ABSTRACT The Ribeira Belt (RB) of southeastern Brazil represents an important manifestation of the Brasiliano Orogeny formed during the assembly of West Gondwana. Contemporaneous sedimentation and volcanism within the RB provide a basis for helping understand its tectonic evolution and paleogeography. U-Pb monazite data from the basal metavolcanic rocks of the São Roque Group indicate a crystallization age of 628 Ma and the upper sequence is cut by a 605 Ma (U-Pb zircon) rhyolite intrusion. Zircon and monazite analyses of metavolcanic (mafic) rocks indicate that they were derived in part from the asthenospheric mantle (consistent with emplacement in an extensional setting), whereas the felsic bodies appear to have come from the melting of Paleoproterozoic lithosphere. The paleogeographic reconstruction of part of the RB suggests that the São Roque/Açungui groups represent extensional sequences, with features of backarc basins, which evolved during the syn-collisional phase of the Brasiliano Orogeny. These data suggest that the hypothesis that we have a rapid evolution (10-20 Ma) between extensional and compressional tectonics during the geological history of the São Roque/Açungui Backarc.

Keywords: Paleoproterozoic lithosphere. The paleogeographic reconstruction of part of the RB suggests that the São Roque/Açungui groups represent extensional sequences, with features of backarc basins, which evolved during the syn-collisional phase of the Brasiliano Orogeny. These data suggest that the hypothesis that we have a rapid evolution (10-20 Ma) between extensional and compressional tectonics during the geological history of the São Roque/Açungui Backarc.

INTRODUCTION The Ribeira Belt (RB) (Almeida et al. 1973) is a Brasiliano-Pan-African mobile belt along the southeastern Brazilian coast comprising lithologies of different origins and ages. The present work was carried out in the central portion of the RB in the southern part of the São Paulo State and the northeast of the Paraná State. The lateral positioning of blocks and exposure of different crustal levels have hindered the understanding of the Brasiliano Cycle in the area (Fig. 1).

Among the several models for the tectonic history of RB, Trompette (1994) considered an evolution beginning with west-dipping subduction followed by collision between the São Francisco, Congo and Paraná cratons. Formation of a backarc in the region, however, was not considered in that model.

To the north, in the State of Rio de Janeiro, the RB records four tectonic phases (Heilbron et al. 1995, Machado et al. 1996) subdivided into 1) pre-collisional (630-600 Ma); 2) syn-collisional (590-565 Ma); 3) late-collisional (540-520 Ma) and 4) post-tectonic (520-480 Ma). In the central area, in the State of São Paulo, the RB is subdivided, according Campos Neto and Figueiredo (1995) as Brasiliano Orogeny (670 - 600 Ma) and Rio Doce Orogeny (590 - 480 Ma).

Recent studies based on distinct Sm/Nd signatures recognize the juxtaposition of different terranes related to accretion and reworking in the central section of RB (Dantas et al. 1999). Hackspacher et al. (1999) proposed the existence of a Neoproterozoic Backarc related to the evolution of the RB.

The late-collisional phase is characterized by intense lateral escape tectonics with related NE/SW transcurrent/transpressive shear zones and associated subalkaline granitogenesis. These tectonic features are responsible for the present block configurations and alternating high and low metamorphic grades in the metasedimentary sequences within the central section of the RB (Hackspacher and Godoy 1999).

The period of the opening and closing of paleo-basins of the RB is still an unresolved controversy. The depositional history of the São Roque Group was believed to have initiated around 1.8 Ga (Van Schmus et al. 1986), as post-Transamazonian crustal extension. Campanha and Sadowksi (1999), among others, proposed an evolution starting at this time for the Açungui Supergroup. On the other hand, this evolution is difficult to reconcile owing to the presence of the 1.4 Ga Serra do Iaberaha Group (Juliani et al. 1986) below the São Roque Group.

In this sense, the main propose of the present work is to constrain the timing of sedimentation and volcanism in the São Roque and Açungui groups and to evaluate a possible correlation between the two (Fig. 2). A secondary objective of this work is to develop a geotectonic model for the evolution of the Central RB. To achieve these goals, a systematic study integrating geochronological studies (U/Pb zircon and monazite, and Sm/Nd whole-rock methods), geochemical studies and traditional field investigations of the metasedimentary sequences and surrounding basement was undertaken.

LITOSTRATIGRAPHY The greenshist facies São Roque and Açungui groups are separated from the higher grade Itapira and Embu groups (amphibolite facies), and Archean and Paleoproterozoic
According to Bergmann (1988) the São Roque Group (Fig. 2) is composed by: the basal Pirapora do Bom Jesus Formation, consisting of metavolcanics and metatuffaceous layers with smaller intercalations of phyllites and metatuffaceous volcanics; and the Boturuna Formation, composed of quartzites and metatuffaceous rocks. All the lithologies are slightly deformed with normal to northwest vergent folds that are strongly stretched adjacent to shear zones. Metamorphism associated with deformation varies between middle and upper greenschist facies. This deformation is intimately associated to late-collisional transcurrent/transpressive processes (Hackspacher and Godoy 1999) responsible for huge shear zones, such as the Itu – Jundiaí, Taxaquara and others of the Ribeira Belt (Fig.1).

The São Roque Group was deposited over parts of the Serra do Itaberaba Group and probably over sections of the Embu and Itapira groups. Juliani et al. (2000) recognized metamorphosed pebbles of the lower Serra do Itaberaba Group in basal metaconglomerates of the São Roque Group. The metavolcanics of the Pirapora do Bom Jesus Formation are probably representative of subaqueous flows, as evidenced by the presence of pillow structures (Figueiredo et al. 1982). Chemically, these flows are sub-alkaline tholeitic basalts, with enriched E-MORB signatures, and appear to have been deposited in an oceanic environment, as evidenced by negative Ce anomalies (Oliveira et al. 1999). The depositional environment is consistent with a shallow sea or typical backarc setting, with sediments ranging from proximal deltaic facies to deeper water turbidites, accompanied by subaqueous volcanic activity (Bergmann 1988).

The Açungui Supergroup in the State of São Paulo is characterized by greenish schists facies supracrustal rocks discordantly overlying basement rocks. Campanha and Sadowski (1999) describes i) continental margin assemblages laterally represented by the Itaiaiaco Group to the northwest and Capiu Formation to the southeast; ii) a central domain with a carbonate platform in the western part and deeper turbidite facies, with associated mafic rocks (ocean floor and/or immature island arc) to the east (Itájede and Ribeira subgroups of the Votuverava Group) (Fig. 2). The Iporanga Formation (Ribeira Subgroup) represents both continental and oceanic margin associations that include mafic volcanic rocks whose geochemistry indicates a transition from a more oceanic island arc environment to MORB to the southeast. Campanha (1991) interpreted this association as representing advanced oceanic basin development, while Maniesi and Oliveira (1999) identify E-MORB character as belonging to a young or restricted ocean basin.

The Apiaí metagabbro is intrusive in the superior portion of the Açungui Group, Lajeado Subgroup (Campanha 1991). It was only slightly affected by Brasiliano metamorphism, hence preserves a geochemistry revealing an original magmatic liquid with a saturated tholeitic character, whose ETR patterns present a sub-horizontal alignment corresponding to oceanic basaltic with characteristics of enriched MORB (Maniesi et al. 1999).

GEOCRONOLOGY To constrain the timing of sedimentation and volcanism in the two groups presented above, U/Pb date determinations of zircons and monazites were done on their basal igneous units and on igneous intrusions that cut the upper levels of the sequences.

Both zircon and monazite fractions from the basal mafic metavolcanic (H351) of the Pirapora do Bom Jesus Formation of the São Roque Group (Fig. 2) were analyzed to determine the age of this unit. The best estimate of the crystallization age comes from a nearly concordant monazite age of 628 ± 9 Ma (Fig. 3a). Numerous single grain analyses of zircons in this rock demonstrate the presence of several inherited populations, ranging between 730 and 2000 Ma (Table 1), suggesting a complex basement structure, as well as the presence of some Neoproterozoic crust. High Samarium enrichment (relative to Nd) in sample H351 precludes obtaining any meaningful Sm-Nd data from it. Additional samples from this unit are required to assess whether or not this enrichment is pervasive throughout the body.

Mafic metavolcanic rocks (A13) of the Iporanga Formation (Fig. 2) contain two different zircon populations, the first with light pink prismatic grains, yielding nearly concordant data with the upper intercept of 614 ± 19 Ma (Fig. 3c), reflecting the age of crystallization of this rock. Other populations of metamorphic, broken, prismatic, milky grains define different components of isotopic inheritance between 1.8 and 2.2 Ga (Table 1). The positive epsilon (Hf, Nd) of 0.85 obtained from this rock unit indicates that was derived primarily from...
asthenospheric mantle rather than from the older surrounding Paleoproterozoic lithosphere. The presence of some older zircons, however, do show that older lithosphere was involved in the genesis of this body. Owing to an enriched \frac{^{147}\text{Sm}}{^{144}\text{Nd}} ratio (i.e. >0.150), the calculated T(DM) age of 2.03 Ga suggests that Archean lithosphere may exist in the region, but additional studies are required to evaluate this possibility. The Apiaí granite (A17) is intrusive in the Açungui Supergroup (Fig.2). One zircon and one monazite fraction (very close to concordia) yield an upper intercept age, the error on this upper intercept age should be ignored (Table 2).

The Apiaí metagabbro (A44) is intrusive in the Açungui Supergroup (Fig.2). A rhyolite dike (H352) near Araçariguama (Fig.2), that cuts the Açungui Supergroup (Fig.2) being considered related to the late-collisional magmatism.

An EpsilonNd(t=600) value of –0.89 from this sample also indicates that it was derived in large part from asthenospheric mantle, but the slightly negative EpsilonNd(0) value and the presence of older zircons attest to contributions from older lithosphere. This body also has an enriched \frac{^{147}\text{Sm}}{^{144}\text{Nd}} ratio (i.e. >0.150), thus calculated T(DM) age of 2.03 Ga is an overestimate of the mantle extraction age and should be ignored. Spidergram anomalies of Rb, Ba and Th also suggest that the origin this body is comparable to that of E-MORB (Maniesi et al. 1999). A rhyolite dike (H352) near Araçariguama (Fig.2), that cuts the upper Estrada dos Romeiros Formation, places constraints on the minimum age of deposition. Four zircon fractions from this rhyolite plot on a chord having an upper intercept age of 607 ± 28 Ma (Fig.3b), which we interpret to be the crystallization age. Because one of the fractions yields a concordant age, the error on this upper intercept age is highly overestimated. An \epsilon_{\text{Nd}}(t=600) value of –18.67 from this sample shows that it represents a melt of the older surrounding lithosphere. A T(DM) of 2.99 Ga suggests that Archean lithosphere may exist in the region, but additional studies are required to evaluate this possibility.

The Apiaí granite (A17) is intrusive in the Açungui Supergroup (Fig.2) being considered related to the late-collisional magmatism. Data from four zircon fractions define a collinear array with an upper intercept age of 605 ± 3 Ma (Fig 3e), which we interpret to be the age of crystallization of this rock. A T(DM) of 2.36 Ga from this unit indicates that it was probably derived from older Paleoproterozoic lithosphere.

The data above suggest that the rocks of the São Roque and Açungui groups represent identical and continuous paleogeographical environments in which a Paleoproterozoic (and possibly some Archean) crust suffered rifting with subsequent incipient ocean formation during the Neoproterozoic.

Table 1 - U-Pb results for the studied rocks.

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Size (mg)</th>
<th>U (ppm)</th>
<th>Pb (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H351</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M(1)</td>
<td>0.004</td>
<td>636</td>
<td>56</td>
</tr>
<tr>
<td>M(0.75)2</td>
<td>0.006</td>
<td>1287</td>
<td>1280</td>
</tr>
<tr>
<td>M(0.75)6</td>
<td>0.004</td>
<td>978</td>
<td>725</td>
</tr>
<tr>
<td>M(0.75)7</td>
<td>0.006</td>
<td>1066</td>
<td>1668</td>
</tr>
<tr>
<td>M(2)</td>
<td>0.005</td>
<td>418</td>
<td>41</td>
</tr>
<tr>
<td>M(0)3</td>
<td>0.004</td>
<td>409</td>
<td>35</td>
</tr>
<tr>
<td>M(0)15</td>
<td>0.005</td>
<td>772</td>
<td>57</td>
</tr>
<tr>
<td>M(1)16</td>
<td>0.022</td>
<td>474</td>
<td>92</td>
</tr>
</tbody>
</table>

Table 2 - Sm-Nd results for the studied rocks.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Nd ppm</th>
<th>Sm ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>H352</td>
<td>13.34</td>
<td>2.89</td>
</tr>
<tr>
<td>A13</td>
<td>11.52</td>
<td>3.36</td>
</tr>
<tr>
<td>A17</td>
<td>240.22</td>
<td>40.67</td>
</tr>
<tr>
<td>A44</td>
<td>5.69</td>
<td>1.63</td>
</tr>
</tbody>
</table>

1: M = magnetic, single digit numbers in parentheses indicate side tilt used on Frantz separator at 1,5 amp, (0.75) = 0.75 amps at 10 degree side tilt (indicates monazite).
2: Total U and Pb concentrations corrected for analytical blank.
3: Not corrected for blank or non-radiogenic Pb.
4: Radiogenic Pb corrected for blank and initial Pb: U corrected for blank.
5: Ages given in Ma using decay constants recommended by Steiger and Jäger (1977)
6: Values of inherited zircon grains and zircon grains with inheritance shown in italics
**DISCUSSION AND CONCLUSIONS**

Age constraints on the initiation and termination of magmatism and sedimentation in the Sáo Roque and Açungui groups suggest that formation of backarc complex in the central RB, between the states of São Paulo and Paraná, began between 628 and 614 Ma and continued until around 607 and 605 Ma. This indicates that these localized basins formed and evolved rapidly, i.e., ca. 10 to 20 m.y., during the syn- and late-collisional phases of the Brasiliano Orogeny.

Based on the available data, we propose the following paleogeographic reconstruction for this scenario: i) a beginning platformational deposition the Embu, Itapira and corresponding sequences (possibly around 700-750 Ma based on the presence of detrital zircons of this age in other regional supracrustal units); ii) westward subduction of oceanic crust beneath the RB; iii) syn-collisional phase through collision with the formation of a cordilleran magmatic arc around 620 Ma (Hackspacher et al., 1999), along with migmatization and calcium-alkaline plutonism, represented by the Piedade/Ibiúna body in the Embu Complex, the Cachoeira body in the Itapira Complex and other related granite in the Setuva Complex. Janasi (1999) defined a main phase of metamorphism at 625 Ma related to this collisional process. At present, it is unclear if this collisional phase in the RB involved any exotic terranes, but further studies should help to resolve this question. Structurally, this collisional process in São Paulo State involved a northwest main thrusting, and in the State of Paraná transport was to the southeast, which may reflect a backthrust. T/DM model age of mafic rocks is shown by the tholeitic subalkaline geochemistry. The Nd data indicate that these mafic bodies were derived largely from Neoproterozoic asthenospheric mantle, further reinforcing the rifting hypothesis; v) the late-collisional phase, around 600 Ma is characterized by lateral escape tectonics with the northeast/southwest shear zones and emplacement of granitic bodies (Hackspacher and Godoy, 1999). As magmatic representatives we have calc-alkaline to alkaline granites of the I-type, locally S-type in the São Paulo/Paraná, indicates a diacronism in the evolution of the belt.

The syn-collisional phase, in the central part of RB, has an older evolution, when compared with same phase of deformation in the State of Rio de Janeiro to the north. This fact, associated with the presence of an extensional phase (backarc) in São Paulo/Paraná, indicates a diacronism in the evolution of the belt.

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