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Precambrian granitic magmatism in Brazil

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This article provides an overview on Precambrian granitic rocks of Brazil, highlighting their most outstanding aspects. In the Amazon craton, five groups of Archean granitoids (2.96 to 2.55 Ga) were identified in the Carajás region. Proterozoic A-type and within-plate rapakivi granites are grouped into several age intervals (1.88–0.98 Ga). They are meta- to peraluminous with subordinate peralkalic terms and are tin-mineralized with associated Y, REE, Th, F (cryolite), Zr and Nb. Nine groups of Neoproterozoic granitoids and syenitoids are recognized in the Borborema province, northeastern Brazil, on the basis of mineralogical, geochemical and isotopic features. These characteristics indicate both lateral and vertical differences among the three major domains in this province, which are separated from each other by continental-scale shear zones. Study of calc-alkalic to high-K calc-alkalic magmatic epidote-bearing granitoids, common in this area, yields a preliminary estimate of the speed of magma upward transport and emplacement. The 0.58 Ga-old syenites in the syenitoid line in the Borborema province constitute one of the few Neoproterozoic ultrapotassic plutonic provinces in the world. Granitoids in the Araçuai/Coastal foldbelt in eastern Brazil, are deeply exposed together with the roots of a Neoproterozoic mobile belt and recorded several of the evolutionary history of this belt. In central Brazil, the A-type granites of the Goiás tin province, the Neoproterozoic arc granitoids of Mara Rosa and Arenópolis, the Neoproterozoic peraluminous granites of southern Goiás and the late to post-orogenic bimodal magmatism are a proxy for the tectonic evolution of the Brasilia foldbelt. Most Neoproterozoic granitic magmatism in southern Brazil is possibly related to mantle source of the EM1 type.

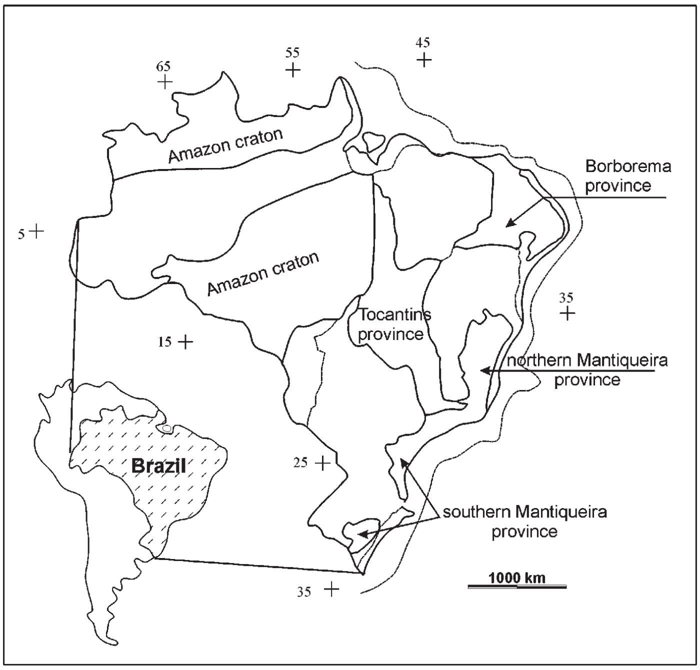

***Figure 1** Map of Brazil, showing the structural provinces discussed in this synthesis (Amazon craton; Borborema, northern Mantiqueira, Tocantins and southern Mantiqueira provinces). Modified from Almeida et al., 1981.*

Introduction

The study of granitoids in Brazil has been a subject of growing interest. Even so, our current knowledge of these rocks in this country is still very heterogeneous for several reasons. The enormous area of the Brazilian territory associated to the lack of mapping of some areas at an adequate scale has limited the granite studies to specific areas of immediate interest. However, a substantial improvement of the knowledge of Precambrian granites in Brazil is portrayed by the increasing amount of published material dealing with multiple aspects of granitoids during the past 15 years.

The most interesting features of the Brazilian granitoids will be examined in this synthesis according to the geographic distribution of these plutons in tectonic provinces from northern to southern Brazil (Figure 1). Important sources of information on the granitology of this country are the Extended Abstract volumes of two International Symposia on Granites and Associated Mineralizations (ISGAM) held at Salvador, Bahia, Brazil, in 1987 and 1997; recent special issues of the Journal of South American Earth Sciences (vol. 11, 1998), Anais da Academia Brasileira de Ciências (vol. 71, 1999), Lithos (1999, vol. 46) and Revista Brasileira de Geociências (vol 29, n.1, 1999, in press), the Workshop MAGMA and the Rapakivi Symposium (Anais da Academia Brasileira de Ciências, respectively in 1993, vol. 65 and 1997, vol. 69).

The Amazon craton, northern Brazil

The Amazon craton can be divided into large tectonic blocks shown in Figure 2 with approximate limits of the geochronologic provinces defined by Teixeira et al. (1989) and modified by Sato and Tassinari (1997). Granitoids intruding these blocks can be grouped into: (1) Archean granitoids of the eastern block, (2) Paleoproterozoic calc-alkalic granitoids of the central block; (3) Paleoproterozoic to Early Neoproterozoic A-type granites (rapakivi series) distributed throughout the craton, and particularly more abundant in the eastern, central and southwestern blocks; (4) Mesoproterozoic granitoid group, restricted to the Rio Negro region, in the northwestern block.

The knowledge of the Archean granitoids of the eastern block (Carajás metallogenic province), has been much improved recently. Five granitoid groups, formed in the 3.0 to 2.5 Ga interval, are distinguished according to their geochemical and petrological features (Dall'Agnol et al., 1997 and references therein): (1) TTG-type tonalitic-trondhjemitic series (2.96–2.87 Ga); (2) the Rio Maria granodiorite and similar plutons (2.87 Ga) that display affinities with Mg-rich granitoids; (3) calc-alkalic potassic leucogranites (>2.85 Ga); (4) leucogranites of the Plaquê Suite (ca. 2.73 Ga); (5) subalkalic, foliated, A-type granites (~ 2.55 Ga). The oldest granitoids occur in the Rio Maria granite-greenstone terrain, emplaced in a relatively short time interval (~100 m.y.). The occurrence of Archean A-type granitoids in the Serra dos Carajás region, whose emplacement was related to ballooning, followed by flattening and mylonitization, was reported by Barros et al. (1997). The relationship between gold-sulfide mineralization and this subalkalic magmatism is being investigated.

Paleoproterozoic calc-alkalic granitoids (1.98–1.88 Ga) are abundant in the central block of this craton, together with volcanic sequences. In this block, they are present in the Pitinga, Mapuera, Tapajós and Xingu regions. The existence of a 1.95–1.80 Ga magmatic arc (Ventuari-Tapajós Province) in the western part of this block was proposed by Sato and Tassinari (1997). This type of rocks also occurs in the Juruena region, southwestern block (Figure 2).

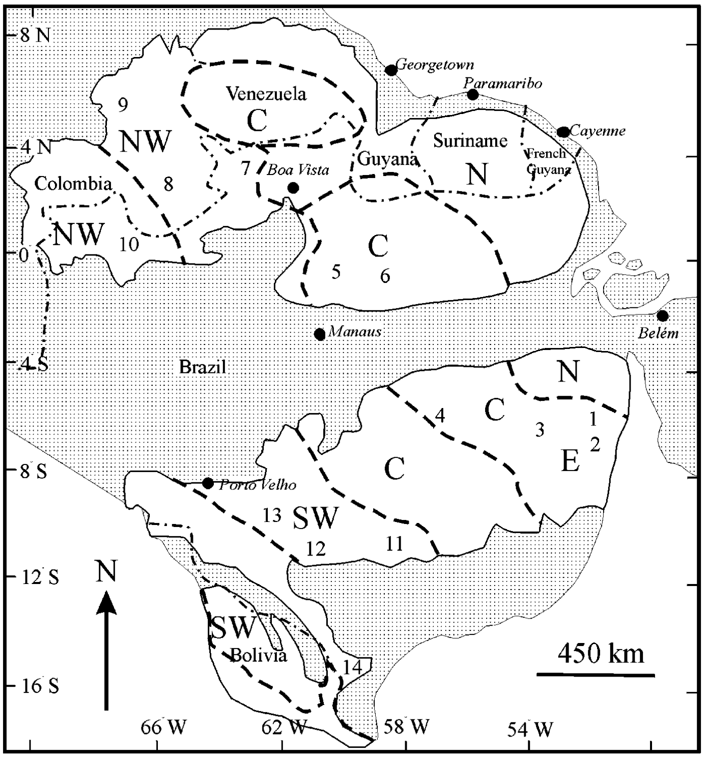

***Figure 2** Simplified tectonic blocks of the Amazon craton (Dall'Agnol et al., 1999a), showing the limits of the geochronological provinces proposed by Teixeira et al. (1989, modified). Tectonic blocks: E = eastern, N = northern, C = central, NW = northwestern, SW = southwestern. Regions mentioned in the text: 1 – Serra dos Carajás, 2 – Rio Maria, 3 – Xingu, 4 – Tapajós, 5 – Pitinga, 6 – Mapuera, 7 – Roraima, 8 – Amazonas territory of Venezuela, 9 – Parguaza, 10 – Rio Negro, 11 – Juruena, 12 – Serra da Providência, 13 – Rondônia, 14 – Santa Helena magmatic arc. The heavy dashed lines correspond to the limits between the geochronological provinces.*

The relationship between some of these calc-alkalic granitoids (Paruari, Agua Branca and similar suites) and Uatumã Supergroup volcanic sequence, which is supposed to be an A-type suite, has been a subject of debate. Geochemical similarities and geochronological data provide evidence that, at least in part, these two magmatic events were coeval (Dall'Agnol et al., 1999a, and references therein). In northern Roraima state, Fraga et al. (1997) studied the calc-alkalic 2.05 Ga-old Pedra Pintada granitoids and interpreted them as a product of a post-collisional magmatism related to the Transamazonian orogenic cycle, and a similar tectonic setting was assumed for the Uatumã volcanic rocks by Sidder and Mendoza (1991). In the Tapajós region, gold mineralization is associated to the Parauari granitoids and to the Uatumã volcanic rocks.

Anorogenic A-type granitoids essentially encompass felsic complexes, with ages ranging from Late Paleoproterozoic to Early Neoproterozoic (Dall'Agnol et al., 1999a; Bettencourt et al., 1999). Most of them belong to the rapakivi-series granites, as redefined by Haapala and Rämö (1992). The oldest A-type granites (1.88 Ga) are found in the eastern block (Dall'Agnol et al., op cit.) and in the Tapajós region in the central block (1.88 Ga, Lamarão et al., 1999). Tin-bearing A-type granites (~1.83 Ga) are found in the Pitinga region, central block, while younger (~1.54 Ga) plutons (Parguaza, Surucucu and Mucajaí) are found in the northwestern block. The Mucajaí suite is a typical AMCG suite (Emslie, 1991), encompassing charnockitic and anorthositic complexes. In the southwestern block, the A-type granitoids yielded ages between 1.60 and 1.0 Ga (Bettencourt et al., 1999). Mangerite and charnockite complexes are associated to rapakivi granites in Rondônia, but massif anorthosites are absent. The origin of the anorthositic, charnockitic and coeval mafic magmatisms has involved likely the anatexis of different crustal rocks caused by basic magma underplating. This hypothesis is supported by geochemical and Nd isotopic data, as well as by experimental petrology studies performed on some granitoids of the eastern block (Dall'Agnol et al., 1999b).

The Proterozoic A-type granites of the Amazon craton can be correlated in age to their counterparts of Laurentia-Baltica cratons. However, tin mineralizations, locally with associated Y, REE, Th, F (cryolite), Zr and Nb, are more extensive in the Amazon craton, as revealed by the Rondônia and Pitinga deposits.

The Mesoproterozoic granitoid group is restricted to the Rio Negro region, in the northwestern block. In spite of the controversy on the interpretation of the tectonic evolution of that region, several authors agree that it was intensely affected by an 1.80–1.50 Ga event. Granitoids in this region are poorly known, but the occurrence of 1.50 Ga A-type granitoids, as well as ~1.40–1.20 Ga two-mica granitoids with strongly peraluminous metamorphic rock enclaves, has been recorded. Tonalites to granites of the NW-trending Santa Helena magmatic arc are described in the southwestern block (Geraldes et al., 1998). U-Pb and Nd isotopic data indicate an age of 1.45 Ga to this arc and that, at least in part, it represents a juvenile crust.

The Borborema Province, northeastern Brazil

The Borborema structural province, northeastern Brazil, encompasses an area of 380,000 km^2 and is composed of a complex network of Proterozoic supracrustal belts surrounding Archean to Paleoproterozoic blocks or inliers. Two large E-W trending megastructures, the Patos and Pernambuco shear zones, subdivide the Borborema Province into three domains: Northern, Transverse Zone and Southern (Figure 3). These domains evolved through reworking and amalgamation, during the late Neoproterozoic (0.70–0.50 Ga), of several tectonostratigraphic terranes and major crustal blocks, previously deformed during Meso- and Paleoproterozoic orogenic cycles (Santos, 1996). Petrological and geochemical characteristics of undeformed Neoproterozoic granitoids and syenitoids in these domains allow their classification into nine groups (Ferreira et al.,

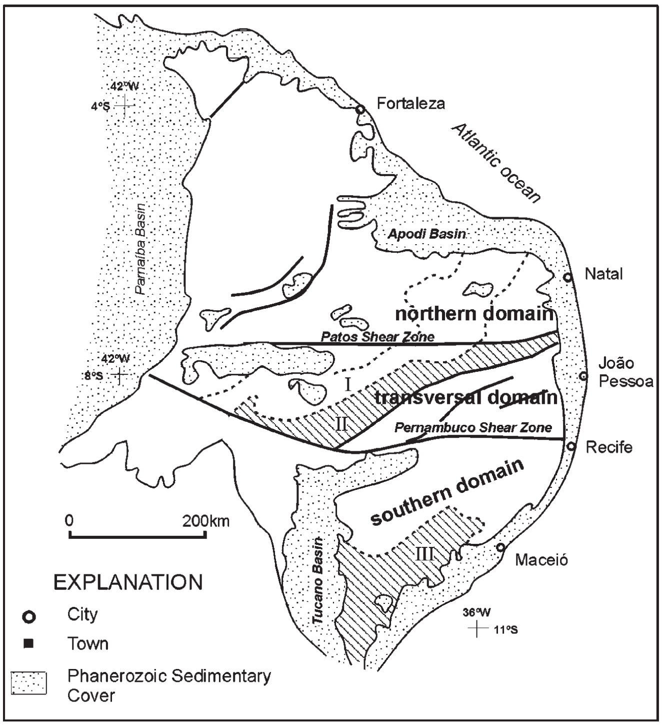

Figure 3 Simplified geological map of the Borborema province, indicating the location of the Cachoeirinha-Salgueiro (I), Alto Pajeú (II), and Macururè (III) terranes, cited in the text.

1998 and references therein). All groups are enriched in K and Ba and have low Nb (usually < 20 ppm), which seems to be a peculiar feature of the lithosphere in this province. The characteristics of these groups point to important contrasts among the three major tectonic domains.

Calc-alkalic magmatic epidote (mEp)-bearing granitoids in the Northern Domain (ND) display ε_{Nd} (0.6 Ga) from –15 to –20, T_{DM} model age > 2.0 Ga (Ketcham et al., 1995), low $\delta^{18}O$ (+6 to +8‰$_{SMOW}$), and magnetic susceptibility (MS) > 1.0 × 10^{-3} SI. Within the Transverse Zone Domain (TZD), in contrast, calc-alkalic and high-K calc-alkalic mEp-bearing granitoids display high $\delta^{18}O$ (+10 to +13‰$_{SMOW}$), lower MS (0.4 × 10^{-3} SI), lower ε_{Nd} (–1 to – 4), and younger T_{DM} (1.1 to 1.4 Ga) (Sial et al., 1999 and references therein). In high-K calc-alkalic mEp-free granitoids, ε_{Nd} cluster ~ –9 (e.g., Itaporanga pluton, Van Schmus et al., 1995) and ~ 14 (e.g., Campina Grande pluton, Almeida et al., 1997).

Unique peralkalic ultrapotassic syenite plutons (0.58 Ga) are found aligned for several km along the boundary between the Cachoeirinha-Salgueiro and the Alto Pajeú terranes. This alignment has been called the *syenitoid line* (Ferreira and Sial, 1986). Intrusions along this line show negative ε_{Nd} (–15 to –19), T_{DM} from 2.1 to 2.4 Ga, and MS from 0.7 to 1.0 × 10^{-3} SI, being regarded as derived from a metasomatized lithospheric mantle source (Ferreira et al., 1998 and references therein). Petrological, geochemical and isotopic data suggest that a large-scale liquid immiscibility process was the mechanism responsible for the generation of the ultrapotassic syenite-alkalic mica pyroxenite association observed in these plutons (Ferreira et al., 1994).

Al-in-hornblende barometry in several of the mEp-bearing granitoids (calc-alkalic plutons that intruded phyllites and high-K calc-alkalic plutons that intruded high-grade terrains) in the TZD indicates that, in most cases, amphibole crystallized at P ~ 5–7 kbar (Sial et al., 1999). Kyanite-garnet-staurolite bearing thermal aureoles (Caby and Sial, 1997) surrounding granitoids that intruded phyllites support pluton emplacement at intermediate to high P. An estimate of corrosion of individual epidote crystals included in plagioclase in some of these granitoids yielded estimates of magma transport rate from 70 to 350 m.year^{-1} (Sial et al., 1999).

Granitoids in the Southern Domain (SD) are isotopically more complex. Three T_{DM} Nd-model age intervals (1.0–1.5, 1.8–2.2 and 2.4–2.5 Ga) are found in the Pernambuco-Alagoas terrane (Silva Filho et al., 1997), the largest one within this domain. MS values are rather low, approaching zero in leucocratic granitoids, and up to 15 × 10^{-3} SI in high-K metaluminous syenitoids. Calc-alkalic mEp-bearing plutons in the Macururé terrane are similar to those in the TZD in all aspects and distinguish this terrane from the neighbouring ones in this Domain.

Altogether, the geochemical and isotopic characteristics of the different granitoid types suggest that (Ferreira et al., 1998): (1) the ND is rather homogeneous, at least vertically, in spite of lateral differences in terms of composition of source rocks and magmatic processes that produced the granitoids; (2) the TZD has lateral and vertical heterogeneities, except for the Cachoeirinha-Salgueiro terrane, which is very homogeneneous; (3) the SD is even more heterogeneous than the TZD. It had a long and complex accretionary history, as suggested by the presence of a large number of *in situ* leucocratic melts associated with large areas of migmatization, both at the northern and southern boundaries of the Pernambuco-Alagoas terrane, coupled with a large volume of high-K calc-alkalic granitoids emplaced in several pulses.

The Araçuaí/coastal foldbelts, northern Mantiqueira Province, eastern Brazil

The Araçuaí, eastern border of the São Francisco craton, is a monoclinic Neoproterozoic foldbelt, whose major features developed during a collisional event (the Araçuaí orogen) between the São Francisco and the West Congo cratons (Figure 4). Its Atlantic margins are also known as Coastal or Ribeira foldbelt. During this orogen, two peaks of magmatism are recognized: a pre- to syn-collisional (~ 0.60 Ga) and a tardi- to post-collisional (0.56–0.48 Ga). The oldest magmatic event was followed by a regional metamorphic event between 0.59 and 0.58 Ga. The late- to post-collisional magmatism was preceeded by a charnoendebertization event (~ 0.56 Ga).

Most of the magmatic sequences of this orogen crop out along the internal tectonic domain or anatectic core of the Araçuaí foldbelt, which is subdivided into two distinct blocks (Pedrosa Soares and Noce, 1998). The northern block runs NNE-NE from the Doce river in the south, up to the 16˚S latitude. In this block, high-amphibolite facies metamorphism ranges from the garnet to the sillimanite zone and is intimately associated with granitic anatexis. Large extensions of pre- to post-collisional S-type granitoids predominate. In comparison to the southern block, this one corresponds to a shallower crustal depth.

The southern block corresponds to a NNE-trending ductile belt, which is limited to the north by the Doce River. Granulites to high-amphibolite facies gneisses evidence exposure of deep crustal levels. P-T conditions (T ~ 700˚C and P ~ 8–10 kbar) obtained by thermobarometric studies (Costa et al., 1993; Seidensticker and Wiedemann, 1992) confirm that this region segment discloses the deepest part of the Araçuaí orogen.

Basin closure and collisional stages, in the whole belt, started after 0.65 Ga (Noce et al., 1999). Two magmatic suites are characteristic for this pre- to syn-collisional stage: the first one (G_1) consists of peraluminous S-type granitoids (0.59 Ga-Sr_0 ~ 0.708; Litwinski, 1985; Siga Jr., 1986; ε_{Nd} values ~ –8). The second one (G_2) is predominantely metaluminous and includes I-type granitoids (tonalite, granodiorite and granite, also called Galiléia suite (Bilal et al., 1998; Pedrosa Soares et al., 1998) crystallized at 0.59–0.58 Ga (Nalini et al., 1997, Söllner et al., 1991). This suite is geochemically similar to volcanic arc granitoids with important mantle components, formed in a subduction zone (Geiger, 1993; Campos Neto and Figueiredo, 1995), under a high H_2O pressure. Part of the syn-colli-

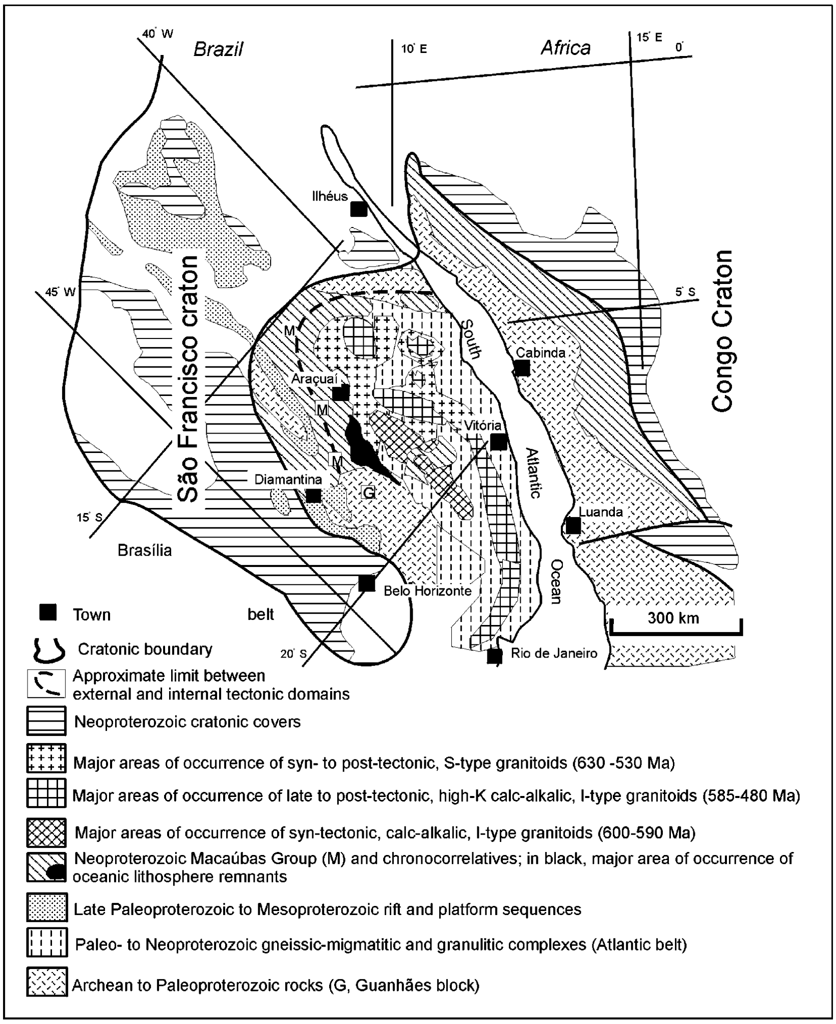

Figure 4 Geologic sketch map of the Araçuai-West Congo Orogen and its granitoids, northern Mantiqueira province (Modified after Pedrosa Soares et al., 1998).

sional metaluminous G_2 suite crystallized under catazonal dry conditons and high CO_2-pressures (Fritzer, 1991; Wiedemann et al., 1997; Mendes et al., 1997), bearing magmatic charnockitoids.

With the relaxation of the crustal shortening event, three additional late- to post-collisional granite suites were generated. The first one (G_3) corresponds to the remelting of peraluminous G_1 and yielded a series of small coalescent or isolated intrusions, which may grade into diatexites (Pedrosa Soares et al., 1998). U-Pb ages of 0.59 Ga (zircons from sillimanite-garnet-biotite migmatite) are certainly inherited and date the generation of the source G_3 granitoids (Siga Jr., 1986).

The second late- to post-collisional magmatic event (G_4) is characterized by several inversely zoned diapirs, compositionally grading from tholeiite, calc-alkalic to alkalic, intruding regional metamorphic sequences. In the region of Espírito Santo state, the erosional level reveals the roots of these diapirs, whose inverse zoning is, in many cases, formed by interfingering of basic to intermediate magmas in the core and sienomonzonitic to granitic borders, showing widespread magma mingling structures. The igneous foliation is, generally, well developed and parallel to the foliation of the host rocks. Geochemical data from the Jequitinhonha as well as from the Espírito Santo state indicate the predominance of high-K, calc-alkalic metaluminous I-type granitoids, originated in the lowermost continental crust with an important mantle component (Fernandes, 1991; Wiedemann, 1993; Faria, 1997; Celino, 1999). Rb-Sr data indicate magmatic crystallization between ~0.57 Ga (Sr_0 = 0.7064; Santo Antônio do Jacinto batholith) and 0.48 Ga (0.52 Ga, Padre Paraíso charnockite; Siga Jr., 1986; 0.51 Ga, Santa Angélica; 0.48 Ga, Söllner et al., 1991). Along the whole foldbelt, the G_4-related intrusions become progressively younger from northern Minas Gerais state towards southern Espírito Santo state.

In the Jequitinhonha region, this suite also includes granitic batholiths with charnockitic (e.g., Padre Paraíso charnockite and Caladão Granite) or enderbitic (e.g., Mangalô enderbite) cores or borders (Pinto et al., 1998, Carvalho and Pereira, 1997). Allanite, titanite, apatite, zircon and magnetite are common accessory minerals in this suite, while garnet is scarce to absent. Hypersthene and dark green perthitic K-feldspar phenocrysts characterize the charnockitic portions. Both porphyritic granitoids and charnockites display similar textures and structures. Green charnockite often grades into light-colored granitic facies.

In the Coastal complex (the easternmost rock sequence of the Araçuaí/Coastal fold-belt), there is clear field geochemical and geochronologic evidence of a charnoenderbitization process around 0.56 Ga (Sluitner and Weber-Diefenbach, 1989; Wiedemann et al., 1997; Söllner et al., 1991). A package of S-type orthogneisses (G_2) is locally metamorphosed to low-pressure granulites, via CO_2-rich fluid fronts.

The remelting of metasediments associated with intensive metasomatism produced a third post-collisional suite (G_5 around 0.52 Ga; Sr_0 = 0.711; Siga Jr., 1986) , which is partially coeval with the late stage of G_4. This suite crops out along the western limit of the belt (in the Salinas Formation), closer to the San Francisco craton. It is the source of a myriad of lithium- and/or tourmaline-rich pegmatites. In comparison to the other studied suites, the G_5 suite originated from shallower crustal levels.

Proterozoic granitic magmatism in the Brasília foldbelt, Central Brazil

The Brasília foldbelt, Tocantins province, central Brazil, represents a large and well preserved Proterozoic orogenic belt developed between three main continental blocks: the Amazon, São Francisco-Congo and Paraná cratons (Figure 5). During the last decade, detailed field and geochronological studies of key areas of the Brasília Belt have demonstrated the importance of the granitic magmatism in the evolution of this orogen. The discovery of Neoproterozoic juvenile arc rocks in the westernmost part of the belt and of collisional-type, peraluminous granites associated with metasedimentary units have challenged previous ensialic evolution models. The main field, geochemical and geochronological characteristics of four granite associations recognized within the Brasília foldbelt are briefly reviewed below:

(i) *A-type granites of the Goiás Tin Province, northern part of the belt.* These are 1.77–1.58 Ga old rift-related shallow level granite intrusions and associated bimodal volcanics of the Araí Group (Pimentel et al., 1991, 1999). These are alkali-rich rocks with high F, Sn, Rb, Th, Y, Nb, Ga and REE contents and form two groups of intrusions: G_1 granites are older (ca. 1.77 Ga), more potassic, with very clear alkalic characteristics; G_2 granites are younger (1.6–1.58 Ga), and have lower K/Na ratios and higher Li, Rb, Sn and Ta. Sn and In mineralization are always associated with the G_2 family. For both groups, Nd T_{DM} model ages are between 2.0–2.6 Ga, suggesting remelting of the Paleoproterozoic crust. These rocks are thought to represent an aborted Mesoproterozoic rift system.

(ii) *Neoproterozoic Arc Granitoids of Mara Rosa and Arenópolis.* Most of the arc magmatism is represented by metaplutonic rocks ranging in composition from tonalitic to granodioritic. They are exposed between narrow NNW to NNE belts of arc-type volcano/ sedimentary sequences (Pimentel and Fuck 1992, Pimentel et al., 1997). The oldest representatives of this arc system are ca. 0.90–0.85 Ga-old tonalitic-dioritic orthogneisses with very primitive isotopic and geochemical characteristics ($Sr_0 \leq 0.704$, positive ε_{Nd} (T) values, and T_{DM} model ages of ca. 1.0 Ga). They are interpreted as being formed in intraoceanic island arc systems. Younger (*ca.* 0.76 to 0.63 Ga) arc metavolcanics and granitoids are also identified and display more evolved geochemical and isotopic nature, being interpreted as formed in a continental arc setting;

(iii) *Neoproterozoic peraluminous granites of southern Goiás.* Recent detailed mapping projects have identified a large number of syn- to late-tectonic granite intrusions associated with the metasediments of the Araxá and Ibiá Groups in the southern part of the Brasília Belt. These granitoids vary in composition from granodioritic to granitic, with slight to strong peraluminous character. U-Pb zircon ages and Rb-Sr whole-rock isochrons indicate crystallization ages between ca 0.79 and 0.70 Ga (Pimentel et al., 1999). In contrast with the arc granitoids in the west, Sr_0 are higher than 0.705 and T_{DM} model ages are mostly in the range between ca. 1.7 and 2.4 Ga.

(iv) *Late- to Post-Orogenic bimodal magmatism*. The last tectono-metamorphic event(s) in the Brasília Belt happened between ca. 0.63 and 0.59 Ga. During the final stages or immediately after this last deformation, a number of small mafic-ultramafic layered complexes, gabbro-dioritic intrusions and coeval large K-rich granite plutons were emplaced into the western part of the belt. Rb-Sr whole-rock isochrons show intrusion ages between ca. 0.60 and 0.48 Ga, with Sr_0 between 0.703 and 0.710. T_{DM} model ages vary between ca. 0.9 and 1.2 Ga (Pimentel et al., 1996). Isotopic compositions indicate that these granites are the product of remelting of the Neoproterozoic juvenile crust due to the emplacement of late- to post-orogenic mafic magmas during uplift and extension.

The rock units above suggest that during most of the Neoproterozoic, the present western margin of the São Francisco continent faced a large oceanic basin, where consumption of oceanic lithosphere started at ca. 0.9 Ga. The arc magmatism is represented by the rock units in the Arenópolis and Mara Rosa areas. Final ocean closure happened at ca. 0.6 Ga being followed by uplift, extension and emplacement of a bimodal post-orogenic suite.

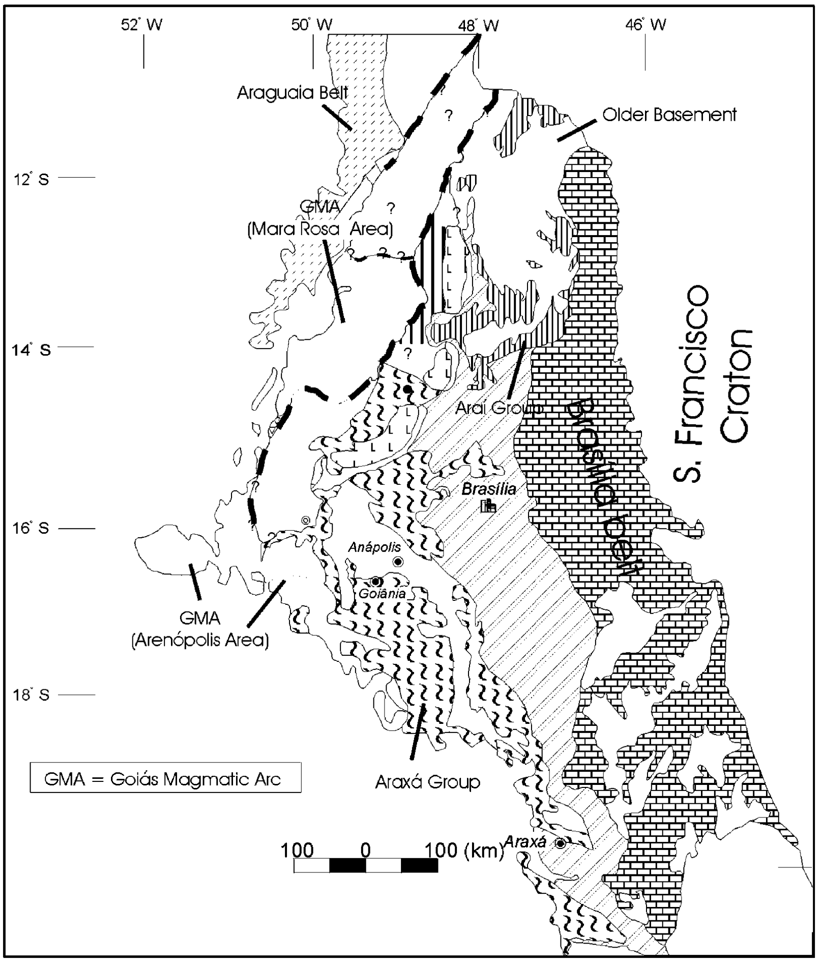

Figure 5 Geologic sketch map of the Brasilia foldbelt, central Brazil.

Granitic magmatism in southern Mantiqueira Province

Most of the currently exposed crust in southern Brazil is composed of granite associations formed during the Neoproterozoic (Basei et al., 1995, Janasi and Ulbrich, 1991). The earliest granitic associations are typical of magmatic-arc settings with tonalites and trondhjemites, mainly in the northwestern (Silva Filho and Soliani Jr., 1987) and southwestern portions of the Sul-rio-grandense shield (Figure 6). Their ages are ~ 0.70 Ga, as indicated by Rb-Sr and U-Pb data (Leite et al., 1995, Silva Filho and Soliani Jr., 1987).

Calc-alkalic granitoids (quartz diorites, tonalites, trondhjemites and granodiorites) are present in the western portion of the shield in the Lavras do Sul and São Gabriel regions. Their geochemical features are consistent with rocks produced through the differentiation of low to medium-K calc-alkalic magmas, probably in an active continental margin as suggested by Silva Filho and Soliani Jr. (1987). Compositionally similar metagranitoids are also present in the Pelotas batholith, in the eastern portion of this shield, and interpreted as part of a magmatic arc. The western tonalitic associations have ages ~ 0.70 Ga, according to Leite et al. (1995), whereas the eastern association is slightly older (0.78 Ga; Silva et al., 1999). Their normalized trace-element patterns are similar to collisional or continental arc granites of medium-K calc-alkalic affinity.

The tonalitic associations are followed by widespread biotite granodiorites and granites with subordinate dioritic components (high-K calc-alkalic granitoids) mostly related with transcurrent shear zones, which constitute the most prominent tectonic feature in Precambrian areas of southern Brazil. This magmatism is represented by several granitic associations with ages varying from 0.64 to 0.54 Ga (e.g., Babinski et al., 1997; Basei et al., 1995; Wernick et al., 1984). A peraluminous granitic magmatism with garnet-bearing two mica granitoids (ca. 0.61 Ga), also associated to this same tectonic event, was probably generated by melting of orthogneiss sequences (Nardi and Frantz, 1995). Trace element composition of both magmatisms is consistent, respectively, with high-K calc-alkalic rocks and crustal-melting derived granitoids, similar to those associated with collisional settings. The intrusion of high-K calc-alkalic granitoids was contemporaneous with basic magmatic activity, expressed mainly as mafic microgranular enclaves. These evidences are lacking in the peraluminous granitoids, reinforcing their crustal derivation.

High-K calc-alkalic granitoids are also related to the late stages of transcurrent tectonics. They gradually move towards more alkalic compositions when the transcurrent tectonics is replaced by an extensional regime (Janasi and Ulbrich, 1991, Bitencourt and Nardi, 1993).

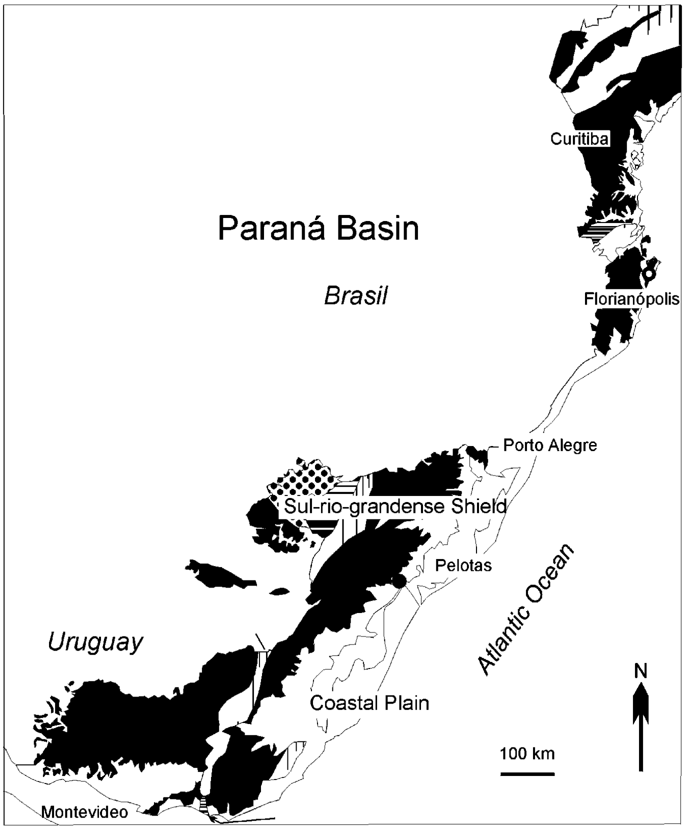

Figure 6 Geologic sketch map of the Sul-rio-grandense craton, southern Brazil and Uruguay (southern Mantiqueira province).

In the northern part of this region, strongly deformed charnockites, quartz mangerites and 0.63 Ga-old syenites are associated with the high-K calc-alkalic magmatism (Janasi, 1997).

In the western region of the Sul-rio-grandense shield, granitoids and volcanic rocks of shoshonitic affinity (Lima and Nardi, 1998) are associated with the early stages of molassic sedimentation in the Camaquã Basin. Rb-Sr and U-Pb data suggest ages from 0.64 to 0.59 Ga for this magmatism, with Sr_0 close to 0.7040. Granitoids of shoshonitic affinity are also widespread in the Neoproterozoic southern areas. Shoshonitic magmatism is produced through partial melting of the mantle lithospheric edge, hydrated and metasomatised by fluids related with a previous crustal subduction mechanism.

Metaluminous A-type granitoids, with subordinate peralkalic terms younger than 0.59 Ga, are related to the silica-saturated alkaline association in the Sul-rio-grandense shield (Nardi and Bonin, 1991) and are widespread throughout the southern region (e.g. Basei et al., 1995, Janasi and Ulbrich, 1991).

Rapakivi granites (~0.6 Ga) have been reported from the State of São Paulo, in the northern part of this region. The high La/Nb ratios, as well as relatively heavy REE-fractionated patterns, suggest that most of this magmatism is related to partial melting of mantle sources modified by oceanic crust subduction, as proposed for calc-alkalic and shoshonitic magmatisms in the western regions. Crustal melting and assimilation can not be ruled out for the evolution of some of these metaluminous granites, particularly for those with high Sr initial ratios and relatively low contents of HFS and RE elements (Gastal and Lafon, 1998). The recurrence of calc-alkalic magmatism, usually of the high-K calc-alkalic type, long after the subduction cessation, in late- to post-collisional settings, is probably related to the effect of deep shear zones promoting melting in metasomatised lithospheric edges.

Isotopic data for the Neoproterozoic magmatism in southern Brazil confirm that most of this magmatism is related with mantle sources similar to EM1 type probably reflecting previous subduction events during Paleoproterozoic and Neoproterozoic ages. Crustal melting was particularly important in the generation of peraluminous syn-transcurrent granitoids.

Conclusions

To date, Neoproterozoic granitoids in Brazil seem to be the most widespread and studied granitoid plutons in the country, although some older granitoids have also received attention, especially in the Amazon region. The most striking features among the known granitoids in this country are: (a) large volumes of Proterozoic rapakivi granites in the northern region, (b) the magmatic epidote-bearing granitoids (calc-alkalic, high-K calc-alkalic and shoshonitic granitoids) and the ultrapotassic province in northeastern region, (c) the unique Neoproterozic island arc granitoids in central Brazil, and (d) the use of granitoids to understand the steps of evolution of metamorphic belts in eastern, central and southern Brazil. In this regard, the study of arc-related metagranitoids provided important tools to reevaluate geotectonic models based on an purely ensialic evolution for Neoproterozoic orogens. Other relevant contributions from detailed studies on late- to post-collisional granitoids are: (1) the importance of deep faults in the control of complex regional magmatic zoning; (2) with the exception of the Brasilia foldbelt and granitoids in the southern Mantiqueira province, peculiar geochemical signatures mostly of basic and intermediate rocks showing abnormal isotopic and incompatible elements enrichment, probably due to an enriched mantle source since Precambrian times.

One of the most important features of granitic magmatism in Brazil is the large volume of < 0.61 Ga late- and post-orogenic granite plutons which intrude the Neoproterozoic (Brasiliano) orogens in northeastern, central, eastern and southern parts of the country. This post-orogenic event is broadly coeval in all these regions and the intrusions formed bear many similarities beween them. Most of this post-orogenic magmatism is the product of remelting of Paleoproterozoic continental crust, the exception being the K-rich granitoids of central Brazil, which are the result of remelting of Neoproterozoic juvenile crust. Many granitoids in southern Brazil and the ultrapotassic syenites in northeastern Brazil are mantle-derived.

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