Research Article

Zircon U–Pb Dating and Lu–Hf Isotope of the Retrograded Eclogite from Chicheng, Northern Hebei Province, China

Xu Kong,¹ Xueyuan Qi,² Wentian Mi ,^{2,3} and Xiaoxin Dong²

¹Department of Geology, Northwest University, Xi'an 710069, China

²Inner Mongolia University of Technology, Hohhot 010051, China

³Key Laboratory of Western China's Mineral Resources of Gansu Province, Lanzhou University, Lanzhou 730000, China

Correspondence should be addressed to Wentian Mi; miwentian1982@imut.edu.cn

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We report zircon U–Pb ages and Lu–Hf isotopic data from two sample of the retrograded eclogite in the Chicheng area. Two groups of the metamorphic zircons from the Chicheng retrograded eclogite were identified: group one shows characteristics of depletion in LREE and flat in HREE curves and exhibit no significant Eu anomaly, and this may imply that they may form under eclogite facies metamorphic condition; group two is rich in HREE and shows slight negative Eu anomaly indicated that they may form under amphibolite facies metamorphic condition. Zircon Lu–Hf isotopic of ϵ_{Hf} from the Chicheng eclogite has larger span range from 6.0 to 18.0, which suggests that the magma of the eclogite protolith may be mixed with partial crustal components. The peak eclogite facies metamorphism of Chicheng eclogite may occur at 348.5–344.2 Ma and its retrograde metamorphism of amphibolite facies may occur at ca. 325.0 Ma. The Hongqiyngzi Complex may experience multistage metamorphic events mainly including Late Archean (2494–2448 Ma), Late Paleoproterozoic (1900–1734 Ma, peak age = 1824.6 Ma), and Phanerozoic (495–234 Ma, peak age = 323.7 Ma). Thus, the metamorphic event (348.5–325 Ma) of the Chicheng eclogite is in accordance with the Phanerozoic metamorphic event of the Hongqiyngzi Complex. The eclogite facies metamorphic age of the eclogite is in accordance with the metamorphism (granulite facies or amphibolite facies) of its surrounding rocks, which implied that the tectonic subduction and exhumation of the retrograded eclogite may cause the regional metamorphism of garnet biotite plagioclase gneiss.

1. Introduction

The tectonic evolution of the central part of the northern margin of the North China Craton has become a hot academic research focus in recent years. As a significant component of the dismembered ophiolite mélange of the Hongqiyngzi Complex [1], the retrograded eclogite which recorded the evolution history of the Paleasian Ocean has been attracting more and more attention [2–9].

The tectonic evolution of the Chicheng retrograded eclogite can be classified into four stages [10]: (1) the protolith formation stage, (2) the peak eclogite facies stage, (3) the granulite facies stage, and (4) the amphibolite facies stage. Previous chronology studies shows that the metamorphic age of the retrograded eclogite are still under

disputes: 325 Ma of SHRIMP zircon U–Pb age was recommended as the peak metamorphic age by Ni et al. [10]; 355 Ma of SHRIMP zircon U–Pb age was proposed as the peak metamorphic age by Kong et al. [11]; 1847–1840 Ma of SIMS zircon U–Pb age was recommended as the peak metamorphic age by Liu et al. [1]; 1.85–1.80 Ga, 460–420 Ma, and 360–270 Ma of zircon U–Pb age was proposed as the peak metamorphic age, retrograded metamorphic age, and amphibolite facies metamorphic age, respectively, by Zhang et al. [8].

Because zircon geochemistry and chronology are very effective methods applied to metamorphism chronology research of the eclogite, this paper attempts to provide more zircon U–Pb and Lu–Hf isotopic composition of the eclogite and may be beneficial to solve these disputes.

2. Geological Background and Petrological Characteristics

The Chicheng area, including Zhenningpu, Luhepu, and Qilidun, is located on the north side of the Chongli-Chicheng Fault, northern margin of the North China Craton (NCC) (Figures 1(a)–1(c)). Retrograded eclogite, which occur as separate tectonic lenses within the Hongqiyingsi Complex, range in size from 1–5 cm to 30–50 m and their elongation is consistent with regional schistosity or gneissosity (Figure 2(a)).

Based on the differences of the mineral assemblages and the degree of retrograde metamorphism, the retrograded eclogite from Chicheng can be divided into the weakly amphibolitized eclogite and the intensely amphibolitized eclogite [11]. The intensely amphibolitized eclogite are characterized by the existence of amphibole and plagioclase, very little or no omphacite and vermicular symplectite of Na-poor clinopyroxene and plagioclase; garnets are replaced completely by a granular symplectite of amphibole and plagioclase. The weakly amphibolitized eclogite are characterized by the existence of remnant omphacite and vermicular symplectite of Na-poor clinopyroxene and plagioclase.

3. Sample Descriptions

The weakly amphibolitized eclogite of sample 160601, from the east of Chicheng town, is fine-medium grained, with a mineral assemblage of omphacite (60 vol.%) + garnet (13 vol.%) + diopside (2 vol.%) + amphibole (5 vol.%) + plagioclase (15 vol.%) + quartz (5 vol.%). The weakly amphibolitized eclogite of sample 160602 from Luhepu, is medium grained, with a mineral assemblage of omphacite (63 vol.%) + garnet (12 vol.%) + diopside (2 vol.%) + amphibole (5 vol.%) + plagioclase (15 vol.%) + quartz (5 vol.%).

4. Sample Selection and Analytical Methods

Two samples (sample 160601 and 160602) of retrograded eclogite from Chicheng were used in this research and were performed by zircon ICP-MS U-Pb dating, zircon Lu-Hf isotopic analysis, and zircon trace elements analysis.

4.1. Zircon Selection and Cathodoluminescence Study. Zircons from sample 160601 and 160602 were sorted in the laboratory of the Hebei Regional Geological Investigation Brigade in Langfang city. First, the rock samples were broken into 80–100 mesh grains; then, the zircons were sorted by conventional magnetic separation and then purified by manual picking under a binocular microscope. Before dating, the purified zircons were mounted in an epoxy resin target and polished to half of their thickness.

4.2. Zircon ICP-MS U-Pb Dating, Lu-Hf Isotopic Analysis, and Trace Elements' Analysis. The zircon U-Pb dating of sample 160601 and 160602 was conducted using an Analyte Excite (Bozeman, Montana, USA) 193 nm Laser ablation system

combined with a Nu Plasma II ICP-MS (Wrexham, Wales, UK) at Nanjing FocuMS Technology Co. Ltd. The details of the analytical procedures and methods are similar to the dissertations elaborated by Griffin and Yuan [12, 13]. The diameter of the ion beam was approximately 32 μm at 8 Hz repetition rate, the depth of the ablation was 20–35 μm , and the duration of the ablation was 40 seconds. In the process of testing, 1 point of the standard zircons was measured after every 5 points of the purified zircons to control the stability and the accuracy of the ion counts. The uncertainty for each measuring point is $\pm 1\sigma$, and uncertainty of the final concordia ages is $\pm 1\sigma$. The isotope ages of $^{206}\text{Pb}/^{238}\text{U}$ were corrected by standard zircons 91500 (1064 Ma) [14]. Due to the small amount of ^{207}Pb formed in the Phanerozoic zircons, the $^{206}\text{Pb}/^{238}\text{U}$ ages were used to constrain the metamorphic ages for the retrograded eclogite, and the detailed U-Pb isotopic dating data are shown in Table 1.

The zircon Lu-Hf isotopic analysis of sample 160601 and 160602 was conducted after the zircon U-Pb dating was finished. For instrumental mass bias correction, Hf isotope ratios were normalized to $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$ and Yb isotope ratios to $^{172}\text{Yb}/^{173}\text{Yb} = 1.35274$, and the mass bias behavior of Lu was assumed to follow that of Yb. Correction for the isobaric interferences of ^{176}Yb and ^{176}Lu with ^{176}Hf utilizes $^{176}\text{Yb}/^{173}\text{Yb} = 0.796218$ and $^{176}\text{Lu}/^{175}\text{Lu} = 0.02655$ [15]. The Hf isotopic data process details were described by Vervoort et al. [16] and Vervoort [17]. The weighted mean $^{176}\text{Hf}/^{177}\text{Hf}$ ratio of standard zircon 91500 is 0.282303 ± 28 (2σ), which is indistinguishable with a weighted mean $^{176}\text{Hf}/^{177}\text{Hf}$ ratio of 0.282307 ± 31 (2σ) [18]. The weighted mean $^{176}\text{Hf}/^{177}\text{Hf}$ ratio of standard zircon GJ1 is 0.282017 ± 26 (2σ), which is indistinguishable with a weighted mean $^{176}\text{Hf}/^{177}\text{Hf}$ ratio of 0.282013 ± 19 (2σ) [19].

Calculation of Hf TDM1 ages is based on a depleted-mantle source with present-day $^{176}\text{Hf}/^{177}\text{Hf} = 0.28325$, using the ^{176}Lu decay constant $1.867 \times 10^{-11} \text{ year}^{-1}$ [20]. The zircon trace elements analysis of sample 160601 and 160602 were also performed by ICP-MS at the Nanjing FocuMS Technology Co. Ltd. The testing procedures and parameters are similar to zircon U-Pb dating and the analytical error is about $\pm 10\%$ for light rare Earth elements and $\pm 5\%$ for the other rare Earth elements.

5. Results

5.1. Zircon Trace Elements' Analysis. The chondrite-normalized REE (rare-earth element) patterns of zircon from sample 160601 (Table 2) are characterized by flat HREE curves and no significant Eu anomaly, indicating that the zircon may form under eclogite facies metamorphic conditions (Figure 3(d)). Two groups of the zircon chondrite-normalized REE curves from sample 160602 can be distinguished: group one is similar to sample 160601 and characterized by flat HREE curves and exhibit no significant Eu anomaly, suggesting that the zircon may form under eclogite facies metamorphic conditions (Figure 3(e)); group two (including two spots, spot 1.1 and 3.1) exhibits steep HREE curves and slight negative Eu anomaly (Figure 3(f)) and has characteristics of metamorphic origin in CL images

FIGURE 1: Geological sketch map showing the location of retrograded eclogite in the Chicheng area, North Hebei Province (modified after [3]). 1 denotes Quaternary cover; 2 denotes Jurassic; 3 denotes Hongqiyingsi complex; 4 denotes Archean rocks; 5 denotes monzonitic granite; 6 denotes porphyritic granite; 7 denotes granitic gneiss-mylonite; 8 denotes metamafic rocks (retrograded eclogite); 9 denotes ultramafic rocks (serpentinized peridotite); 10 denotes Chongli-Chicheng Fault; 11 denotes schistosity; 12 denotes sample location.

FIGURE 2: Field photographs and photomicrographs of the retrograded eclogite. (a) The retrograded eclogite occurs as separate tectonic lenses within the Hongqiyngzi Complex. (b) Macrophoto of the symplectite of light-colored minerals around garnet. (c) Photomicrograph of minerals in sample 160602 (single-polarized light). (d) Photomicrograph of minerals in sample 160601 (single-polarized light). Omp: omphacite; Grt: garnet; Pl: plagioclase; Q: quartz.

TABLE 1: Zircon LA-ICP-MS U-Pb geochronological analyses of the eclogite (sample 160601 and 160602).

Spot	Pb (ppm)	Th (ppm)	U (ppm)	Th/U	207Pb/ 235U	$\pm(1\sigma)$	206Pb/ 238U	$\pm(1\sigma)$	207Pb/235U age (Ma)	$\pm$ Ma (1 σ)	206Pb/238U age (Ma)	$\pm$ Ma (1 σ)
Sample 160601												
1.1	6.2	3.1	108	0.029	0.4104	0.0203	0.0556	0.0009	349.2	14.6	348.6	5.2
2.1	4.6	0.2	73	0.003	0.4387	0.0275	0.058	0.0012	369.3	19.4	363.7	7.1
3.1	6	0.2	91	0.002	0.4724	0.0236	0.058	0.001	392.9	16.3	363.6	6.0
4.1	16.1	1.7	280	0.006	0.4091	0.0133	0.0559	0.0007	348.3	9.6	350.7	4.2
5.1	7.7	0.6	127	0.005	0.4156	0.0194	0.0568	0.0008	352.9	13.9	356.4	5.0
6.1	3.4	0.4	57	0.006	0.4247	0.0219	0.0545	0.0008	359.4	15.6	342.1	4.8
7.1	6.1	0.7	106	0.006	0.4121	0.0173	0.0561	0.0007	350.4	12.4	352.0	4.1
8.1	11.7	1.4	205	0.007	0.4078	0.0112	0.055	0.0005	347.3	8.1	345.0	2.9
9.1	3	0.7	48	0.014	0.402	0.0205	0.0552	0.0008	343.1	14.9	346.2	5.0
10.1	2.5	0.3	40	0.009	0.4293	0.0232	0.0569	0.001	362.7	16.5	356.5	5.9
11.1	5.2	0.4	92	0.004	0.4042	0.0133	0.0541	0.0006	344.7	9.6	339.4	3.4
12.1	1.2	0.1	20	0.004	0.4452	0.0332	0.0569	0.0014	373.9	23.3	356.9	8.3
13.1	6.2	0.8	111	0.007	0.398	0.0122	0.0543	0.0005	340.2	8.8	341.2	3.1
14.1	2.6	0.4	39	0.01	0.4367	0.0243	0.0565	0.0009	367.9	17.2	354.4	5.5
15.1	3.7	0.3	58	0.006	0.4577	0.021	0.0579	0.0008	382.7	14.6	362.6	5.1
16.1	3.6	0.6	61	0.009	0.416	0.016	0.0556	0.0006	353.2	11.5	348.9	3.5
17.1	3	0.1	50	0.002	0.4143	0.0184	0.055	0.0007	352	13.2	345.1	4.2

TABLE 1: Continued.

Spot	Pb (ppm)	Th (ppm)	U (ppm)	Th/U	207Pb/ 235U	$\pm(1\sigma)$	206Pb/ 238U	$\pm(1\sigma)$	207Pb/235U age (Ma)	$\pm Ma$ (1 σ)	206Pb/238U age (Ma)	$\pm Ma$ (1 σ)
Sample 160602												
1.1	3.9	1	59.4	0.017	0.4743	0.034	0.0559	0.0019	337.6	9.6	324.9	3.6
2.1	29.3	23.5	529.5	0.044	0.3702	0.0186	0.0525	0.001	342.9	9	340.6	3.1
3.1	30.7	22.3	562.4	0.04	0.3714	0.0209	0.0512	0.0012	335	6.1	325.1	2.6
4.1	23.3	2.2	413.3	0.005	0.4263	0.0209	0.0554	0.001	360.5	7.4	347.4	3.1
5.1	38.5	42.9	722	0.059	0.3908	0.0168	0.0517	0.0008	341.6	10.3	333.1	3.3
6.1	12.7	21.2	231.8	0.091	0.3945	0.0264	0.0517	0.0012	362.7	20.1	352.0	7.8
7.1	8.2	1	147.3	0.006	0.3999	0.0283	0.053	0.0011	365.2	17.7	358.3	5.8
8.1	13.2	2.4	240.6	0.01	0.4017	0.0248	0.0543	0.001	394.2	18.6	350.9	5.7
9.1	4.6	1.1	81.5	0.014	0.4146	0.0352	0.0539	0.0016	352.2	12.6	338.4	4.8
10.1	4.5	5.6	77.9	0.072	0.4168	0.0382	0.0532	0.0014	353.7	13.7	333.9	4.2
11.1	25.5	20.3	432.9	0.047	0.4388	0.0303	0.0556	0.0013	378.3	9.4	357.7	3.4

(Figure 4), and thus, they may grow under amphibolite facies metamorphic condition [22].

5.2. Zircon U-Pb Dating. The zircons from sample 160601 are colorless with subhedral to oval crystals, lengths ranging from 40 to 120 μm with length/width ratios of 1:1 to 2:1 (Figure 4(a)). Cathodoluminescence photos show cloudy zoned or unzoned features for metamorphic zircon. The 17 analytical points were made on this sample, which have similar low Th/U values (0.002–0.029) and yield mean ages of 348.5 ± 3.7 Ma (Figure 3(a)).

The zircons from sample 160602 are also colorless with subhedral to oval crystals, lengths ranging from 50 to 180 μm with length/width ratios of 1:1 to 3:1 (Figure 4(b)). Cathodoluminescence photos show metamorphic features of nebulous zoned or unzoned. The 9 analytical points of group one zircons have low Th/U values (0.005–0.091) and yield mean ages of 344.2 ± 7.3 Ma (Figure 3(b)). The 2 analytical points of group two zircons have low Th/U values (0.017–0.04) and yield mean ages of 325.0 ± 4.1 Ma (Figure 3(c)).

5.3. Zircon Lu-Hf Dating. Fifteen Lu-Hf spots on the zircon cores were obtained on zircon grains from sample 160601. On the basis of a metamorphic age of approximate 348.5 Ma, initial $^{176}\text{Hf}/^{177}\text{Hf}$ ratios and $\epsilon\text{Hf}(t)$ values are calculated by assuming $t = 348.5$ Ma (Table 3). The metamorphic zircons have a $^{176}\text{Lu}/^{177}\text{Hf}$ ratio of 0.000003–0.000013 and $^{176}\text{Hf}/^{177}\text{Hf}$ (348.5 Ma) of 0.282726–0.283025, corresponding to ϵHf (348.5 Ma) ranging from 6.0 to 16.6 (Figure 5).

Nine Lu-Hf spots on the zircon cores were obtained on zircon grains from sample 160602. On the basis of a metamorphic age of approximate 344.2 Ma, initial $^{176}\text{Hf}/^{177}\text{Hf}$ ratios and $\epsilon\text{Hf}(t)$ values are calculated by assuming $t = 344.2$ Ma (Table 3). The metamorphic zircons have a $^{176}\text{Lu}/^{177}\text{Hf}$ ratio of 0.000005–0.000559 and $^{176}\text{Hf}/^{177}\text{Hf}$ of 0.282921–0.283069, corresponding to ϵHf (344.2 Ma) ranging from 12.8 to 18.0 (Figure 5).

6. Discussion

6.1. The Protolith and Metamorphic Condition of the Eclogite. Previous studies shows that the protolith of the Chicheng retrograded eclogite is tholeiitic oceanic crust with

geochemical characteristics of midocean ridge basalt (MORB) or island arc tholeiite (IAT) [10] and experiences the peak eclogite facies metamorphism caused by the subduction of Paleo-Asian Ocean crust beneath the NCC and the granulite facies or amphibolite facies metamorphism resulted from its exhumation into the Hongqiyngzi Complex. The peak eclogite facies metamorphism is marked by the existence of a small amount of granular omphacite within the garnets ($P > 1.40$ – 1.50 GPa and $T = 680$ – 730°C) [10]. These features indicate that the Chicheng eclogite has the oceanic or mantle affinity, and thus, the protolith of the eclogite is of “foreign” origin [23, 24]. Zircon Lu-Hf isotopic of ϵHf from the Chicheng eclogite has larger spans range from 6.0 to 18.0, which suggests that the magma of the eclogite protolith may mix with partial crustal components.

6.2. The Metamorphic Ages of the Eclogite. As presented above, the mineral assemblages from the retrograded eclogite are omphacite, garnet, amphibole, plagioclase, and quartz. Considering the low Th/U ratios and flat HREE curves with no significant Eu anomaly, the zircon age of 348.5 ± 3.7 Ma from sample 160601 and 344.2 ± 7.3 Ma from group one of sample 160602 are interpreted as the time of the eclogite facies metamorphism. Due to low Th/U ratios and steep HREE curves with slight negative Eu anomaly, the zircon age of 325.0 ± 4.1 Ma from group two of sample 160602 is interpreted as the time of the retrograde metamorphism of amphibolite facies. The eclogite facies metamorphic age of 348.5–344.2 Ma is older than the previous study of 325 Ma [10] and a little younger than the previous study of 355 Ma (Kong et al. [11]).

6.3. The Relationship of the Metamorphism between the Eclogite and Its Country Rock. According to previous studies, the Hongqiyngzi Complex may experience multistage metamorphic events (Figure 6), mainly including Late Archean (2494–2448 Ma), Late Paleoproterozoic (1900–1734 Ma, peak age = 1824.6 Ma), and Phanerozoic (495–234 Ma, peak age = 323.7 Ma). The zircon U-Pb dating for retrograded eclogite shows that the peak eclogite facies metamorphism may occur at 348.5–344.2 Ma and its retrograde metamorphism of amphibolite facies may occur at ca. 325.0 Ma. Thus,

TABLE 2: Trace element concentrations of zircons in retrograded eclogite (ppm).

Spot	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y	ΣREE	LREE	HREE	LREE/HREE	δEu	δCe
Sample 160601																					
1.1	0.001	0.066	0.000	0.035	0.170	0.313	3.74	1.37	7.75	1.07	2.05	0.33	2.60	0.40	34.11	19.90	0.59	19.32	0.03	0.56	2.30
2.1	0.010	0.098	0.007	0.047	0.225	0.390	3.79	1.04	5.50	0.86	1.73	0.25	1.78	0.23	24.20	15.96	0.78	15.18	0.05	0.68	2.78
3.1	0.004	0.073	0.002	0.020	0.194	0.324	2.77	0.96	5.38	0.62	0.98	0.14	0.91	0.13	18.07	12.50	0.62	11.89	0.05	0.76	6.26
4.1	0.001	0.146	0.001	0.048	0.276	0.322	3.22	1.10	6.69	0.79	1.56	0.21	1.71	0.18	23.24	16.25	0.79	15.45	0.05	0.64	27.37
5.1	0.000	0.065	0.001	0.019	0.321	0.370	4.68	1.92	12.21	1.62	2.49	0.30	2.23	0.31	46.56	26.53	0.77	25.76	0.03	0.51	33.37
7.1	0.003	0.132	0.001	0.046	0.482	0.573	6.05	1.49	6.21	0.67	1.22	0.17	1.11	0.16	20.81	18.31	1.24	17.07	0.07	0.61	24.06
8.1	0.003	0.070	0.003	0.016	0.259	0.391	4.70	1.42	7.53	0.88	1.26	0.17	1.37	0.17	24.53	18.24	0.74	17.50	0.04	0.55	6.11
9.1	0.000	0.110	0.003	0.023	0.265	0.371	4.54	1.23	6.59	0.84	1.48	0.23	1.53	0.20	23.72	17.41	0.77	16.64	0.05	0.54	13.62
12.1	0.000	0.100	0.000	0.021	0.347	0.539	5.04	1.51	7.95	1.09	2.06	0.26	1.91	0.24	31.00	21.07	1.01	20.06	0.05	0.69	3.86
16.1	0.009	0.058	0.002	0.044	0.302	0.465	4.96	1.73	9.91	1.24	1.75	0.26	1.85	0.23	32.94	22.81	0.88	21.93	0.04	0.61	3.30
17.1	0.000	0.110	0.003	0.025	0.138	0.196	2.61	1.05	7.67	1.16	2.22	0.32	2.34	0.31	31.71	18.15	0.47	17.67	0.03	0.50	12.88
Sample 160602																					
1.1	0.000	0.542	0.000	0.123	0.361	0.219	3.55	1.50	20.68	8.95	43.97	10.33	113.19	20.43	248.97	223.84	1.25	222.60	0.01	0.38	3.66
2.1	0.000	1.110	0.005	0.081	0.987	1.187	11.46	3.28	21.75	4.03	9.68	1.40	10.02	1.36	117.34	66.34	3.37	62.97	0.05	0.66	65.89
3.1	0.011	0.157	0.000	0.040	0.085	0.115	0.95	0.54	7.79	3.29	14.35	2.88	25.76	4.67	111.01	60.63	0.41	60.22	0.01	0.77	2.65
4.1	0.005	0.709	0.005	0.107	0.564	0.704	8.74	3.07	20.86	3.36	6.84	0.95	6.60	0.99	87.20	53.51	2.09	51.41	0.04	0.53	29.44
5.1	0.043	0.619	0.015	0.107	0.406	0.588	6.88	2.82	23.57	4.60	10.48	1.41	10.22	1.43	122.36	63.17	1.78	61.39	0.03	0.56	6.01
6.1	0.010	0.652	0.004	0.048	0.615	1.091	14.75	5.45	34.85	5.02	9.00	1.10	7.56	1.08	130.40	81.22	2.42	78.80	0.03	0.50	23.52
7.1	0.085	0.745	0.008	0.057	0.573	0.571	5.94	2.32	18.24	3.68	11.29	1.89	18.53	3.02	97.20	66.94	2.04	64.90	0.03	0.60	5.44
8.1	0.006	0.462	0.004	0.058	0.479	0.436	5.66	2.41	20.07	3.64	8.47	1.14	9.04	1.21	109.72	53.10	1.44	51.65	0.03	0.49	23.57
9.1	0.043	1.384	0.012	0.262	0.830	1.104	10.69	3.87	29.21	5.22	11.55	1.69	12.14	1.74	154.76	79.75	3.63	76.11	0.05	0.66	14.63
10.1	0.077	0.552	0.010	0.101	0.411	0.479	7.22	3.07	26.75	5.50	13.42	1.93	15.02	2.12	162.40	76.66	1.63	75.03	0.02	0.44	4.24
11.1	0.005	0.534	0.000	0.000	0.428	0.554	7.07	3.04	24.19	4.90	11.59	1.72	12.61	1.87	137.70	68.51	1.52	66.99	0.02	0.51	80.78

FIGURE 3: Concordia plot (Figures (a)–(c)) showing the zircon analysis from the retrograded eclogite. Chondrite-normalized REE plot (Figures (d)–(f)) of the retrograded eclogite from the Chicheng area. The values for chondrite are from [21].

FIGURE 4: Cathodoluminescence (CL) images of analyzed zircons from the retrograded eclogite. The red circles represent the sites of analyzed points with diameter of $32\mu\text{m}$. The ages depicted in the pictures are $^{206}\text{Pb}/^{238}\text{U}$ ages. (a) 160601. (b) 160602.

TABLE 3: Isotopic features of zircon Lu-Hf from the retrograded eclogite (sample 160601 and 160602).

Spot	$^{206}\text{Pb}/^{238}\text{U}$ age (Ma)	$^{176}\text{Yb}/^{177}\text{Hf}$	$\pm(2\sigma)$	$^{176}\text{Lu}/^{177}\text{Hf}$	$\pm(2\sigma)$	$^{176}\text{Hf}/^{177}\text{Hf}$	$\pm(2\sigma)$	$^{178}\text{Hf}/^{177}\text{Hf}$	$\pm(2\sigma)$	ϵHf (t)	TDM (Ma)
Sample 160601											
1.1	348.6	0.000269	0.000007	0.000009	0.000000	0.282893	0.000014	1.467956	0.000052	12.0	495.8
2.1	363.7	0.000164	0.000004	0.000004	0.000000	0.283015	0.000008	1.467831	0.000033	16.3	326.7
4.1	350.7	0.000625	0.000011	0.000013	0.000000	0.282726	0.000009	1.468006	0.000031	6.0	725.8
5.1	356.4	0.000306	0.000004	0.000005	0.000000	0.282868	0.000009	1.467985	0.000028	11.1	529.7
6.1	342.1	0.000195	0.000004	0.000004	0.000000	0.282892	0.000007	1.468000	0.000026	11.9	497.8
7.1	352.0	0.000378	0.000008	0.000006	0.000000	0.282869	0.000008	1.468050	0.000027	11.1	529.0
8.1	345.0	0.000678	0.000004	0.000011	0.000000	0.282815	0.000008	1.468060	0.000030	9.2	603.0
9.1	346.2	0.000192	0.000003	0.000004	0.000000	0.282908	0.000007	1.468048	0.000027	12.5	475.2
10.1	356.5	0.000163	0.000003	0.000002	0.000000	0.283025	0.000008	1.468040	0.000028	16.6	312.7
11.1	339.4	0.000437	0.000003	0.000008	0.000000	0.282961	0.000007	1.468070	0.000030	14.4	402.0
13.1	341.2	0.000632	0.000004	0.000009	0.000000	0.282997	0.000008	1.467967	0.000026	15.6	351.7
14.1	354.4	0.000129	0.000003	0.000003	0.000000	0.282904	0.000006	1.467954	0.000028	12.3	480.8
15.1	362.6	0.000326	0.000003	0.000005	0.000000	0.282962	0.000008	1.467977	0.000029	14.4	399.7
16.1	348.9	0.000199	0.000003	0.000003	0.000000	0.282952	0.000008	1.468013	0.000024	14.0	414.0
17.1	345.1	0.000173	0.000003	0.000003	0.000000	0.282986	0.000008	1.468018	0.000024	15.2	367.3
Sample 160602											
2.1	340.6	0.007992	0.000018	0.000279	0.000001	0.283009	0.000013	1.468003	0.000038	15.9	337.3
3.1	325.1	0.015006	0.000064	0.000559	0.000005	0.283069	0.000012	1.468001	0.000045	18.0	255.4
4.1	347.4	0.000633	0.000004	0.000012	0.000000	0.282946	0.000009	1.467974	0.000030	13.7	422.2
5.1	333.1	0.012529	0.000078	0.000313	0.000003	0.283008	0.000012	1.467899	0.000052	15.8	340.0
6.1	352.0	0.011790	0.000083	0.000438	0.000004	0.282982	0.000010	1.467996	0.000036	14.9	377.1
7.1	358.3	0.000262	0.000004	0.000005	0.000000	0.282921	0.000008	1.468039	0.000025	12.8	457.6
8.1	350.9	0.001480	0.000055	0.000043	0.000001	0.282948	0.000009	1.468046	0.000033	13.8	420.6
9.1	338.4	0.001213	0.000023	0.000027	0.000000	0.282974	0.000010	1.467941	0.000034	14.7	383.7
10.1	333.9	0.001200	0.000008	0.000024	0.000000	0.282972	0.000010	1.468016	0.000030	14.6	387.0

the metamorphic event of 348.5–325 Ma from the Chicheng eclogite is in accordance with the Phanerozoic metamorphic event of the Hongqiyangzi Complex. The metamorphism (granulite facies or amphibolite facies) of the eclogite country rock (garnet biotite plagioclase gneiss) occurred from 351 Ma to 343 Ma (our unpublished data). Combined with the fact

that the retrograded eclogite occurs as separate tectonic lenses or lumps in the garnet biotite plagioclase gneiss and its major axes direction is in line with regional gneissosity, we come to the conclusion that the tectonic subduction and exhumation of the eclogite may lead to the regional Mesozoic metamorphism of Hongqiyangzi Complex.

FIGURE 5: The $\epsilon_{\text{Hf}}(t)$ value of zircons from the retrograded eclogite.

FIGURE 6: Frequency histogram of metamorphic ages from the Hongqiyingsi complex [1, 2, 7, 8, 10, 11, 25–28].

7. Conclusions

- (1) Two groups of the metamorphic zircons from the Chicheng retrograded eclogite were identified. Group one shows characteristics of depletion in LREE and flat in HREE curves and exhibit no significant Eu anomaly, and this may imply that they may form under eclogite facies metamorphic condition. Group two is rich in HREE and shows slight negative Eu anomaly and indicate that they may form under amphibolite facies metamorphic condition.
- (2) Zircon Lu-Hf isotopic of ϵ_{Hf} from the Chicheng eclogite has larger span range from 6.0 to 18.0, which suggests that the magma of the eclogite protolith may mix with partial crustal components.
- (3) The peak eclogite facies metamorphism of Chicheng eclogite may occur at 348.5–344.2 Ma and its retrograde metamorphism of amphibolite facies may occur at ca. 325.0 Ma.
- (4) The Hongqiyingsi Complex may experience multi-stage metamorphic events mainly including Late Archean (2494–2448 Ma), Late Paleoproterozoic (1900–1734 Ma, peak age = 1824.6 Ma), and Phanerozoic (495–234 Ma, peak age = 323.7 Ma). The metamorphic event (348.5–325 Ma) of the Chicheng eclogite is in accordance with the Phanerozoic metamorphic event of the Hongqiyingsi Complex.
- (5) The eclogite facies metamorphic age of the eclogite is in accordance with the metamorphism (granulite facies or amphibolite facies) of its surrounding rocks

and implies that the tectonic subduction and exhumation of the eclogite may lead to the regional metamorphism of garnet biotite plagioclase gneiss.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Xueyuan Qi & Xu Kong equally contributed to the work, they are joint first authors.

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