



*The 8th Hutton Symposium on
Granites and Related Rocks*

*Mid-meeting Field Trip
September 23, 2015*

**Neoproterozoic granites and Mesozoic dykes
at some postcard sites of Santa Catarina Island**

EXCURSION GUIDE



Excursion Leaders

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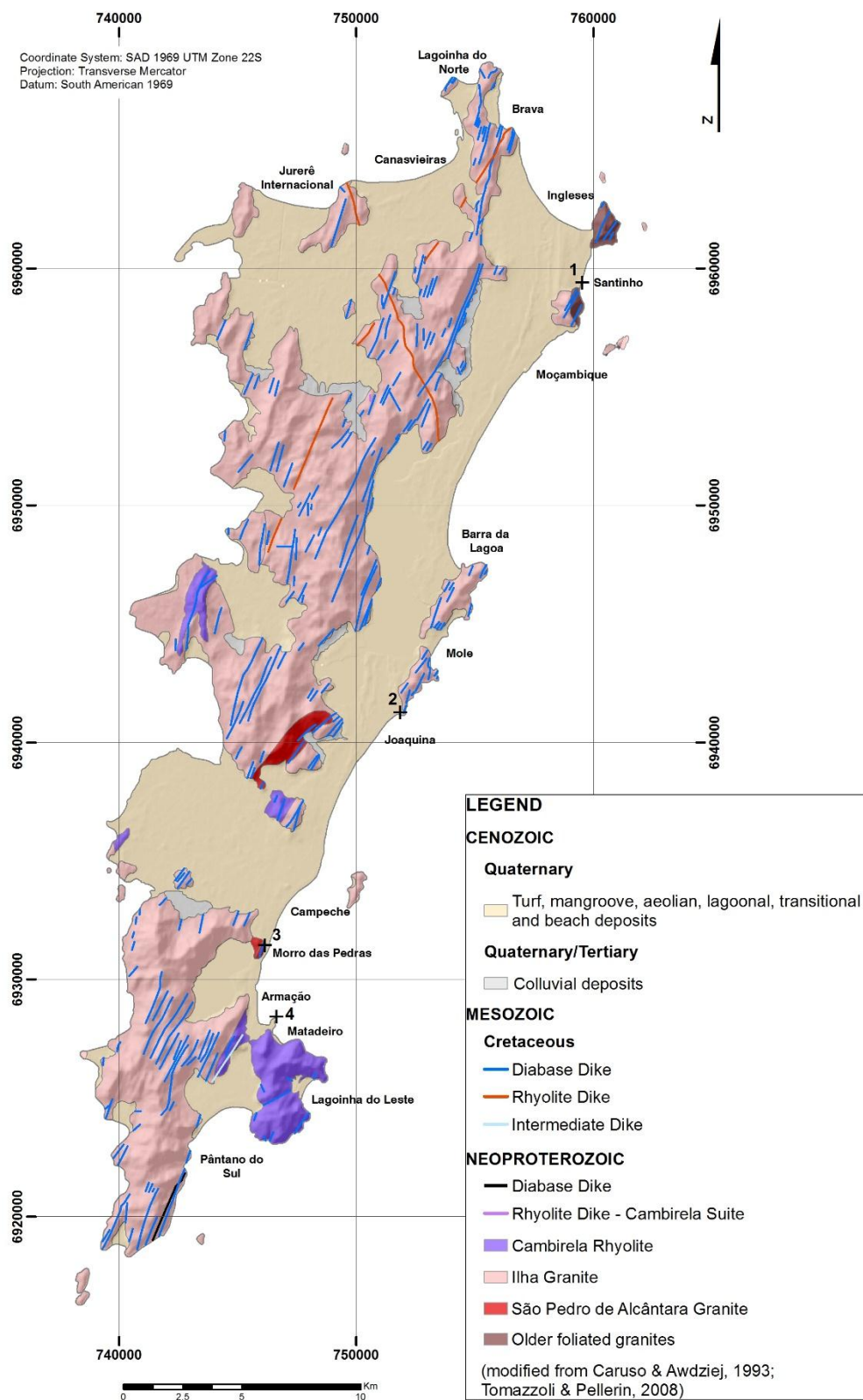
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Simplified Geological Map of Santa Catarina Island with location of Stops



SANTINHO TRAIL



View from Stop 1.1



View of the Costão do Santinho Resort and the cliffs of the Santinho Trail.

JOAQUINA BEACH



Rock exposure at the Joaquina cliff showing the Ilha Granite intruded by a diabase dyke.



Entrance of the Joaquina cliff.

MORRO DAS PEDRAS



View towards south from Morro das Pedras.



The outcrop at Morro das Pedras

ARMAÇÃO AND MATADEIRO BEACHES



Armação Beach and the small peninsula that separates it from Matadeiro Beach.



Trail from Armação to Matadeiro.

Mid-Conference Field Trip

Neoproterozoic granites and Mesozoic dykes at some postcard sites of Santa Catarina Island

The traditional Hutton mid-conference field trip will be held on Wednesday September 23, beginning and ending at the Oceania Convention Center (Departure: 8:30 h; Estimated Arrival: 18:00 h). Participation is free for all Hutton attendants.

Three different options are offered, allowing to take into account different interests of the participants. Most attendants have already adhered to one of these options after registration; a preliminary list of participants in each option was distributed previously, and any changes or new adhesions may be arranged at the Secretary until 14:00 h of Tuesday September 22.

FT-4A (maximum 40 attendants) (leader: Prof. Miguel Basei, with collaboration of Natasha Marteleto and Vinicius Correia): **Santinho Trail** (morning) and **Joaquina Beach** (late afternoon). **Important:** Santinho Trail involves access to some key outcrops through moderate difficulty trails and along coastal cliffs. It will require up to one hour walking through hilly terrain and equivalent time along coastal cliffs. Not recommended for those who circumstantially are not in their best physical condition.

FT-4B (maximum 40 attendants) (leaders: Profs. Breno Waichel and Luana Florisbal): Cambirela Ignimbrites and Granites at **Armação and Matadeiro beaches** (morning), **Joaquina Beach** and **Morro das Pedras Granite** (afternoon).

FT-4C (estimated 80 attendants) (leaders Profs. Profs. Valdecir Janasi, Maria de Fátima Bitencourt and Lucelene Martins): **Joaquina Beach** (morning); **Armação and Matadeiro beaches** (afternoon).

Part I. General aspects of the Geology of Florianópolis

Over its approximate area of 424 km², the Santa Catarina Island offers a remarkable diversity of beautiful landscapes, and a significant variety of geological features. Apart from sedimentary deposits related to recent dynamics (dune fields, beaches, etc), the island is basically composed of Neoproterozoic granites intruded by several Cretaceous dykes of the Florianópolis Dyke Swarm, dominantly of basalt composition.

The Neoproterozoic granites are part of the Florianópolis-Pelotas-Aiguá Batholith (FPAB), a major feature in the evolution of southeastern South America running along the Brazilian coast in the states of Santa Catarina and Rio Grande do Sul and reaching Uruguay (Fig. 1). A possible correspondent in the African side would be the Coastal Terrane of the Kaoko Belt in Namibia (Goscombe & Gray, 2007; Basei *et al.*, 2005, 2015). The FPAB has a distinctive isotope signature (e.g., Nd T_{DM} ~1.4-1.6 Ga; ²⁰⁶Pb/²⁰⁴Pb > 18.0) that sharply contrasts with that of domains to the west (inland), with several exposures of older basement, older crust formation age (Nd T_{DM} > 2.0 Ga), more unradiogenic Pb and low time-integrated Rb/Sr (Basei *et al.*, 2008; Florisbal *et al.*, 2012).

Although the age of collision between the FPAB and the older inland domain is still controversial, its largely granitic composition and younger isotope signature have led several authors to admit that it would correspond to a magmatic arc terrane produced by consumption of a former (Adamastor) ocean. However, calc-alkaline granites typical of magmatic arcs are scarce, notably in the Florianópolis region, where shallow-level A-type granites are largely predominant. These A-type granites may be interpreted as products of remelting of older plutonic rocks that would make up most of the unexposed deeper crust. Several authors consider the FPAB as part of a post-collisional granitic belt involving also the inland Domain north of the Major Gercino Shear Zone (Fig. 1; Bitencourt & Nardi, 1993, 2000; Philipp & Machado, 2005; Oyhantçabal *et al.*, 2007; Florisbal *et al.* 2009, 2012).

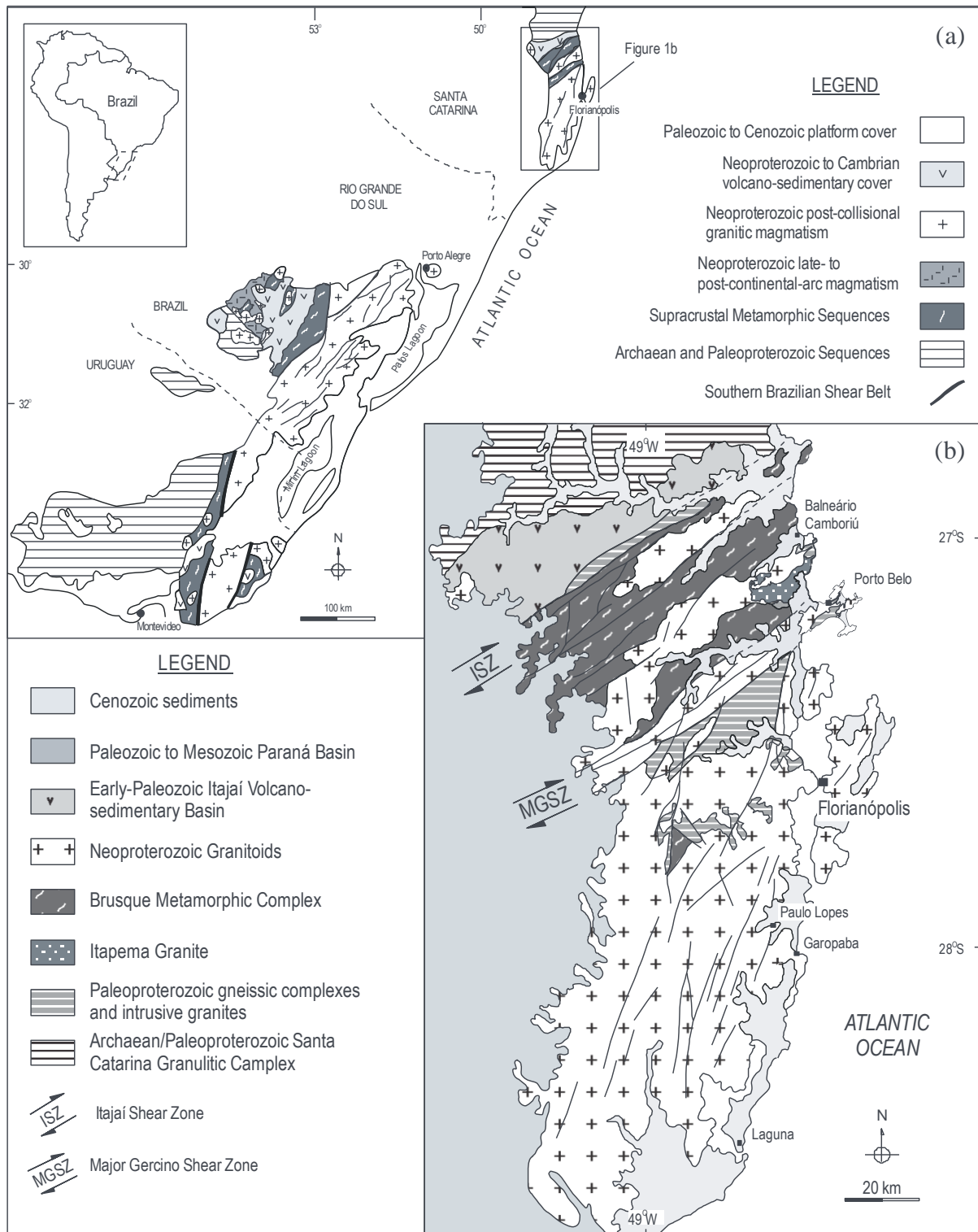


Figure 1.1. Tectonic sketch of the Precambrian geology of South Brazil (modified from Nardi & Bitencourt, 2009).

1.1. Neoproterozoic granitic magmatism

U-Pb zircon ages available in the literature indicate a ~70 Ma (650-580 Ma) range for granitic magmatism in the Florianópolis Batholith. The oldest occurrences, dated at ~650 Ma (Chemale Jr. *et al.*, 2011) correspond to local remnants of orthogneisses with tonalitic to granodioritic composition.

The 625-610 Ma time range is characterized by the intrusion of metaluminous to peraluminous granites of dominantly calc-alkaline affinity that are predominant at the northern portion of the batholith (*e.g.*, Major Gercino and Porto Belo regions; Bitencourt & Nardi, 1993, Passarelli *et al.*, 2010; Florisbal *et al.*,

2012), where these rocks were emplaced under the influence of the Major Gercino Shear Zone, and are usually strongly foliated and deformed. Southward, granites within the same age range are less deformed and were grouped into two suites: Paulo Lopes (porphyritic calc-alkaline granites dated at 626 ± 8 Ma by Silva *et al.*, 2003) and Garopaba (inequigranular granites, as yet undated) (Bitencourt *et al.*, 2008; Florisbal *et al.*, 2009).

A variety of younger, granites showing very little solid-state deformation were emplaced within a short time interval (590-580 Ma) and are predominant in the southern part of the Florianópolis batholith where they are grouped as Pedras Grandes and Cambirela suites, both with A-type character, the latter including extrusive (dominantly pyroclastic) rocks (Bitencourt *et al.* 2008). Magmas of equivalent composition and age are emplaced along the major transcurrent shear zones to the north, and grouped as the Zimbros Intrusive Suite (Bitencourt & Nardi 1993). Contemporaneous, less fractionated granites of calc-alkaline affinity occur locally as in the Morro das Pedras, in Florianópolis, and are grouped as the São Pedro de Alcântara suite (Basei *et al.* 2008; see stop 3.).

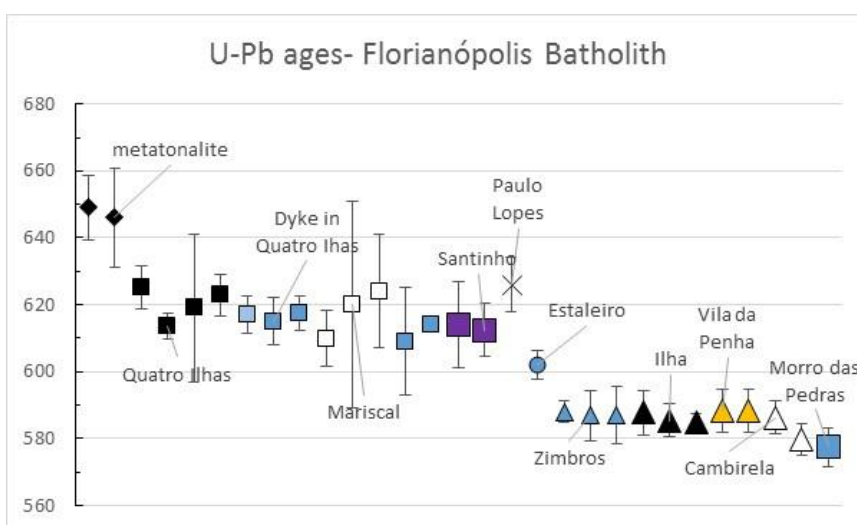


Figure 1.2. U-Pb zircon ages of granites from the Florianópolis Batholith compiled from Chemale Jr. *et al.* (2011), Passarelli *et al.* (2011), Florisbal *et al.* (2012), Janasi *et al.* (2015) and Silva *et al.* (2003). All reported errors at 2σ .

A major contrast exists between the undeformed A-type granites of ~590-580 Ma and the older (650-610 Ma) granites of dominantly calc-alkaline signature. The A-type granites (among which the Ilha Granite and Cambirela Ignimbrite will be visited in this field trip) are typically high-silica (76-78 wt% SiO_2) rocks, their extreme fractionation being also underlined by very low Sr (<80 ppm) and high Rb/Sr (6-11). Their reduced character is indicated by very high Fe/Mg ratios. Both are characterized by REE patterns with strongly negative Eu anomalies ($\text{Eu}/\text{Eu}^* \sim 0.25$); the Cambirela Ignimbrite has moderate REE fractionation ($(\text{La}/\text{Yb})_N = 14-24$) whereas the typical Ilha Granite is less fractionated ($(\text{La}/\text{Yb})_N = 4-6$) and may show seagull-wing REE patterns.

An exception among the younger granites are the hornblende-biotite granites from the São Pedro de Alcântara suite, which are less fractionated (68-72 wt% SiO_2), and plot in the calc-alkaline or oxidized A-type fields and show higher Sr (~200 ppm) and lower Fe/Mg. REE patterns are moderately fractionated ($(\text{La}/\text{Yb})_N = 14-24$, with moderate negative Eu anomalies ($\text{Eu}/\text{Eu}^* = 0.6-0.7$). The São Pedro de Alcântara granites are distinguished from the older calc-alkaline granites of similar silica contents especially by their higher Fe/Mg and Ba/Sr ratios. The granite at stop 3 (Morro das Pedras) belongs to this suite.

The older (~610 Ma) calc-alkaline granites exposed in the Santinho trail (stops 1.1 to 1.3) have a compositional spread from tonalite to leucogranite. Apart from lower Fe/Mg ratio, they are characterized by higher Sr and lower Ba/Sr even when compared to older granites from other portions of the FB. REE patterns are fractionated, with slightly negative (tonalite) to positive (leucogranite) Eu anomalies.

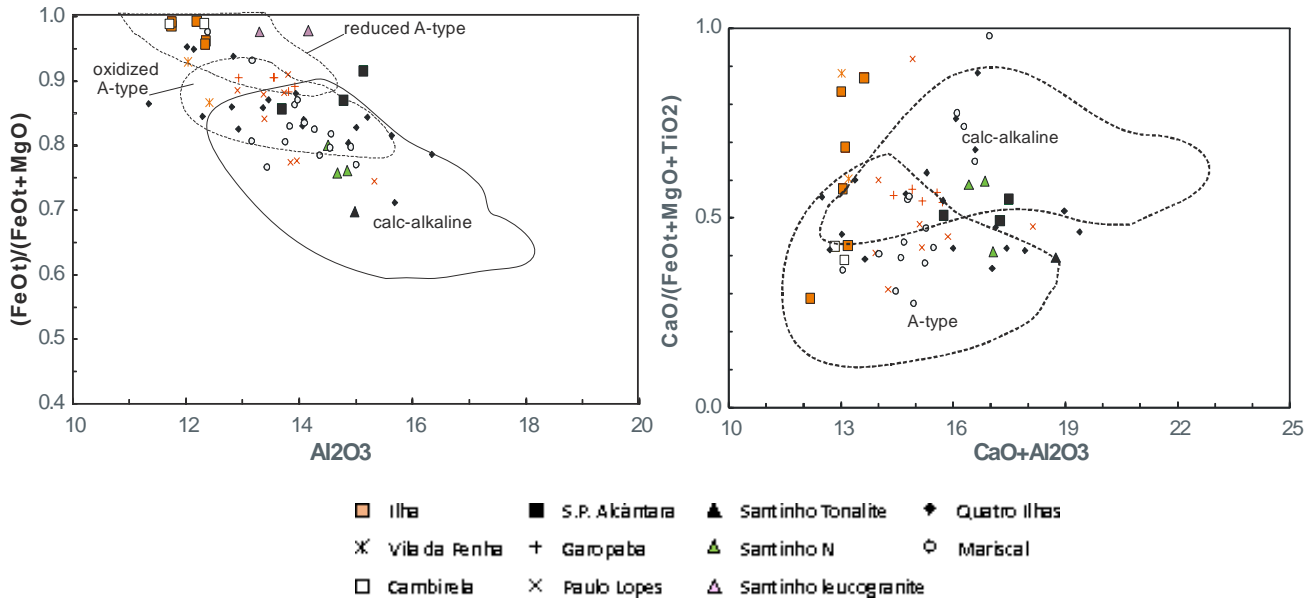


Figure 1.3. Geochemical classification diagrams for granites of the Florianópolis Batholith. Fields from Dall'Agnol & Oliveira (2007). Data from Florisbal *et al.* (2009, 2012), Janasi *et al.* 2015 and V.X. Correia (unpublished).

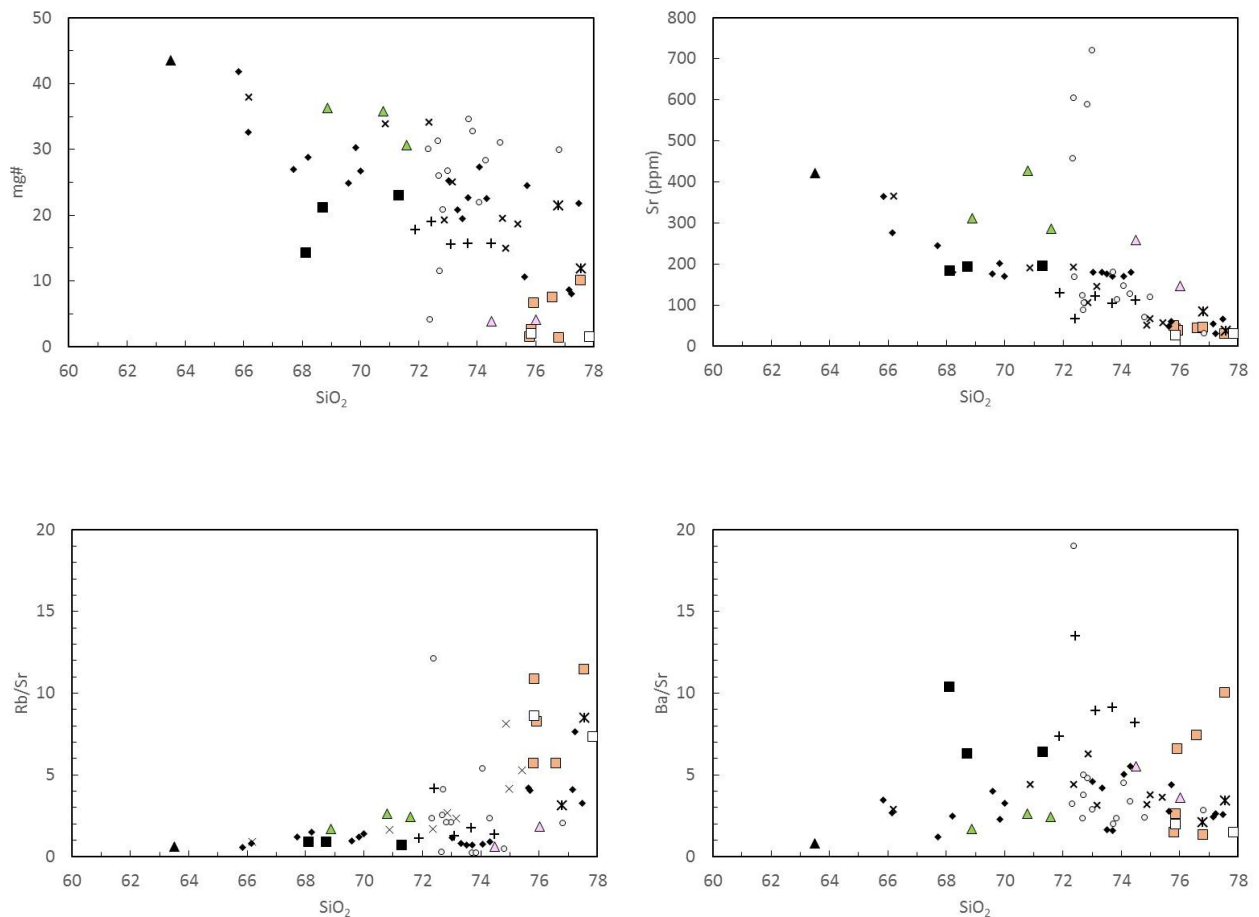


Figure 1.4. Geochemical variation diagrams for granites of the Florianópolis Batholith. Data from Florisbal *et al.* (2009, 2012) and unpublished data from Janasi *et al.* 2015 and V.X. Correia.

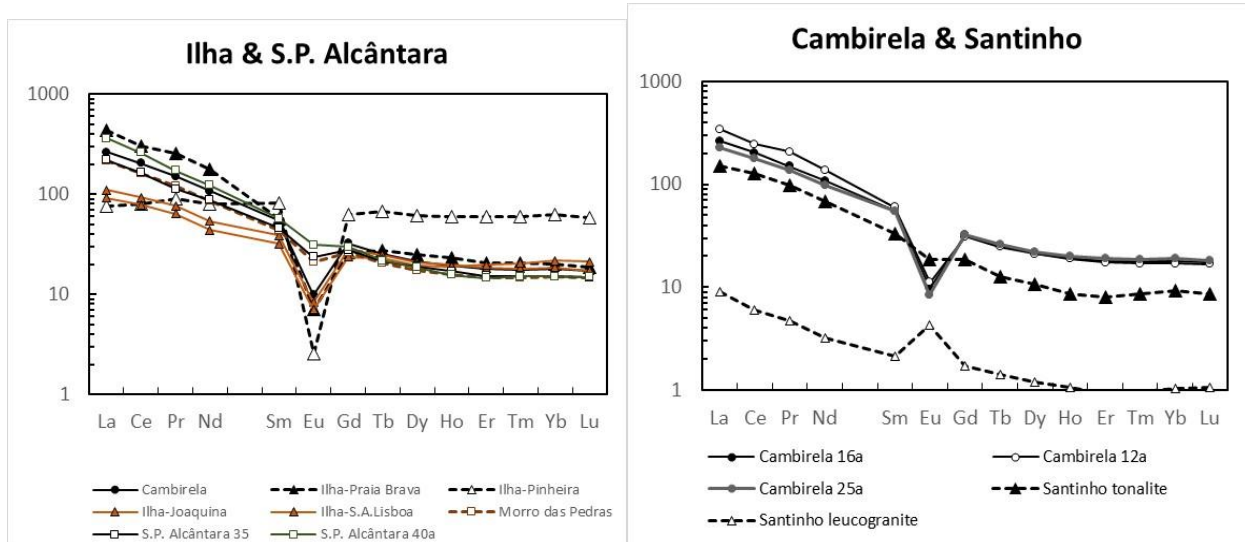


Figure 1.5. Chondrite-normalized patterns of granites from the Florianópolis Batholith (unpublished data from Janasi *et al.* 2015 and V.X. Correia).

1.2. The Cretaceous Florianópolis Dyke Swarm

The Precambrian crystalline rocks from the coastal areas of south Brazil, Angola and Namibia were exposed during post-continental break-up uplift, and are intruded by abundant Eocretacic mafic dykes/sills which must to a large extent represent the preserved plumbing system of the Paraná-Etendeka Magmatic Province (PEMP). In Brazil, this magmatism forms three extensive dyke swarms, each occupying areas of 0.05 to 0.1 Mkm², from north to south, the Santos-Rio de Janeiro, Ponta Grossa and Florianópolis dyke swarms.

The Santa Catarina Island basalt dykes are part of the Florianópolis Dyke Swarm (FDS). Dating of these dykes is based on ⁴⁰Ar/³⁹Ar dates by step-heating in plagioclase (Raposo *et al.*, 1998). Most results yielded poor plateaus, and are difficult to interpret. Three dates in the range 138-142 Ma were discarded due to Ar excess; the remaining seven ages were used to infer two age intervals at 131-127 Ma and 123-121 Ma (Raposo *et al.*, 1998) (*all data recalculated to an age of 28.201 Ma of Fish Canyon sanidine*).

Paleomagnetic data obtained from a wider sampling distribution was used to suggest that dykes younger than 127 Ma would be predominant (Raposo *et al.*, 1998). This has led some authors to interpret these dykes as representative of the youngest magmatic episode in the PEMP, related to extension of the continental crust just prior to the formation of oceanic crust.

However, recent U-Pb baddeleyite/zircon dating of three NNE-oriented dykes from the FDS south of Florianópolis revealed unvarying crystallization ages of 134.7 ± 0.3 to 133.9 ± 0.7 Ma (Florisbal *et al.*, 2014). These ages suggest that the main FDS are feeders of the early Urubici-type basalts from the Paraná lava pile, also characterized by a high Ti-P-Sr chemical signature. Florisbal *et al.* (2014) concluded that the published ⁴⁰Ar/³⁹Ar dates yield unreliable ages due to both excess Ar (associated with assimilation of country granites) and loss of Ar. Low-Ti, NW-oriented dykes that cut the main high Ti-P-Sr dykes occur sparsely in the FDS, and are potentially related to a younger episode of magmatism, but their age remains uncertain.

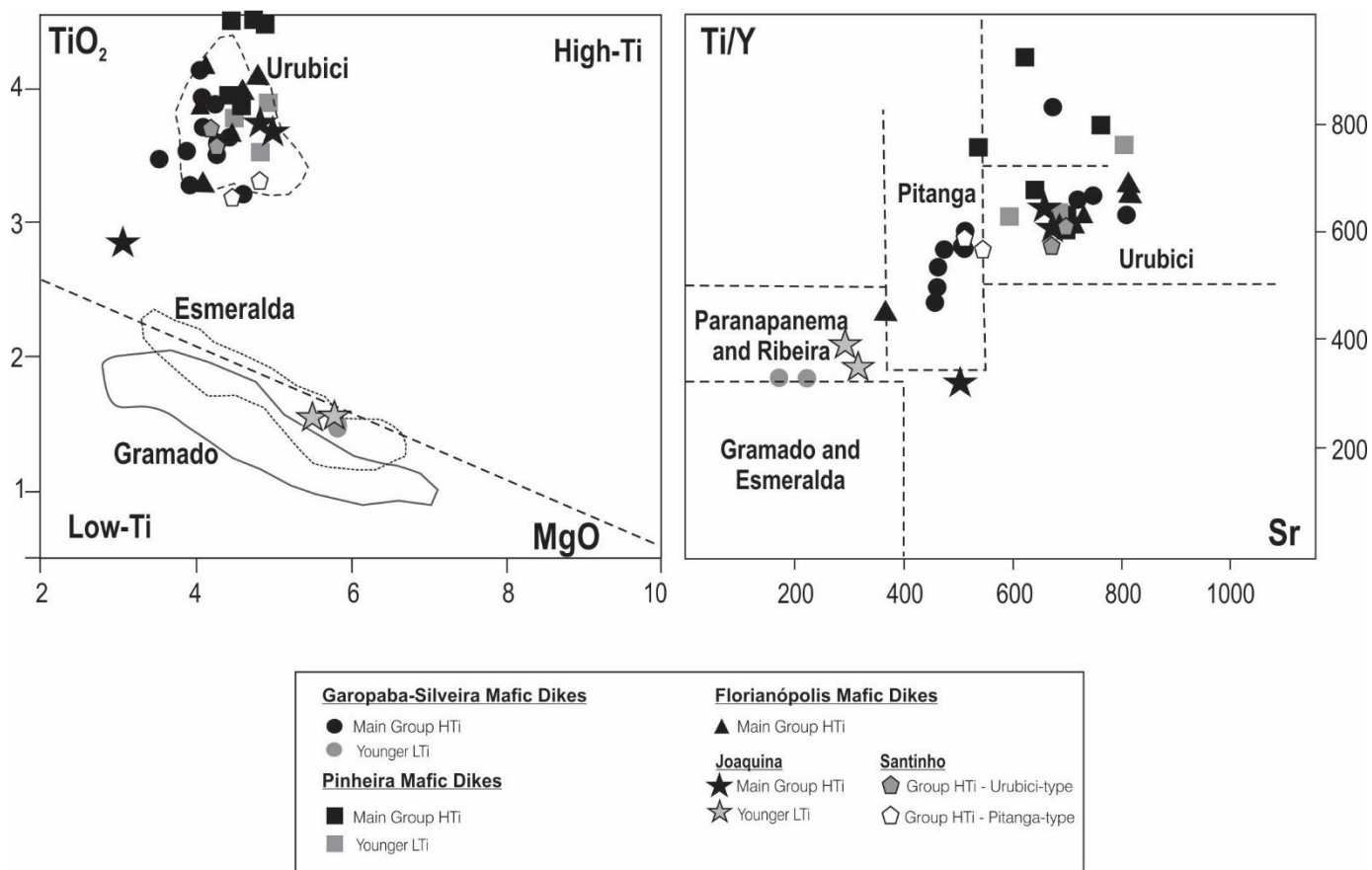


Figure 1.6. Comparative chemical data for basalt dykes from the Florianópolis Dyke Swarm and magma-types from the Paraná Magmatic Province.

1.3. Some notes on Archeology: rupestrian carvings

The Santa Catarina Island hosts a rich set of archaeological features; of particular interest for geologists are engravings produced by carving and scraping directly on the rocks (invariably basic dykes). These archaeological lithic workshop sites are characterized mainly by circular, linear (parallel or not, wavy or as bundles) and more complex geometrical patterns.

One of the most remarkable sites are the anthropomorphic engravings at Costão do Santinho (stop 1.1 of FT-4A). The very name "Santinho" comes from an inscription identified by fishermen as a "saint" due to the presence of a circle in the shape of a halo around the head.

There is some debate about the origin of these graphisms, but it is generally accepted that they represent common life scenes of a pre-historical coastal population, and that the linear and circular marks result from tool sharpening.

Part II. Description of Stops

A simplified geological map of the Santa Catarina Island with location of stops, illustrated with corresponding landscape photographs, is presented in Appendix A. Location of stops is given in UTM coordinates (zone 22J; datum SIRGAS 2000). A .kmz file (for use in Google Earth) is available for download at the Hutton website.

II.1 The Santinho Trail: older (~610 Ma) granites (FT-4A-only)

The Santinho trail, bordering the hill that separates Santinho and Moçambique beaches, begins at the Costão do Santinho Resort and is one of the only, and certainly the best, exposure of older Neoproterozoic granites in the Santa Catarina Island, elsewhere dominated by younger A-type granites.

Stop 1.1. Entrance of the Santinho trail (759257E 6959100N)

This is the site of the Costão do Santinho rupestrian carvings. These represent anthropomorphic and abstract patterns carved in diabase.

The intensity of Mesozoic basalt magmatism is revealed by the presence of three diabase dykes of N10-35E strike that locally cut each other developing chilled margins. All are chemically similar, characteristically with high Ti-P-Sr, but the dyke identified as the second in the sequence of emplacement is distinguished by more primitive signature (Fig. 1.6; Natasha Marteleto, Ms. Thesis in prep.).

The country rock is a inequigranular, heterogeneous leucogranite with fine-grained matrix bearing large, usually angulose xenoliths of foliated tonalite (Fig. 2.3), both intensely affected by cataclasis. The tonalite has a high color index (~30), but no amphibole is present; the mafic minerals comprise mostly a secondary association of biotite, titanite, Fe-Ti oxides, epidote and chlorite.

Interaction between Mesozoic dykes and country granites resulted in local remelting of leucogranite with generation of granite mobilizates; small xenoliths of granite are locally observed within the dykes.



Figure 2.1. Angulose xenoliths of biotite tonalite in strongly cataclastic leucogranite.

Stop 1.2. Gneissic tonalite interacting with leucogranite (759374 6958826)

Stop 1.2 exposes an association of strongly deformed tonalite (M~20-30) and inequigranular, very heterogeneous leucogranite that are intimately interlayered. The outcrop has the general aspect of a migmatite, and intense deformation and interaction results in a mixed rock that can be described as a migmatitic gneiss. However, the main structure possibly results from magma mingling, as both rock types behave plastically and signals of *in situ* melting are not observed. Occasional mafic-rich blocks with sharp contacts with both

tonalite and leucogranite seem to correspond to original dykes that were disrupted and transformed (Fig. 2.4). The mafic mineral association of the gneissic tonalite is the same as in stop 1.1., with biotite and abundant titanite + chlorite + epidote. The REE patterns of both tonalite and leucogranite are parallel, but the leucogranite has very low REE contents and a strong positive Eu anomaly (Fig. 1.5).

Unpublished LA-ICPMS U-Pb zircon dating indicates similar ages (~ 612 Ma) for both (614 ± 13 Ma for tonalite, 612 ± 8 Ma for leucogranite; V.Correia, Ms Thesis in prep.).

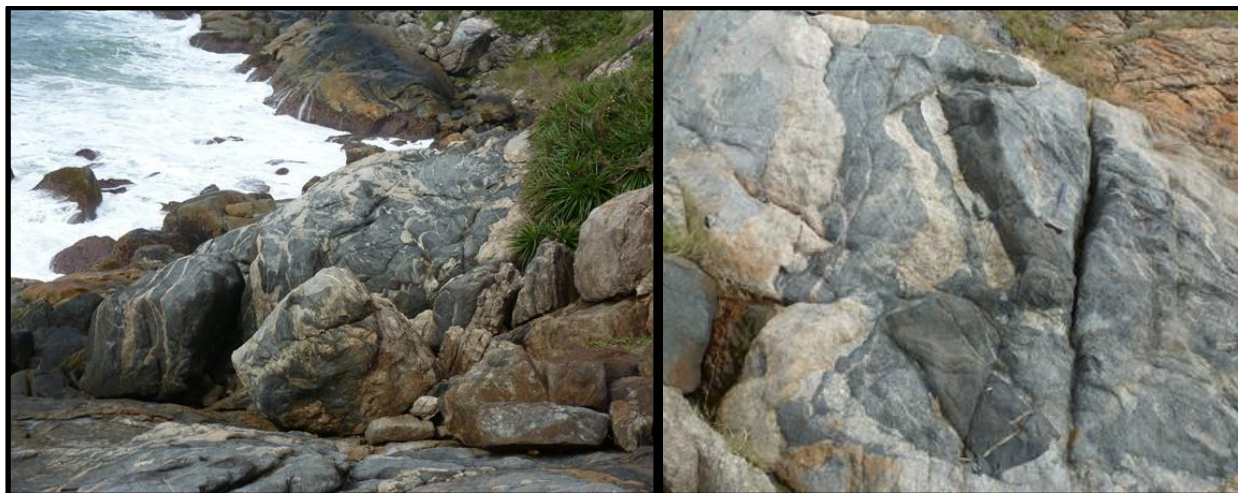


Figure 2.2. Interlayered gneissic tonalite and leucogranite. Mafic biotite tonalite as an angular xenolith in grey tonalite.

Stop 1.3. A syenogranite intrudes the gneissic tonalite (759482 6958444)

Knife-sharp intrusive contact suggest that intrusion of the younger suite of post-kinematic granites that largely predominates in the Santa Catarina Island occurred after total solidification of the older granites. The syenogranite has a slight magmatic foliation and small (cm-sized) mafic microgranular enclaves that are locally abundant and may disrupt into mafic aggregates that merge into the syenogranite matrix; some large enclaves may show drops of syenogranite melt.

A fine-grained granite with subvolcanic texture present in the walls and pavement may be related to the syenogranite, but the field relationships are inconclusive.

A large Mesozoic diabase dyke cuts the granites, and is associated with syn-magmatic faulting.



Figure 2.3. Sharp contact between gneissic tonalite and younger syenogranite



Figure 2.4. Syenogranite shows xenoliths of the gneissic tonalite, mafic microgranular enclaves and mafic concentrations.

II.2. Joaquina Beach: Ilha Granite intruded by different generations of Mesozoic basalt dykes

(752919 6941267 and 751953 6941196)

The world-famous Joaquina Beach is one of the postcards of Florianópolis and the stage for international surfing circuit competitions. Nice exposures of the Ilha Granite, the dominant A-type granite from the Santa Catarina Island, are cut by different generations of Mesozoic basalt dykes.

The Ilha Granite is a fairly homogeneous and very evolved (high-silica), coarse-grained biotite syenogranite locally cut by aplite dykes. A U-Pb zircon LA-ICPMS age obtained from this outcrop yielded 586 ± 5 Ma (V.Correia, in prep.), which is typical of other similar occurrences in the island and neighborhood.

Two generations of Mesozoic basalt dykes are present. The thickest, NNE-striking dykes, correspond to high-Ti-P-Sr basalts interpreted as the feeders for the ~134 Ma Urubici-type lavas from the lower portion of the Paraná-Etendeka Province (Floribal *et al.*, 2014). They are locally cut by two thin NW-oriented dykes with contrasted (low-Ti) chemistry (Fig. 1.6) that are also isotopically more primitive and whose age is still uncertain.

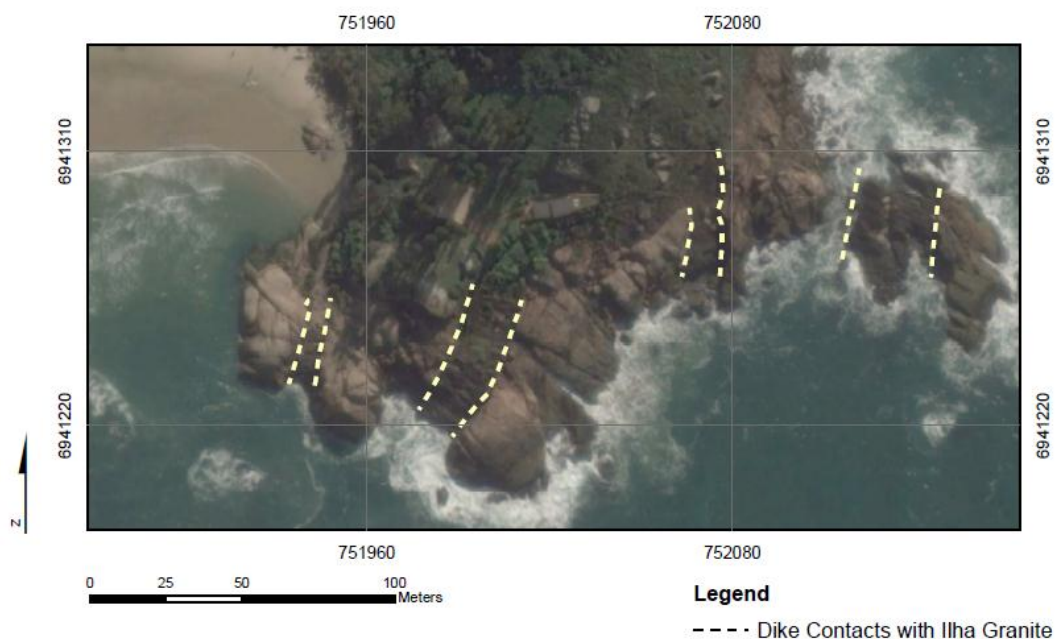


Figure 2.5 Google Earth view from above of the Joaquina cliff highlighting the NNE-oriented diabase dykes.

II.3. Morro das Pedras Granite (745907 6930973)

The granite exposed at Morro das Pedras contrasts with the predominant Ilha Granite for being more mafic-rich and not showing an A-type signature; instead, it seems more akin to high-K calc-alkaline granites.

It corresponds to a inequigranular to locally porphyritic, medium to coarse-grained biotite monzogranite with subordinate amounts of hornblende; allanite is a common accessory phase. Although foliation is poorly-developed, microstructures as chessboard-pattern subgrains in quartz crystals and recrystallization of feldspars are indicative of high-temperature, possibly near-solidus, weak deformation. Cm-sized mafic microgranular enclaves with globular to slightly elongated shape are locally observed; rounded, cm-sized felsic enclaves are less common.

Similar granites occurring sparsely in the Santa Catarina Island are correlated to the São Pedro de Alcântara suite (Fig. 2). A Shrimp U-Pb dating of the granite from this outcrop (578 ± 6 Ma; Janasi et al., 2015) reveals, however, that it is contemporaneous with the Cambirela suite.

A large dyke of medium-grained diabase intrudes the granite with mostly sharp and straight contacts.



Figure 2.6. Texture of the Ilha Granite at Joaquina (left) and Morro das Pedras Granite (right).

II.4. Armação and Matadeiro beaches: ~580 Ma pyroclastic rocks of the Cambirela suite

(746500 6927808 and 746379 6927756)

This stop exposes pyroclastic rocks of the Cambirela suite intruded by Mesozoic basalt dykes. It will be explored in a visit to a large outcrop at the small peninsula that separates the peaceful and idyllic Armação and Matadeiro beaches, followed by a small trail that leads to the Matadeiro beach.

The Cambirela ignimbrites show a well-defined compaction foliation oriented (060; 60SE); the rock has a fine-grained matrix (originally ash) and bears abundant, cm-sized, aligned fragments interpreted as original fiammes and ~0.3-0.5 cm euhedral to subhedral quartz and K-feldspar crystals. Dm- to meter-sized blocks of light-green banded rhyolite cut by abundant secondary quartz veins occur as “xenoliths” in the ignimbrite.

An ignimbrite from this outcrop was dated at 580 ± 5 Ma (U-Pb zircon Shrimp). Two populations of zircon are present, one of CL-bright (low U) crystals with “normal” δO^{18} ($+6.9 \pm 0.2\%$) and the other CL-dark with high U and low δO^{18} ($+3.4 \pm 0.4\%$) (Janasi et al., 2015).

As it is frequent in the Santa Catarina Island, more than one generation of Mesozoic diabase dykes is present. The NE-striking largest dykes correspond to high-Ti-P-Sr basalts that are locally cut by thin ENE-oriented dykes with similar chemistry.

The trail to the Matadeiro Beach shows other nice exposures of ignimbrite and its contact with a basic dyke that carries small fine-grained mafic enclaves and partially absorbed xenoliths of a hornblende-biotite granite that is similar to the granite exposed at Morro das Pedras (Fig. 2.8).



Figure 2.7. Cambirela Ignimbrite with elongate fragments (fiammes) and quartz + K-feldspar crystals (left) and a “xenolith” of banded rhyolite (right).



Figure 2.8. Left: a young thinner diabase dike cuts sharply a previous, large dyke (of similar chemistry) at Armação Peninsula. Right: coarse-grained granite and fine-grained mafic xenoliths in a diabase dyke (Matadeiro trail).

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