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Formation of Cretaceous Cordilleran and post-orogenic granites and their microgranular enclaves from the Dalat zone, southern Vietnam: Tectonic implications for the evolution of Southeast Asia

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ABSTRACT

Cordilleran-type batholiths are useful in understanding the duration, cyclicity and tectonic evolution of continental margins. The Dalat zone of southern Vietnam preserves evidence of Late Mesozoic convergent zone magmatism superimposed on Precambrian rocks of the Indochina Block. The Dinhquan, Deoca and Ankroet plutons and their enclaves indicate that the Dalat zone transitioned from an active continental margin producing Cordilleran-type batholiths to highly extended crust producing within-plate plutons. The Deoca and Dinhquan plutons are compositionally similar to Cordilleran I-type granitic rocks and yield mean zircon U/Pb ages between 118 ± 1.4 Ma and 115 ± 1.2 Ma. Their Sr–Nd whole rock isotopes (I_{Sr} = 0.7044 to 0.7062; $\varepsilon Nd_{(T)}$ = −2.4 to +0.2) and zircon Hf isotopes ($\varepsilon Hf_{(T)}$ = +8.2 ± 1.2 and +6.4 ± 0.9) indicate that they were derived by mixing between a mantle component and an enriched component (i.e. GLOSS). The Ankroet pluton is chemically similar to post-orogenic/within-plate granitic rocks and has a zircon U/Pb age of 87 ± 1.6 Ma. Geobarometric calculations indicate that amphibole within the Ankroet pluton crystallized at a depth of ~6 kbar which is consistent with the somewhat more depleted Sr–Nd isotope (I_{Sr} = 0.7017 to 0.7111; $\varepsilon Nd_{(T)}$ = −2.8 to +0.6) and variable $\varepsilon Hf_{(T)}$ compositions suggesting a stronger influence of crustal material in the parental magma. The compositional change of the Dalat zone granitic rocks during the middle to late Cretaceous indicates that the tectonic regime evolved from a continental arc environment to one of post-orogenic extension. The appearance of sporadic post-90 Ma magmatism in the Dalat zone and along the eastern margin of Eurasian indicates that there was no subsequent orogenic event and the region was likely one of highly extended crust that facilitated the opening of the South China Sea during the latter half of the Cenozoic.

1. Introduction

The formation of Cordilleran-type granitic batholiths is primarily related to the subduction of oceanic crust beneath continental crust. The formation of granitic melts may be generated by partial melting of the oceanic slab and sediments directly or may involve mixing or assimilation of crustal material (Castro, 2013; Castro et al., 2010; Davidson and Arculus, 2005; Ducea and Barton, 2007; Gaschnig et al., 2011; Gromet and Silver, 1987; Lee et al., 2007; Patino Douce, 1999; Scaillet et al., 1995; Silver and Chappell, 1988; Sisson et al., 2005; Taylor and McLennan, 1981, 1985; Wyllie et al., 1976, 1989). Cordilleran-type granitic rocks are one of the most common types of granitoids on the Earth and represent the by-products of crustal recycling and the presence of liquid water (Campbell and Taylor, 1983; Patino Douce, 1996; Rapp et al., 1991; Rudnick, 1995; Wyllie et al., 1976). Consequently the chemical characteristics of Cordilleran batholiths are not necessarily fixed but there a number of salient chemical features which distinguish them from granitoids derived from melting of sedimentary rocks (i.e. S-type granites), differentiation of mafic parental magmas (i.e. A-type) or partial melting of dehydrated middle/lower crust (i.e. peraluminous within-plate granites) which has contributed to their petro-chemical classification as I-type granitic rocks (Barbarin, 1999; Bonin, 2007; Castro et al., 2010; Chappell and White, 1974, 1992; Chappell et al., 1987; Collins et al., 1982; Eby, 1990, 1992; Frost et al., 2001; Pearce et al., 1984; Whalen et al., 1987).

There are a number of Mesozoic Cordilleran (i.e. I-type) granitic batholiths located along eastern margin of Eurasia, specifically the

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eastern portion of the South China Block and into the Indochina Block (Nguyen et al., 2004a,b; Zhou and Li, 2000; Zhou et al., 2008). The middle to late Cretaceous batholiths (i.e. 140 Ma to 90 Ma) are referred to as the 'Late Yanshanian group' and are interpreted as evidence for an Andean-type continental margin at that time (Charvet et al., 1994; Jahn et al., 1976; Jiang et al., 2009; Taylor and Hayes, 1983; Zhou and Li, 2000; Zhou et al., 2008). Unlike the I-type middle Cretaceous (i.e. 120 Ma to 110 Ma) granitic batholiths, the late Cretaceous (i.e. ~90 Ma) granitic rocks are compositionally different and show chemical characteristics indicative of peraluminous A-type or within-plate granitic rocks associated with an extensional tectonic regime possibly related to trench retreat induce by slab rollback (Charvet et al., 1994; Chen et al., 2008; Knittel, 2010; Nguyen et al., 2004a). The late Cretaceous granitic magmatism appears to have either ceased or slowed shortly after 90 Ma which may be related to the accretion of a relatively small continental block (i.e. Luconia–Dangerous Grounds) to the Southeast Eurasian margin (Hall, 2012; Hall and Sevastjanova, 2012; Morley, 2012; Zhou et al., 2008).

The Dalat zone of southern Vietnam is located entirely within the Indochina block of Southeast Asia and contains middle to late Cretaceous granitic batholiths. The Dalat batholiths are contemporaneous with the 'Late Yanshanian' granitoids of the South China block but there are comparatively few geochemical investigations of these rocks (Nguyen et al., 2004a,b). Three plutonic, the Dinhquan, Deoca and Ankroet, bodies were selected for a geochemical and geochronological investigation. In this paper we present new high precision in situ zircon U/Pb age dates and Hf isotopes, whole rock and trace elemental chemistry and Sr–Nd isotopes in order to help understand the tectono-magmatic development of the Southeast Eurasian margin during the Cretaceous as it transitioned from a magmatically active continental margin to a passive continental margin.

2. Geological background

The Dalat zone is located mainly at the south-central part and southeast part of Vietnam, surrounded by the Kontum Massif to the north, Tay Nguyen Highland to the west and the South China Sea to the east and southeast (Fig. 1). Previously, Saurin (1935) named the Dalat zone as "Massif Sud-Annamitique", as an Hercinide orogenic belt. Majority of local geologists consider the Dalat zone to be a Mesozoic active continental marginal belt (Nguyen and Tran, 1979; Tran et al., 1980). The Precambrian basement of the Dalat zone is not exposed, although seismic data (Khoan and Que, 1984) suggest that it is composed of granulite and gneiss. Hence, the Dalat zone is considered to have a similar crustal evolution as the Archean Kontum Massif which experienced multiple Paleoproterozoic to Mesoproterozoic crust building events (Lan et al., 2003; Nam et al., 2001).

The oldest rocks of the Dalat zone outcrop in the northwestern and northern parts as the Dak-Lin window which show upper Paleozoic (Carboniferous to Permian) sedimentary rocks interbedded with intermediate calc-alkaline volcanics and carbonate rocks (Nguyen, 2001). A vast area of the Dalat zone is made up of Mesozoic to Cenozoic sediments, late Mesozoic igneous rocks, Paleogene dikes and Neogene to Quaternary basalts. The Mesozoic formations in this zone are widespread lower to middle Jurassic shallow marine terrigenous sedimentary rocks (i.e. Ban Don Group). The Jurassic formations are slightly folded, but commonly weakly metamorphosed in the contact aureoles of late Mesozoic plutons. In the eastern part of the zone, the Late Mesozoic plutonic and contemporaneous volcanic rocks are widespread, and are interpreted as subduction-related products (Nguyen et al., 2004a,b). The western part is weakly influenced by late Mesozoic tectono-magmatic events but there was relatively widespread basaltic volcanism during the Cenozoic.

The late Mesozoic granitic rocks are divided into three suites: the Dinhquan, the Deoca and the Ankroet suites. The Dinhquan and Deoca suites are northeast–southwest trending belts south of the Kontum Massif and along the coast of South Vietnam. The rock types constituting the Dinhquan and Deoca suites are medium to coarse grained gabbro, diorite, tonalite, granodiorite, quartz monzonite and biotite-bearing granite, with minor fine grained felsic granite. The K–Ar and Ar–Ar isotopic dating of granitic rocks ranges mainly from 80 to 118 Ma (Nguyen, 2001). The ages obtained by Rb–Sr method are in good

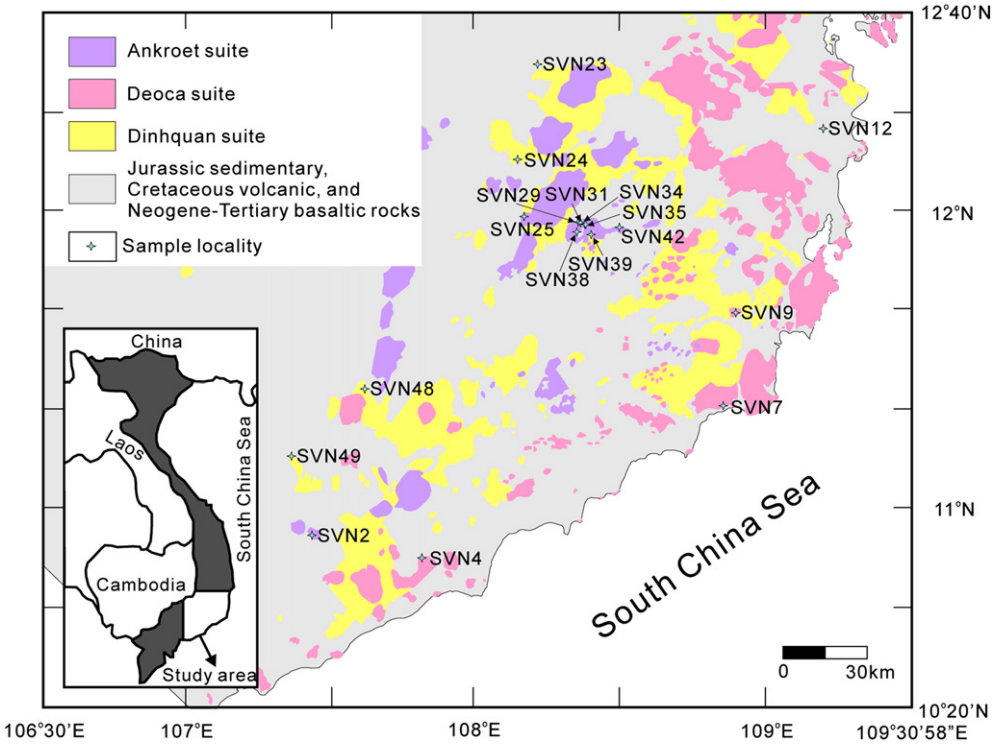

Fig. 1. Simplified geological map of the Dalat zone of Southern Vietnam showing the distribution and sample localities of the middle to late Cretaceous batholiths.