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Genesis of leucogranite by prolonged fractional crystallization: A case study of the Mufushan complex, South China

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ABSTRACT

We present major and trace elemental geochemical data, Sr–Nd–Hf isotopes and zircon U–Pb ages for igneous rocks of the Mufushan complex (~2400 km^2 outcrop area) in South China. The complex intruded episodically from late Jurassic (ca.154 Ma) to early Cretaceous (ca. 146 Ma) with a compositional evolution from diorite through granodiorite and biotite-bearing monzogranite to two-mica leucogranite and garnet-bearing leucogranite dykes. Diorites have high Mg# (up to 71), low SiO_2 and high siderophile elements (e.g. Cr, Ni and V) resembling sanukite or high-Mg diorite. They display isotopic characteristics similar to those of incident enriched mantle-derived mafic rocks, such as low $I_{Sr}(t)$ (0.7080–0.7085), high εNd(t) (−4.3 to −4.8) and εHf(t) (−2.41 to 0.59). In contrast, felsic rocks show a common crustal signature with higher $I_{Sr}(t)$ (0.7115–0.7184), lower εNd(t) (−7.9 to −10.2) and εHf(t) values (−7.73 to −4.04). These felsic rocks display decreasing Al_2O_3, CaO, FeO^{tot}, MgO contents and gradually enhanced depletions in Sr, Ba and Ti and Eu with increasing SiO_2 and decreasing zircon U–Pb age, which implies continuous magmatic evolution towards leucogranites dominated by fractional crystallization. The most evolved SiO_2-rich rocks (two-mica leucogranites) are compositionally similar to the Himalaya leucogranites, indicating that prolonged fractional crystallization of metaluminous granitic magma is a feasible mechanism to form peraluminous leucogranitic magma. The differentiation process of the felsic magma lasted from 152 to 146 Ma as indicated by zircon U–Pb dating, which implies that magma differentiation, emplacement and subsequent solidification in giant batholiths may proceed on a timescale of several million years.

1. Introduction

Two-mica leucogranites are commonly considered as products of partial melting of metasediments, as evidenced by classic case studies from the Himalayan Orogen (e.g., Le Fort et al., 1987; Zhang et al., 2004) and the Hercynian massifs of western Europe (e.g., Bernard-Griffiths et al., 1985; Vidal et al., 1984; Williamson et al., 1996), as well as by partial melting experiments on metapelites and metagraywackes (Acosta-Vigil et al., 2006; Annen et al., 2006; Litvinovsky et al., 2000; Scaillet et al., 1995; Xiong et al., 2002) and other case studies worldwide (e.g., Jung et al., 2009, 2012; Paul et al., 2014; Van de Flierdt et al., 2003). Fractional crystallization is considered relatively difficult in granitic magmas comparable to mafic magmas, because of their high viscosity and of the low density contrasts between minerals and silicate melts (Tartèse and Boulvais, 2010). Nevertheless, several studies proposed fractional crystallization of mafic/intermediate magmas as an important mechanism to generate leucogranites (e.g. Miller, 1985; Secchi et al., 1991; Teixeira et al., 2012). In order to clarify whether or not fractional crystallization is the dominating cause for silicic magma evolution, systematic geochronology and isotope geochemistry data for leucogranite and associated mafic and intermediate rocks in multiphase complex are required to constrain magma sequences and origins, but such comprehensive studies are relatively rare (Scaillet et al., 1990; Secchi et al., 1991).

Quantifying the timescales of magma generation, differentiation and intrusion/eruption is essential to understand and reconstruct the evolution of the lithosphere and the growth rate of the crust (e.g., Hawkesworth et al., 2000, 2004; Schaltegger et al., 2009; Schoene et al., 2012). Recent improvements of analytical techniques make it possible to build a temporal framework for magmatic processes and re-attract attentions to chronometers (e.g., Barboni et al.,

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2013; Hawkesworth et al., 2004; Schoene et al., 2012). For example, the U-series radioactive disequilibria (e.g., ^{238}U, ^{230}Th, ^{226}Ra) provide quantitative constraints for the timing of pre-eruptive activities of recent volcanisms (e.g., Chekol et al., 2011; Kuritani et al., 2011; Reagan et al., 2003). However, the short-lived timescale (generally < 1 Ma) is limited and inappropriate for giant granitoid batholiths since the emplacement and evolution rates of granitic magmas are likely to be much slower due to their high viscosities, massive volumes, and deep intrusive levels (Harris et al., 2000). High-precision dating on minerals, in particular zircons, provides absolute ages for mineral growths and has been utilized to calibrate the timescale of batholiths construction histories, with an assumption that zircon crystallization ages are identical to magma intrusive ages (e.g., Coleman et al., 2004; Leuthold et al., 2012; Matzel et al., 2006; Schaltegger et al., 2009; Walker et al., 2007). Two-mica leucogranites are extensively exposed in the South China block, especially in the hinterland of some orogenic belts (e.g., L. Wang et al., 2008; Wang et al., 2007; X.L. Wang, 2008; Xiong et al., 2002; Zhou and Li, 2000). Unlike the Himalayan leucogranites, these rocks are often accompanied by biotite-bearing granites and intermediate to mafic rocks, and in such igneous complexes leucogranites generally show clear late intrusive contacts towards the other rock units (e.g. L. Wang et al., 2008; Sun et al., 2005; Wang et al., 2007; X.L. Wang, 2008; Xiong et al., 2002; Yu et al., 2007). In addition, some leucogranites are genetically associated with economically significant W, Sn, Nb–Ta and REE deposits, which are widespread in South China (e.g., Lu et al., 2003; Yin et al., 2002; Yuan et al., 2011). Therefore, it is important to better understand the petrogenesis of such leucogranites.

In this contribution, we present systematic zircon U–Pb geochronology, geochemical and Sr, Nd and Hf isotopic data of four dominate rock units (diorite, granodiorite, monzogranite and leucogranite) from the Mufushan complex (MFSC) in South China. We intend (i) to decipher the genesis of the leucogranites and their genetic relationships to the associated rocks and (ii) to estimate the timescale of magma evolution from high-Mg diorite to two-mica leucogranite in the MFSC.

2. Geological setting and petrography

The South China tectonic plate is surrounded by the North China Craton in the north, the Tibetan Plateau in the west and the Philippine Sea Plate in the southeast (Fig. 1). It is composed of the Yangtze Craton and the Cathaysia Block, bounded by the Jiangshan–Shaoxing and Pingxiang–Yushan fault. The Cathaysia Block is characterized by widespread Mesozoic granitoids, which formed in three main stages: (1) 265–205 Ma, Indosinian granitoids; (2) 180–142 Ma, Early Yanshanian granitoids and (3) 142–66 Ma, Late Yanshanian granitoids

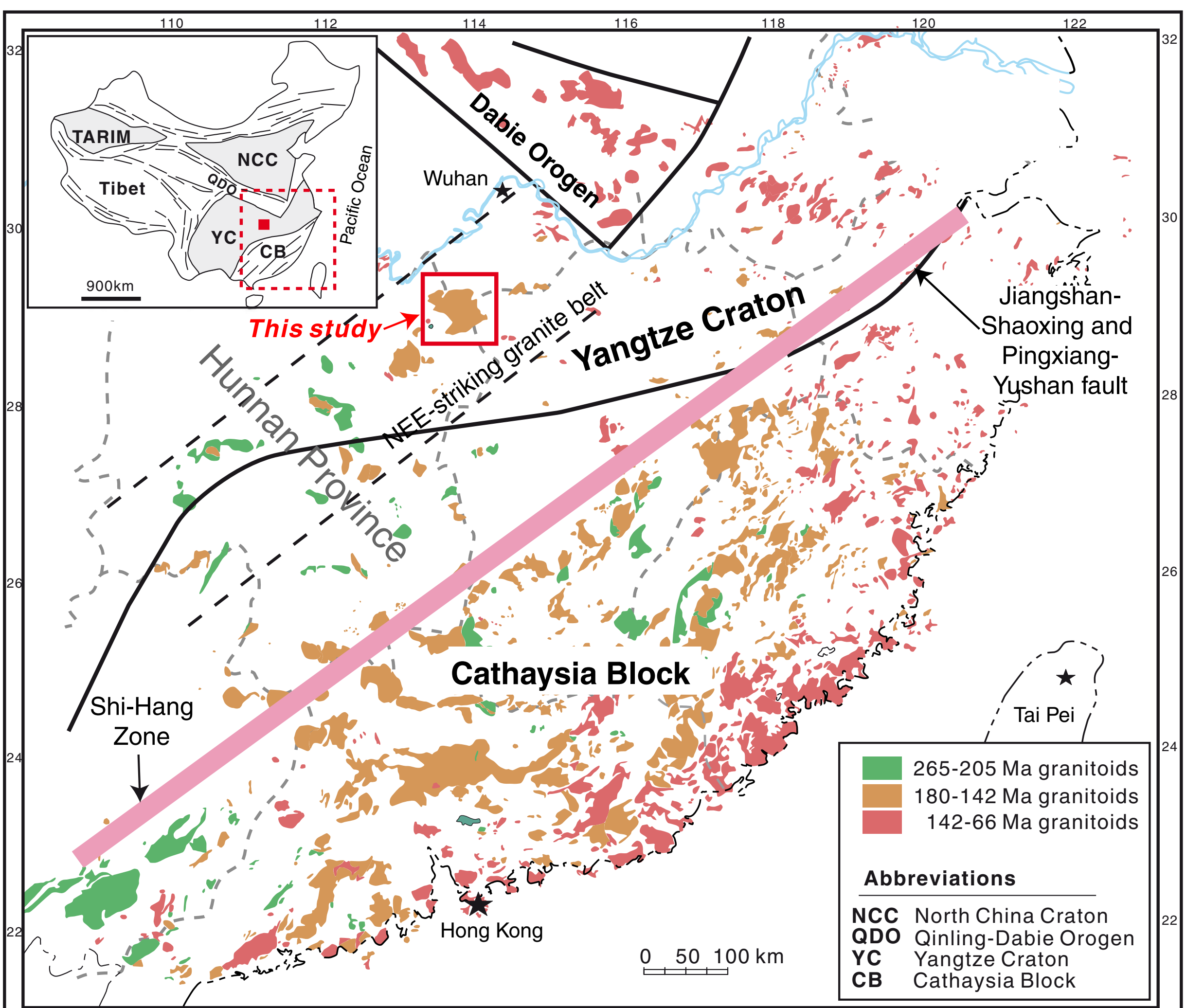

Fig. 1. Geological sketch map of south China showing the distribution and classification of Mesozoic granitic rocks and the location of Mufushan complex (after Zhou et al., 2006).