

## CONTRASTING ZIRCON GROWTH PATTERNS IN NEOPROTEROZOIC GRANITES OF SOUTHERN BRAZIL REVEALED BY SHRIMP U–Pb ANALYSES AND SEM IMAGING: CONSEQUENCES FOR THE DISCRIMINATION OF EMPLACEMENT AND INHERITANCE AGES

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### INTRODUCTION

The Florianópolis Batholith is a major component of northern portion of the Neoproterozoic (Brasiliano Cycle) Dom Feliciano Belt/Pelotas Orogen in Santa Catarina state, southern Brazil. It is exposed over an area of about 12,000 km<sup>2</sup> (200 km long and about 60 km wide), along the Atlantic Ocean coast, extending continuously from 26° 45' S to 28° 45' S.

Despite of recent U-Pb studies (Silva et al., 2002a; Basei, 2000), many uncertainties persist regarding the relationships between magma generation and tectonic evolution within the batholith. We explore these chronological problems by means of the combined use of the U–Pb SHRIMP analyses and backscattered electron (BSE) and cathodoluminescence (CL) imaging of zircons from four critical plutons: Paulo Lopes (Sample 1), Valsungana II (Sample 2), Guabiruba (Sample 3) and Tabuleiro (Sample 4).

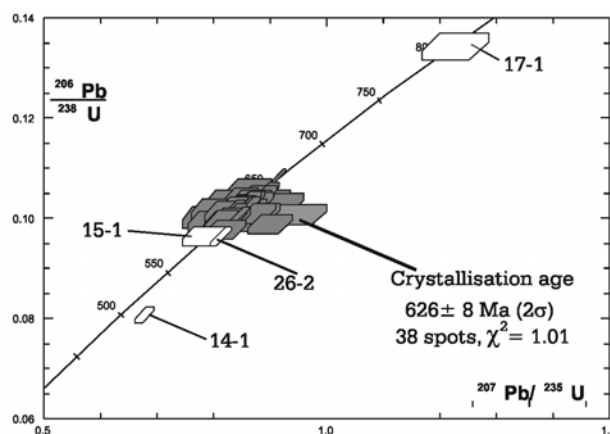
A complete version of this abstract, including Sm-Nd data, analytical tables, concordia diagrams, SEM images and analytical procedures may be found elsewhere (Silva et al., 2003).

No previous SHRIMP U-Pb zircon ages were available for the targeted plutons. The Paulo Lopes Suite yielded an imprecise Pb-Pb single crystal zircon evaporation age of 642 ± 46 Ma (Silva et al., 1997) and a U-Pb crystallization age of 644 ± 20 Ma (Basei, 2000). Basei (2000) obtained a conventional U-Pb crystallisation age of 638 ± 32 Ma for an early phase of the Valsungana Suite, distinct from the Valsungana II Granite dated herein (sample 2). Finally, a facies from the Guabiruba Granite yielded an imprecise age of 573 ± 44 (Basei, 2000).

### SAMPLE 1 - PAULO LOPES GRANITE

Zircons from this sample are morphologically simple, composed of euhedral long-prismatic grains with typical magmatic length:width ratios of 3:1. They are mostly homogeneous, without core/rim separation, with Th/U ratios between 0.2-0.8, typical of felsic magmatic rocks. Forty three analyses were performed on 35 zircons. Most analyses fall in a single cluster of 38 concordant spots (filled error boxes in Fig. 1), with a weighted mean <sup>206</sup>Pb/<sup>238</sup>U age of 626 ± 8 Ma (2σ) and with no scatter beyond that attributed to analytical error (mean χ<sup>2</sup> = 1.01). This date is more consistent than the ca. 640 Ma

previously obtained (Silva et al., 1997; Basei, 2000) and is interpreted as the best estimate of the crystallization age of the magma. Because the granite was emplaced during, or shortly before, the peak of collisional deformation, the date also provides an estimate for the age of syn-collisional strike-slip related transpressive tectonics within the batholith.



**Figure 1.** Concordia plot for zircon data from sample 1.

One crystal (spot 26.1) shows an oscillatory zoned, magmatic textured, high U, euhedral rim, with magmatic Th/U ratio, which consists of a smooth, scalloped overgrowth that truncates the oscillatory-zoned igneous core. These internally irregular overgrowths are relatively brighter patches in BSE and darker in CL images and are caused by metamictisation. The metamict margin, with high U contents and a relatively low <sup>206</sup>Pb/<sup>238</sup>U apparent age of 593 ± 11 Ma (blank error boxes on Fig. 1), is interpreted to be new zircon associated with a post-magmatic melt-precipitated phase, possibly ascribed to post-crystallization granitic intrusions; the data were excluded from the age calculation. Spot 15-1 was also discarded on the basis of its low age (possibly due to radiogenic Pb loss). Spot 2-1 from a xenocryst yielded an age of ca. 1491 Ma and spot 17-1, from an inherited core, an age of ca. 812 Ma. These two analyses were also disregarded in the age calculation.

Some analyses obtained on discrete crystals, cores and overgrowths were rejected on the basis of their high discordance.

## SAMPLE 2 - VALSUNGANA II GRANITE

The zircon population is composed of euhedral long-prismatic forms with typical magmatic length:width ratios between 2:1 and 3:1. Twenty five analyses were performed on seventeen crystals. Sixteen analyses from discrete homogeneous magmatic textured crystals and from complex crystals with magmatic textured cores and overgrowths rims were pooled as a single population, with no excess scatter (mean  $\chi^2 = 0.90$ ) (Fig. 2). With few exceptions in high-U metamict domains (spots 29-1 and 7-1), the Th/U ratios are typically magmatic (0.2-0.8). This group yielded a weighted mean  $^{206}\text{Pb}/^{238}\text{U}$  date of  $593 \pm 16$  Ma (shaded error boxes in Fig. 2), which is interpreted as the crystallization age for the granite.

As the overgrowths, like the cores, have the same isotopic and morphological magmatic signature and roughly equivalent dates the overgrowths are interpreted as a late-magmatic melt-precipitated zircon phase as suggested also by magmatic halos around inclusions. Some analyses (blank error boxes in Fig. 2), obtained on discrete crystals, cores and overgrowths were rejected on the basis of their high discordance.

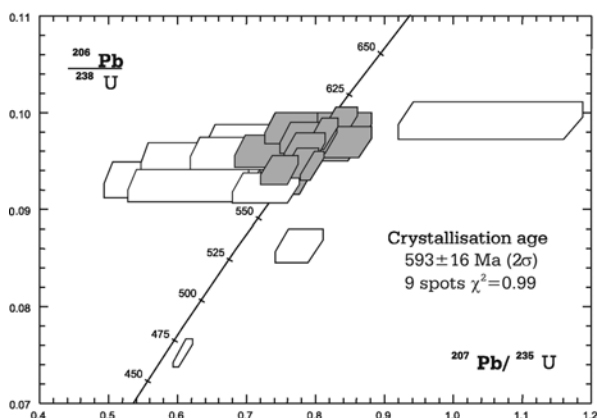


Figure 2. Concordia plot for zircon data from sample 2.

## SAMPLE 3 – GUABIRUBA GRANITE

The zircon population is composed mostly of euhedral long-prismatic forms with typical length:width ratios of 3:1, interpreted as magmatic. Forty two analyses were performed on thirty two crystals. Despite the homogeneity and simplicity of the external morphology of the zircons, the U-Pb data indicate a complex evolution, the results showing a large (70 m.y.), continuous age spread from *ca.* 660 Ma to *ca.* 590 Ma.

One major group of 19 spots were obtained on discrete, euhedral, oscillatory zoned magmatic grains, with magmatic Th/U ratios between 0.1 and 0.8 with few of them presenting ratios slightly higher (1.3). Overgrowth rims around inherited magmatic cores also present magmatic Th/U ratios for normal U-contents (Spot 4.1). Metamict domains also presenting high Th contents (up to ~750 ppm) and are recognized by highly BSE-luminescent, CL-dark luminescence domains which are accompanied by frequent fracturing in radial or

concentric patterns, due to expansion by metamictisation. (spot 4.3). These high-luminescence BSE domains may also be seen as discordant irregular rims of smooth scalloped overgrowths that truncates and corrodes inherited cores. Some crystals show halos around mineral inclusions, seen as bright areas in BSE. The group represents a single data population, with no excess scatter in  $^{206}\text{Pb}/^{238}\text{U}$  (mean  $\chi^2 = 0.85$ ) and an age of  $610 \pm 6$  Ma (light grey error boxes on Fig. 3). As the date was obtained on discrete unzoned crystals and on new zircon overgrowths on corroded inherited cores (see below), we interpret the  $610 \pm 6$  Ma  $^{206}\text{Pb}/^{238}\text{U}$  date as the age of crystallization of the granite.

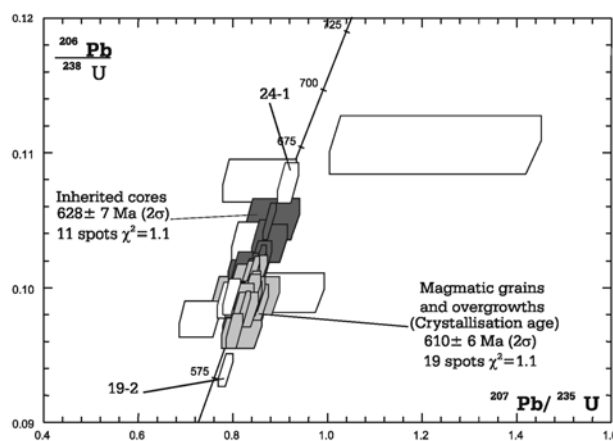


Figure 3. Concordia plot for zircon data from sample 3.

With the exception of spot 19-2 which has experienced recent Pb-loss, and spot 24-1, morphologically distinct, all the others discarded spots (blank error boxes on Fig. 3) were disregarded on the basis of their high discordance.

Eleven spots obtained from magmatic-textured, partly resorbed (corroded) inherited cores and on discrete unzoned grains represent a single U-Pb data population (dark grey error boxes on Fig. 3) with no significant excess scatter (mean  $\chi^2 = 1.1$ ), and furnish a  $^{206}\text{Pb}/^{238}\text{U}$  date of  $628 \pm 7$  Ma. This apparent age coincides within error with the age of the early syn-collisional granitic magmatism, dated at *ca.* 630 Ma (Sample 1). Accordingly, despite uncertainty regarding the source(s), nature and provenance(s) of the inherited cores, it is interpreted as a mean age of crystallization.

## SAMPLE 4 - TABULEIRO SUITE

The morphology of the zircons is fairly homogeneous. The great majority of the grains are euhedral, with low aspect ratios (~2:1) and with well preserved fine-scale magmatic, oscillatory-zoned textures in both the rims and cores. Twenty three spots were analyzed on 21 zircons (Fig. 4). Like sample 3, results from sample 4 show a large continuous spread along concordia (from *ca.* 630 Ma to *ca.* 570 Ma).

A group of 6 analyses obtained from discrete, unzoned, magmatic-textured, euhedral grains and on

magmatic- textured (oscillatory-zoned) melt-precipitated rim overgrowths forms a single data cluster with mean  $\chi^2 = 0.7$  and an apparent  $^{206}\text{Pb}/^{238}\text{U}$  age of  $597 \pm 9$  Ma (light grey error boxes in Fig. 4). Most of these domains have normal (magmatic) U and Th contents and Th/U ratios between 0.2 and 0.7, and the result is interpreted as the crystallization age of the pluton. Only spot 22.1 shows an abnormal enriched U content (1105 ppm) and has bright domains in BSE (and dark in CL) typical of metamict domains. It also has high Th contents (277 ppm) but a normal Th/U ratio (0.25). With the exception of analysis 26-1 (Fig. 4), which has been omitted because it represents a mixed core/rim domain, all the other discarded analyses were rejected on the basis of their highly discordant results (blank error boxes in Fig. 4).

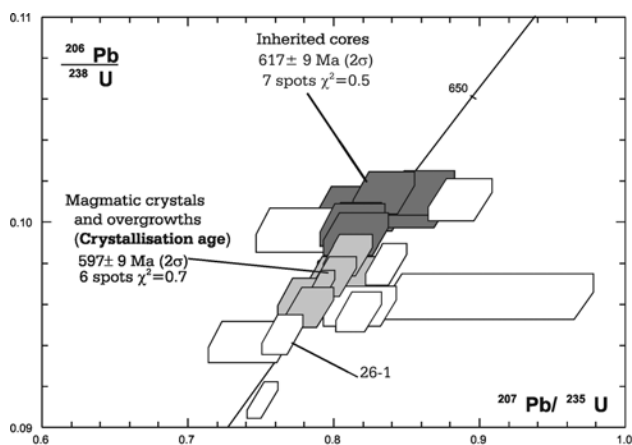


Figure 4. Concordia plot for zircon data from sample 4.

Seven spots obtained from magmatic-textured, partly resorbed (corroded) inherited cores and discrete unzoned grains (spots 9-1 and 9-2) form a single data population (mean  $\chi^2 = 1.1$ ) with a mean  $^{206}\text{Pb}/^{238}\text{U}$  date of  $617 \pm 9$  Ma (dark grey error boxes in Fig. 4). As with sample 3, this apparent age coincides within error with the age of the early syn-collisional granitic magmatism, dated at ca. 630 Ma (Sample 1) and it is interpreted as the crystallization age of an early, short-lived, rapidly recycled granitic source, although this source cannot be identified.

As observed in several crystals from the other analyzed samples, some domains show late-magmatic halos around mineral inclusions seen as light areas in BSE. In some crystals, this process caused the formation of paired bright/dark (in BSE), which are complementarily dark/bright in CL, similar to patterns previously ascribed to solid-state diffusion process by Vavra et al. (1996) and Hartmann et al. (1997). As the ages of these domains coincide within error with the age obtained for the “normal” zones, this textural pattern may not be related to a diffusion process or, if it is, the process must not have caused any important disturbance on the U-Th-Pb systems, *i.e.*, the age.

## DISCUSSION AND CONCLUSIONS

In addition to the tectonic/magmatic repartition of the granitic phases within the batholith, this investigation is also a case study on the growing importance of spatially-resolved U–Pb SHRIMP systematics for the acquisition of reliable ages on inherited and melt-precipitated complex mixed zircon populations. The complex and varied internal structures of the analyzed zircon populations could lead to mixed ages and erroneous conclusions, in the absence of prior BSE/CL imaging. Further, we believe that conventional U–Pb dating of these samples would result in a complete spread of results between the two geological ages, possibly leading to erroneous conclusions. Even using SHRIMP systematics, the observation of only a small number of BSE/CL images may lead to equivocal conclusions. In a first approach to these data, Silva (1999) and Hartmann et al. (2000) overestimated the influence of the diffusion halos around mineral inclusions and the paired bright/dark (in BSE) zoning (diffusion bands?) on zircon U-Th-Pb systems. In light of similar patterns ascribed to solid-state hydrothermally-controlled diffusion process by Vavra et al. (1996), Gebauer et al. (1997) and Hartmann et al. (1997), these features led Silva (1999) and Hartmann et al. (2000) to interpret the younger melt-precipitated overgrowths as hydrothermally altered domains, and accordingly, their apparent ages were considered as the age of a post-magmatic overprinting process. The resorbed inherited cores, in turn, were interpreted as pristine magmatic populations, and their apparent ages as the crystallization ages of the plutons. Based on the study of a larger number of BSE/CL images of the Brasilião granites, and on similar morphologic patterns described in many crustal-derived granitoids elsewhere (*e.g.* Williams, 1998) we believe the present reassessment has delineated the correct evolution of the U-Pb-Th systems and, consequently, ages of inheritance and melt-precipitation were properly discriminated and measured.

On the other hand, interpretations of the new ages as well as previous U–Pb data contradict the usual linear temporal partition between pre- syn- post-collisional and post-tectonic batholithic magmatism. Different tectono-magmatic stages were reached in different domains of the Florianópolis Batholith at the same time, giving rise to the unusual coarsely synchronous accretion from of *ca.* 610 Ma post-tectonic I-Caledonian (Guabiruba Suite); *ca.* 600 Ma post-tectonic A-type (Tabuleiro Suite); *ca.* 590 Ma strike-slip related (Valsungana II Granite). The apparently erratic magmatic evolution is also evident from other U-Pb studies. Silva et al. (2002b) dated an expanded calc-alkaline post tectonic suite (Maruim Suite) ranging in ages from *ca.* 610 Ma to *ca.* 580 Ma, whereas (Basei, 2000) obtained an age of *ca.* 650 Ma for a post-tectonic intrusion (Faxinal Syenite). This evolution implies important short-distance lateral changes in the stress field, giving rise to simultaneous transpressive and transtensive large scale magma generation. The peculiar pattern, uncommon in magmatic arcs within the Mantiqueira Province or elsewhere, emphasizes the necessity for more detailed geological mapping of the

batholith magmatic phases to delineate a better constrained tectono-magmatic evolution.

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