Chemical Geology 342 (2013) 76–93

Contents lists available at SciVerse ScienceDirect

Chemical Geology

journal homepage: www.elsevier.com/locate/chemgeo

Timing of incremental pluton construction and magmatic activity in a back-arc setting revealed by ID-TIMS U/Pb and Hf isotopes on complex zircon grains

Mélanie Barboni [a,c,*], Blair Schoene [a], Maria Ovtcharova [b], François Bussy [c], Urs Schaltegger [b], Axel Gerdes [d]

[a] Department of Geosciences, Princeton University, NJ, USA
[b] Earth Sciences, University of Geneva, Switzerland
[c] Institute of Earth Sciences, University of Lausanne, Switzerland
[d] Goethe University Frankfurt, Institut für Geowissenschaften, Frankfurt am Main, Germany

ARTICLE INFO

Article history:
Received 8 November 2011
Received in revised form 12 December 2012
Accepted 13 December 2012
Available online 27 December 2012

Editor: K. Mezger

Keywords:
U–Pb geochronology
Zircon
Hafnium isotopes
Zircon residence time
Zircon antecryst
Variscan

ABSTRACT

The lifetimes and thermal histories of upper crustal plutons are increasingly determined using geochronology, but complex growth of datable minerals in magmas impedes simple age interpretations. Careful field observation helps constrain zircon U–Pb dates in terms of timing of magma injection, for example because relative ages of successive magma pulses must be honored. We use ID-TIMS U/Pb zircon geochronology and field geology to construct timescales of incremental pluton assembly in the St-Jean-du-Doigt (SJDD) bimodal layered intrusion (Brittany, France). Field evidence suggests that early pulses were injected into a cold environment with little supersolidus interaction among successive magma pulses. Later injections occurred in a progressively hotter environment with protracted mafic and felsic magma interaction. Zircon dates show that early activity ca. 347 Ma predates the thermally mature episode by about 1 Ma, which terminated at ca. 345 Ma. Dates from samples displaying core-rim zircon overgrowths span about 5 Ma (351–346 Ma), which we interpret to represent two distinct crystallization events. Hf isotopic data from cores and rims are homogeneous, precluding zircon inheritance from basement rocks. These textures and dates could instead reflect zircon saturation fluctuations at the emplacement depth, or antecrystic zircon grains recording pre-emplacement magmatic growth.

1. Introduction

A growing body of evidence suggests that pluton emplacement occurs by amalgamation of numerous pulses of magma that accumulate over thousands to millions of years, both in the middle-to-upper crust (e.g., Hill et al., 1985; McNulty et al., 2000; Miller and Paterson, 2001; Mahan et al., 2003; Miller and Miller, 2003; Glazner et al., 2004; Michel et al., 2008; Schaltegger et al., 2009) and in the subvolcanic environment (e.g., Bacon et al., 2007; Charlier et al., 2008; Claiborne et al., 2010). Growth models for incremental upper-crustal laccoliths often involve a succession of accreted sills emplaced through feeder dykes that initially spread laterally along a horizon separating an upper, more rigid layer and a lower, less rigid layer (e.g. Cruden et al., 1999; de Saint-blanquat et al., 2006; Kavanagh et al., 2006; Michel et al., 2008; Menand, 2011). Pluton assembly proceeds through a succession of high flux periods, where magma injections occur much faster than the average pluton construction rate, interrupted by repose periods (with no or few magma injections) (e.g. Matzel et al., 2006; de Saint-Blanquat et al., 2011). In such a model, plutons represent a time-integrated accumulation of magma pulses with little liquid at any one time. Assessing the validity of such models requires robust constraints on the rates of magma injection, the geometry of successive pulses, and the ambient thermal regime (Annen, 2010), which nominally requires combining high-precision geochronology with careful field observation.

U/Pb geochronology of zircon is a widely utilized method to reconstruct the timescales of pluton assembly because Pb diffusion in zircon is negligible at magmatic temperatures (Cherniak and Watson, 2001), and therefore can retain age information from crystallization at different stages of magmatic evolution (source, ascent and emplacement level). Isotope dilution thermal ionization mass spectrometry (ID-TIMS) U/Pb analyses of single zircon crystals can attain precision of better than ca. 0.1% for a single analysis (e.g., Sláma et al., 2008; Davydov et al., 2010; Schoene et al., 2010a), or ±300 ka for ca. 300 Ma zircon. Increased precision now often results in complex spreads in dates within zircon populations, illustrating that zircon grains can crystallize over 10^4 to 10^6 years in many magmatic systems (e.g. Charlier et al., 2005; Matzel et al., 2006; Bachmann et al., 2007; Schaltegger et al., 2009; Memeti et al., 2010; Schoene et al., 2012).

Identification of individual magma pulses in incrementally assembled plutons is complicated by the lack of contrast between the different magma injections (e.g., Glazner et al., 2004). In this paper, we

* Corresponding author.
E-mail address: mbarboni@princeton.edu (M. Barboni).

0009-2541/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.chemgeo.2012.12.011

present ID-TIMS U/Pb zircon crystallization dates that document the magmatic history of the Saint-Jean-du-Doigt (SJDD) bimodal layered intrusion (Brittany, France). This Carboniferous pluton preserves sill-like emplacement of mafic–felsic–hybrid magmas at shallow crustal levels. The bimodal nature of the rocks, shallow emplacement level, and preservation of the pluton roof offer a rare opportunity to identify and date various magma pulses. Despite prolonged zircon crystallization in each hand sample, we use a combination of field observation, geochronology, and zircon Hf isotopic data to arrive at a self-consistent time-frame for the emplacement duration of the SJDD pluton. These results build on and refine efforts using ID-TIMS U/Pb zircon geochronology as a timekeeper of multipulse plutons, and provide crucial inputs for thermal models of the crust during magmatic and orogenic episodes.

2. Geological setting and field relationships

2.1. Overview of SJDD complex

The St. Jean du Doigt (SJDD) massif is located along the seashore close to the city of Morlaix in northern Brittany, France (Fig. 1A). Geologically, it is a sector of the North Armorican massif. Growth and modification of the Armorican massif spans from the Precambrian to the late Paleozoic, characterized by Cadomian events (620 to 540 Ma) and a polyphase Variscan evolution (440 to 290 Ma). Faure et al. (2005) propose a polycyclic history characterized by an Early Paleozoic (Cambrian to Early Devonian) cycle of rifting and convergence of microcontinents and a late Paleozoic (Devonian to Late Carboniferous) cycle corresponding to a continental collision, after closure of the Rheno-Hercynian ocean by southward subduction under the northern margin of Gondwana. This subduction induced calc-alkaline (diorites) arc magmatism and back-arc extension gave rise to the SJDD gabbro and related magmatic rocks.

The SJDD complex is a 200-km^2 heterogeneous layered body emplaced in Precambrian basement rocks and displays complex magmatic interactions (gabbroic and intermediate to granitic compositions) as mapped in broad outline at 1: 50,000 (Chantraine et al., 1986). These characteristics were interpreted as representing magma mingling. Al-in-hornblende geobarometry points to an emplacement at shallow crustal level (6–9 km, 0.3 ± 0.06 GPa, Barboni et al., 2009b; Barboni and Bussy, 2010). Based on gravity data, the SJDD intrusion is tabular in shape and extends at least to depths of 1.5 km below the present-day erosion level. The SJDD mafic facies display chemical characteristics falling between the tholeiitic and calk-alkaline trends, with a dominantly tholeiitic affinity and similar features to Back-Arc Basin Basalts (BABB; Barboni et al., 2007). Preliminary trace-element geochemistry suggests several sources for the associated felsic rocks, including partial melting of quartzofeldspathic continental crust (A-type granites; Barboni and Bussy, 2011) and subsequent mixing with the mafic magma (intermediate rocks; Barboni et al., 2007). The SJDD pluton was built by sill underaccretion (in the sense of Annen et al., 2006) at upper crustal levels in a continental rift or a pull-apart basin, presumably during an extensional or transtensional tectonic phase (see review

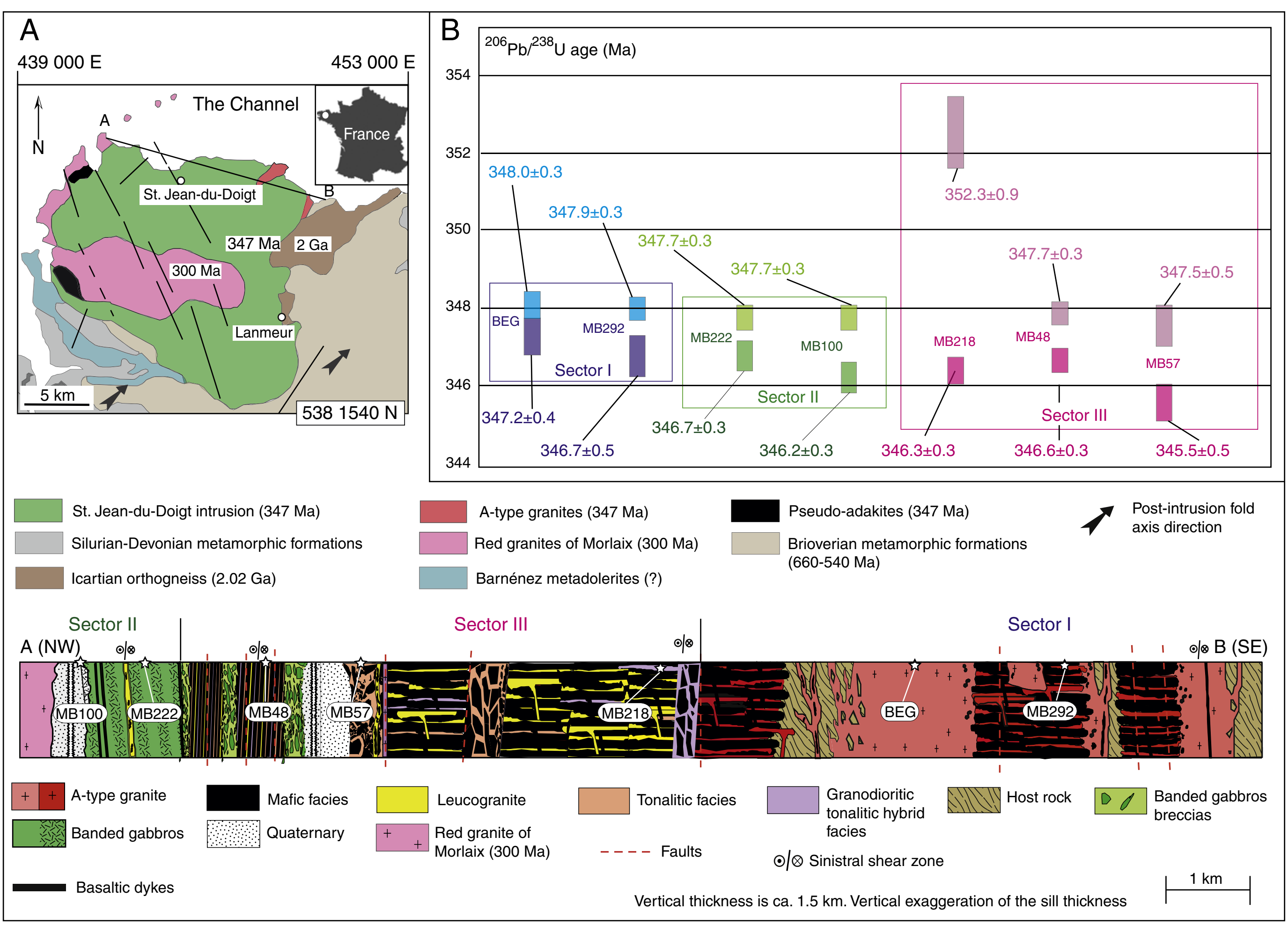

Fig. 1. A) Simplified geological map for the SJDD intrusion and host rocks (modified after Chantraine et al., 1986) and seashore cross-section. Location of the dated samples is indicated on the cross-section. B) Oldest (antecryst) and youngest (autocryst) fractions within each dated sample.