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First report of zircon SHRIMP U-Pb dating from the Dufek granite in the Sør Rondane Mountains, East Antarctica*

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Abstract: We report here the first zircon SHRIMP U-Pb chronological result yielding age of (619±7) Ma (11 spots) for the Dufek granite, the largest one of the Early Paleozoic granitoids in the Sør Rondane Mountains, East Antarctica. The analyzed zircon crystals are euhedral, have zonal patterns and Th/U ratios of 0.22~1.04, indicating magmatic genesis. The single zircon crystal has the $^{206}Pb/^{238}U$ age of 664 Ma to 600 Ma with the analyzed spots being from the core parts and mantle-rim part of the zircon grains. The result of 619 Ma analysis shows beyond doubt that the Dufek granite formed during 620 Ma is much older by at least 70 Ma than that of the previously widely believed (500~550 Ma) obtained by Rb-Sr, Sm-Nd and K-Ar isotopic analyses of the Sør Rondane Mountains Pan-African granitoids. Previous chemical characteristics and isotopic data supported that the Dufek granite has chemical affinity with A-type granites under within-plate setting. The U-Pb age of 620 Ma for magmatic zircons in the Dufek granite therefore may represent the age of earlier melt crystallization that occurred at the Late Neo-Proterozoic during the extensional tectonic setting during/after Gondwanaland formation.

Key words: Zircon SHRIMP U-Pb age dating, Pan-African granite, Tectonothermal event, Sør Rondane Mountains, Antarctica
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INTRODUCTION

The Sør Rondane Mountains is the key area for understanding the Pan-African tectonothermal event because this area records widespread felsic magmatism in the Dronning Maud Land of East Antarctica. They mainly consist of Neo-Proterozoic greenschist- to granulite-facies metamorphic rocks, and Early Paleozoic granitoids (Takahashi *et al*., 1990; Tainosho *et al*., 1992; Arakawa *et al*., 1994; Li *et al*., 2003a; 2003b; 2005). The region can be divided into two terranes: an amphibolite- to granulite-facies northeastern and an epidote amphibolite- to greenschist-facies southwestern terranes, which are separated by the Sør Rondane Suture Zone (Osanai *et al*., 1996).

Two widely distributed episodes of the Late Proterozoic and Early Paleozoic plutonisms are divided on the basis of the ages of 900~1000 Ma and 500~550 Ma. The Early Paleozoic granitoids can presently be grouped into four groups: the Group I granites (Dufek and Lunckeryggen granites), Group II granites (Austkampane, Pingvinane, Rogerstoppane and Vikinghøgda granites), Mefjell Plutonic Complex and Lunckeryggen Syenitic Complex on the basis of different field occurrence, chemical characteristics and isotopic data (Li *et al*., 2003b).

Some geologists (Takahashi *et al*., 1990; Tainosho *et al*., 1992; Shiraishi and Kagami, 1992) made some chronological studies of the Early Paleozoic

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granitoids using the whole-rock Rb-Sr, Sm-Nd and K-Ar isotopic analyses. The (528±31) Ma and (519±98) Ma ages of the Dufek granite samples were obtained respectively by the methods of Rb-Sr whole-rock (Tainosho *et al*., 1992) and Sm-Nd whole-rock isotopic analyses (Arakawa *et al*., 1994), with the latter having a 98 Ma error. These age data were obtained at the beginning of the 1990's, with the present methods such as high-precising zircon SHRIMP U-Pb age dating capable of providing much better age values than the other methods. Furthermore, the Dufek granitic body is the largest intrusive body in the Sør Rondane Mountains and can be a good contribution to magmatic thermal event if its precise age dating can be made. Therefore, in this paper, we first present the zircon SHRIMP U-Pb chronological result for the Dufek granite and then discuss its preliminary implications to the Pan-African magmatic event.

OCCURRENCE OF THE DATED SAMPLE AND PETROGRAPHY

The Dufek granite is exposed in an area of approximately 10×10 km^2 in and around Dufekfellet in the Sør Rondane Mountains (Fig.1). The massive pluton that intruded across the gneissosity in the host gneisses includes abundant tonalite xenoliths in the north and large blocks of gneiss in the south (Li *et al*., 2003a) and consists of medium-grained biotite granite and fine-grained hornblende biotite granite having assemblage of plagioclase, K-feldspar, quartz, biotite and accessory titanite, apatite, zircon and Fe-Ti oxides with or without muscovite but containing hornblende as long prisms and grains interstitial to K-feldspar in the latter. Hornblende typically contains inclusions of accessory minerals such as zircon, apatite, titanite and magnetite with K-feldspar being the most abundant mineral, forming tabular microperthitic crystals and granophyric intergrowths with quartz. It is accompanied by normally zoned plagioclase (An_{33}~An_3). Greenish-yellow biotite is mostly interstitial to K-feldspar but may form subhedral grains in the granophyric parts of the rock. Epidote occurs in some samples, coexisting with titanite.

Sample

The B90012305B sample for zircon SHRIMP age dating is medium-grained biotite granite, and has main heave minerals of apatite and magnetite with accessory of ilmenite, hematite, zircon and garnet after crushing and mineral separation procedures.

Zircon characteristics

The euhedral 250 μm long zircons from B90012305B can be divided into a brown type

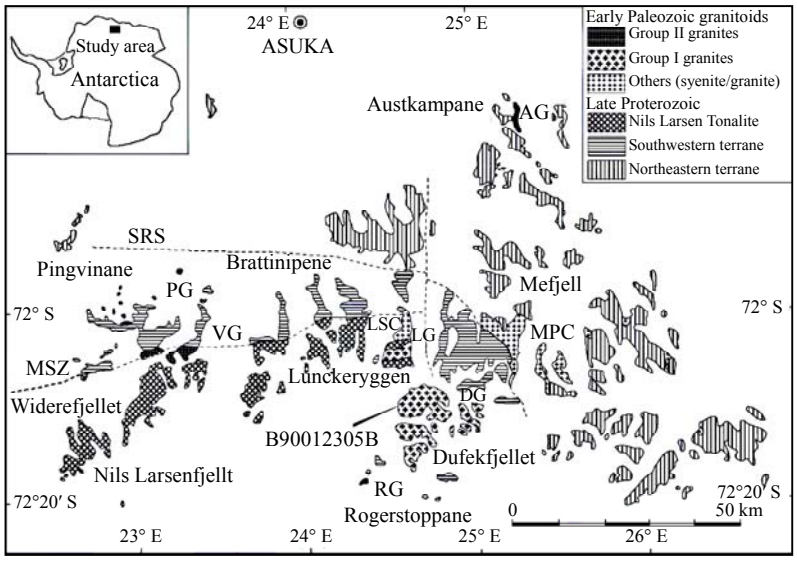

Fig.1 Simplified geological map of the Sør Rondane Mountains (modified from Shiraishi *et al.*, 1997) showing sample locality. The Group I granites are: DG=Dufek granites and LG=Lunckeryggen granites. The Group II granites are: AG=Austkampane granites, PG=Pingvinane granites, VG=Vikinghøgda granites and RG=Rogerstoppane granites. MPC=Mefjell Plutonic Complex; LSC=Lunckeryggen Syenitic Complex; MSZ=Main Shear Zone; SRS=Sør Rondane Suture Zone

with developed fracture, weak transparency and length/width ratios of 3:1~2:1, and a pale-yellow, fine-grained type with good transparency, length/width ratios of 3:1, and partly having some inclusions of magnetite. A hundred grains of brown and pale yellow zircons were selected for measuring using zircon SHRIMP age dating.

ANALYTICAL METHOD

Cathodoluminescence (CL) imaging was used to guide the SHRIMP analyses. The CL study used an FEI-XL30SFEG electron microscope at the Department of Electrony, Peking University. Zircon U-Th-Pb analyses were performed on the SHRIMP II in Beijing SHRIMP Laboratory, Chinese Academy of Geological Sciences following the method described by Song *et al*.(2004). Typically 25~30 μm diameter of spots were used, with a mass-filtered O_2^+-primary beam of ~5 nA. The program SQUID developed by Ludwig (2002) was used for data processing, in which the correction formula of Pb/U fractionation is $(^{206}Pb^+/^{238}U^+)/(^{238}U^{16}O^+/^{238}U^+)^b$ (Black *et al*., 2003), according to the relationship $Pb^+/U^+=a(UO^+/U^+)^b$ with b=2.0 and constant "a" obtained by repeated measurements of TEM standard zircons described by Claoué-Long *et al*.(1995). The error of a single analytical result shown in Table 1 is expressed as 1σ. Common Pb was subtracted from analyzed ^{204}Pb.

RESULTS

The measured isotopic ratios and calculated ages for sample B90012305B are given in Table 1 and illustrated on a concordia plot in Fig.2. Fourteen analyses in total were obtained from 13 randomly oriented zircon crystals of the sample. The measured U concentrations for these zircon grains vary from 1540×10^{-6} to 146×10^{-6}; Th, from 1673×10^{-6} to 66×10^{-6}; and Th/U ratios, from 0.22 to 1.04.

SHRIMP zircon U-Pb dating showed that among 14 spots from 13 zircons of the Dufek granite, 11 spots analyzed yielded (619±7) Ma (*MSWD*=1.8),

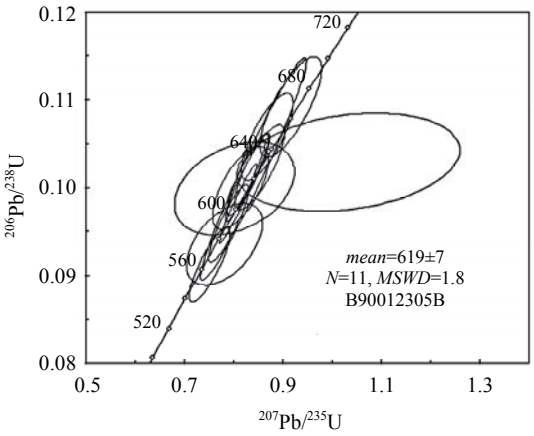

Fig.2 Concordia plot of SHRIMP U-Pb zircon results for sample B90012305B from the Dufek granite
MSWD is mean square of weighted derivates and spots of 1.1, 10.1 and 9.2 were rejected in calculation

Table 1 SHRIMP U-Pb zircon data for the Dufek granite

Spot	U ($\times10^{-6}$)	Th ($\times10^{-6}$)	$^{232}Th/^{238}U$	$^{206}Pb^*$ ($\times10^{-6}$)	$^{206}Pb_c$ (%)	Pb_c corrected $^{238}U/^{206}Pb^*$	±%	Pb_c corrected $^{207}Pb^*/^{206}Pb^*$	±%	Total $^{207}Pb/^{206}Pb$	±%	$^{206}Pb/^{238}U$ Age (Ma)	±%	$^{207}Pb/^{206}Pb$ Age (Ma)	±%
1.1	185	66	0.37	14.8	0.17	10.77	3.1	0.06060	3.40	0.0620	3.00	573	17	625	74
2.1	738	305	0.43	66.8	0.37	9.52	3.0	0.05954	1.60	0.06259	1.10	644	19	587	34
3.1	1153	241	0.22	100.0	0.17	9.92	3.0	0.05929	0.97	0.06072	0.74	619	18	578	21
4.1	146	99	0.70	13.6	5.46	9.79	3.2	0.07280	8.70	0.11680	2.10	627	19	1009	180
5.1	375	121	0.33	32.0	0.32	10.07	3.0	0.05900	2.10	0.06167	1.30	610	18	569	46
6.1	1297	716	0.57	112.0	0.19	9.93	3.0	0.05921	0.91	0.06079	0.69	619	18	575	20
7.1	680	161	0.24	59.3	0.16	9.87	5.6	0.05970	1.30	0.06099	0.98	622	33	593	28
8.1	1598	620	0.40	137.0	0.06	9.99	3.0	0.05925	0.69	0.05971	0.64	615	18	576	15
9.1	4702	1290	0.28	395.0	0.22	10.26	3.0	0.05977	0.49	0.06159	0.34	600	17	595	11
10.1	1662	1673	1.04	136.0	0.05	10.50	3.0	0.05971	0.96	0.06013	0.87	586	17	593	21
11.1	336	92	0.28	29.4	0.08	9.84	3.0	0.06046	1.40	0.06113	1.30	624	18	620	31
12.1	108	71	0.68	9.24	0.78	10.08	3.2	0.05820	5.80	0.0646	3.60	610	19	538	130
13.1	687	517	0.78	64.4	0.68	9.22	3.2	0.06080	1.80	0.06641	0.90	664	20	634	39
9.2	1540	448	0.30	120.0	0.48	11.04	3.0	0.05973	1.20	0.06362	0.69	559	16	594	26

Errors are 1-sigma; Pb_c and Pb^* indicate the common and radiogenic portions, respectively; Common Pb corrected using measured ^{204}Pb

with the spots of 1.1, 10.1, and 9.2 being rejected in calculation. The core and rim ages from the zircons are generally almost the same (Fig.3). The $^{206}Pb/^{238}U$ ages in the spots of 1.1, 10.1, and 9.2 yield 573 Ma, 586 Ma, and 559 Ma respectively (^{204}Pb corrected).

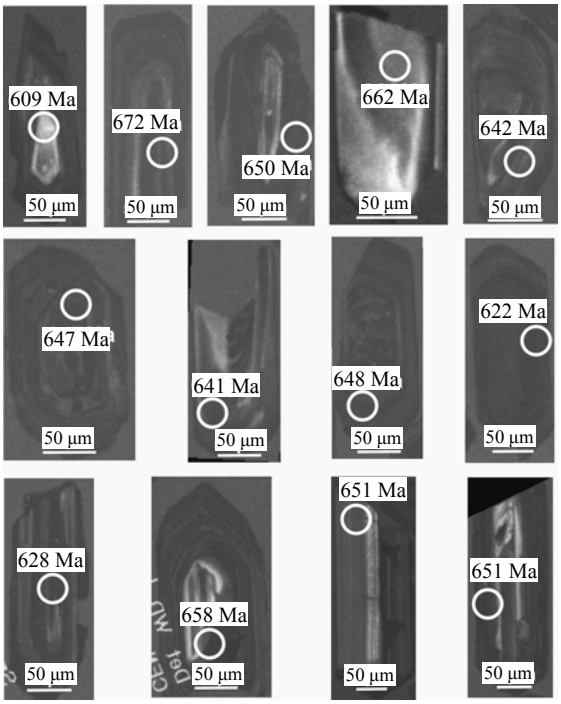

Fig.3 Single age of $^{206}Pb/^{238}U$ of zircon crystals selected from sample B90012305B of the Dufek granite

DISCUSSION AND CONCLUSION

Zircon petrography showed that most zircon grains have well distinguished zonal structure with clear polygonal pattern from the cores to the rims under reflected light microscopy and cathodoluminescence imaging (Fig.3); and that Th/U ratios (0.22~1.04) are high (>0.22) (Table 1), indicating typical magmatic zircon. The zircon grains have $^{206}Pb/^{238}U$ ages ranging from 664 Ma to 600 Ma, showing that the analyzed spots were from not only the core-mantle parts, but also the rim parts of the zircon grains. These ages truly reflect crystallization events of the Dufek granitic magma because the core and rim ages are generally almost the same.

New SHRIMP U-Pb dating results show beyond doubt that the Dufek granite was formed at 620 Ma. The $^{206}Pb/^{238}U$ ages of 573 Ma, 586 Ma, and 559 Ma from the spots of 1.1, 10.1, and 9.2 respectively indicate that these ages are lower than those from the other spots measured although these ages are older than 550 Ma, the maximum limit for the early Paleozoic granitoids. Therefore, it is necessary to carefully reevaluate previous Dufek granite chronological data, and even Sør Rondane Mountains Early Paleozoic granitoids. The age is much more precise and older than the 500~550 Ma pre-existing rock-mineral Rb-Sr, Sm-Nd isochron and K-Ar ages of the Early Paleozoic granitoids; and it constrains the timing of not only the Dufek granite but also the Pan-African magmatic event more reliably. This indicates that the Dufek granite should crystallize at the Late NeoProterozoic, but not Early Paleozoic.

The Late NeoProterozoic magmatic thermal event obtained from the Dufek granite may have genetic correlation with the tectono-metamorphic event of 600~650 Ma in the Sør Rondane Mountains. Through age dating of the Chemical Th-U-total Pb Isochron Method (CHIME), Asami *et al*.(2005) reported recently that ca. 530 Ma represented a large Cambrian event, and that there is existence of minor apparent ages of 620~760 Ma in the cores of monazites of the metamorphic rocks from the Sør Rondane Mountains, and that these results do not accord with the youngest Precambrian ages of 600~650 Ma from the metamorphic rocks obtained by Shiraishi and Kagami (1992), and Shiraishi *et al*.(1999). The age of 620 Ma from the Dufek granite should at least represent a magmatic event episode, and accord with the metamorphic ages of 600~650 Ma (Shiraishi and Kagami, 1992; Shiraishi *et al*., 1999), indicating that a metamorpho-tectono-magmatic event occurred in the Sør Rondane Mountains. Based on the present study, the authors suggest that the Late Neo-Proterozoic~Early Paleozoic magmatic events should have mechanism-associated with the metamorphic events from the Late Neo-Proterozoic to Cambrian.

Previous chemical characteristics and isotopic data supported that the Dufek granite has chemical affinity with A-type granites in the world, and formed under within-plate setting (Li *et al*., 2003b). The U-Pb ages of 620 Ma obtained from the magmatic zircons in the Dufek granite therefore may represent the age of earlier melt crystallization and the beginning emplacement during the extensional tectonic setting during/after Gondwanaland formation.

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