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Stratigraphy and tectonism of the Brasiliano Cycle in southern Brazil

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Juvenile crustal accretion in the Brasiliano Cycle occurred in the São Gabriel Block of southern Brazil, whereas the Dom Feliciano Belt along the Atlantic coast corresponds mainly to Brasiliano granites, gneisses and migmatites mostly derived from a Palaeoproterozoic to Archaean crust. These geotectonic units are separated by a volcano-sedimentary rift-related sequence of probable Mesoproterozoic age, strongly reworked during the Neoproterozoic. The basement rocks are represented by Palaeoproterozoic granulites and the Uruguayan granite-greenstone belts that define an important geotectonic cycle in southern Brazil, the Trans-Amazonian Cycle. However, the Brasiliano Cycle was most significant in the region, defined by two main tectonic events, the São Gabriel (750-700 Ma) and Dom Feliciano (around 600 Ma) events. W- and NW-verging thrust-related tectonics and later strike-slip deformation are recognised in the region. Granitic and effusive magmatism is abundant as a late manifestation of the Brasiliano Cycle in southern Brazil, along with the generation of foreland sedimentary basins.

Introduction

The Archaean to Early Palaeozoic of southern Brazil is covered by younger Phanerozoic sequences. These units have been strongly affected by the Brasiliano Cycle (1000 to 470 Ma) resulting in a complex tectonic arrangement, juxtaposing Palaeoproterozoic units to Brasiliano terranes.

The Brasiliano Cycle in the region includes a complex tectonic stratigraphic arrangement of granite-migmatitic-gneissic terranes, volcano-sedimentary supracrustal metamorphic rocks and late- to post-tectonic volcano-sedimentary sequences. The latter represent the final stages of the Brasiliano Cycle, during which the assembly of West Gondwana occurred. The Mantiqueira Province (Fig. 1) is one of the main Brasiliano geotectonic units, and is the location of the study area within Brazil (Almeida *et al.*, 1977).

Several authors have applied plate tectonic models to this part of Brazil using regional geological data, and by correlating the Brasiliano/pan-African belts such as the Ribeira, Dom Feliciano, Damara and Gariep Belts in southern Brazil and southern Africa respectively (Porada, 1979, 1989; Basei, 1985; Brito Neves and Cordani, 1990; Frãgoso-Cesar, 1991; Fernandes *et al.*, 1992). Nevertheless, several questions still remain unanswered. The study area does not display complete sequences and in spite of extensive geological mapping, little reliable isotope data used in the above mentioned papers are available to formulate a consistent tectonic model.

The main purpose of this paper is to present the stratigraphy of different geological terranes affected by the Brasiliano Cycle in southern Brazil (Fig. 2) and sketch the main tectonic features, with support of field geology, geochemistry and available geochronological results. We also propose a lithospheric model to explain the data.

Geological setting

The study area covers part of the Mantiqueira Province (Fig. 1) which consists of Archaean to Late Palaeozoic units formed during at least four main orogenic cycles, namely the Jequié (3330-2600 Ma), Trans-Amazonian (2600-1800 Ma), Uruçuano (1800 to 1000 Ma) and Brasiliano (1000-450 Ma) (Almeida and Hasui, 1984). The Mantiqueira Province, a NE-SW-trending geotectonic unit, has been strongly affected by Brasiliano tectonics. This has resulted in multiple granitic intrusions and reworking of Archaean to Mesoproterozoic granite-gneiss terranes as well as some Mesoproterozoic greenschist to amphibolite supracrustal sequences. This Province can be divided into northern, central and southern sectors, only the last being discussed in this paper. The southern segment of Mantiqueira Province is situated, running from south to north, in Uruguay and the Rio Grande do Sul (RS) and Santa Catarina (SC) states of Brazil, comprising the following units (Fig. 2):

a) Palaeoproterozoic granite-greenstone terrane and the Ismael Cortinas mafic dyke swarm which corresponds to Palaeoproterozoic units in Uruguay, called the Florida Block by Frãgoso-Cesar (1991).

b) Palaeoproterozoic high-grade terranes, the Santa Catarina Granulite Complex (SCGC on Fig. 2b) and Santa Maria Chico Granulite Complex (SMCGC on Fig. 2b). Both are somewhat affected by the Brasiliano Cycle, resulting in strike-slip tectonic reactivation, intrusion of granites and deposition of late- to post-tectonic volcano-sedimentary sequences (e.g. Itajaí Basin and Taquerembó volcanic rocks).

c) The Tijucas belt is made up of greenschist to amphibolite facies supracrustal rocks with some exposures of Palaeoproterozoic gneissic rocks. U/Pb zircon data from metavolcanic rocks give a minimum age of 1400 Ma (Orlandi Filho *et al.*, 1990) for the Formation of these rocks. However, the belt was deformed during the Dom Feliciano Event (see below).

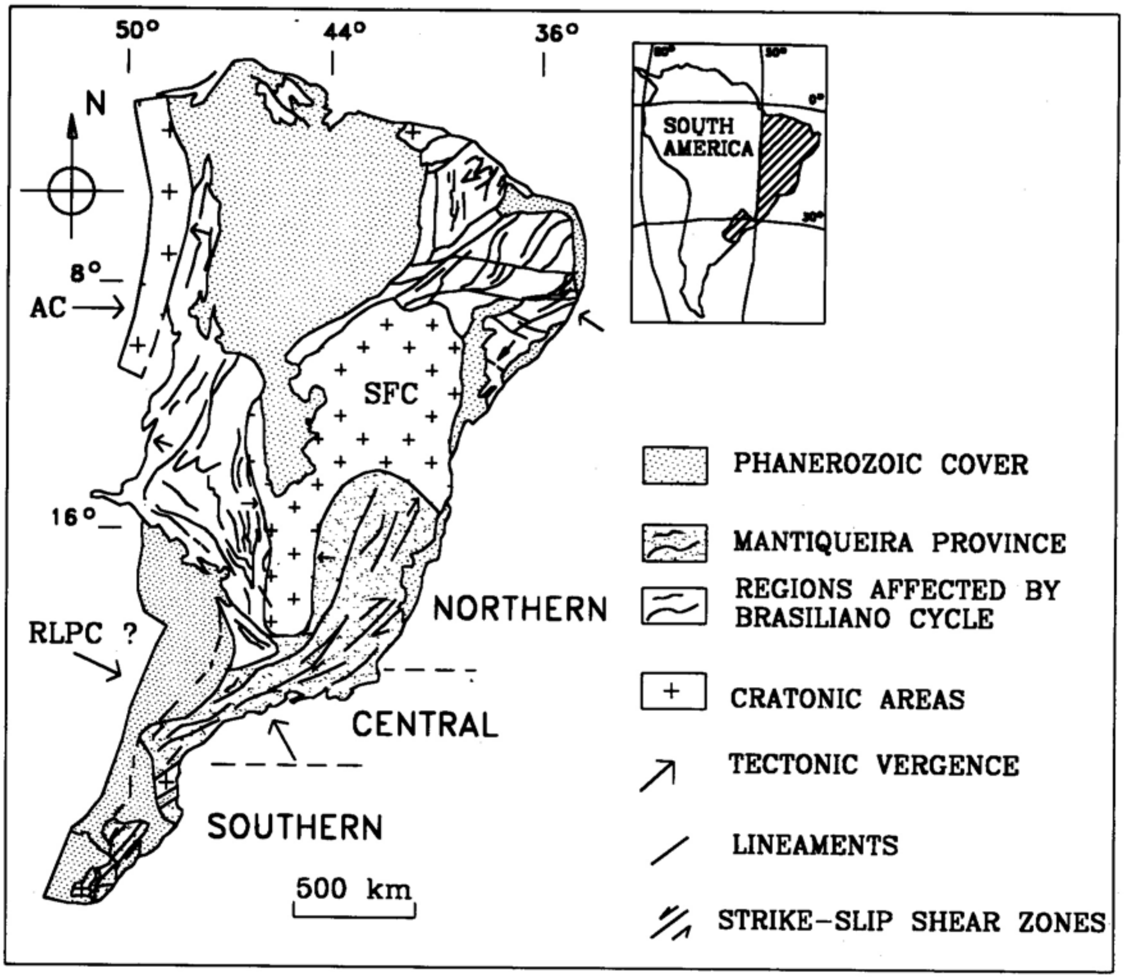

Figure 1: Map of eastern Brazil showing the areas affected by the Brasiliano deformation.

d) The Neoproterozoic to Early Palaeozoic Vila Nova Belt is represented by tonalitic to granodioritic gneisses, greenschist to amphibolite facies volcano-sedimentary rocks, mafic-ultramafic units (with a close relation to the volcano-sedimentary rocks), foliated granites, formed and/or deformed by the Silo Gabriel Event between 700-750 Ma (Chemale *et al.*, 1994a).

e) The Neoproterozoic to Early Palaeozoic Dom Feliciano Belt is represented by different types of Brasiliano granitic rocks and units of older cycles. This belt corresponds to an association of Brasiliano flat-lying migmatic gneisses and granites as well as some Archaean to Palaeoproterozoic remnants of tonalitic-trondjemitic gneisses, amphibolites, paragneisses and anorthosites. These units have been formed/deformed during the Dom Feliciano Event with the main tectono-metamorphic peak at 562-616 Ma (Chemale *et al.*, 1994b).

f) Late to post-tectonic plutono-volcanic-sedimentary sequences, the Seival and Itajaí Associations, which are foreland manifestations of the Dom Feliciano Event in the Palaeoproterozoic Granulite Complexes and in the Vila Nova Belt.

Geology of basement rocks

Santa Catarina Granulite Complex

This complex is made up mostly of depleted TTG granulitic orthogneisses, and contains small interleaved supracrustal lenses composed of banded iron Formation, quartzites, calc-silicate gneisses and rare kinzingites (Hartmann *et al.*, 1979). Undepleted bimodal orthogneisses and small bodies of basic-ultrabasic rocks of tholeiitic affinity occur in restricted areas.

The regional planar fabric in these rocks consist of NS-trending, subvertical gneissic banding, intensely transposed along the southern border of the complex by strikeslip mega-shear zones oriented at N45°E (Perimbó shear zone, Fig. 3). In the interior of the complex there is a Neoproterozoic tectonic reactivation of NE-SW and E-W faults.

The main metamorphic high-grade event occurred at 2.2 Ga during the Trans-Amazonian orogeny (Hartmann *et al.*, written com., 1993; Basei, 1985). However, these rocks formed during the late Archaean (Basei, 1985; Mantovani *et al.*, 1987).

Santa Maria Chico Granulite Complex

The Santa Maria Chico Granulite Complex occurs SW of the lbaré Shear Zone (Fig. 4). It is made up of quartz-feldspathic gneisses (tonalites and trondhjemites), mafic gneisses, anorthosites, ultramafics and supracrustal rocks metamorphosed up to amphibolite and granulite grade (Nardi and Hartmann, 1979). The regional planar fabric is E-W, developed during the high grade metamorphism at 2100 Ma (Sm-Nd mineral age, Hartmann, 1987). However, these rocks were accreted during the Archaean (Tdm Sm-Nd age, Hartmann, written com., 1993).

The Complex is intruded by Brasiliano (younger than 600 Ma) granites and partly covered by early Palaeozoic, late to post-tectonic volcano-sedimentary rocks. The Brasiliano Granites are included in the Santo Afonso Suite. In the Isla de Rivera, extensive gold mineralisation occurrences are associated with Brasiliano strike-slip shear zones oriented WNW-ESE and N-S.

Uruguayan granite-greenstone belt

The Uruguayan granite-greenstone belt comprises of dioritic to granodioritic granite-gneiss complexes (2070 and 2020 Ma, Umpierre and Halpern, 1971; Cingolani *et al.*, 1990) and low-grade volcano-sedimentary belts intruded by late granites. These granites yield a Rb/Sr age of 1970 Ma (Umpierre and Halpern, 1971).

The Ismael Cortinas mafic dyke swarm occurs as several N60°-80°E-trending mafic dykes cutting the granite-greenstone terrane. K-Ar, Rb-Sr and Sm-Nd radiometric results of these dykes point to a meaningful crustal stretching event at 1800 Ma (Bossi *et al.*, 1993).

Stratigraphy and Tectonism of the Brasiliano Belts in Southern Brazil

The authors recognise the following Brasiliano geotectonic units in southern Brazil, the Vila Nova Belt, Tijucas Belt and Dom Feliciano Belts. While the Vila Nova Belt corresponds to one of few areas in Brazil with Brasiliano accretion (Babinski *et al.*, in prep.), the Tijucas and Dom

Feliciano Belts are pre-Brasiliano crust with strong reworking during the Neoproterozoic. Especially in the DFB, where there occurs a great volume of Brasiliano granites, migmatites and gneisses that always display negative epsilon Nd (600) values and Tdm from 1.3 to

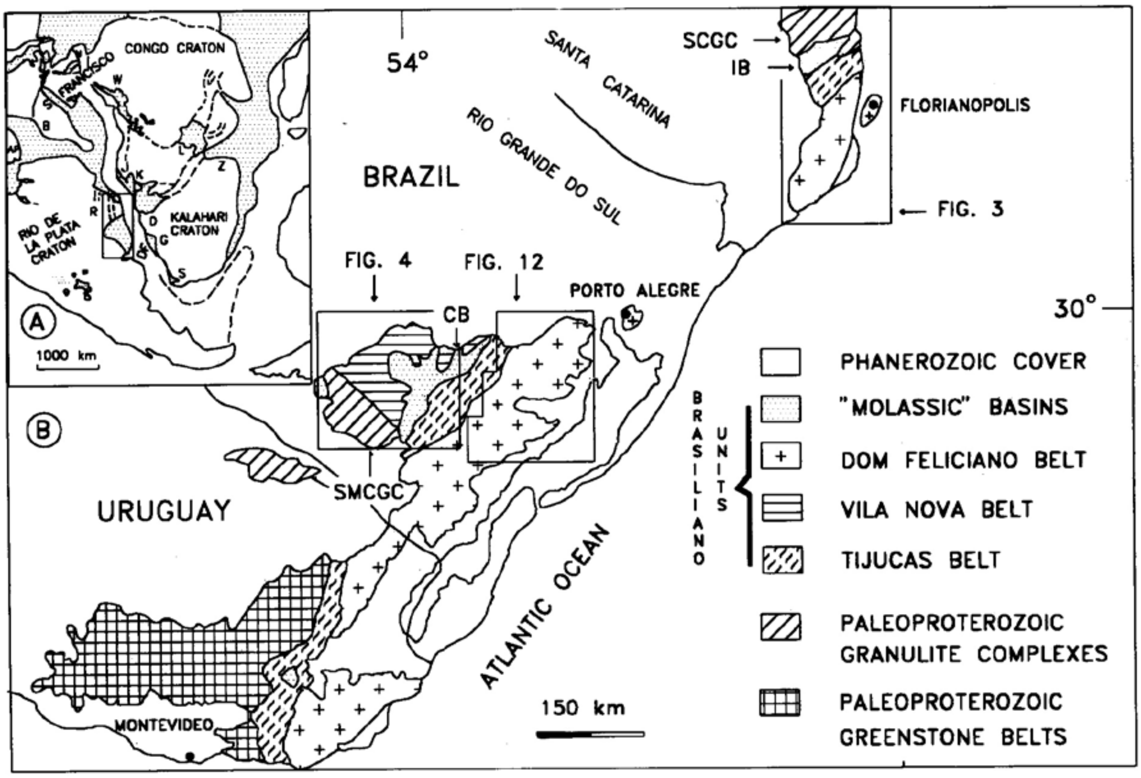

Figure 2: a) Brasiliano and Pan-African areas in South America and southern Africa (modified after Porada, 1989) with location of Fig. 2b indicated. b) Geological map of southern segment of Mantiqueira Province, modified after Jost and Hartmann (1984). SCGC = Santa Catarina Granulite Complex, SMCGC = Santa Maria Chico Granulite Complex, IB = Itajaí Basin, CB = Camaqu Basin

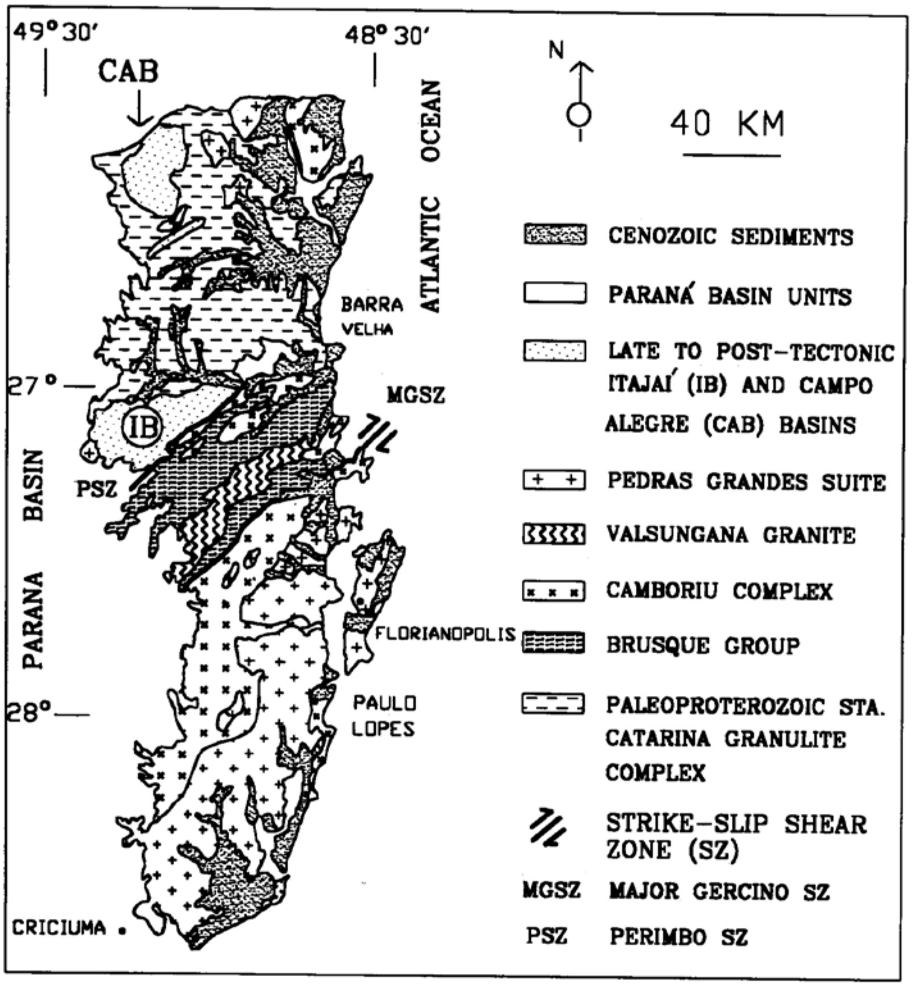

Figure 3: Simplified geological map of the Santa Catarina Shield (modified after Silva, 1987). The Dom Feliciano Belt comprises the Camboriu Complex and Pedras Grandes Suite southeast of the Brusque Group.

2.3 Ga (Mantovani *et al.*, 1987; Basei, 1990).

The geochronological dating allows us to characterise two main tectonic events in the Brasiliano belts in southern Brazil (Chemale *et al.* 1994b), the São Gabriel Event (700 to 750 Ma) and the Dom Feliciano Event (ca. 600 Ma).

Vila Nova Belt

The Vila Nova Belt is exposed in the central-western part of the Rio Grande do Sul state and shows a complex lito stratigraphic arrangement (Fig. 2b). It may correspond to an extension of the Ribeira Belt, but hidden under Phanerozoic cover. It is subdivided into the Vacacaí Supergroup and the Cambaí Group (Fig. 4). The rocks of the Vila Nova Belt are mostly generated between 1.0 Ga and 0.7 Ga (Babinski *et al.*, in prep.).

Despite the scarcity of suitable data, this region has been considered either as part of the Palaeoproterozoic Rio de La Plata Craton (Frãgoso-Cesar, 1980; Ramos, 1988), the Brasiliano intraoceanic island arc (Frãgoso-Cesar, 1991), a back-arc basin (Vacacaí Supergroup units) and as a continental magmatic arc (Cambaí Group) association (Fernandes *et al.*, 1992). Recently, Babinski *et al.* (in prep.), on base of Sm-Nd WR results and some U-Pb zircon dating, define this region as a juvenile accreted area at 700-750 Ma, representing a volcanic arc.

Cambaí Group

The Cambaí Group comprises monzogranitic, granodioritic, dioritic, tonalitic and trondhjemitic gneisses intercalation with amphibolites, meta-ultramafics and marbles, all metamorphosed to amphibolite facies. The Cambaí Group is subdivided into two Formations (Fig. 5).

The Cerro Mantiqueiras Formation occurs as isolated bodies of mafic-ultramafic sequences, e.g. in the Cambaízinho (Fig. 6), Cerro Mantiqueiras and Passo do Ivo regions (as C on Fig. 4). The Formation is dominated by Mg-rich schists, serpentinites, metaharzburgites and amphibolites, all metamorphosed to amphibolite facies (Remus, 1990; Leite, in prep.). However, a retrograde metamorphism of greenschist facies is often identified.

The dioritic-tonalitic-granodioritic gneisses and metagranites have a calc-alkaline affinity (Silva Filho and Soliani, 1987), and are included in the Cambaízinho Formation. At least five lithological associations have been recognised in this Formation (Chemale *et al.*, 1995): a) polydeformed dioritic gneisses, which are intruded by b) banded metatrondhjemites, c) folded monzogranitic pegmatite, d) foliated metadiorites, and e) undeformed pegmatite.

U/Pb zircon data from the dioritic gneisses yield an age of 704 ± 12 Ma which is interpreted as zircon crystallisation during deformation (E on Fig. 4) (Chemale *et al.*, 1994a).

Detailed WR Sm-Nd analyses yield Nd(700) values of these gneissic and metagranitic rocks range between +2.8 and +4.5, and the model ages (Tdm) are close to the U/Pb zircon crystallisation varying from 1.03 to 0.83 Ga (Babinski *et al.*, in prep.). These results point to a juvenile crust formed from a Brasiliano oceanic material.

The Cambaí Group units are strongly affected by ductile dextral lateral-shearing (represented by S_2 on Fig. 6), cutting an earlier flat-lying structure (as S_1 on Fig. 6).

Vacacaí Supergroup

This supergroup hosts deformed and metamorphosed volcano-sedimentary and juxtaposed mafic-ultramafic rocks of the Palma Group and stratiform basic-ultrabasic bodies.

The **Palma Group** comprises three Formations (Fig. 7), from base to top: Cerro da Cruz Formation, Passo Feio Formation and Campestre Formation. The magnitude of deformation varies from minor (Batovi sequence, southern part of Passo Feio Formation, northern part of Campestre Formation) to intense (Passo Feio Formation close to the Caçapava do Sul Batholith, and southern part of Palma Group). The grade of metamorphism ranges from lower greenschist (e.g. Campestre Formation in the Ibaré Shear Zone region and NE of Ramada Plateau) to amphibolite facies (e.g. Passo Feio Formation).

The Palma Group occurs as a NE-SW elongated unit, separated by the Ramada Plateau (RP on Fig. 4) and exposed to the west of Caçapava do Sul town, as a N-S elongated metamorphic unit (Passo Feio Formation) surrounding the Caçapava do Sul Batholith, and as WNW-ESE elongated units controlled by the Ibaré Shear Zone. The western exposure holds the most complete sequence, consisting of thrust sheets comprised of units from greenschist to lower amphibolite facies, displaying a structural vergence to SE. They are repre-

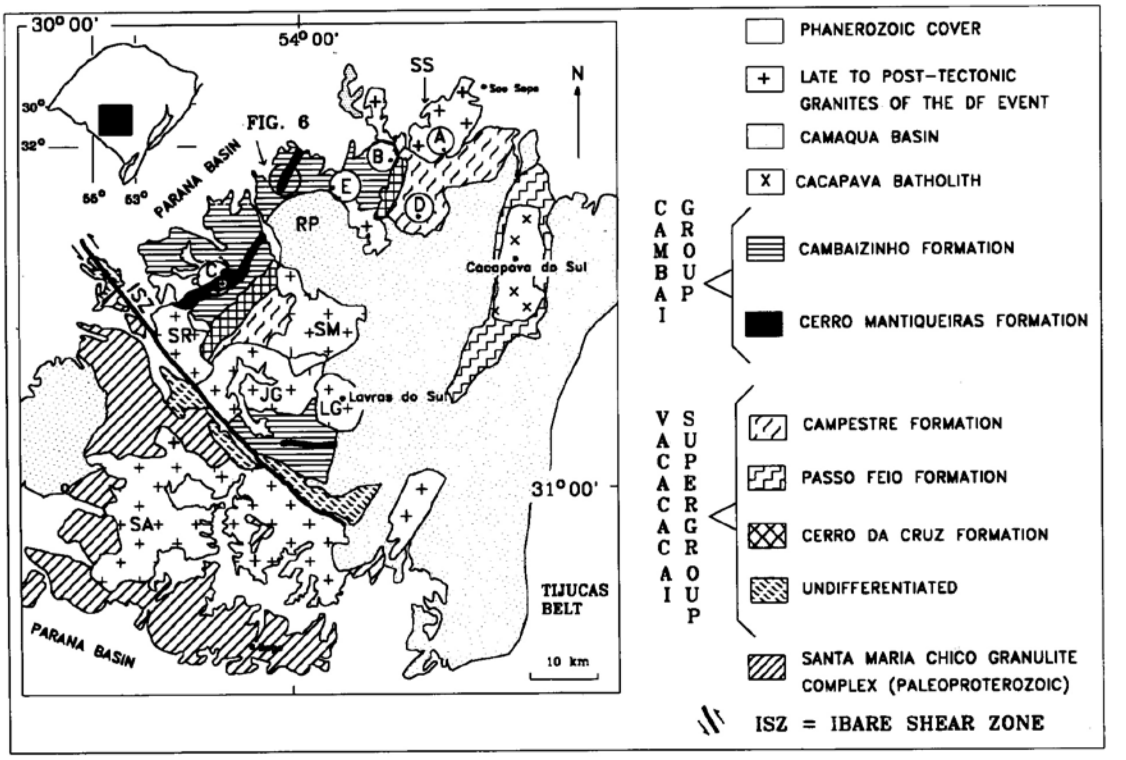

Figure 4: Geologic map of the western part of the Sul-rio-grandense Shield (after Chemale *et al.*, 1995). A = Pedras Pretas Complex, B = Mata Grande Gabbro, C = Passo do Ivo Complex, D = U-Pb dated metavolcanic rock of the Campestre Fm., E = U-Pb dated gneiss of the Cambaí Group, JG = Jaguari Granite, L = Lavras do Sul Granite, SM = São Manoel Granite, SS = São Sepé Granite, SR = Santa Rita Granite, SA = Santo Afonso Suite, RP = Ramada Plateau.

Stratigraphic unit	Lithological description	Tectonic environment
Cambaizinho Formation	Calk-alkaline, dioritic, tonalitic and trondhjemitic gneisses with intercalations of marbles and amphibolite and intrusioin of foliated granites (e.g. Sanga do Jobim Granite)	Root of volcanic arc
Cerro Mantiqueiras Formation	Amphibolites and metaultramafites (Mg-rich schists, serpentinite and metaharzburgite)	Slab of oceanic crust and upper mantle

Figure 5: Stratigraphic column of the Cambaí Group.

sented by the Cerro da Cruz and Campestre Formations, exposed in reverse stratigraphic order with a structural contact at the base of the succession.

The **Cerro da Cruz Formation** consists of mafic-ultramafic rocks such as Mg-rich schists, serpentinites and metabasalts (tholeiitic to high-Mg composition) with intercalated quartzites and marbles (Naumann *et al.*, 1984).

The **Campestre Formation** comprises calc-alkaline, rhyolitic to andesitic-basaltic volcaniclastic rocks and lavas, associated with epiclastic (metamorphosed graphitic pelites, sandstones and siltstones) and chemical rocks (cherts and iron formations) (Koppe, 1990). U-Pb zircon age determination of an agglomeratic metatuff from the Campestre Formation yields 753 ± 2 Ma which is interpreted as the formation age of this unit (Machado *et al.*, 1990). Nevertheless the upper intercept age is 1034 Ma indicates inheritance of older Pb.

The Passo Feio Formation surrounds the Caçapava do Sul Batholith. It comprises mainly pelites, amphibolites, amphibole-bearing schists and gneisses, metagabbros and meta-volcaniclastic rocks, with subordinate Mg-rich schists, quartz-feldspathic gneisses, marbles, quartzites and pillowed metabasalts (with tholeiitic affinity). They are interpreted to represent a passive margin sequence (Frãgoso-Cesar, 1991). Both the Passo Feio Formation and the Caçapava do Sul Batholith have been affected by strong deformation and metamorphism. Early thrust-related structures are overprinted by strike-slip tectonics, influencing the evolution of the metamorphic grade from amphibolite to greenschist facies.

The **stratiform basic-ultrabasic bodies** appear closely related to the supracrustal units of the Palma Group. The 20 km^2 Mata Grande Gabbro (B on Fig A) and 2.55 km^2 Pedras Pretas Complex (A on Fig. 4) are two of the main mafic plutonic bodies of the Vila Nova

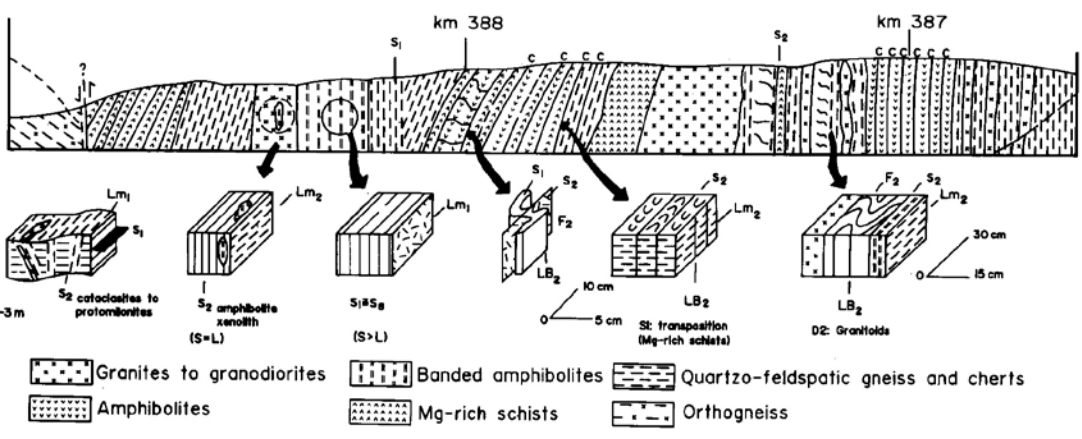

Figure 6: Structural-geologic profile along the Br-290 at the Cambaizinho region (after Remus, 1990). S_1 = flat-lying gneissic banding, Lm_1 = mineral lineation on S_1, S_2 = foliation formed by dextral strike-slip ductile deformation (most cases transpose S_1 foliation), Lm_2 = streatching mineral lineation on S_2, F_2 = folding of S_1 foliation, LB_2 intersection lineation S_1 x S_2.

Stratigraphic unit	Lithological description	Tectonic environment
Campestre Formation	Calk-alkaline, rhyolitic to andesitic-basaltic volcanic-clastic rocks and lavas, graphite schists, metapelites, cherts and BIFs	Volcanic arc association,
Passo Feio Formation	Amphibole-bearing schists, amphibloites and gneisses, quartzites, marble, Mg-rich schists, metagabbros and pillowed metabasalts	Passive margin association,
Cerro da Cruz Formation	Mafic to ultramafic rocks with tholeiitic affinity such as metabasalt, Mg-rich schists and serpentinites with intercalations of chert layer	oceanic crust and upper mantle fragments,

Figure 7: Stratigraphic column of the Palma Group.

Belt. They are stratiform and display 1 mm to m-thick banding, and compositionally vary from peridotite to anorthosite, with a dominant gabbroic composition. They are two-pyroxene tholeiitic rocks and the. Mata Grande Gabbro is dominantly troctolitic in composition.

The magmatic textures of both basic-ultrabasic bodies are well preserved, albeit for the superposition of subsequent regional and contact metamorphic events. A regional metamorphism of transitional greenschist/amphibolite grade and contact metamorphism of hornblende-hornfels has been described for them (Rêgo, 1981).

Tijucas Belt

The Tijucas Belt is probably a pre-Brasiliano unit, but reliable ages for this tectonic unit are not available. To the east it is limited by the Dom Feliciano Belt and to the northwest by the Santa Catarina Granulite Complex and Itajaí Basin (SCGC), Camaqu Basin (CB) and Uruguayan Palaeoproterozoic terrane (Fig. 2b). In Santa Catarina it is called the Brusque Group (Fig. 3), in Rio Grande do Sul the Porongos Group and in Uruguay the Lavalleja Group (Jost and Bittencourt, 1980).

Brusque Group

The Brusque Group is exposed in a belt 75 km long and 45 km wide and elongated in a direction N45°E (Fig. 3). It is a volcano-sedimentary sequence intruded by the Brasiliano Valsungana and Guabiruba granites. The sediments are dominantly marine, and consist of immature clastic rocks, such as turbidites, K-graywackes and tholeiitic volcaniclastic sediments. It also contains basic to ultrabasic subaqueous flows of alkaline to sub-alkaline composition (Sander, 1992), with massive, pillowed and variolitic structures (Silva, 1991). Chemi-

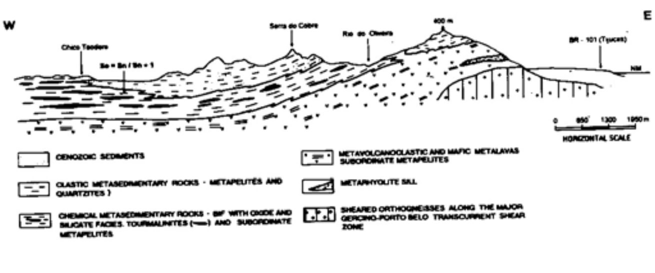

Figure 8: Geological section of the Brusque Group in the Rio do Oliveira region (after Silva, 1991).

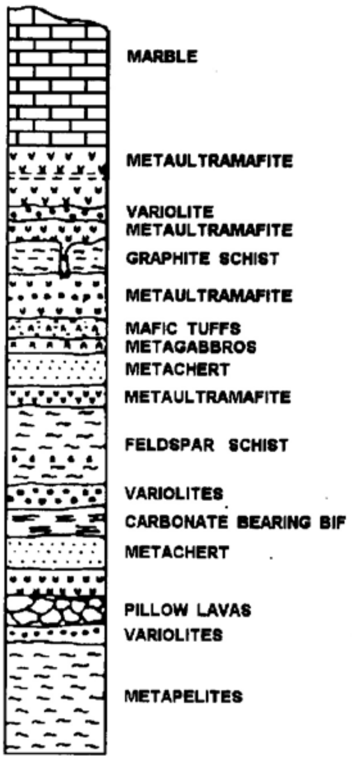

Figure 9: Stratigraphic column of the Brusque Group (SC) in the Rio do Ouro region. Planar fabric is parallel to the compositional layering (after Silva, 1991).

cal exhalative interflows are common, including silicate-oxide and stratabound tourmalinitic banded iron formations as well as calc-silicate bands. Felsic volcanogenic rocks occur along the borders of the group (Silva, 1991). Figs 8 and 9 are a section and stratigraphic column respectively, showing the close intercalation of volcanic-exhalative, chemical and clastic units.

Early thrusting tectonics caused the regional deformation, superimposed to varying degrees by N45°E-trending strike-slip shear zones. The latter structures determine the general configuration of the schist belt. Metamorphic grade varies from lower greenschist to amphibolite facies.

The Valsungana Granite is a N45°E elongated batholithic intrusion, with foliated biotite monzogranites along its borders. It is a metaluminous, homogeneous I-Caledonian type granite (Silva, 1991). An U-Pb zircon age of 648 ± 40 Ma (Basei, 1985) and a Sm-Nd Tdm of about 2000 Ma (Mantovani *et al.*, 1987) have been obtained, suggesting an origin from melting of Palaeoproterozoic crust during Neoproterozoic times.

The Guabiruba is a less deformed two-mica granite which intrudes the Valsungana Granite and the Brusque Group. It comprises several stocks of gray, fine-grained syenogranite with a peraluminous character (S-type, after Basei, 1985).

A direct correlation between the Tijucas Belt in Santa Catarina and the Damara Belt in Namibia has been proposed by Porada (1979,1989), Kaul (1979) and others. Studies by Silva (1991), however, based on field mapping and U/Pb zircon data of 1.6 Ga for metavolcanic rocks of the Brusque Group (Basei, 1990), suggest that this belt corresponds to a Palaeo to Mesoproterozoic event of ensialic rifting with later opening and closure of an ocean basin. This belt has been subsequently affected by Brasiliano tectonics.

Porongos Group

The volcano-sedimentary Porongos Group consists of pelites, arkoses, acid to intermediate metavolcanics, quartzites and marbles (lost and Bittencourt, 1980), metamorphosed from greenschist to amphibolite facies (Fig. 10). Mylonitic granites of probable Neoproterozoic age are described by Porscher and Fernandes (1990) and Remus *et al.* (1990) interleaved with supracrustal rocks. This sequence has been interpreted as a Brasiliano back-arc association (lost and Bittencourt, 1980; Fernandes *et al.*, 1992), but the few available dates yield a Mesoproterozoic age for the metavolcanic rocks (Orlandi Filho, 1990).

Several NE-trending, NW-verging thrusts deformed this sequence forming four regional antiforms with N30°E-trending axes. Porscher and Fernades (1990) suggest that these structures were generated in a thrust regime. The Porongos Group structurally overlies Palaeoproterozoic tonalitic gneisses, the Encantadas Gneisses (Fig. 12), which are exposed in the core of the antiform structures (lost and Bittencourt, 1980; Soliani, 1986). The sinistral NE- and dextral NS-trending strike-slip tectonics occur superposed on tangential tectonics.

Dom Feliciano Belt

The DFB is a predominantly granitic-gneissic-migmatitic terrane which extends from Uruguay to Rio Grande do Sul (RS) and Santa Catarina (SC) states in southern Brazil (Fig. 2). It is bordered to the west by the Tijucas Belt. A tectonic contact between the two belts is well exposed in the Porto Belo region (SC) where it is known as the Major Gercino Transcurrent Zone. To the east the DFB is covered by Mesozoic to Cenozoic deposits. The main lithostratigraphic units of the DFB are divided into (Fig. 11) pre-Brasiliano units and the Brasiliano units.

Pre-Brasiliano units

The Chan Gneisses correspond to para- and orthogneisses metamorphosed to upper amphibolite facies (Frantz *et al.*, 1984; Fernandes *et al.*, 1989), which are exposed to' the south of highway BR-290 (Fig. 12). The paragneisses are comprised of andalusite ± sillimanite ± cordirite ± garnet ± biotite gneisses, calc-silicate gneisses, quartz-feldspathic gneisses and small amounts of marble and amphibolite lenses. The orthogneisses oc-

Stratigraphic unit	Lithological description	Deformation age
Porongos Group	Metacherts, meta-pelites with lenses of graphite schist, marble and quartzites. Intercalations of andesitic, traqui-andesitic and dacitic metavolcanic rocks	During the Dom Feliciano Event (ca. 600 Ma)
	quartzites and monzogranitic to syenogranitc mylonites**	During the Dom Feliciano Event (ca. 600 Ma)
Encantadas Gneisses	Polydeformed granitic and trondhjemitic-tonalitic gneisses with lenses of amphibolite	Transamazonian event (Paleoproterozic)

* Probable deposition age of this volcano-sedimentary sequence is Mesoproterozoic (Orlandi Filho *et al.*, 1990)

** The granitic rocks of this sequence are the result of mylonitization of the Encantadas Gneisses during the Dom Feliciano Event (Porsche and Fernandes, 1990).

Figure 10: Stratigraphic column of the Tijucas Belt in the Rio Grande do Sul state (modified after Porscher and Fernandes, 1990).

cur as banded granodioritic to tonalitic rocks (Frantz *et al.*, 1984). There is no radiometric age determination for the Chan Gneisses, but they are considered the oldest unit of the Dom Feliciano Belt.

The Capivarita Anorthosite (Formoso, 1972) is a 170 km^2 massive body with intercalations of banded amphibolite and some inclusions of calc-silicate rocks as well as intrusions of Brasiliano granites. Mineralogically it consists of plagioclase-labradorite (90%) and accessory quartz, sphene, K -feldspar, corresponding to the same metamorphic conditions of upper amphibolite facies that affected the surrounding Chan Gneisses. An association of sericite, carbonates, epidote and chlorite give evidence for a retrograde metamorphism of greenschist facies conditions. Hartmann (oral commun., 1992) obtained a U/Pb single-crystal zircon age of 602 Ma (at the Royal Ontario Museum, Canada) which is interpreted here as the time of metamorphic crystallisation.

Brasiliano units

The Pinheiro Machado and Camboriú Complexes are exposed in RS (Fig. 12) and SC states (Fig. 3), respectively. They correspond to an association of gneisses, migmatites and granites with high-K calc-alkaline signature, showing a flat-lying foliation, commonly folded or cut by the younger strike-slip tectonics. In some places, there are small pre-Brasiliano, tonalitic-throndjhemitic-granodioritic blocks (Basei, 1985) and supracrustals such as calc-silicates, BIFs, quartzites and amphibolites (Silva and Dias, 1981).

Frãgoso-Cesar (1991) and Fernandes *et al.* (1992) described two main deformational events for the units of Pinhein? Machado Complex. The first deformation (D_1) is registered as flat-lying shear zones associated with NW- or W-verging thrusting. The thrust fabric is strongly affected by large NE-SW-trending, sinistral strike-slip shear zones (D_2 deformation) with associated magma generation (see strike-slip related granites) (Fig. 13). These authors, based on a 885-775 Ma Rb/Sr WR isochron, calc-alkaline signature and low $^{87}Sr/^{86}Sr$ (after Soliani, 1986), describe these rocks as a continental magmatic arc generated around 800 Ma.However, Sm-Nd data (Mantovani *et al.*, 1987; Basei, 1990) and Pb-Pb zircon data indicate that this complex is dominated by older crustal rocks remelted during the Brasiliano, Chemale *et al.*, (1994b) believe the main tectonometamorphic event took place around 600 Ma, implying the Rb-Sr ages may be mixing ages.

Strike-Slip-related Granites

Several NE-elongated granitic bodies displaying deformation related to younger strike-slip tectonics (Fig. 12), referred to as syn-transcurrent or strike-slip related granites (Frãgoso-Cesar, 1991; Fernandes *et al.*, 1992;

Philipp *et al.,* 1993). These granites intrude the Pinheiro Machado and Camboriú complexes. They display a magmatic flow and metamorphic foliation oriented at N40°E and NS with a sub-horizontal to horizontal stretching mineral lineation. These bodies may be divided into having either a metaluminous (e.g, Arroio do Moinho) and peraluminous character (e.g. Cordilheira Leucogranites) (Fig, 12) with high-K calc-alkaline to sub-alkaline signatures. These rocks have a direct relationship with development of the strike-slip megashear zones such as the Dorsal de Canguçu (Fernandes *et al*. 1992) and Major Gercino shear zones (Bitencourt, 1995).

The metaluminous granites are syeno: to monzogranite in composition, and calc-alkaline to high-K calc-alkaline (Mesquita, 1991). The Cordilheira Leucogranites are strongly deformed syn-strike-slip sheets of leucogranite which consist of quartz, K-feldspar, and albite/oligoclase with muscovite, biotite, tourmaline, apatite, zircon, ilmenite and garnet as accessories (Nardi and Frantz, 1995). Tin and tungsten mineralisation, greisens and beryl-bearing pegmatites, columbite and tourmaline occur associated with the granites. Both granite types are mylonitised, and metamorphosed to greenschist facies.

Encruzilhada do Sul/Pedras Grandes Suites

These granites occur as large, irregular bodies intruded into Pinheiro Machado and Camboriú complexes. The Encruzilhada do Sul Suite includes Dom Feliciano and Encruzilhada do Sul Granites. A porphyritic biotite-granite facies is common in these suites, Petrographically their composition varies between syenite and monzogranite with a dominant syenogranitic facies. Mineralogically, they are composed of quartz, K-feldspar and plagioclase oligoclase. Biotite, sphene, ilmenite, zircon, epidote and apatite occur as accessories.

In Santa Catarina the Pedras Grandes Suite comprises diverse magmatic activity, including deformed pre- and syn-strike-slip bodies in addition to the dominant late- to post tectonic granites (Fig. 3).

Brittle to ductile-brittle, subvertical strike-slip shear zones are interpreted as belonging to the late- to post-tectonic strike-slip event D_2. Since these rocks are sub-alkaline and have high $^{87}Sr/^{86}Sr$ ratio, they are in-

Age	Stratigraphic Unit	Description	Other characteristics
ca. 500 Ma	Asperezas Rhyolites	Post-tectonic, alkaline, volcanic acid rocks	post-tectonic volcanism
500 to 550 Ma	Subida Granites/ Passo da Fabiana Gabbros	Alkaline to peralkaline post-transcurrent granites/ non-deformed basic ultrabasic stratiform bodies	post-transcurrent magmatism
around 562 Ma	Arroio do Moinho Granite, Cordilheira Granite and Pedras Grandes and Encruzilha do Sul Suites	Metaluminous and peraluminous, sub-alkaline to calc-alkaline granites with flow magmatic and state-solid textures related to the strike-slip tectonic phase (early, syn and late)	strike slip (transcurrent)-related granites
562 to 616 Ma	Pinheiro Machado and Camboriú Complexes	High K-Calc-alkaline, flat-lying foliated granitic-gneissic rocks with different degrees of migmatitization, associated to the W- to NW-verging thrusting tectonic phase	tangetial-related igneous rocks
older than 2000 Ma	Capivarita Anorthosite*/ Chanã Gneisses and older nuclei*	Paleoproterozoic anorthosite with calk-silicate and amphibolitic intercalations/ Remnants of Archaean to Paleoproterozoic tonalitic-throndjemitic gneisses. amphibolites and medium to high grade supracrustal rocks	Pre-Brasiliano units

Figure 11: Stratigraphic column of the Dom Feliciano Belt.
* These units have been strongly deformed by the Dom Feliciano Event

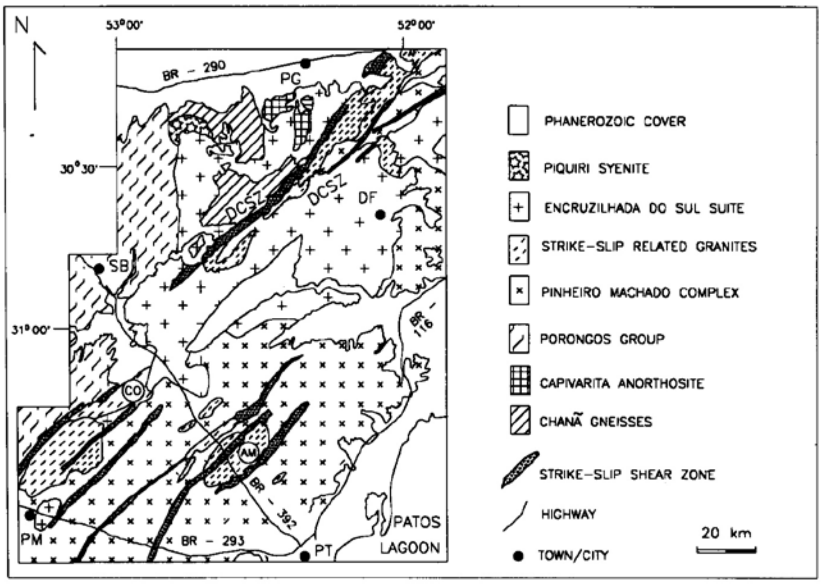

Figure 12: Geological map of the Dom Feliciano Belt in Rio Grande do Sul state, after Chemale *et al.* (1995). AM = Arroio Moinho Metagranite, CO = Cordilheira Metagranites. Localities as DF = Dom Feliciano, PG = Pantano Grande, PT = Pelotas, PM = Pinheiro Machado and SB = Santana da Boa Vista. DCSZ = Dorsal do Cangaçu Shear Zone.

terpreted as a crustal melt magma (I-Caledonian type) with metaluminous character (Basei, 1985; Silva, 1991; Frãgoso-Cesar, 1991).

Piquiri Syenite

The Piquiri Syenite is a hook-shaped, homogeneous, 130 km^2 batholith (lost *et al.*, 1985) (Fig. 12), situated close to Pantano Grande. It consists of syenite with large K-feldspar phenocrysts (<5%) and orthoclase, hornblende and diopside; accessories include quartz, microcline, plagioclase and biotite, sphene, ilmenite, apatite and zircon. The syenite contains a characteristic igneous banding. There is no agreement with respect to emplacement age, but it should be late- to post-orogenic with respect to the Dom Feliciano Orogeny. It is intruded by the Encruzilhada do Sul granitic rocks.

Passo da Fabiana Gabbros

They are undeformed basic-ultrabasic bodies, tens to a few square kilometers large (Frãgoso-Cesar, 1986) which are exposed close to Pinheiro Machado and Dom Feliciano localities. They are stratiform basic-ultrabasic lenticular bodies distributed in the Dom Feliciano Belt. A magnetic survey by Costa *et al.* (1990) in the Pelotas Block shows possible NE-SW-oriented km-size bodies in the subsurface, which may be related to the Passo da Fabiana Gabbros.

Late to post-tectonic associations related to the Dom Feliciano Event in a foreland situation

There is an important magmatic and sedimentary manifestation in foreland portions of the granitic-gneissic-migmatitic Dom Feliciano Belt (e.g. where it is overlying Palaeoproterozoic basement and the Vila Nova Belt) that has a minor to non-deformed, well preserved lithological record. These rocks are represented by foreland sedimentary, volcanic-sedimentary rocks and granitic plutons of various sizes (Fig. 4) which were generated just after the main tectonic phases of the Dom Feliciano event (around 600 Ma).

The Piedras de Afilar Formation is a cratonic cover succession deposited on the Uruguayan Palaeoproterozoic greenstone belt and mafic dyke swarm units probably during the Neoproterozoic (Frãgoso-Cesar, 1991). It is represented by sandstone, pelite and carbonate rocks which are undeformed or weakly deformed and which reached only anchimetmorphic grade.

The Santa Maria Chico Granulite Complex rocks are intruded by the Santo Afonso Suite (SA on Fig. 4) which consists of a monzogranitic batholith with subvolcanic dacites intruded by bodies of perthite-granite containing riebeckite and aegerine (Hartmann and Nardi, 1982). The dacites are probable the hypabyssal manifestation of the monzogranite batholith, because the monzogranitic and dacitic rocks display the same subalkaline geochemical signature. On other hand the perthite-granites have an alkaline tendency. Rb-Sr radiometric data yield an isochron of 586 ± 32 Ma for the monzogranite (analytical data from Soliani, 1986). Because they are undeformed and have high $^{87}Sr/^{86}Sr$ initial ratio, these units are interprete as post-tectonic crustal melts.

To the western portion of the Santa Maria Chico Complex the Taquerembó volcanic rocks are exposed, consisting of alkaline, subhorizontal stratified ignimbrites.

However, in the Vila Nova Belt and in the Santa Catarina Granulite Complex region the two large plutono-volcanic-sedimentary associations are exposed, the Itajaí and Seival Associations. They were the loci for deposition of the volcano-sedimentary detritus from the Dom Feliciano Belt to the east. But sedimentation and related volcanism also occurred during the post -strike-slip phase of the Dom Feliciano event.

Itajaí plutono-volcanic-sedimentary Association

This association consists of the Itajaí Group, Apiúna Rhyolites and Subida Granites. The Itajaí basin is situated in Santa Catarina State (Fig. 3), on the foreland of the Dom Feliciano Belt. It is coeval to the late-orogenic units of the Camaqu basin (RS). Three main sequences have been described in the Itajaí basin (Silva and Dias, 1981; Krebs, 1992; Rostirola and Soares, 1992). The first comprises continental to platform deposits represented by a fining-upward sequence composed of conglomerates, sandstones and shales. The second is a dominant deep-water fining-upwards sequence represented by paraconglomerates, sandstones, rhythmites and lamites, corresponding to turbiditic subaqueous fan deposition. The third sequence is a transgressive package represented by rhythmites, shales and mudstones. A fourth sequence, described by Rostirola and Soares (1992), may represent a regressive coastal system with sandstones, mudstones and conglomerates. However, Krebs (1992) interpreted this sequence as representing tectonic inversion caused by thrusting of the first sequence over the third. There are intercalated acid tuff layers in all units. Structural data analyses suggest brittle-ductile deformation in a dominantly strike-slip regime, with a thrusting component.

The Apiúna/Campo Alegre Rhyolites and the Subida Granite intruded the sequence between 535 and 523 Ma (recalculated Rb-SR WR data after Basei, 1985, in Chemale *et al.*, 1995), coeval with the Acampamento Velho Rhyolites and related plutonic rocks of the São Gabriel Block.

Epizonal plutons of peralkaline composition intrude the Santa Catarina Granulite Complex and Itajaí and Campo Alegre basins (Fig. 3). These 535 ± 22 Ma old plutons (recalculated Rb-Sr WR data after Basei, 1985, in Chemale *et al.*, 1995) consist of perthitic- and syenogranite with riebeckite and arfvedsonite.

Seival Plutono-volcanic-sedimentary Association

This magmatic-sedimentary association is widely distributed in southernmost Brazil and occurs in the Vila Nova Belt. It comprises late- to post-tectonic granitic bodies including volcanogenic (mostly pyroclastic and flow tuffs) and sedimentary sequences. The sub-volcanic and plutonic units show local crosscutting relationships with the supracrustals.

The **Camaqu basin** is the most extensive depositional locus of such sequences, including all lithological units attributed to the late- to post-tectonic volcano-sedimentary records of the Brasiliano Cycle, related to the Dom Feliciano event. The basal units are represented by the Maricá Formation (Ribeiro and Fantinel, 1978) which are affected by thrusting and younger dextral strike-slip zones in ductileruptile conditions. These units correspond also to the first depositional sequence as proposed by Paim *et al.* (1991) that represent alluvial, deltaic and lacustrine/marine systems, faulted and folded.

Overlying the Maricá Formation occurs the Bom J ardim Group, which is made up of alluvial, deltaic and lacustrine rocks with intercalated volcanogenic deposits (Wildner and Lima, 1992). Basic traps less than 3 m thick represent the first volcanic manifestation of this group. They correspond to basalts and traqui-basalts with a high-K calc-alkaline (Caçapava do Sul region) to shoshonitic affinity (Lavras do Sul region). The shoshonitic volcanism, which is the major component, includes traqui-basalts to rhyolites. However, traqui-andesitic rocks are widely distributed (Nardi *et al.*, 1992) throughout the unit. The intrusive terms are the rocks in the core of the Lavras Granite (LG on Fig. 4), Sao Manoel (SM on Fig. 4) and Santa Rita Monzogranites (SR on Fig. 4). The volcanic intermediated rocks belong to the Hilário Formation.

SiO_2-supersaturated, alkaline volcanic rocks occur as ignimbritic rhyolites, usually on the top of this group. They correspond with the Acampamento Velho. The Jaguari (JG on Fig. 4), Sao Sepé (SS on Fig. 4) and Santa Zélia Granites are coeval acid intrusions, with some alkaline signature.

The Santa Barbara and Guaritas Formations (Ribeiro and Fantinel, 1978), which are usually subhorizontal to slightly tilted, were deposited in an angular conformity on the rocks of the Maricá Formation and Born Jardirn Group.

The Santa Barbara Formation is represented mainly by clastic sedimentary rocks formed-in an alluvial to deltaic system, while the Guaritas Formation was also developed in alluvial to deltaic systems (Paim *et al.*, 1991), but with an important eolian record at its top. The volcanic rocks of the Guaritas Formation (top of the Camaqu Basin deposits) are included in the Rodeio Velho Member which is dominately of traqui-andesites to basalts. They are related to fissure volcanism formed during the Brasiliano orogen collapse (around 500 Ma).

The available Rb-Sr and K-Ar data imply ages of 570 to 530 Ma for volcanic rocks of the Born Jardim Group and its related intrusive bodies (Soliani, 1986; Vieira and Soliani, 1989). Therefore, the units of the Maricá Formation are probably older than 570 Ma, and the Santa Barbara and Guaritas Formations younger than 530 Ma.

Proposed tectonic model

The geological evolution of the region is rather complex, placing side by side older Palaeoproterozoic units and younger Neoproterozoic to Eo-Palaeozoic units.

The Santa Maria Chico (Fig. 4) and Santa Catarina granulitic terranes (Fig. 3) are dominantly tonalitic to trondhjemitic in composition, and were probably accreted in the Archaean with the main granulite-facies metamorphism taking place in the Palaeoproterozoic. In Uruguay, the granite-greenstone terranes (Fig. 2b) were probably formed in the Palaeoproterozoic and stabilised at approximately 1800 Ma as indicated by the emplacement of mafic dike swarms (Bossi *et al.*, 1993). Rocks in all these terranes present a conspicuous gneissic banding that differs markedly from planar structures in the younger units, because they are weakly affected by the Brasiliano deformational events.

All the remaining units were generated and/or intensely deformed in the Brasiliano Cycle. This cycle was dominated by two major tectonic events, the São Gabriel and Dom Feliciano events (Chemale *et al.*, 1994a and b), with tectono-metamorphic peaks at 753-704 and around 600 Ma respectively.

The Vila Nova Belt corresponds to one of the few areas of juvenile crustal accretion in the Brasiliano Cycle, with rocks displaying positive Nd (t= 700) values and Tdm between 1.0 and 0.58 Ga (Babinski *et al.*, in prep.). The granitic-gneissic Cambaí Complex shows a low Sr^{87}/Sr^{86} initial ratio (0.704) (Soliani, 1986) and U/Pb zircon age of 704 ± 13 Ma (Chemale *et al.*, 1994a). The calc-alkaline volcano-sedimentary association of the Vacacaí Supergroup were deformed in conditions of greenschist to amphibolite facies, with a U/Pb zircon age of 753 ± 2 Ma (Machado *et al.*, 1990). A tentative model proposed here relates the tonalitic gneissic-granitic terrane and the mafic-ultramafic and the volcano-sedimentary sequences in a context of an oceanic lithosphere, probably formed at the end of the Mesoproterozoic or beginning of the Neoproterozoic. The contained basin was strongly deformed during the Brasiliano Cycle, mostly around the dated São Gabriel orogenic Event of 750-700 Ma and later the ca. 600 Ma Dom Feliciano Event. NW-SE shear zones like the Ibaré Lineament have been considered transform faults (Frãgoso-Cesar, 1991; Fernandes *et al.*, 1992). This lineament forms the contact between the Vila Nova Belt and the Santa Maria Chico Granulite Complex. The contact between the Vila Nova Belt and a possible Rio de La Plata Craton, as presented by Ramos (1988), is still undefined. The tectonic structures of the Vila Nova Belt suggest mass transport from NW to SE and subsequent dextral movement in a NE-SW direction, that may be associated with an eastward downward subducting slab at 700-750 Ma as well as with deformational processes of the Dom Feliciano Event.

The Tijucas Belt (Fig. 1b) corresponds to an intracontinental basin that may have evolved into a small ocean during the Mesoproterozoic. Its basement still preserves the older Trans-Amazonian structures. The later Dom Feliciano event strongly affected this basin, leaving only a preserved NE-SW elongated belt.

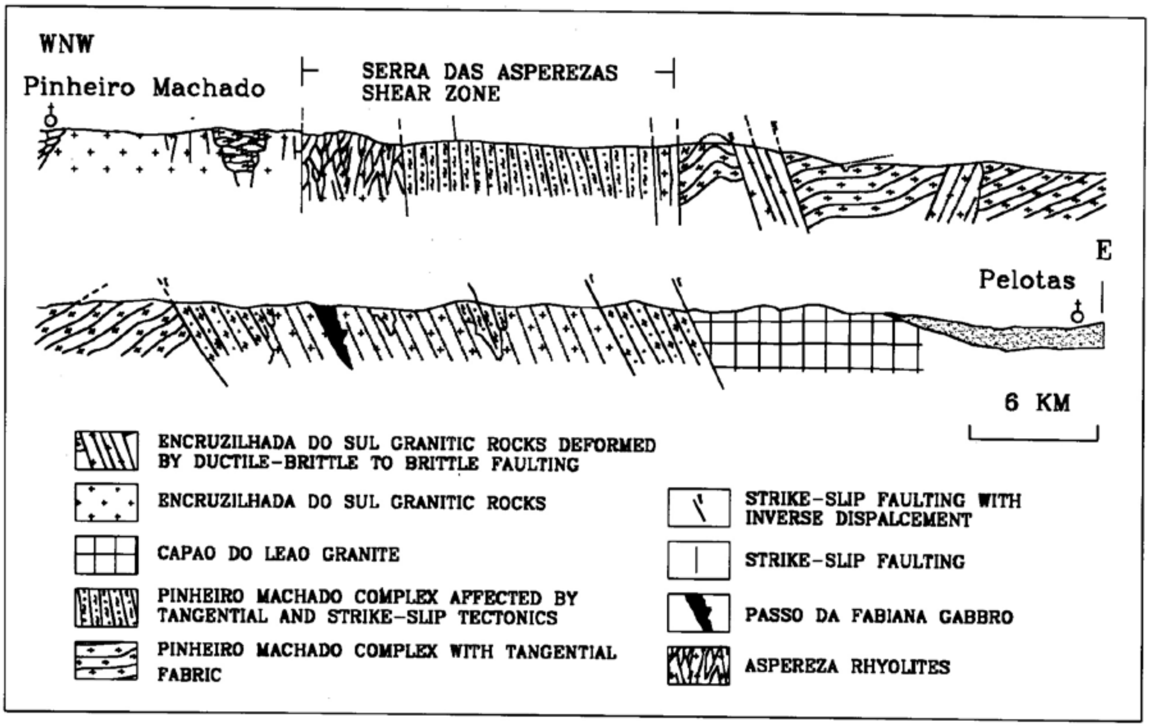

Figure 13: Geologic section along the Dom Feliciano Belt (RS), after Frãgoso-César (1991), from Pinheiro Machado town to Pelotas city (see highway BR-293 on Fig. 12).

The Dom Feliciano Belt corresponds to a granitic-gneissic-migmatitic terrane of pre-Brasilia no crustal accretion, strongly deformed and metamorphosed during the Brasiliano Cycle. Many granitic intrusions were formed around 600 Ma by crustal fusion. This proposal contradicts previous models (e.g. Frãgoso-Cesar, 1992; Fernandes *et al.*, 1992), which included the formation of a Brasiliano Cycle magmatic arc at 800 Ma (Rb/Sr data). Recent Pb/Pb zircon data show that the Dom Feliciano Belt contains older remnants of Archaean and Palaeoproterozoic age and abundant younger high-K calc-alkaline to sub-alkaline Brasiliano granites resulting from the fusion of the older crustal components (Chemale *et al.*, 1994b). This view is supported by Sm/Nd data (Mantovani *et al.*, 1987; Basei, 1990) showing negative epsilon Nd values for all units in the belt and also by the high Sr^{87}/Sr^{86} values (Soliani, 1986). The crustal fusion may have been caused by the underplating of basic magmas, which are not abundant but are widespread in the belt, or else by the presence of a hot mantle plume below the crust in the Neoproterozoic. In the Dom Feliciano Belt there are two structural phases, the first is associated with NW-verging thrust tectonics that generated a flat-lying fabric, and evolved to NE-SW-trending strikeslip shear zone (Fernandes *et al.*, 1992).

The late- to post -tectonic granitic rocks in the Dom Feliciano Belt are synchronous with the plutono-volcano-sedimentary Itajaí and Seival Associations. These associations are a foreland manifestation of the Dom Feliciano event around 600 Ma, overlying or intruding the older units such as Palaeoproterozoic granulite complexes (SC, RS) and the Vila Nova Belt units (RS). Opposite to their basement, the rocks of both associations are not metamorphosed, just deformed by NW-verging ductile-ruptile thrusting and transcurrent shear zones. The intermediate and upper stratigraphic sections of the Seival Association were formed in a transtensional tectonic setting, while the basal ones (Maricá Formation and Itajaí Group units) in a thrust tectonic setting. However, the post-tectonic magmatic and sedimentary manifestation, i.e., post-transcurrent rocks, are interpreted to be formed during the orogenetic collapse of the Dom Feliciano Orogeny (younger than 530 Ma), generating a small-volume widespread post-orogenic alkaline magmatism.

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