ABSTRACT The ages of three facies of syn-orogenic metametaluminous granites from the Três Córregos Batholith (Southern Ribeira Belt, São Paulo) were obtained by conventional U-Pb zircon dating. A typical porphyritic hornblende-biotite granite from the Saival massif yielded 605 ± 2 Ma. Two other samples of foliated granites show signs of inheritance, and no precise ages of crystallization were obtained. Their lowest 207Pb/206Pb ages, however, are only slightly discordant, and yield reliable upper limits that are, in both cases, around 608-610 Ma, demonstrating that these more deformed varieties are products of the same magmatic event that formed the bulk of the batholith, and not older orthogneisses, as admitted in some previous works. Calculated to the age of crystallization, the 143Sm/147Sm ratios show a wide spread (0.710 to 0.717). A clear negative correlation, in a batholith scale, with the Sr contents, is attributed to mixing with an old, high Rb/Sr mid-crustal component, and can explain the older isochron ages typically obtained in these and similar granites. High 143Sm/147Sm, high Sr mafic microgranular enclaves seem to point to a contribution from enriched sources in the continental mantle lithosphere to the Três Córregos magmatism.

Keywords: U-Pb dating, Rb-Sr isotope geochemistry, granite, Ribeira Fold Belt, Neoproterozoic.
Porphyritic granites and foliated granites

Equigranular biotite granites with abundant migmatitic structures, hornblende-biotite granites with centimeter-sized (typically 3-4 cm) augen-gneisses.

Accessory minerals are opaques (mostly magnetite), titanite, apatite and zircon. Secondary chlorite, muscovite, carbonate and epidote occur in some samples.

The foliated granites are in most cases deformed varieties of porphyritic granites, occurring as border zones in some massifs or along zones of more intense deformation. The foliation is defined by the orientation of mafic minerals and locally by quartz and feldspar of the groundmass, and also of the eye-shaped pink K-feldspar megacrysts. The modes and mineralogy are the same as in the porphyritic granites, but the secondary minerals may be abundant in more deformed varieties. Leucocratic facies (pink gneissic granites with IC lower than 5) occur in some areas around the Barra do Chapéu massif (e.g., samples E-1, E-2 and E3, Fig. 2).

Mafic enclaves are common both in the porphyritic and in the foliated granites. They are fine-grained, dark grey, equigranular quartz diorites to quartz monzodiorites, and may show complex contacts with the enclosing granites, suggestive of interaction in a magmatic state.

**Figure 1** - Geological sketch of part of the Ribeira Fold Belt in parts of the states of Paraná and São Paulo, Brazil, with location of the studied area. 1 = Phanerozoic cover and intrusive rocks; 2 = Late pull-apart basins; 3 = post-orogenic granites; 4 = syn-orogenic granites (batholiths); 5 = Cutuporanga; TC = Três Córregos; AG = Agudos Grandes; 5 to 7 = metasupracrustal rocks of the Açungui Supergroup; 8 = schists of unknown origin; 9 = gneissorogenic granites; 4 = syn-orogenic granites (batholiths: C = Cunhaporanga; B = Barra do Chapéu; Ca = Capote; CB = Córrego do Butiá; Sa = Saival; PT = Paiol de Telha. Sample locations: B5, ET18 etc.

**Figure 2** - Geology of the eastern portion of the Três Córregos Batholith north of Apiaí, State of São Paulo, with location of the samples analysed for Rb-Sr and U-Pb isotope (1 = metasedimentary rocks; 2 = migmatic granites; 3 = augen gneisses; 4 = foliated granites; 5 = porphyritic granites; 6 = post-orogenic granites; 7 = geologic contacts; 8 = faults; 9 = diabase dikes; 10 = alluvial deposits. BC = Main massifs composed of syen-orogenic porphyritic granites; BC = Barra do Chapéu; Ca = Capote; CB = Córrego do Batuí; Sa = Saival; PT = Paiol de Telha. Sample locations: B5, ET18 etc.

Foliated enclaves are locally abundant, and may show complex structures suggestive of an intimate interaction with the enclosing augen-gneisses.

The migmatitic granites are mostly heterogeneous, grey, equigranular biotite granites with abundant migmatitic structures, specially nebulous and schlieren.

**Porphyritic Granites and Foliated Granites**

Porphyritic hornblende-biotite granites with centimeter-sized (typically 3-4 cm) euhedral to oval-shaped K-feldspar megacrysts are the main rock types of the Três Córregos Batholith in the studied area. Modal analyses (Gimenez Filho et al. 1995) indicate the predominance of monzogranites, with variations to quartz monzonites and granodiorites. The petrographic indices (IC) are typically in the range 10-15. The faces with IC as low as 5 are present in some massifs (e.g., Saival, Córrego do Butiá and LaJeado; Fig. 2). The accessory minerals are opaques (mostly magnetite), titanite, apatite and zircon. Secondary chlorite, muscovite, carbonate and epidote occur in some samples.

Analytical procedures

Samples chosen for analyses, weighing 8 to 10 kg, were crushed in steel bar crushers and then sieved and separated into two size fractions (48-100 mesh and 100-270 mesh). The heavy minerals were concentrated from both fractions using a wiffle table at the Instituto de Pesquisas Tecnológicas (IPT). The separation of different magnetic fractions, crystal abrasion, dissolution, chemical separation and analysis of Pb and U was done at the Isotope Geochemistry Laboratory (IGL), University of Kansas, USA. Details of the analytical procedures used in the thermal ionization analysis of U and Pb isotopes at IGL are given in Janasi et al. (2000).

**Results**

**Saival Hornblende-Biotite Granite (Sample S-15)**

Sample S-15 is a porphyritic hornblende-biotite quartz monzonite from the Saival massif (Fig. 2). Four zircon fractions, each including six to twelve grains and weighing 0.008 to 0.027 mg, were chosen for analysis. All fractions are slightly discordant and have similar $^{206}Pb/^{238}U$ ages with no traces of inheritance (Table 1, Fig. 3). Fraction m(0) is concordant at 605 ± 3 Ma. An average of the $^{206}Pb/^{238}U$ ages of all four fractions, which is obtained as a discordia line with the lower intercept forced to zero, is here considered as the best estimate of the crystallization age of the rock, and yields 605.1 ± 2.0 Ma.

**Foliated Granite (Sample E-3)**

Sample E-3 is a leucocratic foliated granite from the border of the Barra do Chapéu massif.

Four zircon fractions consisting of 5 to 8 non abraded prismatic, transparent grains, were analysed. Fraction m(0), with the youngest $^{207}Pb/^{206}Pb$ age (610 ± 3 Ma) is the closest to concordance, and has the lowest error. Fraction m(+1) has clearly an inherited component, as shown by the $^{207}Pb/^{206}Pb$ age in excess of 670 Ma (Table 1, Fig. 4). The other two fractions yield $^{207}Pb/^{206}Pb$ ages 5 to 10 Ma older than m(0). If all three are included in a regression forced to zero, a large uncertainty is associated with the age (615 ± 54 Ma with MSWD = 12). We interpret that the old ages shown by fractions m(0) and m(+2) reflect a small inherited component, and that the $^{207}Pb/^{206}Pb$ age of fraction m(0) (610 ± 3 Ma) places a reliable upper limit on the crystallization age of this sample.
AUGEN-GNEISS (SAMPLE MN-15) Sample MN-15 is a quartz monzodioritic augen gneiss. As discussed above, this unit was separated from the rest of the Três Córregos batholith on the basis of its peculiar, more sodic composition, and on the presence of dioritic enclaves dated by Rb/Sr at ca. 1.8 Ga (Gimenez Filho 1993).

The four magnetic fractions dated consisted of 3 to 8 prismatic, transparent grains, and weighed 0.008 to 0.018 mg each. The large prismatic grains included in one of the m(-1) fractions are much more radiogenic than the others, and yield a very discordant result with a 207 Pb/206 Pb age of 1267 ± 4 Ma (Table 1).

The remaining three fractions yield 207 Pb/206 Pb results in the same range observed for sample E-3 above (610-620 Ma). A regression forced to zero yields a similar age also with large and undesirable error (611 ± 43 Ma; MSWD = 7.8; Fig. 5). One of the fractions (m(+1)) has a large analytical error and the other two are more discordant as compared to E-3. We consider the youngest 207 Pb/206 Pb age yielded by fraction m(-1)b (608 ± 5 Ma) to place an upper limit on the crystallization age of this rock.

Forced to a lower intercept of 605 Ma, that is, admitting that all Pb loss occurred at the time of crystallization of the magma, the large crystals making up fraction m(-1) would have an upper intercept of 2095 ± 42 Ma, pointing to a Transamazonian source for the inheritance (Fig. 5, inset).

Discussion Sample S-15 is a representative of the predominant rock-type making up the eastern half of the Três Córregos Batholith, and its U-Pb results yield a reliable, precise age for the main period of granite generation in the area. The obtained age (605 ± 2 Ma) is younger than the Rb-Sr and even some of the K-Ar ages previously available for rocks of the batholith (cf. Souza 1990, Gimenez Filho 1993).

Table 1 - Results of U-Pb isotope determinations for granites of the Três Córregos Batholith.

<table>
<thead>
<tr>
<th>Crystal description</th>
<th>Fraction</th>
<th>Size (mg)</th>
<th>Pb (ppm)</th>
<th>U (ppm)</th>
<th>Pb/U ratio</th>
<th>% error</th>
<th>206 Pb/238 U</th>
<th>% error</th>
<th>207 Pb/235 U</th>
<th>% error</th>
<th>207 Pb/206 Pb</th>
<th>% error</th>
<th>Ages (Ma)</th>
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<tr>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>8g.tr.pr nm(0)</td>
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<td>528.8</td>
<td>0.09653</td>
<td>1.20</td>
<td>0.80028</td>
<td>1.23</td>
<td>0.06013</td>
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<td>597.0</td>
<td>608.1</td>
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<td>647.3</td>
<td>0.09784</td>
<td>0.71</td>
<td>0.80984</td>
<td>0.73</td>
<td>0.06003</td>
<td>601.7</td>
<td>602.4</td>
<td>604.8</td>
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<tr>
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<td>65.1</td>
<td>580.6</td>
<td>0.09227</td>
<td>0.84</td>
<td>0.76388</td>
<td>0.88</td>
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<td>576.3</td>
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<td>0.80984</td>
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<td>598.3</td>
<td>599.3</td>
<td>603.1</td>
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<td>E-3 leucocratic foliated granite</td>
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<tr>
<td>pr,na nm(0)</td>
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<td>56.6</td>
<td>507.8</td>
<td>0.09820</td>
<td>0.79</td>
<td>0.81699</td>
<td>0.81</td>
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<td>606.4</td>
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<td>593.0</td>
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<td>MN-15 Hbl-Bt gneiss</td>
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<td></td>
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<td>1.48773</td>
<td>1.19</td>
<td>0.08291</td>
<td>788.7</td>
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<td>479.1</td>
<td>0.09413</td>
<td>0.99</td>
<td>0.78027</td>
<td>1.02</td>
<td>0.06012</td>
<td>579.9</td>
<td>585.6</td>
<td>607.9</td>
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<tr>
<td>9g.tr.pr m(0)</td>
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<td>59.2</td>
<td>527.7</td>
<td>0.09506</td>
<td>0.62</td>
<td>0.79082</td>
<td>0.63</td>
<td>0.06034</td>
<td>585.4</td>
<td>591.6</td>
<td>615.7</td>
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<tr>
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<td>12.1</td>
<td>96.9</td>
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<td>0.84340</td>
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<td>624.3</td>
<td>621.0</td>
<td>609.0</td>
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</tbody>
</table>

G = grain; tr = transparent, pr = prismatic, lg = large, sm = small, na = non-abraded, Hbl = hornblende, Bt = biotite.
remarkable negative correlation between the Sr content of the rock and for the wide scatter of the data in isochronic diagrams (Fig. 6). (T able 2), is observed in each of the three occurrences, and responds evolution in which a more mafic, Sr-rich magma (such as the 86 Sr 605  ratios, of 0.002-0.003 units, well above the analytical error end of the studied area, which might correspond to a border facies of syn-orogenic granites: porphyritic granites of the Barra do Chapéu and samples (Table 2). calculated at the age of crystallization, assumed to be 605 Ma for all given by the U-Pb method. For that purpose, the 87 Sr/ 86 Sr ratios were why they yield ages older than those of magmatic crystallization as 1993, Reis Neto 1994). The result however leaves no doubt on its reliability, and is further reinforced by the U-Pb ages recently obtained for petrographically similar syn-orogenic granites from the neighboring Agudos Grandes Batholith (ca. 610 ± 2 Ma; Janasi et al., 2000). Although an equally precise age could not be determined for the other two samples studied (E-3 and MN-15) because of problems with inheritance, the data herein reported provide important clues to the batholith stratigraphy. The upper limit of 608-610 Ma determined for the crystallization age of both samples clearly indicates that they are related to the same event that built up the bulk of the batholith, and most probably have undistinguishable ages, within error, from those of the Saival granite. Their foliated character should thus reflect differences in the partition of the strain on a regional scale during or shortly after the crystallization of the magmas, and not a pre-tectonic character. This is particularly significant for the augen-gneiss sample MN-15 to which a Transamazonian age was admitted up to now.

Rb-Sr ISOPO TE GEOCHEMISTRY In an early attempt to know the crystallization age of the syn-orogenic granites of the Três Córregos Batholith, an extensive program of Rb-Sr isotope determinations was carried out at the Centro de Pesquisas Geocronológicas (CPGeo), Instituto de Geociências, Universidade de São Paulo, Brazil (see Gimenez Filho 1993 and Tassinari 1988 for details of the analytical procedures at CPGeo in the early 90s). Outcrop isochrons were targeted, but all of them resulted in very imprecise ages owing mainly to the small scattering on the Rb/Sr ratios. Ages between 790 and 660 Ma, with errors typically above 60 Ma, were calculated for different sets of granite samples (Fig. 6). In the approach here adopted, the Rb-Sr isotope results are used as a tool to investigate petrological processes affecting the magmas of the Três Córregos Batholith, including the understanding of the causes why they yield ages older than those of magmatic crystallization as given by the U-Pb method. For that purpose, the 87 Sr/ 86 Sr ratios were calculated at the age of crystallization, assumed to be 605 Ma for all samples (Table 2).

Analytical results are available for three different occurrences of syn-orogenic granites: porphyritic granites of the Barra do Chapéu and Córrego do Butiá massifs and foliated granites cropping out at the NE end of the studied area, which might correspond to a border facies of the Paiol de Telha massif (Figure 2). A significant scatter of the 87Sr/ 86Sr ratios, of 0.002-0.003 units, well above the analytical error (Table 2), is observed in each of the three occurrences, and responds for the wide scatter of the data in isochronic diagrams (Fig. 6). If all three massifs are considered together, the result is a remarkable negative correlation between the Sr content of the rock and its 87Sr/ 86Sr ratio (Fig. 7). This is consistent with a petrological evolution in which a more mafic, Sr-rich magma (such as the hornblende-biotite Barra do Chapéu granite) is progressively contaminated by a low-Sr, high time-integrated Rb/Sr felsic material (crust-derived melts), resulting in more felsic magmas with higher 87Sr/ 86Sr ratios (such as the Córrego do Butiá granites). As shown by several authors (Vlach & Cordani 1986, Heaman & Smalley 1994), Rb-Sr isochronic ages older than the age of magmatic crystallization of a granite are frequently the result of such mixing processes (i.e., where the 87 Sr/ 86 Sr ratio is a feature of a mantle-derived, basic component represented by the enclaves, and that granites such as those of the Barra do Chapéu...
CONCLUSIONS

The U-Pb zircon age of sample S-15 (605.1 ± 7 Ma) is interpreted as the best estimate of the crystallization age of the typical porphyritic hornblende-biotite granite type). Some of the proposed models for the age and duration of the "syn-orogenic" period in the Três Córregos and Agudos Grandes batholiths are based on previous Rb-Sr dating that yielded ages varying from 640 to 780 Ma (Souza 1990, Gimenez Filho 1993, Reis Neto 1994, Leite 1997). Apart from the large errors involved (of 50 Ma or more), doubts have been raised about the significance of these results, that remained in unpublished thesis.

The U-Pb results presented here and elsewhere (Janasi et al. 2000) point to a much shorter duration (<10 Ma?) and a slightly younger age than previously attributed to the "syn-orogenic" period in the Três Córregos and Agudos Grandes batholiths.

The reassessment of the Rb-Sr data of Gimenez Filho (1993) for the Três Córregos batholith suggests that the anomalous isochronic ages obtained in the Rb-Sr system could be explained as a result of a systematic variation on the 87Sr/ 86Sr initial ratio, that seems to show a positive correlation, in a batholith scale, with the Rb/Sr ratio. Such correlation could reflect a progressive contamination of more mafic, Sr-rich granitic magmas by felsic crustal melts having high time-integrated Rb/Sr. Thus, once precise assumptions about the crystallization ages of these granites can be made, the existing Rb-Sr isotope datasets can be used as powerful tools to unravel their petrogenetic evolution. In the case of the Três Córregos Batholith, the nature of the very high 87Sr/ 86Sr initial ratios of the Sr-rich mafic dioritic enclaves, possibly a result of enriched sources in the mantle, is one of the most intriguing features that needs further investigation.

No U-Pb dates exist so far for the late, "post-orogenic" granitic plutons that intrude the Três Córregos Batholith, such as the Sguarro and Correass massifs. Gimenez Filho (1993) obtained Rb-Sr isochron ages clearly too young (respectively, 523 ± 21 Ma and 480 ± 19 Ma), since K-Ar ages on biotites from the same samples yielded older ages, in the 560-600 Ma range. Goraieb (1995) presented a well-fitted 603 Ma oriented quartz phenocrysts in the Três Córregos batholith suggests that the anomalous isochronic ages of the Rb-Sr system could be explained as a result of a systematic variation on the 87Sr/ 86Sr initial ratio, that seems to show a positive correlation, in a batholith scale, with the Rb/Sr ratio. Such correlation could reflect a progressive contamination of more mafic, Sr-rich granitic magmas by felsic crustal melts having high time-integrated Rb/Sr. Thus, once precise assumptions about the crystallization ages of these granites can be made, the existing Rb-Sr isotope datasets can be used as powerful tools to unravel their petrogenetic evolution. In the case of the Três Córregos Batholith, the nature of the very high 87Sr/ 86Sr initial ratios of the Sr-rich mafic dioritic enclaves, possibly a result of enriched sources in the mantle, is one of the most intriguing features that needs further investigation.

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Filho et al. 1995, Reis Neto 1994), the batholith was a part of a magmatic arc developed within a continental crust.

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