



## Pluton emplacement in a releasing bend in a transpressive regime: the arrozal granite in the Paraíba do Sul shear belt, Rio de Janeiro

ALEXIS R. NUMMER<sup>1</sup>, RÔMULO MACHADO<sup>2</sup> and NOLAN M. DEHLER<sup>3</sup>

<sup>1</sup>Universidade Federal Rural do Rio de Janeiro, Itaguaí, Km 47, 23851-970 Seropédica, RJ, Brasil

<sup>2</sup>Universidade de São Paulo, Instituto de Geociências, Rua do Lago, 562, 05508-900 São Paulo, SP, Brasil

<sup>3</sup>RH/UP – Universidade Petrobrás, Av. General Canabarro, 500, Maracanã, 20031-912 Rio de Janeiro, RJ, Brasil

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### ABSTRACT

The Arrozal Granite, situated in the southwestern region of the State of Rio de Janeiro, has a granitic to granodioritic composition. It contains a strong mylonitic foliation along its border, passing gradually to a well-developed magmatic foliation towards its center. Structural analysis indicates that the Arrozal Granite was emplaced along the Além-Paraíba Shear Zone in a dextral transpressive tectonic regime. A regional shift of the trend along this shear zone from NE–SW to E–W, observed in the area, is interpreted to be casually related to the creation of space for the emplacement of the granite. Our data indicate that releasing bends may have played an important role for space generation during the emplacement of the Arrozal Granite and other plutons.

**Key words:** releasing-bend, transpression, Arrozal Granite, emplacement.

### INTRODUCTION

The importance of shear zones in the emplacement of granitoid plutons is well known, and for many syntectonic plutons have been related to transpressive deformation regimes (e.g. Hutton 1982, Hutton and Reavy 1992, McCaffrey 1992), pull-apart structures and space-generation flexures or releasing bends (e.g. Guineberteau et al. 1987, Hutton 1988a, b). In all these cases it is important to understand the internal fabric of the granitoids, as well as their relationship with the regional structure and the framework of the magmatic flow and solid-state deformation (e.g. Paterson et al. 1989 for review). In transpressive orogens, post-tectonic intrusions in the upper crust may be coeval with syn-tectonic plutons emplaced in the middle crust (D'Lemos et al. 1992).

The Além-Paraíba Shear Zone is one of the most important structures in the central part of the Paraíba do Sul Shear Belt. This tectonic structure has been classically regarded as a dextral shear zone developed in response to a transpressive regime which produced wide mylonitic zones (Ebert et al. 1991, 1993, Correa Neto et al. 1993, Machado and Endo 1993). Determination of stress directions from plagioclase fabrics has confirmed the kinematics of this deformation regime, suggesting that pure shear was more important than simple shear (Egydio-Silva and Mainprice 1999).

This paper focuses on the geometric and kinematic analysis of the Arrozal pluton and its host rocks. The pluton is one of the Neoproterozoic granites that crop out in the central part of the Paraíba do Sul Belt, in the southwestern region of the State of Rio de Janeiro.

Correspondence to: Rômulo Machado  
E-mail: rmachado@usp.br

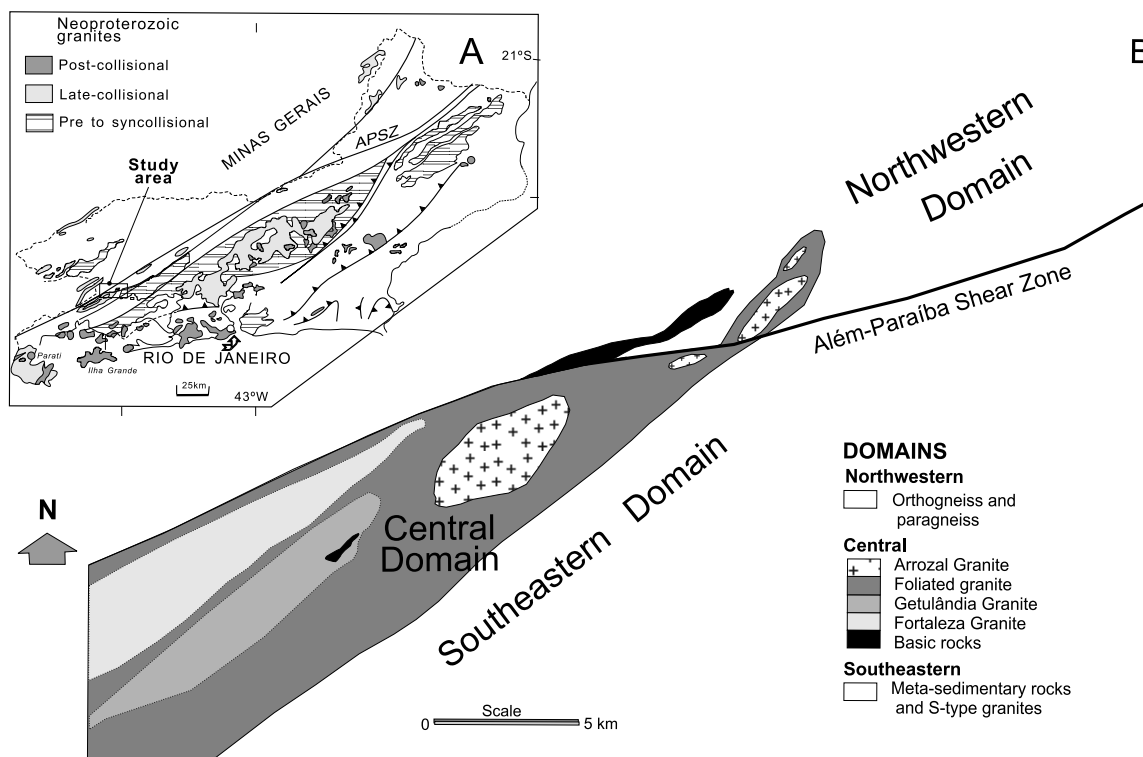


Fig. 1 – (A) Geological sketch map of the Neoproterozoic granites of the State of Rio de Janeiro (B) and Map of the Arrozal Granite.

### REGIONAL GEOLOGY

Regional syntheses concerning the Neoproterozoic granite plutons of the Paraíba do Sul Belt, also called Ribeira Belt, in Rio de Janeiro State were published by Machado and Peggia (1987), Machado and Demange (1994, 1998), Junho (1998), Heilbron et al. (2000, 2004). A considerable amount of work has focused on isolated plutons, mainly those in the vicinity of the cities of Rio de Janeiro, Petrópolis and Teresópolis, and concentrates on the petrography and geochemistry of these plutons. Only few accounts include detailed structural studies, geochronology and mineral chemistry.

Rb/Sr and U/Pb data for the pre-, syn- and post-collisional granitic magmatism of the belt indicate ages ranging from 634 Ma to 490 Ma (Figueiredo and Campos Neto 1993, Cordani et al. 1973, Machado et al. 1996b, Machado 1997, Heilbron et al. 2000, 2004), with the following sub-ranges: 590–570 Ma, 560–530 Ma and 520–450 Ma (Figueiredo and Campos Neto 1993, Wiedemann 1993). These data suggest three phases of magmatism.

Furthermore, R. Machado (unpublished data) suggested older ages for the main groups of granite plutons, respectively: 650–620 Ma (pre-collisional), 600–590/570 Ma (collisional) and 560–530 Ma (late collisional).

Two magmatic arcs involving calc-alkaline, medium to high potassium and metaluminous to slightly peraluminous magmatism have been proposed for this area, the Rio Paraíba do Sul Arc with an ages between 650 to 600 Ma (Machado and Demange 1998), and the Rio Doce Arc, with ages between 590 and 540 Ma (Figueiredo and Campos Neto 1993, Campos Neto and Figueiredo 1995, Wiedemann 1993).

### CHARACTERISTICS AND DISTRIBUTION OF THE GRANITOID PLUTONS

Neoproterozoic granitic magmatism of the Paraíba do Sul belt in Rio de Janeiro State has been divided into three main groups: (i) pre to syn-collisional; (ii) late collisional; and (iii) post-collisional (Machado et al. 2000, Heilbron et al. 2000, 2004) (Fig. 1A).

Pre- to syn-collisional batholiths are distinguished by their well-developed linear and foliated structures, which are aligned parallel to the regional trends. Granites with I-type and S-type affinities are the characteristic components of these batholiths. I-type granites have an expanded magmatic composition (granite/granodiorite and tonalite) and are comparable in volume to those of the S-type association. As suggested by Machado and Demange (1998), and Machado et al. (2000), the pre- to syn-collisional granites are comparable to I-type Cordilleran batholiths, based on petrological and geochemical studies. Towards the Atlantic coast, the I-type granites are associated with charnockite or rocks with similar mineral assemblages. S-type granites occur in the southernmost part of the area. They involve leucocratic rocks of granitic to granodioritic composition, containing mica-rich enclaves and muscovite, garnet, tourmaline and sillimanite.

The late-collisional granites are mainly distributed along the Além-Paraíba Shear Zone (APSZ, Figs. 1A, 1B). The Arrozal Granite (Fig. 1B) is an example of this group. These granites have an ellipsoidal shape and exhibit steep-dipping magmatic foliation sub-parallel to the mylonitic fabric of the shear zone. They are characterized by an inequigranular to porphyritic texture, a pink color, and their main composition is monzogranitic (Machado and Demange 1994). U/Pb ages on monazite yielded  $535 \pm 1$  Ma to  $528 \pm 1$  Ma for the Getulândia Granite (Machado et al. 1996a), supporting their correlation to the late-collisional granite group (see Fig. 1A).

The Arrozal Granite has petrographic and structural features similar to the Getulândia Granite. Charnockitic (0.5 to 3 m) and dioritic (0.3 to 0.5 km) enclaves are present in this granite. Their forms display evidence for heterogeneous magma mixing with granitic magma. The enclaves are round to ellipsoidal or irregular in shape and display transitional contacts with their host granite. Euhedral crystals of K-feldspar and plagioclase derived from the granite are found inside the charnockitic enclaves, indicating at least partial coexistence of the two magmas.

The post-collisional granites occur mainly in the southeastern part of the state (Fig. 1A). They are distributed along an E-W trend, suggesting that emplacement was not related with the regional structures of the

older granites. The emplacement of these granites occurred during an extensional regime. Available U/Pb and Rb/Sr isotope data on the Mangaratiba and Sana plutons indicate comparable ages of  $492 \pm 15$  Ma (U/Pb, on titanite) and  $488 \pm 3, 6$  Ma (Rb/Sr), respectively (Machado et al. 1996a, b).

#### ARROZAL GRANITE (AG)

The Arrozal Granite (AG) is an elongated body, with magmatic foliation in its central part and solid-state deformation at the border. The magmatic fabric includes alignment of K-feldspar and biotite. In general, textures are medium- to coarse-grained, inequigranular and porphyritic. Basic to intermediate enclaves occur locally. The composition of the AG is syeno- to monzogranitic and, subordinately, granodioritic. Biotite is the main mafic mineral, followed by hornblende. Muscovite, apatite, titanite, zircon, garnet and magnetite are the accessory minerals. Leucogranite, unrelated to the Arrozal pluton, with muscovite, tourmaline, garnet and sillimanite occur in the eastern (Passa Três region) and southern parts of this pluton.

#### RESULTS AND DISCUSSION

The area was divided into three structural domains: Northwestern (ND), Central (CD) and Southeastern (SD) (Fig. 2). An expressive high-angle ductile shear zone (Além-Paraíba Shear Zone – APSZ) appears at the contact between the northern and central domains (Fig. 2). There are also other important high-angle ductile shear zones that occur in the internal portion of the northern domain, which are sub-parallel to the SW-NE regional trend (Fig. 2). Both shear zones display dextral movement and are considered to be transpressive structures associated with the formation of mylonites (Ebert et al. 1991, 1993, Correa Neto et al. 1993, Machado and Endo 1993).

Paleoproterozoic orthogneiss is the predominant rock-type in the northern domain. Granitic rocks are the most important components of this domain, whereas the southern domain is mainly composed by metasediments, with orthogneiss and granite as minor components.

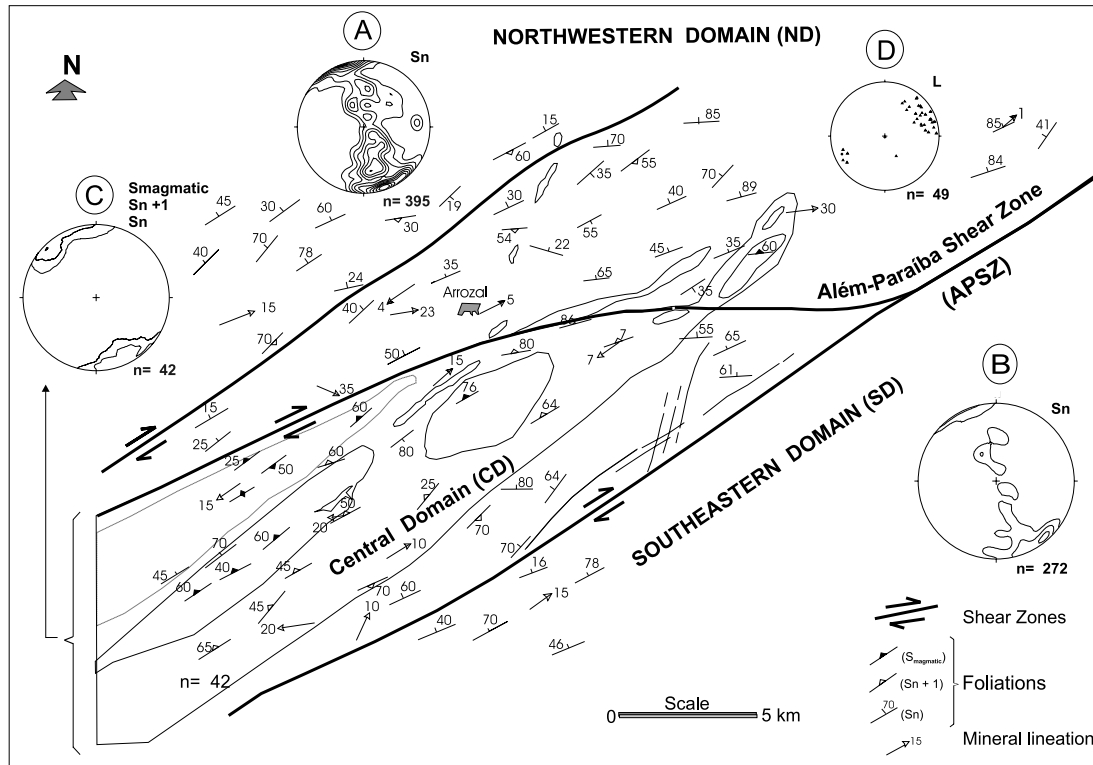


Fig. 2 – Structural map of the Arrozal Granite and its surroundings, southwestern region of the State of Rio de Janeiro, with stereographic plots (lower hemisphere projections) of three structural domains: (A) and (B)  $S_n$  foliation (gneissic banding), (C) magmatic foliation ( $S_{\text{magmatic}}$ ) and foliation in the solid-state ( $S_{n+1}$ ) and (D) Mineral stretching lineation.

#### NORTHWESTERN DOMAIN (ND)

Two foliations were observed in orthogneiss of this domain, referred to as  $S_n$  and  $S_{n+1}$ .

The  $S_n$  foliation corresponds in several places to a sub horizontal gneissic banding in the orthogneiss. Tight to isoclinal folds and rootless structures with thickened hinges and thinned limbs were observed along this banding. These features suggest transposition of older structures during the deformation related to the generation of the banding, characterized by discontinuous, alternating centimetric to decimetric bands of quartz-feldspar and biotite-amphibole, respectively.

In this domain, the  $S_n$  foliation generally strikes  $N75^\circ E$ , with sub-vertical to moderate dip towards NW. The  $S_n$  distribution in the stereogram appears to show the influence of a younger folding phase with an average axis plunging  $S70^\circ W/10^\circ$  (Fig. 2A). The  $S_n$  foliation

surfaces display an ENE-trending and contain a biotite lineation with gentle plunges to NE or SW (Fig. 2D).

The  $S_{n+1}$  foliation is generally discontinuous and poorly developed except near the shear zones where it is well developed, being mainly parallel to the  $S_n$  banding.

#### SOUTHEASTERN DOMAIN (SD)

Metasedimentary rocks and S-type granitoids are the main components of this domain. The average trend of the main tectonic foliation  $S_n$  is  $N69^\circ E$ , with moderate to sub-vertical dips to NW and SE (Fig. 2B). In this domain a well-developed stretching lineation plunging slightly to NNE occurs, defined by sillimanite, biotite and feldspar, and contained in the  $S_n$  foliation plane.

#### CENTRAL DOMAIN (CD)

The Arrozal Granite (AG) is included in this domain. Two foliations were observed in the CD: a magmatic one

and another interpreted to be generated by deformation in the solid-state. These two foliations are sub-parallel and sub-vertical with ENE–WSW trend, containing a maximum at N45°E/80°SE, as shown in Figure 2C.

The magmatic foliation is observed in the northern part of the central domain, where the pluton apparently escaped solid-state deformation superimposed by APSZ. According to the features shown on the structural map and corresponding diagrams (Fig. 2) the general NE trend is deflected to ENE near the Além-Paraíba Shear Zone.

The mineral stretching lineations plunge gently to ENE, or to WSW (Fig. 2D). The geometric relation between the foliation orientation and the stretching lineation in the ND (see Figs. 2A and 2D) is compatible with a predominance of transcurrent movements. The same type of movement is also inferred for the CD and SD, based on the relation between these two structures.

A geometric analysis of the three structural domains indicates a very similar framework from the ND to the SD (Figs. 2A and 2B). However, only the first domain shows a continuous girdle in the stereoplot, suggesting the existence of regional folds with NE–SW axial surfaces and axes plunging gently to SW, as confirmed by field observations. The CD shows a slightly different structural trend, in which the foliation displays a clockwise change in direction of about 30° in the northern part of the domain (Fig. 2).

The geological framework and the tectonic model for the emplacement of the Arrozal Pluton are shown in Figure 3.

Figure 3A shows the regional pattern of the Além-Paraíba Shear Zone. Figure 3B sketches the relationship between the main orientation of magmatic foliation in the Arrozal pluton and the orientation of the local trend of the Além-Paraíba Shear Zone. Figure 3C shows a NW–SE cross-section across the CD (for location, see Fig. 2). The steep dips of the Arrozal pluton and shear zones are supported by gravimetric data available for the region (A.R. Nummer, unpublished data). The horizontal trace of the high-angle dextral Além-Paraíba Shear Zone displays significant changes in its regional trend, varying from N45°E to N70°E in its southern segment (Fig. 1B). The dispersion of stretching lineations (Fig. 2D) in the stereogram is compatible with

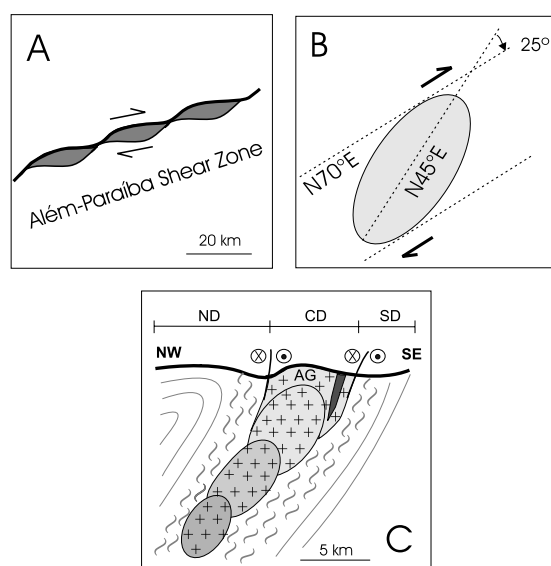


Fig. 3 – Simplified sketch of the Além-Paraíba Shear Zone (APSZ): A) Model of displacement along the APSZ and creation of transtensional spaces; B) Geometric relation between the APSZ and probable orientation of magmatic foliation during the emplacement of the Arrozal Granite; C) Schematic NW–SE geological section cross-cutting the Arrozal Granite.

this change of foliation trend. We argue that a releasing bend associated with the curved trace of this shear zone created transtensional domains, providing space for the emplacement of granitic magmas (Figs. 3A and 3C), as reported in several cases of syntectonic plutons associated with transpressional regime shear zones (e.g. Hutton 1982, 1988b, Guineberteau et al. 1987, Hutton and Reavy 1992). The dextral displacement observed in the northern part of the APSZ was possibly synchronous with the emplacement of granitic magma (Fig. 2, Central Domain).

The Arrozal Granite displays a magmatic foliation preserved in parts of low strain, and a weak solid-state subsequent deformation, mostly in the central part of the pluton (Central Domain: Fig. 2). On the other hand, protomylonite and mylonite, which were developed by the dextral displacement of the Além-Paraíba Shear Zone, are found along the intrusion margins.

#### FINAL REMARKS

The structural data presented and discussed in this paper are compatible with the development of a releasing

bend in the southwestern segment of the Além-Paraíba Shear Zone. If correct, this model implies that the emplacement of the Arrozal Granite is related to the dextral movement of the Além-Paraíba Shear Zone. U/Pb ages in monazite of  $535 \pm 1$  Ma and  $528 \pm 1$  Ma (Machado et al. 1996a) were obtained for the Getulândia Granite, which is considered to be contemporaneous to the Arrozal Granite (Arrozal Suite of A.R. Nummer, unpublished data). This age is related to the cooling of the syntectonic granite, and it appears to be also the age of emplacement of the Arrozal Granite, which is related to the tectonic phase Dn+1.

The development of a mylonitic foliation at a small angle with the trend of the magmatic foliation of the Arrozal Granite is compatible with the development of a magmatic fabric within a transtensional environment at a local scale. Crystallization possibly occurred coeval with the deformation related to the dextral displacement of the Além-Paraíba Shear Zone (regional scale). In addition, the granitic rocks exhibit an increasing deformation towards this structure, suggesting that solid-state deformation occurred after the magmatic crystallization fabrics. Therefore, we argue for a model of releasing bends in a transpressive regime associated with the sinuous trace of this steep-dipping dextral shear zone. Such kinematic conditions may have developed space favorable for the ascension and emplacement of granitic magmas.

The gravimetric modeling (A.R. Nummer, unpublished data) of the Arrozal Granite shows that the emplacement of granitic magma occurred along steeply NW dipping shear zones (see Fig. 3C) and that the attitude of the foliation of the Northwestern Domain changes from horizontal to subvertical near the boundary of the shear zone.

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#### RESUMO

O Granito Arrozal ocorre na porção sudoeste do Estado do Rio de Janeiro e associa-se à Zona de Cisalhamento de Além-Paraíba. Possui composição granítica a granodiorítica e exibe predomínio de estruturas magmáticas na parte central, e estruturas de alto *strain* (miloníticas) nas bordas. Os dados estruturais sugerem colocação em segmentos extensionais (*releasing bends*) associados a uma tectônica transcorrente dextral, sob regime transpressivo. A forte mudança do *trend* estrutural desta zona de cisalhamento na região, passando de NE-SW para próximo de E-W, criou condições para geração de espaços que favoreceram a colocação do Granito Arrozal, além de outros granitos associados à referida zona.

**Palavras-chave:** “zonas de alívio”, transpressão, Granito Arrozal, colocação.

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