Chapter 2
Geological Background

Abstract The North China Craton is a general term referred to the Chinese part of the Sino-Korea Craton, and it consists of Archean to Paleoproterozoic metamorphosed basement overlain by Mesoproterozoic to Cenozoic unmetamorphosed cover. The Precambrian basement of the North China Craton can be subdivided into the Eastern Block, the Western Block, and the Trans-North China Orogen. Details of the regional geology are reviewed in this chapter.

Keywords North China Craton · Precambrian basement

2.1 Introduction

The North China Craton is a general term referred to the Chinese part of the Sino-Korea Craton, occupying ~1.5 million km^2 in most of northern China, the southern part of northeastern China, Inner Mongolia, the Bohai Sea, and the northern part of the Yellow Sea (Fig. 2.1; Zhao et al. 2005). It is roughly triangle in shape and bounded by faults and younger orogenic belts, with the Late Paleozoic Central Asian Orogenic Belt to the north, the Early Paleozoic Qilianshan Orogen to the southwest, the Mesozoic Qinling-Dabie Orogenic Belt to the south, and the Mesozoic Su-Lu ultrahigh-pressure metamorphic belt to the southeast (Fig. 2.1; Zhao et al. 2005). The craton consists of Archean to Paleoproterozoic metamorphosed basement overlain by Mesoproterozoic to Cenozoic unmetamorphosed cover. The Eoarchean to Mesoarchean basement rocks with ages ranging from 3.85 to 2.8 Ga have only been reported from local places, such as the Anshan–Benxi area (Liu et al. 1992; Song et al. 1996), and they are sparsely exposed as enclaves, boudins and sheets within the widespread Neoarchean tonalitic–trondhjemitic–granodioritic (TTG) gneisses and granites (Wu et al. 1991). The petrographic evidence for Eoarchean to Mesoarchean metamorphic events has been completely obliterated by the widespread and intense reworking during Neoarchean tectonothermal events at ca. 2.5 Ga (Zhao et al. 2001, 2005, 2012 and reference wherein). Comparatively, Neoarchean basement rocks are

M. Wu, *Ages, Geochemistry and Metamorphism of Neoarchean Basement in Shandong Province*, Springer Theses, DOI 10.1007/978-3-662-45343-8_2

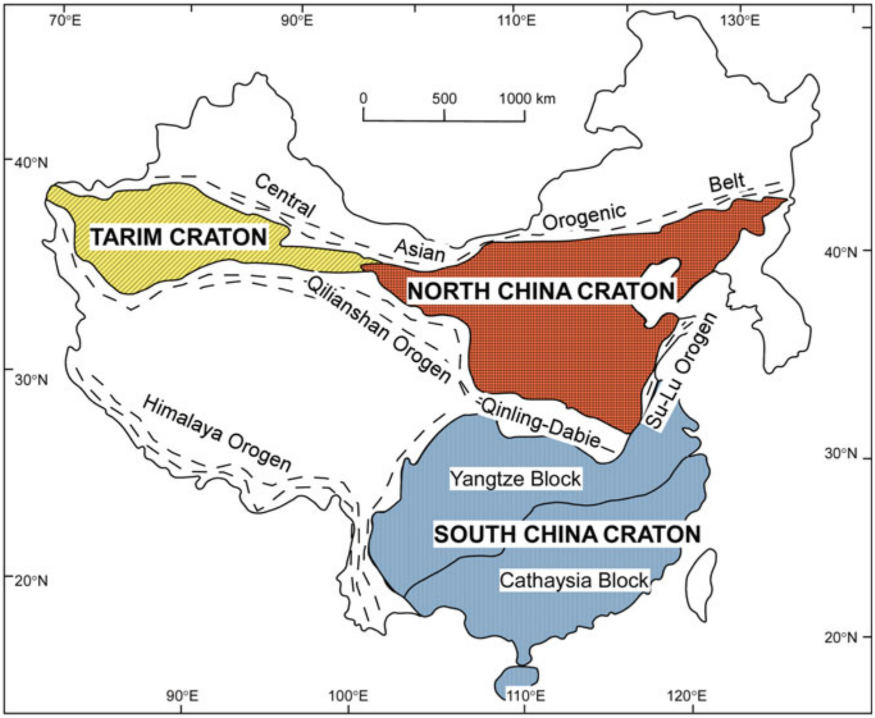

Fig. 2.1 Schematic tectonic map of China showing the major Precambrian blocks and Late Neoproterozoic and Paleozoic orogenic belts (after Zhao et al. 2000a)

widespread over the NCC and are composed of 2.6–2.5 Ga TTG gneisses, ~2.5 Ga granites and minor rafts of supracrustal rocks (Fig. 2.2), experiencing polyphase deformation and greenschist to granulite facies regional metamorphism at ca. 2.5 Ga (Cui et al. 1991; He et al. 1991; Jahn and Zhang 1984; Kröner et al. 1998; Liu et al. 1985; Shen et al. 1987).

As mentioned in Chap. 1, major advancements have been achieved in understanding the Neoarchean to Paleoproterozoic evolution of the NCC following recognition of three Paleoproterozoic tectonic belts, namely the Trans-North China Orogen, Khondalite Belt, and Jiao-Liao-Ji Belt (Fig. 2.2; e.g., Zhao et al. 1998, 2001, 2005, 2012), of which the NS-trending Trans-North China Orogen (TNCO) divides the NCC into two discrete blocks, named the Eastern and Western Blocks (Fig. 2.2; e.g., Zhao et al. 1998, 2001, 2005, 2012). The EW-trending Khondalite Belt divides the Western Block into the Yinshan Block in the north and the Ordos Block in the south, whereas the Jiao-Liao-Ji Belt separates the Eastern Block into the Nangrim and Longgang Blocks (Zhao and Zhai 2013; Zhao et al. 2001, 2005, 2012, and references therein). An extensive overview of the lithological, geochemical, structural, metamorphic, and geochronological differences between these blocks and Paleoproterozoic tectonic belts has been given by Zhao et al. (2001,

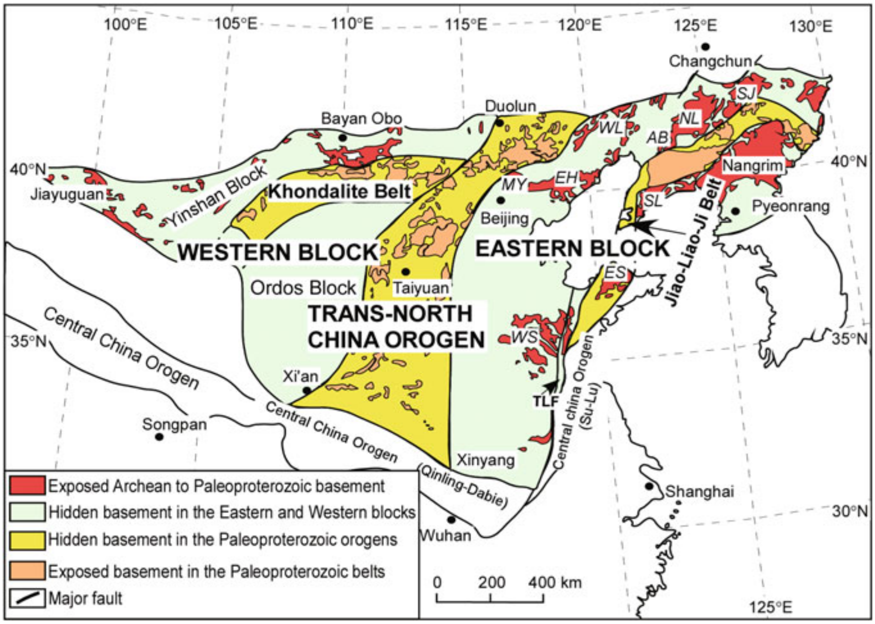

Fig. 2.2 Tectonic subdivision of the North China Craton (after Zhao et al. 2005). *AB* Anshan–Benxi; *EH* Eastern Hebei; *ES* Eastern Shandong; *MY* Miyun; *NL* Northern Liaoning; *SL* Southern Liaoning; *SJ* Southern Jilin; *WL* Western Liaoning; *WS* Western Shandong; *TLF* Tancheng–Lujiang fault

2005, 2012) and are not repeated here. What this thesis focuses on is the Eastern Block, whose general geology is summarized as follows:

The Eastern Block consists of Archean basement rocks and Paleoproterozoic Jiao-Liao-Ji Belt, of which the former exposed as complexes in the Anshan–Benxi, Eastern Hebei, Miyun, Southern Jilin, Northern Liaoning, Southern Liaoning, Western Liaoning, Eastern Shandong, and Western Shandong domains (Fig. 2.2; Zhao et al. 2005).

The Archean basement of the Eastern Block is predominated by Neoarchean (2.7–2.5 Ga) high- and low-grade TTG gneisses and ~2.5 Ga syntectonic granitoid, with minor Paleoarchean to Mesoarchean (3.9–2.9 Ga) granitoid gneisses and supracrustal rocks (Jahn et al. 2008; Liu et al. 1992, 2008; Song et al. 1996; Wilde et al. 2008; Zhao et al. 1998, 2001, 2005), partially covered by Mesoproterozoic to Cenozoic sequences.

The Paleo-Mesoarchean rocks occur as enclaves, boudins and sheets within the Neoarchean TTG gneiss and syntectonic granites (Wu 1991), and have been found only in the Anshan and Eastern Hebei areas, including fuchsite-bearing quartzites with 3.9–3.4 Ga detrital zircons and ~3.5 Ga amphibolites in the Caozhuang area of the Eastern Hebei Complex, and the 3.8–3.3 Ga granitoids and metasedimentary rocks in the Anshan Complex (Liu et al. 1992, 2008; Song et al. 1996; Wu et al. 2005;

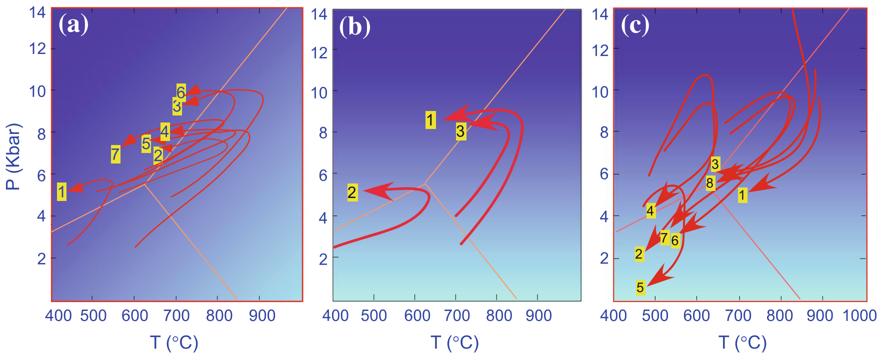

Fig. 2.3 *P–T* paths of metamorphic rocks in the **a** Eastern Block, **b** Western Block and **c** Trans-North China Orogen. **a** Eastern Block: *1* Western Shandong domain; *2* Eastern Hebei; *3* Western Liaoning; *4* Northern Liaoning; *5* Eastern Shandong; *6* Miyun–Chengde; *7* Southern Jilin. **b** Western Block: *1* Guyang–Wuchuan; *2* Sheerteng; *3* Daqingshan–Wuchuan. **c** Trans-North China Orogen: *1* Hengshan; *2* Wutai; *3* Fuping; *4* Lüliang domain (Zhao et al. 2000a); *5* Zhongtiao; *6* Huaian; *7* High-pressure granulite. References for *P–T* paths of the Eastern Block, Western Block and Trans-North China Orogen are given in Zhao et al. (1998, 1999a, b, 2000a), respectively

Wilde et al. 2008). In addition to the Anshan and Eastern Hebei domains, ~3.6–2.9 Ga zircons have also been reported from felsic granulite xenoliths in the Mesozoic volcanic rocks in the Xinyang area in the southwestern part of the Eastern Block (Zheng et al. 2004), suggesting that the pre-Neoarchean crust is not only restricted to the northern part of the Eastern Block, but also exists in the southern part of this block (Zheng et al. 2004; Zhao et al. 2005). However, although all these early Archean rocks may have undergone multiple episodes of metamorphism and deformation in the period of 3.9–2.5 Ga, the major petrographic and isotopic information of those early tectonothermal events has been strongly obliterated by the latest granulite facies metamorphic event at ~2.5 Ga (Jahn et al. 1984, 1987; Kröner et al. 1998; Song et al. 1996; Zhao et al. 1998). Therefore, the tectonic settings and evolution of these Paleo-Mesoarchean rocks remain unclear.

The Neoarchean basement rocks of the Eastern Block are composed predominantly of TTG gneisses (up to 70 %) and ca. 2.5 Ga syntectonic granitoids, with minor rafts of supracrustal rocks including ultramafic (komatiitic), mafic and felsic volcanic and sedimentary rocks (Bai and Dai 1998; Wu et al. 1998; Zhao et al. 1998, 2001). All these rocks experienced polyphase deformation and widespread greenschist to granulite facies metamorphism at ca. 2.50 Ga (Bai and Dai 1998; Ge et al. 2003; Zhao et al. 1998). Previous metamorphic studies reveal that the late Neoarchean (2.6–2.5 Ga) rocks are characterized by anticlockwise *P–T* paths involving isobaric cooling (IBC) (Fig. 2.3a; Cui et al. 1991; Chen et al. 1994; Ge et al. 1994, 2003; Li 1993; Sun et al. 1992, 1993; Zhao et al. 1998), which are similar to those *P–T* paths of the Neoarchean basement rocks in the Western Block (Fig. 2.3b), reflecting an origin related to the intrusion and underplating of mantle-derived magmas (Zhao et al. 1998). These *P–T* paths are distinctively different from

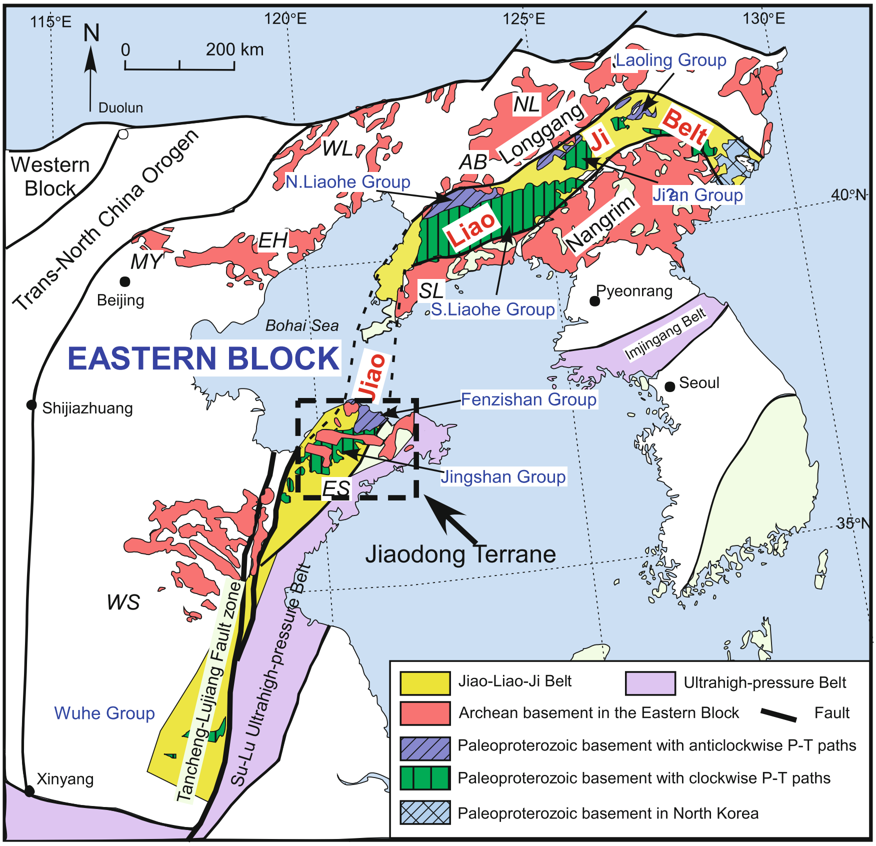

Fig. 2.4 Map of the Paleoproterozoic Jiao-Liao-Ji Belt in the Eastern Block of the North China Craton (after Zhao et al. 2005; Tam et al. 2011)

those clockwise *P–T* paths involving near-isothermal decompression of the Trans-North China Orogen (Fig. 2.3c; Zhao et al. 2000a, b), which are generally consistent with tectonic settings related to subduction and collision.

Structurally, the Archean basement of the Eastern Block is dominated by domes of various scales composed by 2.6–2.5 Ga TTG gneisses, separated by linear supracrustal rocks belts (Zhao et al. 2001). Many domiform batholiths are composed chiefly of TTG gneisses that generally underwent upper greenschist to granulite facies metamorphism, with quartz monzonites in amphibolite facies areas or charnockites in granulite facies areas as the cores of domes (Zhao et al. 2001).

The Paleoproterozoic Jiao-Liao-Ji Belt (JLJB) lies in the Eastern Block in NE–SW direction, with its southern segment extending across the Bohai Sea into the Eastern Shandong Complex and its northern segment between the Northern Liaoning–Southern Jilin Complex and the Southern Liaoning–Nangrim Complex (Fig. 2.4; Zhao et al. 2005, 2006). The northern segment includes Macheonayeong

Group in North Korea, the Laoling and Ji'an groups in southern Jilin, and the North and the South Liaohe groups in eastern Liaoning Peninsula, while the southern segment includes the Jingshan and Fenzishan groups in eastern Shandong and the Wuhe Group in Anhui Province (Fig. 2.4; Zhao et al. 2005).

The Jiao-Liao-Ji Belt is dominated by greenschist to lower amphibolite facies volcanic and sedimentary successions, associated with granitic and mafic intrusions (Luo et al. 2004, 2008; Li et al. 2005; Li and Zhao 2007; Zhou et al. 2008b). These rocks range from a basal clastic-rich sequence and a lower bimodal volcanic sequence, through a middle carbonate-rich sequence, to an upper pelite-rich sequence (Luo et al. 2004, 2006; Li et al. 2005; Lu et al. 2006; Zhao et al. 2005). The associated granitic intrusions consist of deformed A-type granites and underformed alkaline syenites and rapakivi granites, whereas mafic intrusions are composed of dolerites and gabbros metamorphosed in greenschist to amphibolite facies (Li et al. 2004, 2005; Lu et al. 2006). Previous geochronological studies suggest that most of the deformed sedimentary and volcanic successions and undeformed granites were formed during 2.2–2.0 Ga, metamorphosed and deformed at ~1.9–1.85 Ga (Luo et al. 2004, 2006; Li et al. 2005; Liu et al. 2012; Lu et al. 2006; Tam et al. 2011).

Stratigraphically, the JLJB is subdivided into a northern belt and a southern belt by a ductile shear zone (Fig. 2.4; He and Ye 1998; Lu et al. 1996; Li et al. 2005; Zhao et al. 2005), of which the northern belt contains the Fenzishan, North Laiohe, and Laoling groups, whereas the southern belt contains the Jingshan, South Liaohe and Ji'an groups (Fig. 2.4; He and Ye 1998; Lu et al. 1996; Li et al. 2005; Zhao et al. 2005). Previous metamorphic studies showed that the two belts have contradictory metamorphic evolutions, in which the northern belt is characterized by medium-pressure metapelitic rocks with clockwise *P–T* paths, whereas the southern belt is characterized by low-pressure metapelitic rocks and metavolcanic rocks with counterclockwise *P–T* paths (He and Ye 1998; Lu et al. 1996; Li et al. 2005; Zhao et al. 2005). However, this is challenged as recent metamorphic studies have revealed that the medium- to high-pressure mafic and pelitic granulites from both of the Jingshan and Fenzishan groups are characterized by clockwise *P–T* paths (Tam et al. 2012a, b, c).

The tectonic setting of the Jiao-Liao-Ji Belt is still hotly debated, with some researchers considering it as a continent–arc–continent collisional belt (Faure et al. 2004; Lu et al. 2006), whereas others arguing that it involved the opening and closure of an intracontinental rift basin (Luo et al. 2004, 2008; Li et al. 2005; Li and Zhao 2007). Moreover, most recently, some scholars have proposed that this belt represented a continent–continent collisional belt involving subduction (Tam et al. 2012a, b, c; Zhao et al. 2012; Zhao and Zhai 2013).

2.2 Eastern Shandong Complex

The Eastern Shandong Complex, one of the largest Precambrian basement complexes exposed in the Eastern Block (Fig. 2.2; Zhao et al. 2005), is located in the northeastern part of the Shandong Province, and it is bounded by the Tancheng–Lujiang Fault zone (TLF) in the west, the Wulian-Yantai Fault in the east and the Jiaolai Basin in the south (Fig. 2.5). The Eastern Shandong Complex consists of the Archean Jiaodong Terrane and uncomformably overlying Proterozoic metasedimentary cover sequences.

The Archean Jiaodong Terrane, best exposed in the Qixia area, is composed predominately of granitoid gneisses (over 90 %) with minor supracrustal rocks (Figs. 2.5 and 2.6; Bai and Dai 1998; Tang et al. 2007). The pre-tectonic granitoid gneisses consist dominantly of TTG gneisses with minor granitic rocks (Fig. 2.6), while the supracrustal rocks, traditionally known as the "Jiaodong Group," include numerous amphibolites and minor biotite–plagioclase gneisses, both of which are sparsely exposed as enclaves or tectonic lenses within the granitoid gneisses (Fig. 2.6).

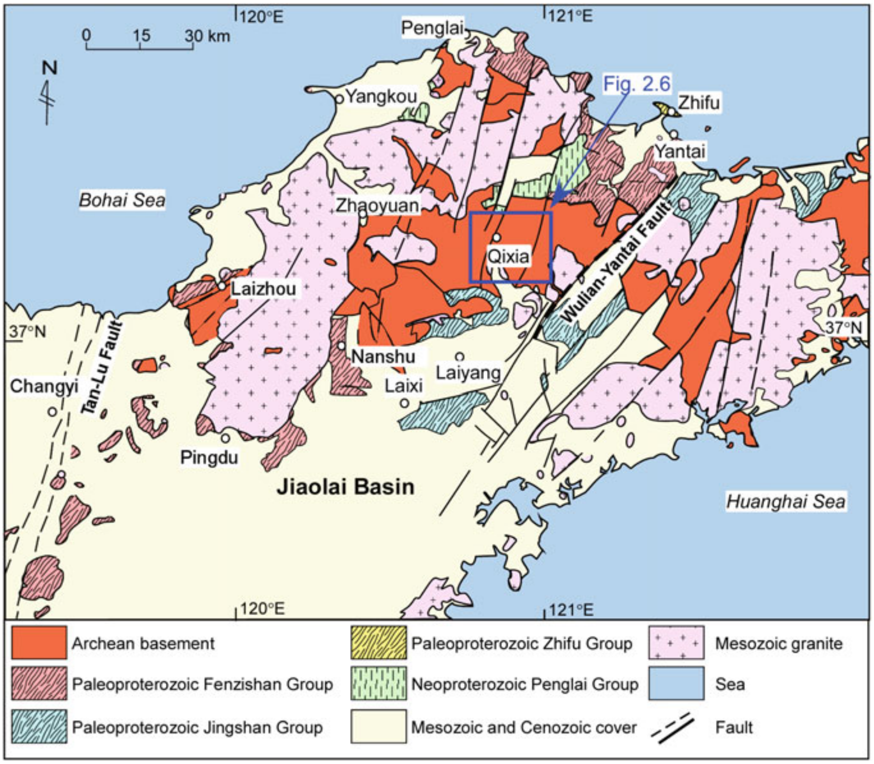

Fig. 2.5 Geological sketch map of the Eastern Shandong Complex (after Zhou et al. 2008a, b; Tam et al. 2011)

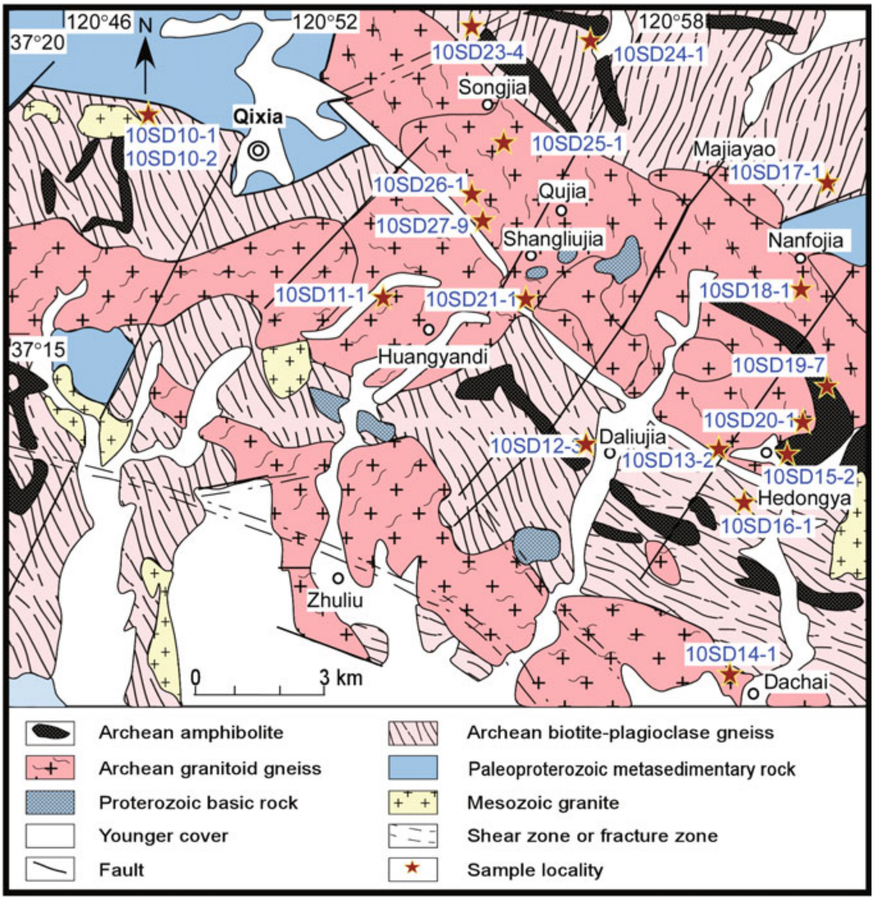

Fig. 2.6 Geological sketch map of the Jiaodong Terrane (after Jahn et al. 2008)

Previous zircon U–Pb ages obtained for these lithologies have shown that their protoliths were emplaced between 2.9 and 2.5 Ga (mainly at ~2.7 Ga) (Jahn et al. 2008; Liu et al. 2013a, b, c; Tang et al. 2007; Zhou et al. 2008a), different from the most significant magmatism at 2.6–2.5 Ga in the NCC (e.g. Geng et al. 2006; Wu et al. 2013; Yang et al. 2008). Notably, Mesoarchean and Neoarchean granitoid gneisses are indistinguishable in the field as they display similar geological and petrographic characteristics. The Archean Jiaodong Terrane was metamorphosed in amphibolite facies, locally in granulite facies, and available metamorphic zircon U–Pb ages from this terrane show two metamorphic events at ~2.5 Ga and ~1.9–1.8 Ga (Bai and Dai 1998; Jahn et al. 2008; Tang et al. 2007; Zhang et al. 2003; Zhou et al. 2008a). In addition, sparse whole-rock Nd and zircon Hf isotopic data indicate that these Archean rocks may have been derived mainly from juvenile crust with limited additions of old crustal material (Jahn et al. 2008; Liu et al. 2013a).

The overlying Paleoproterozoic Jingshan and Fenzishan groups were metamorphosed from amphibolite facies to granulite facies (Liu et al. 2013a; Tang et al. 2007; Wan et al. 2006; Zhai and Liu 2003; Zhai et al. 2005; Zhao et al. 2005; Zhou et al. 2004, 2008b), while the Paleoproterozoic Zhifu Group and Neoproterozoic Penglai Group were metamorphosed from upper greenschist facies to amphibolite facies (Faure et al. 2001, 2003; SBGMR 1991; Zhou et al. 2008a). Previous SHRIMP U–Pb zircon age data showed that the Fenzishan and Jingshan groups were formed in the same period of 2.2–1.9 Ga and experienced metamorphism at ~1.88 Ga (Wan et al. 2006). Recently, high-pressure (HP) mafic and pelitic granulites from the Jingshan and Fenzishan groups have been recognized and they experienced peak high-pressure granulite facies metamorphism at 1.93–1.90 Ga, characterized by clockwise *P–T* paths (Tam et al. 2011, 2012a, b, c; Zhou et al. 2004, 2008b). Detrital zircon ages of 2.9–1.8 Ga obtained for the Penglai and Zhifu groups show two major populations of 2.45–2.1 and 2.0–1.7 Ga (Liu et al. 2013b; Zhou et al. 2008a), indicating that their sources were most likely from the Paleoproterozoic Fenzishan and Jingshan groups.

2.3 Western Shandong Complex

The Western Shandong Complex, one of the largest complexes in the Eastern Block, covers an area of more than 15,000 km^2 and is bordered by the Liaocheng-Lankao fault to the west and the Yi-Shu fault (YSF) to the east (Figs. 2.2 and 2.7). It consists of the low-grade Luxi Granite–Greenstone Terrane in the west and the high-grade Yishui Terrane in the east, separated by the NS-trending TLF (Fig. 2.7; Bai and Dai 1998; Shen et al. 1993). The Luxi Granite–Greenstone Terrane makes up 85 % of the Archean basement exposure in the Western Shandong Complex, whereas the Yishui Terrane is mainly located within the TLF zone that extends roughly in a NE–SW direction (Fig. 2.7).

2.3.1 Luxi Granite–Greenstone Terrane

In the Luxi Granite–Greenstone Terrane, the greenstones are composed of ultramafic to felsic supracrustal rocks metamorphosed at greenschist to lower amphibolite facies, whereas the granites consist of pre-tectonic orthogneisses of TTG composition and syn-tectonic granitic rocks. Extensive zircon U–Pb dating and Hf isotopic analyses have been carried out on the Luxi Granite–Greenstone Terrane in the past few years (Du et al. 2010; Jiang et al. 2010; Wan et al. 2010, 2011, 2012a, b; Wang et al. 2010). The results show that the volcanic rocks from the supracrustal sequences, represented by the Taishan Group and the Jining Group, were formed during 2.75–2.55 Ga and the sedimentary rocks were deposited at 2.56–2.52 Ga. The results

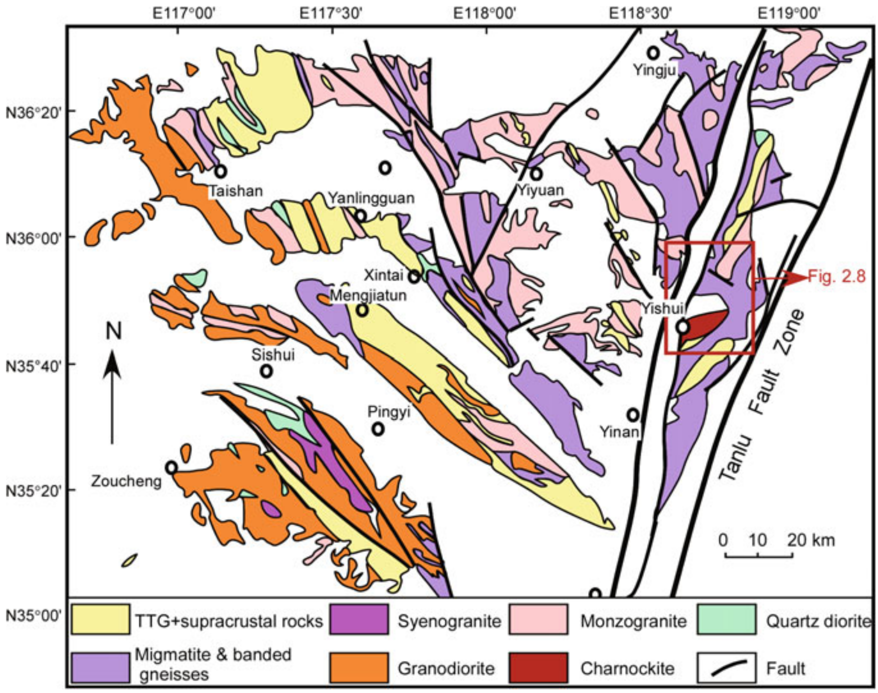

Fig. 2.7 Geological sketch map of the Western Shandong Complex (after Wan et al. 2010)

also reveal that most of the pre-tectonic TTG gneisses and massive granitoids (monzonites, granodiorites, and syenogranites) in the Luxi Granite–Greenstone Terrane were emplaced at 2.55–2.50 Ga and metamorphosed at ~2.50 Ga, whereas minor TTG rocks were emplaced at ~2.75 Ga and metamorphosed at ~2.65 Ga. Hf isotopic data indicate that the supracrustal rocks, TTG gneisses and ~2.5 Ga syn-tectonic granites were derived from a depleted mantle at 2.85–2.70 Ga (Jiang et al. 2010; Wan et al. 2011). This crustal accretionary event is interpreted as coeval with the formation of komatiitic rocks in the Luxi Granite–Greenstone Terrane (Polat et al. 2006). Therefore, the Luxi Granite–Greenstone Terrane in the Western Shandong Complex recorded both the 2.75–2.70 and 2.55–2.50 Ga crust-forming events.

2.3.2 *Yishui Terrane*

The Yishui Terrane is mainly confined to the Yishui-Tangtou Fault zone to the east of the Yishui County, Shandong Province (Fig. 2.8). It consists of high-grade metamorphosed granitoid plutons that make up to 75 % of the total exposure, and supracrustal rocks traditionally called the Yishui Group.

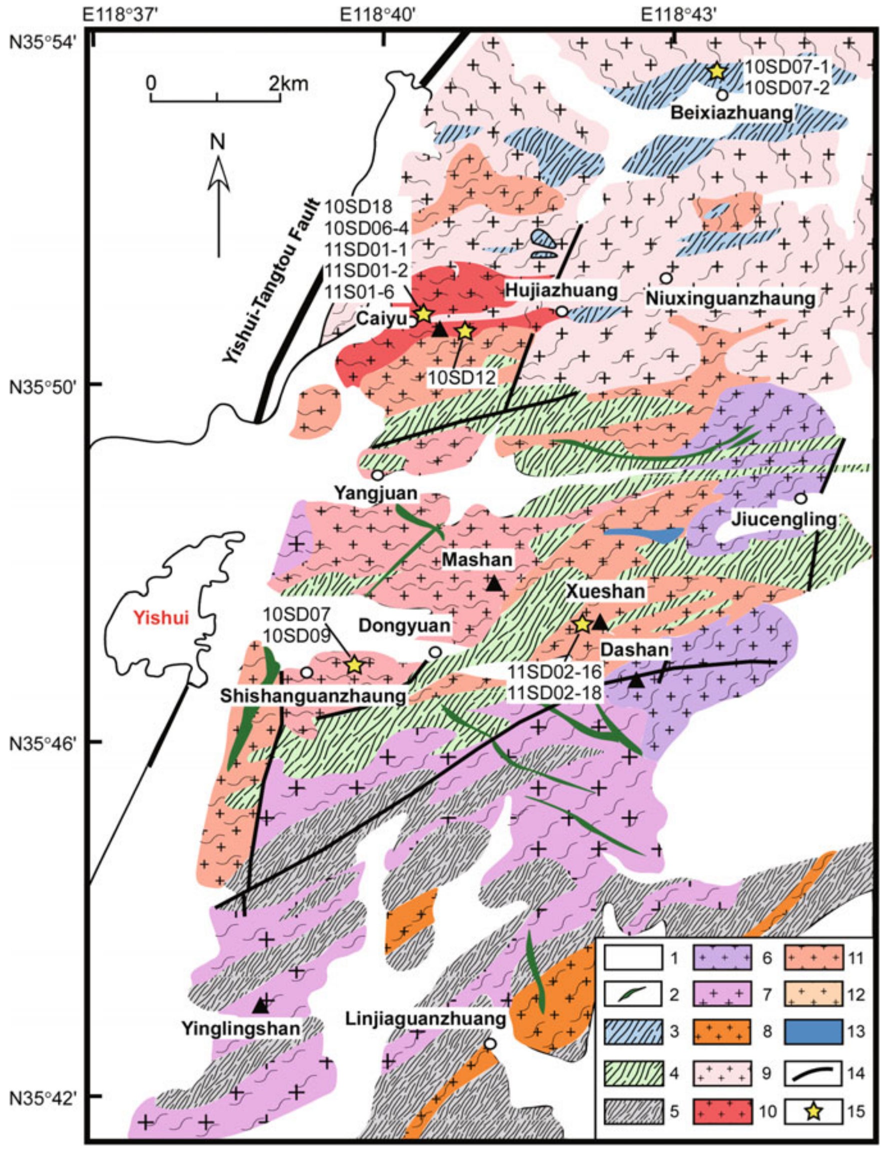

Fig. 2.8 Geological sketch map of the Yishui Terrane (after Shen et al. 2000). *1* Phanerozoic covers; *2* veins; *3* Beixiazhuang assemblage; *4* Shishanguanzhuang assemblage; *5* Linjiaguanzhuang assemblage; *6* Dashan pluton; *7* Yinglingshan pluton; *8* Linjiaguanzhuang pluton; *9* Niuxinguanzhuang pluton; *10* Caiyu pluton; *11* Xueshan pluton; *12* Mashan pluton; *13* gabbro; *14* faults; *15* sample locations

The Yishui Group is composed predominantly of mafic granulites as well as minor pelitic and felsic gneisses (granulite facies), which crops out as irregular boudins and ribbons within the granitoid gneisses. Based on distinct lithological units, the Yishui Group has been subdivided into three assemblages, called the Linjiaguanzhuang, Shishanguanzhuang, and Beixiazhuang assemblages (Fig. 2.8; Shen et al. 2000). The former two assemblages consist mainly of metabasites with minor felsic gneisses, whereas the Beixiazhuang assemblage is dominated by felsic and pelitic gneisses with minor metabasites. Using the SHRIMP dating technique, Zhao et al. (2009b) obtained metamorphic zircon ages of 2,522–2,496 Ma for the metabasites from the Linjiaguanzhuang and Shishanguanzhuang assemblages, which are interpreted as the timing of regional metamorphism. Zhao et al. (2009a) also dated magmatic detrital zircons from a metapelitic sample near the Niuxinguanzhuang area, which did not yield concordant ages due to different degrees of Pb loss.

The granitoid plutons are composed dominantly of weakly deformed granitoid gneisses and charnockites, which are mainly exposed in the Niuxinguanzhuang, Caiyu, Dashan, Mahsan, Xueshan, Yinglingshan, and Linjiaguanzhuang areas (Fig. 2.8). Available geochronological data suggest these plutons were formed in the late Neoarchean (2.56–2.50 Ga) with Mesoarchean inherited zircons of 3.09–2.93 Ga from local areas (Shen et al. 2004, 2007), and they all underwent regional metamorphism at ca. 2.50 Ga (Shen et al. 2004).

References

Bai, J., & Dai, F. (1998). Archean crust of China. In X. Ma & J. Bai (Eds.), *Precambrian crustal evolution of China* (pp. 15–86). Beijing: Springer, Geological Publishing House.

Chen, N. S., Wang, R. J., Shan, W. Y., & Zhong, Z. Q. (1994). Isobaric cooling P-T-t path of the western section of the Miyun Complex and its tectonic implications. *Scientia Geologica Sinica, 29*, 354–364 (in Chinese with English abstract).

Cui, W., Wang, C., & Wang, S. (1991). Geochemistry and metamorphism P-T-t path of the Archean Jianping metamorphic complex in Western Liaoning Province. *Acta Petrologica Sinica, 7*, 13–26.

Du, L., Yang, C., Zhuang, Y., Wei, R., Wan, Y., Ren, L., et al. (2010). Hf isotopic compositions of zircons from 2.7 Ga metasedimentary rocks and biotite-plagioclase gneiss in the Mengjiatun formation complex, western Shandong Province. *Acta Geologica Sinica, 84*, 991–1001.

Faure, M., Lin, W., & Le Breton, N. (2001). Where is the North China–South China block boundary in eastern China? *Geology, 29*, 119–122.

Faure, M., Lin, W., Monié, P., Le Breton, N., Poussineau, S., Panis, D., et al. (2003). Exhumation tectonics of the ultrahigh-pressure metamorphic rocks in the Qinling orogen in east China: New petrological-structural-radiometric insights from the Shandong Peninsula. *Tectonics*, *22*, 1018.

Faure, M., Lin, W., Monie, P., & Bruguier, O. (2004). Palaeoproterozoic arc magmatism and collision in Liaodong Peninsula (northeast China). *Terra Nova, 16*, 75–80.

Ge, W., Sun, D., Wu, F., & Lin, Q. (1994). The Metamorphic PTt Path of Archean Granulites in Huadian Area, Jilin Province. *Acta Petrologica et Mineralogica, 13*, 232–238.

Ge, W. C., Zhao, G. C., Sun, D. Y., Wu, F. Y., & Lin, Q. (2003). Metamorphic P-T path of the Southern Jilin complex: Implications for tectonic evolution of the Eastern Block of the North China Craton. *International Geology Review, 45*, 1029–1043.

Geng, Y., Liu, F., & Yang, C. (2006). Magmatic event at the end of the Archean in eastern Hebei Province and its geological implication. *Acta Geologica Sinica-English Edition, 80*, 819–833.

He, G. P., & Ye, H. W. (1998). Two types of early Proterozoic metamorphism in the eastern Liaoning to southern Jilin and their tectonic implication. *Acta Petrologica Sinica, 14*, 152–162 (in Chinese with English Abstract).

He, G. P., Lu, L. Z., Ye, H. W., Jin, S. Q., & Ye, T. S. (1991). *Metamorphic evolution of the early Precambrian basement of the Eastern Hebei and Southeastern inner Mongolia areas* (pp. 1–16). Changchun: Jilin University Press (in Chinese).

Jahn, B.-M., Vidal, P., & Kröner, A. (1984). Multi-chronometric ages and origin of Archaean tonalitic gneisses in Finnish Lapland: A case for long crustal residence time. *Contributions to Mineralogy and Petrology, 86*, 398–408.

Jahn, B., Auvray, B., Cornichet, J., Bai, Y., Shen, Q., & Liu, D. (1987). 3.5 Ga old amphibolites from eastern Hebei Province, China: Field occurrence, petrography, Sm-Nd isochron age and REE geochemistry. *Precambrian Research, 34*, 311–346.

Jahn, B. M., Liu, D. Y., Wan, Y. S., Song, B., & Wu, J. S. (2008). Archean crustal evolution of the Jiaodong Peninsula, China, as revealed by zircon SHRIMP geochronology, elemental and Nd-isotope geochemistry. *American Journal of Science, 308*, 232–269.

Jiang, N., Guo, J., Zhai, M., & Zhang, S. (2010). ~2.7 Ga crust growth in the North China craton. *Precambrian Research, 179,* 37–49.

Kröner, A., Cui, W. Y., Wang, S. Q., Wang, C. Q., & Nemchin, A. A. (1998). Single zircon ages from high-grade rocks of the Jianping Complex, Liaoning Province, NE China. *Journal of Asian Earth Sciences, 16*, 519–532.

Li, Z. L. (1993). Metamorphic P–T–t path of the Archean rocks in the eastern Shandong Province and its implications. *Shandong Geology, 9*, 31–41 (in Chinese).

Li, S., & Zhao, G. (2007). SHRIMP U–Pb zircon geochronology of the Liaoji granitoids: Constraints on the evolution of the Paleoproterozoic Jiao-Liao-Ji belt in the Eastern Block of the North China Craton. *Precambrian Research, 158*, 1–16.

Li, S. Z., Hao, D. F., Zhao, G. C., Sun, M., Han, Z. Z., & Guo, X. Y. (2004). Geochemical features and origin of Dandong granite. *Acta Petrologica Sinica, 20*, 1417–1423.

Li, S., Zhao, G., Sun, M., Han, Z., Luo, Y., Hao, D., et al. (2005). Deformation history of the Paleoproterozoic Liaohe assemblage in the Eastern block of the North China Craton. *Journal of Asian Earth Sciences, 24*, 659–674.

Liu, D., Page, R., Compston, W., & Wu, J. (1985). U–Pb zircon geochronology of late Archaean metamorphic rocks in the Taihangshan—Wutaishan area, North China. *Precambrian Research, 27*, 85–109.

Liu, D. Y., Nutman, A. P., Compston, W., Wu, J. S., & Shen, Q. H. (1992). Remnants of 3800 Ma crust in the Chinese Part of the Sino-Korean craton. *Geology, 20*, 339–342.

Liu, D., Wilde, S. A., Wan, Y., Wu, J., Zhou, H., Dong, C., et al. (2008). New U-Pb and Hf isotopic data confirm Anshan as the oldest preserved segment of the North China Craton. *American Journal of Science, 308*, 200–231.

Liu, P. H., Liu, F. L., Yang, H., Wang, F., & Liu, J. H. (2012). Protolith ages and timing of peak and retrograde metamorphism of the high-pressure granulites in the Shandong Peninsula, eastern North China Craton. *Geoscience Frontiers, 3*, 923–943.

Liu, J., Liu, F., Ding, Z., Liu, C., Yang, H., Liu, P., et al. (2013a). The growth, reworking and metamorphism of early Precambrian crust in the Jiaobei terrane, the North China Craton: Constraints from U–Th–Pb and Lu–Hf isotopic systematics, and REE concentrations of zircon from Archean granitoid gneisses. *Precambrian Research, 224*, 287–303.

Liu, J., Liu, F., Ding, Z., Yang, H., Liu, C., Liu, P., et al. (2013b). U–Pb dating and Hf isotope study of detrital zircons from the Zhifu Group, Jiaobei Terrane, North China Craton: Provenance and implications for Precambrian crustal growth and recycling. *Precambrian Research, 235*, 230–250.

Liu, P., Liu, F., Liu, C., Wang, F., Liu, J., Yang, H., et al. (2013c). Petrogenesis, P–T–t path, and tectonic significance of high-pressure mafic granulites from the Jiaobei terrane, North China Craton. *Precambrian Research, 233*, 237–258.

Lu, L. Z., Xu, X. C., Liu, F. L. (1996). *Early Precambrian Khondalites Series in North China*. Changchun: Changchun Press, p. 276 (in Chinese with English abstract).
Lu, X. P., Wu, F. Y., Guo, J. H., Wilde, S. A., Yang, J. H., Liu, X. M., et al. (2006). Zircon U-Pb geochronological constraints on the Paleoproterozoic crustal evolution of the Eastern Block in the North China Craton. *Precambrian Research, 146*, 138–164.
Luo, Y., Sun, M., Zhao, G., Li, S., Xu, P., Ye, K., et al. (2004). LA-ICP-MS U–Pb zircon ages of the Liaohe Group in the Eastern Block of the North China Craton: Constraints on the evolution of the Jiao-Liao-Ji Belt. *Precambrian Research, 134*, 349–371.
Luo, Y., Sun, M., Zhao, G., Li, S., & Xia, X. (2006). LA-ICP-MS U–Pb zircon geochronology of the Yushulazi Group in the eastern block, North China Craton. *International Geology Review, 48*, 828–840.
Luo, Y., Sun, M., Zhao, G., Li, S., Ayers, J. C., Xia, X., et al. (2008). A comparison of U–Pb and Hf isotopic compositions of detrital zircons from the North and South Liaohe Groups: Constraints on the evolution of the Jiao-Liao-Ji Belt, North China Craton. *Precambrian Research, 163*, 279–306.
Polat, A., Li, J., Fryer, B., Kusky, T., Gagnon, J., & Zhang, S. (2006). Geochemical characteristics of the Neoarchean (2800–2700 Ma) Taishan greenstone belt, North China Craton: Evidence for plume–craton interaction. *Chemical Geology, 230*, 60–87.
Shandong Bureau of Geology and Mineral Resources (SBGMR). (1991). *Regional geology of Shandong Province* (pp. 5–262). Beijing: Geological Publishing House (in Chinese).
Shen, Q. H., Liu, D. Y., Wang, P., & Gao, J. F. (1987). U–Pb and Rb–Sr isotopic ages of m metamorphic rock series from the Jining Group, southern Inner Mongolia. *Journal o f Chinese Institute of Geology, 16*, 165–178 (in Chinese).
Shen, B. F., Peng, X. L., Luo, H., & Mao, D. B. (1993). Archean greenstone belts in china. *Acta Geological Sinica, 3*, 001.
Shen, Q. H., Shen, K., Geng, Y. S., & Xu, H. F. (2000). *The composition and evolution of the Yishui Complex*. Beijing, Shandong Province: Geological Publishing House.
Shen, Q. H., Song, B., Xu, H. F., Geng, Y. S., & Shen, K. (2004). Emplacement and metamorphism ages of the Caiyu and Dashan igneous bodies, Yishui County, Shandong Province: Zircon SHRIMP chronology. *Geological Review, 50*, 275–284.
Shen, Q. H., Song, B., Xu, H. F., Geng, Y. S., & Shen, K. (2007). Emplacement and metamorphism ages of the Caiyu and Dashan igneous bodies, Yishui County, Shandong Province: Zircon SHRIMP chronology. *Geological Review, 50*, 275–284.
Song, B., Nutman, A. P., Liu, D., & Wu, J. (1996). 3800 to 2500 Ma crustal evolution in the Anshan area of Liaoning Province, northeastern China. *Precambrian Research, 78*, 79–94.
Sun, X., Xu, K., Ren, Q., & Keays, R. R. (1992). Mineralogy and P–T conditions of metamorphism of Jiapigou granulite facies rocks, Jilin Province. *Mineralogy and Petrology, 12*, 17–26.
Sun, D. Y., Liu, Z. H., & Zheng, C. Q. (1993). *Metamorphism and tectonic evolution of early Precambrian rocks in Fushun area, the Northern Liaoning Province* (pp. 90–120). Beijing: Seismological Press (in Chinese).
Tam, P. Y., Zhao, G., Liu, F., Zhou, X., Sun, M., & Li, S. (2011). Timing of metamorphism in the Paleoproterozoic Jiao-Liao-Ji Belt: New SHRIMP U–Pb zircon dating of granulites, gneisses and marbles of the Jiaobei massif in the North China Craton. *Gondwana Research, 19*, 150–162.
Tam, P. Y., Zhao, G. C., Sun, M., Li, S. Z., Iizuka, Y., Ma, G. S.-K. i., et al. (2012a). Metamorphic P–T path and tectonic implications of medium-pressure pelitic granulites from the Jiaobei massif in the Jiao-Liao-Ji Belt, North China Craton. *Precambrian Research, 220–221*, 177–191.
Tam, P. Y., Zhao, G. C., Sun, M., Li, S. Z., Wu, M. L., & Yin, C. Q. (2012b). Petrology and metamorphic P–T path of high-pressure mafic granulites from the Jiaobei massif in the Jiao-Liao-Ji Belt, North China Craton. *Lithos, 155*, 94–109.

Tam, P. Y., Zhao, G. C., Zhou, X. W., Sun, M., Guo, J. H., Li, S. Z., et al. (2012c). Metamorphic P–T path and implications of high-pressure pelitic granulites from the Jiaobei massif in the Jiao-Liao-Ji Belt, North China Craton. *Gondwana Research, 22*, 104–117.

Tang, J., Zheng, Y. F., Wu, Y. B., Gong, B., & Liu, X. (2007). Geochronology and geochemistry of metamorphic rocks in the Jiaobei terrane: Constraints on its tectonic affinity in the Sulu orogen. *Precambrian Research, 152*, 48–82.

Wan, Y. S., Song, B., Liu, D. Y., Wilde, S. A., Wu, J. S., Shi, Y. R., et al. (2006). SHRIMP U-Pb zircon geochronology of Palaeoproterozoic metasedimentary rocks in the North China Craton: Evidence for a major Late Palaeoproterozoic tectonothermal event. *Precambrian Research, 149*, 249–271.

Wan, Y., Liu, D., Wang, S., Dong, C., Yang, E., Wang, W., et al. (2010). Juvenile magmatism and crustal recycling at the end of the Neoarchean in Western Shandong Province, North China Craton: Evidence from SHRIMP zircon dating. *American Journal of Science, 310*, 1503–1552.

Wan, Y., Liu, D. Y., Wang, S., Yang, E., Wang, W., Dong, C., et al. (2011). ~2.7 Ga juvenile crust formation in the North China Craton (Taishan-Xintai area, western Shandong Province): Further evidence of an understated event from U–Pb dating and Hf isotopic composition of zircon. *Precambrian Research, 186,* 169–180.

Wan, Y., Wang, S., Liu, D., Wang, W., Kroner, A., Dong, C., et al. (2012a). Redefinition of depositional ages of Neoarchean supracrustal rocks in western Shandong Province, China: SHRIMP U–Pb zircon dating. *Gondwana Research, 21,* 768–784.

Wan, Y., Dong, C., Liu, D., Kroner, A., Yang, C., Wang, W., et al. (2012b). Zircon ages and geochemistry of late Neoarchean syenogranites in the North China Craton: A review. *Precambrian Research, 222–223,* 265–289.

Wang, W., Wang, S. J., Liu, D. Y., Li, P. Y., Dong, C. Y., Xie, H. Q., et al. (2010). Formation age of the Neoarchaean Jining Group (banded iron formation) in the western Shandong Province: Constraints from SHRIMP zircon U–Pb dating. *Acta Petrologica Sinica, 26*, 1175–1181.

Wilde, S. A., Valley, J. W., Kita, N. T., Cavosie, A. J., & Liu, D. (2008). SHRIMP U-Pb and CAMECA 1280 oxygen isotope results from ancient detrital zircons in the Caozhuang quartzite, Eastern Hebei, North China Craton: Evidence for crustal reworking 3.8 Ga ago. *American Journal of Science, 308*, 185–199.

Wu, F. Y. (1991). The Archaean structural setting and crustal evolution of North Liaoning. *Land and Resources, 148–157*.

Wu, C. H., Li, H. M., Zhong, C. T., & Cheng, Q. A. (1998). The ages of zircons and rutiles from khondalite in the Huangtuyao area, Inner Mongolia. *Geology Review, 44*, 618–626 (in Chinese).

Wu, F., Zhao, G., Wilde, S. A., & Sun, D. (2005). Nd isotopic constraints on crustal formation in the North China Craton. *Journal of Asian Earth Sciences, 24*, 523–545.

Wu, K. K., Zhao, G., Sun, M., Yin, C., He, Y., & Tam, P. Y. (2013). Metamorphism of the northern Liaoning Complex: Implications for the tectonic evolution of Neoarchean basement of the Eastern Block, North China Craton. *Geoscience Frontiers, 4*, 305–320.

Yang, J.-H., Wu, F.-Y., Wilde, S. A., & Zhao, G. (2008). Petrogenesis and geodynamics of Late Archean magmatism in eastern Hebei, eastern North China Craton: Geochronological, geochemical and Nd-Hf isotopic evidence. *Precambrian Research, 167*, 125–149.

Zhai, M., & Liu, W. (2003). Palaeoproterozoic tectonic history of the North China Craton: A review. *Precambrian Research, 122*, 183–199.

Zhai, M., Guo, J., & Liu, W. (2005). Neoarchean to Paleoproterozoic continental evolution and tectonic history of the North China Craton: A review. *Journal of Asian Earth Sciences, 24*, 547–561.

Zhang, X. O., Cawood, P. A., Wilde, S. A., Liu, R., Song, H., Li, W., et al. (2003). Geology and timing of mineralization at the Cangshang gold deposit, north-western Jiaodong Peninsula, China. *Mineralium Deposita, 38*, 141–153.

Zhao, G. C., Wilde, S., Cawood, P., & Lu, L. Z. (1998). Thermal evolution of Archean basement rocks from the Eastern part of the North China Craton and its bearing on tectonic setting. *International Geology Review, 40*, 706–721.

Zhao, G., Wilde, S. A., Cawood, P. A., & Lu, L. (1999a). Tectonothermal history of the basement rocks in the western zone of the North China Craton and its tectonic implications. *Tectonophysics, 310*, 37–53.

Zhao, G., Wilde, S. A., Cawood, P. A., & Lu, L. (1999b). Thermal evolution of two textural types of mafic granulites in the North China Craton: Evidence for both mantle plume and collisional tectonics. *Geological Magazine, 136*, 223–240.

Zhao, G., Cawood, P. A., Wilde, S. A., Sun, M., & Lu, L. (2000a). Metamorphism of basement rocks in the Central Zone of the North China Craton: Implications for Paleoproterozoic tectonic evolution. *Precambrian Research, 103*, 55–88.

Zhao, G., Wilde, S. A., Cawood, P. A., & Lu, L. Z. (2000b). Petrology and P–T path of the Fuping mafic granulites: Implications for tectonic evolution of the central zone of the North China Craton. *Journal of Metamorphic Geology, 18*, 375–391.

Zhao, G., Wilde, S. A., Cawood, P. A., & Sun, M. (2001). Archean blocks and their boundaries in the North China Craton: Lithological, geochemical, structural and P–T path constraints and tectonic evolution. *Precambrian Research, 107*, 45–73.

Zhao, G., Sun, M., Wilde, S. A., & Sanzhong, L. (2005). Late Archean to Paleoproterozoic evolution of the North China Craton: Key issues revisited. *Precambrian Research, 136*, 177–202.

Zhao, G., Sun, M., Wilde, S. A., Sanzhong, L., Liu, S., & Zhang, J. (2006). Composite nature of the North China Granulite-Facies Belt: Tectonothermal and geochronological constraints. *Gondwana Research, 9*, 337–348.

Zhao, Z. R., Song, H. X., Shen, Q. H., & Song, B. (2009a). Geochemistry and age of a metapelite rock in the Yishui complex, Shandong Province. *Acta Petrologica Sinica, 25*, 1863–1871.

Zhao, Z. R., Song, H. X., Shen, Q. H., & Song, B. (2009b). The Petro-geochemical characters and SHRIMP U-Pb zircon ages of Meta-mafic rocks from the Yishui Complex, in Yishui County, Shandong Province. *Geological Review, 55*, 286–299.

Zhao, G., Cawood, P. A., Li, S., Wilde, S. A., Sun, M., Zhang, J., et al. (2012). Amalgamation of the North China Craton: Key issues and discussion. *Precambrian Research, 222–223*, 55–76.

Zhao, G. & Zhai, M. (2013). Lithotectonic elements of Precambrian basement in the North China Craton: Review and tectonic implications. *Gondwana Research, 23,* 1207–1240.

Zheng, J., Griffin, W. L., O'Reilly, S. V., Lu, F., Yu, C., Zhang, M. et al. (2004). U-Pb and Hf-isotope analysis of zircons in mafic xenoliths from Fuxian kimberlites: Evolution of the lower crust beneath the North China craton. *Contributions to Mineralogy & Petrology, 148,* 79–103.

Zhou, X. W., Wei, C. J., Geng, Y. S., & Zhang, L. F. (2004). The Discovery and implication of high-pressure pelitic granulite in the Qixia area of Jiaobei. *China Academic Journal, 49*, 1424–1430 (in Chinese).

Zhou, J. B., Wilde, S. A., Zhao, G. C., Zheng, C. Q., Jin, W., Zhang, X. Z., et al. (2008a). SHRIMP U–Pb zircon dating of the Neoproterozoic Penglai Group and Archean gneisses from the Jiaobei Terrane, North China, and their tectonic implications. *Precambrian Research, 160*, 323–340.

Zhou, X. W., Zhao, G. C., Wei, C. J., Geng, Y. S., & Sun, M. (2008b). EPMA U-Th-Pb monazite and SHRIMP U-Pb zircon geochronology of high-pressure pelitic granulites in the Jiaobei massif of the North China Craton. *American Journal of Science, 308*, 328–350.

Springer

http://www.springer.com/978-3-662-45342-1

Ages, Geochemistry and Metamorphism of Neoarchean Basement in Shandong Province
Implications for the Evolution of the North China Craton
Wu, M.
2015, XXIX, 221 p. 53 illus., 49 illus. in color., Hardcover
ISBN: 978-3-662-45342-1