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Chemical Significance and Chronology of Mesoproterozoic Clastic Rocks in Huainan Area

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After the 1.8Ga cracking event, the North China Craton entered the development stage of paraplatform, its southern margin, the Huainan area is in lack of accurate age data, so its stratigraphic sedimentation time limit has been controversial. Therefore, this paper conducts a zircon U-Pb geochronology study on the clastic rocks of the North China Craton in the Bagongshan Fm in Huainan area. The purpose is to determine the stratigraphic sedimentation time limit of the Huainan area by the age of the clastic zircon, so as to provide a basis for the geological events happened in the North China Craton during the Neoarcheozoic-Neoproterozoic era. The results of the dating show that the youngest clastic zircon age of the Bagongshan Fm is 1120 Ma, which might belong to the system-to-be-built of the Mesoproterozoic erathem. The age peaks of clastic zircon in the Bagongshan Fm are mainly ~2.1Ga and ~2.5Ga, which have a low structural maturity, indicating that the provenance is relatively close, and the detrital matters may be mainly derived from the inside of the craton, so the age groups of clastic zircons had recorded important geological events in the Neoarcheozoic-Neoproterozoic era in North China Craton. The age older than 3.0Ga recorded the Neoarchean geological events in the North China Craton. The age groups of 2.9~2.7Ga, ~2.5Ga, 2.3~2.0Ga, and 1.9~1.8Ga recorded important geological events such as crust growth, cratonization, rifting and orogeny happened in the early Cambrian in the North China Craton. The age groups of ~1.74Ga and ~1.6Ga recorded the multi-period rifting events happened during the Paleoproterozoic-Neoproterozoic era.

1. Introduction

In Huainan area, which located in the southern margin of the North China Craton, the Meso-Neoproterozoic strata are overlaid on the Fengyang Gr. of the Paleoproterozoic era, including the Caodian Fm, the Bagongshan Fm, the Liu Laobei Fm, the Shouxian Fm (Sishilichangshan Fm), Jiuliqiao Fm of the Huainan Gr. from the bottom up, and the Sidingshan Fm of the Xuhuai Gr. The overlying strata are the Cambrian Houjiashan Fm. In the Shouxian County Bagongshan area and the Huoqiu Shishilichangshan area, the Fengtai Fm with lithology of mix-conglomerate can be seen in the lower part of the Houjiashan Fm (Yang et al., 1980). The age of this part of the strata has been controversial, and the focus of the predecessors' disagreement on the age of the strata in the Huainan area is: whether the Huainan strata in the southern North China Basin is located at the Neoproterozoic erathem, or earlier era. Therefore, it is necessary to rethink and relocate the late Precambrian strata in the southern North China Craton. The determination of the time limit of the Huainan area in the southern North China Basin is not only related to the comparison between the northern Sinian system and the southern Sinian system, but also related to the establishment of a new theory of the origin and evolution of Metazoa on early earth, and other major theoretical frontier issues. At the same time, it also provides new ideas for the exploration of Meso- Neoproterozoic oil and gas (Dou, 2018).
Previous studies in the Huainan area mainly focused on the use of isotopic chronology data, lacking high-precision zircon U-Pb age data. Based on clastic zircon U-Pb age analysis of the sedimentary rocks in the

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Huainan area of the southern North China Basin, this paper comprehensively analyzes predecessors' research results of the southern North China area, re-forms the stratigraphic framework of Huainan area, and re-compares and re-divides the Meso-Neoproterozoic erathem of the southern margin in the North China platform, so as to provide a basis for the geological events happened in North China Craton during the Neoarcheozoic-Neoproterozoic era (Yuan et al., 2018).

2. Stratigraphic features

The Huainan Depression belongs to the Huainan-Fengyang stratigraphic minor region in the Jiangsu-Shandong-Anhui stratigraphic subregion of the North China strata (Figure 1), it's mainly the Huainan Gr. of the Meso-Neoproterozoic era. To the south, the Gushi-Hefei fault zone is the southern boundary of the North China Craton; to the north, cross the Bengbu-Jieshou uplift zone is the Huaibei-Xuzhou stratigraphic minor region; to the east, it stops at the Tanlu fault zone.

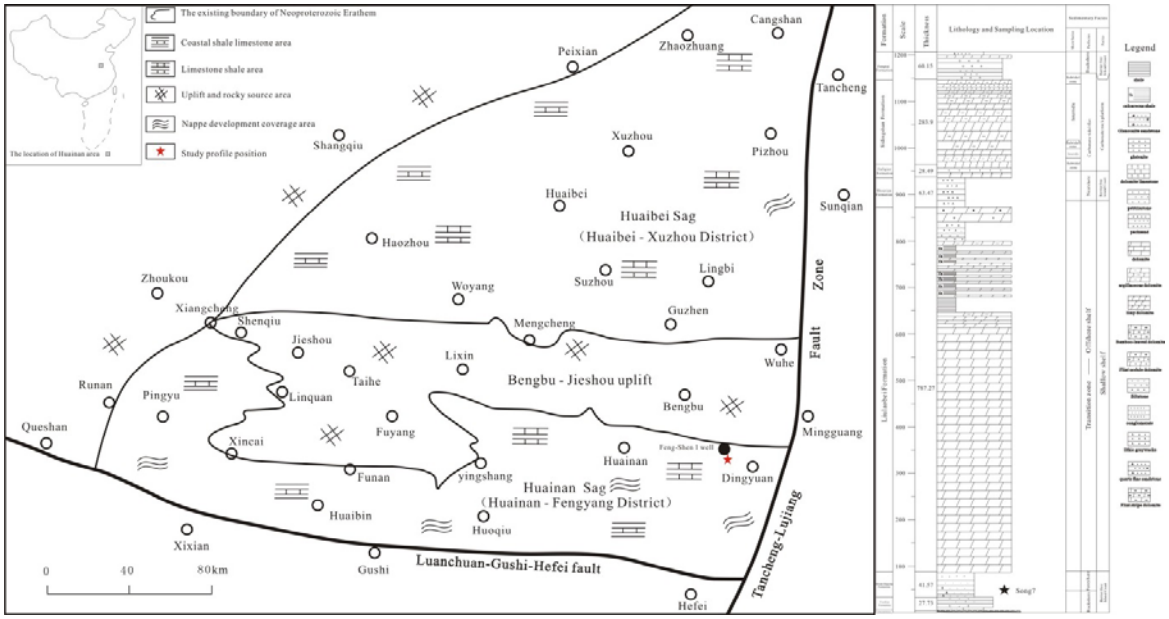


Figure 1: Tectonic units and stratigraphic minor regions of Huainan Depression (Liu et al., 2016)

The samples in this study were taken from the Songji section, where the Meso-Neoproterozoic strata developed well, the outcrops were continuous, the boundaries were clear, the structure was simple, and the fossils were abundant (Figure 1). The Huainan Gr. consists of glutenite, shale and sandy limestone, the thickness is about 1200 meters. It distributed along the east-west direction, and it's in contact with the upper Fengyang Gr. unconformity and the lower Houjiashan Fm unconformity. In the Songji section, the Caodian Fm and the Bagongshan Fm can be observed. The lithology of the Caodian Fm is mainly purple-red iron-containing quartzitic conglomerate, mega-thick layer conglomerate, glutenite, etc., the sorting is poor, large gravels of 50cm can be seen in local area, and the thickness is 28m. The lithology of the Bagongshan Fm is mainly light gray-green quartz sandstone, glauconite-containing quartz sandstone, and medium-thick layer quartz conglomerate at the bottom, with a thickness of 42 m (Figure 1).

3. Dating method

The sorting of zircon was carried out in the laboratory of the Langfang Regional Geological Survey of Hebei Province. After the samples were crushed to 80 mesh, after they were subjected to rough water elutriation, high magnetic separation, electromagnetic sorting and fine alcohol washing, the samples were picked under a stereomicroscope, and a zircon epoxy target was produced using the picked zircon.

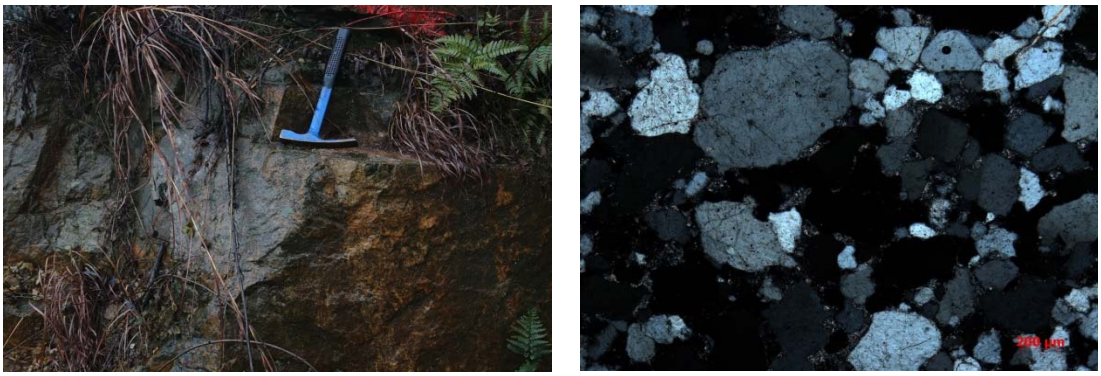
Cathodoluminescence images and zircon U-Pb isotopic dating were performed at Wuhan Shangpu Analytical Technology Co., Ltd. The laser ablation system for analysis was GeoLas Pro HD, and the plasma mass spectrometer was Agilent 7900. The laser energy was 80 mJ and the frequency was 5 Hz. In the laser ablation process, helium was used as carrier gas and argon was used as compensation gas to adjust the sensitivity. The two are mixed by a T-joint before entering the ICP. A small amount of nitrogen is added to the plasma

central gas stream (Ar-He) to improve the sensitivity of the equipment, reduce the detection limits, and improve analytical precision. During the sample test, the beam spot diameter was 24μm, and each time-resolved analysis data included a blank signal of approximately 20-30 s and a sample signal of 50 s. The analysis process is: for U-Pb isotope dating, use zircon standard 91500 as an external standard for isotope fractionation calibration, for each analysis, analyze 5 sample points, and analyze 91500 twice. For the U-Th-Pb isotope ratio drift associated with the analysis time, correct it by linear interpolation using the change of 91500. Off-line processing of analytical data (including selection of sample and blank signals, instrument sensitivity drift correction, elemental content and U-Th-Pb isotope ratio and age calculation) was performed using software ICPMSDATACAL10 (Zou et al., 2017).

4. Samples and test results

4.1 Bagongshan Fm quartz fine sandstone

The sample Song-7 was collected from the Bagongshan Fm located at the central part of the 7th layer of the Songji section in Shouxian county area (Figure 2a). The lithology was light gray-green medium-thick layer quartz fine sandstone, which was developed in parallel bedding. The content of quartz in the sample was as high as 95% or more, the structure was grain supported, argillaceous cementation and calcareous cementation can be observed, and the cement accounted for about 5%. The quartz was mainly single crystal, with wavy extinction, secondary overgrowth can be observed, the particles were sub-rounded and sub-angular in shape, with a particle size of 50~500μm, showing poor sorting and rounding (Figure 2b). The cathodoluminescence image shows that the zircon was mostly sub-rounded and sub-angular, a single zircon was about 40~80μm long, and the aspect ratio was about 1.5:1~2:1. The sorting was normal, the rounding was medium, showing that the zircon had a short transport distance and a relatively close provenance. The lightening of zircon was not uniform, and the internal annulus structure cannot be seen clearly in some zircon, which is mainly due to the high content of Th and U. Most of the zircons in the sample have an annulus structure, indicating that they are magmatic zircons, and a small number of zircons have a bright edge due to metamorphic growth, indicating that zircon particles may be affected by the hydrothermal action in later stages (Figure 3).



(a) (b)

Figure 2: Field outcrop (a) and photomicrograph (b) of Bagongshan Fm in the study area

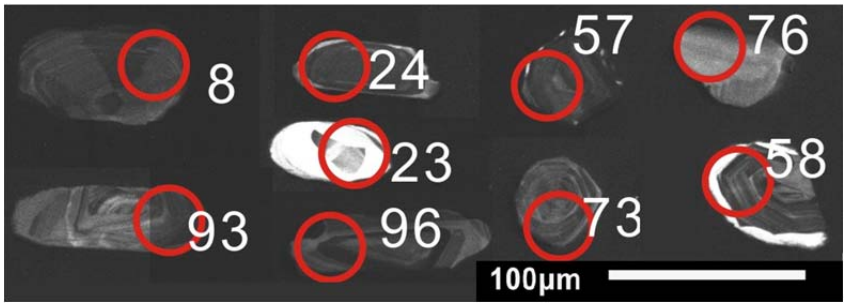
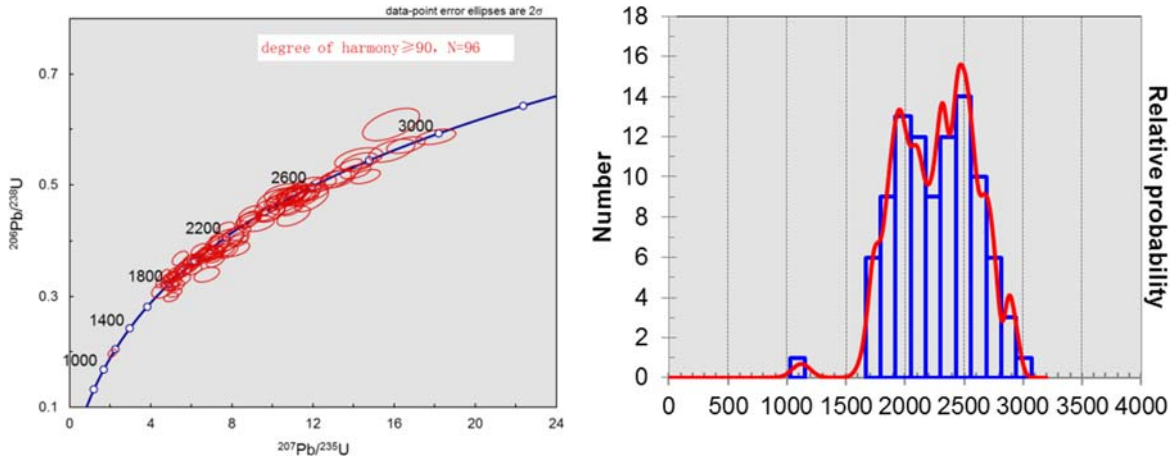


Figure 3: Clastic zircon CL image of Bagongshan Fm in the study area

We randomly selected 106 zircons and performed dating analysis. The results are shown in Table 1. Except that the Th/U ratio of one zircon was less than 0.1, the Th/U ratio of the rest 105 zircons was 0.19~1.83, which indicates the characteristics of magmatic zircon. Among them, the harmonic data of 96 zircons were better (the harmonic degree was greater than 90%), the minimum age of 207Pb/206Pb was 1120Ma, and the maximum age of 207Pb/206Pb was 2948Ma. The age of the main peak was 2531 Ma and the age of the secondary peak was 2065 Ma (Figure 4).



(a) (b)

Figure 4: Clastic zircon U-Pb age harmonic diagram (a) and histogram (b) of the Bagongshan Fm of Huainan Gr. in Huainan area

5. Discussion

5.1 Age of strata in Huainan area

5.1.1 Zircon age limit

As mentioned before, for a long time, due to the lack of reliable isotope dating data, the time limit of the stratigraphic sedimentation in Huainan area has always been controversial. In this study, the time limit of the sedimentation of Huainan Gr. was accurately determined by zircon U-Pb dating. Previous studies have shown that although the age obtained from multiple youngest clastic particles is more consistent with the age of sedimentation, the age obtained from the youngest individual clastic particle is also 95% consistent with the age of sedimentation (Dickinson and Gehrels, 2009). Therefore, a common method of defining the maximum age of sedimentation of strata is to determine it by the age of the youngest clastic zircon in the sample. The youngest zircon age of the sample Song-7 is 1120 Ma, which can determine the maximum sedimentation age of the Bagongshan Fm is 1120 Ma, indicating that the Bagongshan Fm belongs to the system-to-be-built of the Mesoproterozoic erathem. It is proved that the Huainan Gr. spanned from the Mesoproterozoic erathem to the Neoproterozoic erathem, and the oldest stratum should be older than 1100 Ma, which is consistent with the prediction of the predecessors.

5.2 Provenance of clastic zircon

In sample Song-7, in the quartz fine sandstone of the Bagongshan Fm in the southern area, the detrital matters were mainly quartz with a content of more than 95%, the quartz particles were mainly sub-rounded and sub-angular in shape, the zircons in the CL image were also mainly sub-rounded and sub-angular in shape, and the sorting and rounding were poor (Figure 2a, b, Figure 3), indicating that these detrital matters in the clastic rocks originated from closer provenance. The main age peak of zircon was at ~2.1Ga, the ~2.5Ga age peak and a few peaks at the ages of ~3.0Ga were corresponding to the age of the important tectonic-magmatic-thermal events of the Mesoarchean era-Proterozoic eon, and the North China Craton might be the main provenance for these detrital matters.

5.3 Geological events of North China Craton recorded by clastic zircons

The clastic zircons of the Bagongshan Fm in the Huainan Gr. in Huainan area were mainly from the inside of the North China Craton. Therefore, the age of these zircons can record the geological events of the North China Craton, especially they can provide certain evidences for the suspected geological events of the Precambrian period.

5.3.1 Zircon age older than 3.0Ga

In this study, the age data obtained from one zircon in the Song-7 sample is greater than 3.0 Ga, which is the oldest zircon age currently found in Huainan area. Predecessors have found ancient rocks older than 3.0Ga in Anshan area of the North China Craton, which may represent a more important magmatic event in this period, indicating that the North China Craton may have significant growth in the mainland during this period. At the same time, from a regional perspective, there is a Neoarchean geological record in the Xuchang landmass of the North China Craton. Therefore, zircons older than 3.0Ga in the study area may indicate that the Neoarchean Taihua complex and the Dengfeng complex in the North China Craton are one of the provenances of these clastic rocks (Zhai et al., 2000).

5.3.2 Crust growth of 2.9~2.7Ga and cratonization event of ~2.5Ga

In the clastic zircons of the Bagongshan Fm of the Huainan Gr. in Huainan area, the age peak of ~2.5Ga and a few age peaks of ~2.7Ga were recorded (Figure 4b). The CL image shows that most of these zircons are magmatic zircons with wavy annulus structure, and there are also metamorphic zircons with uniform internal structure (Figure 3) and high Th/U. 2.9 ~ 2.7Ga is considered to be the period of large-scale continental crust growth in North China Craton. The rocks in this period are mainly the trondhjemite-tonalite-granodiorite (TTG) gneisses associated with the melting of the basic crust. The age of ~2.7Ga clastic zircons in the Bagongshan Fm also supports the prevalence of 2.9-2.7Ga rocks, indicating that there was large-scale continental crust formation in the North China Craton during this period. The clastic zircon age peak with ~2.5Ga as the main peak corresponds to the age of the important tectonic-magmatic-thermal event of the North China Craton in the Precambrian period. According to previous statistics, the ~2.5Ga clastic zircon age is widely distributed in the North China Craton. During the North China Craton ~2.5Ga period, the activity of crust-melting granite is quite active, and the granite event is closely related to the regional high-grade metamorphism and mixed lithification. This period is considered to be the period of the cratonization of the early North China Craton (Zhai et al., 2000).

5.3.3 Rift formation of 2.3~2.0Ga and geological events of 1.9~1.8Ga

In the clastic zircons of the Bagongshan Fm of the Huainan Gr. in Huainan area, the peak of ~2.1Ga and a few peaks of 1.9~1.8Ga were recorded. The CL image of 1.9~1.8Ga age clastic zircon shows both wavy annulus structures and uniform internal structures with dim glows, indicating that zircons of this age have both magmatic zircons and metamorphic zircons (Figure 3). After ~2.5Ga, the North China Craton experienced a period from rift formation to closed intracontinental orogeny during 2.3~2.0Ga, in central areas, Zhongtiao, Lvliang, Zanhuang, Wutai, fuping, Hengshan, Huai'an, in Jiaodong-Liaoning-Jilin belt and in its possible southern extension of the Bengbu area, metamorphic basic and acidic volcanic rocks, granites, basic intrusive rocks and basic dyke swarms of this period have been reported. The North China Craton experienced a large-scale metamorphism event during 1.9~1.8Ga, and there were also high-pressure and ultra-high temperature granulite. At the same time, during ~1.85Ga, the continental crust uplifted and decompressive melting occurred, a large number of S-type granite magma intrusion occurred in the khondalite rock zone and the central tectonic belt, which may indicate that the collisional orogeny is nearing the late stage and transforming into the spreading and stretching evolution stage. After that, further stretching and cracking occurred in a large area, and the 1.78Ga mafic dyke swarm invasion occurred, marking that the ultimate cratonization of the North China landmass almost ended, and then entered the stable evolution stage of craton cap rock sedimentation (Zhai, 2011).

5.3.4 Multi-period rifting events during late Paleoproterozoic-Neoproterozoic era

In the clastic zircons of the Bagongshan Fm of the Huainan Gr. in Huainan area, a small number of age groups ~1.74Ga and ~1.6Ga were recorded. In the development of North China Craton during late Paleoproterozoic until Neoproterozoic era, there were corresponding magma activities of the cracking effect of these rift valleys or aulacogens, such as: 1.68~1.75Ga non-orogenic magma intrusion of anorhosite, mangerite, charnockite, and rapakivi granite (the AMCG combination); 1.62~1.68Ga Dahongyu Fm potassic volcanic rocks (Wang et al., 2015).

6. Conclusion

(1) Zircon dating results and regional stratigraphic comparison indicate that the strata of Huainan area spanned from the Mesoproterozoic erathem to the Neoproterozoic erathem, and the Bagongshan Fm belongs to the system to be built.

(2) The age peaks of the clastic zircon in the Bagongshan Fm are mainly 2.1Ga and 2.5Ga, and the detrital matters are mainly derived from the inside of the craton.

(3) The age of clastic zircons from the Bagongshan Fm recorded important geological events in the Precambrian of the North China Craton: the age older than 3.0 Ga recorded the Neoarchean geological

events of the North China Craton; the age groups of 2.9~2.7Ga, ~2.5Ga, 2.3~2.0Ga and 1.9~1.8Ga recorded important geological events such as crust growth, cratonization, rifting and orogeny in the early Cambrian of North China Craton; the age groups of ~1.74Ga and ~1.6Ga recorded late Neoproterozoic multi-period rifting event that began in the North China Craton after the final cratonization.

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