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U–Pb zircon age dating of a rapakivi granite batholith in Rangnim massif, North Korea

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Abstract – Rapakivi granites and several small leucogabbroic and gabbroic bodies are located in the Rangnim Massif, North Korea. The largest batholith in the Myohyang Mountains covers an area of 300 km^2 and was intruded into Precambrian metamorphosed rocks. It has a SHRIMP U–Pb zircon weighted mean ^{207}Pb/^{206}Pb age of 1861 ± 7 Ma. The country rocks of rapakivi granites are Neoarchaean orthogneisses and Palaeo-Mesoproterozoic graphite-bearing metasedimentary rocks of granulite facies, and they are similar to those of the rapakivi granites and anorthosites exposed in South Korea and in the North China Craton. We conclude that the three massifs in the Korean Peninsula commonly record an identical Palaeo-Mesoproterozoic anorogenic magmatic event, indicating that they have a common Precambrian basement with the North China Craton.

Keywords: Rapakivi granite, SHRIMP U–Pb zircon age, Rangnim Massif, North Korea.

1. Introduction

There has been considerable debate over the past decade on whether, and how, the Sulu orogenic Belt (Fig. 1) extends eastward to the Korean Peninsula (Yin & Nie, 1993; Ernst & Liou, 1995; Chang, 1995; Lee & Cho, 1995; Lee *et al.* 1997; Zhai & Liu, 1998; Lee *et al.* 2000; Lee & Cho, 2003; Sagong, Cheong & Kwon, 2003; Li *et al.* 2001, 2003; Liu *et al.* 2005; Oh *et al.* 2005).

The Korean Peninsula is traditionally divided into three massifs: from north to south, the Rangnim, Gyeonggi and Yeongnam massifs (Fig. 1), which are separated by two orogenic belts, the Imjingang and Ogcheon belts (Lee, 1987; Paek, 1993). Two Palaeozoic basins, the Pyeongnam and Taebaek basins, developed on the basement of the Rangnim Massif and Gyeonggi–Yeongnam massifs, respectively (Lee & Lee, 2003; Jeong & Lee, 2004).

Our recent studies (Zhai *et al.* unpub. data) conclude that the Rangnim, Gyeonggi and Yeongnam massifs have a single Precambrian basement, which has affinities to the North China Craton. The Taebaek and Pyeongnam basins also have tectono-stratigraphic sequences similar to the Palaeozoic sedimentary sequences of the North China Craton. We consider that they belonged to the North China Craton (Sino-Korean Craton) during the Palaeozoic period. However, an eclogite-bearing high-pressure metamorphic slab (the Hongseong Complex) has been recognized from the southwestern Gyeonggi Massif (Guo *et al.* 2004; Zhai & Guo, 2005). Therefore, Zhai *et al.* (2005) proposed a crustal-detachment and thrust model, and suggest that the collision occurred between the Yangtze Block and the North China Craton (Sino-Korea Craton) along the western margin of the Korean Peninsula.

As further geological evidence for correlation of the Precambrian basement of the North China Craton with the Korean Peninsula, Mesoproterozoic anorogenic magmatism, including rapakivi granites and associated anorthosites and gabbros with 1.9–1.7 Ga ages, have been identified (Yu *et al.* 1996; Ge, Lin & Fang, 1991; Xiao *et al.* 2004; Paek, 1993; Choe, 2005). Zhai *et al.* (2005) recognized a rapakivi granite with a SHRIMP U–Pb zircon age of 1839 ± 10 Ma from the Yangyang district in the northeastern part of the Gyeonggi Massif in South Korea (Fig. 1). However, the rapakivi granite in North Korea (Ri, 1963, 1965) has not been reliably isotopic age dated. This paper reports a SHRIMP U–Pb zircon age for this rapakivi granite batholith, located in the Myohyang Mountains, North Korea (Fig. 1), and indicates that the Myohyang rapakivi granite is comparable to those of the Yangyang rapakivi in the Gyeonggi Massif and the Miyun rapakivi in the North China Craton (Zhai *et al.* 2005).

2. Rapakivi granite

2.a. General geology

The Rangnim Massif is located north of the Imjingang Belt and south of the northern border of Korea (Fig. 1), and is mainly composed of the Rangnim and Jungsan complexes metamorphosed to granulite facies

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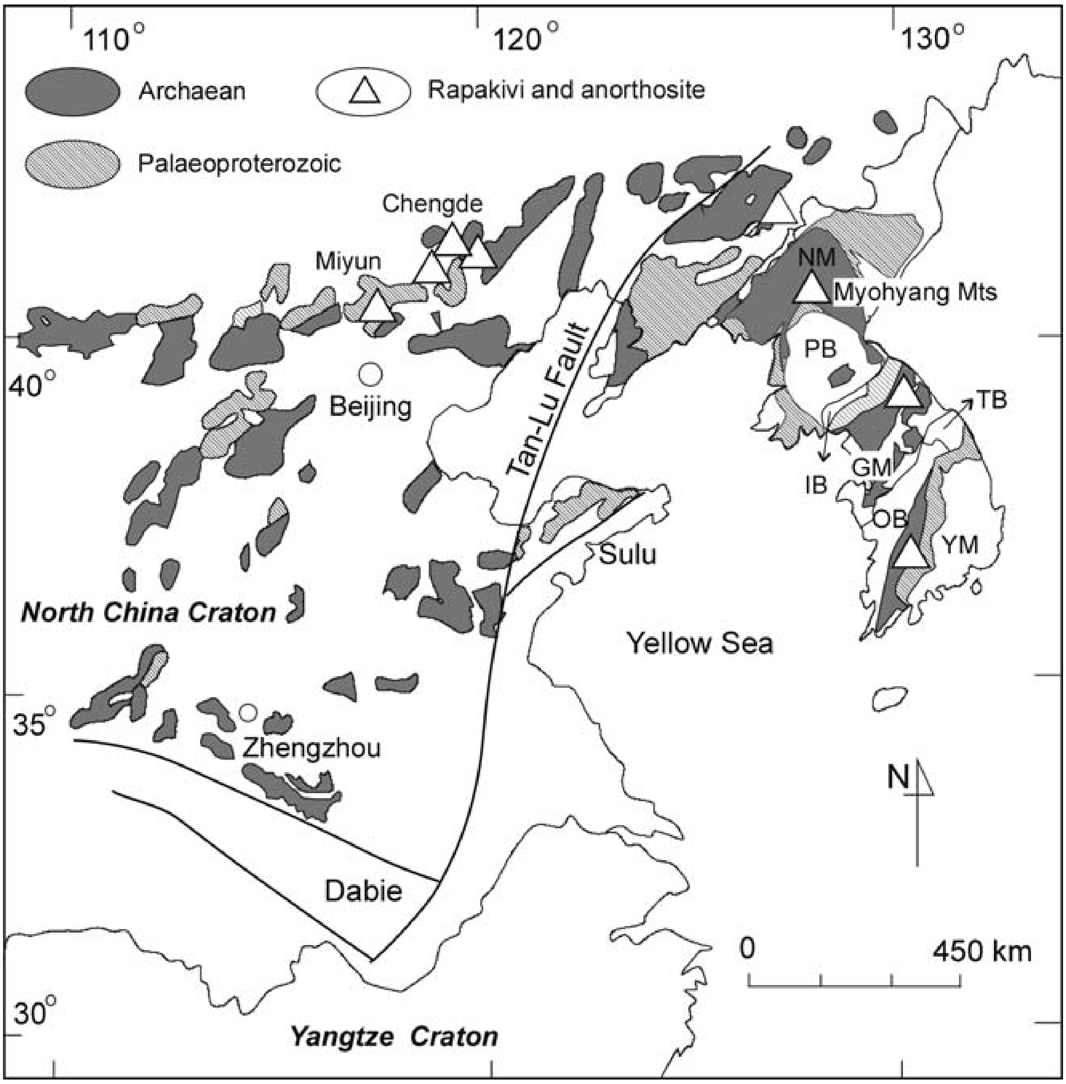

Figure 1. Geological sketch map of the Early Precambrian North China Craton and the Korean Peninsula. NM – Rangnim Massif; IB – Imjingang Belt; GM – Gyeonggi Massif; OB – Ogcheon Belt; YM – Yeongnam Massif; PB – Pyeongnam basin; TB – Taebaek basin.

(Choe, 2005; Fig. 2). The Rangnim Complex consists of composite orthogniesses and supracrustal rocks. The zircon U–Pb ages for cordierite-bearing gneiss from Huichon are 2.5–2.58 Ga (Paek, 1993). The Jungsan Complex is mainly exposed in the southern part of the Rangnim Massif and it is composed of metamorphosed sedimentary rocks (the Jungsan Group) and granites (Fig. 2). The Jungsan Group is a metasedimentary sequence and includes garnet–sillimanite gneiss, graphite–plagioclase gneiss, mica quartzite, biotite gneiss and amphibolite (Choe, 2005). Zircon U–Pb ages from the garnet–sillimanite gneiss are 2160, 1980 and 1850 Ma, and the first two are interpreted to be inherited ages and the last one the metamorphic age of the granulite facies (Paek, 1993; Choe, 2005). Meso-Neoproterozoic sedimentary sequences also locally occur in the southern Rangnim Massif and they are believed to correlate with the Changcheng, Jixian and Qingbaikou units in the North China Craton (Paek, 1993, Paek & Rim, 2005).

The rapakivi granites and several small leucogabbroic and gabbroic bodies are located in the Myohyang Mountains, near Huichon city (Fig. 2). The largest batholith covers an area of 300 km^2 and was intruded into the Jungsan and Rangnim complexes, and is unconformably overlain by the Sangwon and Kuhyon 'systems' in the southwest. Previous studies suggested that the Myohyang rapakivi granites are anorogenic magmatic intrusions similar to the Miyun–Chengde rapakivi–anorthosite bodies in the North China Craton (Qian, 1986, 1997; Ryong, 1993; Choe, 2005). However, the Myohyang rapakivi granites have not been reliably dated, with only a few imprecise ages of K–Ar, and Rb–Sr ages of *c.* 1500–2010 Ma showing a peak of 1909–1870 Ma reported by Ri (1965) and Ryong (1993).

2.b. Petrography and geochemistry

The Myohyang rapakivi granites have characteristically porphyritic and mega-porphyritic textures with ovoid

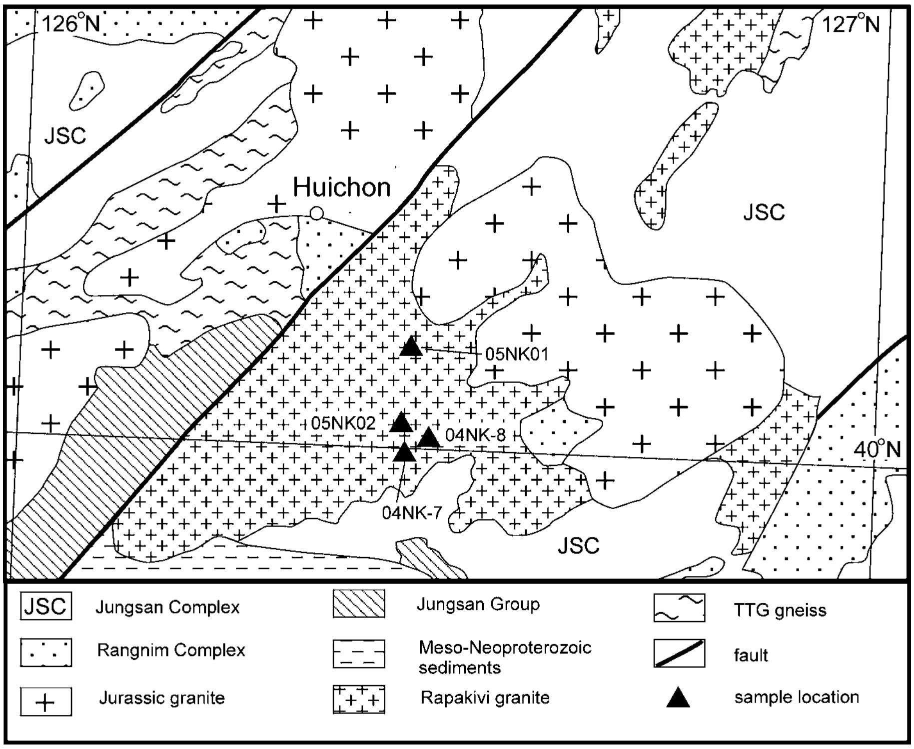

Figure 2. Geological map of the Myohyang Mountains, North Korea, showing sample sites.

Table 1. Major element analyses (wt %) for rapakivi granites from Korea and China

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3T	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	K_2O/Na_2O
05NK02A	68.95	0.28	16.37	1.74	0.02	0.32	1.18	2.1	8.38	0.21	0.67	100.22	3.99
05NK02B	68.35	0.33	15.84	2.47	0.04	0.41	1.77	2.86	5.81	0.1	0.73	98.71	2.03
05NK03	67.93	0.42	16.12	2.15	0.06	0.49	1.96	2.46	8.43	0.13	0.2	100.35	3.42
05NK04	68.21	0.3	16.41	2.26	0.05	0.44	1.30	2.06	7.83	0.11	0.74	99.71	3.80
04NK-01a	72.44	0.31	13.00	3.44	0.01	0.53	0.72	2.74	5.43	0.12	1.20	99.94	1.98
04NK-7	71.56	0.37	12.44	2.97	0.03	0.69	0.70	2.39	7.24	0.22	1.51	99.61	3.02
04NK-8*	70.56	0.4	13.99	3.55	0.05	0.33	1.44	2.85	5.47	0.04	0.99	99.67	1.91
YY-4*	70.32	0.24	14.56	1.78	0.04	0.31	1.19	4.38	5.57	0.08	0.09	99.46	1.27
SC1*	68.86	0.48	14.61	3.23	0.05	0.39	1.62	3.19	5.76	0.12	1.5	99.81	1.80
LP-05*	68.68	0.74	14.24	4.71	0.07	0.55	1.57	3.13	5.37	0.18	1.04	100.28	1.71

Samples 05NK02A, 05NK02B, 05NK03, 05NK04, 04NK-01a, 04NK-7 and 04NK-8 are from Myohyang Mts, Rangnim Massif; YY-4 from Gyeonggi Massif; SC1 from Miyun, NNC; LP-05 from Luanping, NCC.
*Data for last four samples are from Zhai *et al.* (2005).

alkali feldspars distributed homogeneously throughout the granite. The ovoid alkali feldspars range from 10–40 mm to 600 mm in diameter and most of them are mantled by plagioclase, with sharp regular contacts. Nine samples with medium- and small-porphyritic textures were collected (Fig. 2). Mineral compositions were analysed using a CAMECA SX-51 microprobe analyser in the Institute of Geology and Geophysics, Chinese Academy of Sciences. Analyses were performed with a 15 kV accelerating voltage, and a 12 nA beam current was used for plagioclase and K-feldspar to avoid Na migration. Confidence errors are better than 98 %. Porphyritic alkali feldspars have an Al_2O_3 content of 18.75 wt % and K_2O content of 16.18 wt % (Or = 96). Plagioclases have Na_2O contents of 8.89 wt % and CaO content of 4.18 wt % (Ab = 79).

The rapakivi granites are rich in K-feldspar (> 45–55 %) and poor in quartz (< 20–25 %). Their SiO_2 content averages 71.19 %, Al_2O_3 13.14 %, and the K_2O/Na_2O ratio is 2.3 (Table 1).

3. SHRIMP ion microprobe U–Pb zircon analyses

Rapakivi granite sample 05NK02A was collected from the south slope of Myohyang Mountain and prepared. Zircons were extracted from about 10 kg of rock, using standard density and magnetic separation techniques. More than 200 grains of zircon were mounted in an epoxy disc together with the Temora (417 Ma) standards and then polished to expose the centre of zircon grains. Cathodoluminescence (CL) images were obtained using a JEOL scanning electron microscope in order to show obvious internal textures.

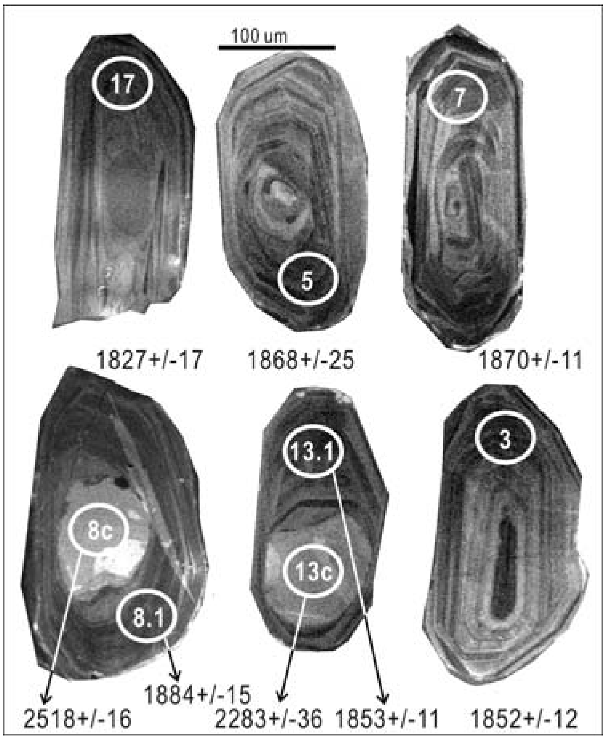

Figure 3. CL images of zircons from rapakivi granite sample 05NK02A, showing sites of SHRIMP analyses. Numbers refer to spots listed in Table 2.

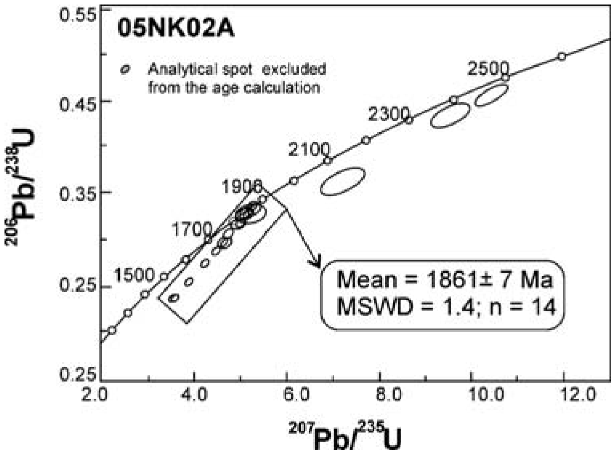

Figure 4. Concordia diagram of SHRIMP U–Pb analyses from sample 05NK02. The shaded spots are excluded in age calculations.

The sample was analysed for U–Pb on the SHRIMP II ion microprobe at the Beijing SHRIMP Center, Chinese Academy of Geological Sciences, following standard operating techniques detailed in Miao *et al.* (2002). Circular to oval areas of 20–30 μm were analysed on morphologically distinct domains chosen by means of the CL images (Fig. 3). Data collection was performed for five scans in dynamic mode. Correction for common Pb was made using the measured ^{204}Pb and the model common Pb composition of Stacey & Kramers (1975).

The results of 21 analyses on 17 euhedral zircon grains are given in Table 2. Three spots from the cores of zircon grains have variable Th contents of 17–236 ppm, U contents of 47–140 ppm and Th/U ratios from 0.37 to 1.74, and give slightly discordant apparent ^{207}Pb/^{206}Pb ages of 2518 ± 16 Ma, 2451 ± 22 Ma and 2283 ± 36 Ma, respectively (Table 2, Fig. 4). We interpret these as the ages of basement rocks in the area, with the zircon cores representing inherited grains derived from the region. The remaining analyses show a range of Th contents from 50 to 615 ppm, U contents from 141 to 829 ppm and Th/U ratios from 0.11 to

Table 2. SHRIMP U–Pb zircon analytical results for sample 05NK02A

Spot	U ppm	Th ppm	^{206}Pb* ppm	^{206}Pb$_c$ %	^{204}Pb/^{206}Pb	^{232}Th/^{238}U	Total ^{238}U/^{206}Pb	± %	^{207}Pb*/^{206}Pb*	± %	^{207}Pb/^{235}U	± %	^{206}Pb*/^{238}U	± %	^{207}Pb*/^{206}Pb* age	
1.1	658	125	164	0.06	3.7E-5	0.20	3.450	0.58	0.11305	0.59	4.515	0.83	0.2897	0.58	1849	±11
1.2	452	50	124	0.06	4.1E-5	0.11	3.131	0.63	0.11465	0.72	5.046	0.96	0.3192	0.63	1874	±13
2	503	107	146	0.05	3.5E-5	0.22	2.963	0.60	0.11342	0.63	5.274	0.87	0.3372	0.60	1855	±11
3	518	140	133	0.06	4.0E-5	0.28	3.351	0.61	0.11324	0.67	4.656	0.91	0.2982	0.61	1852	±12
4	523	102	138	0.07	4.5E-5	0.20	3.246	0.59	0.11268	0.66	4.782	0.89	0.3078	0.59	1843	±12
5	762	149	207	0.01	4.5E-6	0.20	3.166	0.58	0.11420	1.4	4.974	1.5	0.3158	0.58	1868	±25
6	613	615	135	0.22	1.4E-4	1.04	3.900	0.58	0.11112	0.76	3.919	0.96	0.2558	0.58	1818	±14
7	548	150	151	0.09	6.1E-5	0.28	3.128	0.59	0.11438	0.63	5.036	0.86	0.3194	0.59	1870	±11
8*c*	140	236	55	0.16	1.2E-4	1.74	2.193	1.00	0.16600	0.93	10.42	1.4	0.4550	1.0	2518	±16
8.1	647	111	165	0.02	1.5E-5	0.18	3.361	0.65	0.11529	0.83	4.728	1.1	0.2974	0.65	1884	±15
9	141	169	39.8	0.34	2.2E-4	1.23	3.048	1.20	0.11630	2.4	5.24	2.7	0.3268	1.2	1900	±44
10	490	70	138	0.13	8.2E-5	0.15	3.038	0.62	0.11460	0.62	5.193	0.88	0.3287	0.62	1874	±11
11	266	52	75	0.20	1.3E-4	0.20	3.053	0.77	0.11390	10	5.129	1.3	0.3268	0.78	1862	±18
12	829	89	197	0.04	2.6E-5	0.11	3.618	0.52	0.11197	0.54	4.265	0.75	0.2763	0.52	1831	±10
13*c*	47	17	15	0.67	4.6E-4	0.37	2.740	1.70	0.14460	2.1	7.210	2.7	0.3619	1.7	2283	±36
13.1	704	81	198	0.08	5.3E-5	0.12	3.051	0.56	0.11338	0.58	5.119	0.81	0.3274	0.56	1854	±11
14*c*	120	50	45	0.24	1.7E-4	0.43	2.302	1.20	0.15960	1.3	9.530	1.8	0.4331	1.2	2451	±22
14.1	810	136	167	0.12	7.9E-5	0.17	4.180	0.53	0.10997	0.62	3.622	0.82	0.2389	0.53	1799	±11
15	820	129	168	0.23	1.5E-4	0.16	4.181	0.52	0.10815	0.66	3.557	0.84	0.2385	0.53	1768	±12
16	249	105	72	0.08	5.3E-5	0.43	2.992	0.80	0.11550	0.93	5.318	1.2	0.3340	0.80	1888	±17
17	318	98	90	0.25	1.6E-4	0.32	3.047	0.73	0.11170	0.94	5.038	1.2	0.3272	0.73	1827	±17

Errors are 1-sigma; Pb$_c$ and Pb* indicate the common and radiogenic portions, respectively. Common Pb corrected using measured ^{204}Pb. ‘c’ after spot number indicates core.

1.23, but mostly between 0.11 and 0.43. The data are concordant to slightly discordant (Fig. 4). Excluding the four most discordant spots, the fourteen remaining analyses give a weighted mean $^{207}Pb/^{206}Pb$ age of 1861 ± 7 Ma, calculated using the Squid and Isoplot programs (Ludwig, 2001). These zircons show distinct oscillatory zoning of magmatic origin and we interpret this age to be the crystallization time of the Myohyang rapakivi granite.

4. Discussion

Rapakivi granites are commonly associated with gabbro, leucogabbro and anorthosite, representing an anorogenic magmatic association formed in an extensional setting, and resulting from mantle upwelling and lithospheric thinning, notably in the Palaeo- to Mesoproterozoic period (Haapala & Rämö, 1990, 1999; Windley, 1995). In the North China Craton, a rapakivi anorogenic magmatic association and related alkaline volcanic rocks are recognized in the Archaean Miyun and Chengde complexes, near Beijing and Chengde (Fig. 1). Their isotopic ages range from 1950 Ma to 1715 Ma (Xie & Wang, 1988; Yu *et al.* 1994; 1996; Rämö *et al.* 1995; Zhao *et al.* 2002, 2004; Zhai *et al.* 2003; Zhai & Liu, 2003). In South Korea, rapakivi granite with a SHRIMP U–Pb zircon age of 1839 ± 10 Ma intrudes a BIF-bearing orthogneiss and metasedimentary rocks in the northeastern Gyeonggi Massif (Zhai *et al.* 2005; Fig. 1), and ilmenite-bearing anorthosite bodies with Sm–Nd isochron ages of 1792 ± 90 Ma (Park, Kim & Song, 2001) intruded into metasedimentory rocks and orthogneiss in the southwestern Yeongnam Massif (Fig. 1). The country rocks of the rapakivi granite and anorthosite are similar. This study thus establishes that the Myohyang rapakivi granite from the Rangnim Massif, North Korea, is the same age as similar rocks in South Korea and the North China Craton. We conclude that the three massifs in the Korean Peninsula commonly record an identical Palaeo-Mesoproterozoic anorogenic magmatic event, indicating that they have a common Precambrian basement with the North China Craton.

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