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Dating of zircon LA-MC-ICP-MS U-Pb in metabasalt of zhaertai group, Inner Mongolia, China

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Present study consists on the sedimentation age of the Mesoproterozoic Zhaertai Group exposed along the northern margin of the North China Craton using zircon ages. The results showed that the Th/U of zircon varied greatly, from 0.20 to 1.77. Also, the mean ages of the two Concordia Groups of $^{206}Pb/^{238}U$ were 2503.1 ± 2.6Ma (n = 20, MSWD = 1.6), and 1688.0 ± 11Ma (n = 8, MSWD = 1.5), respectively. The age of 2503.1 ± 2.6Ma indicated that the zircon originated from the basement rock, in the underlying late Archean to the early Paleoproterozoic era. The group age of approximately 1688.0 ± 11Ma indicated that the Zhaertai Group underwent a magma accident at approximately 1.7 Ga, which may had some connection with North China's continental cracking event at approximately1850 to 1650Ma. That is to say, the North China Craton's stretch tectonic regime led to non-orogenic magma incidents in the Zhaertai Group at the northern margin of the North China Craton before 1688.0 ± 11Ma. Metabasalt zircons of approximately 1688.0 ± 11Ma also revealed that the sedimentary age of the Zhaertai Group may be approximately 1.7 Ga, and the Zhaertai, Baiyun Obo, and Huade Groups should be considered to be contemporary sedimentary.

[Keywords: Zhaertai Group; metabasalt; dating of zircon U-Pb; North China Craton; magma incident]

Introduction

During recent years, the tectonic evolution of the North China Craton from the Precambrian period has achieved significant progress [1-6]. Studies showed that the North China Craton was formed by different continental blocks in the Precambrian period [7-10]. However, for the division of the block boundaries, as well as their piercing and binding, different views have been put forward [11-14]. A consistent view exists that the North China Craton had been fully consolidated into one whole rigid craton between 1.85 to 1.8 Ga, and then began a stretch tectonic regime development in order to develop a rift basin in the Mesoproterozoic period [15-17]. During approximately 1.8 to 1.6 Ga, northern China experienced a stretch tectonic regime, which formed three rifts at both margins of the North China Craton. These rifts were the Xiong'er-Xiyanghe rifts at southern margin, the Yanshan-Taihangshan rifts at the eastern section of the northern margin, along with the Langshan-Zhaertai and Baiyun Obo rifts at the western section of the northern margin [18].

Some connection exists between the large-scale igneous rock (ring spot granite, anorthosite, mafic dike swarm, and volcanic rocks) which developed in the North China Craton during the Precambrian period, and the breakup of the supercontinent Columbia in the Paleoproterozoic period [19, 20]. There are a great number of geologic records concerning the contemporaneous sedimentation formed on different parts of the block [21], which also includes the Zhaertai and Baiyun Obo groups distributed in the North China Craton. What is more, these were sedimentary along an EW direction at the margin of basin at the time when the Gumengguyang or Langshan-Baiyun Obo rifts were opened [22, 23].

The sedimentation era of the Zhaertai Group has not been clarified at the present time. A geological research team in Inner Mongolia believed that the period of the Zhaertai Group was approximately 1800 to 1400 Ma, which is similar to the Changcheng system in Yanshan [24]. However, Wangji et al. [22] believed it was 1600 Ma. Wang Dongfang [25] discovered a large number of small shell fossils, and concluded the era should be from the late Sinian to early Paleozoic period. According to the age of the zircon LA-ICP-MS U-Pb from the basic volcanic rock, Li et al. [26] determined the era may have started from 1750 Ma. Therefore, this study focuses on the determination of the sedimentation age of the Mesoproterozoic Zhaertai Group, in order to provide some new information regarding the evolutionary history of the northern North China Craton.

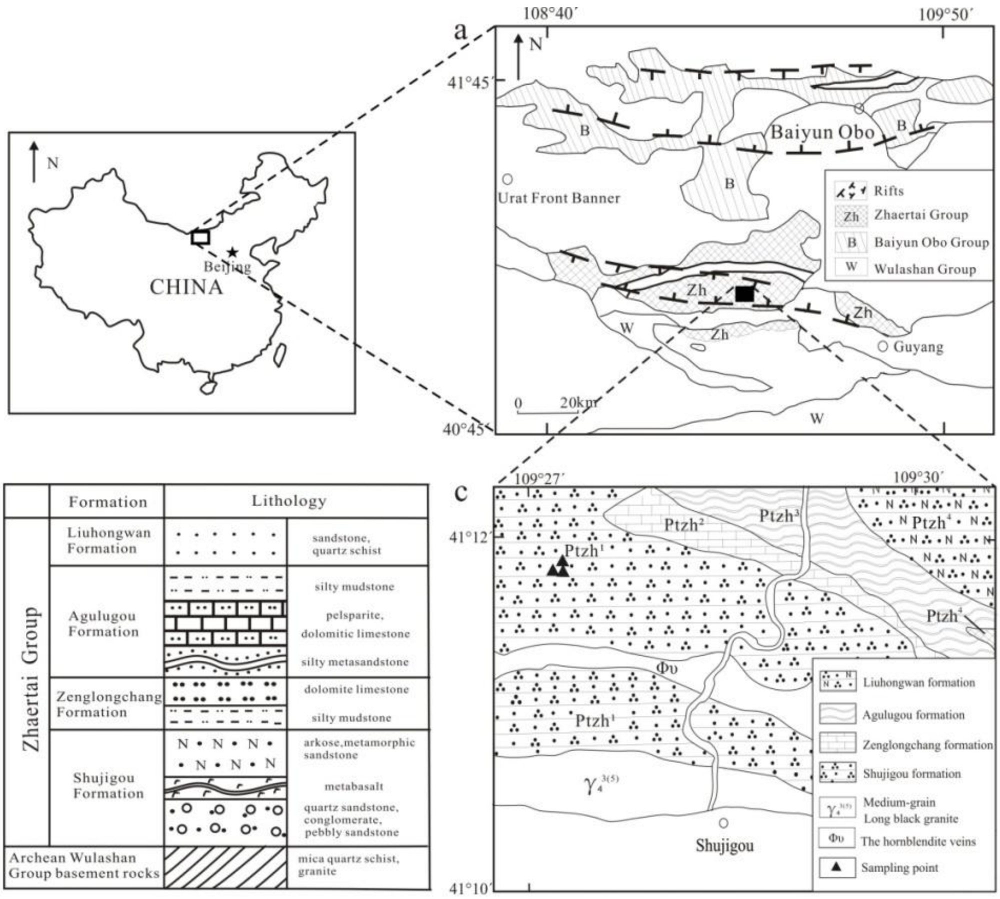

Fig. 1-(a) Simplified geological map of the study area showing the Zhaertai and Baiyun Obo Groups(after [19] (b) Simplified stratigraphic column showing major rock types of the Zhaertai Group and the underlying basement rocks. (c) Sampling locality in Shujigou district

The North China Craton was mainly formed by rocks from the late Archean-Paleoproterozoic period. The north side of the craton was an orogenic belt in the middle of Asia in the late Paleozoic period. The south side of the craton was the early Mesozoic Qinling-Dabie-Sulu UHP orogenic belt, and the South China plate as the boundary [27]. The North China Craton's basement rocks are mainly covered by neoproterozoic-Cenozoic sedimentary, and were invaded by Mesozoic-Cenozoic igneous rocks [27]. In this region, a Mesoproterozoic shallow metamorphic/non-metamorphic rock series is mainly exposed. These groups consist of the Changcheng and Jixian groups in the middle of north China craton; the Xiyanghe-Xiong'er Group at the southern margin; and the Zhaertai, Baiyun Obo, and Huade Groups at the northern margin. These rocks are generally believed to be a sedimentary rock cover layer, which is connected to the Proterozoic period (1.8 to 1.6 Ga) rifts after the cratonization of the North China Craton occurred in the Late Archean period [6, 18].

The Zhaertai Group is widely distributed in the Langshan-Zhaertai Mountains, located in the middle of Inner Mongolia, which is part of the northern side of the North China Craton, or Yinshan block [12]. This group is distributed in an EW direction, approximately 800 km along the Zhaertai Mountains (Fig.1a), and a set of shallow metamorphic rock series. The Zhaertai Group can be divided into four sub-groups beginning from the bottom to the top as follows: Shujigou, Zenglongchang, Agulugou, and Liuhongwan Formations, as shown in Fig.1b. Its rock association is mainly made up of shingly quartzarenite, feldspathic quartz sandstone, carbon sandy slate, carbonatite, and so on. This group is on the hornblende plagiogneiss of the late Archaean Wulashan Group.

The sedimentation of the Zhaertai Group started just after the solidification and basic stabilization of the North China Platform in the late Paleoproterozoic period. In regards to the new solidified platform’s continental crust, it is rather thin and an upwelling of the materials of earth’s mantle exists in the deep section. This tense structural setting caused the rupture of upheaval section, and then produced a fault depression, from which the rudimentary extensional basin of the Zhaertai Mountains gradually formed. The continental sedimentation of the Shujigou Formation began when the rudimentary basin was formed. Although the basin was very small at that time, the high-low difference may have been substantial. The weather-worn clastics in the upwarping region were transported to the basin, and then the sedimentary rock was formed by the stream [28].

A set of metamorphic volcanic rock with amygdaloidal and pillow structures exists in the middle of Shujigou [29]. In the regional distribution, the volcanic rocks are relatively stable, with thicknesses of 67 m in the Shujigou district, and approximately 35 m in the Zhaertai Mountains [29]. For this study, eight samples were collected from the intercalated volcanic layers in the middle section of Shujigou Formation, which were exposed in the Shujigou District, Urad Front Banner, and Inner Mongolia (Fig. 1c). Also, the zircon grains from these samples were dated using a LA-MC-ICP-MS Zircon U-Pb. The analyzed samples contained 49.45 to 58.3 wt.% SiO_2; 2.6 to 3.5 wt.% MgO; 12.6 to 21.2 wt.% total FeO; and 4.2 to 5.3 wt.% K_2O+Na_2O. The samples had an amygdaloidal structure, while the pores were mainly filled by siliceous (Fig. 2). Therefore, this volcanic area is considered to be Metabasalt. The rock is mainly composed of plagioclase, clinopyroxene, and amphibole (Fig. 3). The plagioclase presented a columnar plate, and a scattered distribution, which had developed into polysynthetic twins. The granularity of the plagioclase was from 0.3 mm to 0.5 mm, and the content of the plagioclase was approximately 10%. The hornblende had an irregular shape, and a scattered distribution. The granularity of the hornblende was from 0.2 mm to 0.3 mm, and the content of the hornblende was approximately 15%. The pyroxene presented a columnar-granular shape. The granularity of the pyroxene was from 0.05 mm to 0.1 mm, and the content of the pyroxene was approximately 15%. The matrix was an intergranular, interlaced, or tholeiitic basalt structure, and was mainly composed of an ordinary pyroxene, plagioclase composition, which also contained approximately 15% ilmenite, magnetite, and other opaque minerals. The rocks generally had a low-grade metamorphism. The plagioclase mainly had a sericitization, and some could still be seen in the plate’s appearance. Most of the amphibole had changed to chlorite and epidote, and could also be seen in a small amount of the interspersed terminal siliceous veins (Fig. 3).

Fig. 2-Metabasalt of Zhaertai Group (with amygdaloidal structure)

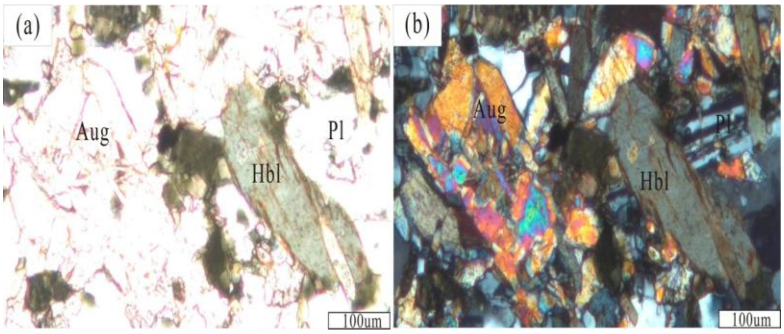

Fig. 3-Microphotographs of microstructure and minerals of metabasalt from the Zhaertai Group. Qz. Quartz; Ms. Muscovite; Bi. Biotite. (a) from single polarized light; (b) from orthogonal polarized light

Materials and Methods

The dating samples were smashed in a below 60 mesh using the conventional method adopted Langfang Regional Geological Survey Institute. They were then separated by a flotation and magnetic separation method. Then, Zircon grains with a crystalline formation and good transparency were selected and photos were taken under transmitted microscope and reflected light. The CL images of Zircon were obtained using a HITACHI S3000-N scanning electron microscope at the Geological Institute of the Chinese Academy of Geological Sciences, which was equipped with a Chroma cathode luminescence probe analytical instrument from the GATA Company. The dating of the LA-MC-ICP-MS Zircon U-Pb was completed in the MC-ICP-MS lab of the Geological Institute of the Chinese Academy of Geological Sciences, and referred to Hou Kejun et al. (2009) [30] for the detailed testing process. The MC-ICP-MS of the Finnigan Neptune with a matched Newwave UP 213 laser ablation system was adopted as the instrument for the dating analysis of the zircon in this study. The spot beam used in the laser ablation was 25 microns in diameter. The Zircon U-Pb dating assumes the Zircon GJ-1 as the external standard, while the U and Th content takes the Zircon M127 (U: 923 PPM; Th: 923 PPM; Th/U: 0.475, [31]) as an external standard for the calibration. An ICP-MS-DataCal program [32] was adopted for the data processing. Ordinary lead corrections were not made for the vast majority of the analysis points ^{206}Pb / ^{204}Pb > 1000, and ^{204}Pb was detected by the ion counter. The analysis point with the exceptional content of ^{204}Pb may have been influenced by the inclusions, as well as other common Pb. The analysis point with exceptional content of ^{204}Pb was rejected in the case of the calculation, and the zircon age harmonic map was obtained by an Isoplot 3.0 program.

Results

For the 27 zircon grains of the samples, the parts without ring overlap, cracks, and inclusions were chosen as the dating analysis of LA-MC-ICP-MS U-Pb, and 28 points were obtained (Table 1). The Zircon CL images for the samples is as shown in Fig. 4. The Metabasalt samples contained two the Concordia Groups of $^{206}Pb/^{238}U$ age (Fig. 5). Eight of the twenty-eight analytical spots had $^{206}Pb/^{238}U$ ages between 1721 Ma and 1676 Ma, and the mean age was 1688.0 ± 11 Ma (n = 8, MSWD = 1.5). The CL image of the zircon grains showed an oscillation band structure (Fig. 4a), and the Th/U of these zircons was 0.61 to 1.14 in size, which indicated they were magmatic zircons [33]. Twenty of the twenty-eight analytical spots had $^{206}Pb/^{238}U$ ages between 2513 Ma and 2496 Ma, and the mean age was 2503.1 ± 2.6 Ma (n = 20, MSWD = 1.6). These zircons contained clear metamorphic hyperplasia edges, and the internal structures presented metamorphic characteristics (Fig. 4b).

Table 1-LA-MC-ICP-MS U-Pb zircon data for the metabasalt from the Zhaertai Group

Point	Th ($\times10^{-6}$)	U ($\times10^{-6}$)	$\frac{Th}{U}$	$\frac{^{207}Pb}{^{206}Pb}$	1σ	$\frac{^{207}Pb}{^{235}U}$	1σ	$\frac{^{206}Pb}{^{238}U}$	1σ	$\frac{^{207}Pb}{^{206}Pb}$ (Ma)	±1σ	$\frac{^{207}Pb}{^{235}U}$ (Ma)	±1σ	$\frac{^{206}Pb}{^{238}U}$ (Ma)	±1σ
1.1	56.28	54.41	1.03	0.10	0.000	4.08	0.029	0.29	0.002	1687.35	7.9	1650.43	5.8	1621.17	8.1
2.1	14.23	18.40	0.77	0.10	0.001	4.11	0.058	0.29	0.004	1675.93	13.3	1655.32	11.6	1641.44	18.7
3.1	29.92	30.63	0.98	0.10	0.001	4.12	0.047	0.29	0.003	1687.04	9.3	1657.80	9.4	1637.82	16.1
4.1	13.12	20.55	0.64	0.10	0.001	4.11	0.055	0.29	0.004	1686.73	11.6	1655.81	11.0	1633.77	18.3
5.1	22.50	36.78	0.61	0.10	0.001	4.10	0.063	0.29	0.004	1695.99	21.3	1655.23	12.4	1624.86	20.4
6.1	14.73	16.49	0.89	0.10	0.001	4.15	0.080	0.29	0.005	1677.78	14.8	1664.98	15.7	1663.82	25.9
7.1	23.86	20.85	1.14	0.11	0.001	4.19	0.054	0.29	0.003	1721.30	11.7	1672.63	10.5	1636.16	17.2
8.1	43.26	46.04	0.94	0.10	0.001	4.11	0.037	0.29	0.002	1679.63	9.9	1656.44	7.3	1639.53	11.4
9.1	87.42	66.15	1.32	0.16	0.001	10.44	0.123	0.46	0.005	2505.25	4.5	2474.67	10.9	2435.74	22.7
9.2	198.88	292.61	0.68	0.17	0.000	10.33	0.072	0.45	0.003	2509.26	3.6	2465.04	6.5	2413.89	13.3
10.1	93.67	90.61	1.03	0.17	0.001	10.42	0.078	0.46	0.003	2509.57	4.5	2472.42	6.9	2428.05	15.0
11.1	43.33	106.22	0.41	0.16	0.000	10.42	0.086	0.46	0.004	2502.16	4.3	2472.73	7.6	2437.53	16.6
12.1	144.95	152.40	0.95	0.16	0.001	10.42	0.084	0.46	0.003	2506.48	5.7	2472.70	7.5	2431.23	15.1
13.1	34.33	54.45	0.63	0.16	0.001	10.37	0.109	0.46	0.005	2497.84	6.9	2468.74	9.7	2432.78	20.2
14.1	59.87	71.69	0.84	0.16	0.001	10.31	0.141	0.46	0.006	2497.84	3.2	2462.65	12.6	2420.78	27.4
15.1	32.72	57.58	0.57	0.16	0.001	10.39	0.110	0.46	0.005	2502.78	5.4	2470.29	9.8	2431.68	20.9
16.1	130.29	66.97	1.95	0.16	0.000	10.43	0.093	0.46	0.004	2497.84	3.9	2474.14	8.3	2445.37	17.6
17.1	143.77	720.33	0.20	0.16	0.000	10.27	0.059	0.45	0.003	2495.99	3.4	2459.21	5.3	2415.31	11.0
18.1	180.13	112.91	1.60	0.16	0.000	10.36	0.063	0.46	0.003	2498.15	4.8	2467.91	5.7	2433.11	11.7
19.1	143.78	169.44	0.85	0.16	0.000	10.43	0.059	0.46	0.003	2505.86	3.7	2473.32	5.2	2433.98	11.2
20.1	64.07	131.97	0.49	0.16	0.000	10.30	0.080	0.46	0.003	2498.15	5.1	2462.06	7.2	2420.97	14.9
21.1	100.54	59.12	1.70	0.17	0.001	10.48	0.090	0.46	0.004	2513.27	6.6	2478.34	8.0	2435.75	16.1
22.1	19.55	156.35	0.13	0.16	0.001	10.31	0.078	0.45	0.003	2500.93	3.9	2462.57	7.0	2416.89	14.8
23.1	44.62	32.95	1.35	0.17	0.001	10.45	0.126	0.46	0.005	2509.26	8.3	2475.83	11.2	2437.27	22.5
24.1	79.91	57.13	1.40	0.16	0.001	10.43	0.097	0.46	0.004	2498.46	4.5	2473.38	8.6	2443.26	18.5
25.1	39.61	93.53	0.42	0.16	0.000	10.34	0.080	0.46	0.003	2501.85	4.8	2465.56	7.2	2423.46	15.1
26.1	182.89	260.23	0.70	0.17	0.001	10.19	0.090	0.45	0.004	2512.04	5.6	2452.44	8.2	2380.67	16.7
27.1	291.90	164.86	1.77	0.17	0.000	10.45	0.066	0.46	0.003	2510.80	3.4	2475.16	5.9	2432.07	12.5

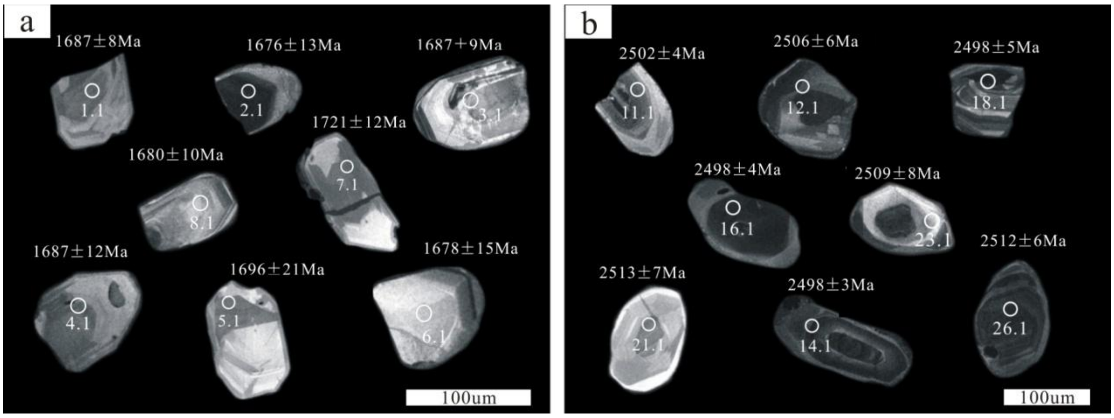

Fig. 4-Representative CL images of zircons from the metabasalt from the Zhaertai Group

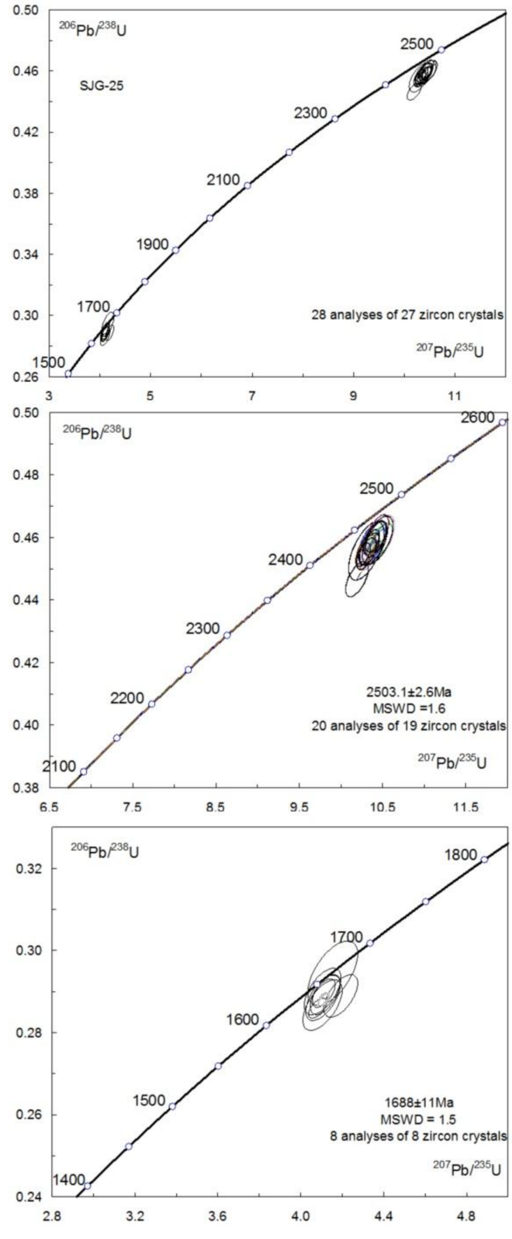

Fig. 5-Zircon U/Pb Concordia diagrams for the metabasalt of the Zhaertai Group

Discussion

The basement level of the North China Craton from the Archean paleoproterozoic period has gone through very complicated tectonic-thermal events. These events include the formation of a continental nuclei and micro landmass > 3.0 Ga; accretion of a continental crust of 2.7 to 2.9 Ga; magma, metamorphism, and cratonization of 2.5 Ga; paleoproterozoic activity (orogenic) belt of 2.3 to 1.9 Ga; and the basement uplift and rifts, and non-orogenic magma events of 1.8 Ga [6, 20].

From the age frequency distribution of the zircon of the metabasalt from the Shujigou Formation of the Zhaertai region, the age of the zircon has been determined to be mainly between 2503.1 ± 2.6 Ma and 1688.0 ± 11 Ma. The former represents the age of the detrital zircon formed during late Archean to early Proterozoic era, and the later represents the metamorphic events at early to middle Proterozoic era. These ages are consistent with the important tectonic-thermal events which occurred in the North China Craton. Taking into consideration that the quartz sandstone at the bottom of the Zhaertai Group and its underlying migmatization granite contain a vast number of zircon particles formed during late Archean to early Proterozoic era (the ages of the detrital zircon of quartz sandstone were mainly 2500 Ma, the magmatic zircon of migmatization granite were manly 2511 ± 26 Ma, [26]), the age of 2503.1 ± 2.6 Ma for the zircon of metabasalt in Zhaertai Group therefore reflected that the basaltic magma captured the detrital zircon from the underlying rocks during the ascent of the basaltic magma.

Conclusions

The other group age of 1688.0 ± 11 Ma reflected that the Zhaertai Group was influenced by the magmatic thermal events of approximately 1.7 Ga. This group of ages is consistent with the geologic records which were saved good on a series of orogenic cracking events at approximately 1.7 Ga, such as the age (1683 ± 67 Ma) of the authigene zircon in the trachyandensite in the Tuanshanzi Formation of the Changcheng System, with the type section during the middle to upper Proterozoic period [34]; the age of 1728 ± 5 Ma of the single zircon U-Pb in the metabasalt sample at the bottom level of the Baiyun Obo Group [35]; and the age of the $^{207}Pb/^{206}Pb$ Maculosus hornblende biotite granite from the Miyun area of 1683 ± 4 Ma [35]. Therefore, the precise zircon U-Pb from the ferruginous rock wall groups that are widely distributed in the North China Craton was determined to be mainly 1800 to 1750 Ma [18]. Regionally, there was found to be some connection between the magma events the Zhaertai Group experienced at approximately 1.7 Ga, and the cracking events of the North China continent that during 1850 to 1650 Ma (series of geological events, such as the basement uplift in Precambrian, dike swarms, orogenic magmatism, and rift formations). What is more, a relationship may also exist with the mantle plume construction, and Columbia supercontinent cracking. During 1800 to 1700 Ma, the North China Craton entered into the stretch tectonic system magma incidents of the Baiyun Obo and Zhaertai Groups slag at the northern margin of the North China Craton, which occurred in succession at 1728 ± 5 Ma and 1688.0 ± 11 Ma.

The age of 1688.0 ± 11 Ma for the zircon of the metabasalt of the Zhaertai Group also reflected that the sedimentation age of the Zhaertai Group was approximately 1700 Ma, which is consistent with the approximate 1800 Ma age [16] for the oldest sedimentation of the Huade Group, and the 1728 ± 5 Ma age [35] for the single zircon U-Pb in the metabasalt sample from the bottom level of the Baiyun Obo Group. These age data showed that the Zhaertai, Baiyun Obo, and Huade Groups should be considered to be comtemporary sedimentary.

Acknowledgment

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