



**Gondwana Geodiversity and Geological Heritage:
Examples from the North Coast of São Paulo State, Brazil**
Geodiversidade do Gondwana e Patrimônio Geológico:
Exemplos da Costa Norte do Estado de São Paulo, SP

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Resumo

A região do Litoral Norte do Estado de São Paulo é caracterizada por registros de uma história geológica relacionada ao supercontinente Gondwana Ocidental, amalgamado durante o Ciclo Brasileiro, no Neoproterozoico-Cambriano e fragmentado no Jurássico-Cretáceo. Reativações durante o Cenozoico foram também responsáveis pela configuração atual da Serra do Mar e da linha de costa. Além disso, a região detém a mais importante área de Mata Atlântica preservada no Brasil, o que aumenta sua importância como zona protegida. A estes aspectos físicos somam-se registros de uma história que remonta a 2500 anos, além de inúmeras 101-11 construções do período colonial que contam uma história de desafios entre os povos nativos e os conquistadores. O conjunto destes aspectos deu origem a uma cultura rica, caracterizada pela mistura de costumes de populações tradicionais diversas e que delinearão os valores culturais atuais. Este trabalho tem como escopo principal associar os principais eventos geológicos que ocorreram durante o Neoproterozoico-Paleógeno, incluindo fusão e separação do Supercontinente Gondwana e processos associados, aos valores da Geodiversidade da região. O objetivo destas ações é incluir locais com reconhecido valor geocientífico em programas de Geoturismo locais, incluindo apoio à sustentabilidade, preservação da história e da cultura tradicional, integração da população costeira e geração de emprego e renda.

Palavras-Chave: geoturismo; Gondwana Ocidental; Litoral Norte SP; patrimônio geológico

Abstract

The North Coast of São Paulo is marked by a geologic history related to the Western Gondwana supercontinent, amalgamated during the Brazilian Cycle in the Neoproterozoic-Cambrian, and fragmented in the Jurassic-Cretaceous. Reactivations during the Cenozoic were also responsible for the current configuration of the Serra do Mar Mountain Range and the coastline. Moreover, the region holds the largest preserved area of Atlantic Forest in Brazil, which increases its importance as a protected zone. In addition to physical aspects records of history dating back 2500 years, as well as numerous buildings from the colonial period that tell a story of challenges between native peoples and conquerors occurred in the area. Together these features led to a rich culture, characterised by a mixture of customs of diverse traditional populations and that outlined the current cultural values. The aim of this work is to associate the main geological events that occurred during the Neoproterozoic-Paleogen, including merging and fragmentation of Gondwanaland and associated processes, to Geodiversity values. These actions are intended to include sites of recognised geoscientific value into local geotourism programs, including support for sustainability, preservation of history and traditional culture, integration of coastal population, and income generation.

Keywords: geotourism; West Gondwana; North Coast of SP; geological heritage

1 Introduction

Since the creation of IPHAN (Institute for National Historical and Artistic Heritage), in 1933, the necessity to protect valuable registers of the national culture (our built, natural, and immaterial environment) has started to be debated among the several segments of society. From the debates emerged the first ideas concerning the Natural Heritage in Brazil, since that a number of testimonies of natural heritage have been protected both by the Federal, State, and Municipal organs and by municipal and state offices (Delphin, 2009). Only recently the geological aspects of the natural materials and landscapes were taken in account in the process of valuing our natural heritage.

Unlike other countries, the concepts of Geodiversity and Geological Heritage have started to be understood and effectively applied only in the 1990's, when the Brazilian Commission of Geological and Paleontological Sites (SIGEP) brought about in order to implement the national inventory of geosites. Currently, the Geological Survey of Brazil (CPRM) carries out two projects geoconservation: one is the creation of Brazilian Geopark network and the other one, the state geodiversity map.

In São Paulo, the creation of the State Council of Geological Monuments (CoMGeo) in 2009 linked to the Department of Environment (SMA-SP) and to the Geological Institute (IG), had as main goals to inventory, to conserve, and to disseminate information about the selected geosites. Until now, six sites have been approved as geological monuments, such as the Varvite Park, in Itu and the Moutonéé Rock Park, in Salto.

It is noteworthy that since the International Year of Planet Earth (2007- 2009) with the institutional support of the United Nations Educational, Scientific and Cultural Organization (UNESCO) the International Union of Geological Sciences (IUGS), given to issues related to Environment and Protected Areas, in particular the Geoparks (along the lines of Unesco). In this respect Brazil is far behind other countries regarding the preservation and dissemination of natural landscapes. The Geopark Araripe, in the State of Ceará, is so far the only one, but several proposals for creation of geoparks are being organised in order to protect and promote the geological and paleontological sites in Brazil.

Despite these difficulties some initiatives have been widely successful, as the “Caminhos Geológicos”, coordinated by the Department of Mineral Resources of the State of Rio de Janeiro (DRM-RJ), the “Geological Monuments of the State

or Paraná”, by the Geological Survey of Paraná (Mineropar), and other of more local character. The success of these initiatives demonstrates that the public is, indeed, attracted by information about the history of their planet, especially the surrounding landscapes that make part of their own histories, as the distribution of the populations, as well as the natural hazards, are closely related to the several geological events and processes that took place along the history of the Earth.

On the basis on these facts this work intends to link the main events that came about along the Neoproterozoic-Paleogen history of the North Coast of São Paulo (Figure 1), which includes fusion and breakup of the Gondwana Supercontinent and associated processes, with some geological materials and features that compound the Geodiversity of the region. The description of the sites must be taken as qualitative, preliminary observations, already to be improved with further inventory and quantification work that will allow dissemination activities such as didactic routes and geotouristic uses (in the sense of the Arouca Declaration, 2011). Also, support to the integration of coastal population and/or generation of employment and incomes by these activities are among the main expected results, because to make scientific knowledge to be not restricted to academic institutions, as well as provide better living conditions for local communities, are the main bases of Geotourism.

2 Geological Background

The region under investigation is part of the Ribeira Belt, which extends as an elongated strip for more than 1000 km along the Atlantic coast of Brazil and is one of the orogens that compose the Mantiqueira Province (Almeida *et al.*, 1977, 1981), of Neoproterozoic age. The origin of this orogen, whose African counterpart is found in Angola and Namíbia, is related to the collision of the São Francisco and West Congo cratons, with associated accretion of several microplates and terranes, which took place between 650 – 510 Ma (Schmitt *et al.*, 2004; Heilbron *et al.*, 2008; Tupinambá *et al.*, 2012) and corresponds to the Brazilian-Pan African Tectonic Cycle. The last collision event has overprinted the former geometry of these accreted terranes, whose limits were organised as NE-SW regional-scale mainly dextral shear zones that have since then worked as zones of weakness, being reactivated in lower crustal levels during later extensional events. Transition to stable platform conditions occurred in the Silurian-Devonian (Brito Neves, 1999).



Figure 1 Location map of the area with the main towns of the North Coast of São Paulo, Brazil and the preliminary geological sites outlined in this work.

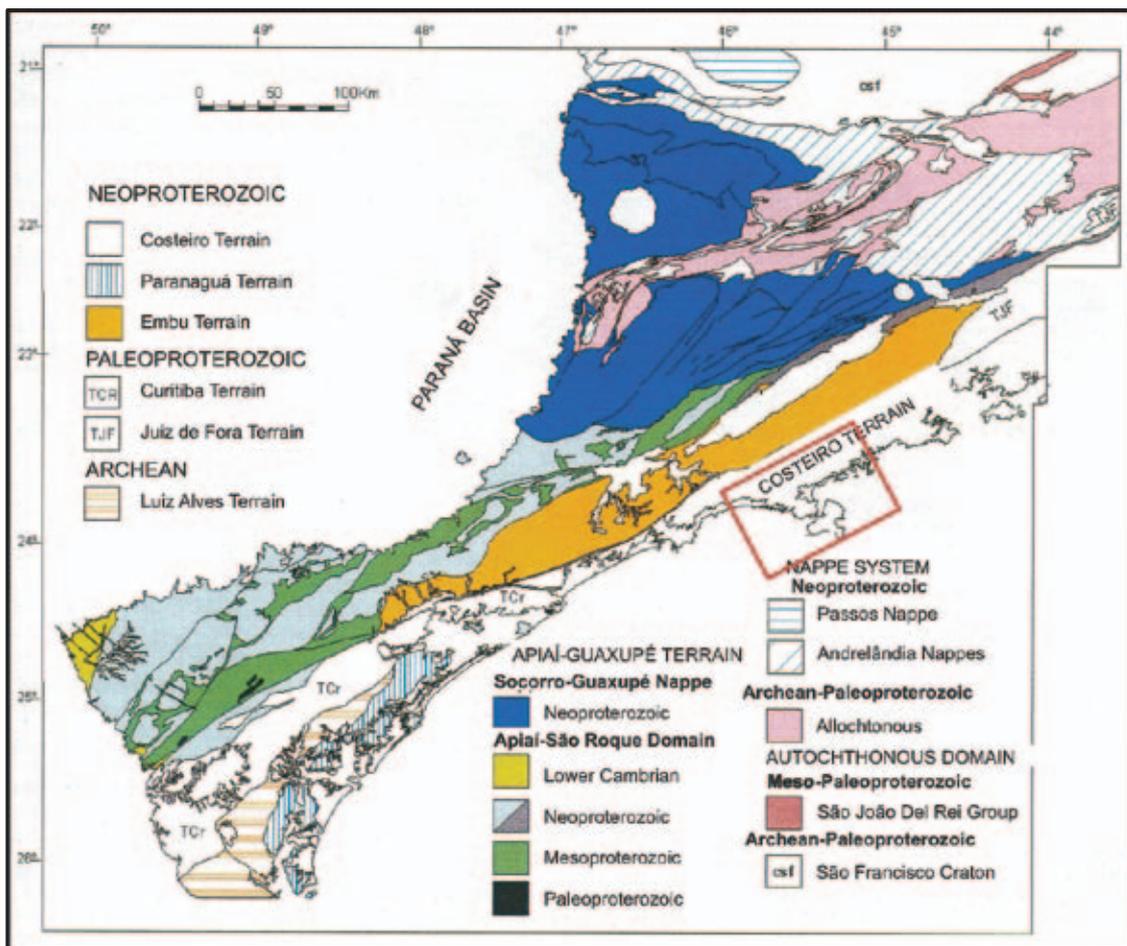


Figure 2 Tectonic map of the Apiaí, Guaxupé, Curitiba, Embu, and Luis Alves terrains (from Heilbron *et al.*, 2004). The red square indicates the area focused in this work.

The Ribeira Belt is subdivided into several geological units, which, in the region focused in this work, is named Costeiro Complex (Hasui *et al.*, 1981) or Domain (Heilbron & Machado, 2003). It is limited to the northwest by the Cubatão Shear Zone and extends until the coastal area, including the islands. It is composed mainly by arc-derived orthogneisses and partially migmatized high-grade metapelitic gneisses, including amphibolitic layers interpreted as paleodykes, being the whole set intruded by many syn- to late-collisional bodies of granitic composition (Campanha & Ens, 1996; Dias Neto *et al.*, 2009; Tupinambá *et al.*, 2012). It represents one of the terranes that have converged during the agglutination of the Supercontinent Gondwana, during the Neoproterozoic / Cambrian (Tupinambá *et al.*, 2007).

In the Early Cretaceous (~ 130 Ma) the Reactivation Stage of the Brazilian Platform took place (Almeida, 1969), characterised by extensional processes related to the breakup of Pangaea Supercontinent, separation between Brazil and Africa and opening of the South Atlantic Ocean (Hasui, 2010). Intense tholeiitic magmatism preceded the early phase of these processes, including the huge Paraná Magmatic Province, being represented in the region by mafic basic and intermediate dykes whose emplacement was controlled by the Neoproterozoic structures and by the Paraná triple junction (Garda & Schorscher, 1996; Coutinho, 2008). Alkaline magmatism represented by stocks and dykes took place both in the rift and ocean stages of the Atlantic margin (Riccomini *et al.*, 2005).

During the Paleogen, variations in the stress regimes of the South American plate led to the development of the Continental Rift of Southeastern Brazil, which extends from the states of Paraná to Rio de Janeiro (Riccomini *et al.*, 2004) and along which a series of small basins were formed, also associated with new episodes of alkaline magmatism. Reactivation of the Neoproterozoic crustal discontinuities under both extension and vertical movements as normal faults was responsible for initial rifting and uplifting of adjacent blocks such as the Serra do Mar e Mantiqueira mountain ranges, characterising a “double scarpment” that reflects a composite evolution related to distinct processes such as reactivation of older Neoproterozoic structures and formation of the rift (Hiruma *et al.*, 2010).

3 Physical and Cultural Aspects

The coastal region of São Paulo corresponds to the largest continuous preserved segment of the

Atlantic Forest in Brazil, most of which included in Serra do Mar State Park (SMSP), which extends from the São Paulo/Rio de Janeiro states limit to the town of Itariri, in the south. In the area focused on this research includes three nucleus: Picinguaba, Caraguatatuba, and São Sebastião. Besides the SMSP, two other conservation are present in the area: the Ilhabela State Park (ISP) and the Ilha Anchieta State Park (IASP), both part of the Atlantic Forest Preservation Project (AFPP). Although these units had been primarily created to preserve biodiversity, the region shows a great touristic potential and geoscientific importance not only because of the fauna and flora, but also for the rock outcrops and landscapes formed in different evolution stages and geodynamic events – the geodiversity.

The Atlantic Forest is also home of great cultural diversity formed by several indigenous groups and other antique cultures, such as the Caiçaras, the Quilombo People, the Caipiras, etc. (Figure 3A). Some of these people live in the protected areas, such as the Guaranis in the Boa Vista Village in the Prumirim Neighborhood, and the Cambury Quilombo, both in Ubatuba. The Caiçara Population is concentrated in the cities of Caraguatatuba and Ubatuba, as well in the south coast. Despite the rich cultural heritage, the urbanization process and development of coastal tourism have made these people to stay somewhat marginalised, being often expelled from their territories (Niemann & Vitte, 2010). Besides the social effects, these same processes can cause physical changes such as erosion, scarpment, and reshaping of the coastal line, due to the extreme fragility of the physical natural system of the region (Cruz, 1975; Ab'Saber, 1986). Even though, according to Pereira *et al.* (2009) the greatest impacts caused by these processes are cultural, social, economics, and politics, being the spatial and ecologic indicators among the less modified. Traditional people normally have deep relationship with the environment in which they live, because of their extreme dependency of the natural heritage. Living from artisanal fisheries, subsistence agriculture, and other extractive activities, their way of life, despite any practices that harm the environment, primarily holds the definition of self-sustainable development, in relation to nature and to the preservation of traditional knowledge. The creation of the protected areas has brought about the discussion on how these populations can be affected by government actions, as an example these caused a sudden ban of use of land for subsistence crops and extraction, making them become dependent on foreign sources of food, a situation that often results in a cultural change (Guillaumon *et al.*, 1989; Nogara, 2005; Matosso, 2006).

On the other hand, the preservation of the Atlantic Forest, through the creation of conservation units, can bring new job opportunities for local people, such as ecotourism, where people can be trained as local guides and municipal staff. In addition, social programs, such as cooperatives and other private and governmental organisations, can be used to create resource management and sustainable extraction, as well as the interaction between legal structure and tradition. A good example is the Juçara Project, performed by the Institute of Permaculture and Ecovillages of the Atlantic Forest (IPEMA), and the Subaquatic Trail Project, of the Institute of Biosciences/USP (Berchez *et al.*, 2007 - Figure 3B).

Vestiges of nomad pre-colonial inhabitants, such as indigenous sambaquis in Ilhabela ca. 2000 years (Bendazolli, 2011) and in the Mar Virado Island and Tenório shell-bearing sites (Abreu, 2000; Uchoa, 2009), found and reveal details of life in this part of Brazilian coast before the arrival of the colonisers, in the 16th century. After those events, the history of the North Coast of São Paulo had been marked by bloody, important fights between the native indigenous people and the conquerors, as well as by incursions of pirates coming from many parts of the world. Records of this period can be found in all of the cities that compound the region (Figure 3C).

4 Concepts and Approaches

The idea of Geodiversity was introduced by Gray (2004) as the natural variety of geological, geomorphological, soil features, and assemblages. According to the author, the term was first used in the 1990's, in Tasmania, to correlate the biological range with the materials and processes of the abiotic environment. Geodiversity comprises all the physical aspects of our planet, including the processes that are continuously giving rise to the geological records. As rocks are the primary substrate for any kind of living life, in a broad sense biodiversity would be strictly dependant of geodiversity (Brilha, 2005).

Geodiversity can be valued by the use of parameters such as intrinsic, cultural, aesthetic, economic, functional, or scientific values (Gray, 2004). This aspect, as well the necessity to protect the most valuable registers, has led to the concept of Geological Heritage, constituted by any kind of geological materials (rock formations, ore deposits, fossils) or features (structures, landscapes) worth to be preserved due to their importance regarding the geological history of a region. These geodiversity



Figure 3 A) Members of the Fazenda Quilombo and the Pinguaba Caiçara communities during dance presentation at the Pinguaba Nucleus (SMSP). Photo: P. Ribeiro; B) Student monitor and visitors during environmental education activity in the Subaquatic Trail Project, Pinguaba; C) Ruins of the old slave market preserved among recent construction in Ilhabela. Photo: E.A. Del Lama.

elements can be grouped as a geosite, defined as a geographically limited site with high values of one or more of the above parameters (Brilha, 2005).

Lima *et al.* (2010) launched a methodological proposal for a common inventory in large territories and its appliance to Brazil. The authors emphasise the importance of participative activities on the collection of scientific information from both published and personal communicated data, as well as the use of definite criteria to classify the geosites, which would allow the comparison between different areas. They also selected three main criteria that would be the most important to select geosites, based on the established geological framework: representativeness, integrity, and scientific value.

Since 1997, the SIGEP has been encouraging geoscientists from the whole country to propose new geosites and the results are published in two volumes, the third already in press. The geosites are classified according to their major geological significance, which may include type of rock, geological environment, geodynamics features, etc. (Schobbenhaus *et al.*, 2002; Winge *et al.*, 2009).

In this work, examples of the geodiversity values of the North Coast of São Paulo State, which are closely related to the Neoproterozoic evolution, opening of the South Atlantic Ocean and formation of the Serra do Mar Mountain Range, are presented. The complex history that includes several geodynamic events, these values comprise the Precambrian basement, basic to alkaline Mesozoic to Cenozoic rocks, and sedimentary processes and deposits of Quaternary age, as well as tectonically shaped landscapes.

In order to inventory and to propose geoconservation strategies for the region, as well as disseminate both geological information and Environment Education, two projects named “BR-101 Geotourism Map Guide - North Coast of the State of São Paulo, SE Brazil” and “Geotouristic-didactic potential of trails in protected areas: the North Coast of São Paulo, SE Brasil” are being carried out by the Center for Research Support in Geological Heritage and Geotourism (GeoHereditas), of the Institute of Geosciences/USP. Both projects are in their initial stages, but all bibliographic research and fieldwork are in execution.

Among the activities related to these projects are dissemination courses for ecotourism guides from the conservation units, in which geological information regarding the local context are given. Initial evaluation of the geosites is being performed qualitatively on the basis on geoscientific, cultural, historical, didactic, and touristic values, in order to insert these points in local geotourism.

5 Selected Examples of Gondwana Geodiversity in the Region

In this section some geological sites used to exemplify the Gondwana geodiversity in the North Coast of São Paulo are described. These consist of landform description and both local- and regional-scale outcrops that were primarily selected for their scientific, touristic, and didactic representativeness. The descriptions are based mainly in bibliographic research and field observations and lack a quantitative approach that will be carried out with further development of the mentioned projects.

5.1 Basement Structures

An example of regional-scale structure is the oriented outcrops characteristic of the region between São Sebastião and Bertioga (Figure 4A). In this part of the coast portions of rock formations are structurally organised as “promontories” that come out from the continent and continue in the islands, following the structural trend of the basement. These features form an important evidence of the role of the basement framework in the present shape of the coast, since the structural NE-SW arrangement of the Ribeira Belt, formed during the amalgamation stage of Gondwana in the Neoproterozoic, is reflected in these features.

5.2 Late Orogenic Magmatism

The Anchieta Island is the second largest island of the São Paulo State. It is located in the south of Ubatuba City and constitutes an important touristic destination. The history includes inhabitants such as Tamoios and Tupinambás and colonisers, and the construction of a penal colony, in 1902, whose project was elaborated by the architect Ramos de Azevedo, followed by several episodes of riots and battles. The ruins of the old prison are still part of the scenery. Ecotouristic and environmental education activities are carried out by local guides and students along the main trails. The main lithotype present in the island is a 500 Ma monzogranite (Azevedo Sobrinho *et al.*, 2011) that represents the southernmost register of the end of the Búzios Orogeny (Schmitt *et al.*, 2004), the last orogenic event before the South Atlantic opening. The most representative outcrop is located at the end of the Saco Grande Trail (Santos & Garcia, 2012) and exhibits a conspicuous igneous layering

that suggests a lack of significant deformation and reinforces its late-tectonic character (Figure 4B).

5.3 Tholeiitic and Alkaline Dyke Swarms

The processes related to Gondwana breakup and subsequent South Atlantic opening and formation of the Serra do Mar Mountain Range were marked by both onshore and offshore fracturing followed by intense magmatism that took place as enormous basaltic flows and as tholeiitic and alkaline bodies that compound the Serra do Mar dyke swarm (Thompson *et al.* 1998). Previous studies indicate that the tholeiitic magmatism is older (~ 190 to 130 Ma) and related to the initial rifting stages, while the alkaline rocks (~ 80-70 Ma) are taken as related to the migration of the Trindade Mantle Plume and to Cenozoic tectonic events responsible for the actual step configuration of the coastal region and to the formation of Tertiary basins (Guedes *et al.*, 2005; Valente *et al.*, 2007). The outcrop showed in figure 4C is located at the southern part of Ilhabela, in the Cachoeira da Boa Vista area, in a private property with no touristic infrastructure. In this place, both tholeiitic and alkaline dykes show complex crosscutting relationships, and field data suggest that the brittle structures are related to a stress field associated to a sinistral, ENE-WSW-oriented binary with $\sigma_{H_{max}}$ at NNE-SSW and $\sigma_{H_{min}}$ at SSE -WNW (Higa, 2011). These data are consistent with the stress field during the emplacement of the dyke swarms in the Santos-Rio de Janeiro and Florianópolis segment during the Cretaceous (Riccomini *et al.*, 2005) and implies in the reactivation of older Neoproterozoic structures.

5.4 The Alkaline Stocks

Alkaline bodies are widespread in the study area and Ilhabela is a good example of their role in the lithological composition of the coastal region. The island is made up of four alkaline stocks, whose size vary from 1 to 10 km and clearly control the shape of the coast, intruded in Precambrian, deformed gneisses from the Costeiro Domain. The smallest body is named Canas Stock, in the northern part of the island, composed by lithotypes that range from ijolites to nepheline gabbros (Garda & Schorscher, 1996) and most representative expression is a group of large blocks that have been a tourist attraction thanks to the metallic sound that comes out of the

blocks when hit with a hammer (Figure 4D) – the Bell Rock at the homonymous beach. With the support of the municipal government and a local merchant that owns the only restaurant at the beach, a boardwalk passing by the main blocks that compound the scenery was built, which confirms the traditional use of the place as a touristic destination. U-Pb dating of zircon from syenitic rocks belonging to the São Sebastião and Serraria massifs provided average ages of 84.8 ± 0.6 Ma and 85.1 ± 0.4 Ma, respectively, interpreted as crystallization ages of felsic alkaline rocks of the region, as previous studies suggest that the intrusion of the smallest stock was coeval with the bigger ones (Sato, 2006).

5.5 The Serra do Mar Mountain Range and Coastal Plains

At the town of Caraguatatuba, an important hill called Santo Antonio (Figure 4E) holds a ramp for widely used by both local and outside sportsmen. The hill also keeps a 15-meters image of its Patron Saint that brings thousands of visitors every year to its top, from where they can have an amazing view of the coastal line, the sedimentary plain, and part of São Sebastião and Ilhabela and the Serra do Mar Mountain Range. According to Fúlfaro *et al.* (1976) the Caraguatatuba Plain constitutes an exception to the pocket beaches that characterise the coastal region to the north and to the south, as the distance between the current surf range and the scarps that limit the Atlantic Plateau are bigger than the adjacent areas (~ 12 km). These differences would be related to both lithological and structural causes, responsible for deposition in distinct periods of transgression and regression, being the sedimentation in this part notably modified by the huge landslide that occurred in 1967, caused by intense and continuous rainfall (Cruz, 1975; Gobbi, 2009). A remarkable morphological feature is represented by the Serra do Mar Mountain Range, geometrically arranged in the region as a series of fault-limited, differently eroded plateaus (Campanha *et al.*, 1994) that can also be distinguished from the Santo Antonio Hill. Since the first times of colonisation, this big mountain chain has acted as an almost impassable barrier to the penetration inside the country and to the flow of economically important goods (Santos, 2004), being part of the cultural and historical background of the region.

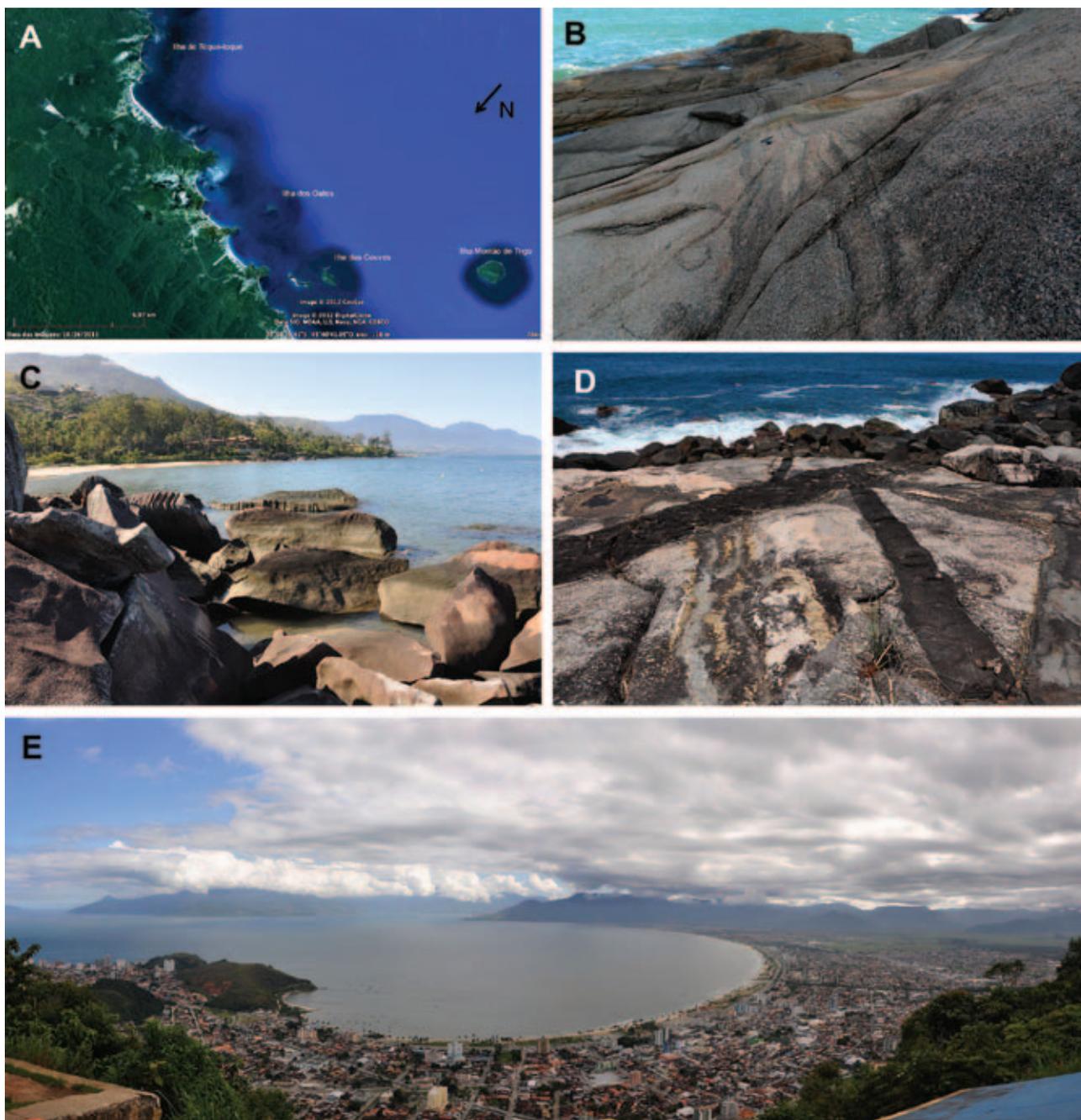


Figure 4 Examples of geological sites related to Gondwana evolution and correlated events in the North Coast of São Paulo State. A) Aspect of the basement structural trends related to Ribeira Belt in the shape of the coastal line and islands between São Sebastião and Bertioga. Source: Google Earth; B) Anchieta Island 500 Ma monzogranite outcrop, Ubatuba; C) Mafic and alkaline dykes showing complex crosscutting histories in the south of Ilhabela. Photo: E.A. Del Lama; D) Basic- to alkaline rocks from the Bell Beach, north of Ilhabela. Photo: E.A. Del Lama; E) View of the sedimentary plain and the Serra do Mar Mountain Range from the Santo Antonio Hill, Caraguatatuba. Photo: E.A. Del Lama.

6 Concluding Remarks

The primary goals of the present report regarding the geodiversity values of the North Coast of São Paulo are threefold. First, to draw attention

to a region that, besides being a traditional touristic destination, holds registers of most of the events that took place during many geological periods, e.g., the Neoproterozoic collision episodes that gave rise to Gondwana Supercontinent, and the further

events that were responsible for the fragmentation and associated manifestations. As described in the previous section, lithological or tectonic features in the different sites, which can be classified as tectonic, igneous, or sedimentary, represent these records. Further work will define the sites with the greatest geotouristic potential, on the basis on parameters as geoscientific value, access facility, fragility of the environment, and use as didactic activity. This clearly leads to the necessity of effectively use these sites as didactic, touristic, or recreational practices, which implies in better accesses, information guides, and supervised visits.

The second goal relates to the role of the physical environment in the distribution of the biodiversity, including human populations and the way people live. Coastal regions have been always main places of human concentrations thanks to the natural facilities, and countries with vast coastlines normally offer many possibilities for geotourism. In the case of the region investigated, fauna communities living in coastal, forest, and other environments that have long determined the circulation of the native human communities represent this biodiversity. In this sense, the region has a great potential in Geotourism activities, which may be primarily used to disseminate the geosciences and their most multidisciplinary branch, which is the observation of nature in the light of interaction of both biotic and abiotic components.

The third goal concerns to the integration of coastal population with Geotourism activities, by means of generation of employment and incomes, as well as appropriation of the geodiversity values by the local people. The original definition of Geotourism was proposed by Hose (1995) to conceptualise the type of tourism that takes as attractive many geological features, such as rock formations and structures. Recently, new concepts have been incorporated to the initial idea, and according to the National Geographic's Center for Sustainable Destinations, Geotourism can be defined as "tourism that sustains or enhances the geographical character of a place—its environment, culture, aesthetics, heritage, and the well-being of its residents". This approach harmonises with that proposed in the I International Geotourism Congress, known as the Arouca Declaration, 2011.

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