Neoproterozoic Era of South China Craton

Yuan-Sheng Geng

Abstract The Neoproterozoic of the Yangtze block may be subdivided into early Pt_3 (1000–850 Ma), middle Pt_3 (850–780 Ma), and late Pt_3 (780–541 Ma). The Neoproterozoic sequence is most developed in the Jiangnan orogenic belt. The early Pt_3 strata, or the lower structure sequence of Neoproterozoic, include the Sibao (Guangxi Province), Fanjingshan (Guizhou Province), Lengjiaxi (Hunan Province), Xiko (Anhui Province), Shuangxiwu (Zhejiang Province), and Pingshui (Zhejiang Province) Groups. The middle Pt_3 strata, or the upper structure sequence of Neoproterozoic, include the Danzhou (Guangxi Province), Xiajiang (Guizhou Province), Banxi (Hunan Province), Likou (Anhui Province), and Heshangzhen (Zhejiang Province) Groups. The upper sequence unconformably overlies the lower sequence. The tectonic movement between the two sequences was responsible for the amalgamation of the Yangtze and Cathaysian blocks, thus formed the South China craton. But it is still controversy on the time and mechanism of the movement. The early and middle Pt_3 strata are represented by the Yanbian Group, the Suxiong, and Kaijianqiao Formations at the western Yangtze block. The Huodiya and Xixiang Groups occur at the northern margin. Besides the Pt_3 strata, voluminous magmatic rocks of the period are present from Panxi (Panzhihua and Xichang regions in western Sichuan Province) to Hannan region in southern Shaanxi Province, including the basic gabbros to intermediate-acid granites during 850–780 Ma ago, so forming the Panxi-Hannan magmatic belt. In the Cathaysian block, the early and middle Pt_3 sequences are characterized by the Chencai and Longquan Groups, while the late Pt_3 strata in the South China Craton are manifested by the Nanhua System (corresponding to the Cryogenian System) and the Sinian System (corresponding to the Ediacaran System), which are widely distributed as the cover sequence in southern China after the consolidation of the South China Craton.

Keywords South China Craton · Neoproterozoic · Jiangnan (orogenic) belt · Nanhua system · Sinian system

Y.-S. Geng (✉)
Institute of Geology, Chinese Academy of Geology Sciences,
100037 Beijing, China
e-mail: ys-geng@cags.ac.cn

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1 Introduction

Conventionally, the Neoproterozoic strata sequences of the South China Block are categorized into the Qingbaikou System (1000–800 Ma), Nanhua System (800–680 Ma), and Sinian System (680–543 Ma), with geochronological boundaries of 800 and 680 Ma (National Commission of Stratigraphy, China, 2001; NCS). However, recent geological investigations published a lots of high-quality in situ zircon U-Pb isotopic dating data that revealed obvious angular-unconformity boundary within the Qingbaikou System of the South China Craton, indicating that the lower boundary of Nanhua System was not so old as the previous classification, and then promoted intensively debates on lower boundary of the Nanhua Systems (Zhang et al. 2003; Wang 2005; Wang et al. 2008), leading some researchers to suggest building a new system between the Qingbaikou and Nanhua systems (Wang 2008). Consequently, the NCS (National Commission of Stratigraphy, China) organized some related specialists to systematic investigation for the boundary, and then suggested that the boundary between Qingbaikou and Nanhua Systems need to be revised although a new system can be not built, therefore, redivided the Neoproterozoic strata of the South China Craton into the Qingbaikou System (1000–780 Ma), Nanhua System (780–635 Ma), and Sinian System (635–541 Ma). In the South China Craton, the Qingbaikou System consists mainly of strongly deformed, greenschist phase metamorphic rocks in the lower structural layer (e.g., Sibao Group in Guangxi, Fanjingshan Group in Guizhou, Lengjiaxi Group in Hunan, Shuangqiaoshan Group in Jiangxi, Xikou Group in southern Anhui, and Shuangxiwu Group in western Zhejiang), overlain by the weakly deformed and low-greenschist phase metamorphic rocks of the upper structural layer with unconformable contacts (Danzhou Group in Guangxi, Xiajiang Group in Guizhou, Banxi Group in Hunan, Xiushui Group in Jiangxi and Likou, and Heshangzhen Groups straddling border of Anhui, Zhejiang, and Jiangxi). Therefore, in this contribution, we categorize the Neoproterozoic strata systematics of the South China Craton into the Early Neoproterozoic (1000–820 Ma), Middle Neoproterozoic (820–780 Ma), and Late Neoproterozoic (780–541 Ma), and the Late Neoproterozoic contains the Nanhua System (780–635 Ma) and Sinian System (635–541 Ma). The Nanhua System is coincident with the international Cryogenian with a set of aqueoglacial deposits, and the Sinian System is synchronous with the Ediacaran with a set of carbonates and abundant fossil records during marine transgression.

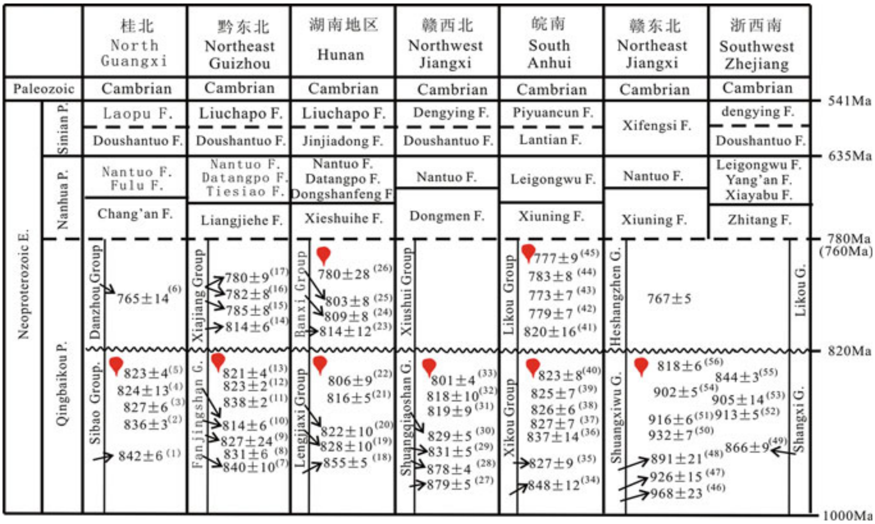
The interior of the Yangtze Block is composed mainly of terranes of Late Neoproterozoic Nanhua System and Sinian System, and the western margin of the Yangtze Block is dominated by the Early Neoproterozoic volcanic sedimentary sequences and deformed granites, and the Late Neoproterozoic Sinian System strata. The Neoproterozoic strata of the Jiangnan (orogenic) belt consists of the Early Neoproterozoic greenschist phase metamorphosed volcanic sedimentary rocks and S-type granites, the Middle Neoproterozoic low-greenschist phase metamorphic sedimentary sequences and synchronous undeformed granites, and the

Late Neoproterozoic aqueoglacial deposits of Nanhua System and carbonates of Sinian System during widely marine transgression. The Cathaysian Block is composed of the Paleo–to Mesoproterozoic amphibolite phase metamorphic volcanic and sedimentary rocks, overlain by Sinian covers. Stratigraphic division and correlation of the Neoproterozoic strata for blocks of the South China Craton are listed in Table 1, and we can figure out that the unconformity between the lower and upper structural layers at ca. 820 Ma and the boundary between the metamorphic basement and Nanhua System at ca. 780 Ma.

2 Early to Middle Neoproterozoic of South China Craton

The Early Neoproterozoic geological bodies in the South China Craton have been constrained well at 860–820 Ma, and the 1000–860 Ma old geological records exposed limitedly in the Shuangxiwu area—straddling the Anhui, Zhejiang, and Jiangxi Province—and the Shennongjia area—northwestern Hubei Province. The Neoproterozoic tectonic environment of the South China Craton, especially the Yangtze Block and the Jiangnan (orogenic) belt, remains still controversial. Some workers considered that the Yangtze Block and Cathaysian Block amalgamated before 850 Ma, and the later mantle plume upwelling results in the formation of the NE–SW striking Huanan rift, the south–north striking Kangdian rift, and east–west striking Bikou-Hannan rift (Li et al. 1999, 2002a, 2003, 2008a, b; 2002a, 2008, 2009; Wang and Li 2003; Zhu et al. 2008a, b; Wang et al. 2006, 2011). Other researchers, on the basis of the Early Neoproterozoic (mostly 850–820 Ma) volcanic rocks with island-arc-type or back-arc-type geochemical features, proposed existence of Jiangnan and Panxi-Hannan island arc belts in the margin of the Yangtze Block (Zhou et al. 2002a, b, 2006a, b; Zhao and Zhou 2008; Zhao et al. 2011; Liu et al. 2013; Zhang et al. 2013; Yao et al. 2014). Zhao and Cawood (2012) provided systematic assessments on the previous models for the Jiangnan belt and proposed that each model has its own lines of geological evidence but the unexplainable problems still existed. Consequently, Zhao and Cawood (2012) put forward the bifurcation two-way subduction model and renamed the Jiangnan belt as the Jiangnan folding belt and the Neoproterozoic tectonic belt in the northern margin of the Yangtze Block as the Panxi-Hannan folding belt. Before the final determination of the tectonic environment (rift or orogenic belt?), we consider that the nomenclature of “folding belt” is much more suitable for the tectonic belts above. Therefore, in this contribution, the tectonic belts will be nominated as Jiangnan folding belt (abbreviated for the Jiangnan belt) and Panxi-Hannan folding belt (abbreviated for the Panxi-Hannan belt).

Table 1 Stratigraphic division and correlation of Neoproterozoic strata in the South China Plate (Revised after Gao et al. 2010a, b)



Note the isotopic ages above are listed with unit of Ma, data from (1): tuff from Sibao Group, Gao et al. (2010b); (2): Zhaigun granite, Wang et al. (2006); (3): Motianling granite, Gao et al. (2010b); (4): Dongma granite, Wang et al. (2006); (5): Bendong granite, Wang et al. (2006); (6): tuff from Sanmenjie Formation of Danzhou Group, Zhou et al. (2007); (7): tuff from Fanjingshan Group, Gao et al. (2010b); (8): basalt from the Huixiangping Formation of Fanjingshan Group, Zhou et al. (2009); (9): basalt from the Huixiangping Formation of Fanjingshan Group, Zhou et al. (2009); (10): basalt from the Xiaojiahe Formation of Fanjingshan Group, Zhou et al. (2009); (11): muscovite granite intruded into Fanjingshan Group and overlain by Xiajiang Group, Wang et al. (2011); (12): Gangbian granite unconformity overlain by Xiajiang Group, Chen et al. (2007); (13): gabbro intruded into Fanjingshan Group, Xue et al. (2012); (14): tuff from the Hongzixi Formation of Xiajiang Group, Gao et al. (2010a); (15)–(17): tuff from the Ejiaao Formation of Xiajiang Group, Wang et al. (2010); (18): tuff from Cangxi Group, northeastern Hunan Province, Gao et al. (2011b); (19): volcanic rock from the Yunjunli of Lengjiaxi Group; Bai et al. (2010); (20): bentonite from Lengjiaxi Group, and Linxiang, Hunan Provinces, Gao et al. (2011a); (21): Zhangbangyuan granite in northeastern Hunan Province, Ma et al. (2009); (22): Yexijiang granodiorite in Bucheng country of Hunan Province, Bai et al. (2010); (23): dacitic agglomerate from the Cangshuipu Formation of Banxi Group, Wang et al. (2003); (24): tuff from the Wuqiangxi Formation of Banxi Group, Zhang et al. (2008b); (25): bentonite from the Zhangjiawan Formation of Banxi Group, Gao et al. (2011a); (26): trachybasalt intruded into Banxi Group and overlain by Nanhua System, Zhou et al. (2007); (27): rhyolitic tuff from the Hengyong Formation of Shuangqiaoshan Group, Wang et al. (2008); (28): quartz-keratophyre from the Hengyong Formation of Shuangqiaoshan Group, Wang et al. (2008); (29): fuff from the Hengyong Formation of Shuangqiaoshan Group, Gao et al. (2008a); (30): tuff from the Anlelin Formation of Shuangqiaoshan Group, Gao et al. (2008a); (31): Jiuling cordierite-bearing granodiorite intruded into Shuangqiaoshan Group, Li et al. (2003a); (32): cordierite-bearing granodiorite,Li et al. (2001); (33): gabbro intruded into Shuangqiaoshan Group,Wang et al. (2008); (34): gabbro from ophiolites in southern Anhui Province, Ding et al. (2008); (35): wehrlite from ophiolites in southern Anhui Province, Ding et al. (2008); (36): Shexian granite, Xue et al. (2010); (37): Xucun granite, Wu et al. (2006); (38): Xiuning granite, Xue et al. (2010); (39): Xiuning granite, Wu et al. (2006); (40): Xucun granite, Li et al. (2003a); (41): tuff from the Jingtan Formation, Wu RX et al. (2007); (42)–(43): dacites from the Jingtan Formation, Wu et al. (2007);(44)–45: Shiershan granite, Xue et al.

(2010); Wu et al. (2005a); (46): Jadeite-kyanited anorthosites in Xiwan area, Li et al. (1994b); (47): rhyolite from the Beiwu Formation of Shuangxiwu Group, Li et al. (2009); (48): rhyolite from the Zhangcun Formation of Shuangxiwu Group, Li et al. (2009); (49): dacite from the Niuwu Formation of Shangxi Group, Gao et al. (2009); (50): high-Mg diorite intruded into Shuangxiwu Group, Chen et al. (2009); (51): basaltic porphyrite intrude into Shuangxiwu Group, Chen et al. (2009); (52): Taohong granite intruded into Shuangxiwu Group, Ye et al. (2007); (53): Xiqiu granite intruded into Shuangxiwu Group, Ye et al. (2007); (54): plagioclase granite, Chen et al. (2009); (55): pyroxenolite,Wangs et al. (2012; (56): quartz diorite, Wang et al. (2012); (57): tuff from the Heshangzhen Group, Gao et al. (2008a)

2.1 The Early to Middle Neoproterozoic Jiangnan Belt

Abundant Early to Middle Neoproterozoic geological bodies exposed in Jiangnan belt, which are composed of extremely thick volcanic sedimentary sequences, except for some granitic intrusions. This volcanic sedimentary suite shows bilayer structure: the lower structural layer comprises Sibao Group exposed in Guangxi, Fanjingshan Group in Guizhou, Lengjiaxi Group in Hunan, Xikou Group in Anhui, Shuangxiwu and Pingshui groups in Zhengjia, etc.; the upper structural layer includes Danzhou Group exposed in Guangxi, Xiajiang Group in Guizhou, Banxi Group in Hunan, Likou Group in Anhui, and Heshangzhen Group in Zhejiang. The lower structural layer was considered to be the Mesoproterozoic strata sequence in the published papers (Cheng 1994; BGMRGX 1985; BGMRGZ 1987; BGMRHN 1988; BGMRJX 1984;

BGMRZJ 1989; Xu et al. 2008). However, recent SHRIMP and LA-ICP-MS zircon U-Pb dating revealed these complexes formed at the Early Neoproterozoic. The upper structural layer was overlain on the lower structural layers with unconformable contacts (Fig. 1b), and distinct orientations of them and boundaries with uneven surfaces could be observed locally (Fig. 1a–c). The tectonic event of Wuling Orogeny was considered to result in the unconformity between two structural layers. In Lucheng, Linxiang City of the Hunan Province, it can be recognized that the Banxi Group of the upper structural layer was overlain on the Lengjiaxi Group of the lower structural layer with unconformable contact. The SHRIMP zircon U-Pb dating revealed that the tuffs in the Lengjiaxi Group gave an age of 822 ± 10 Ma and tuffs in the overlain Banxi Group yielded an age of 803 ± 8 Ma (Gao et al. 2011a), which constrained the Wuling Orogeny during 820–803 Ma. The lower structural layers are characterized by the developments of high-angle closed upright folds and chevron folds (Fig. 1d), and the upper structural layers are characterized by developments of relax folds (Fig. 1c). Conglomerates usually develop at the bottom of the upper structural layers (Danzhou, Xiajiang, and Banxi Groups) (Fig. 1f), and these conglomerates contain mainly gravels of quartzite (quartz vein), phyllite, slate, and granite. The stratigraphic division and correlation of the Early to Middle Neoproterozoic strata for diverse areas of the Jiangnan belt and respective isotopic ages are listed in Table 1.

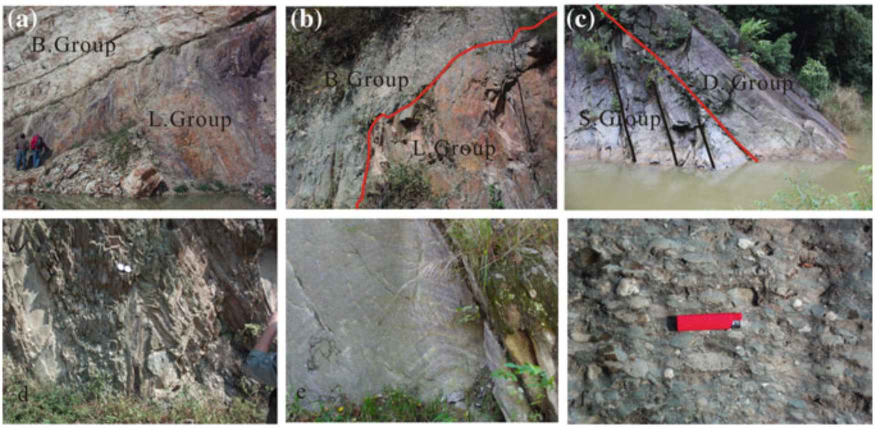


Fig. 1 Unconformities and tectonic features between the lower and upper structural layers **a** Hunan Linxiang-Lucheng Banxi group (*B.Group*) unconformably blanketed on the Lengjiaxi group (*L.Group*); **b** Hunan Yuanling-Madiyi Banxi group (*B.Group*) unconformably blanketed on the Lengjiaxi group (*L.Group*) with uneven surface; **c** Guangxi Luocheng-Huangjin Danzhou group (*D.Group*) unconformably blanketed on the Sibao group (*S.Group*); **d** Hunan Yuanling-Madiyi Lengjiaxi group, tight homoclinal folding; e-Guizhou Taihe Xiajiang group of upper structural layer with rolling fold with axial plane cleavages; **f** Hunan Yuanling-Madiyi Banxi group of the upper structural layer with conglomerates at the bottom

In the Jiangnan belt, terranes of the lower structural layers, e.g., Sibao, Fanjingshan, Lengjiaxi, Xikou, and Shuangxiwu Groups, consist mainly of a set of low-grade metamorphic volcanic sedimentary rocks, and these rocks show distinct lithological associations and timings in diverse areas.

In the border land of Anhui–Zhejiang–Jiangxi Provinces, the Shuangxiwu Group of the Jiangnan belt consists of a set of basic–intermediate and intermediate–acidic lavas, and pyroclastic rocks interbedded by the sandy, siliceous, carbonaceous shale and limestone lens. Some researchers suggested that the combination of these rocks was similar to ophiolitic melange (Zhou et al. 1989, 1990; Zhou and Zhao 1991; Zhou 1997; Shen et al. 1992; Li et al. 1994a; Zhao et al. 1995), and later blue schists were discovered in this complex (Zhou et al., 1989; Gao 2001). The high-pressure metamorphic rocks consist mainly of aragonite–jadeite blue schists (Zhou 1989), jadeite-bearing aegirine albite hornblende schists, jadeite-bearing aegirine quartz albite rocks, glaucophane quartz albite schists, and torendrikite quartz schists (Gao 2001), and the pressure of the peak metamorphism has over 12 kbar (Zhou et al. 1989, Zhou 1997; Gao 2001). The SHRIMP zircon U-Pb dating revealed the rhyolites of the Shuangxiwu with ages of 891–926 Ma, which was interpreted to represent their crystallization ages (Li et al. 2009). The K-Ar isotopic dating revealed the glaucophane of these blue schists with ages at 866 ± 14 Ma (Shu et al. 1994) and the $^{40}Ar/^{39}Ar$ isotopic dating constrained the crossites with ages of 799 Ma (Hu et al. 1992). These metamorphic ages have provided well constraints on the timing of the high-pressure metamorphism (Shu et al. 1994; Hu et al. 1992;

Gao 2001; Shen and Geng 2012). The zircons from gabbro in Fuchua ophiolite belt yielded two groups of age of 891 ± 13 and 824 ± 3 Ma, the former were interpreted as inherited zircon age, and the latter were interpreted as crystallization age of the gabbro (Zhang et al. 2012). Based on the dating and geochemical feature of gabbro, authors consider that the Fuchuan ophiolite was formed in the back-arc basin at about 825 Ma due to partial melting of the enriched mantle wedge (Zhang et al. 2012).

The Shuangqiaoshan Group (Wannian Group) in the north of Jiangnan belt, northern Jiangxi Province, consists dominantly of the extreme thick muddy, sandy sedimentary rocks, interbedded by minor volcanic rocks. This volcanic suite is composed mainly of splites and quartz keratophyres (Wang et al. 2008; Zhao and Cawood 2012) The Shuangqiaoshan Group, from bottom to top, was categorized into the Hengyong Formation, Jilin Formation, Anlelin Formation, and Xiushui Formation within successions (Gao et al. 2008; Wang et al. 2008) These rocks experienced widely greenschist phase metamorphism and strong deformations (dominantly folding deformations with slaty cleavages but few synchronous faults developed) (Xue et al. 2010). The sedimentary environment for the Shuangqiaoshan Group remains disputed recent years. On the basis of the sedimentary formation, Huang et al. (2003) proposed the gravity flow deposit system of the littoral and bathyal environments for the Shuangqiaoshan Group; however, Chen et al. (2002) suggested turbidity current phase of bathyal and abyssal environments for these sedimentary rocks. The LA-ICPMS zircon U-Pb dating revealed the quartz keratophyres and the rhyolitic tuffs of the Hengyong Formation of lower Shuangqiaoshan Group, respectively, at 878 ± 4 and 879 ± 5 Ma (Wang et al. 2008). The SHRIMP an LA-ICP-MS zircon U-Pb dating has constrained the Shuangqiaoshan Group (Wannian Group) formed during 880–830 Ma (Gao et al. 2008a; Wang et al. 2008; Liu et al. 2013; Yao et al. 2014).

In the southwest of Jiangnan belt, the lower structural layers consist of mainly Sibao Group in Guangxi, Fanjingshan Group in Guizhou, and Lengjiaxi Group in Hunan. These groups are composed dominantly of low-grade, mostly greenschist facies, metamorphic sandstones, siltstones, and slates with interbedded mafic-ultramafic and basaltic volcanic rocks with strong deformations (Fig. 1d). The volcanic sequences, in Sibao area of Guangxi, Fanjingshan area of Guizhou, and Yiyang area of Hunan, are relatively thick and composed mainly of basalts with developments of the pillow structure (Fig. 2), indicating an underwater eruption environment. The ultramafic rocks in Sibao area of Guangxi were previously considered to be komatiites (Yang 1990; Tang et al. 1992). However, lack of spinifex structure and low contents of MgO (<30 wt%) suggested that these ultramafic rocks should belong to the komatiitic basalts and high-Mg basalts with cumulative characteristics (Ge et al. 2001). The mafic-ultramafic volcanic rocks were usually accompanied by the intrusions of mafic gabbros. The published geochronological data have constrained the Sibao Group during 842–830 Ma (Gao et al. 2010b; Wang et al. 2012), the Fanjingshan Group during 840–815 Ma (Gao et al. 2010b; Zhou et al. 2009), and the Lengjiaxi Group during 855–822 Ma (Gao et al. 2011a, b; Bai et al. 2010). The forming environment for

Fig. 2 The pillow lava in Guizhou Fanjingshan group (**a**); Guangxi Sibao group (**b**); and in Hunan Yiyang area (**c**)

these mafic-ultramafic volcanic rocks remains disputed. Some workers considered similar incompatible element distribution characteristics and εNd(t) values between the ultramafic rocks in Sibao area of Guangxi and the dike swarms at Gairdner of Australia, and then suggested these volcanic rocks correlated with the mantle plume resulting in the break off of the Rodinia supercontinent during Neoproterozoic (Ge et al. 2001). Others researchers, on the basis of the enrichments of strong incompatible elements (e.g., LREEs, Rb, Ba, Th, and U), the strong depletion of HFSEs (e.g., Nb and Ta), and the low εNd(t) values, proposed back-arc limited oceanic basin during subduction for these volcanic rocks (Xue et al. 2012; Yao et al. 2014).

In general, the Early to Middle Neoproterozoic strata of the Jiangnan belt show distinct lithologic associations in the diverse area. The eastern Shuangxiwu Group is composed of mainly volcanic sequence with the lithologic combination similar to the ophiolitic melanges. The Shuangqiaoshan Group contains minor volcanic rocks in the north-center of Jiangxi, but more basaltic volcanic rocks with pillow structure in the southwest of Guizhou and Guangxi Province. The distinction in the lithologic associations of the Groups, in diverse areas, demonstrates their possible differences in forming environment. In addition, the isotopic dating constrained the Shuangxiwu Group in the east at 891–926 Ma, the Shuangqiaoshan Group in the north-center at 880–830 Ma, and the Lengjiaxi Group, the Fanjingshan Group, and the Sibao Group in the southwest, respectively, at 855–822, 840–815, and 842 ± 6 Ma, showing younger isotopic ages from the east to the southwest.

Except for the Early to Middle Neoproterozoic strata mentioned above, the Jiangnan belt also contains mounts of granites, which intrude into the lower structural layers and are overlain by the upper structural layers with unconformable contacts, indicating their synchronous emplacements with the lower structural layers. Some granites intruded into the lower structural layer and are exposed without any covers of the upper structural layers. As mentioned above, the Wuling Orogeny (movement), which resulted in the unconformity between the lower and upper structural layers, has been suggested to happen at ~820 Ma, and then we consider the granites with ages older than 820 Ma synchronous with the lower structural layers. In the border of Anhui, Zhejiang, and Jiangxi Province, geochronological data have constrained the high-Mg diorite intruding into the Shuangxiwu Group at 932 Ma (Chen et al. 2009), the Taohong granite at 913 Ma and the Xiqiu granite at 905 Ma (Ye et al. 2007), the plagiogranite at 902 Ma (Chen et al. 2009), and the amphibole pyroxenite at 844 Ma (Wang et al. 2012). A lot of granites exposed along the Qimen-Shexian-Sanyangkeng arc-shaped zone in the southern Anhui Province, which were categorized into two Groups, the S-type and A-type granite. The S-type granites have been considered to be part of the lower structural layer, and the A-type granites, intruding into the Shangshu Formation in the Heshangzhen Group or the Jingtan Formation in the Likou Group of Late Neoproterozoic (Xue et al. 2010), are obviously attributed to the upper structural layer. In this fracture zone, a mass of granites was recognized in the lower structural layer, including the Xucun pluton, Shexian pluton, and Xiuning pluton. The Xucun pluton is composed of gneissic granodiorites, and the SHRIMP zircon U-Pb dating revealed their crystallization age at 823 ± 12 Ma (Li et al. 2002b) and LA-ICPMS zircon U-Pb dating obtained isotopic ages ranging from 852 ± 6 to 820 ± 10 Ma (Xue et al. 2010; Wu et al. 2005b; Li et al. 2003a). The Shexian pluton is composed of granodiorites with weak deformations, and the LA-ICPMS zircon U-Pb isotopic dating obtained their crystallization ages of 823 ± 10 Ma (Wu et al. 2005b) and 837 ± 14 Ma (Xue et al. 2010). The Xiuning pluton consists mainly of the undeformed granodiorites, and the LA-ICPMS zircon U-Pb isotopic dating obtained their crystallization ages of 826 ± 6 and 824 ± 6 Ma for these granodiorites (Xue et al. 2010; Wu et al. 2005b). The Early Neoproterozoic Jiuling pluton, as the largest Neoproterozoic pluton in Jiangnan belt, exposed in the northern Jiangxi with outcrop of ca. 2500 km^2, intruding into the Shuangqiaoshan Group and covered by the Middle to Late Neoproterozoic Dongmen Formation (as section of the Banxi Group in Hunan) with unconformable contacts (Li et al. 2003a). This batholith is composed mainly of cordierite-bearing muscovite diorites. Many synchronous plutonic records were also reported by the previous researchers, such as the muscovite granite at 823 ± 2 Ma, intruding into the Fanjingshan Group and covered by Xiajiang Group with unconformable contacts (Wang et al. 2011); the gabbros at 821 ± 4 Ma (Xue et al. 2012) in Guizhou Province; and the Xiutang pluton and Gangbian pluton, respectively, at 836 ± 5 Ma (Fan et al. 2010) and 823 ± 2 Ma (Chen et al. 2007), intruding into the Sibao Group and covered by the Jialu Formation of the Xiajiang Group. In Guangxi Province, amount of plutons, such as the Gunzhai pluton (836 ± 3 Ma), the Bendong pluton (823 ± 4 Ma), the Dongma pluton (824 ± 13 Ma) (Wang et al. 2006), the Motianling pluton (827 ± 6 Ma, Gao et al. 2010b), and Yanbaoshan pluton (822 ± 5 Ma ~ 833 ± 6 Ma, Yao et al. 2014), intruded into the Sibao Group and were overlain by the Danzhou Group of the upper structural layer with unconformable contacts. These granites show mostly alkali-rich peraluminous to strongly peraluminous features similar to S-type granite (Li et al. 2002b; Wang et al. 2006, 2011; Xue et al. 2010; Fan et al. 2010). These granites show the zircon $\varepsilon_{Hf}(t)$ ranging from −10 to +10 (see Fig. 8 of chapter "Late Archean—Mesoproterozoic geology of the Tarim Craton"), indicating their derivations from partial melting of the crustal rocks. The tectonic environment for these granites remains disputation in recent years. Some researchers suggested syn-collisional emplacements (Xue et al. 2010; Bai et al. 2010; Yao et al. 2014); however, others proposed post-collisional extensional emplacements for these granites (Fan et al. 2010), and some workers considered these granites derived from partial melting of crustal rocks caused by the upwelling mantle plume (Li et al. 2002b; Wang et al. 2006, 2011).

In Jiangnan belt, the upper structural layer of the Early to Middle Neoproterozoic are composed mainly of Danzhou Group in Guangxi, Xiajiang Group in Guizhou, Banxi Group in Hunan, Xiushui Group in northern Jiangxi, Likou Group in southern Anhui, and Heshangzhen Group in northern Zhejiang. These groups consist of low-grade metamorphic sandstone, siltstone, slate, and phyllite, interbedded by volcanic rocks. The lithologic associations are different in diverse area, and various stratigraphic divisions have been proposed, respectively. The Heshanzhen Group, in the northeast of the Jiangnan belt, was divided into the Luojiamen Formation, Hongchicun Formation and Shangshu Formation from the bottom to top, which covered on the intermediate-acidic volcanic rocks of the pre-Sinian Shuangxiwu Group and was overlain by the Zhitang Formation of the Sinian with unconformable contacts. The Luojiamen Formation consists of a set of pyroclastic rocks with dominantly greywackes and sand slates, and the conglomerates show glaciations-related characteristics. The Hongchicun Formation is composed of purple thick sandstones, and the Shangshu Formation consists of mainly terrestrial basic and acidic volcanic associations, which contain basalts in the lower segment and the rhyolites in the upper segment, showing bimodal volcanic features. The Banxi Group in the center of Jiangnan belt is divided into the Cangshuipu Formation, Madiyi Formation, and Wuqiangxi Formation from the bottom to top. The Cangshuipu Formation is composed of meta-andesite, dacitic agglomerate, andesitic–dacitic conglomerate, and dusty tuff within limited outcrop (Gao et al. 2012). The Madiyi Formation consists dominantly of conglomerate, sandy conglomerate, siltstone, muddy slate, calcic slate with interbedded limestone, carbonaceous slate, and sandy slate. The Wuqiangxi Formation contains mainly pebbly sandstone interbedded by sandy conglomerate, sandstone, and siltstone with muddy slate bedding in the lower segment; the silty slate, rhyolitic sandstone, and slate interbedded by crystal pyroclast-bearing sedimentary tuff in the middle segment; and the pebbly sandstone, feldspathic quartz sandstone, silty slate, and sedimentary tuff in the upper segment. The Madiyi Formation and Wuqiang Formation is characterized by the heather intraclastic Formation with purple-gray fuchsia and gray-sage green interbeddings and named as “Hongbanxi,” which stands for red slaty feature in Chinese. The Danzhou Group, in the southwestern Jiangnan belt, is divided into Baizhu Formation, Hetong Formation, Sanmenjie Formation, and Gongdong Formation from the bottom to top. The Baizhu Formation consists of mainly pebbly sandstone, siltstone, sericite schist, and calcic schist, and the Hetong Formation is composed of sericite schist and calcic schist. The Sanmenjie Formation contains dominantly basic volcanic rocks, and the Gongdong Formation consists of mainly sericite quartz schist and slate. The Danzhou Group, Xiajiang Group, and Gaojian Group in the southwestern margin of Jiangnan belt show mostly sage green and rubricans features, and then are named as “Heibanxi,” which stands for black slaty characteristics in Chinese.

The LA-ICPMS zircon U-Pb dating revealed the dacites at 820 ± 16 and 773 ± 7 Ma, and the volcanic tuff at 779 ± 7 Ma in the Jingtan Formation of Likou Group at the northeastern segment of the Jiangnan belt (Wu et al. 2007). SHRIMP zircon U-Pb dating revealed the tuff in Heshangzhen Group at 767 ± 5 Ma (Gao et al. 2008a). In the center of Jiangnan belt, SHRIMP zircon U-Pb dating revealed tuffs in Wuqiangxi Formation of Banxi Group at 809 ± 12 Ma (Zhang et al. 2008b), the dacitic agglomerate of the Cangshuipu Formation at 814 ± 12 Ma (Wang et al. 2003), and bentonites of Zhangjiawan Formation at 803 ± 8 Ma (Gao et al. 2011b). In the southwestern Jiangnan belt, the SHRIMP zircon U-Pb dating revealed the tuff in the Hongzixi Formation of Xiajiang Group at 814 ± 6 Ma (Gao et al. 2010a); three samples of pyroclastic crystal bearing tuffs in the Ejiaao Formation of Banxi Group in nearby Tongren, respectively, at 780 ± 93, 782 ± 8, and 785 ± 8 Ma (Wang et al. 2010); and the volcanic rocks in Sanmenjie Formation of Danzhou Group in northern Guangxi at 765 ± 14 Ma (Zhou et al. 2007). Recently, Gao et al. (2013a) obtained SHRIMP zircon U-Pb ages of 801 ± 3 and 787 ± 6 Ma for the tuffs in the middle segment of the Hetong Formation and upper segment of the Gongdong Formation of Danzhou Group, respectively. But detrital zircon dating demonstrates that the Danzhou Group formed between ~770 and 730 Ma. Geochronological data listed above are mostly older than 780 Ma, and then we consider forming of the Early to Middle Neoproterozoic upper structural layer during 820–780 Ma, suggesting the bottom of the Nanhua System at 780 Ma. However, there are still some geochronological data younger than 780 Ma, such as the 765 Ma old volcanic rocks in Sanmenjie that obviously younger than the bottom age of Nanhua System, and some detrital zircon ages younger than 780 Ma. In summary, the bottom of the Nanhua System remains still debated and deserves considerably studies.

2.2 Early to Middle Neoproterozoic Strata in Panxi-Hannan Belt

Early to middle Neoproterozoic strata in Panxi-Hannan belt are composed of Yanbian Group, Suxiong Formation, and Kaijianqiao Formation in the western Sichuan, Bikou Group in the northwestern of Yangtze Block, and Hannan Complex in the northern Yangtze Block.

Yanbian Group is mainly distributed in the southwestern Yangtze Block and subdivided into Huangtian Formation, Yumen Formation, Xiaoping Formation, and Zhagu Formation from bottom to top (Fig. 3). Huangtian Formation consists of basalts, breccia-bearing volcanic rocks, and breccia lavas, with thin siliceous rocks as intercalated beds. In addition, basalts occurred with pillow structure. The lower segment of Yumen Formation is composed of light-gray to dark-gray carbonaceous slates, sericite slates, and siliceous slates, interbedded with crystalline limestones as lenses, metamorphosed maristones, and sandy limestones. Light-gray sandstones

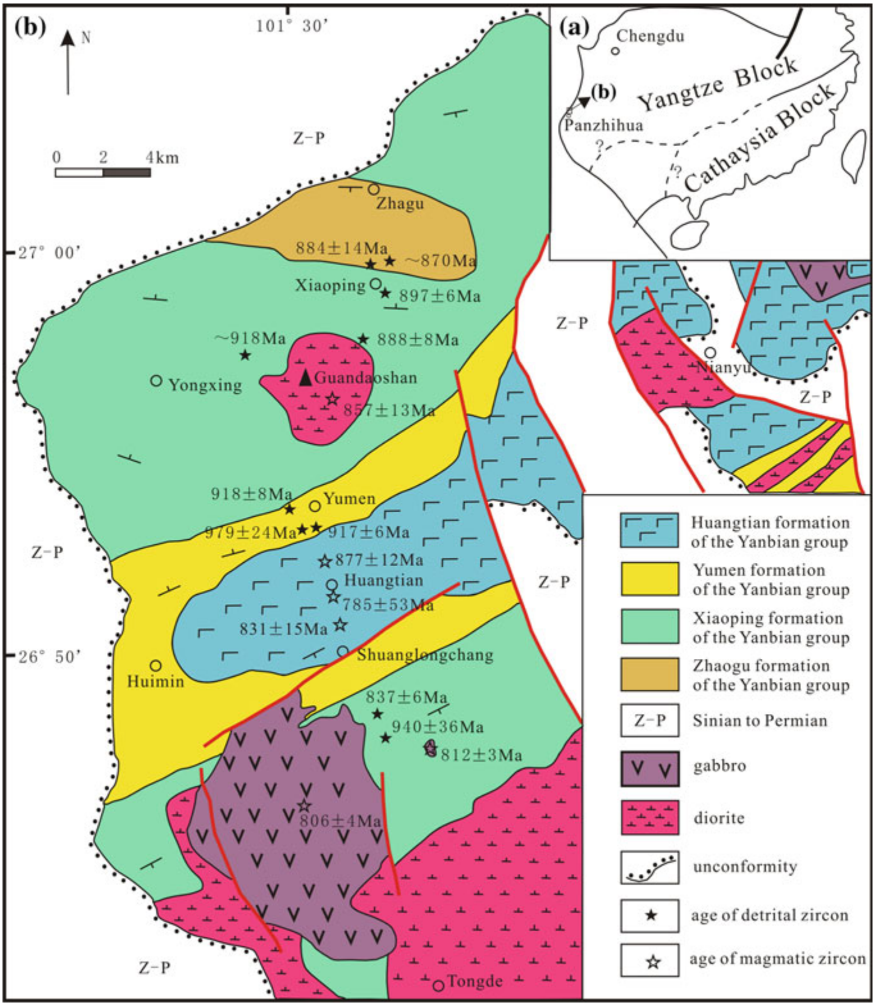


Fig. 3 Geological map of Yanbian area in Sichuan Province *Note* Geochronological data from Du et al. (2005, 2013), Zhou et al. (2006a), Li et al. (2003b), Sun and Zhou (2008), Sun et al. (2009), Du (2010)

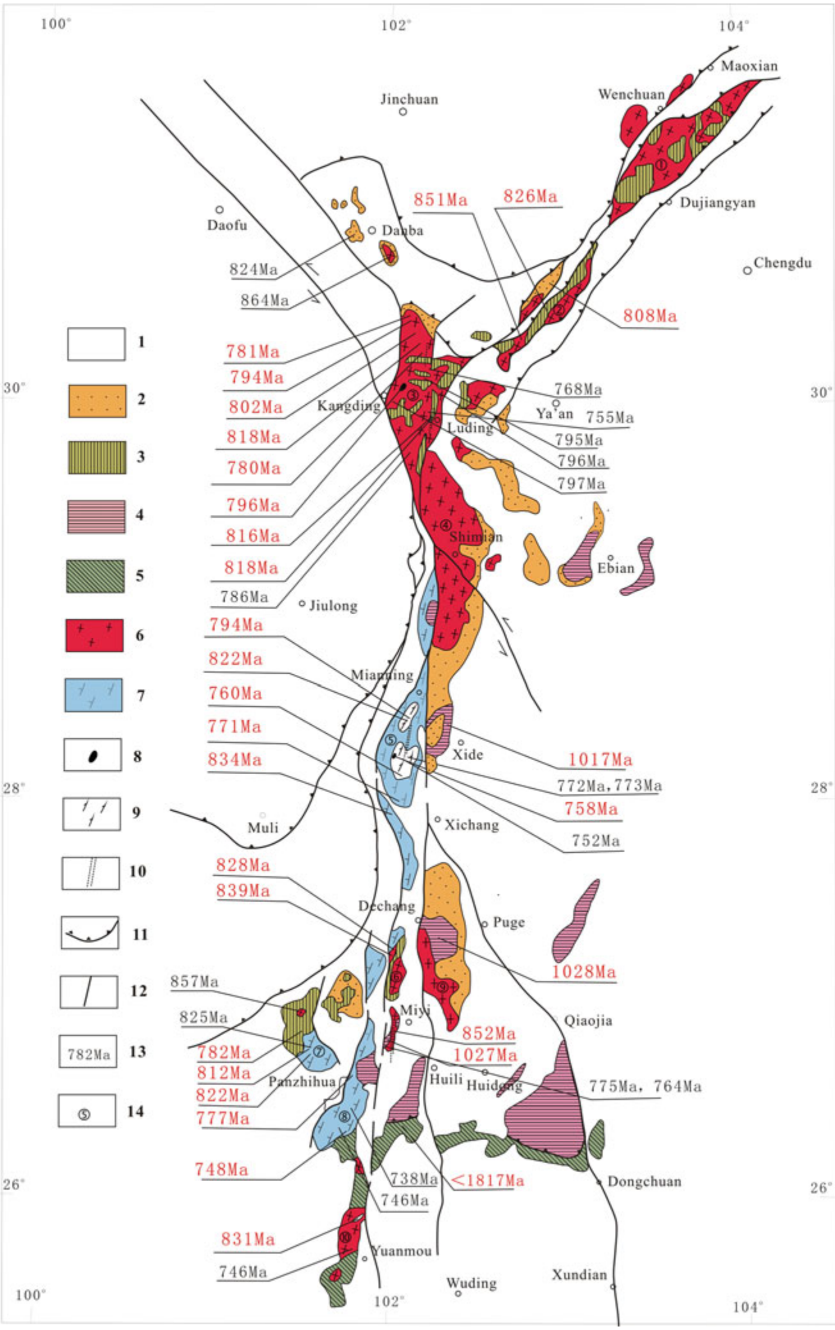
occur as parallel bedding and graded bedding structure. The middle-top segment comprises a rhythmite which consists of metamorphosed tuffaceous slates, sandy slates, and slates with developed folds. Yumen Formation with thickness of about 1,700 m displays a conformable contact with underlying Huangtian Formation. Xiaoping Formation contains light-gray, dark-gray sericite slates, sandy slates, and carbonaceous slates, which are interbedded with metamorphosed sandstones and carbonaceous slates. Thick-bedded metamorphosed tuffaceous fine conglomerate and sandstones constitute the lower segment, and carbonaceous slates constitute the upper segment with increasing thickness, and certain sedimentary tectonics such as convolute bedding and wave erosion surface. Locally, the whole Bouma sequence occurs (Sun et al. 2008) and granitic veins invade. Xiaoping Formation, 2, 260 m thick, occurred in conformable contact with underlying Yumen Formation (BGMRSC, 1991). Zhagu Formation is primarily composed of sericite slates, siltstone, and slate, and its bottom consists of metamorphosed tuffaceous conglomerate or sandy conglomerate as lenses. The gavels are mainly volcanic lavas. The lower segment of Zhagu Formation is composed of carbonaceous slates, metamorphosed fine sandstones, and siltstones, and the upper segment is interbedded with dolomite limestones and slates. Brecciaous dolomite limestones were locally exposed. Zhagu Formation shows parallel uncomfortable contact with underlying Xiaoping Formation. Some researchers (Li et al. 1983; Li 1984; Sun et al. 1994) suggested that volcanic rocks in Huangtian Formation and south Gaojiacun mafic intrusion might be ophiolite suite in last 1980s; however, later investigations negated the “ophiolite”, so it still is a hot-debated issue on the tectonic setting of Yanbian Group. Some researchers argued that both Yanbian Group and contemporary magmatic rocks formed in an extensional environment caused by mantle plume (Li et al. 2003b, 2006). Some researchers believed they formed in arc environment (Zhou et al. 2002a, 2006a, b). Other proposed that Yanbian Group was a back-arc basin which was related to the subduction induced by western oceanic crust of the Yangtze Block (Du et al. 2005; Sun et al. 2007). And some argue the lower segments of Yanbian Group formed in back-arc basin-related setting while the upper Zhagu Formation in foreland basin environment (Jiang et al. 2005).

Yanbian Group was used to consider as the Mesoproterozoic fold basement of Yangtze Block (Li et al. 1983, 1988; BGMRSC, 1991; Cheng 1994). Figure 3 exhibits isotopic age data measured by in situ zircon dating and reveals that the peak ages of detrital zircons range from 979 to 837 Ma, the age of Lengshuiqing pluton which intruded into Yanbian Group is 812 ± 3 Ma, and the age of Gaojiacun pluton which intruded Xiaoping Formation and Yumen Formation is 806 ± 4 Ma (Zhou et al. 2006a). The ages of Guandaoshan pluton which intruded Xiaoping Formation in the north are 857 ± 13, 857 ± 7, 856 ± 6, and 856 ± 8 Ma (Li et al. 2003b; Du et al. 2014). Recent study reveals that the formation ages of basalts from Yanbian Group vary from 877 to 831 Ma (Du 2010; Du et al. 2013). According to various ages mentioned above, the ages of Yanbian Group is likely to be limited between 880 and 830 Ma. In terms of the lithologies and formation ages, Yanbian Group resembles the lower structural layers in Jiangnan belt such as Sibao Group and Fanjing Group.

Except Yanbian Group, early to middle Neoproterozoic low-degree metamorphic strata in the west of Sichuan also consist of Suxiong Formation and Kaijianqiao Formation. Suxiong Formation is primarily composed of extraordinarily thick acid volcanic rocks (mainly rhyolites and dacites, thickness varies from hundreds meters to ten thousands meters), which is interbedded with minor mafic volcanic rocks and pyroclastic rocks. In addition, the proportion of mafic rocks to acid rocks is about 1:9 (Li et al. 2002a). Kaijianqiao Formation mainly comprises purple or gray-green acid pyroclastic rocks and tuffaceous sandstone. Geochemically, the acid volcanic rocks from Suxiong Formation resemble A_2-type granite forming in extensional tectonic setting. SHRIMP zircon U-Pb isotopic dating revealed that an age of acid volcanic rocks from Suxiong Formation is 803 ± 12 Ma (Li et al. 2001b, 2002a) and age of tuff from Kaijianqiao Formation is 801 ± 7 Ma (from Jiang et al. 2012), which are similar to early to middle Neoproterozoic upper structural layer in Jiangnan belt such as Danzhou Group, Xiajiang Group, and Banxi Group.

Various degrees of metamorphic rocks were exposed within a north-south trend belt, which is 700 km long and several ten thousands meters wide and distributed in western Sichuan Province to Yuanmou of Yunnan Province. Researchers used to name them Kangding Group or Kangding Complex, which constitutes an Archean to Paleoproterozoic crystalline basement (BGMRSC 1991; Cheng 1994). For a decade years, however, amounts of studies revealed that abundant deformed rocks occurred within Kangding Complex, such as granitic gneisses with ages of 797 ± 10, 795 ± 11, and 796 ± 13 Ma in Kangding area (SHIRMP U-Pb dating method, Zhou et al. 2002a); biotite trondhjemites in Gezhong area with age of 864 ± 11 Ma (SHIRMP U-Pb dating method, Zhou et al. 2002a); diorites and granodiorites in Guzan area with ages of 768 ± 7 and 755 ± 6 Ma (SHIRMP U-Pb dating method, Li et al. 2003); mozogranite ing Kangding area with an age of 767 ± 24 Ma (SHIRMP U-Pb dating method, Liu et al. 2009); diorites in Tianwan area with age of 823 ± 12 Ma and granites 876 ± 40 Ma in Pianlugang area within Kangding-Luding area (SHIRMP U-Pb dating method, Guo et al. 1998); granites in Huangcaoshan with age of 786 ± 36 Ma and Xiasuozi granites with an age of 805 ± 15 Ma (TIMS zircon U-Pb dating method, Shen et al. 2000); gabbros yielding ages of 752 ± 11 and 752 ± 12 Ma (Li et al. 2003); and granitic gneiss 772 ± 15 Ma (Chen et al. 2005) in Shaba area. We also recognized plenty of early to middle Neoproterozoic deformed magmatic rocks (Geng et al. 2007, 2008; Fig. 4). Figure 4 illustrates Neoproterozoic complex from the western Yangtze Block formed from 746 to 864 Ma, especially focusing during 840–780 Ma. Furthermore, the lithologies of complex vary from granitic, intermediate mafic to ultramafic rocks, and mafic dykes (Zhu WG et al. 2008). It is still not clear that weather these distinguished rocks formed by same geological event.

Neoproterozoic Bikou Group is located in Shaanxi, Gansu, Sichuan Provinces' junction, northwestern Yangtze, from Mianxian in Shaanxi to Pingwu in Sichuan and many places between them like Kangxian, Bikou in Gansu, with an exposed area of about 10,000 km^2. There have been controversies on the constituent and formation age of Bikou Group. One clastic sedimentary suit from above Bikou Group was named Hengdan Group (Zhang et al. 1993; Yan et al. 2004a). Now most researchers proposed that Bikou Group consists of only low-degree metamorphosed volcanic suit (Pei 1989; Xia et al. 1989; Xu et al. 2002; Yan et al. 2003). Bikou Group primarily comprises mafic to intermediate volcanic rocks and pyroclastic rocks. Volcanic rocks are composed of spilites, basalts, andesites, keratophyres, and minor rhyolite. Pyroclastic rocks consist of breccia lava, tuff lava, volcanic breccia, and tuff. The pyroclastic sedimentary rock suit comprises sedimentary volcanic



100°
102°
104°
30°
28°
26°
Maoxian
Wenchuan
Jinchuan
Dujiangyan
Chengdu
Daofu
Danba
824Ma
864Ma
851Ma
826Ma
808Ma
781Ma
794Ma
802Ma
818Ma
780Ma
796Ma
816Ma
818Ma
786Ma
Kangding
Luding
Ya'an
768Ma
755Ma
795Ma
796Ma
797Ma
Shimian
Ebian
Jiulong
794Ma
822Ma
760Ma
771Ma
834Ma
Mianning
Xide
1017Ma
772Ma,773Ma
758Ma
752Ma
Muli
Xichang
828Ma
839Ma
Dechang
Puge
1028Ma
857Ma
825Ma
782Ma
812Ma
822Ma
777Ma
Miyi
852Ma
1027Ma
Qiaojia
Panzhihua
Huili
Huidong
775Ma, 764Ma
748Ma
738Ma
746Ma
<1817Ma
Dongchuan
831Ma
746Ma
Yuanmou
Wuding
Xundian
1
2
3
4
5
6
7
8
9
10
11
12
13
14
782Ma

◀ **Fig. 4** The distribution of lithologies in the western basement of Yangtze terrane and obtained zircon U-Pb age by SHRIMP dating method 1-Geological body younger than Sinian system, 2-Sinian system, 3-Neoproterozoic stratum, 4-Late Mesoproterozoic stratum, 5-Early Mesoproterozoic rocks, 6-Neoproterozoic granites, 7-Neoproterozoic intermediate -mafic intrusions, 8-super mafic rocks, 9-two-pyroxene gneiss, 10-ductile shear zone, 11-thrust fault, 12-fault, 13-SHRIMP zircon U-Pb age, 14-the numbers of magmatic complexes:① Pengguan Complex;② Baoxing Complex;③ Xiasuozi- Kangding Complex; ④ Shimian Complex; ⑤Mianning Complex; ⑥ Mopanshan-Miyi Complex; ⑦ Tongde Complex; ⑧ Datian Complex; ⑨ Moshaying Complex; ⑩ Longchuanjiang Complex. The red age in the figure is from Geng et al. 2008 and the black one from Zhou et al. 2002a, Li et al. 2002a, 2003, Chen et al. 2005

breccia, sedimentary tuff, tuffaceous sandstone, tuffaceous siltstone, and phyllite (Yan et al. 2004a). Moreover, Bikou Group could be subdivided into three volcanic eruption cycles: the lower segment of the first cycle is mainly composed of spilites, the upper primarily quartz keratophyric tuffs which interbedded with thin lavas. Spilites, spilitic porphyrites, and spilitic tuffs constituted the second cycle, upper of which is composed of quartz keratophyric tuffs, with thin lavas as intercalated beds. The lower segment of the third cycle consists of spilites with pillow structure, and the upper part is mainly composed of quartz keratophyric tuffs and interbedded with metamorphosed sedimentary tuffs or siltites as intercalated beds (Xu et al. 2002). The first cycle is characterized by alkaline volcanic rocks, and the second and third cycle by tholeiitic basaltic rocks. Bikou Formation widely underwent low-greenschist face (Wei 1993). The SHRIMP zircon U-Pb dating ages of three mafic volcanic rocks reveal at 840 ± 10, 846 ± 19, and 876 ± 17 Ma, separately (Yan et al. 2003, 2004b), and the ages of 790 ± 15 and 776 ± 13 Ma for two acid volcanic rocks, separately (Yan et al. 2003). Diorite intruded Bikou Group in Guankouya yielded an age of 884 ± 14 Ma and diorite in Pingtoushan of 884 ± 6 Ma, gabbro with an age of 877 ± 13 Ma by LA-ICPMS U-Pb dating method (Xiao et al. 2007), and granodiorite gave an age of 791 ± 13 Ma and diabase of 689 ± 24 Ma by SHRIMP U-Pb dating method (Yan et al. 2004b) in Liujiaping. Monzonitic granites intruded into Daomuliang Group (equal to Bikou Group) gave ages of 793 ± 11 and 792 ± 11 Ma (Pei et al. 2009). All data are accessed to reveal that Bikou Group and related magmatic rocks mainly formed in the early to middle Neoproterozoic era, though these data are to some extent in conflict, for example, the age of diorite which invaded Bikou Group is older than it of Bikou Group. If turbidites from Hengdan Group (Druschke et al. 2006), which are contemporaneous relationship with Bikou Group, and Bikou volcanic rocks are considered as a whole volcanic sedimentary rock suit, then their constituent resembles Yanbian Group (Sun et al. 2008).

Early to middle Neoproterozoic strata in the north of Panxi-Hannan belt comprise Huodiya Group and Xixiang Group. Huodiya Group is an unconformity relationship with the underlying Houhe Group, which is covered by Sinian System in an unconformity relationship. Houdiya Group was subdivided into three Formations from bottom to top, Shangliang Formation, Mawozi Formation, and Tiechuanshan Formation. Shangliang Formation and Mawozi Formation were metamorphic sedimentary rock suit, which is primarily composed of metamorphosed conglomerates, quartzites, carbonatites, siliceous rocks, and slates. Tiechuanshan Formation is volcanic rock suit and mainly composed of red alkaline rhyolites, dacite–rhyolites, tholeiitic basalts, ignimbrite, and pyroclastic rocks, which is characterized by bimodal volcanic rocks geochemically (Ling et al. 1996a). On the basis of the whole-rock Sm–Nd isotopic ages, Huodiya Group was considered as Mesoproterozoic rock series (Ling et al. 1996a). The rhyolite with an age of 817 ± 5 Ma in Tiechuanshan Formation was recognized later by TIMS zircon U-Pb dating method (Ling et al. 2003). According to the comparison with Xixiang Group, Huodiya Group is identified as early to middle Neoproterozoic strata sequence. Xixiang Group is a volcanic sedimentary rock suit and traditionally subdivided into six Formations from bottom to top, Baimianxia Formation, Sanwan Formation, Sanhuashi Formation, Sunjiahe Formation, Dashigou Formation, and Sanlangpu Formation. Some researchers also divide Xixiang Group into two suits: the lower suit is composed of low-K basalts erupting undersea and basaltic andesites, with metamorphosed sedimentary rocks as intercalated beds, while the upper suit consists of calc-alkaline to alkaline basaltic andesites, dacites, rhyolites which erupted under water, above of which is molasse formation (Ling et al. 2003). The ages during 950–895 Ma were obtained from volcanic rocks of Xixiang Group by single-zircon TIMS U-Pb dating method. However, ages new acquired by LA-ICPMS and SHRIMP zircon U-Pb dating method are much younger recent years. For example, basalts and dacites in Sunjiahe Formation yield ages of 845 ± 17 and 833 ± 5 Ma separately by LA-ICPMS U-Pb dating method (Xia et al. 2009; Xu et al. 2010), and dacites 815 ± 5 Ma by SHRIMP U-Pb dating method (Cui et al. 2010). Rhyolites and porphyrites in Dashigou Formation give ages of 803 ± 5 and 776 ± 6 Ma separately, and basalts of 730 ± 13 Ma by LA-ICPMS U-Pb dating method (Xia et al. 2009). All those ages reveal that Xixiang Group mainly formed between 845 and 770 Ma. Except Neoproterozoic Huodiya Group and Xixiang Group, there are large abundant early to middle Neoproterozoic magmatic complexes in Hannan area, which includes Beiba mafic intrusive complex, Tianpinghe granodiorite, Yangjiahe granodiorite, Maoerzhai moyite, Tiechuanshan aegirine granite, Wangjiangshan mafic complex, and Liunan complex (Ling et al. 1996b). According to tremendous study on isotopic ages recent years, all magmatic complex mainly formed between 820 and 700 Ma, except Liushudian gabbro with age of 898 ± 10 Ma (Zhou et al. 2002a, b; Zhao et al. 2010; Dong et al. 2011, 2012; Xu et al. 2010, 2011). The geochemistry of volcanic rocks in Xixiang Group and Hannan complex revealed that they both formed in continental arc tectonic setting (Xu et al. 2010). On the basis of regional analyses, Dong et al. (2012) proposed that the Neoproterozoic magmatic evolution migrated from south to north in the north Yangtze Block. Arc-related magmatic activity in Michangshan range of the south occurred between 870 and 820 Ma, and in Huijiaba of the middle Yangtze Block occurred from 840 to 820 Ma, and in Hannan area of the north Yangtze Block from 825 to 706 Ma. Such migration from south to north supports a tectonic model of accretionary orogenesis around continental marginal arc in the north Yangtze Block.

2.3 *Early to Middle Neoproterozoic in the Cathaysian Block*

The Neoproterozoic geologic bodies in the Cathaysian Block chiefly exposed in the southwestern Zhejiang Province and Wuyi mountain range in Fujian Province, while there is also sporadic exposures in the area of Nanling and Yunkai areas.

The early to middle Neoproterozoic strata comprise Chencai Group and Longquan Group in the southwestern Zhejiang Province and Mayuan Group, Mamianshan Group, Wanquan Group in Wuyi mountain range, Louziba Group, Jiaoxi Formation in the western Wuyi mountains, and Taoxi Formation at the Wuping area in the southwestern Fujian Province. According to the conventional lithostratigraphic unit, previous investigators analyzed and sorted for the regional strata sequences, and divided these strata as different groups and formations (Gong and Lin 1987; Hu et al. 1991; Gan et al. 1993; Zhuang et al. 2000; Zhang et al. 2005b; Xu et al. 2010; Fu et al. 2010). However, recent researches show that these lithological assemblages underwent a complicated structural deformation, with complicated contact relationships among them, especially showing generally structural contact between Formation and Formation instead of the conventional stratigraphic units (Wan et al. 2007; Li et al. 2010). From these strata, Paleoproterozoic age information was obtained (Li et al. 1998; Wan et al. 2007; Li et al. 2009), while vast Neoproterozoic age information also was documented (Li et al. 2005; Shu 2006; Shu et al. 2006, 2011; Wan et al. 2007; Li et al. 2008a; Li et al. 2009; Xu et al. 2010; Yu et al. 2010). Meanwhile, some Paleozoic age information was discovered from the migmatitic gneisses in these strata (Wan et al. 2007; Zeng et al. 2008). The new obtained data one side indicate a complexity of these lithological assemblages and suggested that these strata were mainly formed in the Neoproterozoic era. These rocks may be roughly divided into two structural layers. The lower structural layer is represented by Chencai Group and Mayuan Group, while the upper structural layer is represented by Longquan Group, Mamianshan Group, and Wanquan Group (Hu et al. 1991; Jin et al. 1997; Jin et al. 2008).

In the traditional ideas, high-grade metamorphic Chencai Group in the southwestern Zhejiang Province and Mayuan Group in the northern Fujian Province may be basically contrasted, of which the Chencai Group in the southwestern Zhejiang Province is mainly composed of aluminum-enriched gneisses, leptites, amphibolites, garnet-mica schists, calc-silicate rocks, and marbles. The Chencai Group was usually divided into four rock assemblages (Kong et al. 1994) and was suggested as khondalite series (Lan et al. 1995), which underwent high amphibolite facies metamorphism (Zhao and Sun 1994; Kong et al. 1994; Lan et al. 1995). Mayuan Group in the northern Fujian Province is mainly composed of sillimanite-bearing mica quartzite schists, garnet biotite plagioclase gneisses, amphibolites, and marbles. Some researches consider that it has undergone a high amphibolite to granulite facies metamorphism (Mei et al. 1993; Zhao and Cawood 1999). Chencai Group and Mayuan Group were traditionally regarded as the metamorphosed basement of the Cathaysian Block, forming in the Paleoproterozoic or Mesoproterozoic (Shui

1988; Shui et al. 1988; Zhao 1999; Kong et al. 1994; Fu et al. 2010). However, recent SHRIMP zircon U-Pb chronological data indicate that these two groups of rocks were mainly formed in the Neoproterozoic. For example, A SHRIMP zircon U-Pb age of 857 ± 7 Ma was obtained for the basalts of Chencai Group (Shu et al. 2011) and 838 ± 5 Ma for a metamorphic rhyolite of this group (Li et al. 2009). Similarly, a SHRIMP zircon U-Pb age of 807 ± 5 Ma was obtained for the volcanic rock in upper Mayuan Group (Wan et al. 2007), and the youngest detrital zircon U-Pb age of 879 Ma was obtained by LA-ICPMS dating method for the paragneiss in lower Mayuan Group (Xu et al. 2010), which indicates that the formative period of Mayuan Group was formed after 879 Ma. Furthermore, the SHRIMP zircon U-Pb dating got 858 ± 11 and 836 ± 7 Ma ages for the metamorphic gabbros in Chencai area(Shu 2006; Shu et al. 2011), and similarly, 841 ± 6 Ma for the gabbro-diorites (Li et al. 2009). All of these data indicate that Chencai Group and Mayuan Group were mainly formed in the early to middle Neoproterozoic era.

Longquan Group, Mamianshan Group, and Wanquan Group in the southwestern Zhejiang Province and the Wuyi mountain range are attributed into the upper structure layer. The Longquan Group is divided into three formations, namely Nannong Formation, Qingkeng Formation, and Wanshan Formation (Xu et al. 2010). The Longquan Group is composed mainly of fine-grained garnet-bearing biotite gneisses, mica-quartz schists, amphibolites, epidote amphibolites and marbles, and their protolith of which are mainly volcanic formation and clastic rock formation. The volcanic rocks of Wanshan Formation exhibit the characteristics of the bimodal volcanic rocks (Xu et al. 2010). Mamianshan Group was divided into three formations, namely Longbeixi Formation, Dongyan Formation, and Daling Formation (Xu et al. 2010). The Mamianshan Group is mainly composed of fine-grained gneisses, mica-quartz schists, actinolite schists, amphibolites, and a bit of marbles. The volcanic rocks of Dongyan Formation also display the characteristic of the bimodal volcanic rocks (Zhang et al. 2005a). Wanquan Group is divided into three formations, which are Dutan Formation, Huangtan Formation, and Xiafeng Formation (Xu et al. 2010), and is composed mainly of fine-grained biotite gneisses, biotite–albite gneisses, and mica-quartz schists, with protolith being intermediate-acid volcanic rocks and pelitic-arenaceous sedimentary rocks. Lithological assemblages in the three groups may be contrasted, and all of these three groups underwent high greenschist to amphibolite facies metamorphism (Mei et al. 1993; Jin et al. 1997; Zhao and Cawood 1999). Except for the above three groups, Louziba Group, Dikou Formation, and Jiaoxi Formation in Fujian Province also were attributed to the upper structure layer of the early to middle Neoproterozoic. Based on whole-rock Sm–Nd isochron ages, these rock groups and formations were considered to be attributed to the Mesoproterozoic to Neoproterozoic in previous investigations (Shui 1988; Gan et al. 1993; Jin et al. 1997; Zhou 1997; Fu et al. 2010). However, recent zircon U-Pb chronological data using SHRIMP and LA-ICPMS dating methods indicate that these rock groups and formations were mainly formed in the Neoproterozoic. For example, SHRIMP zircon U-Pb age of 818 ± 9 Ma was obtained for the acid volcanic rock in Mamianshan Group (Li et al. 2005), while the LA-ICPMS zircon U-Pb age is

818 ± 14 Ma (Xu et al. 2010). The SHRIMP zircon U-Pb age of the fine-grained biotite gneiss in this group is 751 ± 7 Ma (Wan et al. 2007) and the 853 ± 4 and 797 ± 7 Ma for basalts (Shu 2006). LA-ICPMS zircon U-Pb ages are 825 ± 18 and 746 ± 6 Ma for metamorphic volcanic rocks in Wanquan Group (Xu et al. 2010), while the SHRIMP zircon U-Pb ages are 728 ± 8 Ma (Wan et al. 2007), 800 ± 14, and 788 ± 27 Ma (Li et al. 2009). SHRIMP zircon U-Pb ages are 841 ± 12 Ma and 837 ± 8 Ma for the gabbros in Zhenghe County of Fujian Province (Shu et al. 2011). All of these data indicate that the Longquan Group, Mamianshan Group, and Wanquan Group were mainly formed in the early to middle Neoproterozoic and were metamorphosed in Caledonian (Zeng et al. 2008; Li et al. 2010; Hu et al. 2011; Yao et al. 2012).

There exists different understanding about the formation environment of geologic bodies in early to middle Neoproterozoic in the Cathaysian Block. According to their characteristic of bimodal volcanic rocks, some researches considered that the eruptions of volcanic rocks in Longquan Group and Mamianshan Group were simultaneous with the Neoproterozoic magmatism which is very widespread in the Yangtze Block and are related to the rifting caused by the mantle plume concomitant with the breakup of Rodinia supercontinent (Li et al. 2005, 2008a, 2010; Shu et al. 2011). Some researchers suggested that the mafic-ultramafic rocks in Longquan Group and Mamianshan Group along Shangyu-Zhenghe Fault Belt might be the components of ophiolitic melange (Nie and Wang 1992; Ren et al. 1997; Wang et al. 1988; Wang and Shu 2007). These mafic-ultramafic rocks were formed in an island arc environment, which reflect a history from arc–arc collision to continental–continental collision (Wang and Shu 2007). Through the study of their geochemical characteristics, some researchers suggested that the metamorphic sedimentary rocks in Longquan Group, Mamianshan Group, and Wanquan Group were formed in an island arc-active continental margin environment (Jin et al.2008).

2.4 Discussions About Tectonic Environment of Jiangnan Belt

The many bifurcations are preserved with respect to cognitions for early to middle Neoproterozoic tectonic environment in South China Plate, and some tectonic questions have been hotly debated, for example, for long time, and whether a controversial tectonic environment of continental accretion, back-arc basin or rift in the northwestern margin of Yangtze Block (Zhou et al. 2002a, 2006a, b; Du et al. 2005; Sun et al. 2007; Xu et al. 2010; Dong et al. 2011, 2012; Li et al. 2003b, 2006; Wang and Li 2003). Moreover, the tectonic rifting environment was derived from whether a mantle plume or island arc in the Cathaysian Block (Li et al. 2005, 2008b, c, 2009; Shu et al. 2011; Nie and Wang 1992; Ren et al. 1997; Wang et al. 1988; Wang and Shu 2007), and tectonic environment of Jiangnan Belt (Orogen) and the time of orogenesis. Some researchers suggested generally that the Jiangnan

Belt (Orogen) was formed during Sibao period, 1.1–0.9 Ga (Li et al. 2002, 2007a, 2008b; 2009, 2012), whereas other researches thought that the Jiangnan Belt (Orogen) may be formed during 850–820 Ma, which is later than that of the Grenville orogenic period. On account of lacking high-grade metamorphic rocks which are the characteristic in the Grenville Orogen, it is hardly affirmed that Jiangnan Belt (Orogen) was formed in the Grenvillian (Zhou et al. 2008). It is not only controversial in the time of Jiangnan orogenic collision orogeny, but also in its formation type. For its formation ways, different scholars put forward different models. Zhao and Cawood (2012) analyze all kinds of structural models about Jiangnan Belt (Orogen) in detail and considered existing three typical models of "plume-rift model" (Li et al. 2003a, 2006, Li et al. 2003; Wang and Li 2003; Wang et al. 2010a), "slab-arc model" (Zhou et al. 2002a, b, 2006a, b; Wang et al. 2004, 2006, 2007; Zhao et al. 2011; Charvet 2013), and "plate-rift model" (Zheng et al. 2007, 2008), and briefly introduced the main idea and argument for each model, and then pointed out that all these models cannot be convincingly proved or are decisively refuted because every tectonic model successfully explained some characteristic of the Jiangnan (orogenic) belt from the late Mesoproterozoic to late Neoproterozoic. On the basis of analyzing the position of junction, the time of collision and the collision patterns between Yangtze Block and Cathaysian Block, Zhao and Cawood (2012) put forward a divergent double subduction model. They suggested that the ocean between Yangtze Block and Cathaysian Block subducted to Yangtze Block and Cathaysian Block from 970 to 825 Ma, and the ocean closed from 825 to 815 Ma. Meanwhile, the margins of the two blocks gathered together. By reason of the two blocks lying in the upper position of subducted plate, extensive continental subduction and crustal thickening did not occurred. Therefore, there is only greenschist facies metamorphism. Nearly, meanwhile, oceanic lithosphere separated from the continental crust, which caused the overlying continental crust sank along orogenic belt and formed a few of sedimentary basins. In these basins, the strata of Banxi Group were uncomfortably deposited above the lower structural layers such as Sibao Group and Fanjingshan Group. This model also could be regarded as a soft-docking model.

Several basic geologic characteristics must be considered in every model. Firstly, the strata of Jiangnan Belt (Orogen) in early to middle Neoproterozoic are divided into a strong folded lower structural layer (composed by Sibao Group, Fanjingshan Group, Lengjiaxi Group, Shuangqiaoshan Group, Shuangxiwu Group, and Shangxi Group) and an upper structural layer (composed by Banxi Group, Danzhou Group, Xiajiang Group, Xiushui Group, Likou Group, and Heshangzhen Group) with the characteristics of broad and gentle fold. The relationship of these two structural layers displays uncomfortably contacts. The differences in structural features indicate that the lower structural layer underwent strong deformation. Secondly, Jiangnan Belt (Orogen) generally underwent greenschist facies metamorphism, and does not appear high-grade metamorphic rocks like the typical continental–continental collision orogenic belt. High-grade metamorphic rocks only appear in the northeast of Jiangnan Belt (Orogen) (Zhou et al. 1989, Zhou 1997; Gao J. 2001). Most of the strata of Jiangnan Belt (Orogen) solely experienced greenschist facies metamorphism. These imply that the Jiangnan Belt (Orogen) differs from typical continental–continental collision model. Furthermore, high-precision zircon dating data indicated that the northeast of Jiangnan Belt (Orogen) formed at an early time (891–926 Ma, Li et al. 2009), and there is a tendency to be younger in the southwest of Jiangnan Belt (Orogen). For example, Shuangqiaoshan Group in north-center Jiangnan Belt (Orogen) formed during 880–830 Ma (Wang et al. 2008; Gao et al. 2008a), and Lengjiaxi Group, Fanjingshan Group, and Sibao Group in the southwest of Jiangnan Belt (Orogen) formed during 855–822 Ma (Gao et al. 2011a, b; Bai et al. 2010; Zhou et al. 2009). Besides, although the relationship between the upper and lower structural layers is unconformity, their forming ages are very similar (820–780 Ma, see above). These indicate that after the lower structural layer was deformed, quickly the upper structural layer was deposited (Wang et al. 2007). Based on these geological characteristics, I suggest that the ocean between Yangtze Block and Cathaysian Block firstly closed during 891–926 Ma in the northeast of Jiangnan Belt (Orogen), together with a depth of subduction, so it reserved not only ophiolites on behalf of oceanic fragments (Zhou et al. 1989, Zhou 1997; Zhou and Zhao 1991; Zhou et al. 1990; Shen et al. 1992; Li et al. 1994a; Zhao et al. 1995), but also formed blueschists on the behalf of regional high-pressure metamorphism (Zhou et al. 1989, Zhou 1997; Gao et al. 2001). Then the subduction of oceanic slabs migrated towards the southwest. Following the subduction of oceanic slabs, Yangtze Block and Cathaysian Block merged with the soft-docking between continental crusts instead of the subduction of continental crust. The later evolution of the Orogen corresponds with the model suggested by Zhao and Cawood (2012).

3 Nanhua System and Sinian System of South China Plate

Nanhua System and Sinian System have a wide distribution and mainly distribute in the Yangtze Block and Jiangnan Belt (Orogen) of the South China Plate. Nanhua System corresponds to international Cryogenian System and Sinian System to Ediacaran System (MacGabhann 2005).

3.1 Nanhua System of South China Block

On the basis of the domestic and international developing tendency, Nanhua System was established by China National Commission of Stratigraphy at 2001 as a chronostratigraphic unit. Its original intention indicates a stratigraphic unit at system level between Qinbaikou System and Sinian System, and whose bottom boundary is the lower boundary of Doushantuo Formation, with the age of the bottom boundary is tentatively determined at 800 Ma (NCS 2001). Recently, the definition of Nanhua System has gradually been determined to the lower bound of Neoproterozoic glacial records (Zhang 2010), which approximately correspond to

Cryogenian System. The lower bound age of Cryogenian System and Nanhua System depends on how to delimit the lower boundary. At recent, Neoproterozoic stratigraphic branch of international commission on stratigraphy is working on the establishment of Cryogenian System. The Neoproterozoic stratigraphic branch of international commission on stratigraphy put forward a consultative draft about how to define the bottom boundary of Cryogenian System at the end of 2008. Through one-year consultation and a vote among committee members, it is finally put forward that the bottom of Cryogenian System ought to be under a certain oldest Neoproterozoic glacial sedimentary layer on one outcrop and must be able to define a GSSP, whereas some researchers did not agree with the definition of the oldest glacial depositions based on the oldest Neoproterozoic Kaigas Glacier which was the mountain glacier (Zhang et al. 2009). Therefore, the study about Cryogenian System's definition is remaining. At the same time, our country also carried out the study about the establishment of Nanhua System. Some researchers put forward that Yangjiaping Profile in Shimen from Hunan Province could be regarded as a representative profile of Nanhua System (Yin et al, 2004). Some others considered Zhaoxing Profile at Liping County in the southeast of Guizhou Province (Zhang and Chu 2007). There are different opinions about stratigraphic division scenario (Table 1). The difference is mainly about the division and times of the lower strata in Nanhua System. The upper Nantuo Formation is mainly composed of grayish green massive pelitic-arenaceous conglomerates. The gravels are of various sizes, poor sorting, shape diversity, and complex components. The gravels display striations and T-shaped pits, which is typical glacial outwash (Xing et al. 2000). The sedimentary thickness of this formation shows a gradually thick tendency from the Three Gorges to Guizhou Province (Peng et al. 2004; Yin et al. 2007). The mid-upper Datangpo Formation composed mainly of black-dark gray siltstones and silty shales intercalating manganiferous shale and manganiferous dolomite, which were the interstadial deposited products. However, the division of the lower part has bigger bifurcations. The lower part could be regarded as a set of glacial outwash on the whole, and is composed of pebbly sandstones, siltstones, moraineous glutenites and pebbly moraineous mudstones. There is a big divergence on Xieshuihe Formation at Shimen of Hunan Province. This formation is mainly composed of mid-fine grained to mid-coarse grained feldspar-quartz sandstone intercalating pebbly sandstones, siltstones, and slates. Some researchers thought that Xieshuihe Formation is the product of non-glacial period and should be correspond to Fulu Formation (Peng et al. 2004). However, its chemical alteration index (CIA) indicates that it has characteristics of cold environment deposition (Feng LJ et al. 2004). The phenomenon of glacial outwash such as glacier pushing structure and ice foot etching was found (Zhang et al. 2008a). The above data indicate that Xieshuihe Formation formed from cold climate environment. With the above Zhang et al. (2008a) consider that Xieshuihe Formation is only equal to Liangjiehe segment of Fulu Formation, and Fulu Formation and Changan Formation of Jiangkou Group belong to the lower glacial period of Nanhua System, which are corresponding to Sturtian glacier period. Yin et al. (2007) thought that Xieshuihe

Formation is a product of a cold event before the Gucheng glacier period, and therefore should be corresponding to Kaigas glacier period (Yin and Gao 2013).

We can find out that the bottom boundary of Nanhua System is 635 Ma from Table 2. It is consistent with the bottom age of Ediacaran System defined by International Commission on Stratigraphy. There is a big difference because it is not clear yet with respect to the definition of bottom. However, Nanhua System comprised within above Banxi Group and Danzhou Group, and these strata mainly formed at 820–780 Ma. Therefore, the bottom of Nanhua System is delimited at 780 Ma on the latest China stratigraphy table. We can also find out that all the obtained ages from the bottom of Nanhua System are younger than 760 Ma from Table 2. As a result, the age of the bottom of Nanhua System is probably younger than 780 Ma, which need to be further determined. The studies of paleomagnetism indicate that South China Plate is between 33 and 38°N (Li ZX and Powell 1996; Evans et al. 2000) and belongs to a mid-latitude region in the early Nanhua System (Zhang and Piper 1997; Zhang et al. 2009).

In period of Nanhua System, the most important geological event is the global clod event. It is also called "Snowball Earth" (Chu XL 2004). It is generally thought that there are four periods of the clod event in Neoproterozoic. Kaigas Glacier Period is the earliest one at $\sim$ 750 Ma. Sturtian Glacier Period is the second period occurred during 720–680 Ma. Marinoan Glacier Period, which is the third period, occurred during 650–625 Ma. Gaskiers Glacier Period, namely the last period, occurred during 592–580 Ma (Huang et al. 2007; Zhang et al. 2009). It is generally thought that the first and last glacier periods were regional event, while Sturtian Period and Marinoan Glacier Period were global records of "Snowball Earth" (Zheng et al 2003; Chu 2004). The lower Gucheng Formation (Jiangkou Group) and the upper Nantuo Formation of Nanhua System in South China Plate are the sedimentary record of these both "Snowball Earth" events in China. There are different opinions about whether existing glacier records below Gucheng Formation. Some researchers suggested that Chang'an Formation lying from western Hunan Province to eastern Guizhou Province is also a sedimentary record of glacier period, named as "Changan Glacier Period". In this opinion, there are three glacier periods in South China Plate (Peng et al. 2004). Some others thought that of Chang'an Formation and Fulu Formation (including Gucheng Formation), constructing Jiangkou Group is the sedimentary record of Sturtian Glacier Period. In the opinion, there are only two sedimentary records of the global cold events in the South China Plate (Zhang and Chu 2007; Zhang et al. 2009). Although there are different understandings about the reasons of "Snowball Earth" (Hoffman et al. 1998; Hoffman and Schrag 2003; Hude et al. 2000; Schrag et al. 2002; Godderis et al. 2003), however, this special geological event displayed a significant influence on the global tectonic framework, the change of the earth environment, and the evolution of subsequent multicellular metazoan. However, it has a lot of questions to study recently. Zheng et al. (2003) summarized the questions and classified them into seven aspects for further study.

Table 2 Stratigraphic correlation table of Nanhua system in South China Plate

Inter. Comm. Stratigranhy, 2012 MacGabhann, 2005			National Comm. Stratigraphy, 2012			Yin CY et al., 2006,2007 Gao LZ., et al.2013b		Zhang QR et al.,2003,2007,2008
Neoproterozoic	Cambrian 寒武系		Cambrian 寒武系			Shuijingtuo F. 水井沱组		
	541Ma		542Ma					
	Ediacaran 埃迪卡拉系	Gaskicrs G. (582-585Ma)	Neoproterozoic	Sinian S. 震旦系	Upper	Dengying F. 灯影组	550±6Ma (4) 551±0.7Ma (4)	Sinian S. 震旦系
					550Ma			
					Lower	Doushantuo F. 陡山沱组	614±7.6Ma (8) 628±5.8Ma (5) 635±0.57Ma (5)	
	635Ma		635Ma					
	Cryogenian 成冰纪	Marinoan G. (635-660Ma)		Nanhua S. 南华系	Upper	Nantuo F. 南沱组	636±4.9Ma (10) 654.5±3.8Ma (10)	Nantuo F. 南沱组
					660Ma			
					Middle	Datangpo F. 大塘坡组	663±4.3Ma (7) 667±9.9Ma (6) 669±13Ma (11)	Datangpo F. 大塘坡组
		Sturtian G. (680-715Ma)				Gucheng F. 古城组		Jiangkou G. 江口群; Fulu F. 富禄组: Gucheng M. 古城段; Liangjiehe M. 两界河段
					725Ma			
		Kaigas G. (735-770Ma)			Lower	Xieshuihe F. 渫水河组	724±12Ma (9) 748±12Ma (3) 758±23Ma (2)	Chang'an F. 长安组
				780Ma				
	850Ma			QingBaikou S. 青白口系		Banxi G. 板溪群	785±19Ma (1) 795±15Ma (1) 809±16Ma (2)	Danzhou G. 丹洲群
	tonian 拉伸纪							

Annotations: the sources of chronological data in the table: (1) the top of Qingshuijiang Formation in Weng'an, Guizhou Province; the bottom of Maluping Formation in Kaiyang, Guizhou; Beiyixi Formation in Kuruktag, Xinjiang Province (after Yin et al. 2007); (2) Laoshanya Formation and Xieshuihe Formation in Yangjiaping, Shimen, Hunan Provinces (after Yin et al. 2003); (3) the lower-mid Liantuo Formation in the eastern Three Gorges, Hubei Province (after Ma et al. 1984); (4) the bottom of Dengying Formation in Jiuqunao, Zigui, Hubei Provinces (Yin et al. 2005b; Condon et al. 2005); (5) the bottom of Doushantuo Formation in Jiuqunao, Zigui, Hubei Provinces (after Yin et al. 2005a; Condon et al. 2005); (6) the lower part of Datangpo Formation in Heishuixi, Songtao, Guizhou Provinces (after Yin et al. 2006); (7) Datangpo Formation at Langgou Profile in Dongbeizhai from Guizhou Province (after Zhou et al. 2004); (8) the middle of Doushantuo Formation in Zhangcunping, Yichang, Hubei Provinces (after Liu et al. 2009); (9) the top of Liantuo Formation in the eastern Three Gorges, Hubei Province (after Gao and Zhang 2009); (10) the upper and bottom of Nantuo Formation in the eastern Three Gorges, Hubei Province (after Zhang et al. 2008c); (11) the lower Fulu Formation in Zhaoxing, Liping, Guizhou Provinces (after Yin et al. 2008)

3.2 Sinian System of South China Plate

Sinian System is an ancient geological terminology and has a history of 130 years in our country. Its connotation has experienced a long-term evolution (Liu 1991; Peng et al. 2012; Liu et al.2012). Today, it is generally thought that Sinian System is a late Proterozoic stratigraphy which lies above the tillite of Nantuo Formation and below Meishucun Stage (Tizhushan segment with small shelly fossils in Dengying Formation) of Early Cambrian (NCS 2002). Some investigators thought that the Sinian System of recent definition is nearly equal to Australian Ediacaran

System, and suggested using world standard "Ediacaran System" instead of the Sinian System (Peng et al. 2012). Oppositely, other researchers consider that the typical biogenic assemblage of Australian Ediacaran System is only equivalent to Miaohe Biota on the upper of Sinian System in China, and lacking lower biogenic associations; therefore, it could not be completely contrasted between the two systems. As a result, Sinian System ought to be reserved (Gao et al. 2013b). Considering long-used history of the Sinian System, this article still makes an introduction in accordance with Sinian System.

Sinian System has a wide distribution in South China Plate, such as Hubei Province, Hunan Province, Guizhou Province, Yunnan Province, Sichuan Province, Chongqing City, Guangxi Province, Jiangxi Province, Zhejiang Province, and Anhui Province. Sinian System includes Doushantuo Formation and Dengying Formation at the standard profile in the east of Three Gorges, Hubei Province. After the end of Nantuo Glacier Period, climate turned warm and ice-snow started to melt. Doushantuo Formation is the first widely transgression depositions at early Sinian System in South China Plate. At first, the grayish-white dolomite was deposited with the characteristics of strong stirring structure. It is commonly known as "cap carbonate," and has a stable horizon and widespread distribution as a sedimentary mark in early Sinian System in South China. Subsequently, gypsolite facies deposition with gypsic horizon appeared, representing a high-energy subtidal deposition in a dry climate. After this, the sea gradually deepened and deposited tabular micrite dolomite intercalating carbonaceous shale with microstratification. Micrite dolomites enriched pyrite and chert nodule, indicating a deep-sea reducing environment. In Late Doushantuo Formation, a set of massive grayish-white dolomites deposited intercalating lentoid chert beds and banded dolomite. Then a set of black silicon argillaceous shale intercalating dolomicrite lenses deposited. Dengying Formation, consisting of a set of thick shallow-deep-shallow carbonatite sedimentary sequence, is conformable overlain on Doushantuo Formation (Xing et al. 2012).

Sinian System is an important stage of biologic evolution. According to the study of the eastern Three Gorges, it could be divided into the early evolution stage of micropaleontology and the later evolution stage of macro-metazoans. In the early stage, it is characterized by extremely prosperous large spinose acritarchs. Spinose acritarchs have a large abundance and a high-degree differentiation. Besides spinose acritarchs, globular and filiform cyanobacteria and multicellular algae were also very prosperous. In the later stage, it is characterized by the appearance of Ediacaran soft-bodied macro-metazoans and extremely prosperous macro-multicellular algae. It represents a beginning of an important biologic evolution stage (Liu et al. 2012).

With the further studies of sequence stratigraphy, biostratigraphy, chemistry stratigraphy, and isotopic chronology in Sinian System, the division of Sinian System becomes more subtle. At first, Sinian System was divided into two stages of the lower Doushantuo Stage and the upper Dengyingxia Stage (Xing et al. 2000; NCS 2002). Afterwards, Wang et al. (2001) divided it into two series with four stages. The lower series of Sinian System comprises Tianjiayuanzi Stage and

Miaohe Stage, and the upper series comprises Sixi Stage and Longdengxia Stage. According to the data of sequence stratigraphy, chemistry stratigraphy, and isotopic chronology, Zhu et al. (2007) divided Sinian System into two series with five stages. The lower series called Xiadong Series comprising the first and second stages. The upper series called Yangtze Series comprising the last three stages. Based on the evolution stage of paleontological groups, Liu et al. (2012) put forward a division scenario, which also has two series with five stages, however, which exists some differences about the specific locations of series and stage between Liu's and Zhu's (2007) scenarios. Although the studies about Sinian System have made advances in the last decade, there are also some questions to further study, such as more subtle divisions of chronostratigraphy and biostratigraphy, detailed correlation about series and stages of Sinian System at different areas of South China Plate, whether Gaskiers Glacier Period has a deposition response in South China Plate, more subtle division of chemistry stratigraphy, and so on.

At the end of Sinian System, South China Plate finished the long-term Precambrian evolution and turned into a Phanerozoic geological evolution stage.

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