2015)

The Chinese Mesoproterozoic–lower Neoproterozoic stratotypes were mostly based on the Jixian Section in Tianjin City (Chen et al. 1980; Fig. 1), and this section comprises the Chinese Changcheng, Jixian, and Qingbaikou Systems with ages of 1800–1600, 1600–1000, and 1000–800 Ma, respectively. However, recent identification of some Mesoproterozoic aged sills in the Xiamaling Fm. (the Qingbaikou Group) has changed this time framework (Li et al. 2009; Zhang et al. 2009). In 2009, the newly published timescale by the Chinese National Commission on Stratigraphy had added an unnamed system between the Jixian and Qingbaikou Systems and reset the timing of the Jixian System to 1600–1400 Ma (Fig. 1).

1 Major Mafic Dyke Swarms and Other Igneous Events

1.1 The 1800–1730 Ma Igneous Events

1.1.1 The 1780–1770 Ma Taihang Dyke Swarm

The Taihang dyke swarm consists of hundreds of NNW-trended (315°–345°) dykes, as well as some E–W-oriented (250°–290°) mainly in the central parts of North China, with an area of >450 × 800 km^2 (Peng 2015). It is named after the Taihang Mts. where dykes are well outcropped (Qian and Chen 1987). The E–W-trended dykes, mainly in the Lvliang but fewer in the Wutai and Zhongtiao Mts., are sometimes grouped as the Lvliang swarm (Figs. 3 and 4). The individual dykes are up to 60 km long and 100 m wide, with typical widths of 10–40 m. These dykes were emplaced at 1780–1770 Ma (Halls et al. 2000; Peng et al. 2005; Han et al. 2007; Peng 2015). Reconstruction of some rotations among active blocks of North China during Mesozoic reveals a fanning geometry for the dykes with magma flow from the southern margin (Peng et al. 2008; Hou et al. 2008a, b). It has also been revealed that the dykes in the Yinshan area were uplifted and exhumed from crustal levels up to 20 km deep (Hou et al. 2001a; Peng et al. 2008).

The ~1780 Ma Xiong'er Group volcanic province has an areal extent of 350 × 500 km^2 and a thickness of 3–7 km and is dominated by thick and continuous lava flows, with rare volcaniclastic thin layers (~2 vol%, Zhao et al. 2002). It is

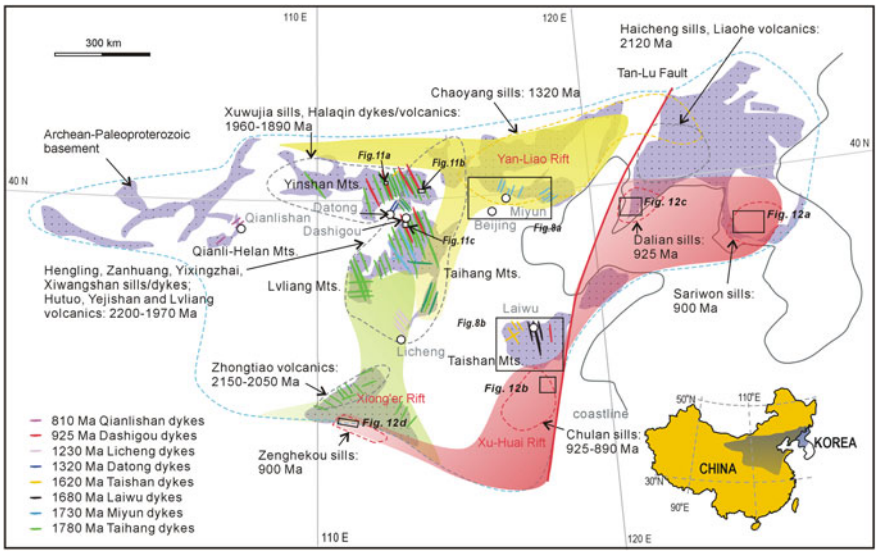


Fig. 3 Sketched map showing the distribution of Proterozoic mafic dyke swarms and related associations in the North China Craton. After Peng (2015)

natural to connect the coeval Taihang dykes and the Xiong'er volcanics as they have roughly overlapped compositions, and more importantly, they are spatially correlated (Peng et al. 2008): They possibly constitute a ~1780 Ma large igneous province by definition, and it was possibly driven by a paleoplume (Peng et al. 2008). Nevertheless, some others have demonstrated that these events were resulted from syn-orogenic/post-collisional uplifting and Andean-style collision (Wang et al. 2004, 2008; He et al. 2009; Zhao et al. 2009a) or intra-continental rift (Hou et al. 2001a, b, 2006; Fig. 5).

The recognition of the southern margin of the eastern North China Craton as the magma center of the Taihang dyke swarm and Xiong'er volcanic province is important; it means that there could have been another paleocontinent which has been connected with North China and which has been drifted away later. A group of paleogeographic reconstruction has been made for the Late Paleoproterozoic based on the 1780 Ma magmatic events (e.g., Peng et al. 2005; Hou et al. 2008a, b). Figure 6 is one hypothetic model of the paleocontinents in the Late Paleoproterozoic, which was based on the comparison of 1780–1730 and ~925 Ma dyke swarms and rift systems (Peng 2015).

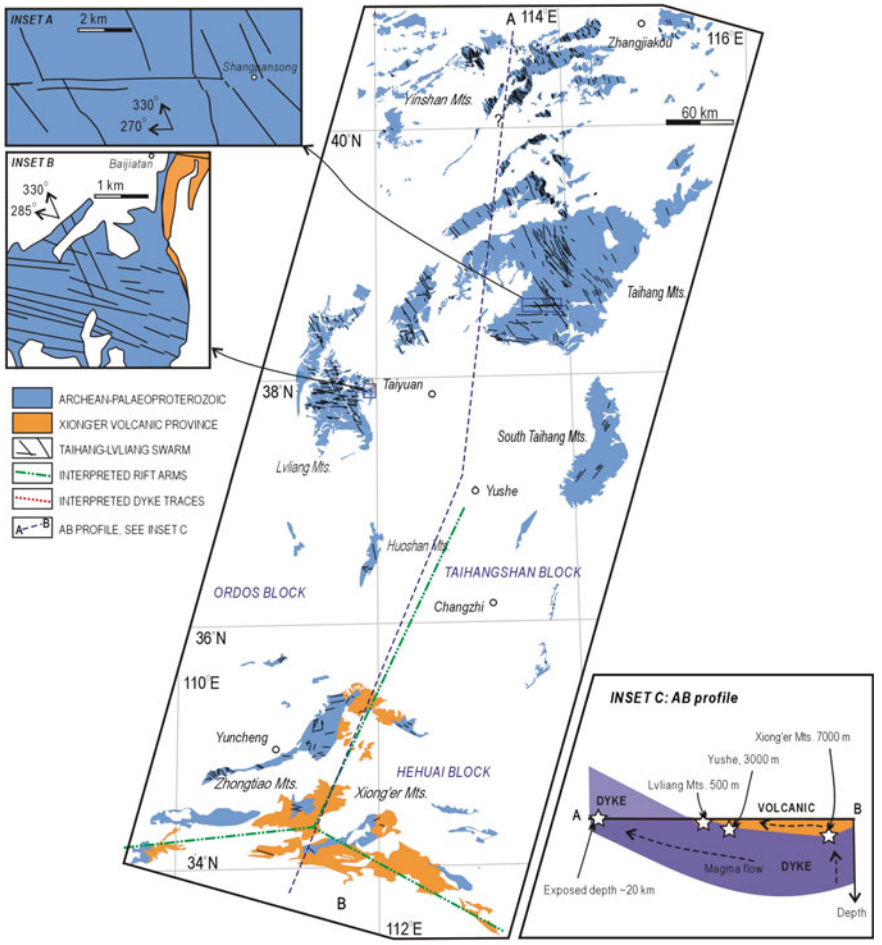


Fig. 4 Map showing the distribution of the Taihang–Lvliang swarm and Xiong'er volcanic province (after Peng 2010). *Insets A* and *B* show enlarged maps of local areas, which show the relationship between the Taihang dykes and the Xiong'er volcanic flows. *Inset C* is a hypothesis profile of the study area

1.1.2 The 1730 Ma Miyun Dyke Swarm

The ca. 1730 Ma Miyun dyke swarm has a total areal extent of 500 × 300 km^2 and consists of NE-trended dykes in the north and east, and NNW-trended in the central of North China (Fig. 3). The dykes are generally several kilometers long and 10–50 m wide. They are typically diabase and composed of plagioclase and clinopyroxene. This swarm is unconformably overlain by the Changcheng Group (Peng et al. 2012). Conglomerates, weathering surface, and direct contacts between the Changcheng Group and the dated dyke (∼1731 Ma) were discovered in Miyun

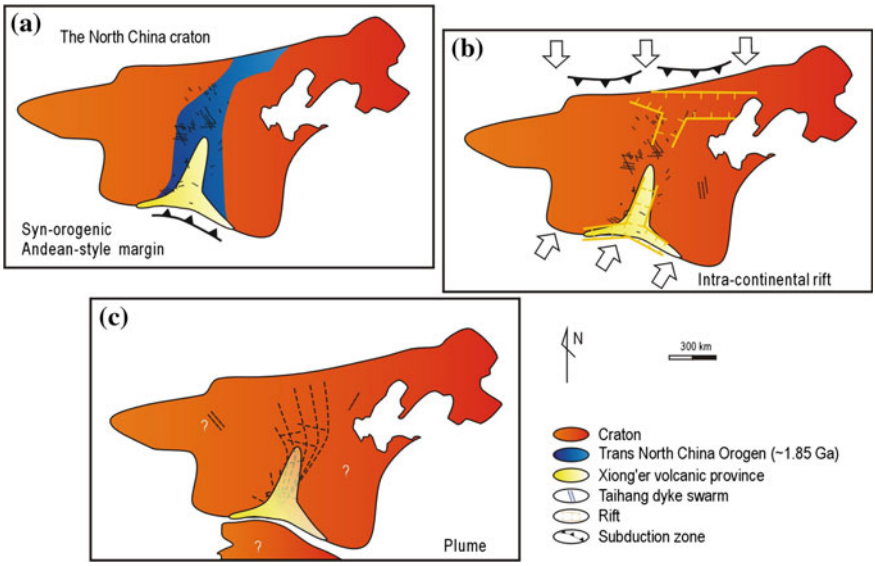


Fig. 5 Cartoons showing tectonic environments for the 1780 Ma dyke swarm and volcanic province. **a** Post-orogenic (e.g., Wang et al. 2004, 2008; He et al. 2009; Zhao et al. 2009); **b** intra-continental rifts evolving along with a paleosubduction (e.g., Hou et al. 2006); **c** plume-related resulted in continental breakup (Peng et al. 2005). After Peng (2010)

(Fig. 7). This clearly indicates that the Changcheng Group is younger than ~1731 Ma.

1.2 The 1730–1600 Ma Igneous Events

1.2.1 The 1730–1680 Ma Damiao–Shachang Anorthosite–Rapakivi Granite–Dyke Complexes

The 1730–1680 Ma Damiao–Shachang anorthosite–rapakivi granite–dyke complexes occur as small plutons or stocks of anorthosite and rapakivi granite and dykes in the Yan-Liao rift (Fig. 8). The distribution of these plutons was likely controlled by the E–W fault systems. These rocks were thought to be anorogenic, possibly related to a global event (Rämö et al. 1995; Yang et al. 2005; Zhang et al. 2007; Zhao et al. 2009b; Jiang et al. 2011; Wang et al. 2013).

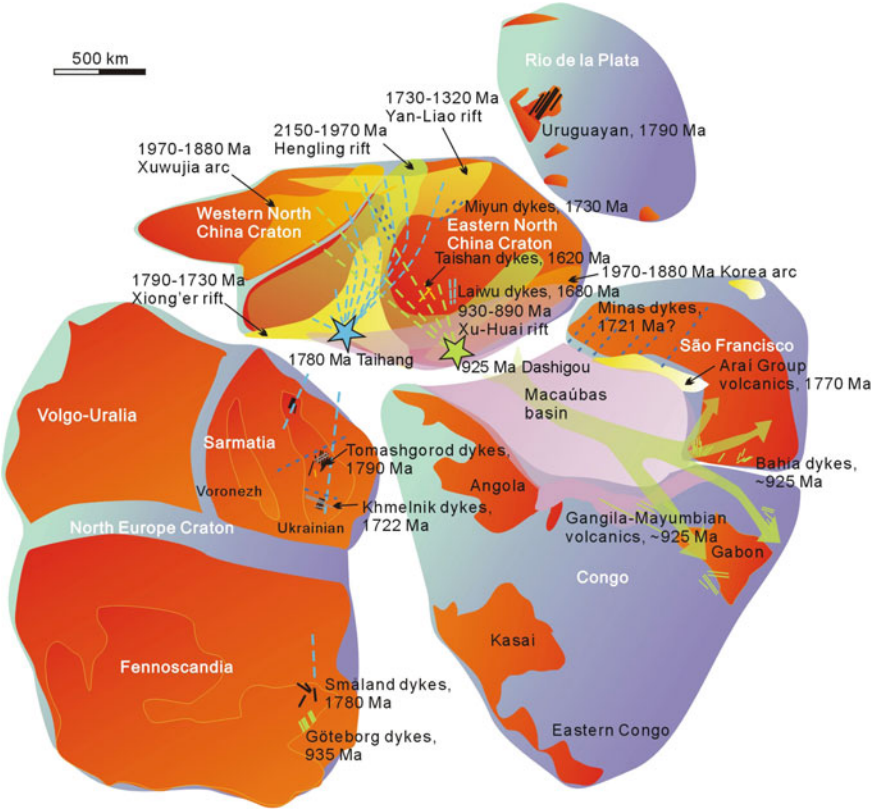


Fig. 6 Hypothetical paleogeography map of North China at ca. 1800 Ma. After Peng (2015)

1.2.2 The 1680 Ma Laiwu Dyke Swarm

The Laiwu dykes are newly discovered in Taishan Mts. (Fig. 8). Most of these dykes are 10–35 m wide, strike NNW (340°–350°), and are subvertical (65°–85° W). They generally outcrop continuously for several kilometers. They are composed of typical diabase (Li et al. 2015). Volcanic rocks with similar ages may exist in the Tuanshanzi Fm. in the Yan-Liao rift (Li et al. 1995a, b).

1.2.3 The 1620 Ma Taishan Dykes and Dahongyu High-Potassium Volcanics

The 1620 Ma Taishan dykes are distributed west to the Laiwu dykes (Fig. 8). Two biggest of them are NNW- and NE-oriented, respectively. Both of them are

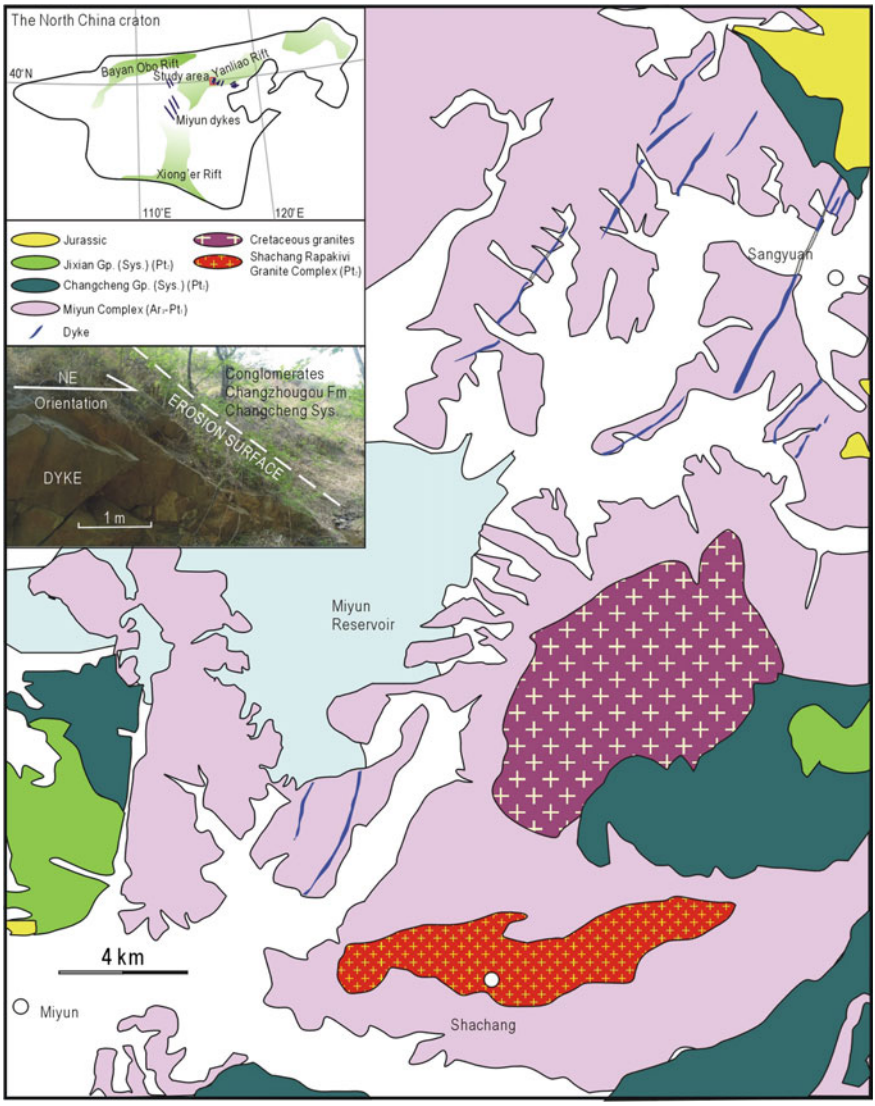


Fig. 7 The 1730 Ma Miyun dyke swarm in Miyun area. After Peng et al. (2012)

~25 km long and up to 40 m wide. The rocks of these dykes are composed of clinopyroxene (~40 vol%) and plagioclase (~55 vol%) (Li et al. 2015). There are also some coeval high-potassium volcanics and sills distributed in the Dahongyu Fm. in the Yan-Liao rift (Lu et al. 2008).

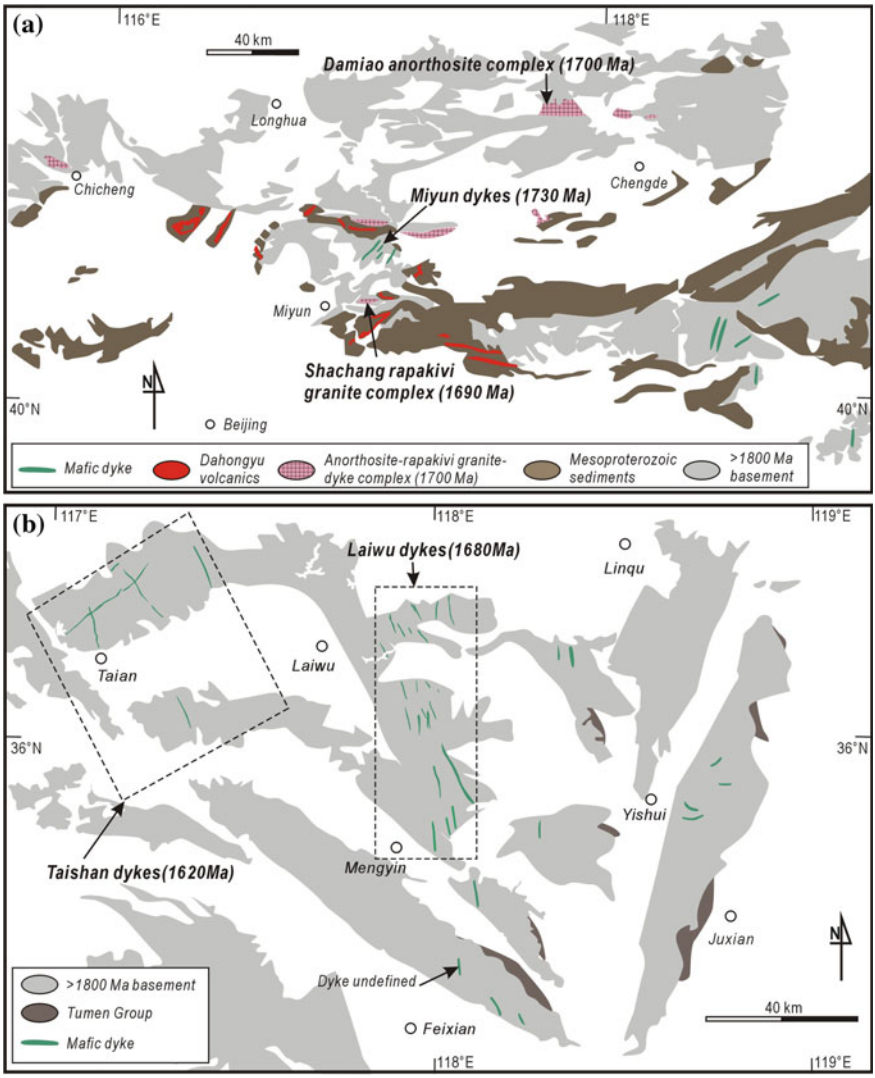


Fig. 8 Distribution of the 1710–1680 Ma anorogenic anorthosite–rapakivi granite–dyke complex and the 1620 Ma Dahongyu volcanic layers (**a**), and the 1680 Ma Laiwu and 1620 Ma Taishan dyke swarms (**b**). After Li et al. (2015)

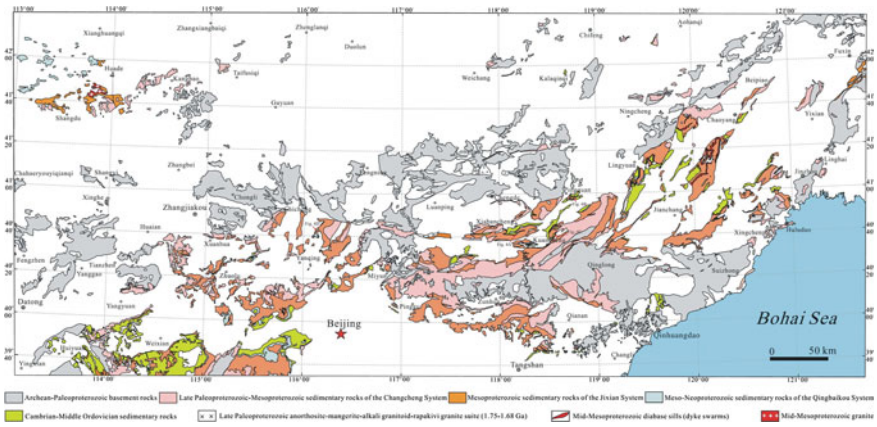


Fig. 9 Dustribution of the ~1320 Ma sills in the adjacent areas of the Yan-Liao rift. Copied from Zhang et al. (2012a)

1.3 The 1400–1200 Ma Igneous Events

1.3.1 The 1320 Ma Datong Dyke Swarm, the (Chaoyang–Kuancheng–Huailai) Sill Swarm and the Granites

The 1320 Ma dykes were discovered from Datong area (Fig. 3; Peng 2015). There are also some carbonatite dykes, possibly with ages between 1400 and 1200 Ma, in/around the Bayan Obo REE (rare earth element)-Nb–Fe-deposit (e.g., Fan et al. 2006; Le Bas et al. 2007; Yang et al. 2011).

The 1320 Ma diabase sills are widespread mainly in the Mesoproterozoic strata in the Yan-Liao rift (Fig. 9; Li et al. 2009; Zhang et al. 2009, 2012a, b). They are several meters to several hundred meters thick, and many of them continue for a few kilometers or even up to several tens of kilometers. They have typical ophitic textures with similar mineral compositions of pyroxene and plagioclase, and minor magnetite and hornblende (Zhang et al. 2009). Zhang et al. (2012a) reported ~1331–1313 Ma granites in Shangdu–Huade area (Fig. 9).

1.3.2 The 1230 Licheng Dyke Swarm

The 1230 Ma Licheng dykes are distributed in the Licheng area in the middle of Shanxi province (Fig. 3; Peng 2015). These NW-trending dykes are ~50 m wide cut the Mesoproterozoic strata and are covered by the Cambrian conglomerates. The rocks are gabbroic. There are also some 1209 Ma gabbros in Taishan Mts. (Peng et al. 2013).

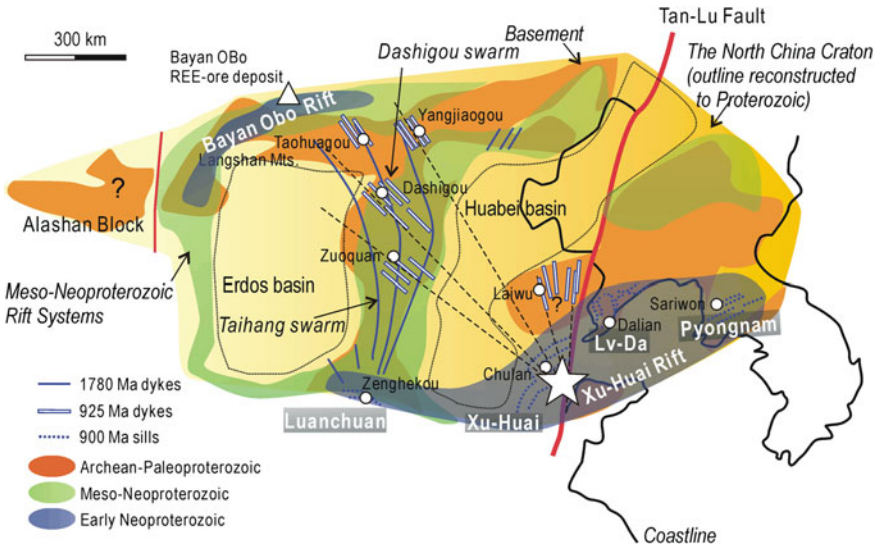


Fig. 10 The relationship of the 925 Ma Dashigou dykes, the 925–900 Ma sills, and the Xu-Huai rift system. After Peng et al. (2011a)

1.4 The 1000–800 Ma Igneous Events

1.4.1 The 925 Ma Dashigou Dyke Swarm

The 925 Ma Dashigou mafic dyke swarm is distributed in the central and a few in the east of North China (Figs. 3, 10 and 11; Peng et al. 2011a). The majority in the central North China covers an area of 200 × 450 km^2. They are typically 10–50 m wide and up to 10–20 km long. Their trends vary from 305°–340° to ~010° from west to east. The rocks comprise gabbro to diabase, unmetamorphosed with a typical assemblage of clinopyroxene and plagioclase, and minor hornblende, K–feldspar, and magnetite, with or without olivine.

1.4.2 The 925–900 Ma Sariwon (Dalian–Chulan–Zenghekou) Sill Swarm

The 925–900 Ma Sariwon sills are distributed along the southeastern margin of the eastern North China Craton, i.e., the Pyongnam Basin (Sariwon, Korea), the Dalian Basin (Liaoning), the Xu-Huai Basin (Chulan), and the Luanchuan Basin (Zenghekou) (Figs. 10 and 12; Peng et al. 2011b; Wang et al. 2011, 2012). The individuals are several meters to 150 m thick and extend for kilometers. The rocks are typical dolerite, metamorphosed up to greenschist facies, and are composed of clinopyroxene and feldspar, superimposed with a metamorphic assemblage of

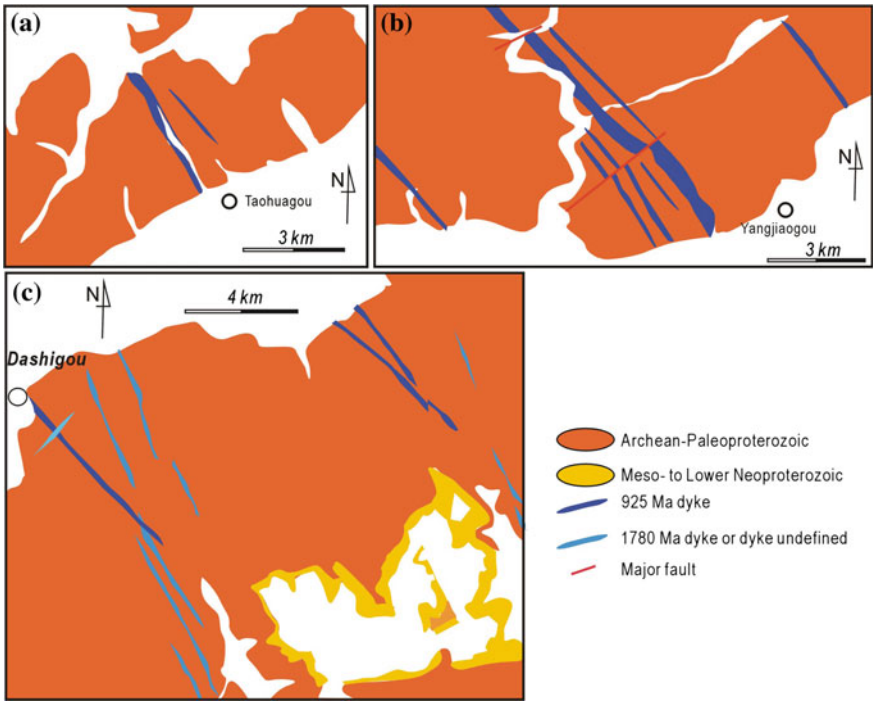


Fig. 11 Representative ~925 Ma dykes in Liangcheng (Taohuagou, **a**), Huai'an (Yangjiaogou, **b**), and Yingxian (Dashigou, **c**). After Peng et al. (2011a). Locations of these maps are shown in Fig. 3

epidote, chlorite, Na-rich plagioclase, and hornblende. They have been slightly deformed. The metamorphism and deformation could have occurred at ca. 400 Ma, resulting from an orogenic process affecting the cratonic margin (Peng et al. 2011b).

Peng et al. (2011a) suggest that these sills are cogenetic with the Dashigou dykes. And as these ~925 Ma dykes are rare in other continents, their global match could potentially suggest a paleogeographic affinity. Based on the geometry reconstruction (Fig. 10) and geological comparison, it is proposed that North China may be paleogeographically neighboring the Congo–São Francisco craton prior to Neoproterozoic (Fig. 6).

1.4.3 The 810 Ma Qianlishan Dyke Swarm

There are tens of ~810 Ma mafic dykes in the Helan and Qianli Mts. (Fig. 3). They are generally several meters wide and within a couple of kilometers long and composed of diabase rocks. They locally cut Mesoproterozoic sediments and unconformably overlain by the Carboniferous strata. More than half of them are

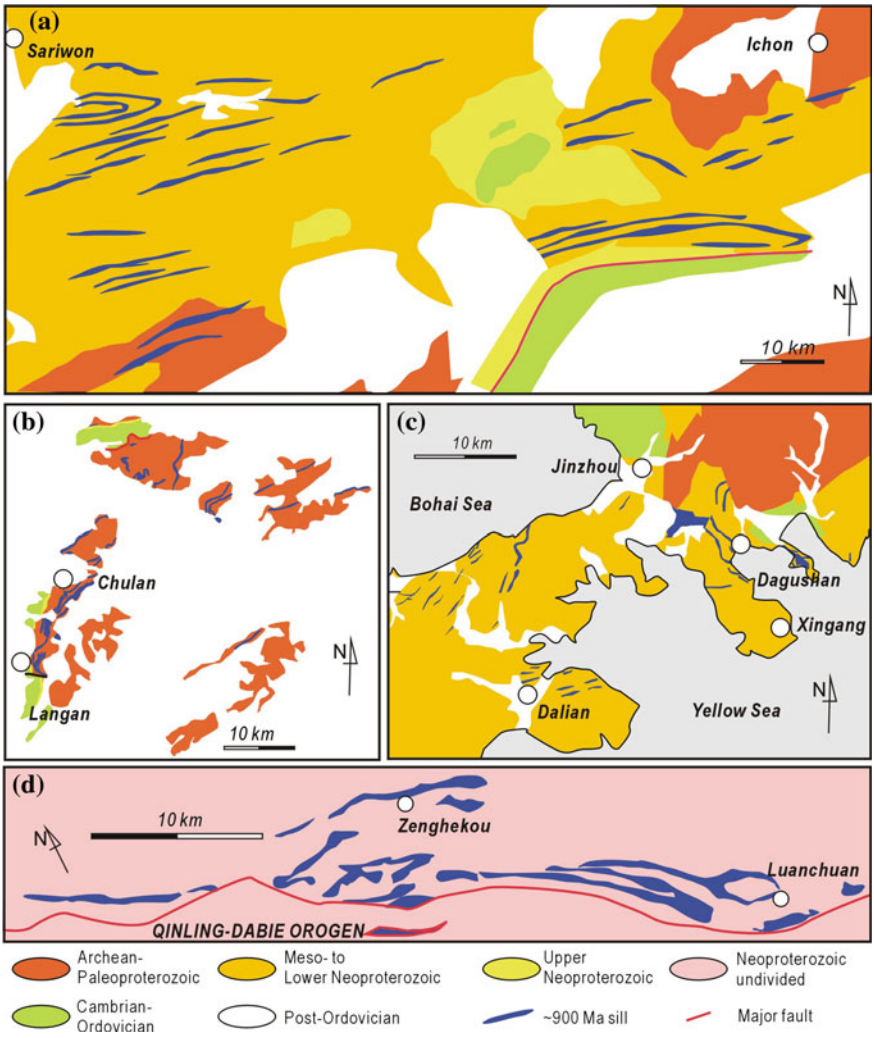


Fig. 12 The representative ~900 Ma sill swarms in the Pyongnam basin (Korea, **a**), the Xu-Huai basin (**b**, Chulan), the Lv-Da basin (**c**, Dalian), and the Luanchuan basin (**d**). After Peng et al. (2011a). Locations of these maps are shown in Fig. 3

NW–trended and the rest is NE-trended. One NE-trended dyke gives an 813 ± 7 Ma baddeleyite $^{207}Pb/^{206}Pb$ age. Peng et al. (2010) reported minor ~810 Ma rhyolitic lavas from the Zhaertai Group in the western Alashan (Alxa) block. Ultramafic intrusions from Jinchuan also have a similar age (Li et al. 2004).

2 Strata and Rift Systems

Figure 13 shows the distribution of the main Late Paleoproterozoic to Neoproterozoic strata in different rift systems. Here in this section, the description of the strata comes from the provincial geology volumes, including Hebei (1991), Inner Mongolia (Neimenggu) (1991), Henan (1989), Shandong (1991), and Liaoning (1989).

The Late Paleoproterozoic to Neoproterozoic rift systems of North China could be summarized as four: the Xiong'er, Yan-Liao, Bayan Obo, and Xu-Huai rift systems (Fig. 13; Peng 2015). Among them, the Xiong'er and Yan-Liao rifts may have evolved from the Late Paleoproterozoic to the Mesoproterozoic, whereas the Xu-Huai rift may be active in the Early Neoproterozoic. The evolution of the Bayan Obo rift system is controversial.

2.1 Strata of the Xiong'er Rift System

The Xiong'er rift system distributes along the southern parts of the eastern North China Craton (Fig. 13). It has three branches with one extended inside the central and two along the southern margin of the craton. It contains the Xiong'er Group, Guandaokou Group, Ruyang (and Luoyu) Group(s), Luanchuan Group, and the Sinian strata of the Huanglianduo, Dongjia, and Luoquan Fms. (Fig. 14). The Xiong'er rift initiated at ~1800 Ma, followed by volcanism mainly at ~1780 Ma

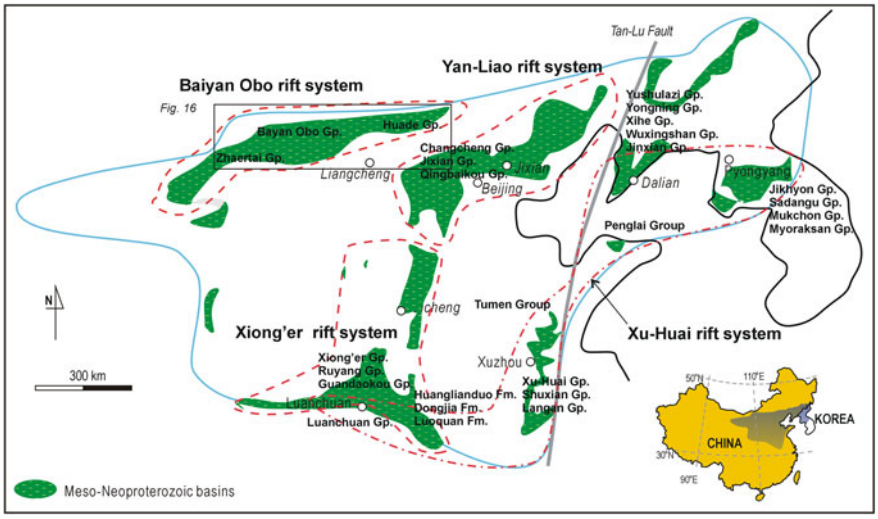


Fig. 13 Distribution of the Late Paleoproterozoic to the Neoproterozoic strata and rift systems in North China. *Gp.* Group; *Fm.* Formation

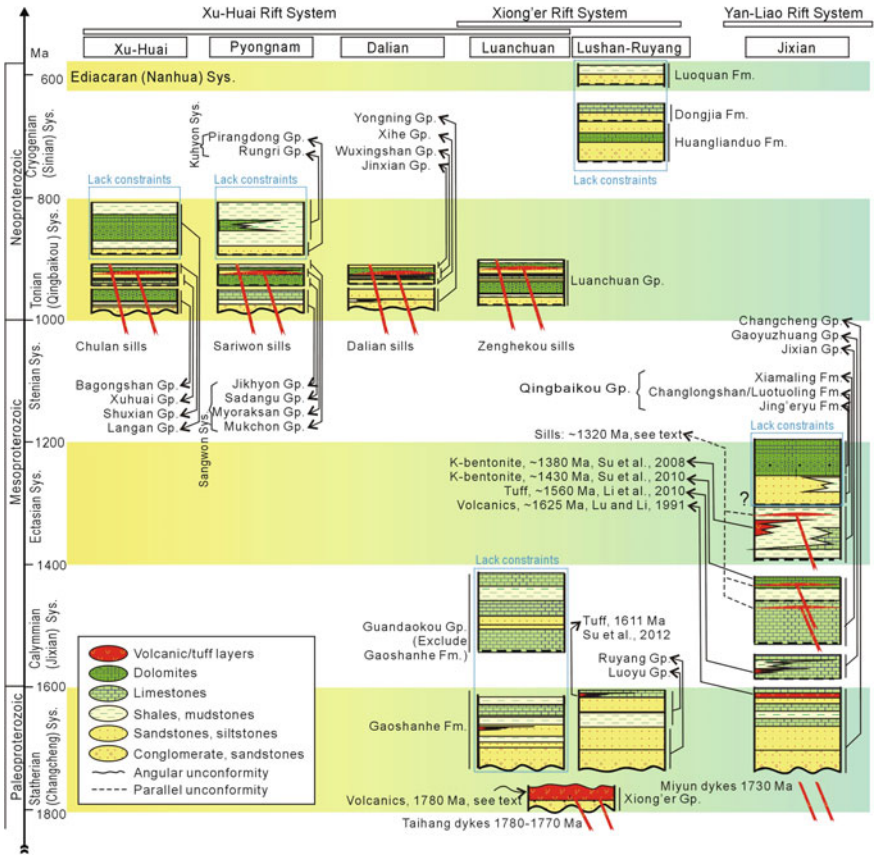


Fig. 14 Representative strata in the Xu-Huai, Pyongnam, Dalian, Luanchuan, Lushan–Ruyang, and Jixian basins of the Xu-Huai, Xiong'er, and Yan-Liao rift systems. After Peng (2015)

(the Xiong'er Group volcanic province) and minor younger events at ~1600 Ma (Su et al. 2012) and ~1400 Ma (Zhao et al. 2009a). The strata are dominantly 1780–1600 Ma clastic sediments (the Ruyang Group and the Luoyu Group) and younger carbonate (the Guandaokou Group) (Fig. 14).

2.1.1 The Xiong'er Group

The Xiong'er Group is distributed in the southern part of the eastern North China Craton (Fig. 13), and it can be subdivided into 4 formations, named Dagushi, Xushan, Jidanping, and Majiahe from bottom to top (Fig. 15a). The Dagushi Fm. is dominated by clastic sediments, but the other three formations are dominated by volcanic rocks (predominantly andesite; Fig. 15b, c). It has been well-constrained that the Dagushi Fm. was deposited after 1800 Ma, the volcanism in the other three

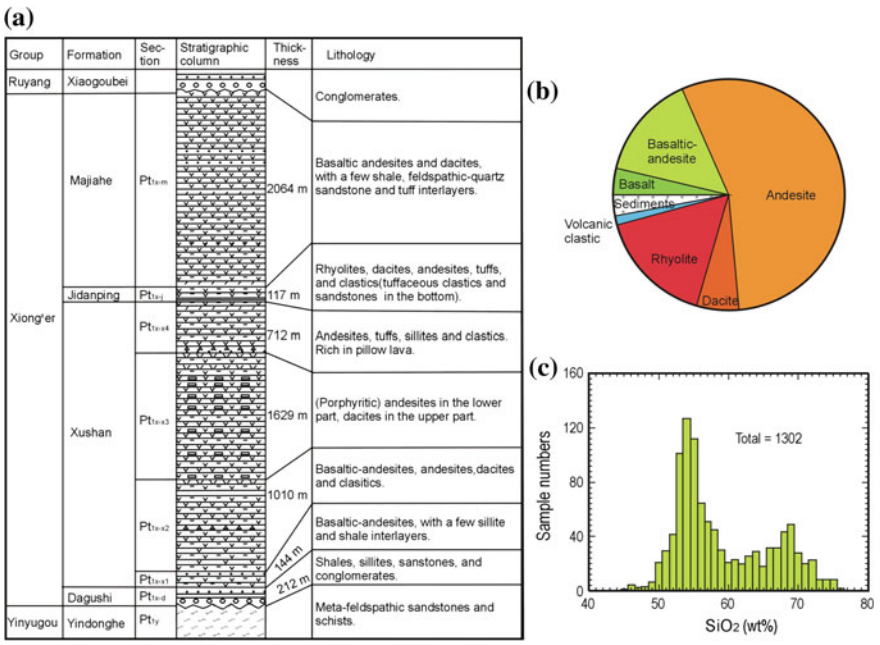


Fig. 15 Strata of the Xiong'er Group (**a**) and the compositions of volcanic rocks (**b**, **c**). After Zhao et al. (2002)

formations is ~1780 Ma (Zhao et al. 2004; He et al. 2009; Cui et al. 2010). It has also been revealed that the uppermost formation of the Majiahe Fm. was intruded by ~1780 Ma dioritic stocks, and thus, the Xiong'er Group volcanism is short-lived (Cui et al. 2010).

The lower part of the Dagushi Fm. comprises of yellowish, yellow-greenish, and amaranthine pebbly feldspathic quartz sandstone; while the upper part is dominated by amaranthine sandstone and shale. The sandstone in this formation is poorly sorted with largely varied composition and thickness. The Dagushi Fm. is 40–289 m thick, and it deposited in a relatively dry and unstable environment from a provenance which was not far away. The Xushan Fm. is composed of andesite, pyroxene andesite, and andesitic basalt, with a few rhyolite and volcaniclastic rock. The volcanic rocks are characterized by plagioclase megacryst and pyroxene. In the lowermost part, there are a few thin feldspathic quartz sandstone and amaranthine shale layers. It is conformably overlain on the Dagushi Fm. or unconformably sitting on the Archean gneisses. The thickness is 2400–3000 m. The Jidanping Fm. is a series of acidic volcanic rocks, including rhyolite, dacite, quartz porphyry, and minor volcaniclastic rocks. Pillow lavas can be found in some places. And there is also lentoid marble. It is conformably lying on the Xushan Fm. and has a thickness

varied from 100 to ~1000 m. The Majiahe Fm. is predominantly andesite, basaltic andesite and pyroxene andesite with minor volcaniclastic rock, sandstone, shale, and limestone layers. It has a thickness of about 2000 m, up to 3910 m in the Xiong'er Mts.

2.1.2 The Ruyang (Ruyang + Luoyu) Group and the Guandaokou Group

The Ruyang Group is limited in the Xiong'er rift (Fig. 13), and it is composed by the Bingmagou (Xiaogoubei), Yunmengshan, Baicaoping, Beidajian, Cuizhuang, Sanjiaotang, and Luoyukou Fms. Sometimes, the Cuizhuang, Sanjiaotang, and Luoyukou Fms. are specially referred as the Luoyu Group. Basically, the Ruyang Group is a slightly metamorphosed series of carbonates and clastic sediments. It is unconformably overlying on the Xiong'er Group or locally on the Archean gneisses; and it is unconformably under the Luoquan and Xinji Fms. The total thickness of this group is about 13,070 m. Among them, the Yunmengshan, Baicaoping, and Beidajian Fms. contain microfossil plants; and the upper part of the Beidajian Fm. has stromatolites.

The Bingmagou Fm. (also called as the Xiaogoubei Fm. in Songshan area) comprises conglomerate, pebbly sandstone, sandstone, sandy shale, and glauconite- and iron-concretion-bearing sandstone. It has a thickness of 880 m. The Yunmengshan Fm. is composed by quartz sandstone and shale, with some iron-ore-bearing conglomerate in the bottom. It is ~276 m thick. The Baicaoping Fm. is mainly composed by red sandy shale with thin layers of quartz sandstone and locally conglomerate and dolomite. It is ~200 m thick. The Beidajian Fm. is dominated by quartz sandstone, feldspathic quartz sandstone and glauconite-bearing quartz sandstone with dolomite on the top. There are also iron-ore layers on the upper part. The thickness is ~198 m. The Cuizhuang Fm. is predominantly shale with minor quartz sandstone. There are oolitic hematite- and siderite-bearing layers in the bottom and middle parts. It is ~213 m in thickness. The Sanjiaotang Fm. is a series of quartz sandstone, with some glauconite-bearing layers in the top part. It has a thickness of 231 m. The Luoyukou Fm. comprises ~146-m-thick carbonates with minor clastic sediment interlayers.

The Guandaokou Group is distributed in the southern parts of the Xiong'er rift (Fig. 13) and is divided into the Gaoshanhe Fm., the Longjiayuan Fm., the Xunjiansi Fm., the Duguan Fm., and the Fengjiawan Fm. It is dominated by a series of clastic rocks and carbonate, rich in microfossil plants and stromatolites. The thickness is varied from 1950 to 5440 m. It is unconformably overlain on the Xiong'er Group.

The ages of the Ruyang and Guandaokou Groups are not well-constrained (Fig. 13), though they were thought to be comparable with the Changcheng Group or the Jixian Group. Recently, Su et al. (2012) discovered a ~1611 Ma tuff layer on the top of the Ruyang (Luoyu) Group, which indicates that it should be the Late Paleoproterozoic in age.

2.2 *Strata of the Yan-Liao Rift System*

The Yan-Liao rift system distributes in the northern parts of the eastern North China Craton (Fig. 13). It contains the Changcheng Group, Jixian Group, and Qingbaikou Group (Fig. 16), which were thought to compose the stratotype section of the Mesoproterozoic to the Early Neoproterozoic in China (Chen et al. 1980). However, recent work suggests that parts of the Qingbaikou Group are older than 1300 Ma (Li et al. 2009; Zhang et al. 2009), and thus, whether there is Neoproterozoic strata in the Yan-Liao rift or not is questionable. In addition, as they

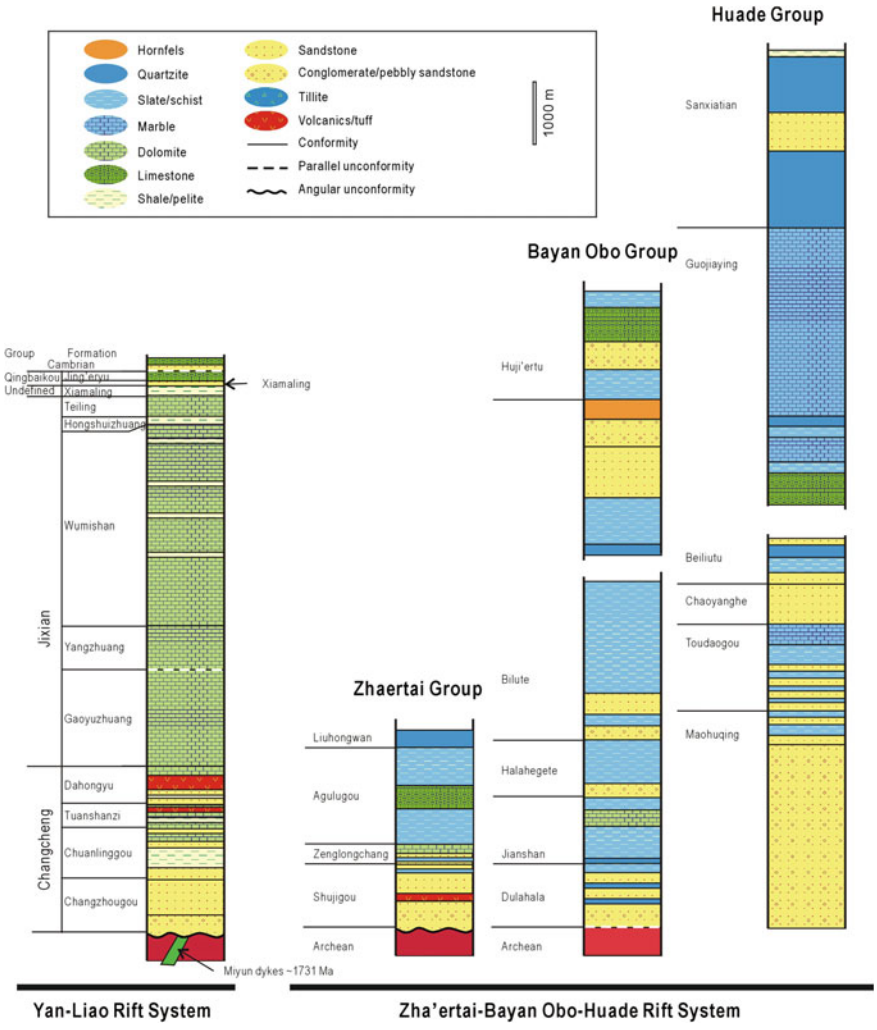


Fig. 16 Strata in the Yan-Liao rift system and the Bayan Obo rift system

were thought to be the cover of the craton (Chen et al. 1980), the lower time limit of the Mesoproterozoic is represented by the initiation of the Changcheng Group at 1800–1700 Ma. However, we think that the cratonization of the eastern North China Craton was completed at ~2500 Ma and the Changcheng–Jixian–Qingbaikou sediments were intra-continental rift deposits rather than covers (Peng 2015).

The Yan-Liao rift initiated at ~1730 Ma (Peng et al. 2012) and contains magmatism and volcanism mainly at 1730–1680, ~1620 and ~1320 Ma (Rämö et al. 1995; Yang et al. 2005; Zhang et al. 2007, 2009, 2012a; Li et al. 2009; Zhao et al. 2009b; Jiang et al. 2011; Wang et al. 2013). It is a long-lived rift system (Zhai et al. 2015).

2.2.1 The Changcheng Group

The Changcheng Group is the initial deposition of the Yan-Liao rift system, and it comprises the Changzhougou, Chuanlinggou, Tuanshanzi, and Dahongyu Fms. from bottom to top (Figs. 14 and 16). The Changzhougou Fm. is unconformably sitting on the crystallized basement and is composed by conglomerate, pebbly sandstone, siltstone, and shales, with locally argillaceous dolomite and stromatolites. The Chuanlinggou Fm. is dominated by black shales or sandy shales, with minor siltstone and dolomite. In the west of the Yan-Liao rift (Xuanhua–Chicheng area), there are so-called Xuanlong-type iron deposits in the sandstone. The thickness of the Chuanlinggou Fm. varies from 10 to 1000 m, and in the middle–upper parts, there are some microfossil plants, e.g., Margominuscula and Dictyosphaera. The Tuanshanzi Fm. is dominated by thick dolomite with minor sandy shale, sandy dolomite, and argillaceous dolomite. The thickness is about ten to several hundred meters. The Dahongyu Fm. is composed by sandstone and feldspathic sandstone with minor potassium-rich shales in the middle–lower parts, and dolomite in the upper part. There are also potassium-rich volcanic layers and volcaniclastic layers in this formation. Meng et al. (2011) suggest that the Changcheng Group was deposited in rift basins that experienced strong subsidence in association with volcanism, and the unconformity above the Changcheng Group may indicate a breakup event.

The deposition age of the Changcheng Group has long been debated, though the age of volcanic layers in the Dahongyu Fm. is well-constrained to be at ~1625 Ma (Lu et al. 2008; Gao et al. 2008a). Wang et al. (1995) revealed that the maximum deposition age of the Changcheng Group is about 1700 Ma based on the Ar–Ar age dating on basement rocks. Wan et al. (2003) suggested that the maximum deposition age is ~1800 Ma based on the ages of detrital zircon. Li et al. (1995a, b) and Gao et al. (2009)'s ages from volcanic rock or diabase dyke suggest that the initial deposition age of the Changcheng Group should be older than 1683–1638 Ma.

Recently, Li et al. (2011, 2013)'s work from a granitic vein, which was seemly cut the Changcheng Group, gave an age of 1673 ± 10 Ma. If this relationship is verified, it suggests that the Changcheng Group is younger than 1673 Ma.

Nevertheless, Peng et al. (2012) have dated a ~40-m-wide ~1730 Ma dyke that has covered by basal conglomerate of the Changcheng Group, which constrains the initiation age to be younger than ~1730 Ma.

2.2.2 The Jixian Group

The Jixian Group is dominated by carbonate, and it comprises five formations, the Gaoyuzhuang, Yangzhuang, Wumishan, Hongshuizhuang, and Tieling from bottom to top (Figs. 14 and 16).

The Gaoyuzhuang Fm. is composed by thick dolomite and chert-bearing argillaceous dolomite. There are plenty of stromatolites in the lower part. The thickness of this formation is up to 2000 m. The Yangzhuang Fm. is dominated by amaranth- and white-colored dolomites with locally sandstone or conglomerate. It is conformably or deceptive conformably contacted with the Gaoyuzhuang Fm. and has a thickness of several ten meters to 1000 m. The Wumishan Fm. is also dominated by dolomite but generally gray in color. The Hongshuizhuang Fm. is composed by black to green illite-bearing shales, with minor thin dolomite in the lower part and thick sandstone in the upper part. It has several ten meters to more than 100 m. The Tieling Fm. contains mainly dolomite and stromatolites rich limestone and dolomite, with some shale. The thickness is 200–300 m.

It has long been thought that the Jixian Group deposited between 1600–1000 Ma; however, recent discovery of ~1350 Ma sills from the Wumishan Fm. reveals that this group ended earlier (Zhang et al. 2009). In addition, Li et al. (2010) got 1559–1560 Ma ages from tuff layers in the Gaoyuzhuang Fm.; Su et al. (2010) obtained ~1437 Ma age from potassium bentonite in the Tieling Fm. These works suggest the deposition age of the Jixian Group to be older than ~1400 Ma.

2.2.3 The Qingbaikou Group

The Qingbaikou Group comprises three formations, i.e., the Xiamaling, Changlongshan (or Luotuoling), and Jing'eryu Fms. (Figs. 14 and 16). The Xiamaling Fm. is dominated by multicolor sandy shale, with minor siltstone and marlstone. There is a parallel unconformity to micro-angle unconformity between the Xiamaling Fm. and the Tieling Fm. The thickness is about one hundred to several hundred meters. The Changlongshan Fm. is made of pebbly feldspathic sandstone, quartz sandstone, glauconite-bearing sandstone, and shale. It is parallel unconformably contact with the Xiamaling Fm. and is locally overriding the Wumishan Fm. The thickness is about 100 m. The Jing'eryu Fm. (also called as the Luotuoling Fm.) contains dolomitic limestone, with some glauconite-bearing feldspathic sandstone or fine conglomerate. It is about several 10 m to >100 m thick.

It has long been suggested that the Qingbaikou Group belongs to the Early Neoproterozoic in age (e.g., Chen et al. 1980). However, two suites of K-bentonite

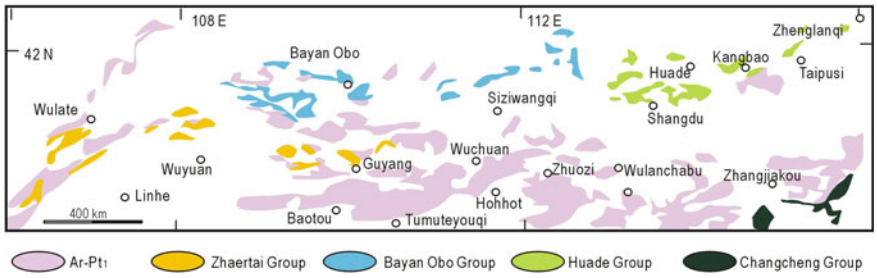


Fig. 17 Distribution of the Zhaertai–Bayan Obo rift strata

beds were discovered in the Tieling and Xiamaling Formations, and they yielded U–Pb zircon SHRIMP ages of ~1440 Ma (Su et al. 2010) and 1380–1366 Ma (Gao et al. 2007, 2008a, b; Su et al. 2008, 2010), respectively. These tuff layers probably originated from the volcanism events around the Yan-Liao rift. Li et al. (2009) and Zhang et al. (2009) discovered some ~1320 Ma sills from the Xiamaling Fm. Thus, the Xiamaling Fm. could be actually 1400–1200 Ma in age; however, the age of the Jing'eryu and Changlongshan Fms. is not well-constrained (Figs. 14 and 16).

2.3 Strata of the Bayan Obo Rift System

The Bayan Obo rift distributes in the central Inner Mongolia (Neimenggu) province (Fig. 13). It contains the Zhaertai, Bayan Obo, and Huade Groups; however, there are no direct contacts between the three groups, or with the Changcheng Group in the Yan-Liao rift (Fig. 17). It is in debating whether the four groups have similar ages. The Bayan Obo rift probably has magmatic events at ~1300–1400 Ma (Fan et al. 2006; Le Bas et al. 2007; Yang et al. 2011; Zhang et al. 2012a, b) and ~810 Ma (Peng et al. 2010; Peng 2015).

2.3.1 The Zhaertai Group

The Zhaertai Group is unconformably sitting on the Archean basement and is composed by the Shujigou, Zenglongchang, Agulugou, and Liuhongwan Fms. (Fig. 16). The Shujigou Fm. comprises meta-conglomerate, meta-feldspathic quartz sandstone and quartzite; the Zenglongchang Fm. is composed of dolomitic slate, stromatolite-bearing crystalline limestone and dolomite; the Agulugou Fm. is dominated by carbonatic slate; and the Liuhongwan Fm. is prominently quartzite. There are minor alkaline basaltic volcanic layers in the top of the Shujigou Fm. (Wang et al. 1992).

Li et al. (2007a) dated a mafic volcanic layer in the Shujigou Fm., and it gives a ~1743 Ma age. In the western parts of the Bayan Obo rift in Langshan area, Peng et al. (2010) have obtained 817–805 Ma acidic lavas, which may indicate some Neoproterozoic strata in this area.

2.3.2 The Bayan Obo Group

The Bayan Obo Group distributes east to the Zhaertai Group (Fig. 17) and is dominated by clastic sediments and clay, and it can be divided into six formations (Fig. 16). The bottom formation is the Dulahala Fm., which comprises quartzite, quartz granule conglomerate, and pebbly feldspathic quartz sandstone. The Jianshan, Halahuogete, and Bilute Fms. compose mainly of pelite and turbidite. The Baiyinbaolage and Hujiertu Fms. comprise clastic sediment and carbonate, with minor volcanic rocks. The Bayan Obo Group is the host of the world-class REE-Nb-Fe-deposit (mainly within the Dulahala–Bilute Fms.: Fan et al. 2006; Le Bas et al. 2007; Yang et al. 2011).

Zhong et al. (2015)'s detrital zircon ages constrained a Late Paleoproterozoic to Mesoproterozoic age for the Bayan Obo Group. The basalt from the lower parts of the Bayan Obo Group gave U–Pb zircon age of ~1730 Ma (Lu et al. 2002), whereas the carbonatite from the Dulahala Fm. gave zircon U–Pb ages of ~1300–1400 Ma (Fan et al. 2006; Yang et al. 2011).

2.3.3 The Huade Group

The Huade Group distributes east to the Bayan Obo Group (Fig. 17) and is characterized by a series of slightly metamorphosed sandstone, graywacke, feldspathic sandstone, pelite, phyllite, schist, slate, marble and limestone, up to ~10,000 m in thickness. In Shangdu area, the lower parts of the Huade Group are comparable with the 6 formations of the Bayan Obo Group. In addition, there is another formation on the top, named the Ayadeng Fm., which is dominated by crystalline limestone with minor sandy slate. The Huade Group in Zhangbei–Kangbao areas is divided into another 6 formations, named the Maohuqing, Toudaogou, Chaoyanghe, and Beiliutu Fms. in the Zhangbei area, and the Gejiaying and Sanxiatian Fms. in Kangbao area. There is no contact between the Huade Group in the two areas. The Maohuqing Fm. is dominated by metamorphosed thick pebbly feldspathic sandstone with minor quartz sandstone, carbon slate, and siltstone. The Toudaogou Fm. composes of metamorphosed pebbly quartz sandstone and quartz sandstone in the lower part, siltstone and carbon slate in the middle part, and carbonate in the upper part. The Chaoyanghe Fm. is dominated by quartz schist and two-mica schist with carbon phyllite and garnet slate. The Beiliutu Fm. is composed by medium- to fine-grained quartz sandstone in the lower part and andalusite-bearing quartzite, meta-feldspathic quartzite and sericite phyllite. The Gejiaying Fm. is a series of calc-silicate rock, metamorphosed carbonate, pelite, and

clastic sediments. The Sanxiatian Fm. is a series of metamorphosed clastic rocks, including meta-quartz sandstone, meta-feldspathic quartz sandstone, and two-mica schist.

It has long been thought that the Huade Group was deposited in the Mesoproterozoic. Zhang et al. (2012a) reported ~1331–1313 Ma granites which have intruded the Toudaogou–Beiliutu Fms. Hu et al. (2009)'s detrital zircon ages constrained the maximum deposit age of the Huade Group to be 1800–1600 Ma. Chen (1993), and Tan and Shi (2000) have claimed Cambrian fossils in some strata. On the contrary, Zheng et al. (2004) and Li et al. (2005) proposed Paleoproterozoic deposit ages based also on the detrital zircon ages.

2.4 Strata of the Xu-Huai Rift System

The Xu-Huai rift system lies on the eastern parts of North China and partly in North Korea. It contains strata of the Xu-Huai, Langan, Tumen, Yongning, Xihe, Wuxingshan, Jinxian, Jikhyon, Sadangu, Mukchon, Myoraksan, and Penglai Groups (Fig. 14). The Xu-Huai rift system mainly evolved in the Early Neoproterozoic, characterized by the development of the 925–900 Ma sills (Peng et al. 2011a, b).

2.4.1 The Xuhuai, Shuxian, and Langan Groups

The strata in the Xuzhou, Huaibei, and adjacent areas are divided into three groups—the Xuhuai, Shuxian, and Langan Groups (Figs. 13 and 14). The Xuhuai Group has 9 formations, i.e., the Lanling, Xinxing, Jushan, Jiayuan, Zhaoxu, Niyuan, Jiudingshan, Zhangqu, and Weiji Fms. from bottom to top. The first three formations are made of mainly conglomerate, quartz sandstone, siltstone, and shales, whereas the rest six formations are made of sandy marlstone, limestone, and dolomite. Locally, the bottom formations (the Lanling and Xinxing Fms.) of the Xuhuai Group are referred as the Bagongshan Group and are subdivided into the Xiaodian, Wushan (Lanling), and Liulaobei (Xinxing) Fms. On the other hand, the Xuhuai Group is included into the Shuxian Group in some other regional maps. The Shuxian Group (the Shijia and Wangshan Fms.) and Langan Group (the Jinshanzhai and Gouhou Fms.) comprise shale, quartz sandstone, siltstone, marlstone, limestone, and dolomite. The Xuhuai Group is unconformably sitting on the Archean basement; and the three groups are unconformably covered by the Cambrian strata of the area.

These strata are thought to be the Neoproterozoic in age (Cao 2000; Xue et al. 2001); and some thought the three groups could have overlapped deposition ages (Qiao et al. 1996; Zhang, 2001). Recently, Wang et al. (2012) reported ~900 Ma sills from the Xuhuai Group, which supports an Early Neoproterozoic age for this group. However, the sedimentation age of the Shuxian and Langan Groups is not well-constrained.

2.4.2 The Tumen Group and the Penglai Group

The Tumen Group is mainly distributed in west Shandong province (Fig. 13), and it can be subdivided into five formations, i.e., the Heishanguan, Erqingshan, Tongjiazhuang, Fulaishan, and Shiwangzhuang Fms. The Tumen Group is dominated by sandstone, shale, and limestone, and it is unconformably sitting on the Archean gneisses and is parallel unconformably covered by the Cambrian strata (the Changqing Group). The Heishanguan Fm. is composed of glauconite-bearing quartz sandstone and fuchsia shale. The Erqingshan Fm. is parallel unconformably sitting on the Heishanguan Fm. and is made of glauconite-bearing quartz sandstone, thin limestone, calcic shale, and marlstone. The Tongjiazhuang Fm. is parallel unconformably sitting on the Erqingshan Fm. and is dominated by dark shale, with some quartz sandstone, algal limestone, and marlstone. In some localities, the Tongjiazhuang Fm. is sitting on the Archean basement. The Fulaishan Fm. is dominated by siltstone with minor shale and sandy marlstone, and it is conformably sitting on the Tongjiazhuang Fm. The Shiwangzhuang Fm. is composed of sandy limestone, limestone, and dolomite, with minor shale. It is conformably sitting on the Fulaishan Fm. In the provincial geological report (Shandong 1991), the Tumen Group is thought to be the Neoproterozoic in age. There are some ~910 Ma Rb–Sr isochron ages from limestone (Zhou and Hu 1998). Hu et al. (2012) suggest that the maximum deposit age is 1200–1000 Ma based on the ages from detrital zircons.

The Penglai Group is distributed in Qixia–Penglai area in eastern Shandong province. It is a series of low-grade metamorphosed sediments, including phyllite, slate, quartzite, crystalline limestone, and marble. The deposition can be divided into 4 formations—the Baoshankou, Fuzikuang, Nanzhuang, and Xiangkuang Fms. The Baoshankou Fm. is unconformably sitting on the Paleoproterozoic Fenzishan Group and is composed by phyllite, slate, marble, and phyllitic slate. The Fuzikuang Fm. is composed by quartzite, silicic slate, and phyllite. The Nanzhuang Fm. is composed by slate, phyllitic slate, marble, calcic slate, and marlstone. The Xiangkuang Fm. is composed by marlstone with minor limestone. Zhou et al. (2008) suggest that the maximum deposit age to be 2000–1800 Ma, whereas Li et al. (2007b) suggest that it is younger than 1200 Ma. It also needs to be mentioned that Zhou et al. (2008) think the provenance to be from the North China Craton, whereas Li et al. (2007b) favor a provenance from the South China craton.

2.4.3 The Yushulazi, Yongning, Xihe, Wuxingshan, and Jinxian Groups

The Yushulazi, Yongning, Xihe, Wuxingshan, and Jinxian Groups are mainly distributed in Liaodong Peninsula (Fig. 13). Specifically, the first four groups are mainly distributed in Fuzhou area, whereas the Jinxian Group is mainly outcropped in Dalian area. The Yushulazi Group is parallel unconformably sitting on the Paleoproterozoic Liaohe Group and is composed mainly by quartzite with phyllite, sericite quartz schist, and meta-sandstone. The Yongning Group/Formation is

parallel unconformably sitting on the Yushulazi Group and is composed by feldspathic quartz sandstone and feldspathic sandstone, with minor conglomerate and pebbly sandstone. The Xihe Group is parallel unconformably sitting on the Yongning Group and comprises the Diaoyutai, Nanfen, and Qiaotou Fms. The Diaoyutai Fm. is composed by fine quartz sandstone, pebbly quartz sandstone, siltstone, and shale. The Nanfen Fm. is dominated by dark sandy shale with minor siltstone in the lower part, crystalline limestone, sandy micrite with minor calcic shale, sandy shale, and calcic sandy shale with minor quartz sandstone in the upper part. The Qiaotou Fm. is composed by quartz sandstone, feldspathic quartz sandstone, with minor glauconite-bearing quartz sandstone and sandy shale.

The Wuxingshan Group comprises the Changlingzi, Nanguanling, and Ganjinzi Fms. from bottom to top. The Changlingzi Fm. is dominated by shale, sandy shale, sandstone, glauconite-bearing quartz sandstone, siltstone, and micrite. The Nanguanling Fm. is dominated by clastic limestone with stromatolite limestone. The Ganjinzi Fm. is composed by stromatolite dolomite and clastic dolomite. The Jinxian Group includes the Yingchengzi, Shisanlitai, Majiatun, Cuijiatun, Xingmincun, and Dalinzi Fms. The Yingchengzi Fm. is composed by micrite and stromatolite limestone. The Shisanlitai Fm. is composed by micrite, oomicrite, stromatolite limestone, and yellow-greenish to purple shales. The Majiatun Fm. is composed of micrite, stromatolite limestone, and calcic shale. The Cuijiatun Fm. is dominated by sandy shale, siltstone, and stromatolite limestone. The Xingmincun Fm. is dominated by siltstone, sandy shale, quartz sandstone, micrite, and calcic shale. The Dalinzi Fm. is composed by black shale, quartz sandstone, micrite, and dolomite, with minor sandy shale, iron–manganese-bearing mudstone, and limestone.

Liaoning (1989) suggests that the Yushulazi Group belongs to the Paleoproterozoic, the Yongning Group and the Diaoyutai and Nanfen Fms. of the Xihe Group belong to the Early Neoproterozoic, and the Qiaotou Fm. of the Xihe Group, the Wuxingshan Group and the Jinxian Group belong to the Late Neoproterozoic. However, some recent works reveal detrital zircon ages of $\sim$1100 Ma from the Yushulazi and Xihe Group (Luo et al. 2006); thus, they could belong to the Early Neoproterozoic (Fig. 14).

2.4.4 The Luanchuan Group and the Huanglianduo–Dongjia–Luoquan Formations

The Luanchuan Group is distributed in the southern edge of the eastern North China Craton (Fig. 13), and it comprises the Baishugou, Sanchuan, Nannihu, and Meiyaogou Fms. It is unconformably overlain on the Guandaokou Group, but unconformably covered by the Sinian or the Cambrian strata (Fig. 14). The thickness is 1700–3100 m. The Baishugou Fm. is composed by carbon sericite phyllite, sericite quartz schist, and feldspathic quartzite, with carbon schist in the lower part, thick fine-grained K-feldspar-bearing quartzite in the middle part, and black slaty carbon phyllite, thin carbon sericite quartzite and carbon marble in the

upper part. The Sanchuan Fm. contains pebbly quartz sandstone, sandstone, siltstone, marble, and sericite schist. It is 320–452 m thick. The Nannihu Fm. is 309–509 m thick and is made of fine-grained quartzite, two-mica schist, carbon sericite schist, and calcic two-mica schist, with minor quartzite and marble. The Meiyaogou Fm. is 855–1154 m thick and comprises meta-siltstone, mica schist, marble, stromatolite- or bone coal-bearing marble, quartzite, and magnetite mica schist.

The Huanglianduo, Dongjia and Luoquan Fms. distribute east to the Luanchuan Group (Fig. 13). The Huanglianduo Fm. composes of conglomerate, pebbly sandstone, sandstone, silicic banded dolomite (contain stromatolites), and banded chert. It is about 252–449 m thick. The Dongjia Fm. composes conglomerate, pebbly sandstone, feldspathic quartz sandstone, quartz sandstone, siltstone, and shales, with minor glauconite-bearing sandstone, dolomite, and micrite. This formation varies from 28 to 353 m. The Luoquan Fm. composes of mudstone, dolomitic tillite (locally changed to dolomite), sandy tillite, shale, slate, and siltstone, with phosphate nodule. It is about 100 m thick. These are thought to be the Late Neoproterozoic strata but with little constraints (Henan 1989).

2.4.5 The Jikhyon, Sadangu, Mukchon, and Myoraksan Groups

In the Pyongnam basin in North Korea, there is a series of 8000–1000-m-thick greenschist facies sediments. The North Korea geologists divided it into two systems, the Sangwon System and the Kuhyon System (Paek et al. 1993). The Sangwon System is composed by the Jikhyon, Sadangu, Mukchon, and Myoraksan Groups, while the Kuhyon System composes of the Pirangdong and Rungri Groups. The Jikhyon Group is subdivided into the Jangbong, Obongri, Jangsusan, and Ansimryong Fms. and is made of mainly conglomerate, quartz sandstone, schist, and phyllite. The Sadangu Group is subdivided into the Unjoksan, Tokjaesan, and Chongsokturi Fms. and is dominated by stromatolite limestone and dolomite. The Mukchon Group is subdivided into the Solhwasan, Okhyonri, and Mukchon Fms. and is dominated by quartz sandstone, phyllite, and micrite. The Myoraksan Group is composed of limestone, dolomite, and sandy phyllite. The Kuhyon System is unconformably sitting on the Sangwon System. The Pirangdong Group of the Kuhyon System is composed by conglomerate, schist, dolomite, pebbly limestone, and phyllite, whereas the Rungri Group of this system is dominated by pebbly phyllite, phyllite, and minor siltstone.

Paek et al. (1993) have suggested that the Jikhyon and Sadangu Groups are Mesoproterozoic in age, whereas the Mukchon and Myoraksan Groups should belong to Neoproterozoic strata. Hu et al. (2012) reported detrital zircon ages which indicate that the Sangwon System could be initiated at the Late Mesoproterozoic to the Early Neoproterozoic. Peng et al. (2011b) have obtained $\sim$900 Ma sills, which have been metamorphosed at $\sim$400 Ma in the Kuhyon System and have suggested the Sangwon and Kuhyon Systems to be the Early Neoproterozoic strata (Fig. 14).

3 Summary: A Prolonged Stepwise Rifting Lasting for Ten Billion Years

Zhai et al. (2015) suggest that the Late Paleoproterozoic to Neoproterozoic sedimentation and rifting in North China are featured as the Earth's 'middle age' by a long-term continuous stable platform or para-platform tectonic setting without any record of the Grenville orogenic event. And it is possible that the Earth's 'middle age' represents a particular tectonic evolution period, during which the Earth had a stable lithosphere with underlying hot mantle that resulted in multistage magmatism and rifting from the Late Paleoproterozoic to the Neoproterozoic.

Although the Proterozoic rifting event in North China is prolonged, it is stepwise as the magmatic events and the strata can be divided into different stages.

Stage 1 (1800–1730 Ma, Early Statherian/Changcheng System): It is represented by the Taihang dykes (1780–1770 Ma), the Miyun dykes (~1730 Ma), and the strata of the Xiong'er Group with volcanism at ~1780 Ma in the Xiong'er rift system. It is dominated by volcanism with a little clastic sedimentation (conglomerate, sandstone, and shale). It is likely in an intra-continental environment.
Stage 2 (1730/1710–1600 Ma, Late Statherian/Changcheng System): It is represented by the Damiao–Shachang anorthosite–rapakivi granite–dyke complexes (1710–1680 Ma), the Laiwu dykes (~1680 Ma), the Taishan dykes (~1620 Ma), and the strata of the Changcheng Group in the Yan-Liao rift, the Ruyang (Ruyang + Luoyu) Group in the Xiong'er rift, probably the Zhaertai Group, lower parts of the Bayan Obo Group, and the Huade Group in the Bayan Obo rift, with the ~1620 Ma Dahongyu volcanic rocks. The strata are dominated by clastic rocks (conglomerate, sandstone, and shale) with a little limestone. There were a few volcanic rocks evolved in the end of this period.
Stage 3 (1600–1400 Ma, the Calymmian/Jixian System): It is represented by the strata of the Jixian Group in the Yan-Liao rift, the Guandaokou Group in the Xiong'er rift, and probably upper parts of the Bayan Obo Group and the Huade Group, with little volcanism and magmatism. The sediments are dominated by the dolomites with a little clastic sedimentation.
Stage 4 (1400–1200 Ma, the Ectasian System): It is represented by the ~1320 Ma dykes/sills/granites, the ~1230 Ma Licheng dyke swarm, and the strata of the Qingbaikou Group in the Yan-Liao rift. The sedimentation is dominated by clastic rocks (sandstone, shale, and siltstone) with a little carbonates (marlstone and limestone).
Stage 5 (1200–1000 Ma, the Stenian System): It is not certain yet if there were any magmatism and deposition during this period. It is probably a period of 'quiet' time with little geological record as from the data available.
Stage 6 (1000–800 Ma, the Tonian System): It is represented by the Dashigou dyke swarm (~925 Ma), the Sariwon (Dalian–Chulan–Zenghekou) sills, the Qianlishan dyke swarm (~810 Ma), and the Bagongshan/Xuhuai/Shuxian, Langan, Jikhyon,

Sadangu, Mukchon, Yongning, Xihe, Wuxingshan, Jinxian, and Luanchuan Groups in the Xu-Huai rift. The sedimentation is dominated by clastic rocks and carbonates. Stage 7 (800–541 Ma, the Cryogenian–Ediacaran/Nanhua–Sinian System): It is uncertain yet if there were any igneous events or sedimentation during this period. Some formations, e.g., the Huanglianduo, Dongjia, and Luoquan Fms. in Henan province thought to be deposited during this time period.

The rifting center was in the Xiong'er rift (1780–1730 Ma), and it then moved to the Yan-Liao rift, which was prolonged and lasted till ~1200 Ma. Then in the Early Neoproterozoic, the rifting was mainly in the Xu-Huai rift (1000–800 Ma). The evolution of the Bayan Obo rift system is likely similar with the Yan-Liao rift, but with uncertainty. This means that there was a stepwise and prolonged rifting lasting 1000 Ma in North China, with the rifting centers shifted from the south (the Xiong'er rift, 1780–1730 Ma) to the north (the Yan-Liao rift, 1730–1200 Ma) and to the southeast (the Xu-Huai rift, 1000–800 Ma).

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