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Cretaceous Granitic Magmatism in South-Central Vietnam: Constraints from Zircon U–Pb Geochronology

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Abstract. South-central Vietnam abundantly presents magmatic rocks with larger volumes of Cretaceous granitic rocks. In this study, zircon U–Pb geochronology of granite samples from the Deoca, Ankroet, and Dinhquan complexes in south-central Vietnam are utilized to investigate Cretaceous granitic magmatism. According to U–Pb analysis results, zircon ages of granitic rocks display the Deoca at ~113–92 Ma, the Ankroet at ~103–98 Ma, and the Dinhquan at ~97–113 Ma. The range of ages is narrow from 113 to 92 Ma, with most common ages date at ~100 Ma. Published data and our results display that Cretaceous granitic magmatism was active between ~87–118 Ma and most active at ~100 Ma in south-central Vietnam. Additionally, the Deoca and Dinhquan complexes show inherited ages in Triassic followed by Proterozoic and Carboniferous to Ordovician. The obtained ages indicate that I-type granitic rocks could be derived from melting of basement rocks. Our study suggests that I-type granitic rocks in south-central Vietnam were significantly intruded around 100 Ma.

Keywords: Cretaceous granitic magmatism, Zircon U–Pb, Granitic rock, South-central Vietnam

1. Introduction

South-central Vietnam is situated in the Indochina block of Southeast Asia and abundantly occurs Cretaceous granitic batholiths [1–3]. The formation of Cordilleran-type granitic batholiths mainly shows a close correlation with the subduction of oceanic crust beneath the continental crust, and they can be products of crustal recycling and the presence of liquid water [4–11]. Generally, cordilleran granitic batholiths consist of different chemical characterizations due to they are formed by melting of sedimentary rocks (i.e., S-type granites), differentiation of mafic parental magmas (i.e., A-type granites), and partial melting of dehydrated middle/lower crust (i.e., I-type granites) [11–13]. In south-central Vietnam, granitic batholiths have been considered to be contemporaneous with the granitoid of the South China block. However, only a few studies were carried out on granitic batholiths in this area for investigating Cretaceous magmatism and granite composition [2, 14, 16, 17, 18]. Therefore, Cretaceous magmatism and the formation of granitic batholiths (subducted material (basalt + sediment) or melted basement rock) is still unclear. In this study, granitic rocks of the Deoca, Ankroet, and Dinhquan complexes are collected for zircon U–Pb analysis to investigate Cretaceous magmatism and granite composition in south-central Vietnam.

2. Geological setting

The continental margin of south-central Vietnam belongs to the Indochina Terrane, and it is surrounded by the Kontum Massif to the north, Central Highlands to the west, and the East Sea to the southeast (Fig. 1). The region is dominated by Mesozoic sedimentary rocks and igneous and basaltic rocks (Fig. 2). Precambrian basement is not exposed, although seismic data Khoan et al. [19] suggests that it is composed of granulites and gneisses. Paleozoic rocks are mostly absent in the area due to the region being an emerged continent at that time [20]. The few outcrops are found in the north to northwest in the Dak-Lin area where Upper Paleozoic sedimentary rocks (Carboniferous to Permian) are exposed including intermediate calc-alkaline volcanoes and carbonate rocks [22]. Hence it is considered to have had a similar geological evolution to the Kontum Massif [15, 23, 30].

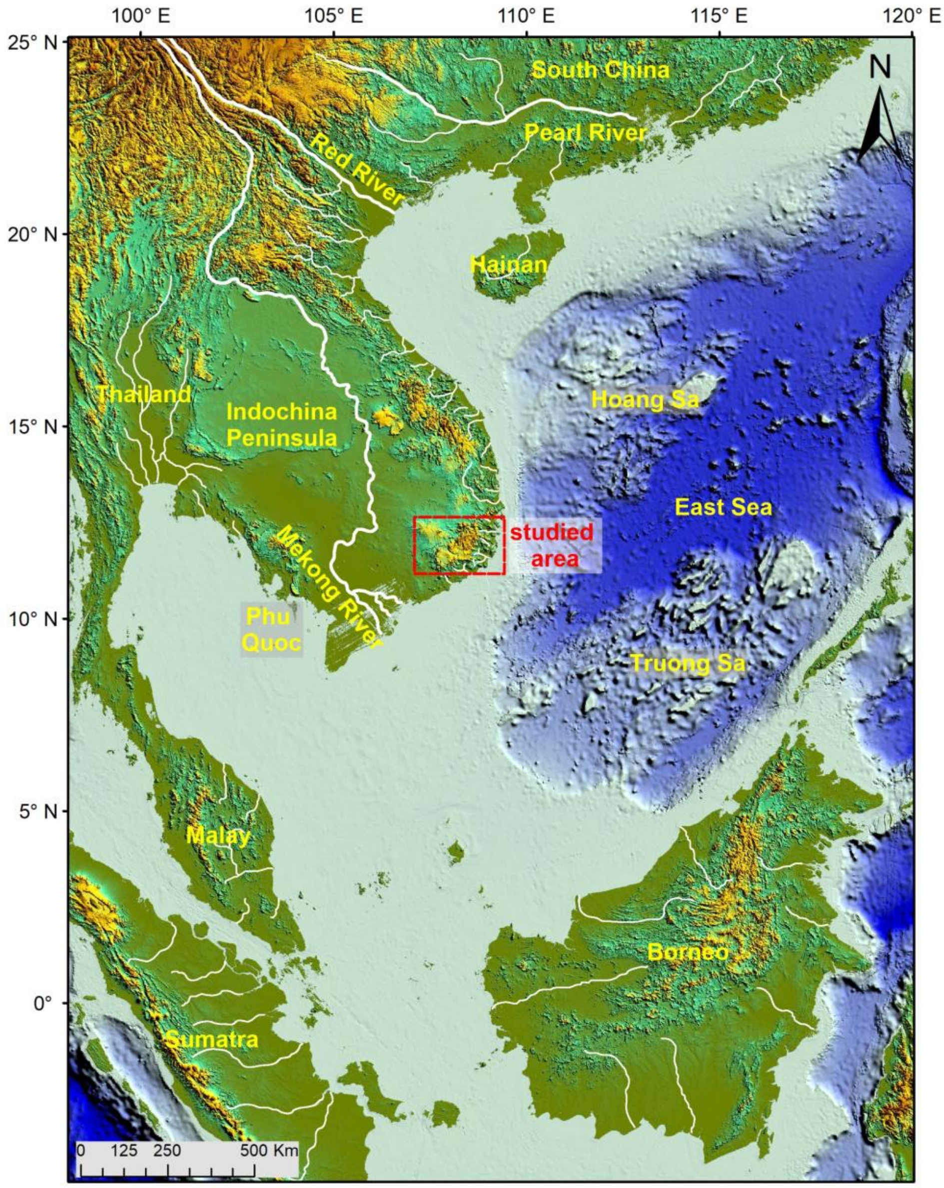

Fig. 1. Topography of the studied area in south-central Vietnam.

Most of the study area is covered by Mesozoic to Cenozoic sedimentary rocks. The Mesozoic formations include widespread Lower to Middle Jurassic shallow marine sedimentary rocks. The Upper Jurassic-Cretaceous sequence consists of the Deo Bao Loc, Nha Trang, and Don Duong formations that formed in a continental environment. These are composed of volcano-sedimentary beds of mainly intermediate, felsic, and alkaline composition [24]. They are slightly folded and display weak contact metamorphism in the aureoles of late Mesozoic plutons. Contemporaneous and widespread volcanic rocks are interpreted as subduction-related products linked to widespread granite plutons [2, 3]. Mesozoic granitoid bodies in the study area are mainly located along the coastline to the south of the Kontum Massif. Early petrological, mineralogical, and structural studies by Vietnamese geologists subdivided these granitoid into three plutonic complexes, called Deoca, Dinhquan, and Ankroet [1], and this scheme was used on the geological map of Vietnam at 1:500.000 scale.

The Dinhquan and Deoca complexes are located northeast-southwest of Kontum and found along the South Vietnamese coast. Petrological characteristics of the Dinhquan Complex comprises hornblende-biotite diorites, granodiorites, and minor granites [23]. The Deoca Complex consists of granodiorite, hornblende-biotite granite (phase I), biotite-hornblende granite, granosyenite, and biotite syenite (phase II), granite porphyr, granular aplite, and pegmatite (dike phase). Sedimentary rocks of the La Nga Formation form smear-slate and were crosscut by granitoid of the Ankroet Complex, and these were overlain by young volcanic rocks of the Don Duong Formation (K_2). K–Ar and Ar–Ar ages of granitic rock from the Dinhquan and Deoca complexes range from 80 to 118 Ma [22], U–Pb zircon ages range from 88±1.5 to 109±7.0 Ma [2], 115.4±1.2–118.2±1.4 Ma [14], 87–104 Ma [17], and 90±0.5–135±2 Ma [18].

The Ankroet Complex is less widespread than the Dinhquan and Deoca complexes and is located further inland, at higher elevations. Its characteristics include medium to coarse-grained porphyroid biotite granite, light-grey in color, with low hornblende content. K–Ar isotopic age ranges of granitic rock from 81.0±1.0 to 99.0±1.0 Ma and Rb-Sr are of 94.0–97.0±1.0 Ma [25] and zircon U–Pb ages of 93.4±2.0 to 96.1±1.1 Ma [2] and 86.8±1.6 Ma [14]. Published granite ages from Nguyen et al. [2] and Shellnutt et al. [14] in this studied area are summarized in Fig. 2.

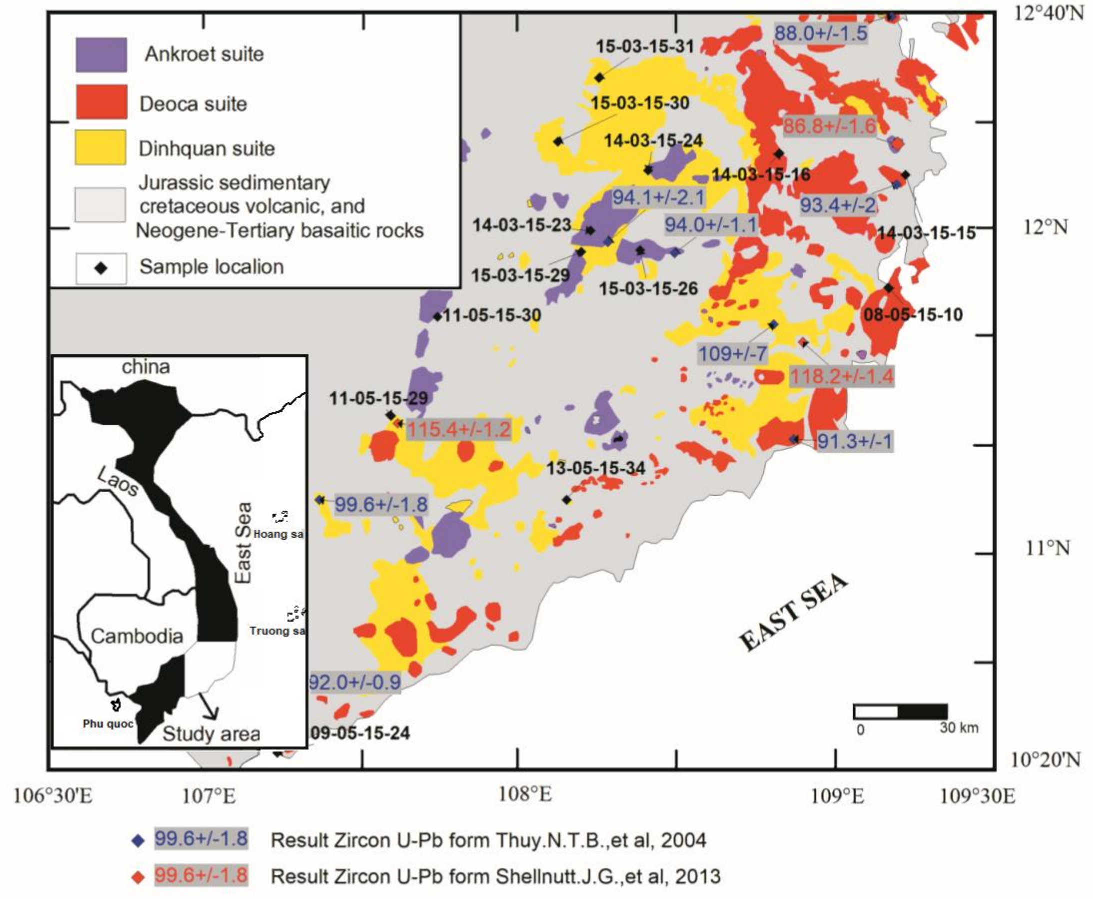

Fig. 2. Simplified geological map of south-central Vietnam, modified from the 1:500,000 Geological Map of Vietnam [20], showing the distribution of sample location and main published zircon U–Pb ages.

The Cretaceous magmatism is associated with an Andean type margin with Meso-Tethyan lithosphere being subduction beneath the margins of South China and Indochina [26]. Geochemical study from Shellnut et al. [14] shows the Middle Cretaceous granitic batholiths are I-type (partial melting of dehydrated middle/lower crust), whereas the Upper Cretaceous (i.e., ~90 Ma) granitic rocks have compositions similar to A-type (differentiated mafic parental magmas) associated with an extensional tectonic regime, most probably trench retreat caused by slab rollback. The Ankroet rocks are associated with this extensional setting. The cartoon in Fig. 2 shows the plate setting at this time.

During the late Cenozoic widespread volcanism both on the Vietnamese mainland and coastal islands produced extensive basaltic lava flows of variable thickness and composition. Basaltic activity in South Vietnam began in the Middle Miocene and is closely related to the East Sea opening and tectonic reactivation of the continental margin. Local fault zones were re-activated, and this facilitated eruption of lavas [27].

3. Materials and Methods

Fifteen representative granite rock samples of the Deoca, Dinhquan and Ankroet complexes from south-central Vietnam were selected for zircon U–Pb geochronological analyses in this study (Fig. 2).

Each 3–5 kg sample was crushed to a medium sand grain size and then rinsed in water to remove the fine dust. The remaining grains were then placed in an oven at 50–70ºC for drying. Grains were then sieved to remove the coarser fraction > 500 μm. After that, detrital zircon grains were separated by standard heavy liquid techniques and mounted on glass slides in epoxy resin. The slides were then polished to expose internal surfaces to enable Cathodoluminescence (CL) imaging and analysis by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). Grains for dating were selected randomly from polished grain mounts and analyzed by laser ablation inductively coupled plasma mass spectrometry at the London Geochronology Centre based in University College London using a New Wave 193 nm laser ablation system coupled to an Agilent 7700 quadrupole-based ICP-MS. Typical ablation parameters used 25 μm spots with a 10 Hz repetition rate and an energy fluence of ca. 2:5 J/cm^2. Instrumental mass bias and depth-dependent inter-element fractionation of Pb, Th, and U were corrected for using Plesovice as an external zircon standard [27]. Time-resolved signals that record evolving isotopic ratios with depth in each crystal were processed using Glitter 4.4 data reduction software. This removed spurious signals caused by inclusions, mixing of growth zones, or fractures. Calculated $^{206}Pb/^{238}U$ ages were used for grains younger than 1000 Ma, and the $^{207}Pb/^{206}Pb$ age for older grains. Grains with a complex growth history or disturbed isotopic ratios, with > +5/–15% discordance, were rejected.

4. Results and discussions

Details of zircon results for granite samples are presented in Tab. 1, without any inherited ages. The range of ages is narrow (from 92 up to 113 Ma), and most of the ages are around ~100 Ma. These ages compare well with the main age range found in river sands and granitic rocks from previous data [2, 14, 29]. Fig. 3 shows the locations of these ages on the geological map. No trends are seen, although older ages tend to be located inland, away from the coast.

Tab. 1. Summary of representative granite zircon U–Pb ages measured in this study.

No	Sample	Unit	U-Pb Age	MSWD	Latitude	Longitude
1	14-03-15-15	Deoca	95.97±0.52	1.9	N12º10’05.1’’	E109º11’30.9’’
2	14-03-15-16	Deoca	92.01±0.25	4.7	N12º13’52.1’’	E108º47’33.3’’
3	07-05-15-06a	Deoca	107.5±0.42	2	N13º03’37.0’’	E109º17’23.1’’
4	07-05-15-06b	Deoca	113.4±0.42	10	N13º03’37.0’’	E109º17’23.1’’
5	08-05-15-10	Deoca	92.88±0.66	0.68	N11º49’14.8’’	E109º08’43.0’’
6	09-05-15-24	Deoca	104.3±0.56	4	N10 º22’51.6’’	E107º15’09.8’’
7	13-05-15-34	Deoca	106.9±0.44	11	N11o09’46.2’’	E108o08’50.2’’
8	14-03-15-23	Ankroet	98.3±0.26	0.84	N11o59’21.0’’	E108o12’06.0’’
9	14-03-15-24	Ankroet	101.8±0.39	3.9	N12 o10’34.2’’	E108o22’44.3’’
10	15-03-15-26	Ankroet	102.6±0.51	1.9	N11o55’53.5’’	E108o21’33.9’’
11	11-05-15-30	Ankroet	101.8±0.39	3.9	N11o43’19.5’’	E107o43’32.3’’
12	15-03-15-29	Ankroet	98.89±0.47	10	N11o55’29.8’’	E108o10’24.4’’
13	15-03-15-30	Dinhquan	96.85±0.43	1.1	N12º15’44.7’’	E108º05’30.0’’
14	15-03-15-31	Dinhquan	105.3±0.35	0.67	N12º27’27.6’’	E108º12’59.2’’
15	11-05-15-29	Dinhquan	113.2±0.37	0.29	N11º24’59.7’’	E107º35’08.7’’

There are two main published studies on granitic rocks in south-central Vietnam [2, 14]. Both suggest Cretaceous magmatism across the study region was active between 87–118 Ma (by U–Pb method). These studies are well compatible with our research, which also shows bedrock granite ages from 92 to 113 Ma, with most ages falling around 100 Ma. Furthermore, the river sands in south-central Vietnam record magmatic ages between 75–120 Ma, although most ages fall between 85–105 Ma with the greatest abundance around 100 Ma [29]. To get an idea of the timing of Cretaceous magmatism across south-central Vietnam and when magmatism was most active, it is useful to examine the distribution of Cretaceous zircons present in the river sands from Nguyen et al. [29]. This study on river sands showed that zircon grains are widely distributed throughout the Cretaceous period from 85–120 Ma, but the most

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common ages, and presumably the main period of magmatism date to 100±10 Ma. Comparing the age range of these zircons to U–Pb age results of granite from previous work by Nguyen et al. [2] and Shellnutt et al. [14] and this study suggests that most zircons in sands from river mouths from Nguyen et al. [29] come from local granites, and therefore the ages reflect the local geology. Therefore, magmatism in the region was most active around 100 Ma and had ended by 85 Ma.

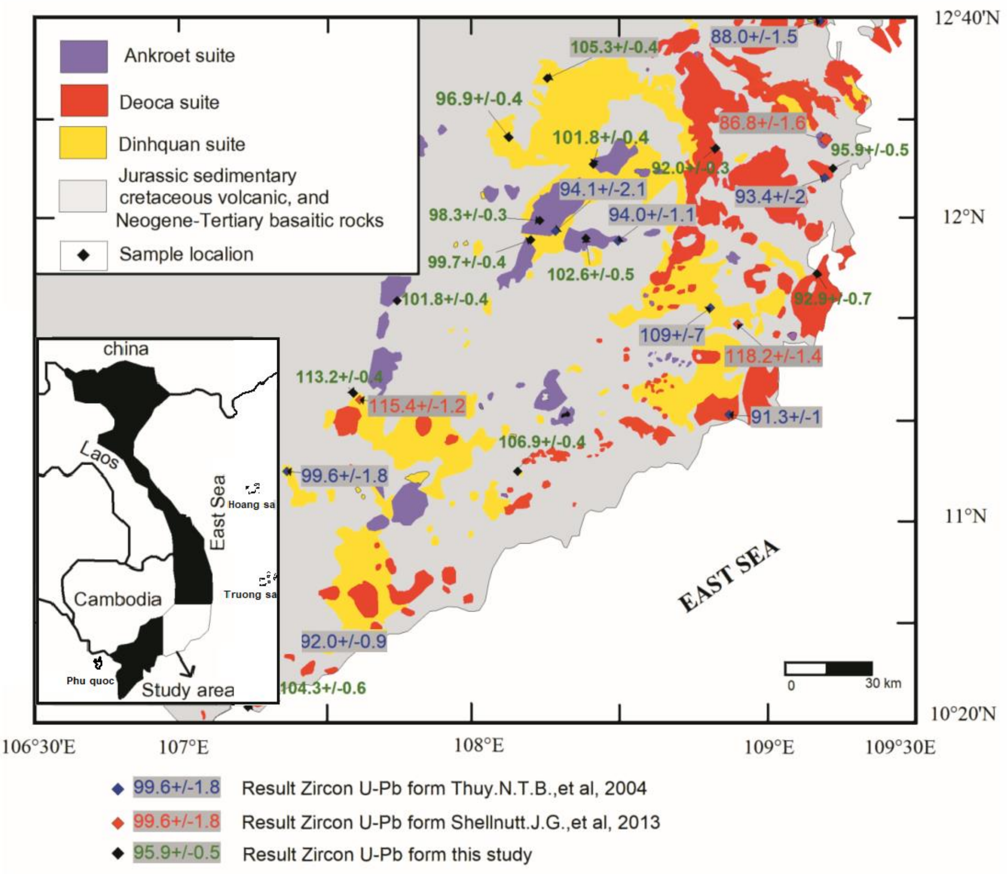

Fig. 3. Geological map to show the location of samples dated for this study as well as main data.

Tab. 2. Summary of zircon inherited ages found in samples from the Deoca and Dinhquan plutons.

Sample	Pluton/Suite	U-Pb Age	(Ma)
07-05-15-06A	Deoca	255±7	961±22
07-05-15-06B	Deoca	253±7 252±6 248±6 235±6 240±7 239±7 263±7 252±7 245±6	2335±54 489±11 335±8 823±20
08-05-15-10	Deoca	249±3	
13-05-15-34	Deoca	254±7	
11-05-15-30	Ankroet		391±9 383±10
15-03-15-29	Dinhquan	228±6	1841±70
15-03-15-30	Dinhquan	234±6 211±6	1868±49
11-05-15-29	Dinhquan		1872±57

Shellnutt et al. [14] noted that Sr–Nd isotope trends required a portion of the parental magma for the Deoca and Dinhquan granite plutons to have been come from melted basement rocks of the Indochina Block. However, as no inherited grains were found during CL imaging and in situ analysis, Shellnutt et al. [14] could not confirm that mixing between mafic melts and partial melts derived from crustal rocks had taken place. This led authors to propose that the mixing required by their Sr–Nd data was associated with subducted material (basalt + sediment) instead of mixing with assimilated basement. Analyses of granite samples for this study found some inherited grains in granites of the Deoca and Dinhquan complexes, and therefore these relict zircons may help to answer the question about the source of mixing. Tab. 2 summarizes the ages found in this study.

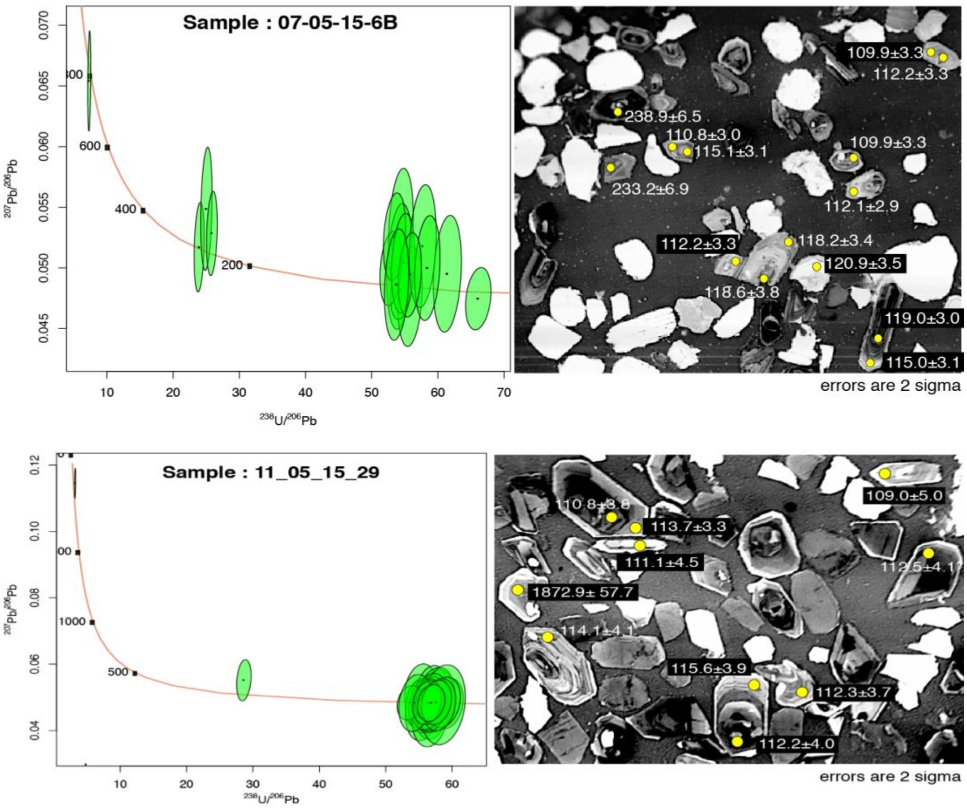

Fig. 3. CL images of zircons from samples 07-05-15-6B and 11-05-15-29 that include grains with inherited cores.

Fig. 3 shows examples of zircon CL images and the location of laser spots and ages. Zircons show oscillatory zoning patterns typical of magmatic grains. Core regions tend to be dark, whilst the analytical strategy was to target grain rims to obtain the youngest ages some grains containing relict zircons and showing both zoned and unzoned cores. The most common inherited ages are Triassic followed by Proterozoic and Carboniferous to Ordovician ages (Tab. 2). These ages match basement rocks in the Kontum region to the north of the study area [21, 23, 29]. Similar basement rocks would be expected to be overlain the sedimentary formations. Shellnut et al. [14] proposed that granite compositions of South Vietnam were the product of either mixing with subducted material (basalt + sediment) or melted basement rock. The inherited core ages found in this study are temporally consistent with basement melting. Based on the inherited core ages in this study and previous publications [2, 14, 18], our study believes that the Ankroet, Deoca, and Dinhquan complexes are primarily I-type granitic rock, which could originate from melting of basement rocks.

5. Conclusions

Granite samples of the Deoca, Dinhquan and Ankroet complexes in south-central Vietnam are analyzed zircon U–Pb to investigate Cretaceous granitic magmatism. This study concludes that:

Bedrock granite ages display the Deoca at ~113–92 Ma, the Ankroet at ~103–98 Ma, and the Dinhquan at ~97–113 Ma. The research confirms that there are much different age values ranging in a wide range between 92 and 113 Ma, with most widespread ages falling around 100 Ma. Comparing with previous studies, this finding indicates that Cretaceous magmatism was active between 87–118 Ma and most active around 100 Ma in south-central Vietnam.

Inherited ages of the Daoca and Dinhquan complexes are Triassic, followed by Proterozoic and Carboniferous to Ordovician ages. This indicates that I-type granitic rocks in south-central Vietnam could be formed by melted basement rocks.

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