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# Pb isotopic zoning of K-feldspar megacrysts determined by Laser Ablation Multi-Collector ICP-MS: Insights into granite petrogenesis

D. Gagnevin,[1,*] J. S. Daly,[1] T. E. Waight,[2] D. Morgan,[3] and G. Poli[4]

[1]Department of Geology, University College Dublin, Belfield, Dublin 4, Ireland
[2]Danish Lithosphere Center, Øster Volgade 10, 1350 Copenhagen K, Denmark
[3]Department of Geological Sciences, University of Durham, South Road, Durham DH1 3LE, United Kingdom
[4]Dipartimento di Scienze della Terra, Piazza Universitá, 06100 Perugia, Italy

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**Abstract**—This study investigates Pb isotopic zoning in magmatic K-feldspar megacrysts from the Monte Capanne pluton (Elba, Italy) using Laser Ablation Multi-Collector-ICPMS. The studied crystals provide an ideal opportunity to use in situ techniques to assess the extent of open-system processes and better characterize the components involved in the genesis of complex magma systems. Earlier investigations of the pluton identified the importance of magma mixing between mantle and crustal-derived magmas.

The investigated K-feldspar megacrysts exhibit strong zoning in $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$, correlated with lead elemental variations. We interpret these variations as reflecting growth zoning, as opposed to secondary diffusive exchange. Despite a great variety of zoning patterns, we were able to correlate different events of megacryst growth, reflecting crystallization in a dynamic magma system. Our two-step model includes (1) growth of a granitic magma chamber by addition of low $^{208}Pb/^{206}Pb$ magma to a high $^{208}Pb/^{206}Pb$ magma contaminated with crustal material (i.e., the megacryst cores) and (2) recharge by mantle-derived magma (i.e., the megacryst rims). We interpret the thorogenic nature of the megacryst rims to reflect the mantle-derived component involved in the mixing process. Taking account of other data from the Tuscan Magmatic Province, the mantle source is inferred to have been metasomatized by continental material during subduction. TIMS Sr isotopic data from microdrilled cores in one megacryst provides general support for the model but show that the two isotopic systems are decoupled. *Copyright © 2005 Elsevier Ltd*

## 1. INTRODUCTION

In contrast to traditional whole-rock analyses, crystal isotope and trace element stratigraphy offer unique insight into the nature and relative timing of open-system magmatic processes (e.g., Davidson and Tepley, 1997; Tepley et al., 1999, 2000; Knesel et al., 1999; Waight et al., 2000), and can constrain crystal residence times and growth rates (e.g., Tepley et al., 1999). These methods have been extensively developed using Sr isotopes in plagioclase phenocrysts from recent (i.e., $<1$ Ma) volcanic systems. However, similar studies have rarely been applied to plutonic rocks (e.g., Cox et al., 1996; Waight et al., 2000). Classically, analyses are carried out on micro-samples extracted from single phenocrysts and analyzed for Sr isotopes by thermal ionization mass spectrometry (TIMS). Recent studies have investigated the potential use of laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS) for Sr analyses to improve the spatial resolution (e.g., Davidson et al., 2001). However, the use of LA-MC-ICPMS techniques for Sr analyses is still limited by larger errors compared to TIMS analyses (Davidson et al., 2001) and isobaric interferences from Rb and complex polyatomics (Davidson et al., 2001; Waight et al., 2002). On the other hand, Pb isotopic analyses using LA-MC-ICPMS yield comparable errors to TIMS analyses and solution-based MC-ICPMS techniques (e.g., Willigers et al., 2002). Because of their low U and Th contents and generally high Pb contents, in situ Pb isotopic studies of K-feldspar provide a new and potentially powerful isotopic tracer of magmas and petrogenetic processes due to preservation of initial isotopic ratios.

Pb isotopic studies by laser ablation are in their infancy. Wolff and Ramos (2003) measured the Pb isotopic composition (determined by MC-ICPMS) of bulk feldspar separates to examine the importance of open-system processes in the genesis of high-silica rhyolites from the Bandelier Tuff. Wolff and Ramos (2003) convincingly concluded that pseudoisochrons obtained using the Rb-Sr method (i.e., positive correlation between $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$) were not the result of in situ radiogenic growth in a long-lived magma chamber, but instead, reflect open-system processes involving components having distinct Pb and Sr isotopic compositions (i.e., crust vs. mantle). Mathez and Waight (2003) analyzed plagioclase-sulfide pairs from the Bushveld Complex by LA-MC-ICPMS, and successfully demonstrated that in situ Pb analyses may be used to gain insights into the complex magmatic and subsolidus history of a large layered intrusion. Ukstins-Peate et al. (2003) used LA-MC-ICPMS analyses of K-feldspar and glass shards to correlate individual ignimbrites in the Red Sea region to ash falls in the Indian Ocean.

This paper presents a Pb isotopic investigation of K-feldspar megacrysts from the Monte Capanne (MC) monzogranite (Fig. 1), which was largely motivated by abundant evidence of magma mixing/mingling. Previous whole-rock studies emphasized the predominant role of magma mixing in the genesis of the intrusion (Poli et al., 1989; Dini et al., 2002; Poli et al., 2002), ultimately responsible for the formation of the widespread mafic microgranular enclaves (MME) (Bussy, 1991;

* Author to whom correspondence should be addressed (Damien.Gagnevin@ucd.ie).

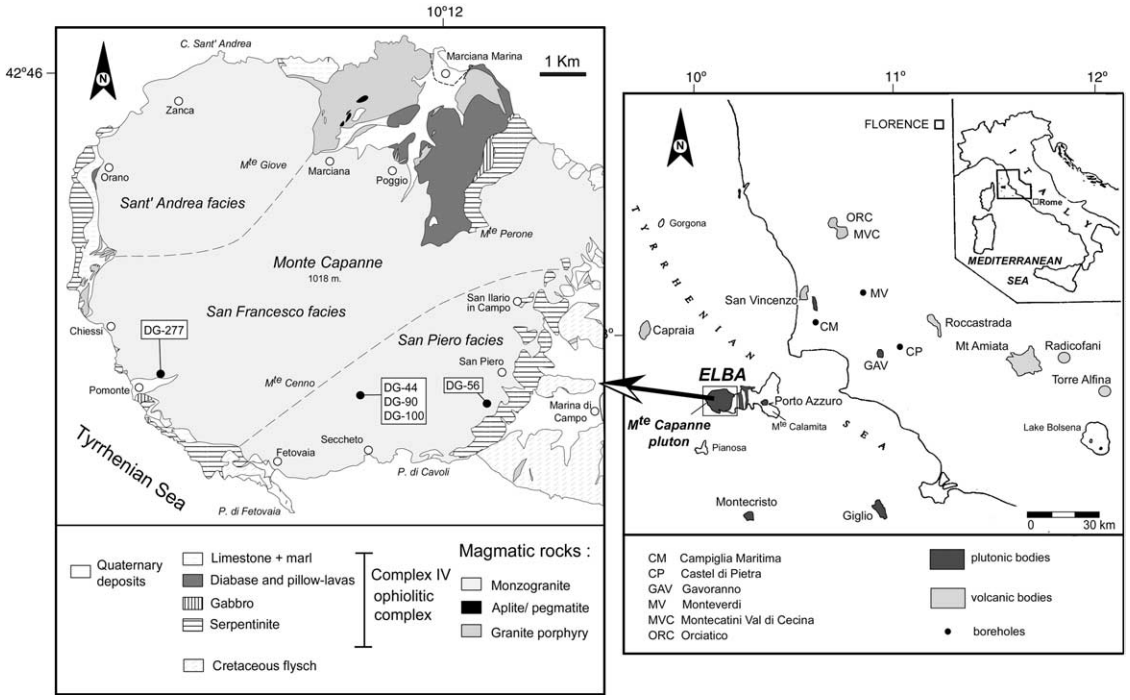


Fig. 1. Map of the Tuscan Magmatic Province and geological map of the Monte Capanne pluton (west Elba Island, after Trevisan and Marinelli, 1967). Black dots indicate sample localities (with associated sample numbers).

Poli, 1992). On the basis of Sr and Nd isotopic data, Dini et al. (2002) concluded that hybrid rocks in the MC pluton were produced by thorough mixing between anatectic and mantle-derived magmas, which was further corroborated by Gagnevin et al. (2004). The importance of mixing of crustal and mantle components has also been suggested for the genesis of the entire spectrum of granitic compositions found in the Tuscan Magmatic Province (Fig. 1; Poli, 1992). In situ analysis using a laser ablation system attached to a MC-ICPMS may potentially unravel the complex growth history recorded by phenocryst phases. K-feldspar megacrysts are good candidates for this approach as they (1) are found in all magma products, (2) display abundant petrographic evidence of disequilibrium, i.e., the occurrence of complex resorption surfaces concentrated toward the rims and only visible using the SEM (Daly and Poli, 1999), and (3) exhibit complex core-to-rim variation in trace elements and Sr isotopic ratios (Gagnevin et al., in press). In particular, the presence of Ba zoning and Sr isotopic gradients in megacrysts reflect growth zoning in crustal granitic magmas recharged by mantle-derived magmas.

We thus aim to constrain this model better using in situ Pb isotopic analyses determined by LA-MC-ICPMS in K-feldspar megacrysts. We will conclusively show that Pb concentration (determined with LA-MC-ICPMS) and Pb isotopic variations largely reflect the combined effect of multistage open-system processes operating throughout the lifetime of the MC plutonic system.

## 2. MONTE CAPANNE PLUTON

The MC pluton forms the western part of Elba Island and is part of the Tuscan Magmatic Province (TMP), comprising the northern portion of the Tyrrhenian Sea, Tuscany and Northern Latium areas (Fig. 1). Tuscan magmatic rocks consist of plutonic (e.g., in Giglio, Montecristo, Elba island, Fig. 1) and volcanic (e.g., San Vincenzo, Roccastrada, Monte Amiata, Radicofani; Fig. 1) rocks. Magma genesis occurred during regional back-arc extension that affected the Northern Tyrrhenian domain from early Miocene time following the westward subduction of the Adriatic plate below the Corsica-Sardinia microplate (e.g., Keller and Pialli, 1990). The Sisco (Corsica) lamproitic rocks (14 Ma) are the oldest dated products of the TMP, whereas the youngest volcanic activity occurred in Monte Amiata (0.2–0.3 Ma; Fig. 1). The TMP is classically considered to have a predominantly crustal signature (Taylor and Turi, 1976) through large-scale anatexis of metasedimentary crustal rocks, although several studies have also shown that mantle-derived magmas contributed significantly to the Tuscan magmas (e.g., Giraud et al., 1986; Poli et al., 1989; Poli, 1992). Pure mantle-derived components are scarce within the TMP. For example, they can be observed in the Capraia volcanic centre (Fig. 1; 7.6–4.7 Ma; Aldighieri et al., 1998), which exhibits a set of high-K andesites and subordinate shoshonitic basalts.

The MC pluton, which is the largest intrusion of the TMP, has been dated by several isotopic methods at ~6.8–7 Ma (Ferrara and Tonarini, 1985; Dini et al., 2002). Together with the Montecristo pluton (Innocenti et al., 1997) and granite porphyries from Central Elba (Dini et al., 2002), they represent the oldest intrusions of the province. The pluton has a monzogranitic bulk composition (the main mineral phases are plagioclase + K-feldspar + quartz + biotite; accessory minerals are zircon + apatite + monazite + tourmaline) and was emplaced at shallow level (i.e., <1–1.5 kbar) within metamorphosed