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Zircon SHRIMP U-Pb dating for the Cangshuipu volcanic rocks and its implications for the lower boundary age of the Nanhua strata in South China

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Abstract **The continental volcanic rocks and volcaniclastic sedimentary conglomerates of the Cangshuipu Formation occur well in Yiyang of Hunan Province, consisting of a wedge-shaped succession of Neoproterozoic strata that overlie with high-angle unconformity the flysch turbidites of the Lengjiaxi Group in the Upper Mesoproterozoic Eonothem. SHRIMP zircon U-Pb dating gives a weighted mean age of 814 ± 12 Ma for the dacitic volcanic agglomerates from the lowest part of the volcanic rocks in the Cangshuipu Formation. This age is younger than previously reported values of 921—933 Ma for the volcanic rocks from the Cangshuipu Formation. Our new dating represents the lower boundary age of the Neoproterozoic System in the studied area. The younger age for the Cangshuipu volcanic rocks is supported by the following observations: (1) Lower Neoproterozoic strata (814—1000 Ma) are missing in the studied area; (2) the Nanhua rift system was initiated at about 820 Ma; and (3) an age of ~820 Ma may be taken as the lower boundary timing of the Nanhua System (even Neoproterozoic) in South China.**

Keywords: Zicon U-Pb dating, Neoproterozoic volcanics, rift basin, Nanhua System.

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Continental volcanic rocks and volcaniclastic sedimentary conglomerates of the Cangshuipu Formation occur as wedge-shaped Neoproterozoic strata in the Yiyang region, Hunan Province. They overlie with a high-angle unconformity the Lengjiaxi Group of the Upper Mesoproterozoic Eonothem. The wedge-shaped Neoproterozoic strata of the continental clastic rocks and the Mesoproterozoic deep marine flysch turbidites of the Lengjiaxi Group represent two distinct stages of basin-tectonic evolution in South China, respectively[1]. The age of the volcanic rocks in the lowest part of the wedge-shaped strata marks the onset of younger depositional cycle in the Neoproterozoic, and thus plays a critical part in dating the lower boundary age of Neoproterozoic strata and unraveling the initial timing of the Nanhua rift system in South China (Fig. 1).

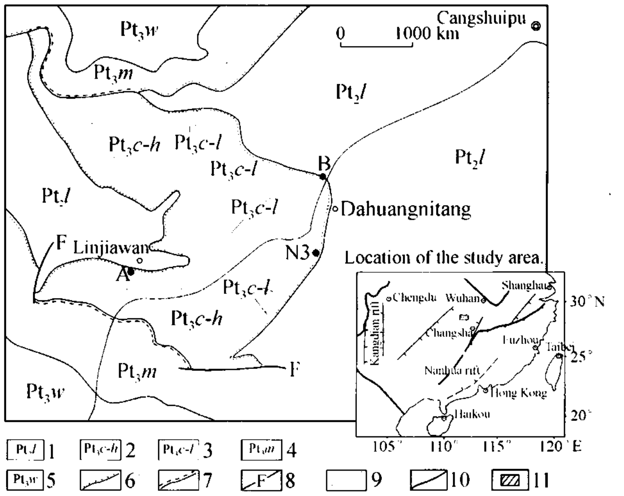

Fig. 1. General geology and sample location (N3) in the Cangshuipu region, Yiyang, Hunan. 1, Mesoproterozoic Lengjiaxi Group; 2, volcanic member of the Cangshuipu Formation; 3, conglomerate member of the Cangshuipu Formation; 4, Madiyi Formation; 5, Wuqiangxi Formation; 6, unconformity; 7, disconformity; 8, fault; 9, lithofacies boundary; 10, road; 11, location of the research area.

Previously published radiometric dates for the volcanic agglomerates of the Cangshuipu Formation include single-grain U-Pb zircon ages of 922—933 Ma[2,4] and a whole-rock Rb-Sr isochron age of 921 Ma[5,6]. As a result, the volcanic rocks in the Cangshuipu Formation, coupled with strata of the overlying Banxi Group, were grouped together in the existing literature and on 1∶50000 regional geological maps as the lower part of the Neoproterozoic System[7,8], and thus were correlated with the Qingbaikou System in North China. However, the published U-Pb zircon data[2] are scattered along the U-Pb concordia curve with $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages ranging from 895 ± 4 to 967 ± 3 and 889 ± 36 to 1035 ± 77 Ma, respectively. Thus the mean of these U-Pb and Pb-Pb ages are statistically meaningless as they are apparently distinguishable within analytical errors. The initial $^{87}Sr/^{86}Sr$ ratio defined by the Rb-Sr isochron from four samples of intermediate-acidic volcanic agglomerates is 0.7039 ± 0.0005[5], close to the value for the Neoproterozoic bulk Earth and/or undifferentiated chondrite uniform reservoir (CHUR). However, this initial ratio is much lower than the Sr isotopic compositions for the normal intermediate-acidic igneous rocks. This implies that the linear relations indicated by the Rb-Sr isotopic data from the 4 samples cited above are probably a "pseudoisochron" or "mixing line"[9]. Thus the previously reported U-Pb and Rb-Sr ages are not acceptable for dating the volcanic rocks from the Cangshuipu Formation.

Our study is based on three periods of field examination, section measurement and the refinement of 1∶50000 regional geological maps. Precise dating is obtained for the lowest boundary of Neoproterozoic strata in the studied area with the aid of zircon SHRIMP U-Pb dating on dacitic volcanic agglomerates from the basal part of the Cangshuipu Formation in Hunan Province. The present dating provides new evidence not only for the stratigraphic division and correlation of Neoproterozoic rocks in Hunan and even throughout South China, but also for unraveling of the breakup of the supercontinent Rodinia. With respect to the division of Neoproterozoic units shown on the International Stratigraphic Chart[10], we suggest that an age of ~820 Ma may be taken as the lower boundary timing of the Nanhua System in South China instead of ~800 Ma as proposed by the China Commission on Stratigraphy[11].

1 Geological background

The volcanic rocks and volcaniclastic sedimentary conglomerates from the Cangshuipu Formation in the Yiyang region, Hunan, were first discovered in 1988 by Pan et al., and were assigned to a succession of wedge-shaped strata bounded by angular unconformities between the older Lengjiaxi and younger Banxi groups[12]. The strata was proposed to be named the "Cangshuipu Group", composed of the "upper" Yinzhuba Formation volcanic rocks and "lower" Linjiawan Formation volcaniclastic sedimentary conglomerates of Mesoproterozoic age[12,13]. Mapping for 1∶50000 regional geological maps and stratigraphic refinement in Hunan, by Hunan Geological Bureau, argued against Pan Chuanchu that a conformable or unconformable contact was present between these strata and overlying strata, and that volcanic rocks lie in the "lower" part while the conglomerate intervals lie in the "upper" part of the section. For this reason, latter workers rejected the stratigraphic term "Canglangpu Group"[6,8,14]. On the basis of our field observations, we propose that the Cangshuipu volcanic rocks and volcaniclastic sedimentary conglomerates are synchronous and facies of one another. The volcaniclastic sedimentary conglomerates unconformably overlie with high-angle the Lengjiaxi Group at two outcrops, one along a small stream ~ 50 m in the southwest of the Linjiawan Village (A, Fig. 1), and the second at Dahuangnitang (B, Fig. 1) and near the sampling site for this study (N3, Fig.1) where the volcanic rocks overlie unconformably at high-angle the Lengjiaxi Group. Moreover, the two rock types exhibit gradational or interfingering contacts above the angular unconformity (Fig.1). The stratigraphic term "Cangshuipu Formation" is used in our study to describe the wedge-shaped strata composed of the "volcanic rocks and volcaniclastic sedimentary conglomerates" in the Cangshuipu region because of the wide use of the term "Cangshuipu volcanic rocks" in the Chinese geological community[1,5,15,16].

The Cangshuipu Formation volcanic rock members are ~317 m thick in the Cangshuipu region. The section from the base upwards consists of four volcanic lithofacies: a volcanic explosive agglomerate facies, a volcanic explosive breccia facies, a subaerially erupted tuff facies and a basalt facies. The volcaniclastic sedimentary conglomerate members are ~341 m thick in the same area and are composed of three lithofacies in an ascending order: a purplish red volcaniclastic polymictic conglomerate facies, a purplish red lapilli-bearing sandstone and mudstone facies, and a sedimentary tuff facies. The composition of the clasts in the gravel is the same as that in matrix, and is composed dominantly of rhyolitic and dacitic, with a minor amount of slate and metamorphic siltstone clasts derived from the underlying Lengjiaxi Group. The characteristics of the volcanic rock members and purplish red volcaniclastic sedimentary conglomerate members indicate that they were formed in non-glacial continental volcanic eruptions and alluvial and fluvial environments[1].

2 Lithology of the sample

The analyzed sample N3 was collected from the volcanic rocks at the base of the Cangshuipu Formation (Fig. 1). The volcanic rocks are grey to light grey, thick-bedded or massive, and contain angular clasts. Clasts generally vary from 10 to 30 cm, up to 60 cm, in diameter, and compositionally simple and almost identical to that in the matrix, derived only from dacitic volcanic rocks. These rocks are described as volcanic agglomerates in the field and after laboratory study, carbonatized and chloritized dacitic volcanic agglomerates.

Microscopically, the rocks have porphyritic textures. The matrix exhibits microlitic-microgranular textures. The phenocrysts make up ~20% of the rock, and consist mostly of plagioclase, quartz and minor amphibole. The plagioclase is andesine and oligoclase with blended zonation. Subhedral-euhedral crystals are common. The quartz phenocrysts are minor, and are corroded to have an embayed outline. The amphiboles display dull rims due to intense oxidation, and tend to be replaced by chlorite or carbonate minerals. The matrix and some of phenocrysts have been carbonatized and chloritized.

3 Analytical methods and results

Zircons are concentrated through gravity and electromagnetic sortings from crushed rock fragments of less than 1 mm, and euhedral and transparent zircons are picked up under a binocular microscope for U-Pb analysis.

Sample zircons, 150—200 μm, are more or less granular, without any fracture, and with aspect ratio of 1.3∶1—3∶1 (Fig. 2). Both target zircons and calibrating zircon TEM (417 Ma) are cast in an epoxy mount, which is then polished to section the crystals. Then sample zircons are examined with transmitted and reflected light micrographs and cathodoluminescence images to reveal any internal structures and textures. Euhedral concentric zoning is found common in most crystals, and indicative of an origin from magmatic crystallization (Fig. 2).

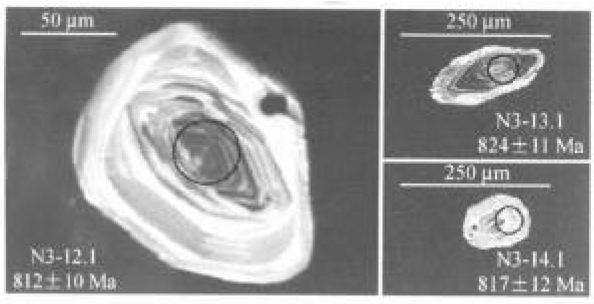

Fig. 2. Morphologies, cathodoluminescence images and $^{206}Pb/^{238}U$ ages of the sample N3 (The circles in the figure indicate the position of the analysed spots). Analysed spots: N3-12.1, a subgranular zircon grain, showing well-defined zonation of magmatic crystallization within the zircon grain; N3-13.1, a short prismatic zircon grain, also showing well-defined zonation of magmatic crystallization within the zircon grain; N3-14.1, a cross section of a zircon grain, in which the zonation of magmatic crystallization may be seen.

Measurements of U, Th, and Pb (Tables 1) are conducted using the SHRIMP Ⅱ ion microprobe at the Center for Ion Microprobe Analysis in Beijing, China, employing procedures described by Williams et al.[17] and Song et al.[18]. The common lead is corrected with the measured ^{204}Pb, and an average crustal composition (Cumming and Richards, 1975) appropriate to the age of the minerals assumed[19]. The data processing is carried out using the Squid and Isoplot programs of Ludwig[20]. The analytical results are listed in Table 1, and shown on a U-Pb concordia plot in Fig. 3. 17 measured point analyses of 15 zircons from sample N3 are obtained. The zircons are relatively low in U and Th contents and high in Th/U ratio (U = 56 to 213 μg/g, Th = 36 to 220 μg/g, Th/U = 0.67 to 1.21). As a result, the extremely low contents of radiogenic lead (^{207}Pb) cause large analytical errors in the $^{207}Pb/^{206}Pb$ ratios. In addition, the inaccurate ^{204}Pb measurements also have significant effect on the common lead

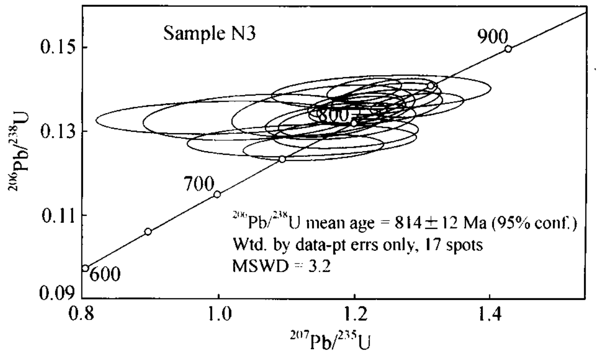

Fig. 3. U-Pb isotopic concordia diagram showing the $^{206}Pb/^{238}U$ ages for the sample N3 used in this study.

Table 1 Zircon SHRIMP U-Pb age determinations for the sample N3 from the dacitic volcanic agglomerates in the study area[a)]

Spot No.	$^{206}Pb^{c)}$ (%)	U /μg・g^{-1}	Th /μg・g^{-1}	$^{232}Th/^{238}U$	$^{206}Pb^*$ /μg・g^{-1}	$^{206}Pb/^{238}U$ Age/Ma	$^{207}Pb/^{206}Pb$ Age/Ma	$^{207}Pb^*/^{206}Pb$ (±1*s* %)	$^{207}Pb^*/^{235}U$ (±1*s* %)	$^{206}Pb^*/^{238}U$ (±1*s* %)
N3-1.1	0.33	122	93	0.79	14.4	823 ± 11	738 ± 75	0.0639 (3.6)	1.200 (3.9)	0.1362 (1.5)
N3-1.2	0.61	56	36	0.67	6.22	785 ± 13	819 ± 120	0.0664 (5.6)	1.186 (5.9)	0.1296 (1.8)
N3-2.1	0.32	63	51	0.84	7.47	833 ± 14	790 ± 80	0.0655 (3.8)	1.245 (4.2)	0.1379 (1.8)
N3-2.2	0.31	180	143	0.82	21.7	844 ± 10	702 ± 57	0.0628 (2.7)	1.212 (3.0)	0.1400 (1.3)
N3-3.1	0.71	90	100	1.14	10.9	842 ± 12	781 ± 64	0.0652 (3.1)	1.254 (3.4)	0.1394 (1.6)
N3-4.1	1.21	67	58	0.89	7.45	776 ± 14	729 ± 210	0.0636 (9.7)	1.12 (9.9)	0.1280 (2.0)
N3-5.1	1.82	76	63	0.85	8.91	808 ± 21	490 ± 210	0.0570 (9.7)	1.05 (10)	0.1335 (2.7)
N3-6.1	0.62	94	92	1.01	10.8	802 ± 17	757 ± 120	0.0645 (5.8)	1.178 (6.2)	0.1326 (2.2)
N3-7.1	0.85	59	42	0.73	7.18	842 ± 15	755 ± 180	0.0644 (8.4)	1.24 (8.6)	0.1395 (1.9)
N3-8.1	0.99	67	50	0.78	7.83	816 ± 23	673 ± 150	0.0620 (7.1)	1.154 (7.7)	0.1350 (3.0)
N3-9.1	0.54	69	60	0.90	7.90	801 ± 13	735 ± 85	0.0638 (4.0)	1.164 (4.4)	0.1323 (1.8)
N3-10.1	1.00	100	116	1.21	10.9	766 ± 11	789 ± 120	0.0655 (5.7)	1.139 (5.9)	0.1262 (1.6)
N3-11.1	2.33	67	55	0.84	7.87	807 ± 15	388 ± 260	0.0544 (12)	1.00 (12)	0.1333 (1.9)
N3-12.1	0.15	213	188	0.91	24.5	812 ± 10	769 ± 47	0.0648 (2.2)	1.199 (2.6)	0.1342 (1.3)
N3-13.1	0.36	194	220	1.17	22.8	824 ± 11	888 ± 67	0.0686 (3.3)	1.291 (3.5)	0.1364 (1.4)
N3-14.1	0.63	98	74	0.78	11.4	817 ± 12	759 ± 74	0.0645 (3.5)	1.203 (3.9)	0.1352 (1.6)
N3-15.1	0.28	59	61	1.07	6.87	822 ± 15	803 ± 95	0.0659 (4.5)	1.236 (4.9)	0.1360 (2.0)

a) The error = 1*s*; Pb_c and Pb^* represent common lead and radiogenic lead, respectively; the standard correction error = 0.28%; the common lead is corrected by measured ^{204}Pb.

correction for the $^{207}Pb/^{235}U$ and $^{207}Pb/^{206}Pb$ values, and occasionally cause reverse discordance for a few U-Pb data. Collectively, all the 17 analyses form a single, concordant group on the U-Pb concordia plot (Fig. 3), with a weighted mean $^{206}Pb/^{238}U$ age of 814 ± 12 Ma (95% confidence, and MSWD = 3.2). We interpret this age as the crystallization age of the zircons from the sample N3, which gives the best estimate for the timing of the volcanic rocks from the Cangshuipu Formation.

4 Discussion

(i) Implications for lower boundary age of Neoproterozoic strata in South China. When were the Neoproterozoic strata first deposited in South China? For the impact of our study we discuss the stratigraphic sequences of Neoproterozoic strata in South China.

There exists a wedge-shaped succession of terrigenous-ominated strata composed of continental alluvial-fluvial to marine rocks sandwiched between the Neoproterozoic glacial sediments (tillites) above and tectonic unconformity below created by the “Jinning-Sibao” orogeny in South China[1] (Fig. 4). The horizons and sedimentary sequences at the base of the wedge-shaped strata vary greatly because of the time difference in deposition between graben and horst areas. Four types of sectional architectures and basin filling succession have been distinguished (Fig. 4). In the regional geological data compiled for individual provinces in South China, several groups such as the Sibao, Lengjiaxi, Shuangqiaoshan, Huili, Kunyang groups and their equivalents, lie without question below the “Jinning-Sibao” unconformity and are assigned to the Mesoproterozoic (Fig. 5). The wedge-shaped strata in the lowermost horizons above the tectonic unconformity thus should represent the basal units of the Neoproterozoic strata in South China. These wedge-haped strata include the Cangshuipu volcanic rocks-sedimentary conglomerates (Types 2 and 3, Succession Ⅰ, Fig. 4) and should be considered as the earliest sediments deposited in the middle of the graben basins in response to the breakup of the supercontinent Rodinia and the opening of the Neoproterozoic rift basins in South China following the Sibao orogeny after a period of prolonged (ca. 180 Ma) erosion and leveling of the study area[1,21—24]. Representatives of these strata include the Baizhu Formation in northern Guangxi, the Zhangjiawan Formation in northwestern Hunan, and the Cangshuipu and Shiqiaopu formations in north-central Hunan. The age of the syndepositional volcanic rocks within the above-mentioned strata represent the age of the initial sedimentation in South China during the Neoproterozoic. Thus, the age of 814 ± 12 Ma for the sample N3 from the bottom of the Cangshuipu Formation represents the age of the basal units of Neoproterozoic strata in South China.

A series of the SHRIMP age data on the basal units of the Neoproterozoic strata in South China have been obtained in recent years, and include: 819 ± 11 Ma[25], TIMS zircon U-Pb age determinations for the basic volcanic rocks from the Yingyangguan Group in northern Guangxi, and 803 ± 12 Ma[26,27], SHRIMP zircon U-Pb age determinations for the volcanic rocks from the Suxiong Formation in the Kang-Dian region. Our unpublished dating also shows the similar results for rhyolite from the Taoyuan Formation in northeastern Jiangxi. These data approximate the results in this study and imply an age of ca. 820 Ma for the lower boundary of the Neoproterozoic strata in South China. Ages for the intrusive rocks overlapped by the Neoproterozoic strata are generally older than 820 Ma. The best examples include the Eshan massif in central Yunnan, the Bendong and Sanfang massifs and basic dike swarms in northern Guangxi, the Xucun massif in southern Anhui and the Huangling granite massif east of the Three Yangtze Gorges in Hubei, all

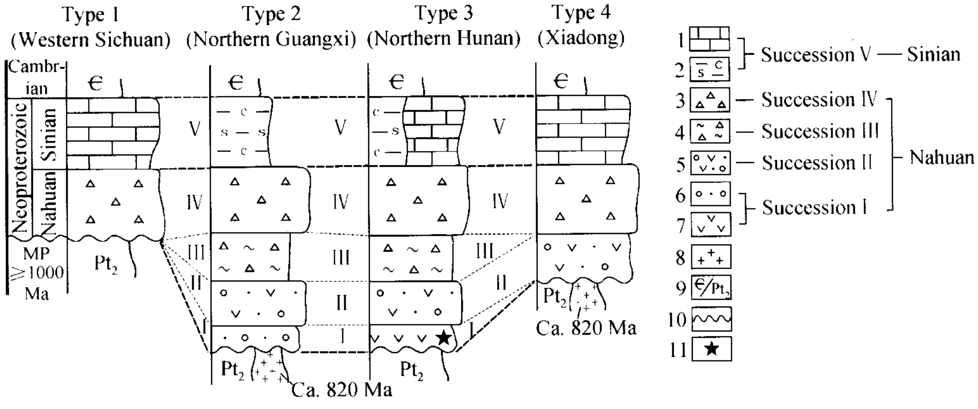

Fig. 4. Sedimentary succession types of the Neoproterozoic in South China. 1, Terrigenous carbonate rock and phosphorite-bearing carbonate rock association; 2, phosphorite-bearing carbonaceous-siliceous rock association; 3, Nantuoan continental tillite and marine tillite association; 4, Chang’ an-Fulu marine tillite and fined-grained terrigenous clastic rock association; 5, volcaniclastic-terrigenous clastic sedimentary rock association; 6, bimodal volcanic-volcaniclastic rocks association; 7, fine-grained terrigenous clastic rock association; 8, granites intruded during > 820 Ma; 9, Cambrian/Mesoproterozoic; 10, “Jinning-Sibao” unconformity; 11, position of sample N3.

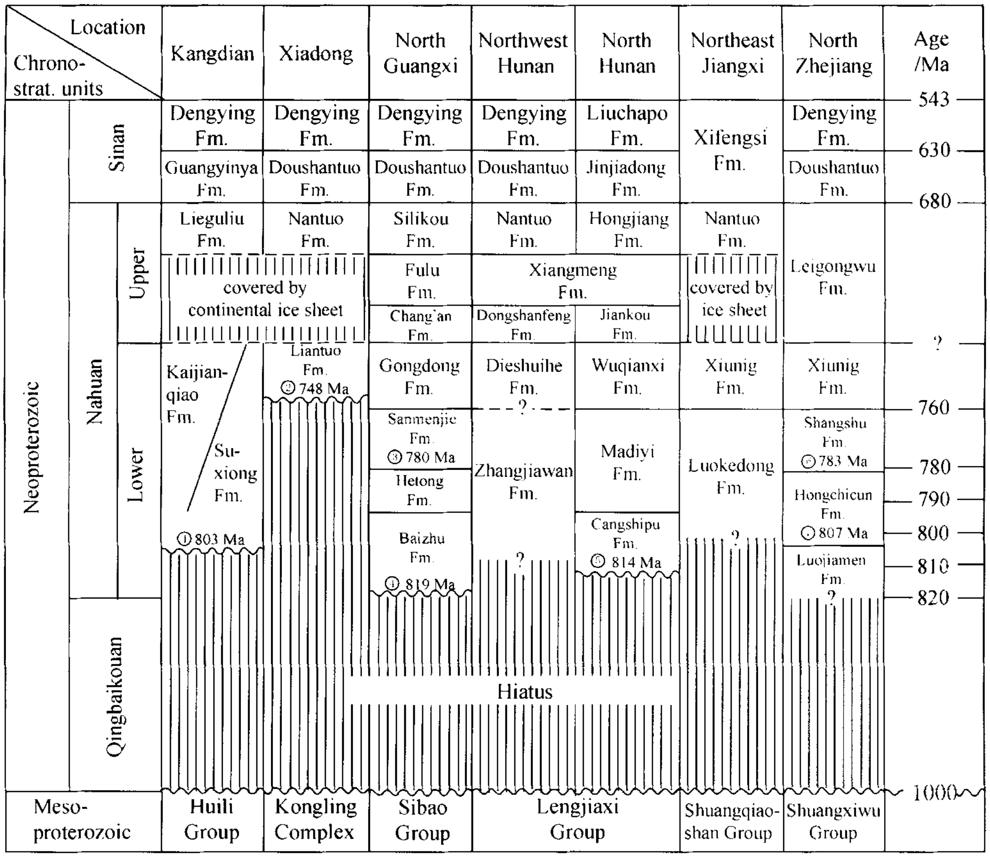

Fig. 5. Division and correlation of the Neoproterozoic strata in South China. ① Li et al. (2002), 803 ± 12 Ma: SHRIMP zircon U-Pb ages for the rhyolite from the Suxiong Formation in the Kang-Dian region[27], ② Ma Guogan et al. (1989), 748 ± 12 Ma: SHRIMP zircon U-Pb ages for the tuff from the Liantuo Formation in Xiadong[37]; ③ Li Xianhua et al. (2003, personal communication), ca. 780 Ma: SHRIMP zircon U-Pb ages for the rhyolite from the Sanmenjie Formation in Longsheng, northern Guangxi; ④ Zhou Hanwen et al. (2002), 819 ± 11 Ma: SHRIMP zircon U-Pb ages for the basic volcanic rocks from the Yingyangguan Group in northern Guangxi[25]; ⑤ this study (2003), 814 ± 12 Ma: SHRIMP zircon U-Pb ages for the dacitic volcanic agglomerates from the Cangshuipu Formation in Yiyang, Hunan; ⑥ Wang Jian et al. (2003, unpublished), ca. 783 Ma: SHRIMP zircon U-Pb ages for the rhyolite from the Shangsu Formation in northern Zhejiang; ⑦ Wang Jian (2000), 807 ± 11 Ma: SHRIMP zircon U-Pb ages for the rhyolite from the Hongchicun Formation in northern Zhejiang[1].

with ages ranging between ca. 820 and 826 Ma[28,29]. All these age data support the reliability of an age of ca. 820 Ma for the lower boundary of Neoproterozoic strata in South China.

In order to clarify whether the early Neoproterozoic Qingbaikou strata in northern China also appear in South China, it is imperative to establish the age at the top of the Qingbaikou strata (see Fig. 5). The absence of syndepositional volcanic rocks at the top of the Qingbaikou strata makes it an unresolved problem dating the top of these older pre-Nanhua rocks[30]. K-Ar ages of 853 and 862 Ma for the local glauconite[31] and the K-Ar age of 855 Ma for illite[32] near the upper part of the Qingbaikou strata, are suggestive that an age of ca. 820 Ma should be given for the upper boundary of the Qingbaikou strata[33]. So far no strata earlier than 820 Ma have been found above the unconformity or above Mesoproterozoic rocks in most of South China, including Hunan, Hubei, Sichuan, Yunnan, Jiangxi and Anhui. It has been previously reported that the ages of Baizhu and Sanmenjie formations in northern Guangxi are greater than 900 Ma[3,15]. Our new age data, however, yield ages of about or less than 820 Ma for the lowermost part of the same strata[1,21,22,25].

If 800 Ma is taken as a limit of lower bounding age of the Nanhua[11], then part of the Suxiong Formation in the Kang-Dian area (803 Ma), Cangshuipu Formation in northern Hunan (814 Ma) and Baizhu Formation in northern Guangxi (819 Ma) should be assigned to the Qingbaikou strata. However, these continuous strata cannot be separated into two by obvious stratigraphic boundary at corresponding points. Furthermore, such a subdivision scheme apparently does not accord with the principles that the division of the "Periods" in the Proterozoic should be based on the boundaries of the "most remarkable tectonic, magmatic and sedimentary events" as proposed by the International Commission on Stratigraphy (ICS)[10].

Thus the age of the lower boundary of the Nanhua or Neoproterozoic strata in most of South China (except northern Zhejiang) should be ca. 820 Ma. The strata dated between 1000 and 820 Ma (corresponding to the Tonian) may be missing, at least in many important parts of South China. There is no favorable evidence to incorporate the Cangshuipu volcanic rocks and the overlying Banxi Group into the lower part of the Neoproterozoic strata in South China, which is correlated with the Qingbaikou strata in northern China.

(ii) Lower boundary age of Nanhua System. In a new stratigraphic scheme, "Regional Chronostratigraphic Scale in China" proposed by the China Commission on Stratigraphy in 2001, the Neoproterozoic strata have been divided into three major chronostratigraphic units, and a new system, "Nanhua System", has been established[11,34] (Fig. 5). The top of the "Nanhua" strata is bounded by the base of the Doushantuo Formation (Fig. 5). However, presently no stratigraphic signatures have defined the lower boundary of the "Nanhua" strata. An age of ~800 Ma was suggested for this boundary[12], which is different from the age (~850 Ma) for the boundary of the Cryogenian (850—650 Ma) proposed by the International Subcommission on Cambrian Stratigraphy[35]. Thus, is it favorable to define ~800 Ma as the lower boundary age of the "Nanhua" strata?

It appears that strata corresponding to the Tonian (1000—850 Ma) are missing in most of South China. Therefore, the base of the "Nanhua" strata should correspond to that of the Neoproterozoic strata in South China (Fig. 4), and its basal age should be at ca. 820 Ma rather than ca. 800 Ma in the light of the age data now available (Fig. 5).

The above-mentioned results of our field and petrographic observations lead us to the following conclusions:

The continental strata of the Cangshuipu Formation were deposited as the earliest fillings in the lowermost horizons in a graben basin during the opening of the Neoproterozoic rift in response to the breakup of the supercontinent Rodinia. The fact that the "starting point" of a major tectonic and sedimentary cycle is taken as the base of the Nanhua strata in South China is in line with the principles proposed by the International Commission on Stratigraphy (ICS) concerning the division of the "Periods" within the Proterozoic[10], and the age of ~820 Ma is close to that of the stratigraphic scheme cited above as well[35].

There is no reliable boundary with an age of ~800 Ma as suggested by CCS to before the regional correlation in the strata between the basal members (820 Ma) of the Neoproterozoic wedge-shaped strata and the base of the tillites. For example, the SHRIMP zircon U-Pb age is 803 ± 12 Ma for the volcanic-volcaniclastic rocks from the Suxiong and Kaijianqiao formations sandwiched between the tillites of the Lieguliu Formation and the "Jinning-Sibao" orogenic unconformity in the Kang-Dian region[26,27]. Rocks dated as at least 808 ± 12 Ma are now well preserved in the Neoproterozoic strata in western Sichuan[38]. We cannot separate these extensive and continuous successions of volcanic rocks into two parts: one to the Nanhua System, the other to the Qingbaikou System.

In short, it is reasonable to take the age of ~820 Ma instead of ~800 Ma as the lower boundary of the Nanhua strata because the former is better to coincide with both the principles on the threefold division of the Neoproterozoic strata proposed by the ICS and the actual conditions in South China.

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