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Geological and Palaeontological Sites of Brazil

SIGEP 002

Saint Peter and Saint Paul's Archipelago

Tectonic uplift of infra-crustal rocks in the Atlantic Ocean

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The Saint Peter and Saint Paul's Archipelago (SPSPA), also known as "St. Paul's Rocks", is the smallest Brazilian oceanic archipelago. It is located in the mid-equatorial North Atlantic Ocean (0º55'02"N; 29º20'42"W), about 821 km from the Brazilian coast and 1,586 km from the coast of Africa. The SPSPA is a distinctive archipelago, because it does not consist of volcanic rocks, as do most oceanic islands. It is composed instead of plutonic rocks originated in the upper mantle of the earth. The origin and age of SPSPA are uncertain. The SPSPA corresponds either to a relic of the sub-continental lithosphere mantle, which is associated with the non-expansive part of the Equatorial Mid-Atlantic basement, or to a protrusion of oceanic mantle uplifted by the action of the St. Paul Fracture, concomitantly with the processes of mylonitization and serpentinization. It is estimated that its formation took place between the periods of 100-35 Ma. The emerged part is composed of serpentinized peridotite and kaesurtite Mylonite of uncertain origin. The mylonitization obliterated the primary textures of these rocks, concomitantly with the serpentinization by pervasive hydrothermal fluids and/or seawater during late tectonic movements that fractured the rocks. The Quaternary Saint Peter and Saint Paul's Formation (QSPSPF), outcropping in certain parts of the archipelago, is constituted of clastic sediments derived from the basement and biogenic activities, cemented by calcium carbonate. The presence of thin marine terraces, which marks 4 paleo-levels above the current sea level, and the variety of lithofacies (stratifications and fossils in the QSPSPF) suggests that the QSPSPF was deposited under a progressive sub-aerial regime dominated by waves. It also suggests that the SPSPA was situated below the current sea level during the beginning of the Quaternary, and that tectonic uplift occurred episodically rather than at a constant rate.

Keywords: Abyssal Peridotite; Mylonite; Serpentinization; Oceanic expansion; Saint Peter and Saint Paul's Archipelago; Equatorial Atlantic.

INTRODUCTION

The Saint Peter and Saint Paul's Archipelago (SPSPA) is the smallest oceanic archipelago in the Brazilian territory. It is an ultramafic complex probably originated in the terrestrial mantle. Considering its peculiar geological, mineralogical and geochemical characteristics, the SPSPA is a subject of special interest to the scientific community because, despite its age uncertainty (100-35 Ma), it can provide information about the nature of the upper mantle of the Earth, the processes of continental breakage and drift (e.g. Laurentia, Gondwana, and Pangea), and its correlation with the opening of the Atlantic Ocean (Melson *et al.*, 1972). These particular characteristics attribute to SPSPA an importance to the conservation of mineral diversity and geologic evolution. Moreover, since the archipelago is located in the Equatorial system of marine currents, it has a strong influence in the life cycle of many migratory species (fishes, crustaceans and birds), which utilize the region as a feeding and reproductive zone. Consequently, SPSPA is a unique area for the study of energy transfer processes along the trophic chain.

The SPSPA is also under the influence of the direct zone of intertropical convergence, whose dynamics influence the rain regimes along the coast of Northeast Brazil, positioning the archipelago in one of the areas with the highest pluviometric indices in the whole Atlantic Ocean, and, consequently, with the smallest levels of superficial salinity. Due to its long distance from the continental coast, part of the wildlife in the SPSPA has a high degree of endemism, which gives the archipelago an additional importance, the conservation of biodiversity.

SITE LOCATION

The SPSPA is located at the farthest point of the Brazilian territory in the North Equatorial Atlantic Ocean, and is the only group of Brazilian oceanic islands in the northern hemisphere. It is localized

62.14 nautical miles (100 km) to the north of the Equator (Fig. 1). The central point coordinates of SPSPA are 0º 55' 02"N E, 29º 20' 42"W. The nearest point to the Brazilian coast, in Cabo do Calcanhar, Rio Grande do Norte State, is approximately 510 nautical miles (1,010 km), at coordinates N 41º 15' E. The archipelago is also approximately 1,210 km from the city of Recife, at coordinates N 32º 30'E. SPSPA is also situated at almost half way to coast of Guinea-Bissau (Africa), at approximately 985 nautical miles (1,824 km).

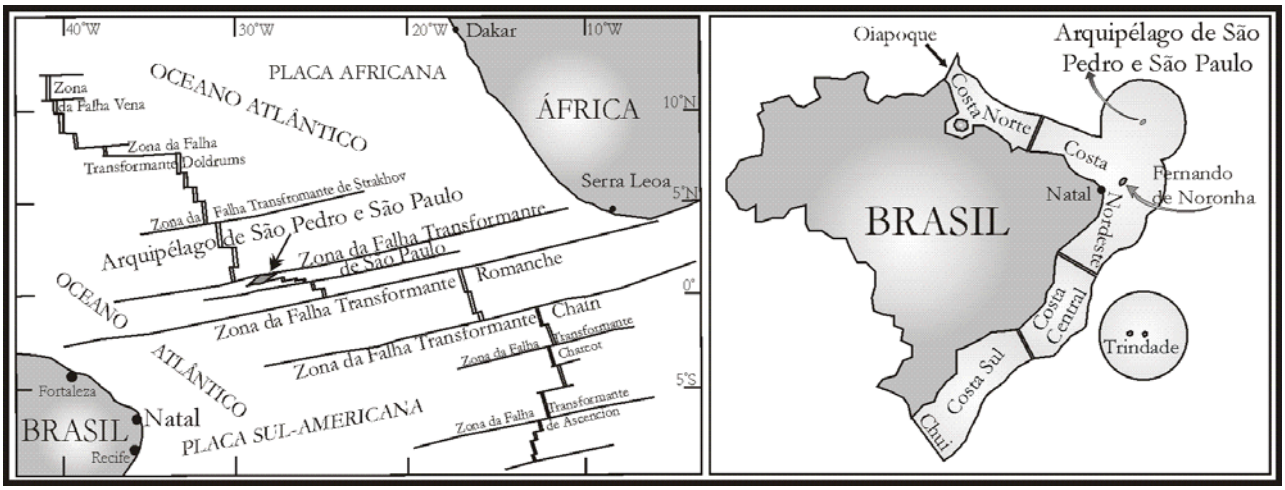

Figure1: a) Location of St. Peter and St. Paul's Archipelago, Equatorial Atlantic; b) Demarcation of 200 nautical miles that define the Brazilian Economic Exclusive Zone (EEZ).

HISTORICAL ASPECTS

The date of the discovery of the SPSPA is uncertain, because the records of exploration were considered state secrets. However, Portuguese historical records suggest that the archipelago was discovered accidentally in 1511, when the Portuguese navigator Manuel de Castro Alcoforado, captain of the *São Pedro* vessel, was separated from the group commanded by D. Garcia de Noronha and ran aground upon the St. Paul's rocks. He was rescued by another vessel of the same group called *São Paulo*, hence the name St. Paul's rocks. However, Spanish historical records indicate that in 1513, the Spanish navigator Juan da Nova de Castello made the first register of the island (the name of the vessel he was leading is unknown). The exact location of the archipelago is not shown on the world's nautical record of 1513, made by the Turkish. However, the Portuguese nautical records suggest that the Portuguese Diego Ribeiro made the first record for the SPSPA in 1529. That is why the world 's nautical record of Mercator, made in 1538, already shows the position of the archipelago.

The first landing on SPSPA was made by the French navigator Beuvet du Losier in 1738, followed by the American navigator Amasa Delano in 1799, who was on board the *S.Y. Perseverance.* In 1813, the Tenant-Capitan George Crichton, who was on board the *H.M.S. Rhin*, elaborated upon the first nautical record of the SPSPA. Charles Darwin, on board the *R.V. Beagle* (England), landed on the SPSPA in 1831, as part of his scientific voyage around the world. He was the first researcher to suggest that the rocks of St. Paul were not volcanic. During the same trip he made the first chemical analysis of the rocks (Renard, 1882). M'Cornick landed on the archipelago with the *H.M.S. Erebus* in 1839, and disagreed with Darwin. He suggested that the SPSPA had a volcanic origin, a statement not confirmed later. In 1873, Tizard *et al.* performed the first systematic study in the geology of the crystalline basement of the archipelago, during the exploratory expedition of the *H.M.S. Challenger* (England), commanded by Sir Charles W. Thomson.

The *S.Y. Scotia*, in its trip to Antarctica in 1902, dropped anchor on SPSPA and made the first photographic register of the rocks. In 1911, the team of the German ship *Deutschland* collected geological and biological samples from the archipelago. The expedition commanded by Shackeleton-Rowett in 1921, landed with the *H.M.S Quest* (England) and conducted the second systematic study in the geology of the rocks from the crystalline basement of the SPSPA. In 1922, an airplane landed in the region of the archipelago for the first and last time. It was the hydro airplane *Luzitania* (Portugal), commanded by the Portuguese navigators Gago Coutinho and Sacadura Cabra.

In 1930, the ship *Belmonte* from the Brazilian Navy, installed the first lighthouse to help navigation. During the Second World War, the ships *U.S.S. Atka* and *U.S.S. Omaha* did some research and modified the

names of some islands previously baptized by the expedition of *H.M.S. Challenger*. During the decade of 1960's, the SPSPA was visited by many American scientific expeditions [e.g.: Wiseman (1960) on board of the *H.M.S. Owen*; Melson *et al.* (1964 and 1968) on board of the *R.V. Chain and H.M.S. Atlantis II*]. Between the years of 1990 and 1994, Russian and German researchers, on board the *R.V. Strakhov* and *R.V. Sonne-84*, did a gravimetric and bathymetric study in the region around SPSPA. In 1996, the Brazilian government, through the Interministerial Commission for the Sea Resources (CIRM), created a group for the occupation and research on the SPSPA, with the goal of installing a scientific station on the Belmont Island. This research expedition was launched from the ship *Canopous*.

With the inauguration of the SPSPA Scientific Station (ECASPSPA) in 1998, the first scientific studies under the program called Pro-Archipelago began. The program allowed the permanent occupation of the archipelago, and also allowed Brazil to add 200 nautical miles to its territory in the Exclusive Economic Zone (EEZ) (Fig.2). Between December 1997 and January 1998, the French and Brazilian researchers on board the submersible *Nautille* and the ship *R.V. Nadir*, conducted a submarine geological study of the area between the Romanche and São Paulo fractures. It was in one of these expeditions that the *Nautille*'s researchers did the first dives in the area, at depths greater than 5,100 meters. In 2001, T. F. C. Campos and the 83rd expedition of the Pro-Archipelago program traveled to SPSPA on board the boat *Transmar II* (Brasil) and did the first systematic study of the 21st century in the geology of the emerged rocks of the basement of SPSPA. In 2002, T. F. C. Campos and the 105th expedition of the Pro-Archipelago program traveled to SPSPA on board of the *Transmar I* (Brasil) and began the first systematic study on the emerged sedimentary rocks of the archipelago (Edwards, 1985; Silveira *et al.*, 2003).

SITE DESCRIPTION

Climatic and Hydrological Aspects

From a hydrological point of view, the SPSPA is inserted in the Equatorial system of marine currents, under the direct influence of the South-Equatorial current that superficially flows EW and the submerged Equatorial current flowing in the opposite direction (WE) at depths between 60 to 100 m, coordinates 1.5º N and 1.5º S. This submerged current is the fastest of all equatorial currents, reaching speeds greater than 2 knots (about 3.6 km/h).

These two currents acting together generate a hydrological pattern of elevated complexity (together with a large influence due to the island ecosystem) called phenomena of nutrient enrichment, due to the resurgence from the interaction between the oceanic currents and the submarine relief. In relation to the meteorological conditions, the SPSPA is under the direct influence of the Intertropical Convergence Zone, whose dynamics affects the rain systems of the Brazilian northeast coast. For this reason, the SPSPA is one of the areas with the largest pluviometric indices in the entire Atlantic Ocean, and consequently, reduced superficial salinity.

Biological Aspects

As a function of its geographical location, which is strategically positioned between two hemispheres and also between the South American and African continents, the SPSPA presents a strong influence in the life cycle of many migratory species like fishes, crustaceans, and birds. These species utilize the archipelago and its surroundings as a shelter, feeding, and reproductive zone.

The low species richness in SPSPA can be associated with its small area and consequent local microhabitat scarcity. The marine substrate is predominantly rocky, sometimes covered by various algae species, which are not very diverse. However, there can be small sandy areas in the marine bottom, where there are species of mollusks, crustaceans, and other typical organisms of this type of substrate.

The fish fauna of the archipelago is known to represent common components of the Brazilian, Caribbean, and African ichthyofauna as a result of dispersion and establishment of larvae, since SPSPA is under influence of two important marine currents. There is a clear zoning process occurring in the distribution of organisms. As an example, individuals of *Entomacrodus vomerinus* (monkey-fish) occur in shallow areas like the Poças de maré (tidelands), while species like the butterfly fish (*Chaetodon obliquus*) and the endemic serranid *Anthias salmopunctatus* occur at greater depths along the rocky walls of the archipelago.

About 14 species of algae were registered in the SPSPA. At the tides' oscillation zone there are incrusted red algae, and at the following sublitoraneous region there are the zoanthid *Pallythoa caribeorum* (at depths from 3 to 8 m) and numerous green algae species *Caullerpa* sp. (at depths from 3 to 30 m). The coral species *Madracis decactis* and *Scolymia wellsi* are concentrated at depths between 30 and 45 m. Two species of black coral (*Anthipates* sp.) were registered in the archipelago, occurring at depths above 45 m. To date, 58 species of reef fishes are already registered (Sergeants, angelfishes, hogfishes, damselfishes, morays, crevalle jacks, basses, butterfly fishes, blennies, etc), and 17 species of pelagic fishes

(sharks, tunas, mackerels, remoras, dolphin fishes, needlefishes, flying fishes, moon fishes), which utilize the archipelago mainly as a feeding zone (e.g. *Thunnus albacares*), and, during some particular periods of the year, as an area for reproduction (e.g. *Cypselurus cyanopterus*).

Among the 58 species of reef fishes, the most numerous families, in terms of occurrence of species are: Muraenidae (with seven species), Carangidae and Pomacentridae (with five species each), and Serranidae and Scaridae (with three species each). About 80% of the reef fishes of SPSPA occur on the Brazilian marine coast due to its continental proximity, as well as the suitability of the sub current that moves from continental Brazil to the archipelago.

Due to its isolation, the SPSPA presents a considerable degree of endemism. As an example, we can cite four species of damselfishes (*Stegastes sanctipauli*, *Enneanectes smith*, *Chaetodon obliquus*, *Anthias salmonpuctatus*). Another example of the effects of isolation is the appearance of the angelfish *Holacanthus ciliares* of various colors, which does not normally occur in other locations, and can reflect a high level of crossbreeding between species. The fishes present other colors, such as blue and white individuals. There are also non-pigmented samples of the pomacentrid *Chromis multilineata*. In the agitated waters surrounding the islands of the archipelago, some rare marine species are found with relative frequency (e.g. Whale shark). The appearance of rare species, together with the presence of dolphins, rays, barracudas, mackerels, tunas, sharks, crevalle jacks, and hundreds of other fishes, promote a spectacle of life worth seeing.

SPSPA is also a landing territory for local populations of marine birds (about 2000 individuals), the brown boobies (*Sula leucogaster*) and the brown noddies (*Anous stolidus*). Due to scarcity of dry areas for nidification, the occurrence of these species is really high. The brown boobies represent 0.4 birds/m^2, which probably hinders the appearance of other migratory birds on the archipelago (Mendes, 2004 – Personal communication).

Geomorphological Aspects

The SPSPA constitutes a small group of islands (10) and many rockheads, situated at proximities of the Mid-Atlantic Ridge, at about 100 km north of the Equator at the coordinates 0º55'02"N and 29º20'42"W (Fig.1 and 2). The total emerged area reaches about 4.2 acres, and the distance between the extreme points – the Erebus and Pillar rocks- reaches 420 m. The islets present irregular and curvilinear, winding contours, and its slopes have strong declivities (>80º).

The four biggest islands (Belmonte, Sudeste, Nordeste, and Cabral) form a horseshoe shape cove, with average dimensions of 100 m of length by 50 m of width, 8 m of depth, and its coverage is pointed towards NW. Narrow channels separate these islands. The cove bottom is constituted of sediments originated through biological activities and desegregation of rocks that constitute the archipelago. The emerged relief of SPSPA is pronounced, and its culminating point (18 m of altitude) is located on the Nordeste Island. The highest point of the Belmonte Island reaches about 16 m of altitude, while on the Sudeste Island the highest elevations reach 17 m. The submarine relief of the archipelago exhibits elongated elevations like a crest, with a slight declivity at EW direction and strong declivity at NS direction.

SPSPA consists of the emerged portion of a mid-ocean transversal mountain chain with EW direction, which is placed parallel to the north edge of the of the São Paulo transform fracture zone, close to the limiting region of the South American and African's divergent tectonic plates. The São Paulo Fracture extends for about 580 km between the coordinates 1ºN-30º20'W and 0º30'N-24ºW. The oceanic crust at the opposite side of the active area of the São Paulo transform fracture zone presents an age difference of about 40 Ma (Rusby, 1993).

The failure zone of the São Paulo transform fracture zone around the archipelago reaches 120 km of width, and its valleys can reach an average depth of –3,600 m. However, in the surroundings of SPSPA, abyssal depths can be observed greater than –5,000 m, at the transform faults as well as at the top of the Atlantic Ridge (Hekinian *et al.*, 2000). Considering the isobath of –3,800 m, this mountainous chain has a sigmoid shape, with about 100 km of length by 40 km of width, and a general orientation NE-SW. According to Hekinian *et al.* (2000), this sigmoid shape can be explained by the junction of two rock massifs that form the submarine mountainous chain.

Geological and Petrographical Aspects

BASEMENT ROCKS

The submarine mountain chain, whose tops constitute the St. Peter and St. Paul's Archipelago, is tectonically active and, consequently, subjected to earthquakes. This mountain chain is situated at the top of the São Paulo transform fracture zone, which indicates that its formation was controlled by the movement of this zone and its group of fractures (Fig.3).

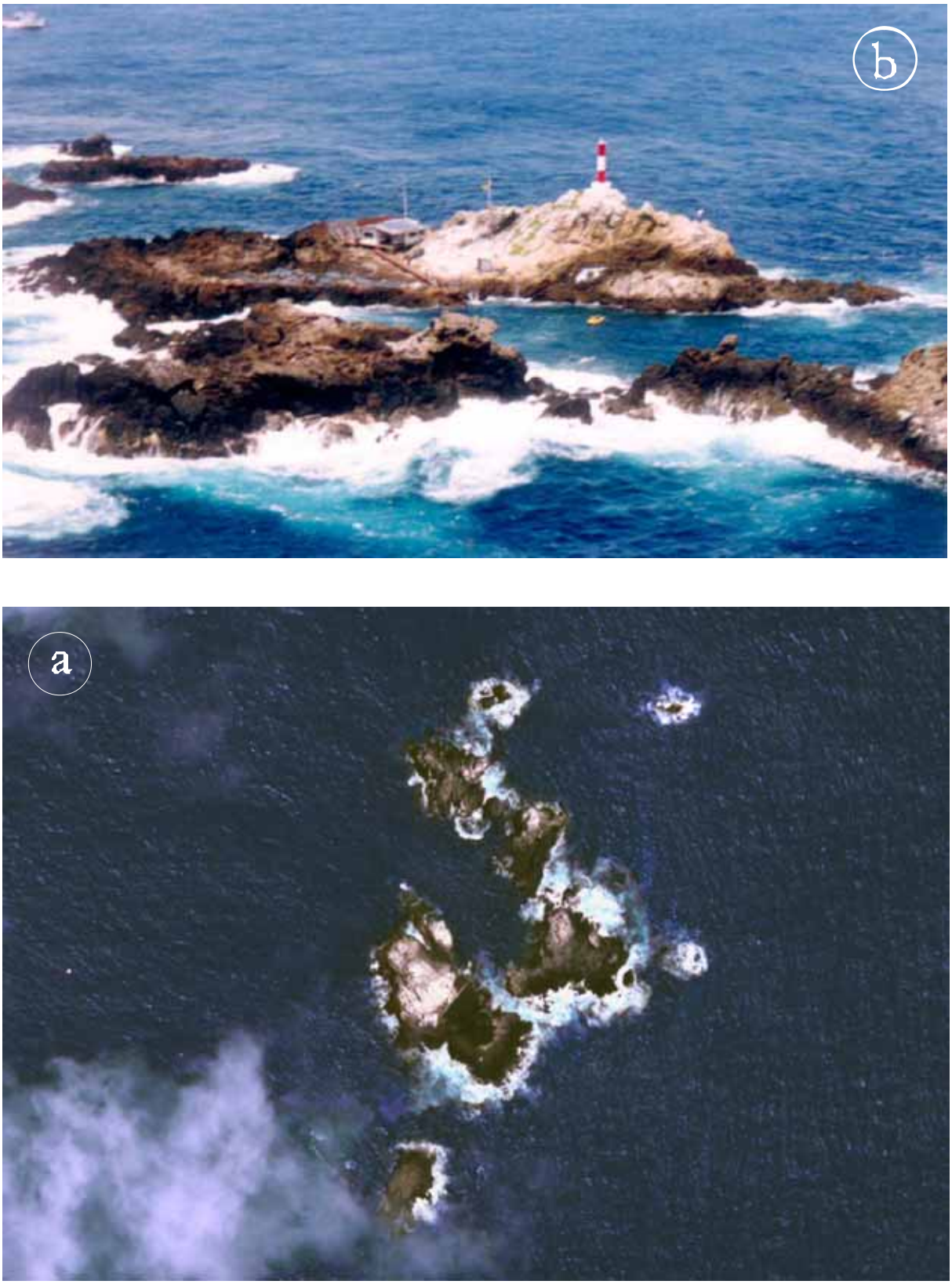

Figure 2: Overview of St. Peter and St. Paul's Archipelago, Equatorial Atlantic:
a) *From QuickBird® satelite; b) From a helicopter.*

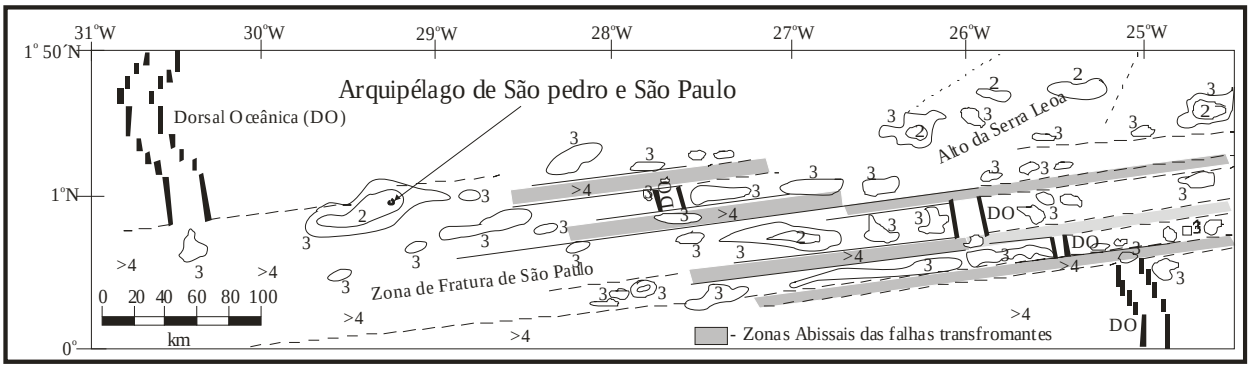

Figure 3: Sketch of the transverse crest-valley system that constitutes the St. Paul's transform fracture zone, Equatorial Atlantic (Gorini, 1981 *apud* Hekinian *et al.*, 2000).

The SPSPA is considered *sui generis* in the Atlantic due to the occurrence of ultramafic plutonic rocks, which were mylonitized while being positioned through the action of tectonic forces related to the breakage of the Pangea continent, and consequent expansion of the Atlantic Ocean. There are no volcanic rocks on the emerged part of the archipelago, only infracrustal plutonic rocks (Bonatti, 1976; Melson *et al.*, 1972).

The rock massif that constitutes the immersed part around the archipelago is divided into two flanks (North and South), probably related to an EW-trending, active transform fault (Hekinian *et al.*, 2000) (Fig.4). A *graben* (<- 2,500 m) is responsible for this division, which presents doleritic intrusions and small basaltic flows. These two flanks present distinct geological characteristics: i) The North flank, where SPSPA is located, is a group of scarps of strongly tectonized rocks, essentially serpentinized peridotite mylonites, serpentinized banded peridotitic mylonites, few gabbroic intrusions, and basaltic flows; ii) The South flank is less tectonized, and is formed by non-deformed serpentinized peridotite, and can also present basaltic flows. This flank is yet covered by hardened calcareous crust.

The mechanism responsible for positioning the SPSP massif inside the São Paulo transform fracture zone is not yet identified. Wolfe *et al.* (1993) and Hekinian *et al.* (2000) proposed two distinct tectonic processes that originated this sigmoid-shaped massif: The South flank would have been formed through the extensional tectonic movement (*pull-apart*), along with diapiric and denudation processes, while the North flank was formed through an extensive transversal strike-slip and thrust fault. The existence of volcanic, sub-volcanic, and serpentinized non-mylonitized Peridotite in the South flank suggests that this part of the lithosphere was once less rigid, and consequently more permeable to the circulation of fluids, contributing to the process of serpentinization and diapiric ascent of this flank. The North flank is part of a block of extensive shearing associated with a transversal thrust fault that was elevated during the transcurrent tectonism, which suggests a more rigid lithosphere than the one of the South flank during the protrusion of the serpentinized peridotite (Fig. 4).

Yet, intra-transform volcanism occurred due to the extensional movements on the top of this massif. In this way, volcanic rocks that rise at the graben structure of the South flank could have been extruded during the tectonic adjustment. Consequently, the positioning of the peridotites that form the SPSPA is related to the combined effect of serpentinite diapirism (protrusion) and differential shearing within the São Paulo transform fracture zone, which resulted in the elevation of a portion of the SPSPA massif above the current sea level.

The outcrops of the emerged part of the whole archipelago are intensely fractured (macro and micro) due to movements after mylonitization. During the lifting of the North flank of the SPSP massif there was sediment deposition that originated the SPSP formation, with a Quaternary age (Campos *et al.*, 2002, 2003, 2004).

The Northwest portion of the Belmonte Island (Fig. 5a) consists of a bulky and homogeneous aphanitic rock of elevated hardness, presenting a grayish-white to grayish-green coloration (Fig. 6a). On the other hand, the Southeast portion of the Belmonte Island and the other islands essentially consist of a heterogeneous aphanitic rock of low hardness, presenting a very diverse coloration, from grayish-white and grayish-green to reddish-brown, or a mixture of all these colorations (Fig. 6c).

The homogenous rock corresponds to a mylonitized peridotite, while the heterogeneous rock corresponds to a fabric of interfingering mylonitic and serpentinized phases, where the serpentinized phase is

developed from the micro-fracturing pattern at the cost of the mylonitic phase, up to the total consumption of the last. At the Southeast Island and, more rarely, at the South portion of the Belmonte Island there are shoots and enclaves of a bulky and homogeneous aphanitic rock of elevated hardness with a gray anthracitic coloration (Fig. 6b), which corresponds to an alkaline mylonitized rock rich in kaersutite. At a small area of the eastern part of the Southeast Island, alternate levels occur showing either incipient serpentinization of peridotitic mylonites or alkaline kaersutitic mylonite, presenting millimetric to centimetric dimensions parallel to each other (Fig. 6d), and sometimes presenting micro-folding.

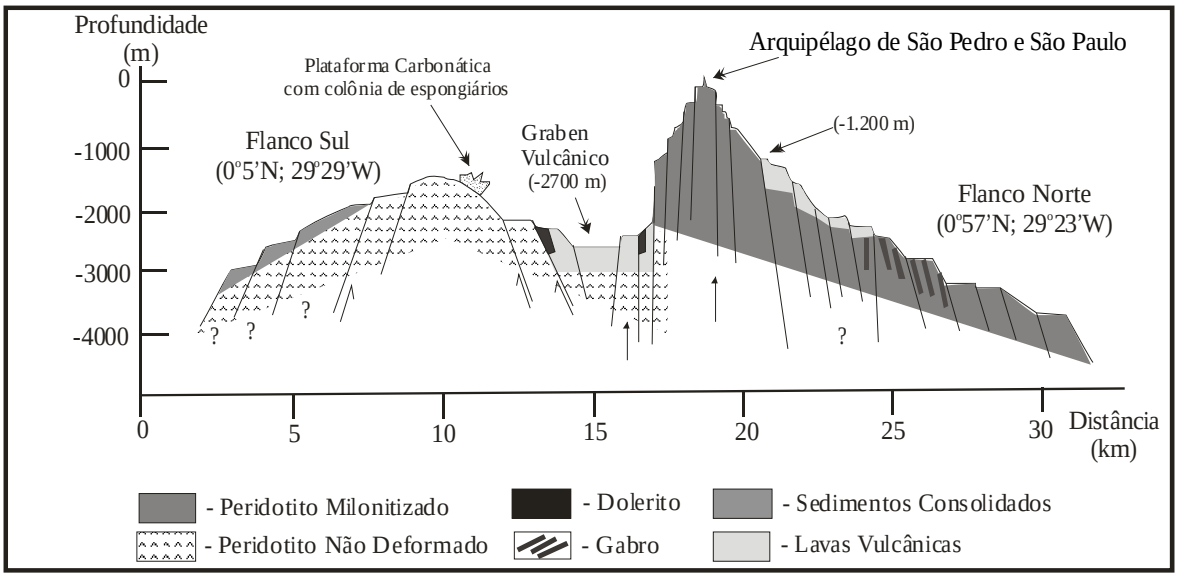

Figure 4: Sketched geological profile of North and South flanks of the St. Peter and St. Paul Archipelago transversal ridge separated by EW active transform fault (*apud* Hekinian *et al.* 2000)

The tectonic processes obliterated almost all the mineral assemblage of the SPSPA's rocks, which made impracticable until now the determination of its modal composition (Melson *et al.*, 1972). The original plutonic nature of these rocks is evident through the existence of ellipsoid porphyroclasts of olivine (0.1 – 2.0 mm, rarely 4.0 mm), pyroxenes (0.5 – 1.5 mm), amphiboles (0.5 – 6.0 mm), and spinel (0.1 – 4.0 mm), which are strongly fragmented and fractured to the point that the plutonic mineral assemblage is mistakenly identified as matrix (< 0.01 mm) of similar composition. The porphyroclasts of olivine correspond to 60% of the total volume of porphyroclasts, and the mylonitic matrix corresponds to more than 60% of the rocks, and it is criptoserpentinized. This suggests that the original phenocrysts were comminuted and recrystallized through tectonic action and sinuously involved in a fine mylonitic matrix (Fig. 7a, b, c, d). This matrix can appear as alternating clear and dark bands, with different granulation with average of 0.01 to 0.02 mm, even though it can reach 0.06 mm (Fig. 7a, b). The dark color is caused by the concentrations of minuscule grains of magnetite originated in the process of matrix serpentinization.

In some cases, it is still possible to identify mylonitic foliation in the matrix, in parallel association with the large axis of the ellipsoid porphyroclasts. However, the porphyroclasts of olivine have an optical orientation that varies, and its crystallographic axis b is generally found perpendicular to the mylonitic foliation (Tilley, 1947; Denisova, 1991). This foliation is reflected in preferential plans of microfracturing presented by some samples.

Petrographically, the ultramafic mylonites of SPSPA still have vestiges of an initial deformation at high temperatures that occurred in the upper mantle, as well as a strong plastic deformation that occurred in the lower crust during the tectonic process that originated the São Paulo transform fracture zone, where the initial peridotites were mylonitized. The combination of the syntectonic recrystallization and the plastic deformation gave rise to a typical mylonitic texture, which obliterated the initial optical orientation of the minerals without producing a new texture on the porphyroclasts. The mylonitic orientation of the archipelago's peridotites is discordant with the direction of the São Paulo transform fault, which indicates that this block was brought to the surface in a series of complex tectonic movements (Melson *et al*, 1972).

Later tectonic movements originated more fractures on these rocks, facilitating the infiltration of fluids responsible for serpentinization (Fig. 7a, b, c, d). The serpentinization process was not uniform, originating rocks with different degrees of serpentinization, from incipient to elevated (Fig. 6c).

On diffractometric X-ray studies of the material

that was most serpentinized, it was only possible to identify lizardite and chrysolite as the minerals of the serpentine group that predominated as a product of alteration of peridotitic mylonites. Magnetite and oxides of iron were also identified. The serpentines are present in a pseudomorphic shape, as well as very fine grains in the matrix.

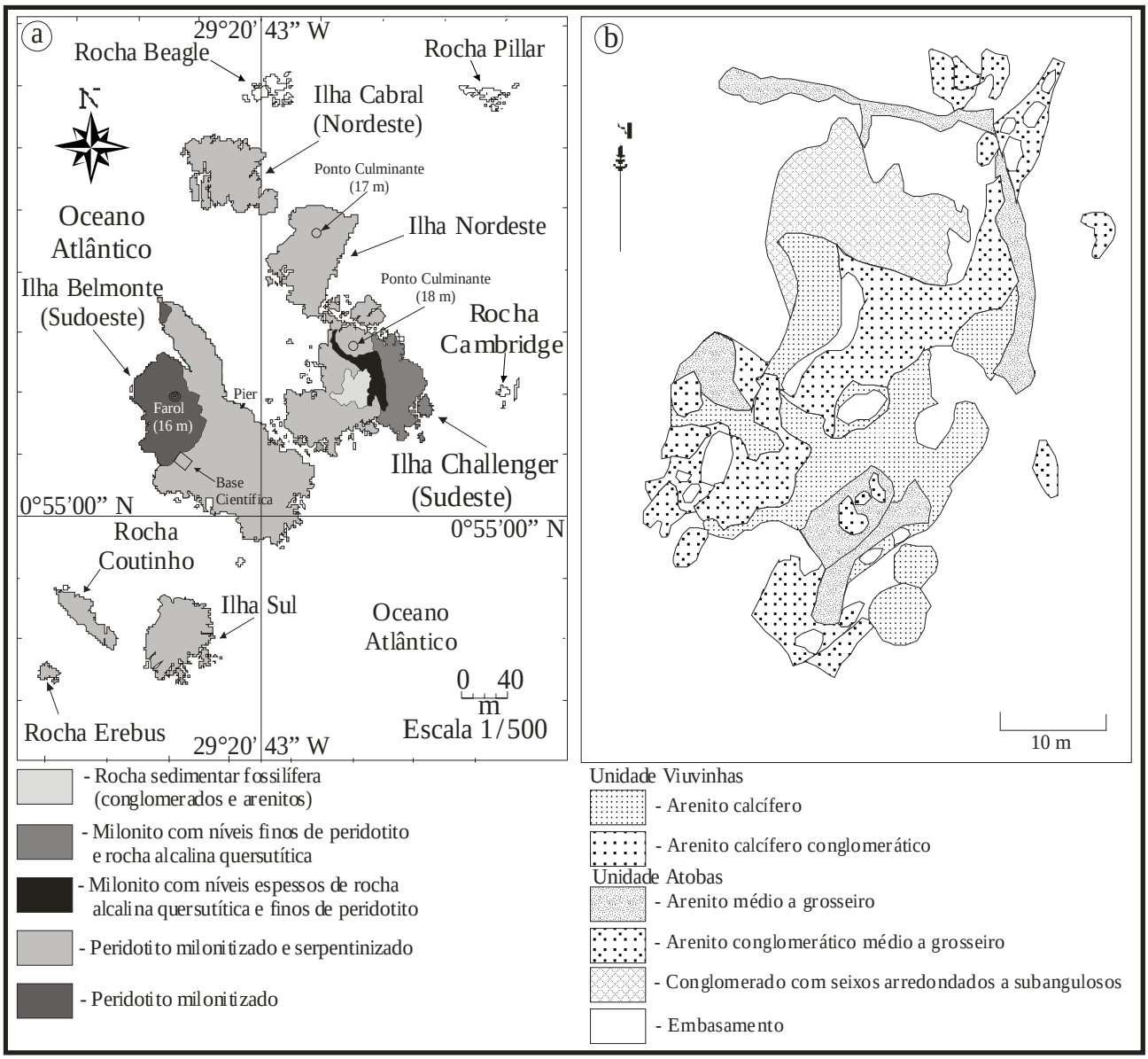

Figure 5: a) Geological sketch map of the emerged area of St. Peter and St. Paul Archipelago, Equatorial Atlantic; b) Geological sketch map of St. Peter and St. Paul Formation.

The rocks of the ultramafic complex of SPSPA have five sequential mineral assemblages. Plutonic relic minerals compose the first sequence; a mylonitic matrix with porphyroclasts of olivine, pyroxenes, pargasites, spinels and kaersutite composes the second; the third sequence is composed by serpentine that affects all the crystals; the fourth also contains serpentine formed by fracturing of the rocks, and the fifth sequence is composed by a white carbonatic mass that cuts the serpentine. The serpentinization process most strongly affected the olivine and pyroxenes, principally the enstatite. The amphiboles were not serpentinized.

ROCKS OF THE SEDIMENTARY COVER

The St. Peter and St. Paul Formation sedimentary rocks that occur in SPSPA (Campos *et al.*, 2002, 2003, 2004) are essentially formed by clastic polymitic sediments shed from the rocky substrate, from consolidated and well-worked biogenic material (Fig. 5b). This biolithoclastic sedimentary sequence rests discordantly over a mylonitized peridotitic basement, and is constituted by two units: i- Atobás unit; ii- Viuvinhas unit.

The origin of this formation is related to the

deposition of marine sediments in superficial waters of a paleo-bay. During the process of deposition there were at least two seismic-tectonic episodes: one generated a hiatus between two periods of deposition, and the other basculated the whole sequence.

The evolution of the St. Peter and St. Paul Formation initiated with the opening of a new barrier, taking advantage of the weak zone originated by fracturing of the basement diaclasamento, with general direction NW. The invasion of seawater caused the deposition of the Atobás unit, essentially formed by pebbles that rolled into the bay due to seismic action and erosion caused by waves. These pebbles remained under the action of the waves until they became rounded. With time, the granulation of the sediments diminished to the point that they deposited as rough sand, although rare angulated pebbles resulted from the watersheds through the waves action and/or seismic activity. An expressive tectonic event caused the inclination of the Atobás unit layers to the SE.

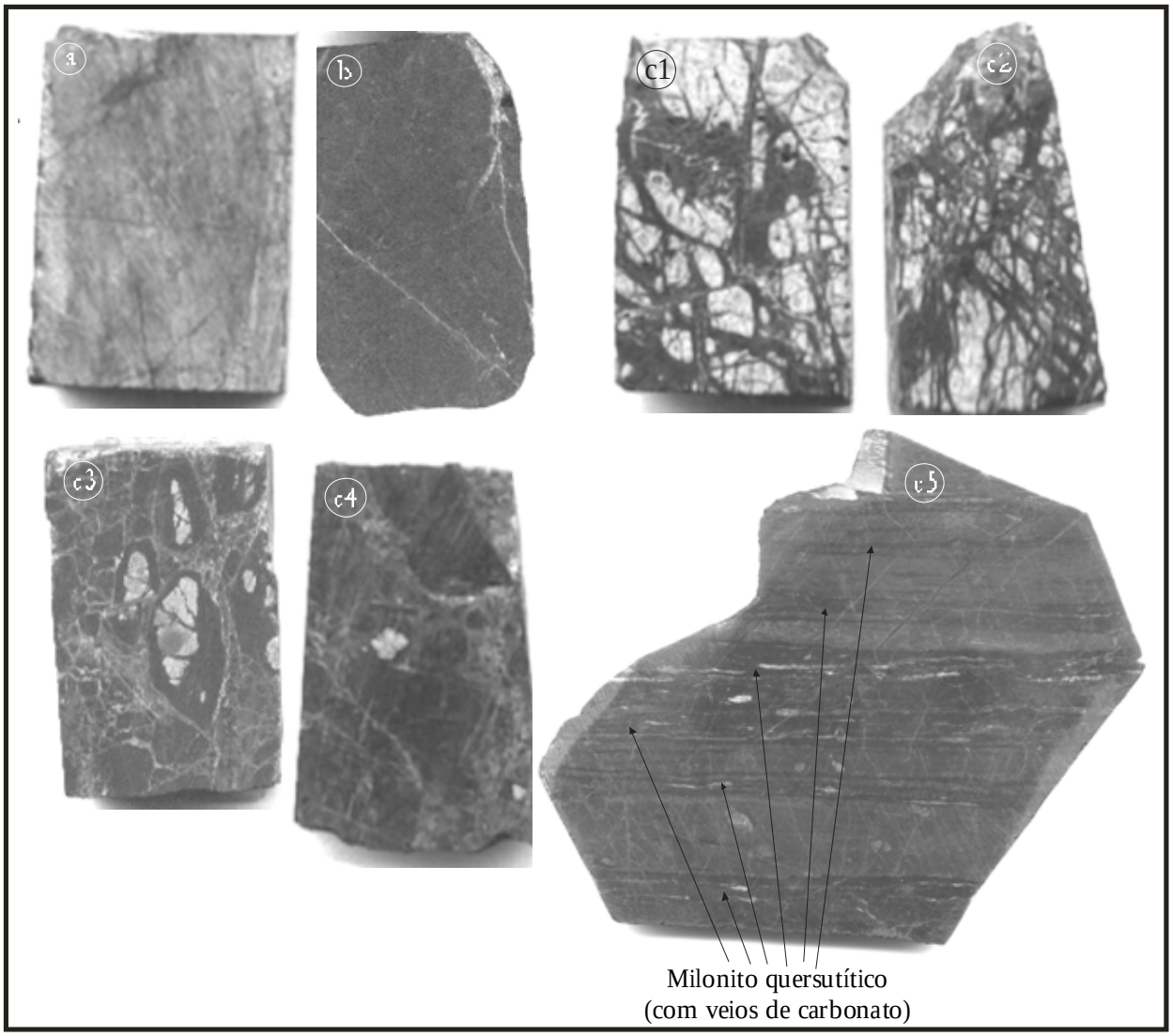

Figure 6: Representative hand-samples of emerged rocks from SPSPA: a) Peridotitic mylonite; b) Kaersutitic mylonite; c- Serpentinized peridotite mylonite; d- Kaersutite-peridotitic banded mylonite

.

This tectonic event also caused an opening in the fracture system of the islands of SPSPA, whose spaces were filled with gray sandstone containing angulated pebbles with length varying between 5 and 15 cm, thus initiating the deposition of the Viuvinhas unit.

The deposition of the Viuvinhas unit covered the limits of the fractures, in a more extensive area. Probably, the seismic activity was responsible for the occurrence of decimetric blocks (1 m) in this unit. With the development of the Viuvinhas unit sequence, there was a deposition of the reddish sandstones in a calmer environment. Finally, a second seismic event caused the inclination of the whole St. Peter and St. Paul Formation, and a new rupture on the opening of the cove turned the island into its current configuration, where only parts of this bay remain

preserved. The presence of coral fossils in the Viuvinhas unit indicates that, at this location, there was a water lamina lower than 30 cm, in contact with the open sea and strong biogenic activity. A third and stronger seismic event reactivated the fracturing of the crystalline basement, and, through propagation, fractured the St. Peter and St. Paul Formation. This fact suggests that the crystalline basement was fractured into two blocks that suffered inclination, because the St. Peter and St. Paul Formation has two flanks with dips of 20º to 330º of azimuth and 35º to 300º of azimuth, respectively.

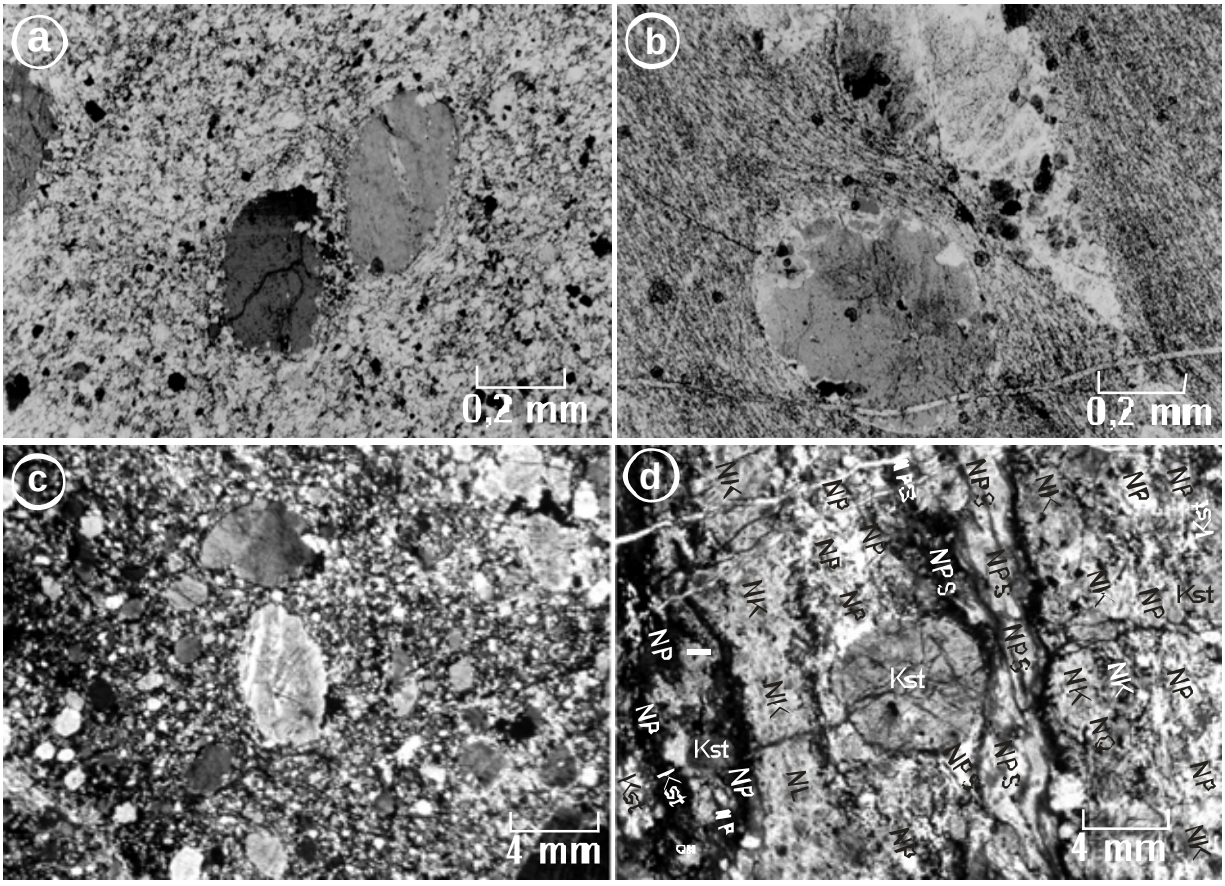

Figure 7: Photomicrograph of the rocks of ASPSP: a) Peridotitic mylonite with olivine porphyroclasts involved by mylonitic matrix. Small clasts derived from olivine and involving the porphyroclasts (mortar texture) are indicated. The opaque grains are spinel (crossed nicols); b) Peridotitic mylonite with enstatite (upper) and olivine (lower) porphyroclasts. The dark grains are spinel. It is pointed out the mylonitic texture of the matrix (crossed nicols); c) Kaersutitic mylonite with kaersutite porphyroclasts (Kst) of different sizes. The opaque grains are magnetite (crossed nicols); d) Layered mylonite with matrix showing alternation of kaersutite + magnetite and peridotite levels. Kaersutite porphyroclasts are indicated in the peridotite layers (parallel nicols). NK: kaersutite layer; NP: peridotite layers; NPS: serpentinized peridotite layer.

The fracturing of the St. Peter and St. Paul Formation caused more erosion damages, and led to the relief as currently presented. The most important sea level indicators found are the barnacles and coral fragments, which indicate sea levels variation zones. The variety of lithotypes, which is a type of stratification and assembly of fossils found on the St. Peter and St. Paul Formation, suggest that these successions were deposited during a sub-aerial marine regime dominated by waves, and that the archipelago was actually under the current sea level during the beginning of the Quaternary. Small terraces with polymitic conglomerates (mylonitic pebbles, sedimentary rock fragments, marine fossils) mark different paleo levels at 3, 6, 10, and 15 m above the current sea level, similar to those found in the Fernando de Noronha Archipelago, Atol das Rocas, and Litoral of Rio Grande do North State, which suggests that the ascent of the archipelago may have occurred episodically. However, it is still unknown if it occurred: I - through seismic-tectonic movements (e.g.: subsidence, ascent, and lateral movement of the oceanic floor) or II - through isostatic or geoidal movements (e.g.: subsidence or ascent of the oceanic floor through the combined action of density differences in the rock column, lower crust/upper mantle, and gravity) (Bonatti, 1978), which are common in the archipelago region, or III – through

eustatic movements (e.g.: oceanic water volume variations) (Angulo & Giannini, 1997; Isla, 1989; Martin *et al*., 1985; Pirazzoli, 1991; Suguio *et al*., 1985).

SITE PROTECTION INITIATIVES

The Saint Peter and Saint Paul Archipelago was turned into an "Área de Proteção Ambiental (APA)" – Environmental Protection Area, decreed by law Nº 92.755, June 5th 1986. The quadrilateral area of the APA of SPSPA is delimitated by the parallels 0º56' and 0º54'N, and meridians 29º20' and 29º21'W.

The APA of SPSPA is in excellent conservation status. Tourist visitations are not allowed. However, the approval of the establishment of the St. Peter and St. Paul Archipelago program (Pro-Archipelago) by the Inter-Ministerial Commission for the Sea Resources (CIRM) in June 1996, and the inauguration of the Scientific Station of the St. Peter and St. Paul Archipelago (ECASPSP) in June 1998, guaranteed the exclusive habitation of researchers related to the Pro-Archipelago and Oceanic Islands (SECIRM-CNPq).

Since then, the scientific community has been developing continuous and systematic research in the region, involving the various areas of study (geology, geophysics, biology, oceanography, meteorology, and fishing resources). In may 2004, the Brazilian Government requested to the United Nations Sea Rights Convention (CNUDM) the delimitation of its sea territory around the APA of SPSPA, an area with 200 nautical miles of radius, denominated the "Exclusive Economic Zone" (Fig. 1b).

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