지질학회지 제 56권 제 6호, p. 727-735, (2020년 12월)
J. Geol. Soc. Korea, v. 56, no. 6, p. 727-735, (December 2020)
DOI http://dx.doi.org/10.14770/jgsk.2020.56.6.727

ISSN 0435-4036 (Print)
ISSN 2288-7377 (Online)

북 콘툼 터레인 I-형 및 S-형 화강암의 저어콘 우라늄-납 연령: 중부 베트남에서의 후기 고생대-중생대 화성작용의 의의

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요 약

인도차이나 육괴의 주요 지구조체 중 하나인 북 콘툼 터레인은 베트남 중부에 위치해 있으며, 다수의 신원생대-신생대 화산암-심성암 복합체로 이루어져 있다. 이 지역의 페름기-트라이아스기 화강암과 화강섬록암은 I-형과 S-형 화강암의 지구화학 친화성을 모두 가진다. 북 컨튬 터레인에서 사장석, 정장석, 석영, 흑운모와 소량의 각섬석으로 구성된 시료(QN-791)와 석영, 사장석, 정장석, 흑운모와 소량의 백운모로 구성된 시료(QN-750)를 채취하였다. 이 시료들에서 산출하는 각섬석과 백운모는 각각 이 시료들이 I-형과 S-형 화강암 기원임을 제시한다. 이 대표적 두 시료로부터 추출한 저어콘 결정들을 다검출기 레이저 삭박 유도결합플라즈마를 이용하여 우라늄-납 연령을 측정하였으며, 이로부터 I-형과 S-형 화강암의 정치시기가 각각 262.0±1.3 Ma (2σ)와 243.3 ±1.0 Ma (2σ)임을 밝혔다. 우리의 지구연대학적 자료는 서 인도차이나 지괴에서의 후기 고생대 화성작용과 함께 컨튬 터레인의 후기 고생대 화성작용이 아마도 석탄기부터 시작된 대륙 호 환경과 관련되어 있으며 베트남 중부에서 일어난 중생대 초기 대륙지각 중첩 작용의 증거를 제공한다.

주요어: 저어콘, 화강암질암, 컨튬 터레인, Ben Giang-Que Son 복합체, 인도차이나 육괴

Nguyen Quoc Hung, Ngo Xuan Thanh and Vu Anh Dao, 2020, U-Pb ages of zircon from I- and S-type granites from northern Kon Tum terrane: Implications for late Paleozoic - Mesozoic magmatism in Central Vietnam. Journal of the Geological Society of Korea. v. 56, no. 6, p. 727-735

ABSTRACT: The northern Kon Tum terrane in central Vietnam, one of the most key tectonic terranes of the Indochina block, consists of numerous volcano-plutonic complexes of the Neoproterozoic to Cenozoic ages. Permo-Triassic granites and granodiorite in the terrane have both I- and S-type geochemical affinities. Two granitic samples collected from the northern Kon Tum terrane show mineral assemblages of plagioclase, K-feldspar, quartz, biotite, and minor hornblende (Sample QN-791) and quartz, plagioclase, K-feldspar, biotite, and minor muscovite (Sample QN-750). The presence of minor hornblende and muscovite in the samples may suggest their I- and S-type origin, respectively. Multicollector Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (MC LA-ICP-MS) zircon U-Pb ages from two representative samples revealed the emplacement of the I- and S-type granites at 262.0 ± 1.3 Ma (2σ), and at 243.3 ± 1.0 Ma (2σ), respectively. Our geochronological data provide an evidence for late Paleozoic magmatism in the Kon Tum terrane along the western Indochina block that probably corresponded to a Carboniferous continental arc and early Mesozoic crustal thickening evolution in Central Vietnam.

Key words: Zircon, granitoids, Kon Tum terrane, Ben Giang-Que Son complex, Indochina block

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1. Introduction

In Central Vietnam, the Tam Ky-Phuoc Son Suture Zone (TPSZ) is extended from the Tam Ky to Phuoc Son areas (Vietnam) over a distance of >100 km (Fig. 1a; e.g., Tran *et al.*, 2014). The

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suture zone is considered to represent either an Early Paleozoic ocean separating the Truong Son terrane in the north from the Kon Tum terrane in the south (Lepvrier *et al*., 2008; Tran *et al*., 2014; Nguyen *et al*., 2019). Along the TPSZ in Vietnam, numerous lenticular-shaped, metamorphosed peridotites (dunite and harzburgite), cumulate gabbros-pyroxenites, gabbros, and plagiogranites occur in a few meters to several kilometers in length, and have been considered as an ophiolitic complex (e.g., Izokh *et al*., 2006; Pham *et al*., 2006). In the southern TPSZ, the Kon Tum terrane is located at the northeastern part of the Indochina terrane (Fig. 1a), and is composed of magmatic and metamorphic rocks (Tran and Vu, 2011). Ordovician-Silurian (e.g., Nagy *et al*., 2001; Usuki *et al*., 2009; Nguyen *et al*., 2019) and Permian-Triassic (e.g. Lepvrier *et al*., 2004; Osanai *et al*., 2004; Nakano *et al*., 2007, 2013; Dinh, 2011) ages were obtained from metamorphic and granitic rocks from the Kon Tum terrane. The magmatic and metamorphic event is attributed to the microcontinental collision tectonics in Asia (e.g., Osanai *et al*., 2004), but it is still controversial whether the timing of the collision is Ordovician-Silurian (e.g., Maluski *et al*., 2005; Tran *et al*., 2014; Nguyen *et al*., 2019) or Permian-Triassic (e.g., Nagy *et al*., 2001; Lan *et al*., 2003; Osanai *et al*., 2004; Nakano *et al*., 2013).

The Permian-Triassic granitoid complex in the northern Kon Tum terrane is composed of granite and granodiorite with both I- and S-type geochemical affinities (Tran and Vu, 2011). Three main granitic complexes have been classified: the I-type Ben Giang-Que Son, and S-type Hai Van and Van Canh. Although the Permo-Triassic metamorphic events have been reported (Osanai *et al*., 2004; Nakano *et al*., 2007, 2013; Bui *et al*., 2020), its corresponding magmatic records are rare (Tran and Vu, 2011). In this study, we report the petrology and zircon U-Pb ages of two granitoid samples each from the Ben Giang-Que Son and Hai Van complexes in the northern Kon Tum

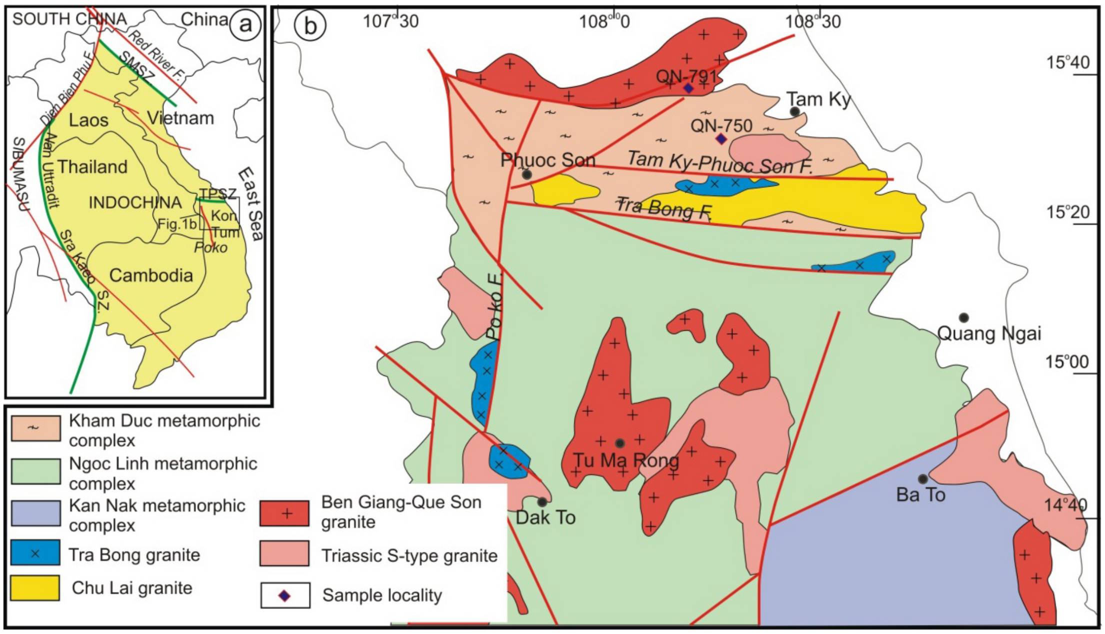

Fig. 1. (a) Simplified tectonic map of Southeast Asia (after Metcalfe, 2013; Metcalfe *et al*., 2017; SMSZ: Song Ma Suture Zone, TPSZ: Tam Ky - Phuoc Son Suture Zone). (b) Simplified geological map of the northern Kon Tum terrane (Central Vietnam) showing distribution of the Tam Ky-Phuoc Son Suture Zone and lithology. Sample localities are also shown.

terrane. Our results contribute to a better understanding of Permo - Triassic magmatism within the Indochina block.

2. Geological setting

The Kon Tum terrane was formerly considered as the Precambrian core of the Indochina block (Hutchison, 1989; Tran and Vu, 2011; Metcalfe *et al*., 2017). However, the late Archean signature was only recorded in a Nd model age of 2.7 Ga for a pelitic granulite of continental crust origin (Lan *et al*., 2003). The Kon Tum terrane is subdivided into three litho-tectonic units: the Kham Duc, Ngoc Linh, and Kan Nack complexes southwards (Tran and Vu, 2011). The Kham Duc unit in the northern part consists of metapelite, metapsammite, and amphibolite of greenschist- to amphibolite-facies. Ultramafic and gabbroic rocks occur locally as lenticular shape in the unit, and recorded the ophiolitic geochemical affinity (Izokh *et al*., 2006). The Ngoc Linh and Ka Nack units are composed of felsic mylonite, pelitic gneiss, and mafic granulite (Nakano *et al*., 2007). High temperature (HT) to ultra-high temperature (UHT) metamorphic rocks were reported with coeval migmatites (e.g., Osanai *et al*., 2004; Nakano *et al*., 2007, 2013). Investigation on the metamorphic ages using the zircon and monazite U-Pb chronometers, and the biotite and muscovite K-Ar and Ar-Ar chronometers revealed at least two metamorphic events: the Ordovician - Silurian (ca. 430-460 Ma; e.g., Nakano *et al*., 2013; Bui *et al*., 2020) and the Permian-Triassic (ca. 240-260 Ma; e.g., Osanai *et al*., 2004; Nakano *et al*., 2007; Bui *et al*., 2020).

The early Paleozoic dioritic-granodioritic-plagiogranitic intrusions are locally distributed in the northern Kon Tum terrane, and are classified as the Tra Bong, Dieng Bong, Chu Lai complexes (Fig. 1b). In general, these rocks belong to peraluminous, calc-alkaline series with enrichment in large-ion-lithophile-elements (LILEs) and depletion in high-field-strength-elements (HFSEs, e.g. Nb, Ta) (e.g., Tran and Vu, 2011), which is interpreted as arc-related magmatism within the Kon Tum terrane (e.g., Tran *et al*., 2014; Gardner *et al*., 2017; Nguyen *et al*., 2019). The Dieng Bong complex has geochemical characteristics of island-arc magma with ca. 500-520 Ma emplacement ages (Nguyen *et al*., 2019). The late Paleozoic to early Mesozoic magmatic intrusions are locally exposed in the northern Kon Tum terrane, and are mainly grouped as the Ben Giang-Que Son, Hai Van, and Van Canh complexes (Tran and Vu, 2011). In general, the Ben Giang-Que Son complex is composed of diorite, granodiorite to granite, and leucogranitic dikes. The K-Ar ages of biotite from these rocks are in the range ca. 232 - 269 Ma. Rare geochemical data of this complex show that the rocks are depleted in HFSE such as Nb, Ta, Ti, and are enriched in Th, U, Cs, which is similar to the modern arc-related magma worldwide (Tran and Vu, 2011). The Hai Van and Van Canh consist of porphyritic granitoids such as granodiorite, granite, and granosyenite dikes. Petrological and geochemical characteristics of these rocks were suggested as S-type granite formed by a crust-thickening event within the Indochina block (Tran and Vu, 2011). The U-Pb isotopic analyses of six representative samples from the Hai Van complex by the LA-ICP-MS show that granites formed at ca. 224-242 Ma (Pham *et al*., 2015). Only a few K-Ar ages of muscovite from the Van Canh complex were reported to be ca. 140-191 Ma (Tran and Vu, 2011).

3. Sample collection, analytical procedure and result

3.1 Sample collection and petrography

In this study, two representative hornblende- and muscovite-bearing granitic samples were collected from the TPSZ (Fig. 1b). Sample QN-791 was collected in a rock quarry of the Ben Giang-Que Son complex. In the field, the rocks are exposed in a large massif of granodiorite in brown color (Fig. 2a). Sample QN-750 was collected in a white granite block exposed in about 15 m width along the Kham Duc complex. Field investigation suggest the boundary between this granite and the Kham Duc amphibolite is intrusive origin (Fig. 2b).

The rock-forming minerals of sample QN-791 are plagioclase, K-feldspar, quartz, biotite, and minor hornblende (Fig. 2c). Plagioclase is subhedral, and is slightly altered to sericite in its rims and cleavages. Hornblende and biotite are mostly anhedral and altered, and biotite is slightly oriented. Accessory minerals include magnetite, pyrite, ilmenite, apatite, sphene, and zircon. Sample QN-750 is composed of quartz, plagioclase, K-feldspar, biotite, and minor muscovite (Fig. 2d). Plagioclase is subhedral, and is highly altered to sericite. Biotite is subhedral, and is partly altered to chlorite. Accessory minerals include magnetite, pyrite, ilmenite, apatite, sphene, and zircon.

3.2 Zircon U-Pb isotopic age dating

Zircon grains were separated by a conventional method, and then were mounted in epoxy resin prior to polishing to expose the interior of the crystals. Cathodoluminescence (CL) images were taken to examine zircon morphology, internal textures, and further to guide spot selection during the U-Pb analyses. The U-Pb dating of zircon was conducted using MC-LA-ICP-MS housed at Korea Basic Science Institute. Zircon 91500 was used as an internal standard for the U-Pb dating. Time-dependent drifts of U-Th-Pb isotopic ratios were corrected using linear interpolation (with time) for every eight analyses according to the variations of standard zircon. U-Th-Pb isotopic

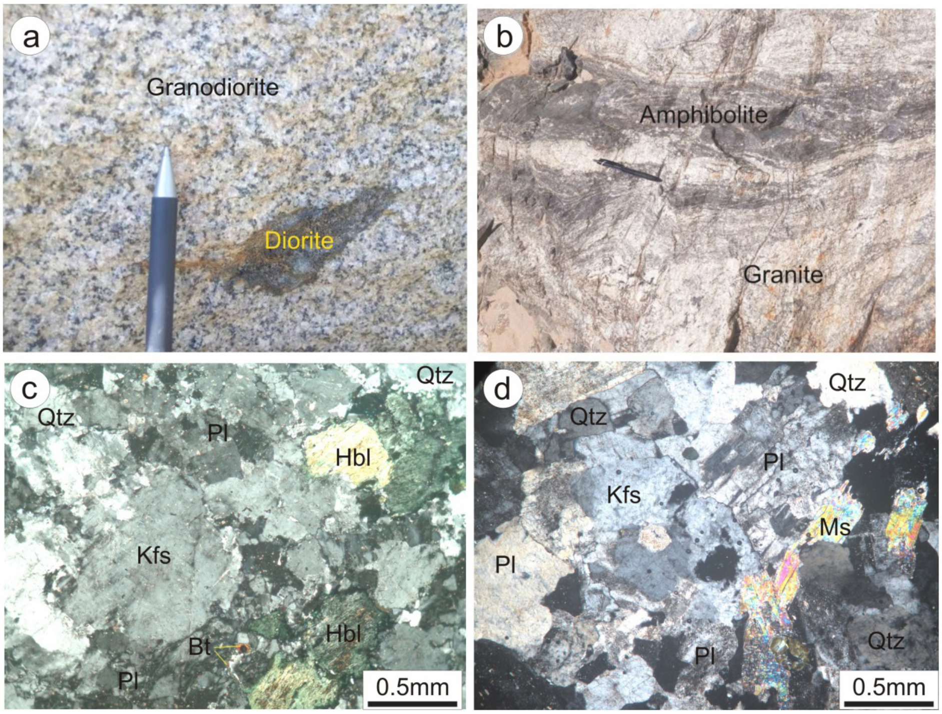

Fig. 2. (a) Outcrop photograph of a granodioritic block within the Ben Giang - Que Son complex (sample QN-791). (b) Outcrop photograph showing the occurrence of the white granite intruded the Kham Duc complex (sample QN-750). (c and d) Photomicrographs showing the representative minerals of the granodioritic sample (QN-791) and granitic sample (QN-750), respectively (Qtz: quartz, Kfs: K-feldspar, Pl: plagioclase, Bt: biotite; Ms: muscovite, Hbl: hornblende).

Table 1. Zircon U-Pb dating results for the late Paleozoic-early Mesozoic igneous rocks in the North Kon Tum.

Spot N	$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$		U (ppm)	Th (ppm)	Th/U	Concordance
	Ratio	± 2σ	Ratio	± 2σ	Ratio	± 2σ	Age	± 2σ	Age	± 2σ	Age	± 2σ				
Sample QN-750																
01	0.2590	0.0380	0.0383	0.0011	0.0509	0.0010	230.0	2.3	242.1	5.7	270.0	40.0	85.1	39.5	0.48	94.0
03	0.2686	0.0059	0.0383	0.0004	0.0514	0.0009	242.2	4.7	242.1	2.7	285.0	20.0	456.0	83.3	0.19	99.0
04	0.2700	0.0048	0.0384	0.0005	0.0511	0.0006	242.9	3.8	242.6	3.3	249.0	15.0	776.0	353.0	0.47	99.1
05	0.2720	0.0200	0.0384	0.0010	0.0514	0.0014	242.0	6.0	242.7	5.9	522.0	69.0	94.8	50.5	0.55	98.7
07	0.2713	0.0076	0.0384	0.0006	0.0513	0.0012	243.3	6.1	242.7	3.4	283.0	25.0	256.3	33.0	0.13	99.2
08	0.1600	0.0200	0.0384	0.0016	0.0515	0.0006	243.0	8.0	242.8	5.8	645.0	87.0	36.1	4.6	0.26	99.1
09	0.2728	0.0033	0.0385	0.0004	0.0515	0.0005	244.9	2.6	243.6	2.3	250.0	12.0	1444.0	344.0	0.25	99.5
10	0.2695	0.0057	0.0385	0.0004	0.0512	0.0011	242.0	4.6	243.7	2.6	269.0	25.0	399.0	112.3	0.29	98.3
12	0.2731	0.0055	0.0385	0.0005	0.0512	0.0009	245.9	4.5	243.7	3.0	278.0	25.0	409.0	101.2	0.24	99.9
14	0.2770	0.0130	0.0386	0.0017	0.0516	0.0008	247.0	6.1	244.0	3.0	305.0	21.0	504.0	305.0	0.63	99.0
15	0.2656	0.0087	0.0386	0.0007	0.0517	0.0012	241.4	7.4	244.3	4.0	256.0	37.0	254.9	32.0	0.13	97.8
Sample QN-791																
01	0.2938	0.0046	0.0412	0.0005	0.0513	0.0004	261.4	3.6	260.0	3.3	256.0	10.0	1779.0	1058.0	0.61	98.5
02	0.2897	0.0060	0.0412	0.0008	0.0515	0.0005	258.0	4.7	260.1	4.7	264.0	12.0	1034.0	482.0	0.48	98.5
04	0.2914	0.0054	0.0412	0.0006	0.0516	0.0005	259.4	4.2	260.4	4.0	261.0	14.0	1055.0	520.0	0.51	99.8
05	0.2932	0.0052	0.0412	0.0006	0.0516	0.0005	260.9	4.1	260.5	3.5	277.0	13.0	1078.0	611.0	0.59	93.7
07	0.2955	0.0054	0.0415	0.0007	0.0518	0.0006	262.6	4.2	262.2	4.5	265.0	16.0	1062.0	542.0	0.52	98.9
08	0.2962	0.0065	0.0416	0.0008	0.0516	0.0007	263.1	5.1	262.9	5.1	269.0	17.0	574.0	187.0	0.34	97.7
09	0.2993	0.0065	0.0418	0.0009	0.0522	0.0005	265.5	5.1	264.0	5.5	276.0	13.0	1465.0	812.0	0.57	95.5
10	0.2970	0.0067	0.0418	0.0008	0.0521	0.0005	263.7	5.2	264.0	5.0	269.0	12.0	1099.0	662.0	0.61	98.1
11	0.2988	0.0060	0.0420	0.0009	0.0520	0.0004	265.1	4.7	265.3	5.4	282.8	9.3	2002.0	1197.0	0.63	93.4
14	0.2976	0.0052	0.0421	0.0007	0.0519	0.0004	264.3	4.1	265.7	4.3	285.6	9.9	1590.0	1077.0	0.70	92.5
16	0.2985	0.0093	0.0417	0.0011	0.0527	0.0010	264.6	7.2	263.6	6.9	286.0	23.0	469.0	277.0	0.59	91.5

ratios for zircon 91500 are from Wiedenbeck *et al.* (1995). Uncertainty of preferred values for the internal standard 91500 was propagated to the ultimate results of the samples. In order to monitor the external uncertainties of measurements, a zircon standard GJ-1 was analyzed. Eight measurements yielded a weighted mean $^{206}Pb/^{238}U$ age of 607 ± 3 Ma, which is in agreement with the recommended age of 608.5 ± 0.4 Ma within uncertainty (Jackson *et al.*, 2004). During the analyses, the spot size of the laser beam was 20 μm in diameter. The detailed analytical procedure is similar to that described by Lee *et al.* (2018). Common Pb correction followed the procedure of Andersen (2002). Concordia plots and weighted mean calculations were carried out using the software Isoplot/EX (Ludwig, 2008). Analytical results are listed in Table 1.

Zircons grains from samples QN-791 and QN-750 are 150-200 μm and 120-250 μm in the longest dimension, respectively. They have morphologies variable from subhedral to euhedral, and length-to-width ratios of 2:1 to 4:1 (Fig. 3a, 3b). The majority of these grains is devoid of inherited zircon cores in the sample QN-791, but a few zircons contain inherited cores in a rounded shape. Moreover, most of the zircon grains show well-developed oscillatory zoning throughout their CL images, indicative of their magmatic origin.

Twenty-two zircon U-Pb isotopic analyses are within 10 % discordance, and their Th/U ratios are over 0.13 (Table 1). All data points on Tera-Wasserburg Concordia diagrams are located on or close to the U-Pb Concordia, suggesting little Pb loss after zircon crystallization (Fig. 3). Ten concordant analyses from sample QN791 yielded a weighted mean $^{206}Pb/^{238}U$ age of 262.0±1.3 Ma (2σ) (MSWD=1.03, Fig. 4a). Eleven analyses within 10 % discordance from sample QN-750 gave a weighted mean $^{206}Pb/^{238}U$ age of 243.3±1.0 Ma (2σ) (MSWD=0.20, Fig. 4b).

4. Discussion and conclusions

Within the Kon Tum terrane, two main magmatic events were recognized: (1) the early Paleozoic subduction and collision between the Truong Son and Kon Tum terranes, forming both I- and S-type foliated granites, during the Cambro-Ordovician Caledonian orogeny (e.g., Nguyen *et al.*, 2019; Tran *et al.*, 2020); and (2) the late Paleozoic-early Mesozoic Indosinian orogeny (e.g., Tran and Vu, 2011; Tran *et al.*, 2020). Granitoids in the latter orogeny are widely exposed in the Kon Tum terrane (e.g., Dinh *et al.*, 2011; Ngo *et al.*, 2011, 2014, 2016; Tran and Vu, 2011; Tran *et al.*, 2020), but tectonic model in association with their petrogeneses is attributed either to the Permo-Triassic subduction/collision

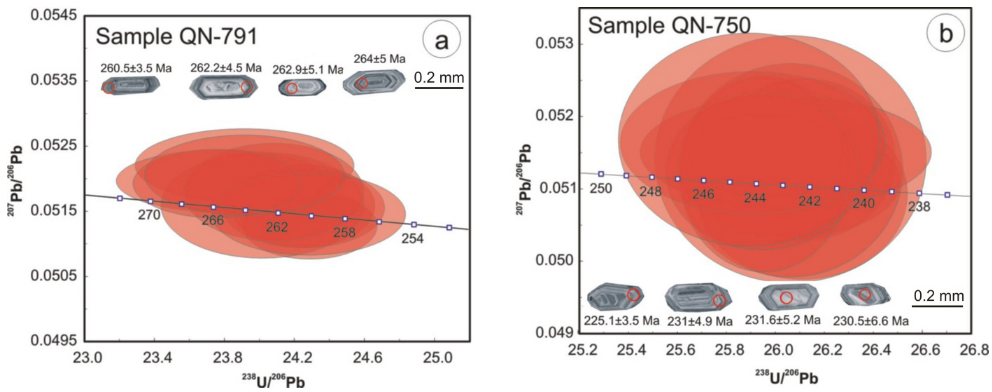

Fig. 3. Representative cathodoluminescence (CL) images of zircons and U-Pb Concordia diagrams of the analyzed samples.

of the South China block underneath the Indochina block (e.g., Ngo *et al.*, 2016) or to the late Carboniferous-Triassic subduction/collision of the Sibumasu block underneath the Indochina block (e.g., Metcalfe *et al.*, 2017).

The Ben Giang- Que Son magmatic complex in the Kon Tum terrane has two magmatic phases: the phase 1 is represented by small dioritic, quartz-dioritic blocks within the main lithology of the phase 2 that are composed of granodiorite and hornblende-bearing granites. The geochemistry and zircon U-Pb ages of the dioritic rocks reported by Pham *et al*. (2015) resulted in their calc-alkaline origin and early Ordovician (479±3 Ma) emplacement. Based on the results, the authors attributed petrogenesis of the complex to the result of the Caledonian orogeny. However, the occurrence of phase 1 (diorite) within the main lithology of phase 2 (granodiorite) in the Ben Giang - Que Son magmatic complex suggests that the diorites are xenoliths representing for earlier magmatism within the Kon Tum terrane (Fig. 2a). The $^{206}Pb/^{238}U$ mean age of 262.0±1.3 Ma from the granodioritic sample (QN-791) in this study is consistent with ages reported by Dinh (2011) and Tran *et al*. (2020) (LA-ICP MS U-Pb ages of zircon) from the granite and granodiorite of the Ben Giang-Que Son complex in the northern Kon Tum terrane, which range from 261±2 Ma to 306±2 Ma. These igneous rocks show typical island arc to active continental margin geochemical signatures such as high LILE enrichment relative to HFSE, and high LREE relative to low HREE (Tran *et al*., 2020), suggesting the existence of active margin during the Carboniferous-Permian within the Kon Tum terrane. The Carboniferous-Early Permian volcanic rocks of andesites, dacites, and basalts with continental arc affinity were also reported in the western and southern part of the Indochina block (e.g., 330-349 Ma andesitic, rhyolitic and tuffaceous rocks, ca. 315 Ma basalts and andesites (Qian *et al*., 2019), and 288-295 Ma granite (Zaw *et al*., 2014) in Laos; 278-301 Ma granitoids (Tran and Vu, 2020) in Cambodia and Thai Land). The magmatic events are relatively older than those reported in North Central Vietnam where most of the ages are middle to late Permian (ca. 270-252 Ma). The tectonic setting of middle to late Permian granitoids in the Kon Tum terrane is still unclear, and it is thus considered that the Ben Giang-Que Son complex in the Kon Tum terrane may be a part of the Carboniferous-Permian suites distributed in Vietnam, Laos, Thailand, and Cambodia, which probably resulted from subduction event of the Sibumasu underneath the Indochina blocks (e.g., Metcalfe, 2013; Metcalfe *et al*., 2017).

Undeformed, muscovite-bearing S-type granite sample QN-750 in the study intruded the Kham Duc amphibolite, and its crystallization age based on the zircon U-Pb dating was 243.3±1.0 Ma. This age is identical to those of S-type gran-

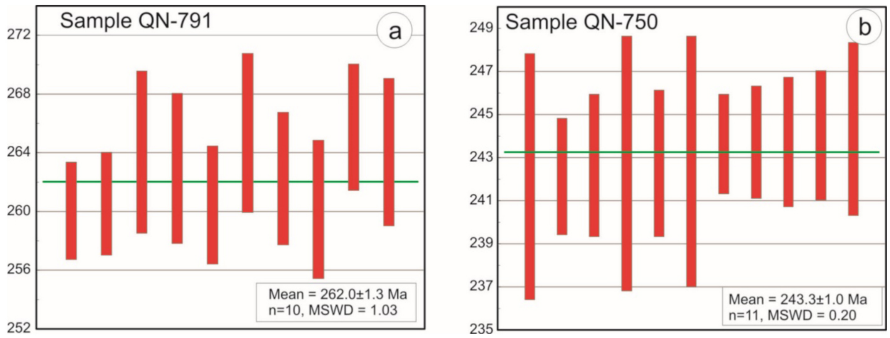

Fig. 4. Diagrams showing weighted mean ages of the analyzed samples.

ite (ca. 242-224 Ma) in the Hai Van complex (Pham *et al.*, 2015), and the U-Th-Pb chemical ages of monazite (ca. 240-260 Ma) from metamorphic rocks in the Kon Tum terrane (Osanai *et al.*, 2004; Nakano *et al.*, 2007; Bui *et al.*, 2020). Pham *et al.* (2015) suggested that the geochemical characteristics of the Hai Van granite has geochemical characteristics of S-type granite formed from partial melting of crustal materials. During middle to late Triassic, collision of the Indochina block to the South China blocks in the north (e.g., Tran *et al.*, 2008) and to the Sibumasu block in the west (e.g., Metcalfe, 2013; Metcalfe *et al.*, 2017) had caused highly crust-thickening within the Indochina block that resulted crustal partial melting to form S-type granites and metamorphic rocks within the Indochina block (e.g., Tran *et al.*, 2008). Thus, the middle to late Triassic S-type granite may originated from the latest stage of crustal thickening during the Indosinian orogeny.

Acknowledgement

We thank the Korean authorities to contribute the U-Pb age analyses. The reviewers have greatly allowed the improvement of this manuscript. This research was performed for the Research Project number B2017-MDA-14DT funded by the Ministry of Education and Training of Vietnam.

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Received : October 5, 2020
Revised : October 8, 2020
Accepted : October 19, 2020