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Cabo de Santo Agostinho Granite, State of Pernambuco

The Only Known Cretaceous Granite in Brazil

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The Cabo de Santo Agostinho region, south coast of Pernambuco, has geological, historical and touristic aspects gathered in the same geographical area. There, it is found the Cabo de Santo Agostinho Granite (or just Cabo Granite), a semi-circular body with about 4 km², representing the only known Brazilian cretaceous granite (102±1 Ma). The Cabo Granite presents one main facies with equigranular, medium-grained texture, hosting microgranite autoliths. Petrographically, they are alkali-feldspar granites, with orthoclase, quartz and sodic plagioclase, besides amphibole (riebeckite-arfvedsonite), magnetite, allanite, fluorite and zircon. At the same time the Cabo Granite emplacement occurred, an important basic to acidic (basaltic to rhyolitic) volcanism was happening in adjoining area. So, about 102 Ma ago the region was the locus of a relatively voluminous volcano-plutonic magmatism. The rocks of the Cabo Granite comprise an acidic, alkaline, volcano-plutonic association, generated by partial melting of the continental crust. Recently, history researchers demonstrated that 400 year ago (January 26, 1500), the Spanish navigator Vicente Yañez Pinzón landed on the Suape bay, about three months before the Pedro Álvares Cabral arrival in Brazil. On the granitic promontory, several buildings were constructed (as the Nazaré village), now transformed in the Metropolitano Armando de Holanda Cavalcanti Park. This one is formed by the Nossa Senhora de Nazaré Church and the ruins of the Castelo do Mar Fort, Old Quarter, Carmelita Convent, Vila de Nazaré Cemetery and the Lighthouse Keeper. The touristic activity is one of the most important in the region, mainly because of the marvellous beaches, as those of Gaibu, Calhetas, Paraíso and Suape.
***Keywords**: Cabo Granite; Cabo Magmatic Province; Pernambuco Basin, geology, history; geotourism.*

INTRODUTION

The Cabo de Santo Agostinho region, located to the South coast of Pernambuco, presents geology, history and tourism altogether and thus constitutes an igneous and/or geotouristic site.

Geologically, it is the only region in Brazil where granitic rocks of Cretaceous age crops out, with recent ^{40}Ar-^{39}Ar of 102±1 Ma indicating its emplacement. The Cabo granite makes part of the igneous rocks of the Cabo Magmatic Province, which extends throughout the Pernambuco sedimentary basin.

Besides this geological peculiarity, the Cabo de Santo Agostinho region has also a historical meaning. Historians showed that on January 26, 1500, about three months before the arrival of Pedro Álvares Cabral to Brazil, the area was visited by the Spanish navigator Vicente Yañez Pinzón, who disembarked in the Suape Bay. Thus, for some historians the area of the Cabo Granite marks the arrival of Europeans navigators into Brazil.

This region has also buildings from the XV century: the Nazaré Church and the ruins of a Carmelita Convent and the Mar Castle Fort. Around all these historical markers, there are lots of beautiful beaches, the most known being the Gaibu, Calhetas, Paraíso and Suape ones.

GEOGRAPHICAL LOCATION AND GEOLOGICAL SETTING

The Cabo de Santo Agostinho Granite is located about 36 km south of Recife city (capital of Pernambuco State) and 9 km to southeast of Cabo de Santo Agostinho town (Fig. 1). The geographic coordinates of the center of the granite are 8°20´57" S and 34°56´49" W. The easiest access to the area may be done from Recife through the federal highway BR-101 until the Cabo de Santo Agostinho town, and then the state highways PE-60 and PE-28 to Gaibu village, reaching the granite region. Unpaved roads and tracks are more common around the granite.

SITE DESCRIPTION

Geology

At the same time the Cabo granite was emplaced some 102 millions years ago, in adjacent areas occurred an important intrusive acidic-basic volcanism (dykes and rhyolitic plugs), extrusive (rhyolites, basalts, trachytes) and even explosive (ignimbrites), forming the so-called Cabo Magmatic Province. In other words, the region where the Pernambuco basin is situated was affected by intense magmatic activity and thus very contrasted as compared to the present quietness.

This basin includes a narrow belt of sedimentary and magmatic rocks of Northeastern Brazil, cropping out on the south coast of Recife (PE). In the onshore portion, a siliciclastic unit of Aptian-Albian age, the Cabo Formation, corresponds to the rift stage evolution of that basin. Carbonate (Estiva Formation) and other siliciclastic units (Algodoais and Barreiras formations), with uncertain ages (Upper Cretaceous to Neogene-Quaternary), define the drift stage. The structural framework of the Pernambuco basin was built mainly in the upper Eo-Cretaceous (Aptian-Albian), before and during the emplacement of the magmatic rocks (Lima Filho, 1998; Jardim de Sá et al., 2003). In a regional scale, the main structures are the asymmetrical Cupe and Piedade grabens, which are separated themselves by the Santo Agostinho high (Lima Filho, 1998). These structures control the thickest piles of the Cabo Formation as well as the greatest volume of magmatic rocks.

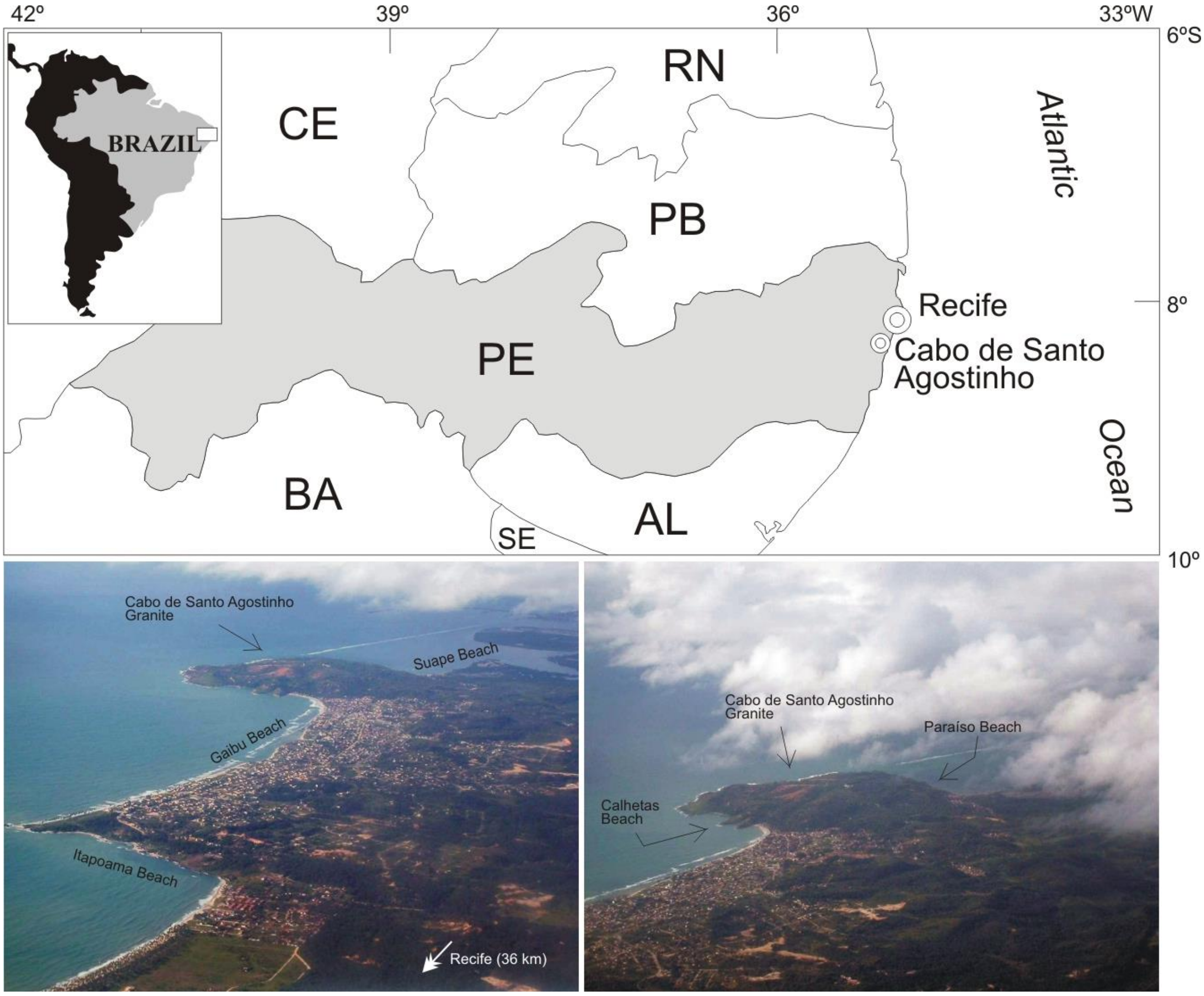

Figure 1 – Geographic location and aerial view of the Cabo de Santo Agostinho granite.

According to some authors (Sial 1976, Vandoros & Valarelli 1976, Sial et al. 1987), the Cabo granite would be related to the last stages of separation between the South America and Africa continents. Sial et al. (1987) suggest that the place where the Cabo granite is today was intercepted by the Ascension plume track, and it could be associated to the anorogenic granites from Nigeria (in the African counterpart). More recent papers (Chang et al. 1992, Lima Neto 1998) show this magmatism may reflect thermal anomalies related to the break-up of the Gondwana continent and, possibly, to the migration of the South America plate over the Saint Helene plume. The presence of this plume in region during the Cretaceous is also admitted by Wilson (1992), O´Connor & Le Roex (1992) and Golonka & Bocharova (2000).

Within the rocks of the Cabo Magmatic Province, it is worth noting the Cabo granite, that forms a promontory with a maximum height of 60m, located between the Gaibu and Suape villages. Its western border is partially covered by sedimentary rocks of the Algodoais and Barreiras formations, whereas the northern, eastern and southern ones are bounded by the Atlantic Ocean (Fig. 1).

The Cabo de Santo Agostinho Granite constitutes a small semicircular stock, with about 4 km2, of outcropping area (see geological map – Fig.2). By using geophysical data (Araújo, 1994), shallow wells (Amaral & Menor, 1979), surface structural and geological data, Cruz (2002) interpreted the Cabo granite as having a tabular shape and emplaced intrusively into the siliciclastic rocks of the Cabo Formation (see cross-section in Fig. 2).

The rocks of the Cabo Granite can be individualized into two main facies, based on field and textural observations (Fig. 3a). The dominant facies is a medium- to coarse-grained, grayish to light-pink granite, whereas the other one comprises fine-grained gray microgranite autholites, which form irregular or, eventually, elliptic bodies which are present mainly in the northeastern and eastern borders of the pluton. In its easternmost portion, the Cabo Granite contains magmatic breccias, which are composed of fragments and blocks of equigranular, rounded to subangular, grayish, finer-grained granite (Figs. 3a, 3b). Both facies have millimetre- to decimetre-size miariolitic cavities, infilled by euhedral white quartz and black tourmaline crystals. These cavities are generated by the exsolution of a flowing phase under low lithostatic pressure, allowing estimating a depth about 1 to 2 km to their formation (Thorpe and Brown, 1999). These cavities and the widespread occurrence of granophyric texture indicate that the Cabo Granite crystallized in a high crustal level (Nascimento et al., 2002).

Along its southern border, the Cabo Granite presents medium-grained, equigranular, monzonites, that show sharp contacts with the main granite facies (Fig. 3c). The monzonites can be clearly distinguished because of its darker color and absence of quartz when compared to the granite.

A number of pseudotachylyte dikes outcrops along the southern and northeastern borders of the Cabo Granite. The dikes cut both granites and monzonites (Figs. 3d, f), defining a brittle deformation event after emplacement and cooling of these lithotypes. Usually, the pseudotachylytes are black and have cryptocrystalline to vitreous texture and angular to subrounded clasts from the hosting granites and monzonites.

Finally, medium- to coarse-grained porphyritic rhyolites, with millimetric-size quartz and sanidine phenocrysts, occur as E-W directed, steep to gentle-dipping dikes (Fig. 3e). The orientation of the dikes indicates a main N-S extension at the time of their emplacement. The contacts between the dikes and the other rocks (Cabo Granite, monzonites and pseudotachylytes) are typically intrusive (Fig. 3f).

Petrography

The modal composition and the textures of the rocks of the Cabo de Santo Agostinho Granite are quite homogeneous. The main lithotype is medium- to coarse-grained, equigranular, hololeucocratic (grayish to light-pink), alkali-feldspar granite. The main mafic mineral is riebeckite-arfvedsonite amphibole (up to 4% - Fig. 4a). The accessories comprise opaque, allanite, apatite, fluorite, zircon, biotite, epidote and carbonate. The microgranite autholites, included into the Cabo Granite, present finer-grained texture, but their mineralogy is similar to the main hosting facies.

Thin section of the granites show that the essential minerals (> 90wt%) are orthoclase, albite and quartz. Plagioclase is typically albite (An_{3-6}), showing polysynthetic twinning and tabulate shape with up to 0.3 mm long. They are commonly mantled by K-feldspar (orthoclase) up to 0.5 mm long and usually altered to fine-grained white mica (sericite). The outlines of the K-feldspar are somewhat rounded or corroded, suggesting reaction with the hosting magma. Other outstanding features are radial granophyres (Fig.4b) and spherulites.

Quartz occur as basal (hexagonal) and prismatic sections or bipyramid-shaped phenocrystals, less than 0.3 mm long, with wave extinction and globular shape, all suggesting hypabyssal emplacement for the magma. Embayment textures of quartz are quite abundant, which reveals reaction between the magma and phenocryst due to pressure changes. A later generation of quartz (called Qz_2) has interstitial habit or infill along fractures and cleavage planes of the K-feldspar.

Amphibole is less than 0.5 long and constitutes long, isolated crystals or occurs as agglomerates of crystals. Optic characteristics such as the strong pleochroism (colors varying from dark-blue along the Z-axis to light-green along the X-axis), low extinction angle (Z^$c = 5$-10^o), 2V angle around 80^o, biaxial negative optic sign, and negative elongation allow to classify it as riebeckite-arfvedsonite. The amphiboles are considered a late mineral-phase, possibly crystallized during the subsolidus stage, as showed by their intersticial or skeletal habits. Commonly, the amphiboles are transformed into carbonate, biotite and opaque (Op). These last ones occur as two textural types: Op_1 is predominantly magnetite which forms small crystals dispersed within the quartz-feldspar matrix. Magnetite crystals are subeuhedral, 0.3 mm long and develop cubic habit. The second generation of opaque (Op_2) is anhedral and is formed from amphibole transformation. Allanite constitutes small anhedral crystals, less than 0.2 mm long, dispersed within the quartz-feldspar matrix. Zircon and the apatite represent the earliest phases, occurring as submillimetric-size inclusions. Fluorite, biotite and epidote are rare, found as small grains (<0.2 mm), the last two representing products of amphibole transformation. Tourmaline and quartz are found inside miariolitic cavities, usually showing euhedral prismatic habit.

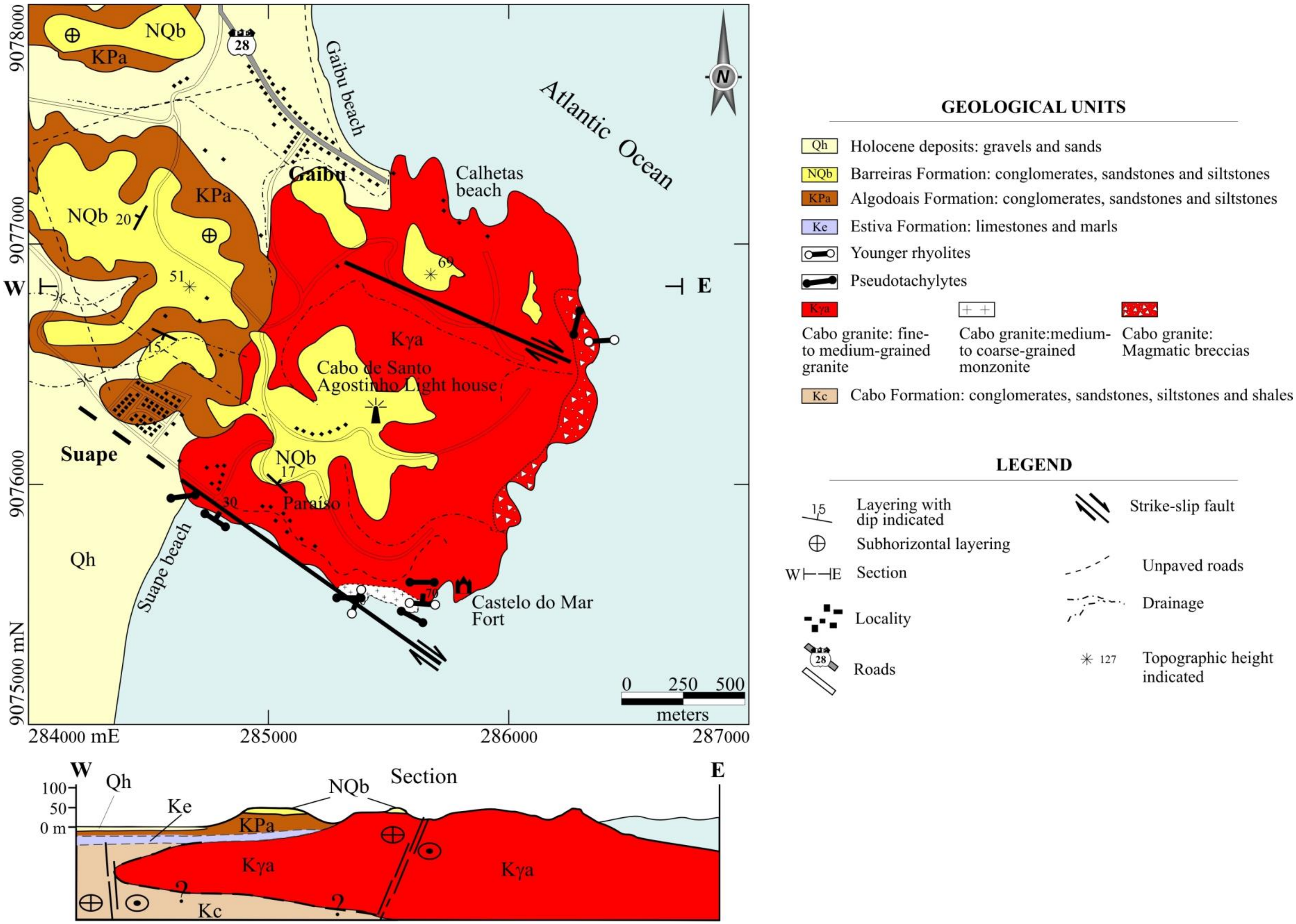

Figure 2 – Geological map of the Cabo de Santo Agostinho granite and schematic W-E cross section (modified after Cruz 2002).

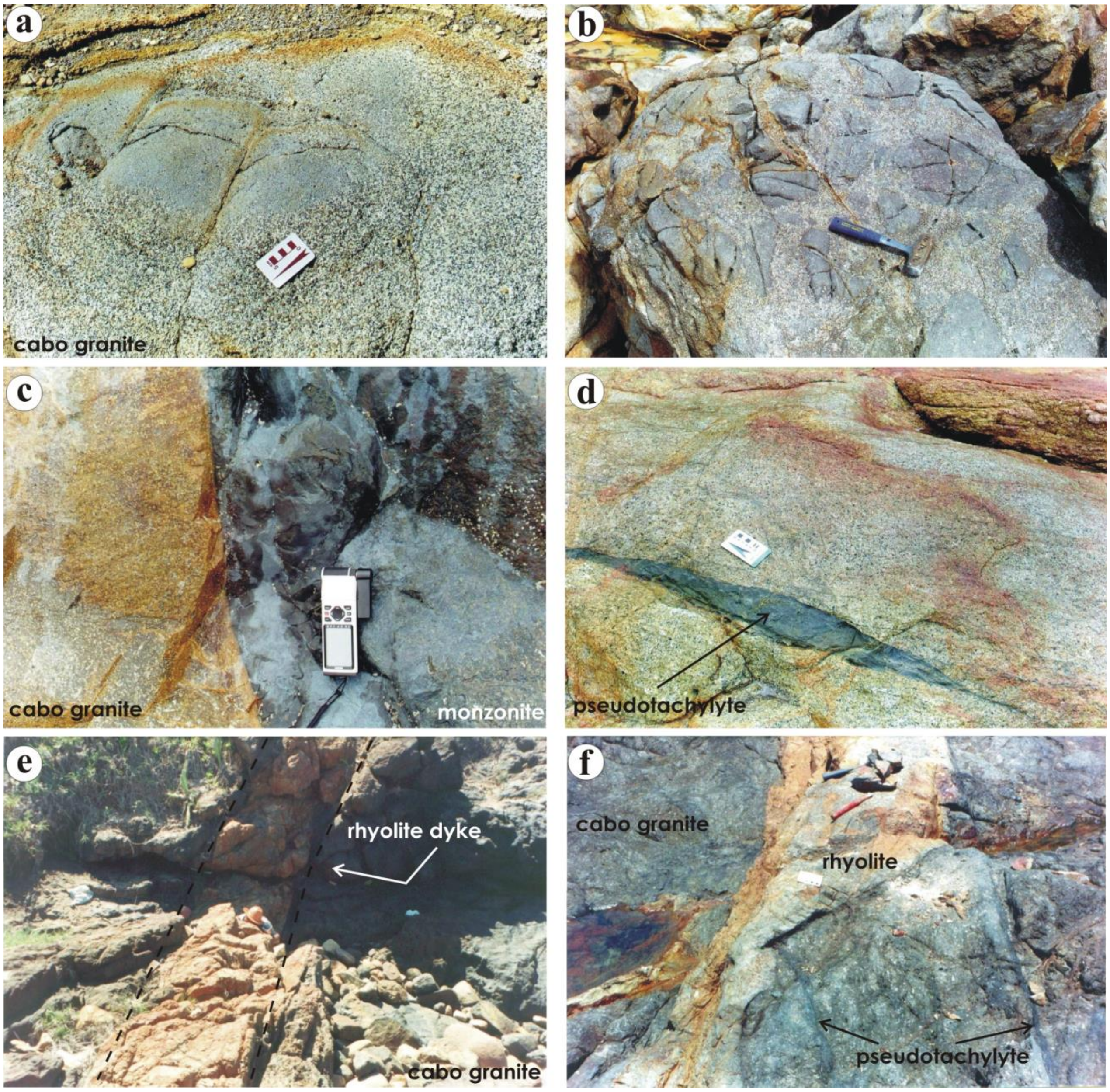

Figure 3 – Field aspects of the Cabo de Santo Agostinho granite and associated rocks. (a) Porphyritic (quartz and sanidine phenocrysts) granite hosting elliptical, equigranular, microgranite. (b) Magmatic breccia with the same components as in (a). (c) Abrupt contact between the monzonite and the granite. (d) Pseudotachylyte veins (black) crosscutting the Cabo de Santo Agostinho granite. (e) E-W directed younger rhyolite dyke crosscutting the Cabo de Santo Agostinho granite. (f) The same rhyolite dyke crosscutting both the Cabo de Santo Agostinho granite and pseudotachylyte.

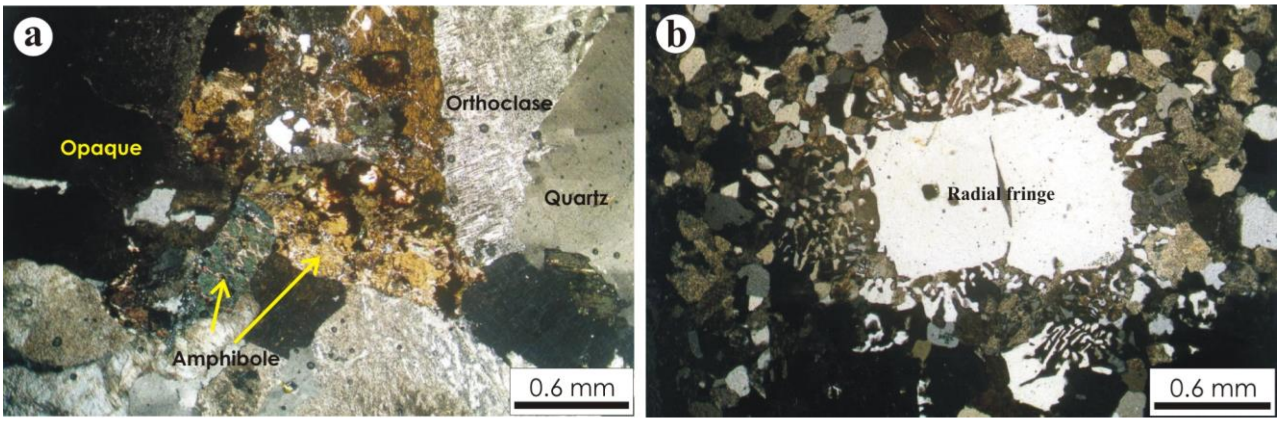

Figure 4 – Microscopic aspects of the Cabo de Santo Agostinho granite. (a) Amphibole (riebeckite-arfvedsonite) within an equigranular matrix with quartz, orthoclase and ore. (b) Radial fringe-like granophyric texture.

Geochemistry and Petrogenesis

Geochemical data recently obtained (Nascimento, 2003) show that the Cabo de Santo Agostinho granite has SiO_2 from 70.2 to 75.5wt%, low amounts of CaO (0.06-0.61wt%), MgO (0.10-0.27wt%), TiO_2 (0.09-0.26wt%) and P_2O_5 (<0.01wt%). It presents A/NK and A/CNK ratios of 1.04-1.09 and 0.99-1.08, respectively, and normative corindon less than 0.5. Several geochemical diagrams, including Na_2O+K_2O vs SiO2, R1-R2 and Wright's plot (1969), confirm the alkaline affinity of the granite (Fig. 5). Rare earth element spectra show variable LREE enrichment (La_N/Yb_N=4.7-58.4) and strong negative Eu anomaly (Eu/Eu*=0.06-0.15). Classical discriminant diagrams, such as Rb vs Y+Nb and Nb vs Y (Pearce et al., 1984), all indicate a withinplate tectonic setting for this granite, the source having strong negative Ba anomaly and Ta-Nb positive anomaly. This corroborates the interpretation that 102 Ma ago this portion of the South America plate still was linked to the African plate (see discussion on the geology item above).

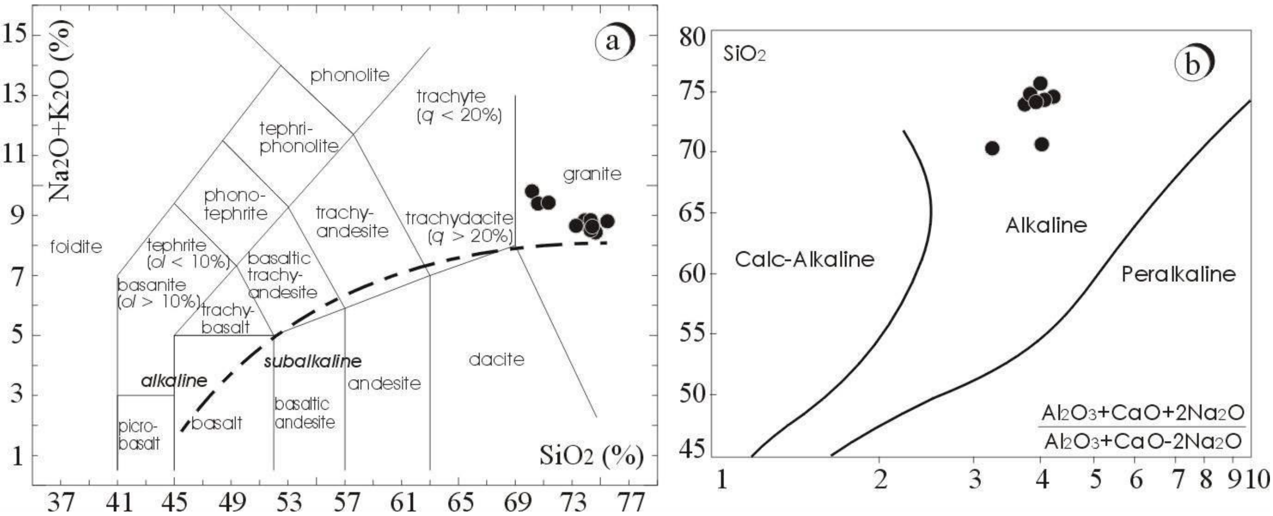

Figure 5 – Geochemical diagrams for the Cabo de Santo Agostinho pluton. (a) Total alkali-silica diagram after Le Bas et al. (1986) with the limit of the subalkaline and alkaline series according to Myashiro (1978). (b) Wright´s (1969) diagram defining the alkaline nature of the Cabo de Santo Agostinho granite.

Compatible and incompatible element ratios and geochemical modeling suggest that the fractional crystallization was the main petrogenetic mechanism for generating the Cabo granite rocks. The fractional crystallization hypothesis was tested by mass balancing of oxides using the XLFRAC program XLFRAC (Stormer Jr. and Nicholls, 1978). Within the samples of the Cabo granite, the less differentiated and most evolved ones were chosen as the initial (L_0 = MD-35B) and most evolved (L_1 = MD-08) liquids, both recalculated to 100% in anhydrous base. Combinations of different minerals (representing the cumulate) were made and the statistical errors and degree of differentiation calculated. As a result, it was obtained a cumulate composed of K-feldspar (49.9wt%), plagioclase (An_{20}; 37.5wt%), biotite (6.5wt%) and magnetite (6.1wt%), for 23% fractional crystallization a statistical error (Σr^2) of 0.25. Simulations done with quartz, hornblende, clinopyroxene and apatite, all together, separated or in different combinations, resulted in very high errors (Σr^2>20) or meaningless negative crystallization rates. The cumulate here reported is the coherent with the petrographic composition observed for the Cabo granite samples. The cumulate as defined above was tested with respect to the rare earth elements by applying the fractional crystallization equation according to Rayleigh (1896). The results show reasonable adjustment between the patterns of the most evolved sample (L_1 = MD-08) and the one calculated ($L_{1'}$) for crystallization ratios between 15 and 30%. However, the best adjustment was obtained by adding small quantities of allanite (0.5%), sphene (0.3%) and zircon (0.1%) to the cumulate. This result is also coherent with the contents of the other trace element.

Sr and Nd isotopes show high initial Sr ratios (ISr>0.7084) and negative εNd (t = 102 Ma – -2.02 to -3.31), characterizing crustal source with mesoproterozoic Nd model age (T_{DM} = 0.94-1.03 Ga). Petrogenetic modelling by using normalized Yb and La/Yb requires about 18% partial melting of the continental crust to generate those rocks. The source should contain garnet (up to 2%), amphibole (7%) and biotite (7%).

Geochronology

The first absolute ages determined by the K-Ar and Rb-Sr methods for the Cabo Magmatic Province were reported by Vandoros et al. (1966), with ages varying between 99 and 85 Ma; the Cabo granite presented ages from 91 to 85 Ma. By using the same data, Vandoros and Valarelli (1976) established a new age interval of 114 to 90 Ma. Some years later, Long et al. (1986) define the Cretaceous age of the Cabo granite by means a whole-rock Rb-Sr isochron, which furnished 105±1.8 Ma and an initial $^{87}Sr/^{86}Sr$ ratio (I_{Sr}) of 0.7084±0.0011. Lima Filho and Szatmari (2002) obtained the first ^{40}Ar-^{39}Ar age (whole-rock) of 111.2±1.3 Ma for this granite. Recently, Nascimento (2003) and Nascimento et al. (2003) reported ^{40}Ar-^{39}Ar dating by the laser incremental heating technique of 3 feldspars, 3 biotites and 3 amphiboles. The nine grains defined excellent plateaus, with weighted mean ages of, respectively, 101.8±0.5, 102.1±1.5 and 103.0±3.0 Ma (Fig. 6). As there is no significant statistical difference among the ages, they interpreted that the Cabo Granite had a relatively fast emplacement and cooling history around 102.0±1.0 Ma.

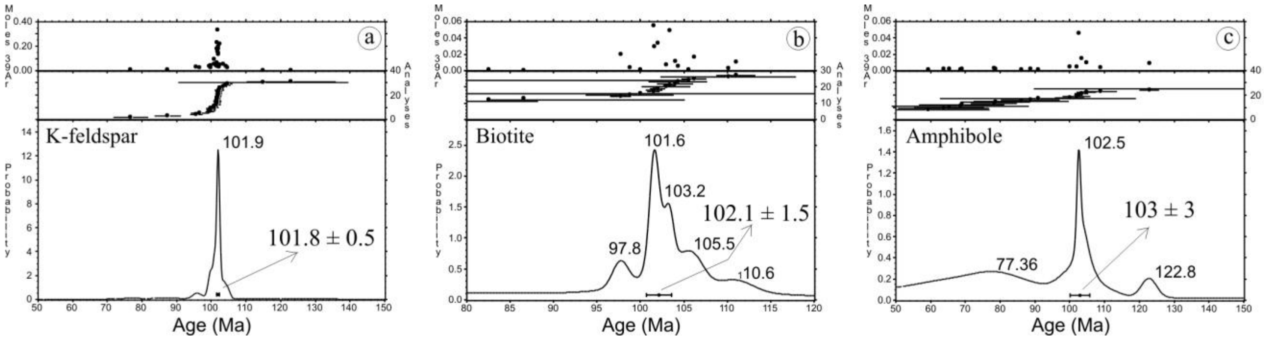

Figure 6 – ^{40}Ar-^{39}Ar ages (2σ deviation) for minerals of the Cabo de Santo Agostinho granite.

HISTORY

In 1902, John Casper Branner did one of the first mentions about the Cabo de Santo Agostinho Granite in his classic work: *Geology along the Pernambuco coast south of Recife*, published in Geological Society of America Bulletin. However, about 400 years before, on January 26, 1500, historians (Guedes, 1975; Abreu, 1976) mentioned that Vicente Yañez Pinzón disembarked in the Pernambuco's western point, anchoring in the Suape Bay, about three months before than Pedro Álvares Cabral, who discovered Brazil.

On the granitic promontory, there are countless monuments that were part of Vila de Nazaré, and were transformed today into the Armando de Holanda Cavalcanti Metropolitan Park. This park is formed by the Nossa Senhora de Nazaré Church (Fig. 7a), built by the Bagnoli Count at about 1579. It is one of the most important monuments of the area and it is located at the highest point of the referred granite. Its walls were risen using whale-oil to link the stone bricks from the Cabo Granite. The bells of the church are the original ones and they are still played until today to call the people to the mass.

The ruins of the Mar Castle or Nazaré Forts, a Portuguese military construction (Fig. 7b), was built on stone and lime, in 1631, by the Bagnoli Count. This fortress served as a protection against invaders to Nazaré Port. It represents one of the main postcards of the area. Close to this fortress, at the high hill, the ruins of the Old Quarter (Fig. 7c), built by the Bagnoli Count and that served as support to the Mar Castle Fort, can be seen.

At the old Vila de Nazaré, it is possible to see, also, the ruins of one Carmelita Convent (Fig. 7d), a Luso-Brazilian construction nearby Nazaré Church, initiated in 1692 and ended during 1731. The Carmelita Covent is considered one of the most important monuments of the Armando de Holanda Cavalcanti Metropolitan Park. In the ruins of this convent, the old lavatory, used at that time by the nuns, can be observed.

Just in XIX Century was built the Vila de Nazaré Cemetery (Fig. 7e) for the eternal rest of the dear beings and the Lighthouse Keeper House (between 1882 and 1883, Fig. 7f), that was destined to be the home of the lighthouse keeper and as deposit of equipment.

GEOTOURISM

The region studied presents strong potential for developing activities such as geotourism, which is a kind of geoscientific and sustainable tourism, aiming to support the preservation of the geological patrimony. Generally speaking, this is threatened due to the lacking of knowledge on its actual importance and, also, the absence of legal measures of protection.

However, nowadays the tourist activities in the region is directed to the beautiful beaches of Gaibu, Calhetas, Paraíso and Suape sites (Fig. 8), the first one being the most visited on the south coast of Pernambuco. One of the main attractions is to climb the granite to appreciate beautiful lookout of the Atlantic Ocean or even visit and swimming in the Calhetas Beach, well located in between the granite promontory and coconut trees. This small bay is considered one of the more beautiful beaches of Brazil, being sought for submarine fishing and diving.

The Paradise Beach is the smallest one, with small cliffs of granite that originate a beautiful landscape and serve as point lookout to the Suape Bay and its harbour.

Finally, the Suape Beach has crystalline waters and few waves, which becomes it the ideal place to swimming and nautical sports. Besides the attractive beaches, the geotourism activities could also explore the geology and history preserved in the area.

Figure 7 – Historical aspects of the Cabo de Santo Agostinho granite. (a) Nossa Senhora de Nazaré Church. (b) Ruins of the Castelo do Mar Fort (or Nazaré Fort), built in 1631, with the Port of Suape in second plan. (c) Ruins of the Old Quarters, which served as a point of support to the Castelo do Mar Fort. (d) Ruins of the Carmelita Convent, a Luso-Brazilian building started in 1692 and ended in 1731. (e) Vila de Nazaré cemetery built in the XIX century. (f) Ruins of the Lighthouse keeper House, built between 1882 and 1883.

MEASURES OF PROTECTION

The rare beauty of the area referred here is now the Armando de Holanda Cavalcanti Metropolitan Park, and is also part of Cabo de Santo Agostinho Historical Site, registered by the Ordinance State no. 16.623 of April 29, 1993. In this site, the Nazaré Church and the ruins of Carmelita Convent are also registered by a federal law since 1961.

The geotourism may be exploited still using the geological and historic beauties of the region. However, a previous and appropriate planning is requested for its complete consolidation and development. Its achievement should be accompanied by local community participation, to generate employment and incomes, to minimize the possible environmental impacts and socioeconomic problems, as well as to do efficient conservation policies for the actual and futures generations.

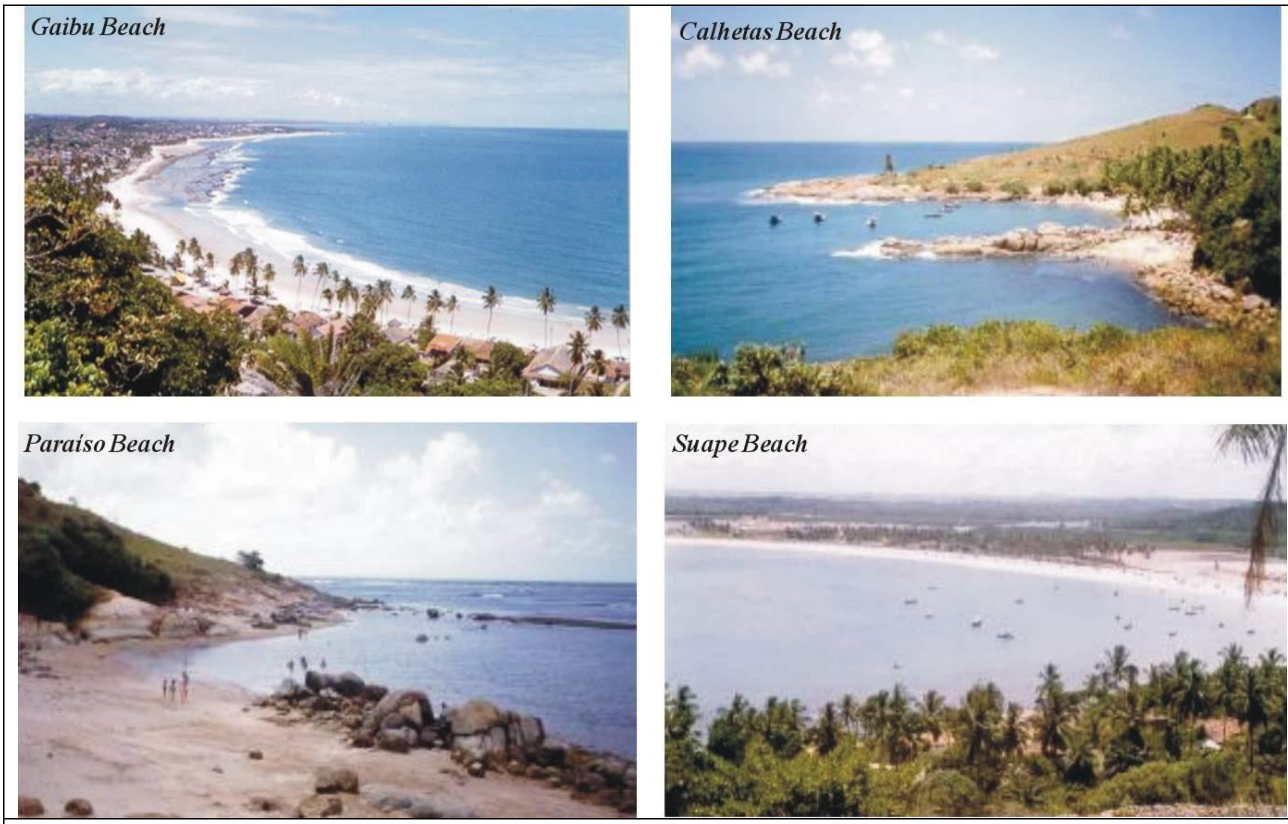

Figure 8 – General aspects of the beaches along the oceanic coast of the Cabo de Santo Agostinho granite. They serve as important tourist points in Pernambuco state.

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