DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2015/82

TiO_2 in the Coastal Sands of Brazil

Christian Knudsen & Roger K. McLimans

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF ENERGY, UTILITIES AND CLIMATE

GEUS

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G E U S

Contents

1. Summary **4**

2. Introduction **6**
2.1 Objectives 6
2.2 Methodology 6
2.3 Brazil geology 7
2.4 Physical geography 10

3. Systematic sampling along the coast **12**
3.1 North Coast of Brazil 12
Gurupi River Area 15
Zircon provenance of sand in Northern Brazil 17
Iguape 18
Fortaleza to Natal 19
3.2 North East – Natal to Salvador 20
Baia Formosa 20
Mataracas 22
Costa Azul 23
Penedo 26
Barreiras Formation 27
3.3 Central Salvador to Rio de Janeiro 28
Belmonte 28
Caravelas 30
Linhares 31
3.4 Summary of results from the systematic sampling 32
3.5 Minor elements in ilmenite and leucoxene 36

4. Rio Do Campo area **39**
4.1 Introduction to the Pratiga deposit 39
4.2 Mineral rights 41
4.3 General geology of the Rio Campo area 42
Marine terraces 42
The heavy mineral deposit 45
Punta do Mota deposit 48
Environmental issues in Pratiga and Punta do Mota deposits 50

5. Other possibilities in Brazil **52**
5.1 Byproduct from kaolin production and kaolin tailings 52
5.2 Bujuru 55

6. References **56**

1. Summary

Brazil is a major titanium province hosting the minerals ilmenite, leucoxene, anatase, and rutile in very large scale geological settings. Brazil contains huge carbonatite complexes that host anatase and perovskite. The Brazil craton contains igneous and metamorphic complexes, such as rutile-bearing eclogites that contain up to 10% rutile. However most of those complexes are highly retrograded, altered, and/or of insufficient volume and grade to be sources of titanium ore minerals.

The very long Brazil coastline with enormous stretches of sand is a prime environment for the formation of heavy mineral sand deposits. Certain climatic zones are excellent for causing alteration of ilmenite and the enhancing of its titanium grade. In Bahia state, huge reserves containing high grade ilmenite (~60% TiO_2) are identified (Pratiga area). There is also an operating heavy mineral mine at Mataracas. Clearly, sectors of the Brazil coastal region contain all the geological parameters necessary for the development of heavy mineral sand deposits that contain higher grade ilmenite.

In the period 2008 to 2012 GEUS and DuPont sampled deposits/localities along ca. 4000 km of Brazilian coast with the focus to locate occurrences of +60% TiO_2 ilmenite and to understand how and where deposits of such ilmenite are formed in Brazil. A total of 143 samples were analyzed via Computer Controlled Scanning Electron Microscopy (CCSEM) at the GEUS labs. Of those, 70 are from the Gurupi River area and other DuPont programs conducted before 2008. 44 have been collected by GEUS as part of the regional sampling program and 26 are from the Pratiga and Punta do Mota deposits just south of Salvador.

The analyses of the samples show that +60 % TiO_2 ilmenite is found at several locations along the Brazil coastline and that there are sizable accumulations of titanium minerals that are not being mined, e.g. at Pratiga south of Salvador. At Pratiga, the Bahia State Geological Survey has identified about 266 million tons of sand with 2.6 % titanium minerals and zircon (ca. 3.1 % total heavy minerals). CCSEM of samples collected in the Pratiga deposit during the present program average 61.7 % TiO_2 for ilmenite and for all titanium minerals, 69.1 % TiO_2. The local authorities have been active in trying to promote mining of the deposits at Pratiga and address environmental issues. However, at the time of writing, it is not clear how mineral rights could be obtained nor if development is possible.

The formation of high grade ilmenite (> 60 % TiO_2) is dependent on a number of factors, but chief among them is climate. On the northern coast of Brazil there is a shift from east to west where the dry climate in the east can be coupled with low TiO_2 ilmenite and immature heavy mineral assemblages whereas to the west, close to the very humid climate in the Amazon basin, high TiO_2 grade ilmenite occurs together with mature heavy mineral assemblages (e.g. without mafic silicates). In general, most of the Brazilian coastal sand deposits are mature.

Kaolinite rich sandstones belonging to the Tertiary Barreiras Formation occur near the Brazilian coast. Such sandstones that are altered to kaolin rich deposits also contain high grade ilmenite and a very mature heavy mineral assemblage. Cretaceous sandstones in the Ama-

zon Basin are also deeply altered and kaolinized and characterised by very mature heavy mineral assemblage and high TiO_2 ilmenite. When such deposits are reworked the grade of the ilmenite is inherited. This is probably the case for ilmenite deposits in both the Gurupi River area and the Pratiga area both with Cretaceous or Tertiary sandstones in the hinterland.

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During the last ½ million years at least 5 episodes of sea level high stands affected coastal processes in Brazil. Beach deposits developed during those episodes are common in Brazil. Where Pleistocene elevated beaches have been exposed to the intense weathering climate of Brazil, the contained ilmenite has a high TiO_2 grade.

2. Introduction

This report is a summary of the work done by GEUS and DuPont in the period 2008 to 2012. The work was done in cooperation with local Brazil entities. The Universidad Federal do Rio Grande do Norte (UFRN), Prof. Helenice Vital, contributed a 4x4 vehicle and the time of one or two students to do sampling. The Brazil survey, CBPM, contributed the help of geologist August Pedreira. The Bahia State Geological Survey provided information on the Pratiga area. The results described herein are principally CCSEM (Computer Controlled Scanning Electron Microscopy) analyses of 70 samples from 50 locations along 4000 km of Brazilian coast.

2.1 Objectives

The objectives are to profile an area of the Brazil coastline to locate the occurrence of heavy mineral sands that contain high grade ilmenite (~60% TiO_2) and to understand how such deposits are formed in Brazil.

2.2 Methodology

1. Systematic sampling along the coast:
2. Sampling of known ilmenite deposits
    a. Barra da Cameratuba (near Millennium's plant at Mataracas)
    b. Rio Campo
3. Sampling of Cretaceous sandstone because:
    a. High grade ilmenite has been found in such sediments associated with kaolinite mining.
    b. Cretaceous sediments may constitute the source of high grade ilmenite deposits generated by reworking of the Cretaceous sediments
4. Sampling of Rivers

    Because analyzing river sand will enable interpretation of the mechanism by which the ilmenite is transported and possibly upgraded on its way to the coastal deposits.

The samples were sieved and the heavy minerals in the fraction 45 to 710 µ was separated using bromoform (2.8 g/cm^3) and heavy mineral separate was put into an epoxy resin and polished for use in the CCSEM. CCSEM combines automatic image analyses on back-scattered electron contrast (BSE) micrographs with energy dispersive X-ray spectrometry (EDX) in a scanning electron microscope (SEM) on individual grains in a polished sample. This technique provides grain size, grain shape, and major and minor element chemistry on each single analyzed grain. A more detailed description of the procedure can be found in Keulen et al. (2008) or Bernstein et al. (2008). The results are automatically classified into 21 different minerals or mineral groups. Analyses, interpreted data, coordinates, BSE images, EDX spectra and outcrop images are stored in the Geochemical Database.

Classified minerals and mineral groups are: Ilmenite, leucoxene, rutile, Ti-magnetite, magnetite, chromite, spinel, garnet, sillimanite-kyanite, staurolite, mica, mafic silicates, feldspar, quartz, other silicates, corundum, pyrite, monazite, xenotime, phosphates, carbonates, and other minerals (unclassified). Measured elements include: Na, Mg, Al, Si, P, S, K, Ca, Ti, Cr, Mn, Fe, Y, Zr.

2.3 Brazil geology

Precambrian crystalline shields cover 36 percent of the Brazilian territory.

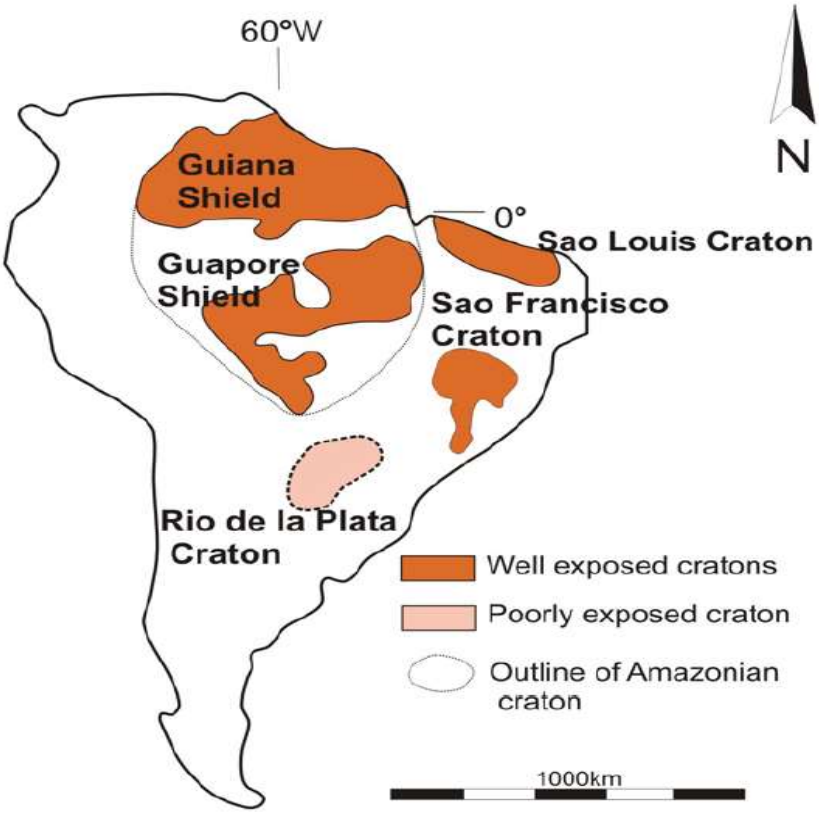


Figure 1 *The Brazilian Shield extends over much of South America to the east of the Andean Chain, and is partly covered by Phanerozoic sedimentary rocks. The three major tectonic units (older than 900 Ma (Ma = million years)) of the shield are the Amazon, São Francisco, and Rio de la Plata Cratons, whereas rocks of the Neoproterozoic (900-550 Ma) Brasiliano Cycle belts surround the cratons in the eastern half of Brazil*.

Paleoarchean rocks (>3200 Ma) occur as small cratonic nuclei in northeastern Brazil, but the cratons contain voluminous 3.000-2.600 Ma granitic and greenstone belts and a large volume of Palaeoproterozoic rocks. Late Mesoproterozoic belts (~1.200 Ma) occur in the western and north-western Amazon Craton and possibly in north-eastern Brazil. There are voluminous Palaeoproterozoic and Mesoproterozoic intrusive and volcanic rocks in the Amazon Craton.

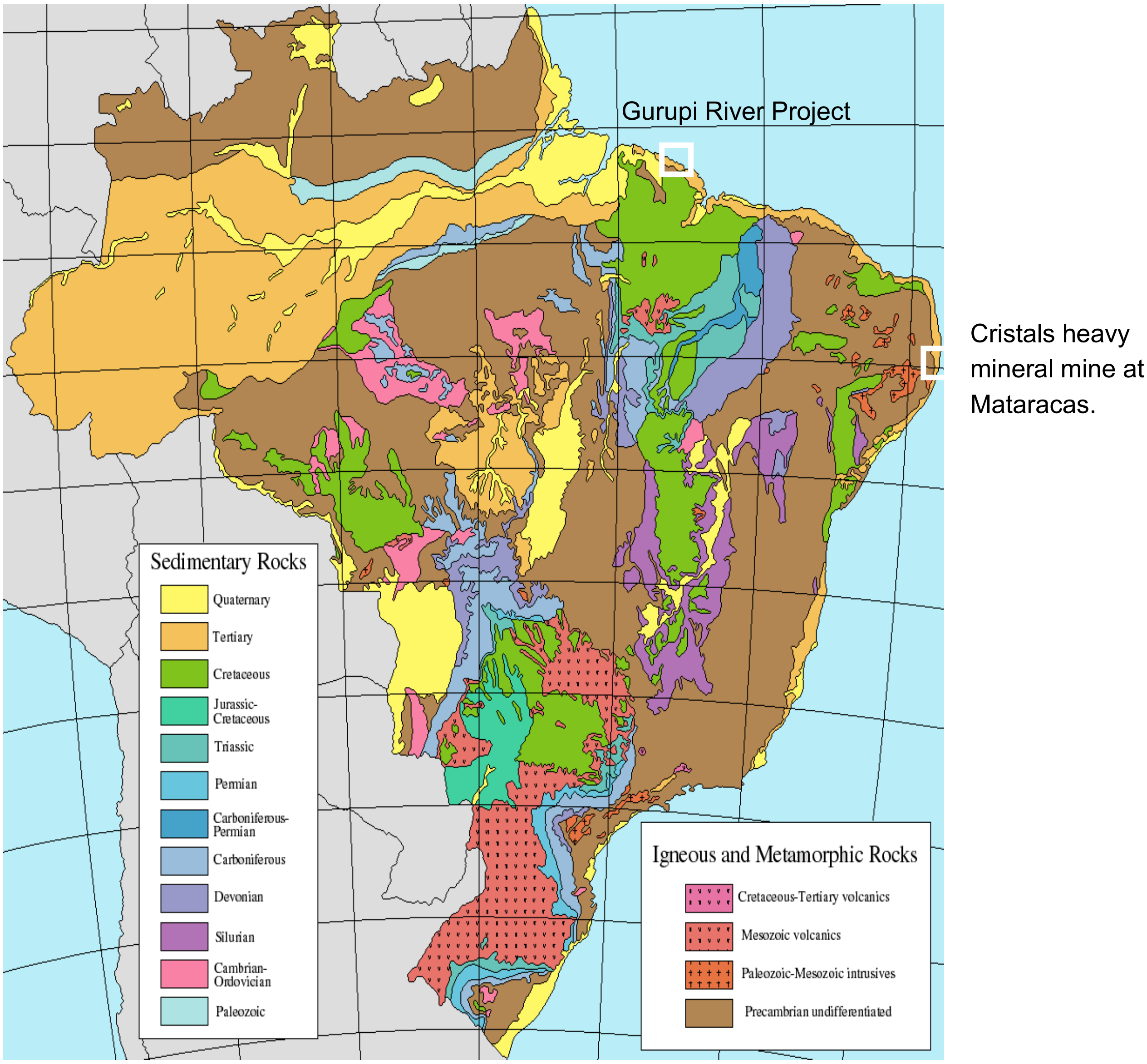


Figure 2 *Geological map of Brazil*

Zones of reworked rocks are common, but the Amazon Craton grew to the N and W by accretion during orogenic events. The Neoproterozoic Brasiliano Orogenic belt is dominantly derived from reworking of older crust.

The basement is covered by a number of sedimentary basins of mainly Mesozoic age (251 – 65 Ma) and kaoline deposits generated by alteration of primarily Cretaceous sandstones are being mined in the region. These are characterised by a very mature heavy mineral assemblage with high grade ilmenite can be found. In the Amazon Basin deposits of Tertiary age (65 – 2,5 Ma - orange on Figure 2) and along the coast they mainly belonging to the Bareiras Formation.

Large volumes of sand has been carried to the coast by the rivers and redeposited by coastal processes during the Quarternary and often acumulated in large dune fields.

Ilmenite mineralization’s in Brazil are plentiful, but the majority is hard rock ilmenite deposits. Alone in the state of Bahia the project “Titânio do Sul da Bahia” (Titanium of Southern Bahia) located 16 occurrences of iron-titanium mineralization’s (da Silva, 2010). These are of magmatic nature, formed by fractional crystallization in magmas of gabbro-anorthosite composition. They may constitute a large fraction of the ilmenite found in coastal deposits in the area such as the one at Rio Campo.

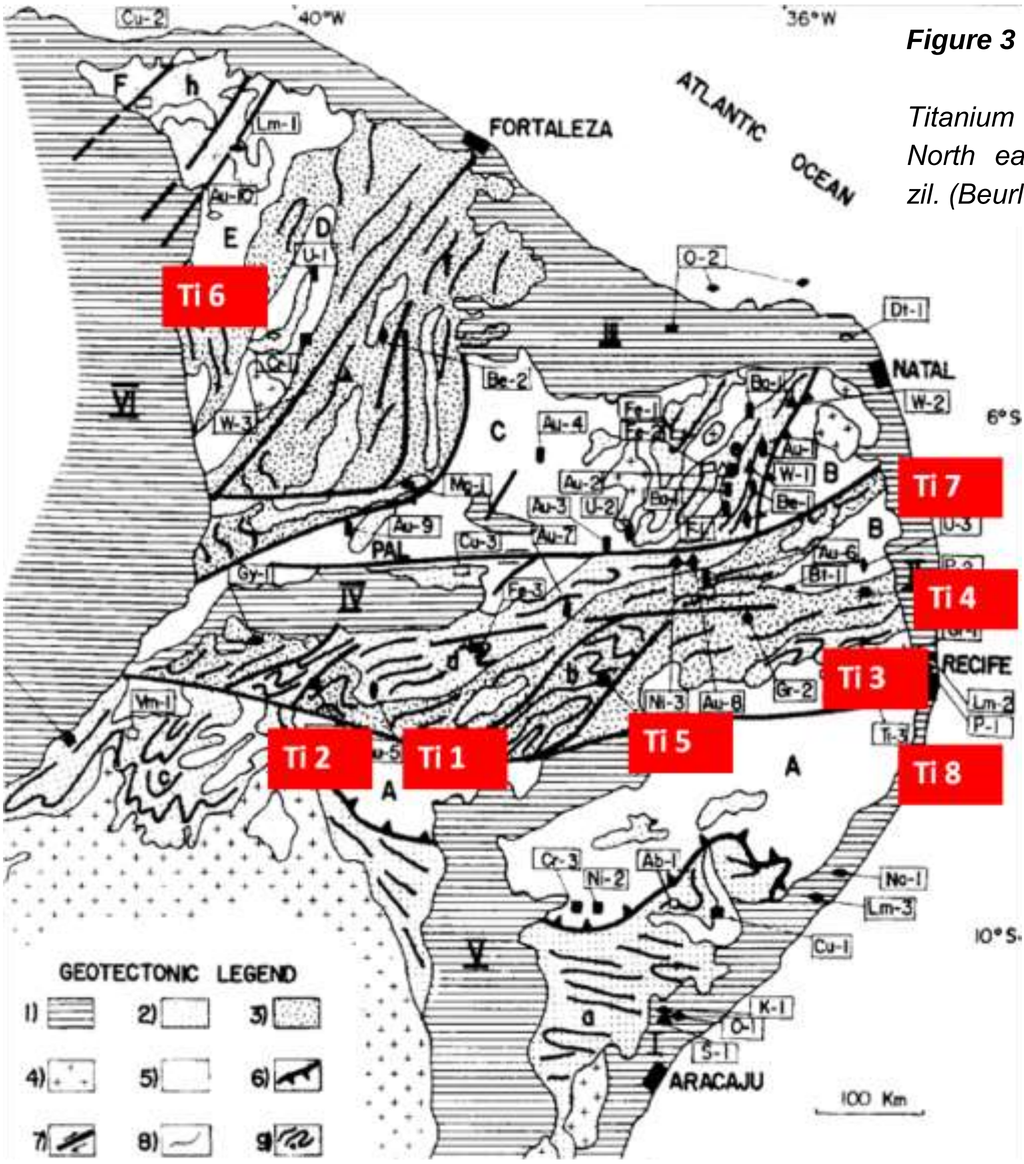


Figure 3

Titanium deposits in North eastern Brazil. (Beurlen, 1995)

High pressure metamorphic conditions indicated by occurrences of almandine-kyanite-muscovite-rutile assemblages tied to the Braziliano Orogenic event (rutile deposit no Ti 6 on Figure 3).

Anatase occurs in Cretaceous carbonatite complexes in Brazil and at one time, DuPont owned the anatase mineral rights for the carbonatite complexes at Salitre and Tapira. Efforts at beneficiation of the anatase deposits were not successful in producing a titanium concentrate that met other trace element specifications for the DuPont process.

Table 1 Titanium deposits in North eastern Brazil. (Beurlen, 1995)

No	*Name*	*Mineral*	*Environment*	*Size*	*Grade*
1	Floresta	Ilmenite	Olivine cumulate	20 Mt	20%
2	Bodocó	Ilmenite	Metapyroxenite	0,2 Mt	
3	Passira	Ilmenite	Anorthosite	nd	
4	Itatuba	Ilmenite	Amphibolite	0,5 Mt	10-20 %
5	Custodia	Ilmenite	Metagabbro	nd	
6	Independencia	Rutile	Gravels	small	
7	Mataracas	Ilmenite/rutile	Dune sand	37 Mt	3 % ilm, 0,5 % rut, 1 % zir
8	Serinhaem	Ilmenite/rutile	Coastal placer	nd	

2.4 Physical geography

Brazil has one of the world's most extensive river systems, with eight major drainage basins, all of which drain into the Atlantic Ocean. Two of these basins - the Amazon and Tocantins-Araguaia - account for more than half the total drainage area.

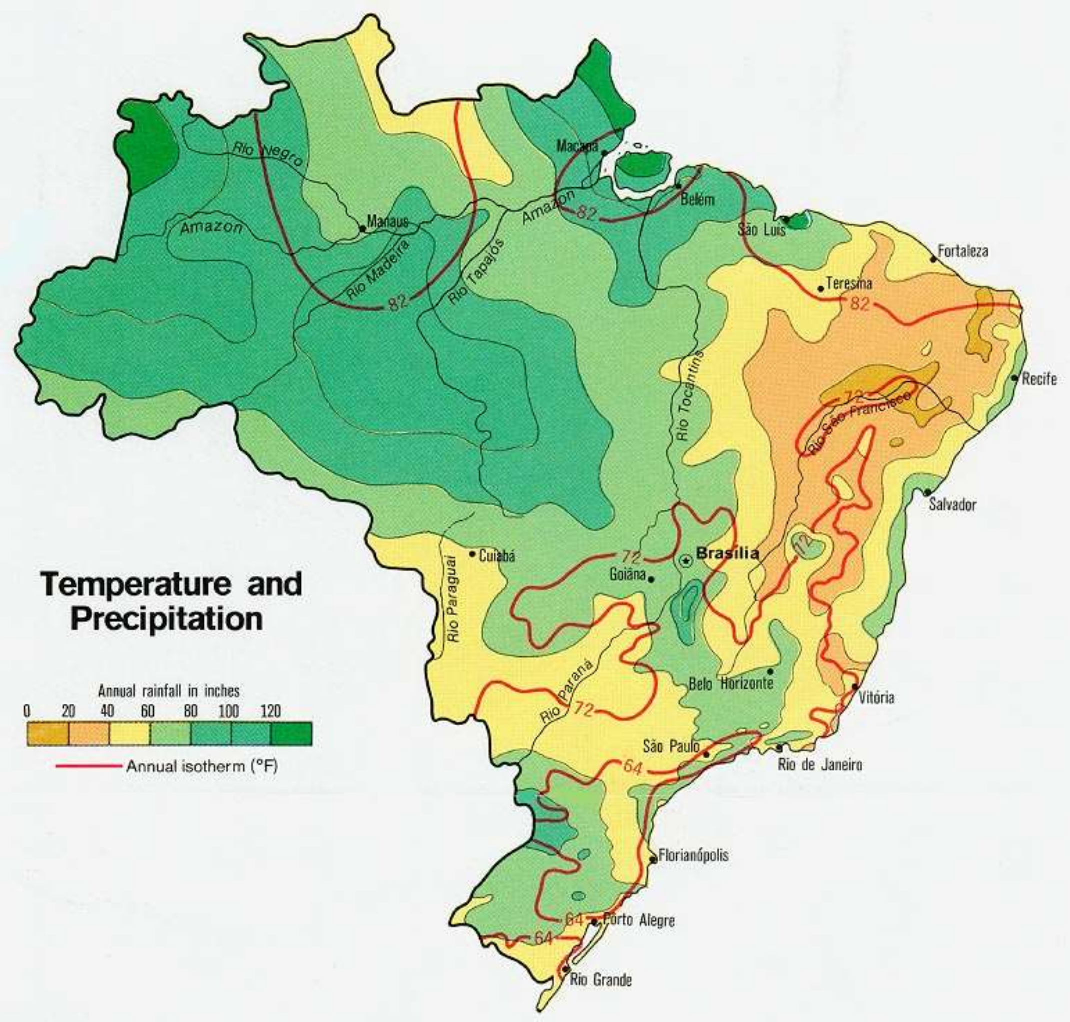


__Figure 4__ Precipitation and temperature (^oF) in Brazil.

The largest river system in Brazil is the Amazon, which originates in the Andes and receives tributaries from a basin that covers 45.7 percent of the country, principally the north and west.

Although 90 percent of the country is within the tropical zone, the climate of Brazil varies considerably from the mostly tropical North (the equator traverses the mouth of the Amazon) to temperate zones below the Tropic of Capricorn (23°27' S latitude). Brazil has five climatic regions - equatorial, tropical, semiarid, highland tropical, and subtropical. Precipitation levels vary widely. Most of Brazil has moderate rainfall of between 1,000 and 1,500 millimeters a year. High and relatively regular levels of precipitation in the Amazon contrast sharply with the dryness of the semiarid Northeast, where rainfall is scarce and there are severe droughts in cycles averaging seven years.

The Northeast is the driest part of the country. The region also constitutes the hottest part of Brazil, where during the dry season between May and November, temperatures of more than 38°C have been recorded. However, the sertão, a region of semi-desert vegetation used primarily for low-density ranching, turns green when there is rain.

These climatic variations (Figure 4) may have impact on the alteration of ilmenite.

3. Systematic sampling along the coast

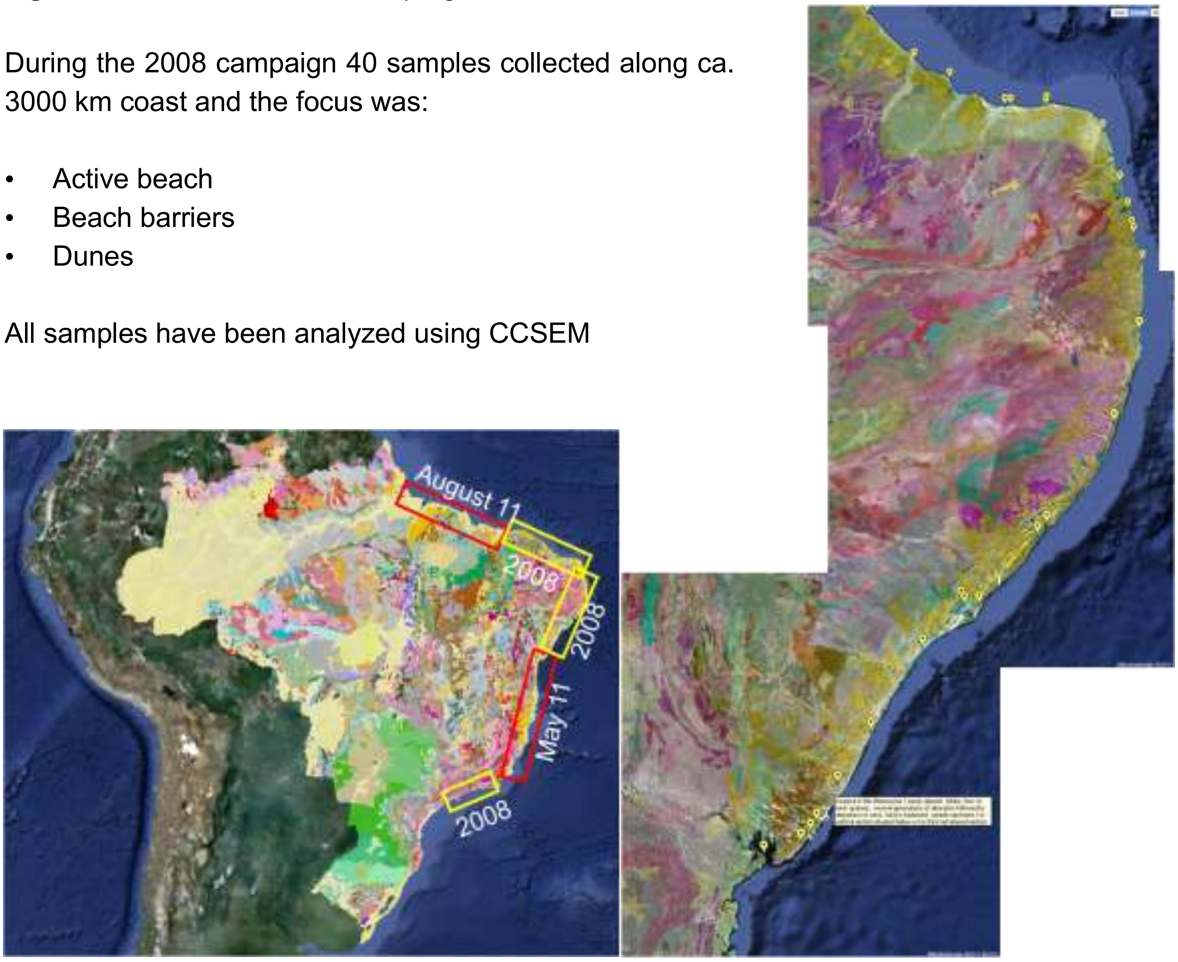
Systematic sampling along the Brazilian coast was initiated to find systematic changes in the ilmenite composition and to locate high grade ilmenite (TiO_2 > 60 %). The sampling was conducted in three campaigns one in 2008 and two in 2011. The spacing between sampling points was ca. 100 km. The sampling was done with a hand auger to a depth of between one and four meters in intervals of one meter.

Figure 5 *2008 & 2011 campaigns:*

During the 2008 campaign 40 samples collected along ca. 3000 km coast and the focus was:

- Active beach
- Beach barriers
- Dunes

All samples have been analyzed using CCSEM



3.1 North Coast of Brazil

The heavy mineral assemblage in the five easternmost beach sand samples on the North Brazilian coast (Figure 6) contains abundant amphibole. The source of these heavy minerals is the Precambrian basement in the hinterland, and a similar, diverse heavy mineral assemblage was also observed by da Silva & Vital (2000) in the Piranhas-Açu River, North-eastern Brazil. The reason for the fairly low degree of attack on the heavy minerals is probably the climate which in this part of Brazil is fairly dry. The heavy mineral assemblage changes towards west with increasing content of alumina-silicates such as staurolite, sillimanite and kyanite. These minerals must be abundant in the hinterland and fingerprint the sediment source in this area. Further west (Figure 6), the heavy mineral assemblage is dominated by heavy minerals such as ilmenite, leucoxene, rutile, staurolite and zircon all characterized as very stable minerals (Morton & Hallsworth 1999).

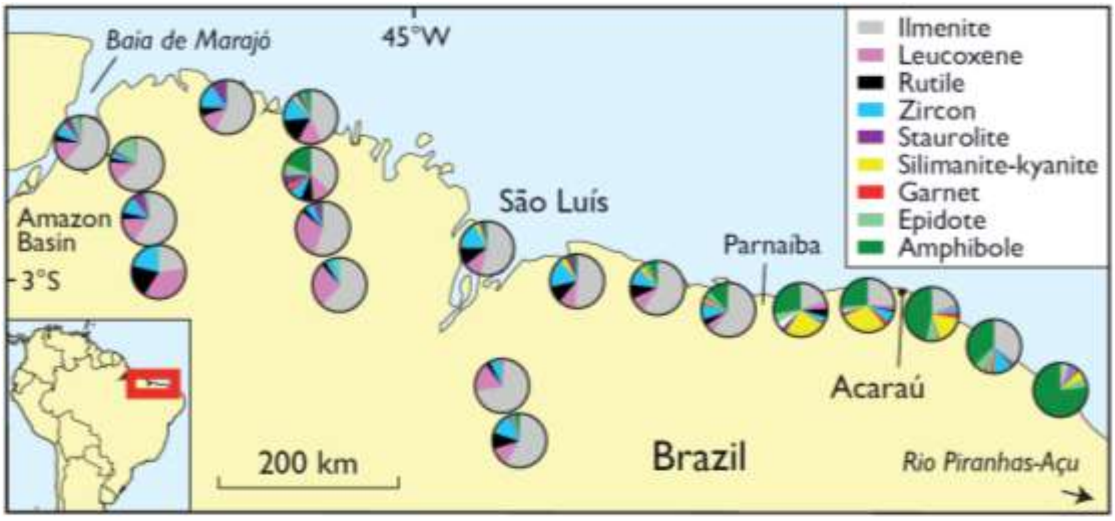


Figure 6 *Modal composition of the heavy-mineral fraction in sand samples from northern Brazil. From Knudsen et al 2015.*

The amount of precipitation increases towards west approaching the Amazon Basin and the combination of hot and humid conditions may account for this change. Further, there is Phanerozoic sedimentary cover-rocks on top of the Precambrian basement, so the higher degree of alteration of the heavy mineral assemblage may be an effect of re-deposition of older sandstones derived from the hinterland.

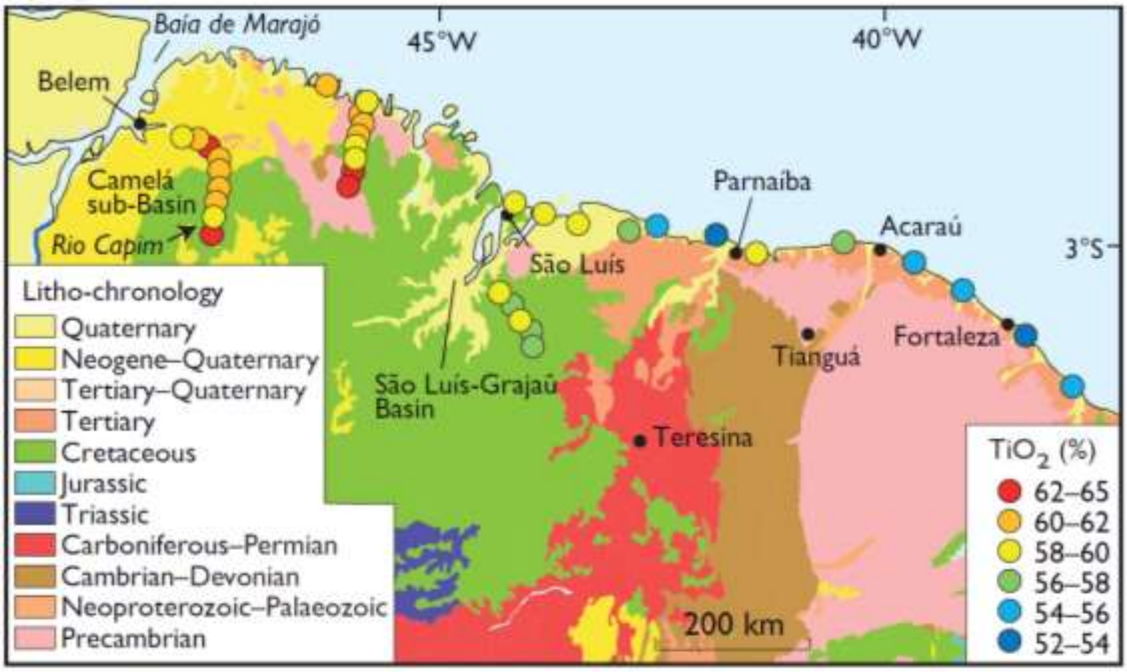


Figure 7 *Average composition of ilmenite and altered ilmenite in samples from beaches, from river beds and from outcrop of Cretaceous sandstone. Knudsen et al 2015.*

The Cretaceous sandstones deposited in the interior of Northern Brazil have been affected by intense kaolinite alteration and Mendes & Truckenbrodt (2009) describes a mature heavy mineral assemblage in the in the Albian sandstones of the Itapecuru Group in the São Luis-Grajaû Basin and Goes et al. (2007) Campanian-Maastrichtian Ipixuna Formation in the Camelá Sub-Basin to the west; in the sense that only very robust heavy minerals such as ilmenite, zircon, rutile and staurolite are present whereas the less stabile heavy minerals are missing (Figure 6).

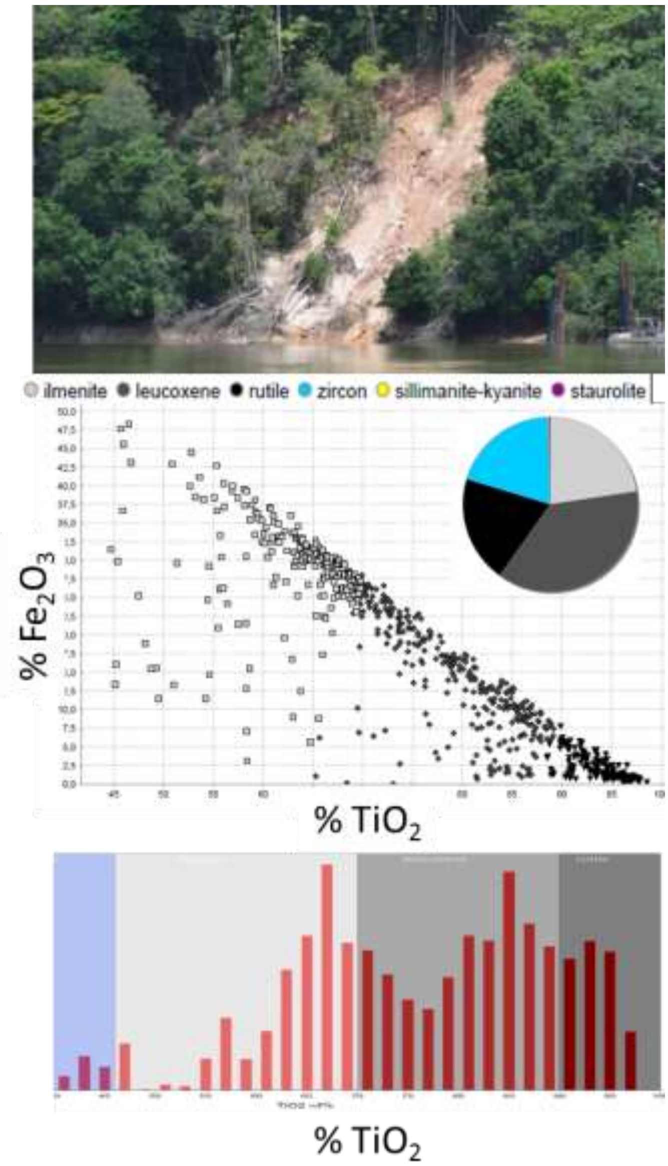


Figure 8

A: Cretaceous outcrop along Rio Capim (sample GGU 538118).

B: CCSEM analysis of titanium minerals from the outcrop. The distribution of TiO_2 versus Fe_2O_3 in the ilmenite, leucoxene and rutile show an inverse relationship between these two components, where Fe_2O_3 decreases with increasing TiO_2 – and with the degree of weathering.

C: Histogram showing the content of TiO_2 in the titanium mineral grains

The composition of the titanium mineral ilmenite changes when it is subjected to chemical attack in the sedimentary environment; iron is leached out and the relative content of titanium increases ultimately to form the mineral leucoxene which almost entirely consists of TiO_2 (Bailey et al. 1956). The average composition of ilmenite is seen on Figure 7 where there is a gradual increase in the TiO_2 content in the ilmenite in the coastal sands towards west. As mentioned above this may purely be an effect of the increasing humidity in the area, but this increase can also be caused by influx of reworked sediment from sandstones in the hinterland. It can be noted, that the TiO_2 content of ilmenite in the Albian sandstones of the

Itapecuru Group in the São Luis-Grajaû Basin (Eastern line of samples in the Cretaceous (Figure 7) is lower as compared to the samples from the Campanian-Maastrichtian Ipixuna Formation in the Camelá Sub-Basin to the west. A Cretaceous outcrop along the Capim River is seen in Figure 8. The heavy mineral assemblage is dominated by ilmenite, leucoxene, rutile and zircon and the content of TiO_2 in the titanium minerals has a bimodal distribution (Figure 8) with almost no ilmenites with the 50 % TiO_2 typical for unaltered ilmenite. The bimodal distribution may suggest that this may be a two stage process.

Gurupi River Area

DuPont explored for and found high-grade ilmenite in coastal sediments in northern Brazil in a pre-2008 period. In that program high grade ilmenite was located in coastal sediments near the mouth of the Gurupi River. The work is reported elsewhere but results are summarized in Figures 9 and 10. The samples analyzed are active sand bodies.

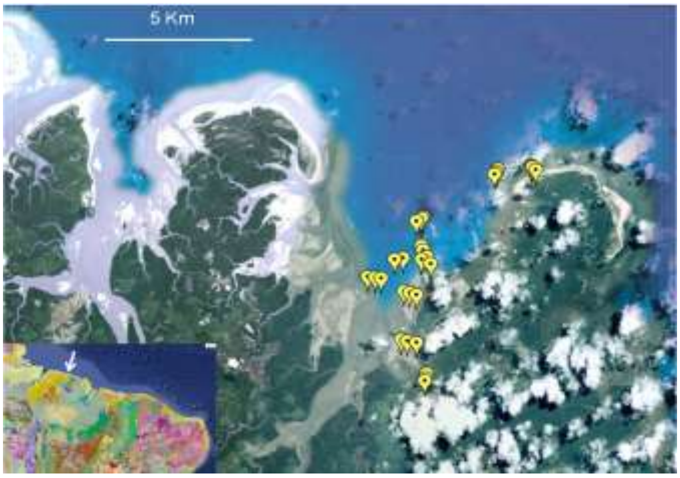


Figure 9

Samples collected by DuPont in the Gurupi River Program.

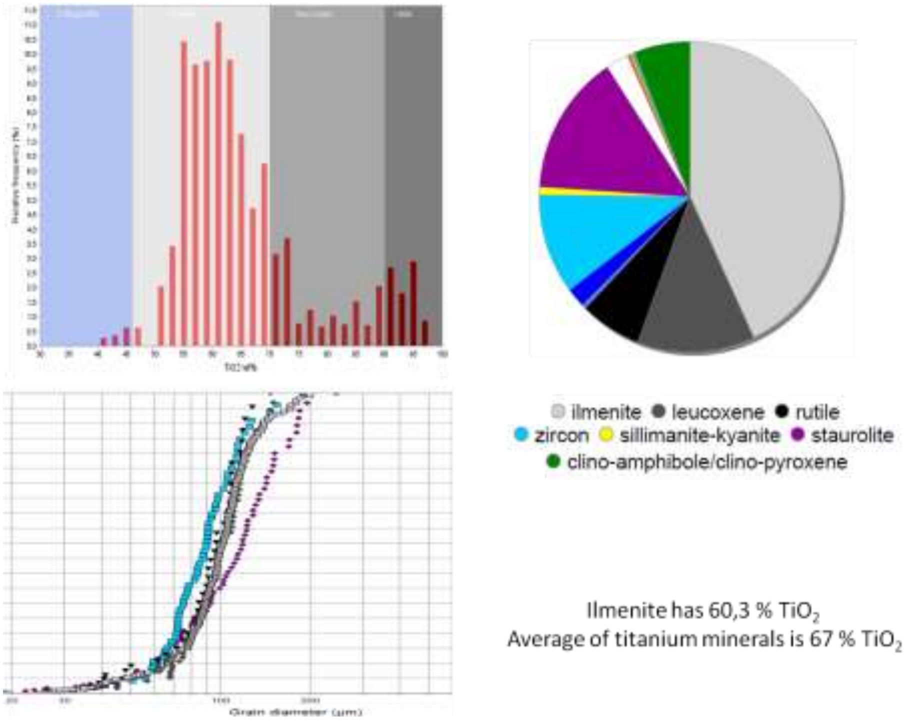


Figure 10 *Titanium distribution in Ti-minerals, heavy mineral assemblage and grain-size distribution in typical Gurupi River sample.*

The costal plain widens eastward, following an inactive cliff 1 m to 3 m in height between the Pirabas and Gurupi bays and abuts a small coastal horst delimiting the northern side of Bragança-Viseu basin. Results from ground penetrating radar (GPR) profiles across the paleo-cliff revealed downward displaced faulted blocks bordering the northern side of the horst. Continuous subsidence has created space to accommodate sediments since the Middle Miocene (Rossetti 2003).

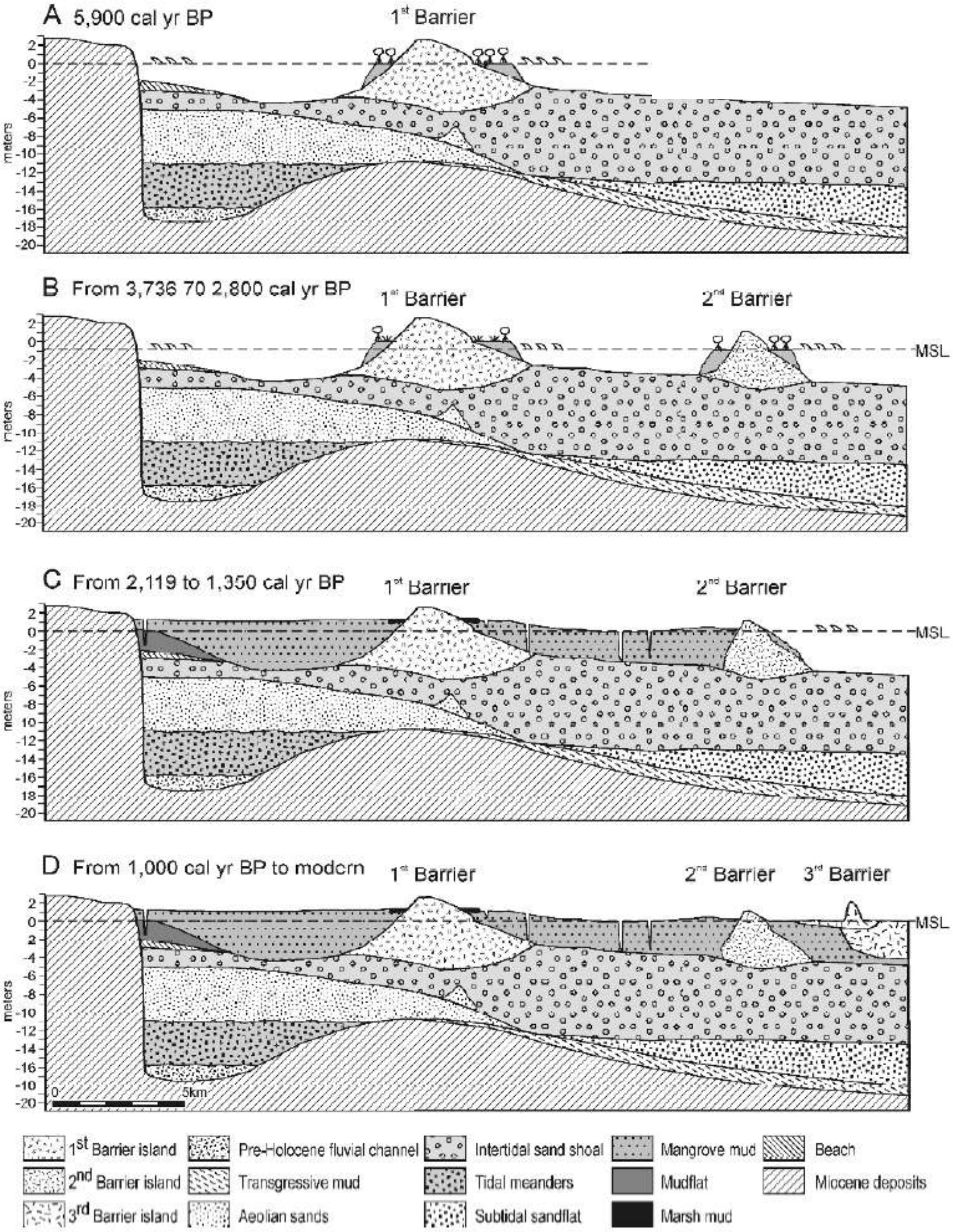


Figure 11 *Schematic model for the evolution of the shoreline in the Caeté barrier estuary system (Souza-Filho et al., 2010) based on a GPR section, Bragança Peninsular.*

The Gurupi horst, from Gurupi to Turiaçu Bay, is a stratigraphic window where Proterozoic rocks outcrop near the coast. Here the coastal plain, limited by the paleo-cliff in the south, reaches its maximum width (40 km), forming a much more jagged coast (Souza-Filho et al., 2010).This setting suggests that there may be preserved fossil barriers containing ilmenite of the composition located in this area.

The Caeté barrier estuary system evolved from a riverine environment into an intertidal muddy area accompanying the last eustatic sea-level rise (Figure 11). Deposition of the marine/estuarine facies has occurred in association with three generations of barrier islands, the last two generations apparently related to at least two small subsidence episodes in the last 3,000 years. The absence of mangrove deposits with ages between 5,913 and 2,800 yrs BP, as well as a general decrease of mangrove pollen in the whole region, suggests that a drop in sea level preceded the development of the second barrier-island. In the last 2,000 years, a relatively more stable sea level has apparently been conducive to the most significant progradation phase, when mangrove swamps prograded more than 20 km. Similar sedimentary processes might have occurred throughout the Eastern Pará coast, where mangrove plains and small barriers exist despite the varying size of the numerous estuaries and catchment areas.

Zircon provenance of sand in Northern Brazil

The U/Pb age distribution patterns for 8 samples from Northern Brazil on Figure 12 represent the ages of zircon sand-grains. Four of these are from Cretaceous sandstone, 2 represent riverbed sand and 2 represent coastal sand. The zircon was derived from somewhere else and they show the age of formation in the area from where the zircon was derived.

A common feature of all the age distributions (Figure 12) is that they are complex with many different ages present suggesting a complex source for all the analysed sands. A complex source is often equivalent to a large source area. Archean zircons are present in all the sands, but the dominating zircon age is Paleoproterozoic and in the range 2,2-2,0 Ga equivalent to the Trans Amazonian Orogeny of the Sao Francisco Craton (Alkmim, & Marshak 1998) and to the Birimian terrain/Eburnean Orogeny in the West African craton (Kalsbeek et al. 2013).

The Cretaceous samples have an overall similarity suggesting that they share source terrain, with the easternmost sample in the Camelá Sub-Basin characterised by a large population of ca. 2050 to 1750 Ma. This may be in accordance with higher contribution of sediment from the Amazonian Craton where the Ventuari–Tapajós Geochronological Province yields zircons with ages in the range 1950–1800 Ma. Nascimento et al. (2007). The zircons with ages around ca. 600 Ma is linked to the Braziliano Orogeny (or Pan African Orogeny) suggesting a source in the North Eastern Brazil

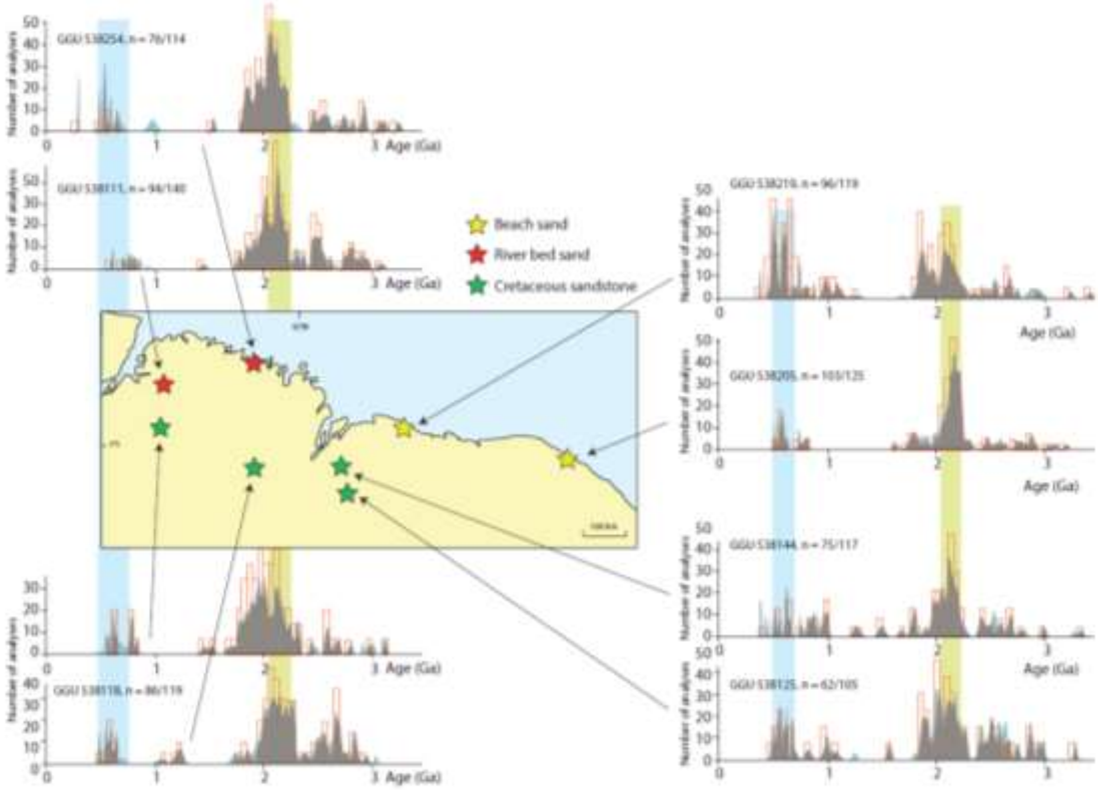


Figure 12 *U/Pb age distributions of detrital zircons from samples from northern Brazil. The two green stars to the east represent sandstone samples from the Albian Itapecuru Group and the two green stars to the west represent sandstone samples from the Campanian–Maastrichtian Ipixuna Formation. From Knudsen et al 2015.*

Iguape

Active dune field with 30 to 40 m high dunes. The sand is fine-grained.

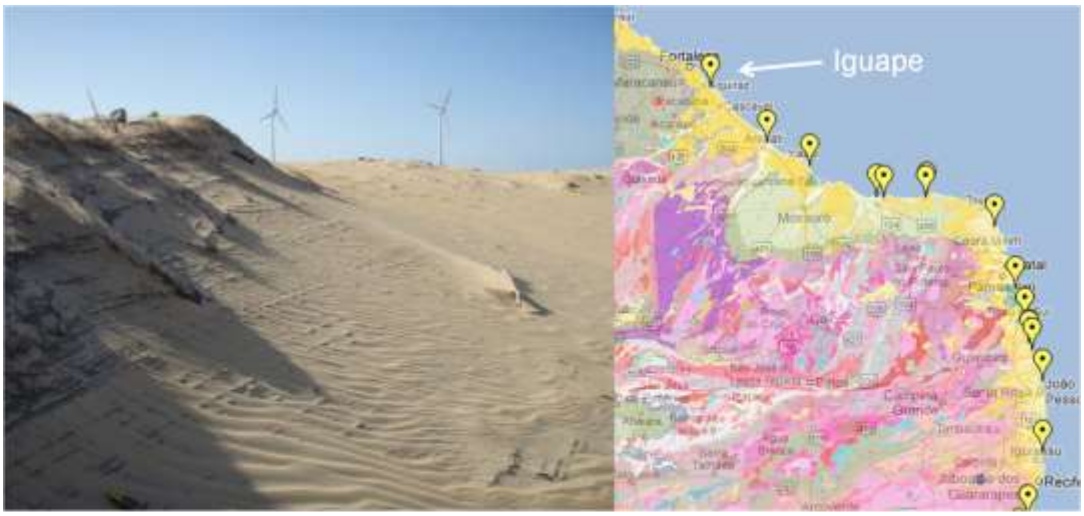


Figure 13 *Active dunes at Iguape. Map at right denotes the sample locations.*

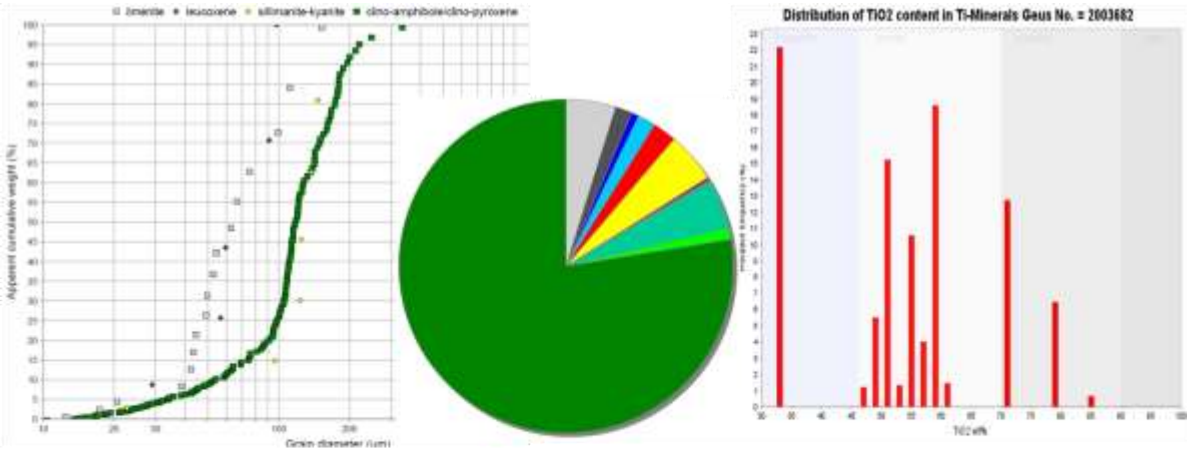


Figure 14 *Titanium distribution in Ti-minerals, heavy mineral assemblage and grain-size distribution at Iguape.*

The heavy mineral assemblage at Iguape (Figure 14) is very different compared to what is found to the west at Gurupi River (Figure 10) – and on the east coast of Brazil. The TiO_2 in the ilmenite is 53,8 % here and accordingly very low grade. The best explanation offered is that the very dry semi dessert climate in this region does not facilitate the alteration of the heavy minerals seen elsewhere.

Fortaleza to Natal

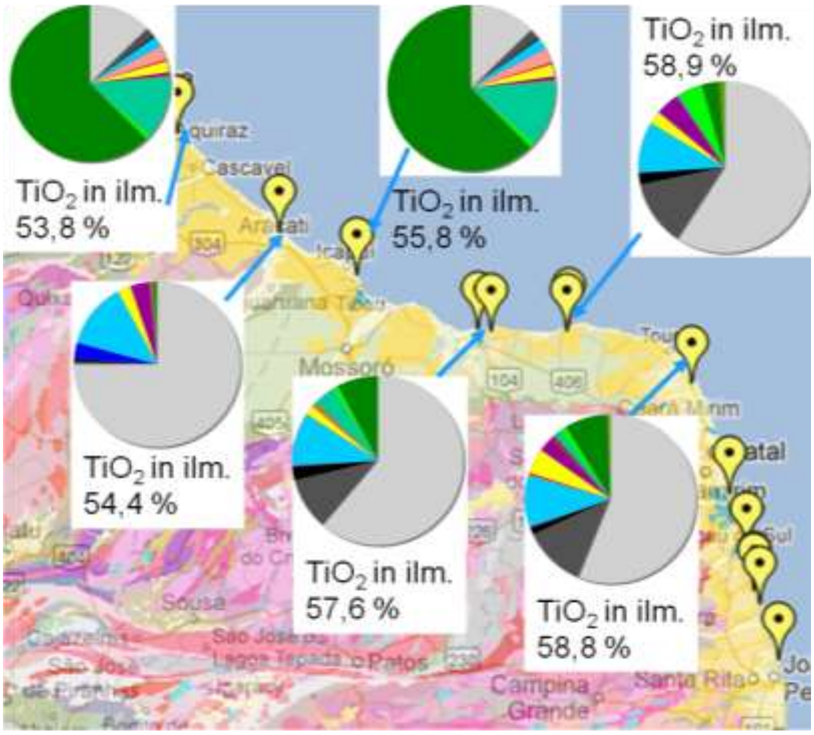


Figure 15 *TiO_2 % in ilmenite and heavy mineral assemblage in SE Brazil.*

The heavy mineral assemblages (Figure 15) changes along the coast, with mafic silicates being common in most samples to the west and less frequent going east. Further, the ilmenite is low grade (53 – 59 % TiO_2) in the western samples with increasing TiO_2 % towards the east. The ilmenite contain 59 – 60 % TiO_2 around Natal e.g. at Baia Formosa and Mataracas described below.

The current and sediment transport is towards the west between Fortaleza and Natal. At about the midpoint of this zone to the west the sand is more immature in mineral content (high amount of mafic silicates) and the ilmenite TiO_2 grade is low. It is likely that results from the local input of immature and unaltered sand, a result of the local arid climate. To the east of the midpoint toward Natal, the climate becomes more humid resulting in an influx of more mature sands with higher TiO_2 grade ilmenite.

3.2 North East – Natal to Salvador

Baia Formosa

The Baia Formosa locality is situated just 30 km north of the Cristal mine at Mataracas in a similar setting i.e. dunes on top of the Barreiras Formation. The sand is fine-grained buff coloured and the sample taken ca. 2 to 6 m below surface. The dunes are ca 30 m high ca. 2 km wide and 10 km long. The ilmenite contain 59,1 % TiO_2 and the Ti-minerals on average 61,8 % TiO_2.

Figure 16 *Baia Formosa. The sample was taken in an old dune complex resting on deeply weathered sandstones belonging to the Bareiras Formation.*

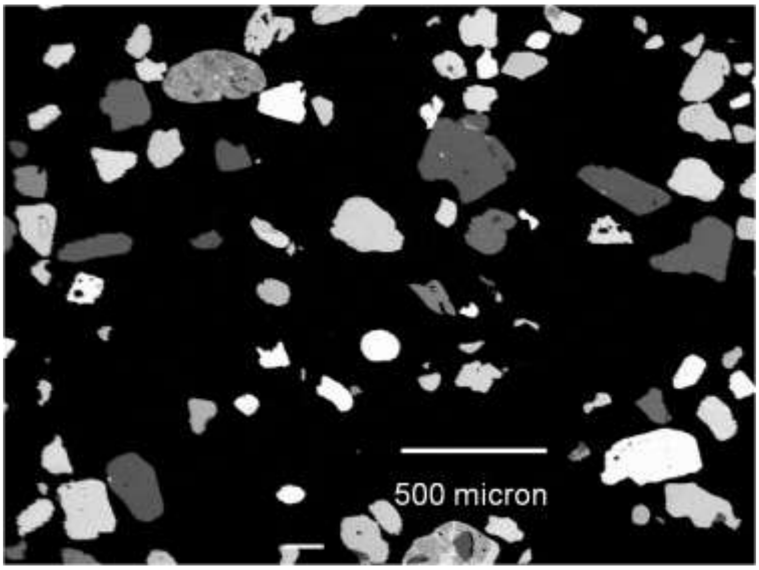
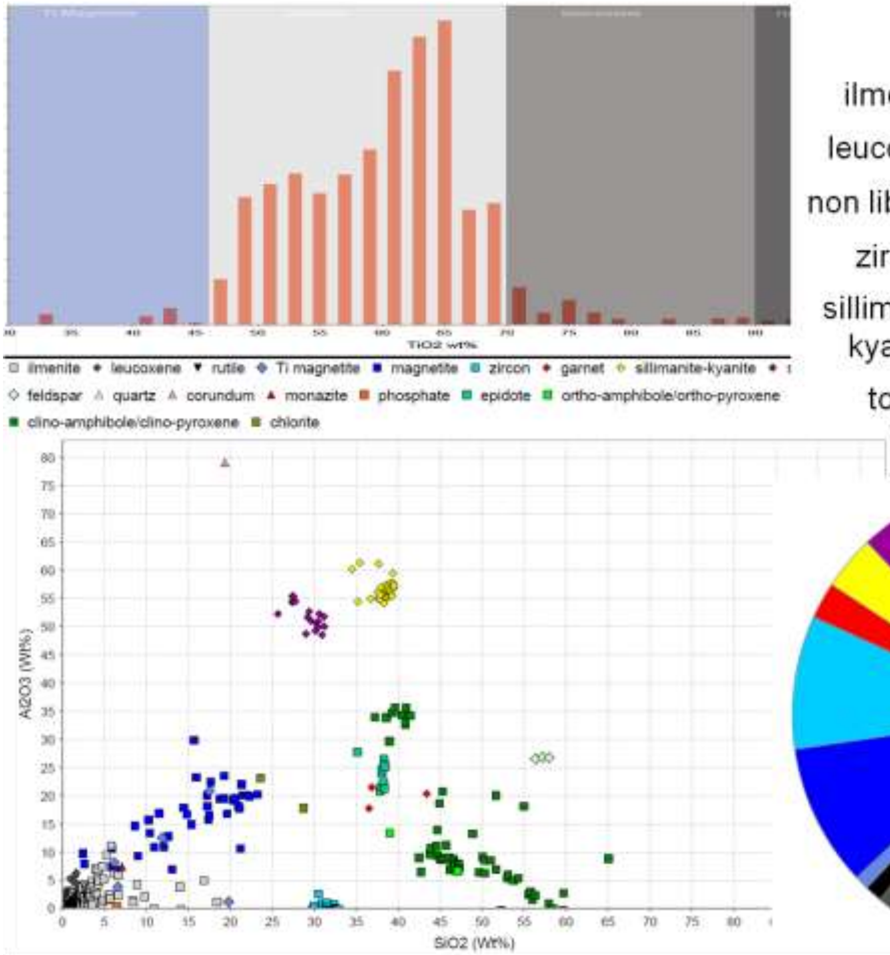


Figure 17 Backscatter image of heavy mineral sand from Baia Formosa.

The dark grey grains are silicates the light grey ilmenite and the white are zircon.

The composite grains are the ones seen as blue dots on Figure 18 and mentioned as non liberated in the table on Figure 18.



	% of HM	% in raw sand
ilmenite	54.3	1
leucoxene	4.7	0,1
non liberated	9.4	0,2
zircon	8.8	0,2
sillimanite-kyanite	3.6	0,1
total		1,6

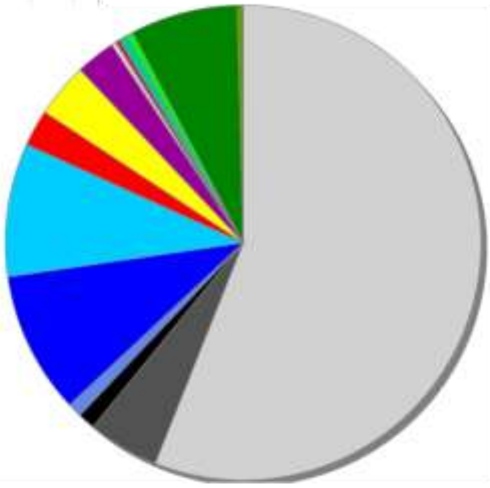


Figure 18 *CCSEM data. Lower left diagram is a cross plot of Al_2O_3 versus SiO_2. The blue dots represent ilmenite attached to silicates seen as inhomogeneous grains on Figure 13. Purple dots represent staurolite, yellow is sillimanite/kyanite, green is amphibole.*

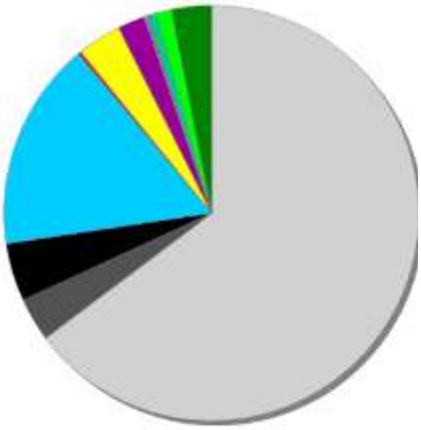
Mataracas

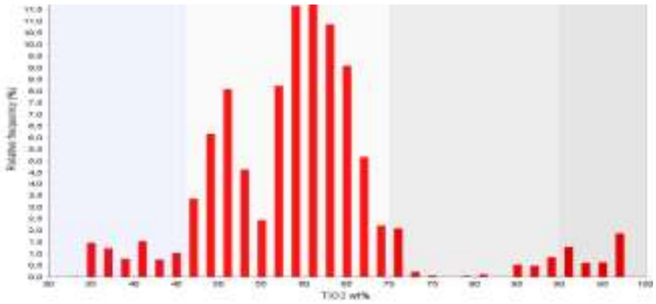
The Mataracas or Paraíba Mine is working the coastal dunes just near the coast (Figure 19 lower left). Beurlen (1995) states that the heavy mineral content is 3 % ilmenite, 0,5 % rutile and 1 % zircon. However, the CCSEM mineral ratios are 3 to 0,15 to 0,5 (Figure 16). The ilmenite contains 59,7 % TiO_2 and the Ti-minerals average 61,9 % TiO_2. The sample has 2.3 % heavy minerals in the raw sand. The Paraiba Mine (Fig. 15) is located in the municipality of Mataracas, about 1,100 km from Crystals Bahia pigment plant, to which it ships the titanium minerals. It was formerly Millennium Inorganic Chemicals but now belongs to Crystal (Crystal, 2009). The mine occupies 1,186 hectares. It is comprised of a floating plant and dredge that perform the extraction of the heavy minerals from coastal dunes. The separation of ilmenite, zircon, rutile and kyanite is done in four land based plants (Crystal, 2009).

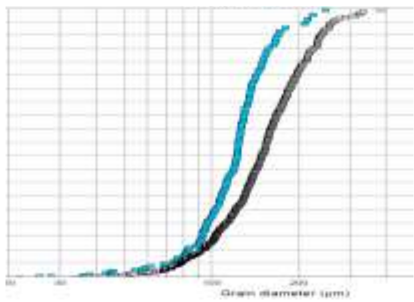
Figure 19 *The Paraíba Mine located in coastal dunes (upper left). The dunes are ca. 40 m high here (lower left). Lower right is the beach ridge Barra da Cameratuba.*

Figure 20

CCSEM data from beach ridge 3 km south of the mine. The TiO_2 distribution in the titanium minerals are seen as histogram (50 to 100 % TiO_2), the heavy mineral assemblage is shown as pie diagram and in the cumulative grain-size curves zircon is blue and ilmenite gray







Costa Azul

The sample is collected on the active beach (Figure 21) in fine- to medium grained sand with a high content of heavy minerals. Behind the beach there are dunes.

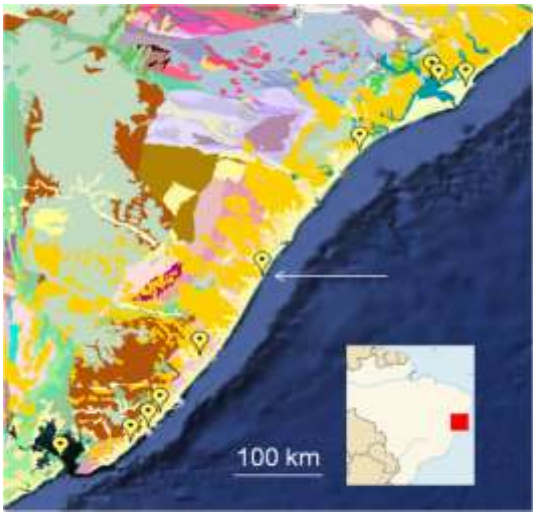


Figure 21 *The beach at Costa Azul and at right the geological map to the right shows the hinterland dominated by the Miocene Barreiras Fm. (orange). Further inland the Precambrian basement (multicolored on the map) is overlain by Cretaceous sandstones (light green).*

The heavy mineral assemblage (Table 2 and Figure 22) is very mature i.e. all mafic heavy minerals such as amphiboles and pyroxenes have been removed by alteration.

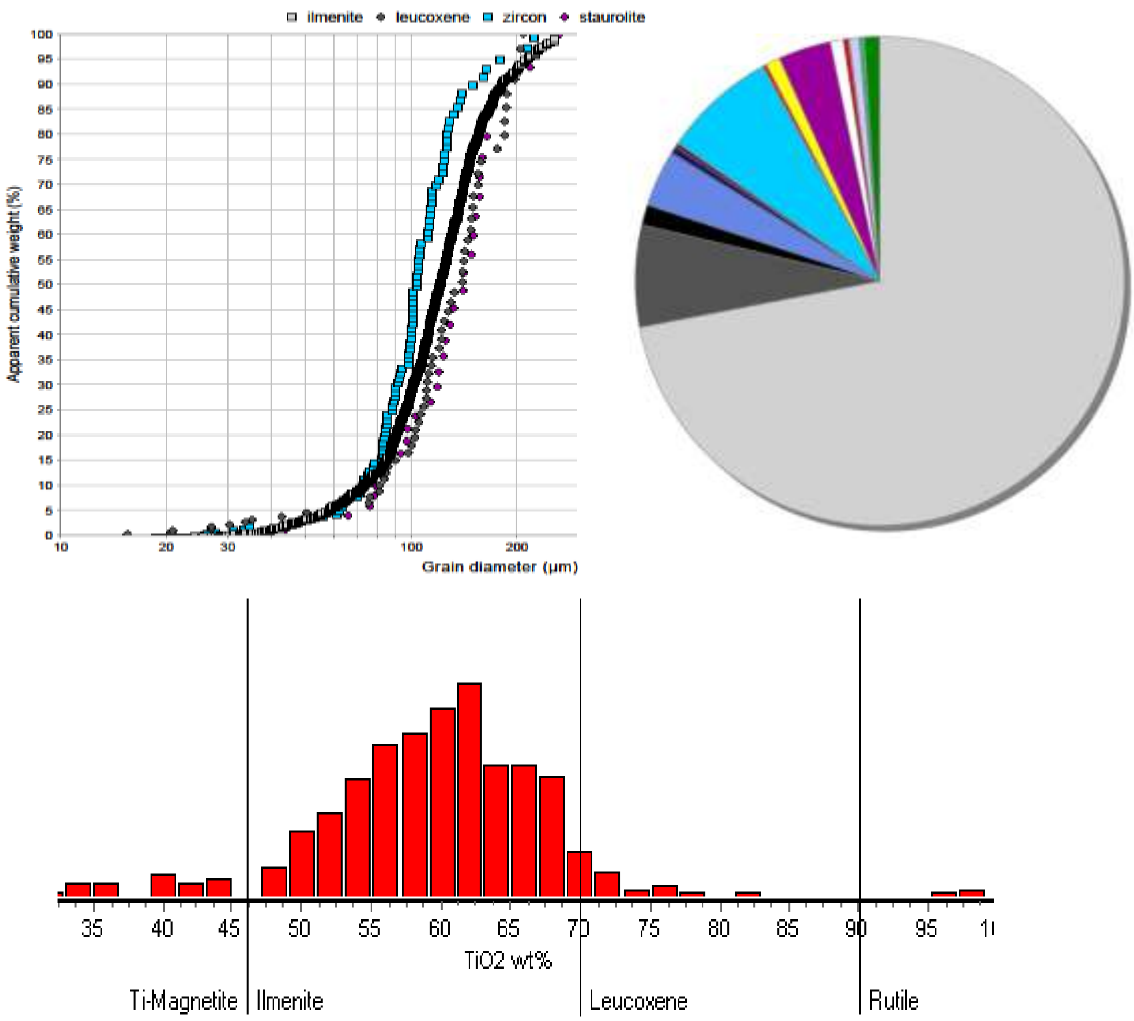


Figure 22 *Grain size distribution of the most common minerals at Costa Azul together with their abundance (circle, right) and the distribution of TiO_2 among the titanium minerals (bottom). The average TiO_2 in the titanium minerals is 61 %.Legend as Figure 17.*

Table 2 Heavy mineral concentrations at Costa Azul

	% in HM	% in raw sand
ilmenite	67.0	5,6
leucoxene	6.3	0,5
rutile	1.3	1
zircon	7.0	0,6
sillimanite-kyanite	0.9	0,1
staurolite	3.2	0,3
Total		8,1

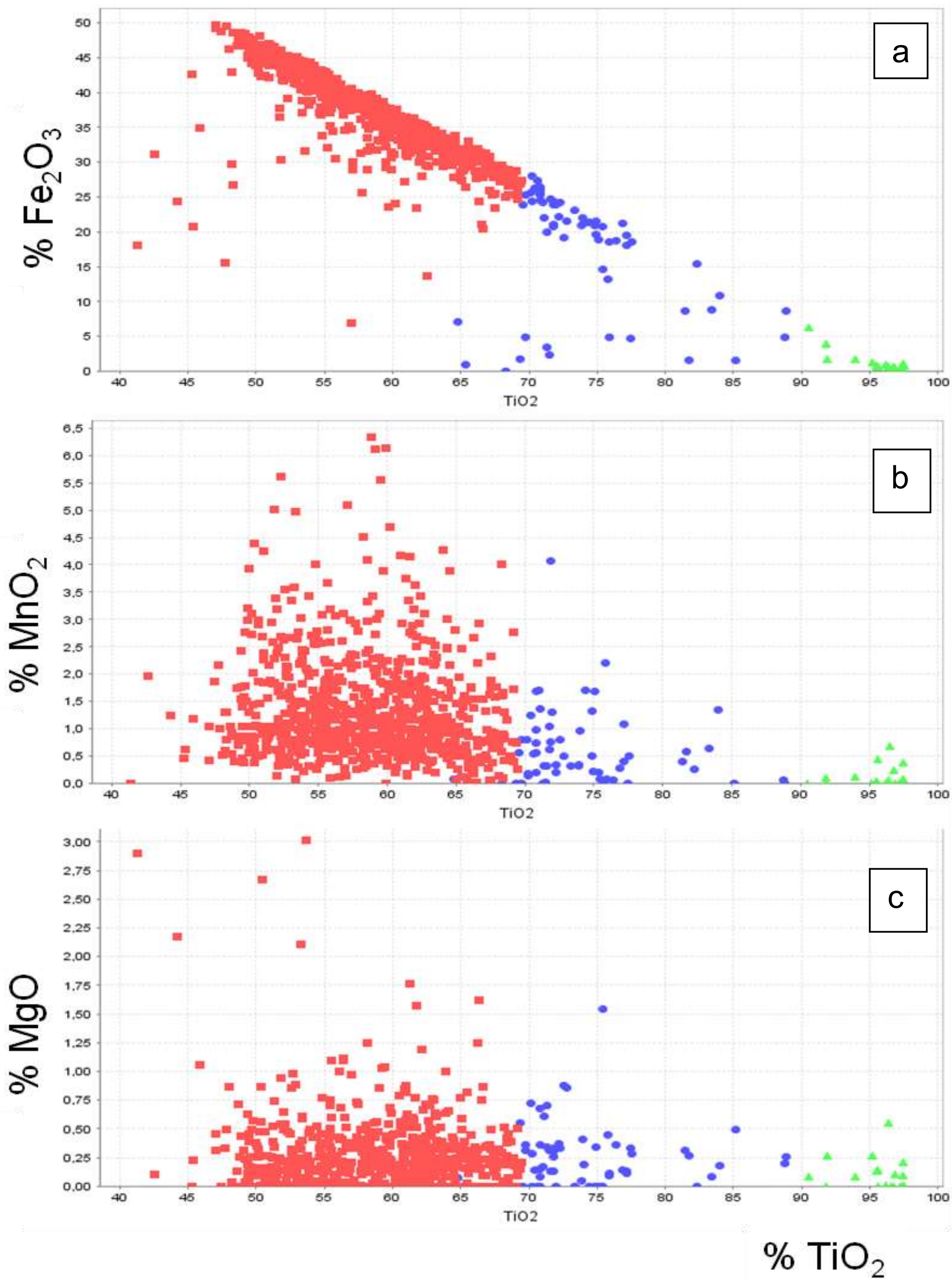


Figure 23 *Cross plot of MgO, MnO and Fe_2O_3 versus TiO_2 in titanium minerals in the sample from Costa Azul. Red dots are ilmenite, blue leucoxene and green is rutile.*

Figure 23 a shows ilmenite compositions (red) from unaltered ilmenite with ca. 50 % Fe_2O_3 and TiO_2 towards the leucoxene (blue) with less iron, a result of preferential leaching of the iron from the ilmenite. Figure 23b and 23c it is seen that the content of Mn and Mg also decreases in the ilmenite and leucoxene with increasing TiO_2. Such alteration generally proceeds from the ilmenite rims to the core as shown in Figure 24.

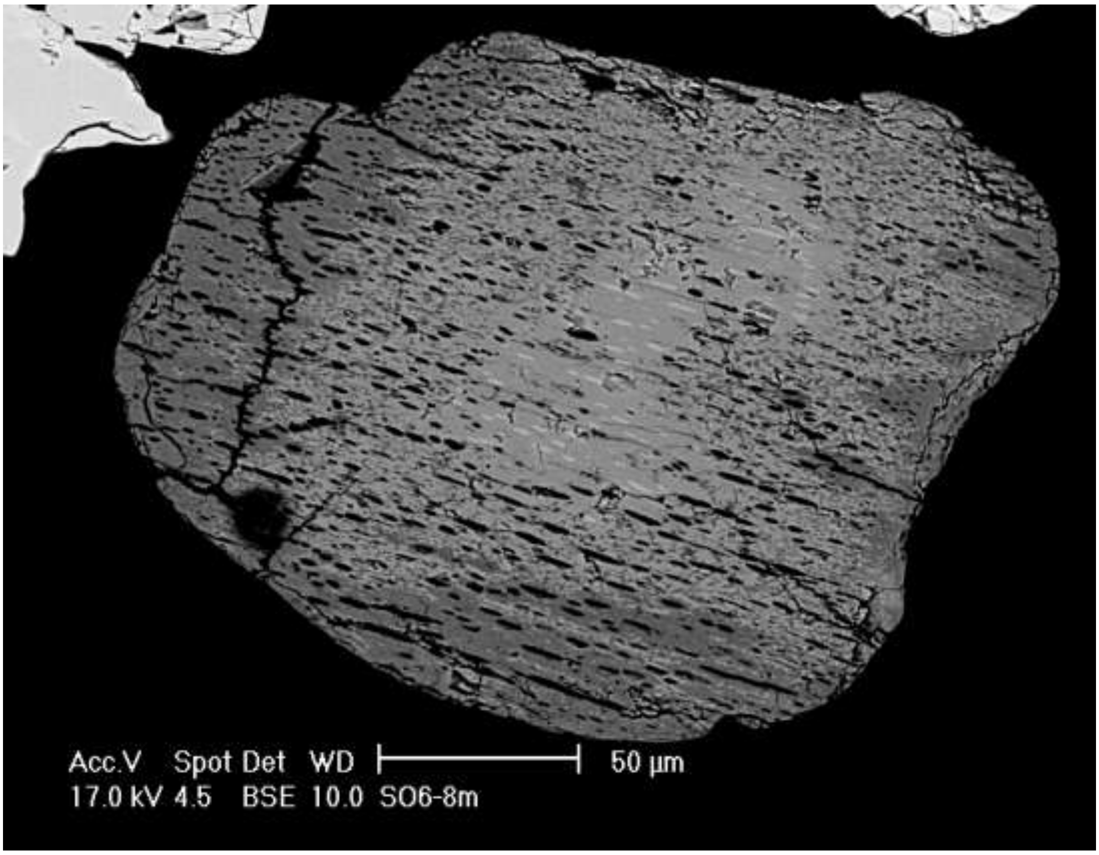


Figure 24 *Backscatter image of an ilmenite grain with increasing degree of leaching of the iron component towards the rim. In the core hematite exsolution lamina are seen (white). Where these are removed by leaching the grain has a micron scale porosity. The gray rim is pseudorutile.*

Penedo

Three samples were collected in the Penedo area where the river has built a delta out into the Atlantic ocean. The river cut into the Barreiras Formation (yellow on Figure 25), with elevated terraces of Pleistocene age. The Holocene terraces (buff) are lower in the landscape there are active dunes (white) near the ocean.

In Figure 25 the geological map of the area is shown together with data from the CCSEM analysis. It shows that the samples from the elevated terrace has higher TiO_2 in the ilmenite (63,1 % and 64,4 % TiO_2) and higher grade for combined Ti-minerals (70,7 and 69 % TiO_2).

The heavy mineral assemblage is also mature here i.e. with high contents of zircon (blue) staurolite (purple) and sillimanite (yellow). This is likely to be caused by leaching during the time since the deposition in Pleistocene time. This in contrast to the sample from the more recent marine terrace where the range of ilmenite compositions is wider and with lower TiO_2 in the ilmenite (57,3 % TiO_2) and in the Ti minerals (67,4 % TiO_2). The heavy mineral assemblage is less mature i.e. with more mafic silicates such as epidote (light green) and amphibole (green).

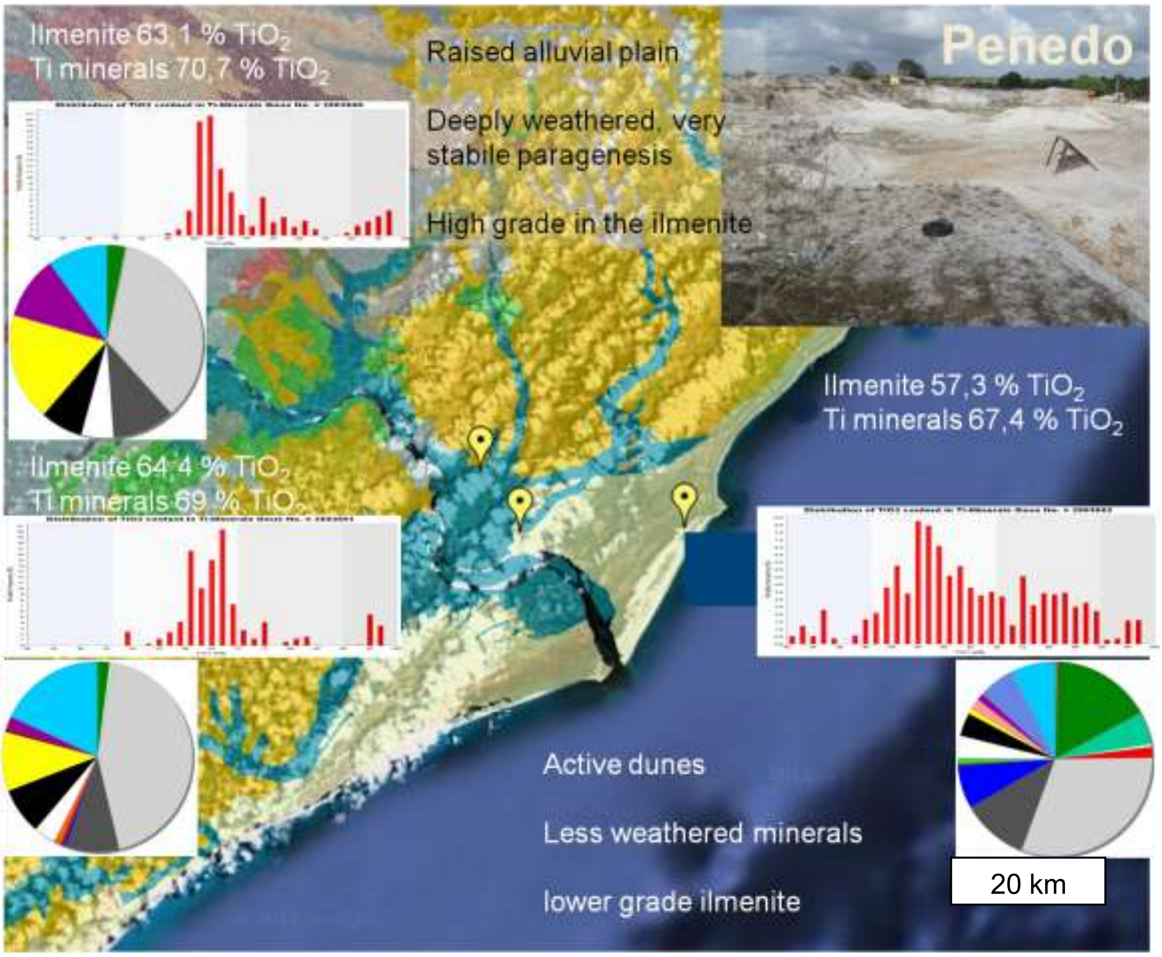


Figure 25 *Geological map of the Penedo area with the three sample sites (yellow dots). The blue color on the map indicates an elevated Pleistocene (1 – 0.01 Ma) terrace (see inset picture). The buff color is the Holocene (< 11.700 y) terrace. The TiO_2 distribution in the titanium minerals are seen as histograms. And the heavy mineral assemblage is shown as pie diagrams. The insert picture (upper right) is a sandpit in the elevated terrace.*

Barreiras Formation

The Tertiary Barreiras Formation is deeply weathered and kaolinized. The mafic heavy minerals are weathered out and a very mature heavy mineral assemblage only consisting of stabile heavy minerals is left. The TiO_2 in the ilmenite is upgraded during this process and > 60 % TiO_2.

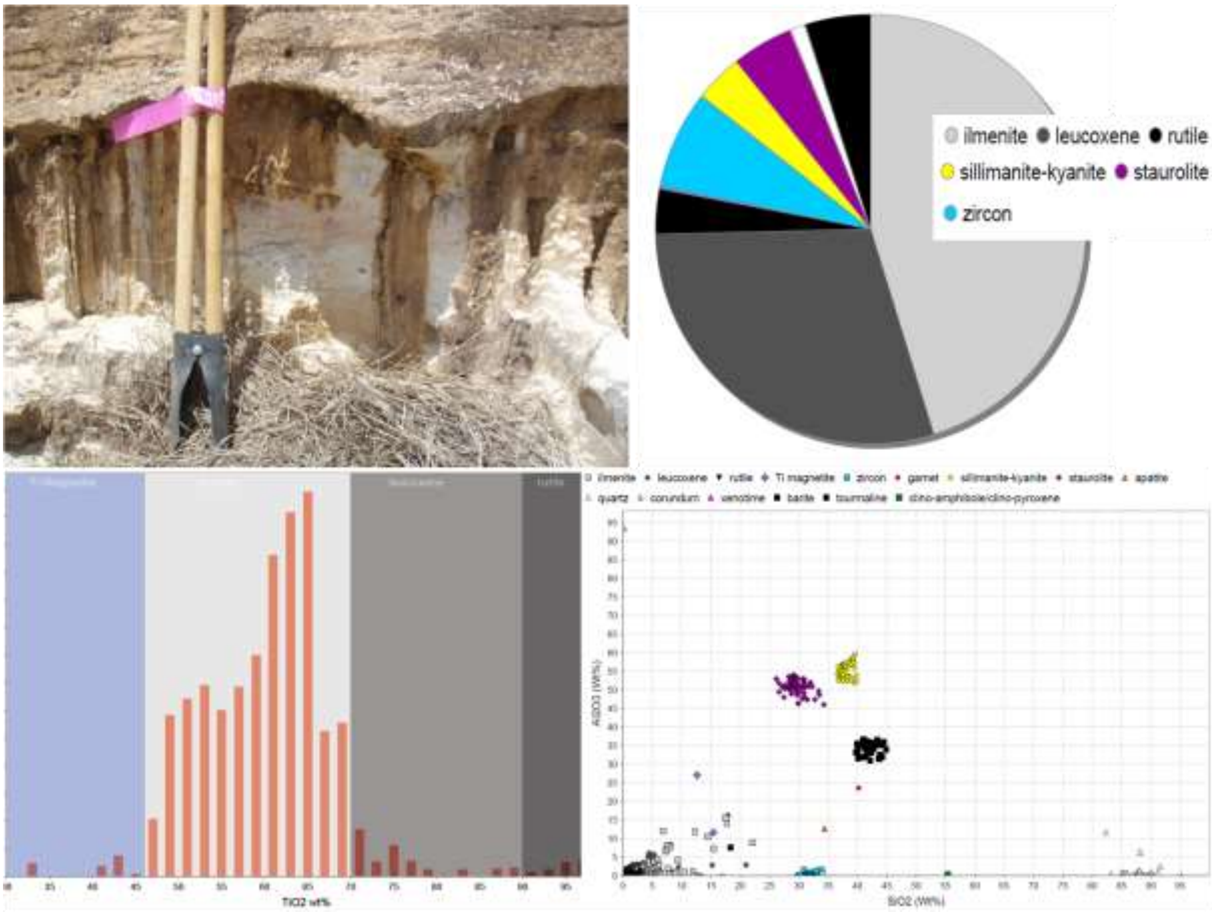


Figure 26 *White kaolinized sandstone belonging to the Tertiary Barreiras Formation. Apart from zircon, rutile, leucoxene and ilmenite, the heavy mineral fraction consists of staurolite, sillimanite and tourmaline.*

3.3 Central Salvador to Rio de Janeiro

Just south of Salvador we find the Rio Campo deposit which was visited as part of a specific investigation and this deposit is described in Chapter 4.

Belmonte

The area constitutes the sandy deposits from the Jequitinhonha River built out into the Atlantic Ocean. The present day coast north of the river mouth consists of narrow barriers in front of an estuary (Figures 27, 28) whereas it is a beach with a small beach ridge with an elevation of ca. 1 m south of the river mouth.

The content of heavy minerals is very low here (0,4 %) but the TiO_2 content in the ilmenite is 59,2 % TiO_2 and average TiO_2 in the titanium minerals is 63,7 %.

Figure 27 *The Belmont area. The sample analyzed by CCSEM from this area is marked with an asterix on the map. The sample is taken in a small sandpit in a Pleistocene terrace (lower left). Distance from north to south on the map is 50 km.*

Figure 28 *The Belmont area. The strandlines showing the Holocene evolution of the area. The relief is very low as seen on Figure 27 (upper left).*

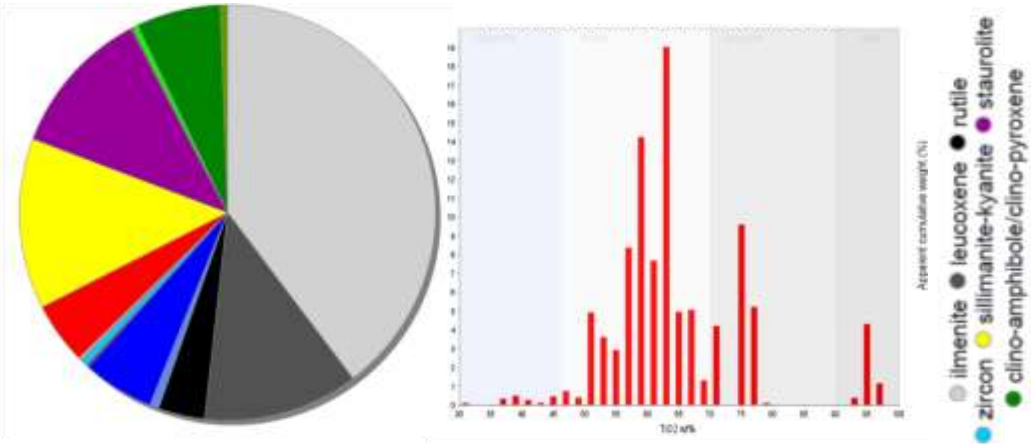


Figure 29 *TiO_2 distribution (right) and relative abundance of heavy minerals (circle, left) in the Belmonte area.*

Caravelas

The area here is a large estuary (Figure 30) dominated by medium grained sand. However, at two locations we drilled down into fine-grained orange sand (D50 of heavy minerals is 75µ) very rich (17 %) in heavy minerals of which zircon constitute a large fraction (Figure 26). but the TiO_2 grades of ilmenite, and the average for all Ti minerals are low at 54.0% and 55.4%, respectively.

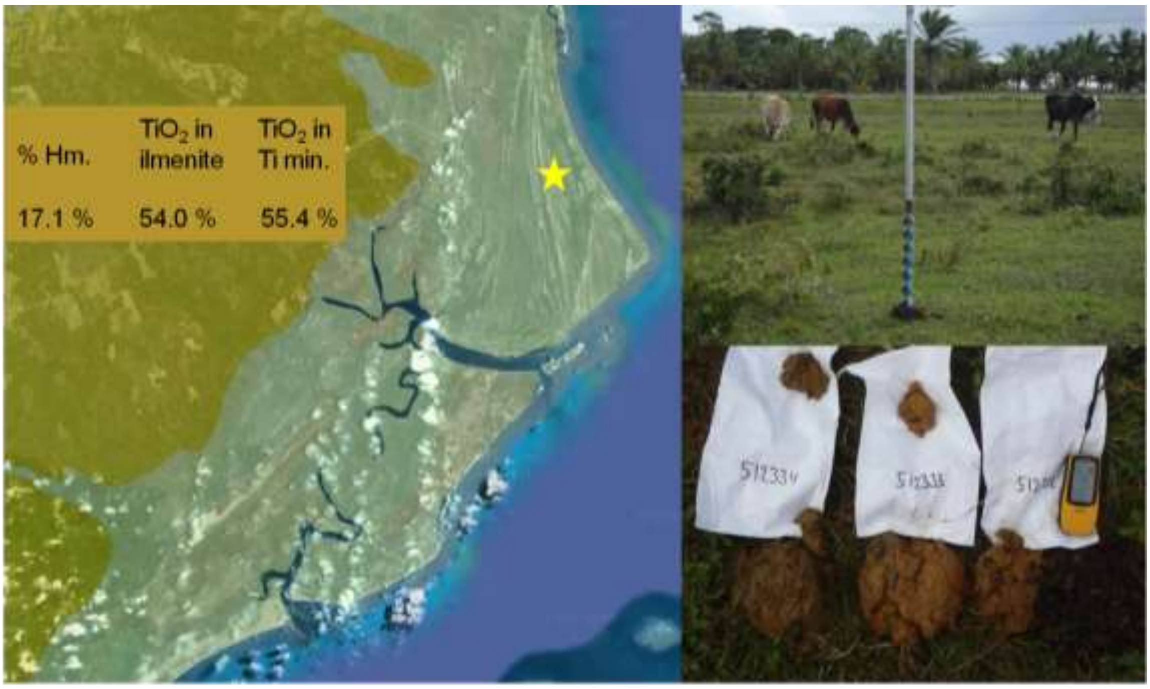


Figure 30 *Landscape and fine-grained heavy mineral rich sand in a three meter interval. and the grades for Ti minerals in a fine-grained 3m zone (center) obtained by auger. Also shown is the character of the landscape at Caravelas, sparsely populated except for grazing cattle.*

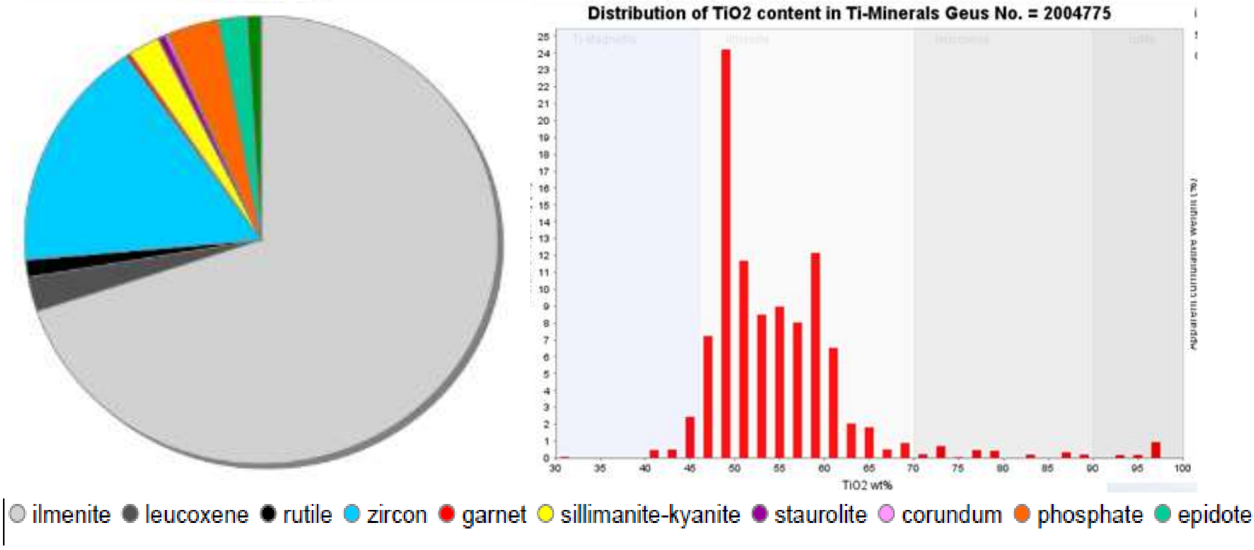


Figure 31 CCSEM results from Caravelas

Linhares

The Linhares area is a large sand deposit built out into the Atlantic Ocean by deposition from the river Doce (Figure 29).The sand is rich in heavy minerals (6%), but the heavy mineral assemblage is dominated by fine-grained magnetite (Figure 28). In addition, the TiO_2 content in the ilmenite is very low at 50.4 % and mafic silicates are abundant. Those factors indicate immature sediments with very little alteration. The observations are consistent with the very dry climate in this area and hence low degree of alteration.

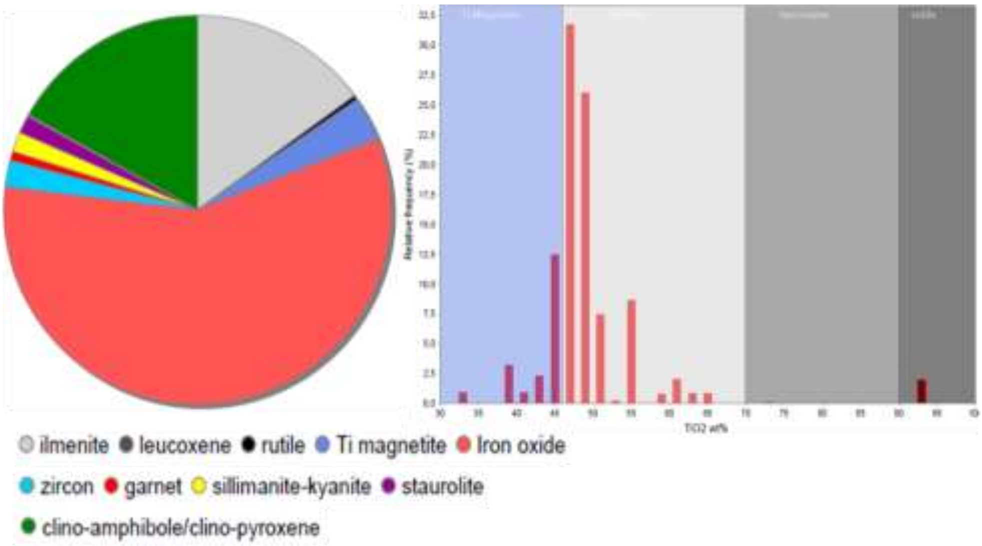


Figure 32 *CCSEM results from Linhares. Heavy mineral assemblage left and TiO_2 histogram for the Ti-minerals.*

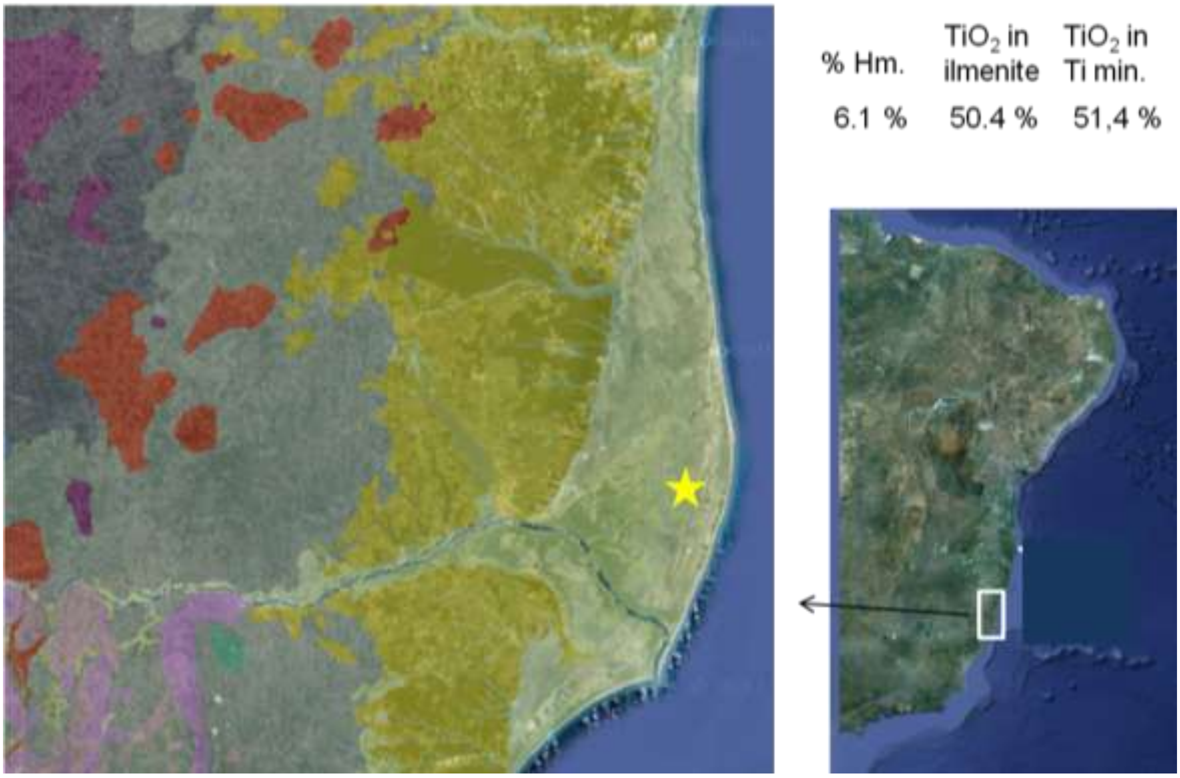


Figure 33 *Linhares area and CCSEM results from here. Vertical axis of the map is 60 km.*

3.4 Summary of results from the systematic sampling

Along the Salvador to Rio coast, the grade of the ilmenite is moderate to low, TiO_2 ranges from 50 to 59 % and the TiO_2 for all Ti-minerals ranges from 51 to 64 %. Unfortunately, the highest TiO_2 contents are found in coarse sands with low total heavy mineral contents.

The best combination of TiO_2 in ilmenite and total heavy mineral contents on Brazils east coast is found in the Pratiga deposit (apart from Crystals mine). The Pratiga deposit is located in an area where the sand is accumulated by the longshore drift – both from South and North. The Mesozoic sandstones of the Reçoncavo-Camamu rift basin occur in the hinterland. The concentration of ilmenite and its elevated TiO_2 grade at Pratiga or Rio Campo may be the result of the combined effects of the reworking of the Mesozoic sands together with the elevated amount of precipitation in the Salvador region (Figure 4).

The coarse sand in the beaches between Ilheus and Rio de Janeiro are exposed to the high energy of the Atlantic Ocean and contain few heavy minerals. The high contents of heavy minerals shown in Pratiga and Caravelas (Figure 34) are related to fine-grained sands that may have been deposited on the outer shoreface and later covered by the prograding delta. Such finer-grained outer shoreface deposits may be located below the strandlines e.g. at Belmont where the composition of the ilmenite and the heavy mineral assemblage is favourable. However, prospecting for such hidden deposits would require a drilling program.

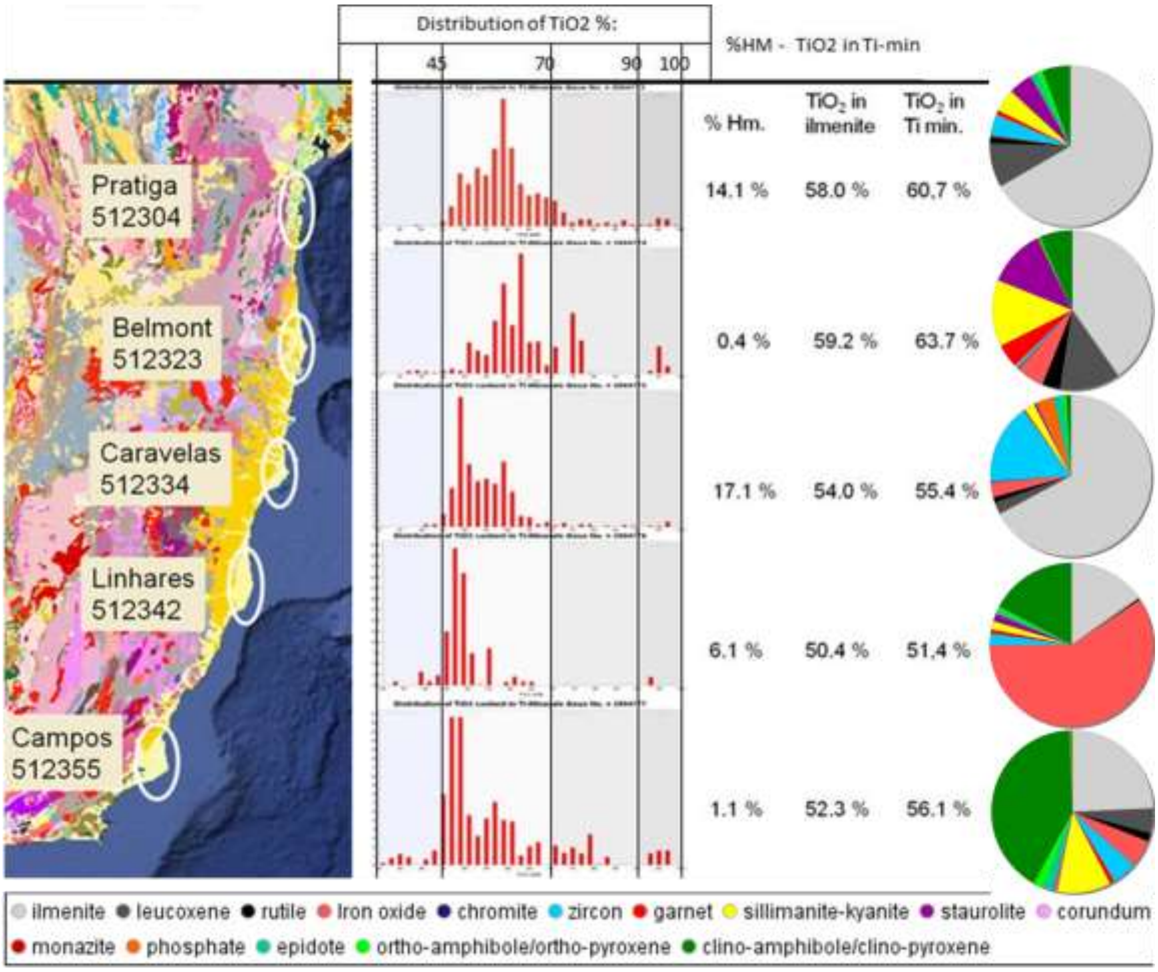


Figure 34 *Compilation of the CCSEM results from the region between Salvador and Rio de Janeiro sampled in 2012. The distance from north to south on the map is ca. 1000 km.*

The data collected for the samples from Belem (Gurupi River) at the north coast to Rio de Janeiro is summarized in Figures 35 to 42. Unfortunately, because the sampling was done at very different times by different personnel, the sampling density is not uniform; however some general conclusions are given below.

The Gurupi River samples are characterized by a mature heavy mineral assemblage and high contents of rutile and staurolite. The garnet content is low in almost all samples regardless of other indications of maturity. Immature assemblages are denoted by a high content of mafic silicates, particularly found near Fortaleza and Rio which suggest that chemical and mechanical alteration was relatively low at those locations, consistent with lower TiO_2 grade ilmenite (Figure 35 and 36).

The result of the systematic sampling is a compilation of the regional variations along the coast as shown in Figures 35 to 43.

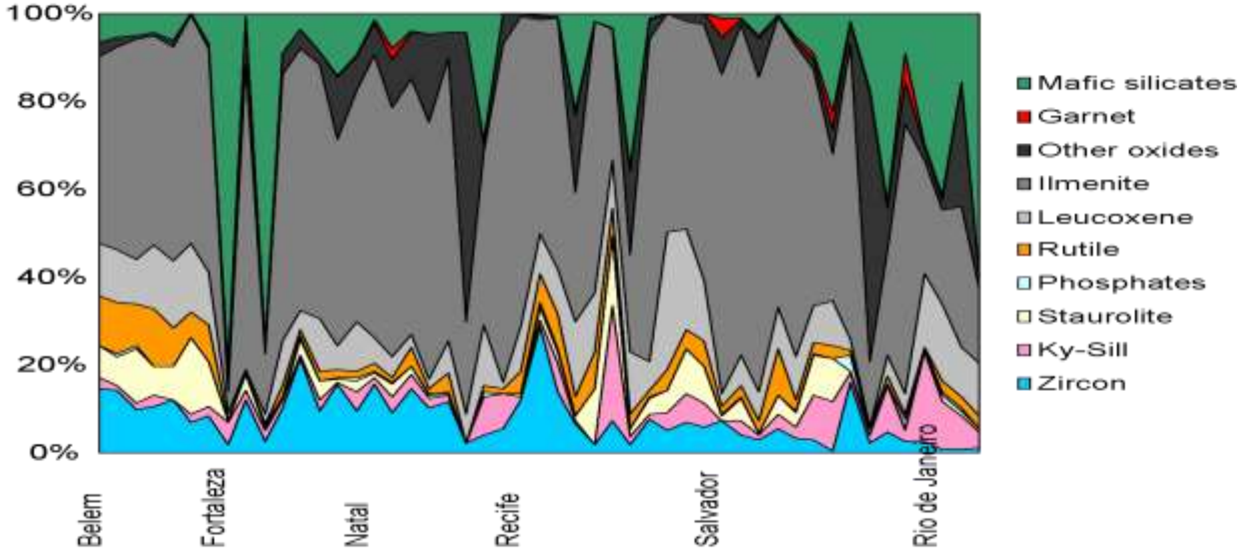


Figure 35 *Variation in the heavy mineral assemblage in a profile from Belem in the North to South of Rio de Janeiro.*

The most prominent feature (Figure 35) is the very high proportion of stabile heavy minerals in the heavy mineral assemblage. Only very locally unstabile heavy minerals such as amphiboles and magnetite are common. Further, it is remarkable that the content of garnet is low in almost all samples. This is surprising as garnet is a common mineral in the Brazil basement that constitute the source terrains for the heavy minerals.

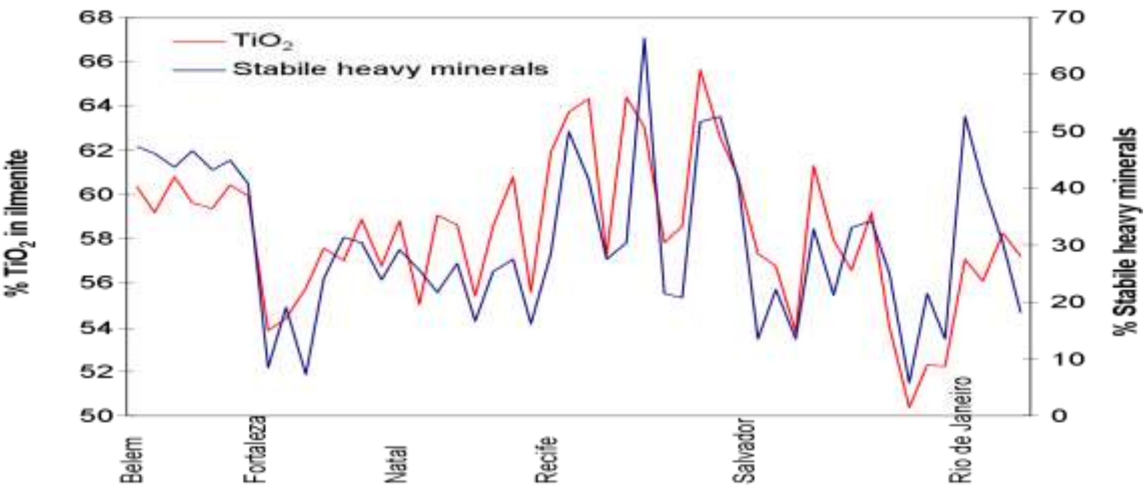


Figure 36 *Profile showing the variation in the TiO_2 in ilmenite together with the fraction of stabile heavy minerals (ilmenite, leucoxene, rutile, zircon, staurolite and kyanite/sillimanite as % of total heavy minerals).*

Figure 36 & 37 shows that the grade (% TiO_2) of ilmenite co-varies with the maturity of the heavy mineral assemblage. During alteration, less stable heavy minerals such as mafic silicates (magnetite, amphibole, epidote, pyroxene, and garnet) are leached away and iron is leached out of ilmenite increasing its titanium grade.

There is a general relation of climate to ilmenite grade. The Gurupi River area in the north has very high annual precipitation (Figure 4) and extensive weathering, mature heavy mineral assemblage (Figure 35) and high grade ilmenite (Figure 36 and 37) in contrast to the area between Fortaleza and Recife is dry with lower grade ilmenite less mature heavy mineral assemblage.

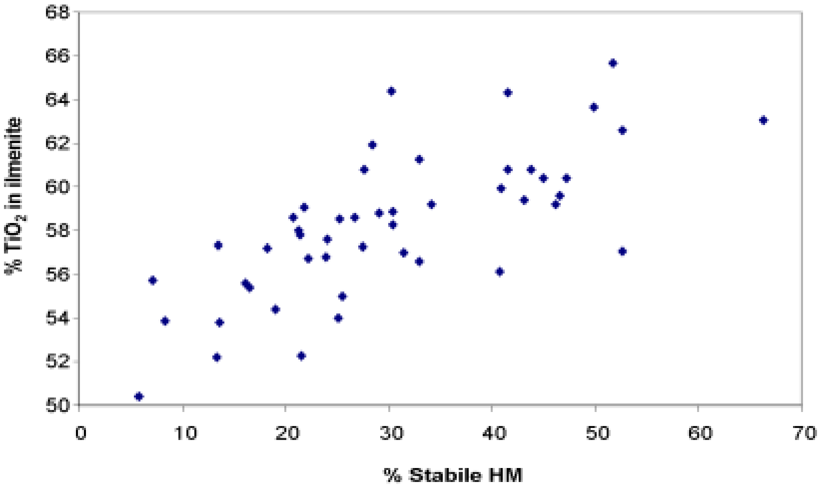


Figure 37 *TiO_2 in ilmenite versus the fraction of stabile heavy minerals in the heavy mineral fraction.*

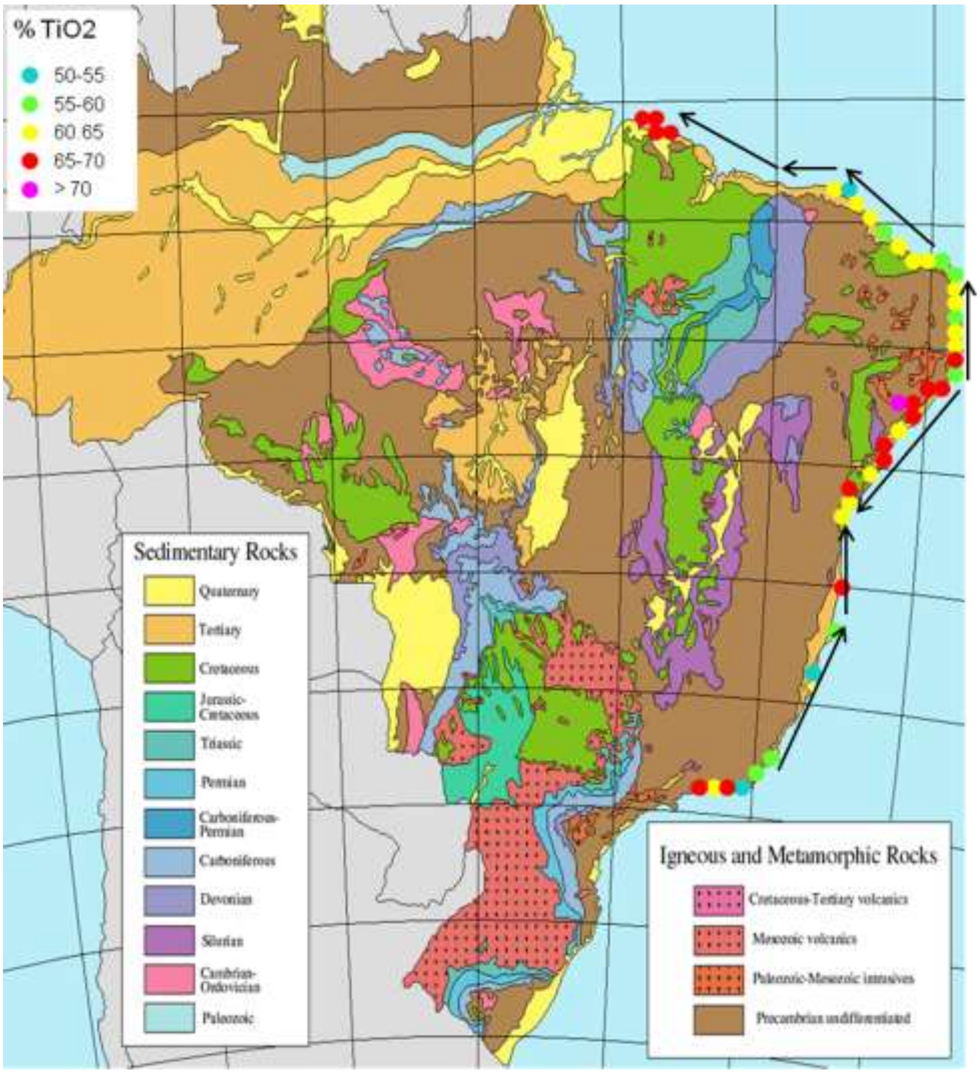


Figure 38

TiO_2 content in titanium minerals in coastal sediments in Brazil.

Direction of long-shore current is indicated by arrows.

A similar feature is seen between Recife and Salvador where high grade ilmenite is also concentrated (Figure 36, 38) which may be caused by more humid climate. The Crystal ilmenite mine is located in this region (Figure 2).

Apart from the direct influence of the climate, reworking of altered /weathered and kaolinized. Bedrock is likely to be an important component in the formation of high grade ilmenite. Miocene Barreiras Formation as well as Jurassic and Cretaceous sandstones are reworked and deposited on the coast and may be the source of deposits with elevated TiO_2 in ilmenite.

In elevated beaches deposited during the Pleistocene, the TiO_2 in ilmenite is elevated as well. This is e.g. the case in Penedo (Figure 25). This is likely to be caused by weathering of the heavy mineral assemblage in the time that has passed since the deposition.

3.5 Minor elements in ilmenite and leucoxene

Ilmenite is the titanium-iron oxide mineral with the idealized formula $FeTiO_3$. However, Ilmenite often contains appreciable quantities of magnesium and manganese Ilmenite because of solid solution with geikielite ($MgTiO_3$) and pyrophanite ($MnTiO_3$) which are magnesian and manganiferous end-members of the solid solution series and accordinly the full chemical formula can be expressed as $(Fe,Mg,Mn,Ti)O_3$. Apart from these elements, vanadium (V), niobium (Nb) and chromium (Cr) are common minor elements in the ilmenite and those elements may provide insight to the provenance of ilmenite (McLimans et al., 2005; Lloyd et al., 2005).

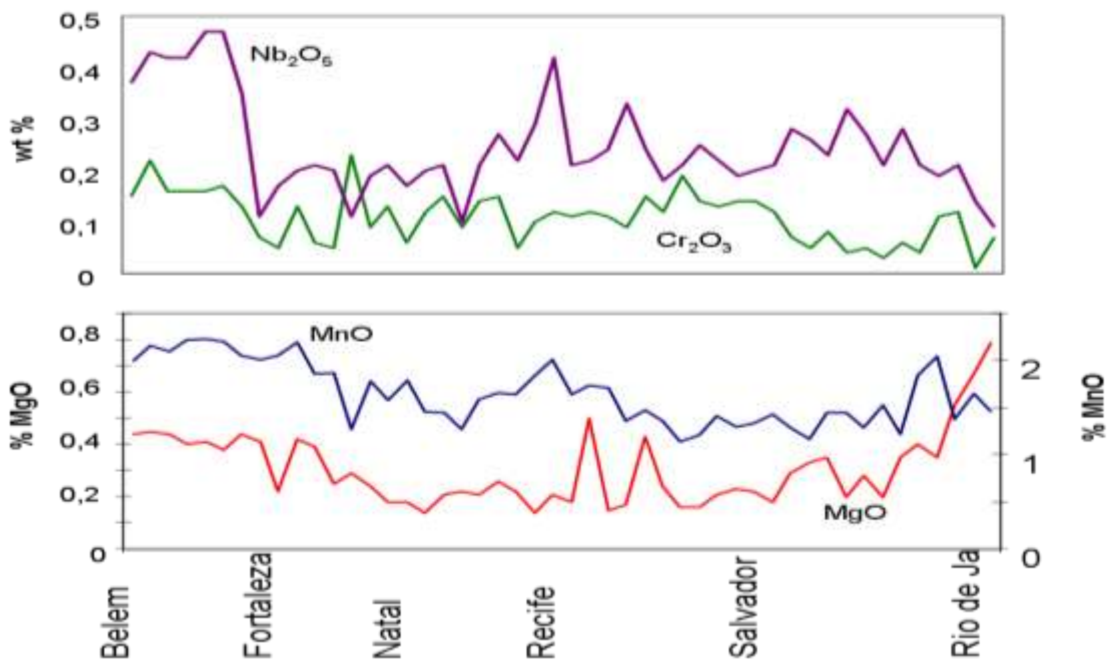


Figure 39 *Minor components in the ilmenite. The data represent CCSEM analysis of many grains per sample (average 345 per sample).*

The samples along the Brazil coast are spaced at very large distances and thus it is tenuous to interpret provenance on the basis of single samples. However, the data suggest that regions of the coast show distinct differences in ilmenite composition and may have different provenance. Based on the data in Figure 39 and the values below, the major probable and original source rocks for the Brazil coastal samples are a dominance of anorthosite, tholeiitic gabbro, and high grade metamorphics with a component of alkali felsic igneous rock. The Gurupi River area (Belem to Fortaleza) is distinct in Nb_2O_5 > 0.2 % and may have a large component of alkali felsic igneous rock. Near Rio de Janeiro, this felsic component is absent and there may be in influx of ilmenite from basic igneous rocks. The provenance inference is for the original ilmenite source, coastal heavy mineral deposits may also be composed of reworked older sands and/or sandstones in the hinterland.

Ilmenite Type	Attribute	Possible Source Rock
Sig Mg	>0.2<1 % MgO	Anorthosite, tholeiitic gabbro, high grade metamorphic
Sig Nb	>0.2<1 % Nb_2O_5	Alkali felsic igneous

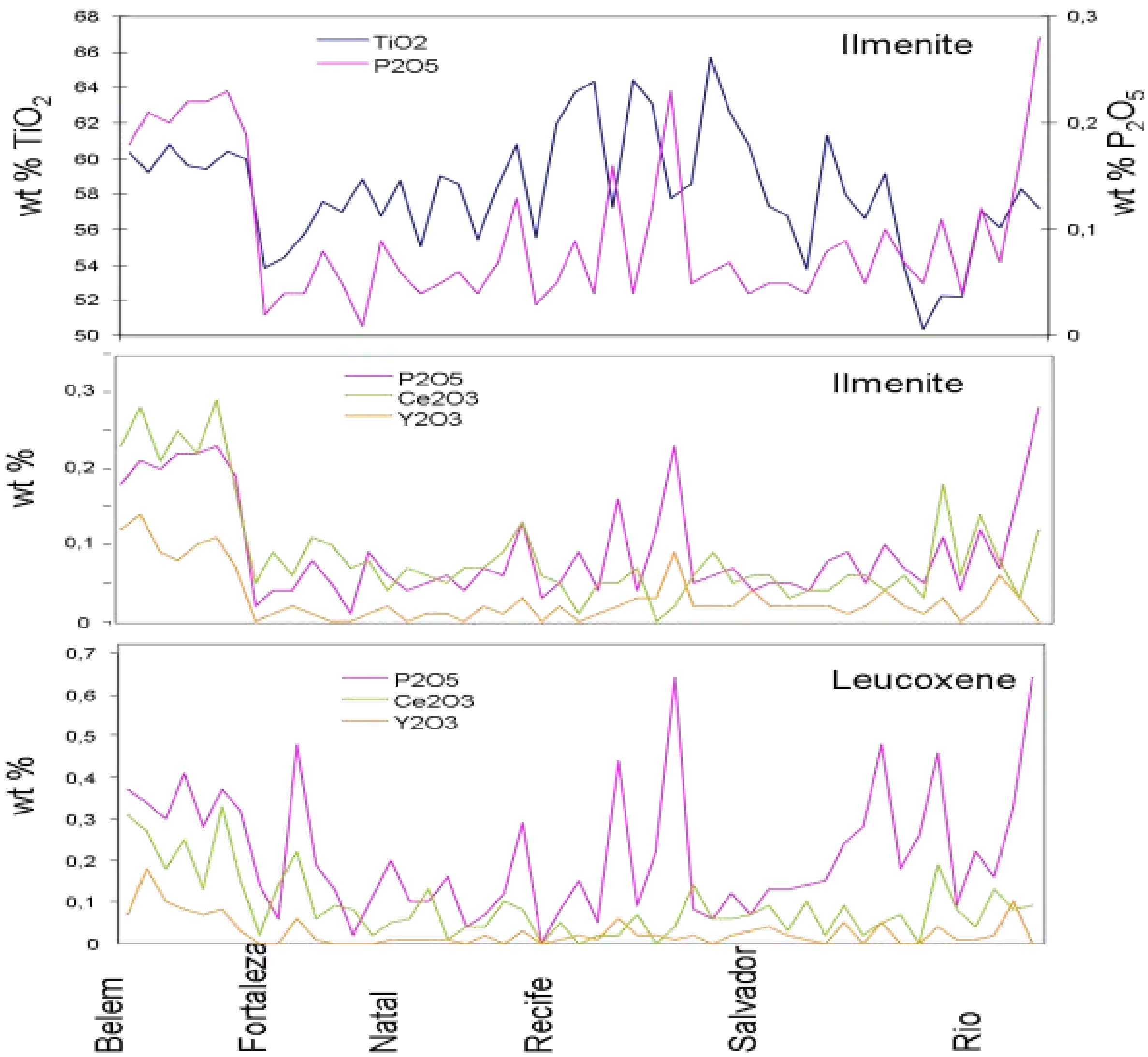


Figure 40 *Content of TiO_2, P, Ce and Y in ilmenite and leucoxene along the coast.*

The TiO_2, in the ilmenite is a function of the degree of alteration of the ilmenite. On Figure 36 and 37 it can be seen that the content of P, Ce and Y is high where the ilmenite is altered. One explanation for this could be that the mineral grains are mineralised with a P and REE bearing mineral. However, the phosphorus enrichment varies among the regions e.g. with high content of TiO_2. In Gurupi River area (between Belem and Fortaleza) P, Ce and Y is very high as compared to e.g. high Ti areas around Recife and Salvador (Figure 36). It is remarkable that the CCSEM analysis can yield consistent analytical results for elements like Ce and Y. The fact that REE such as Ce and Y co-varies with phosphorus and occur in equal amounts suggesting that they occur in ilmenite and leucoxene in a form that may include monazite ((Ce,La)PO_4). The observation that the content of both P_2O_5 and Ce_2O_3 in ilmenite can be correlated to the content in leucoxene from the same sample indicate that A the analytical procedure yield results that can be interpreted and that the process that is responsible for the mineralisation" of ilmenite add both P and REE.

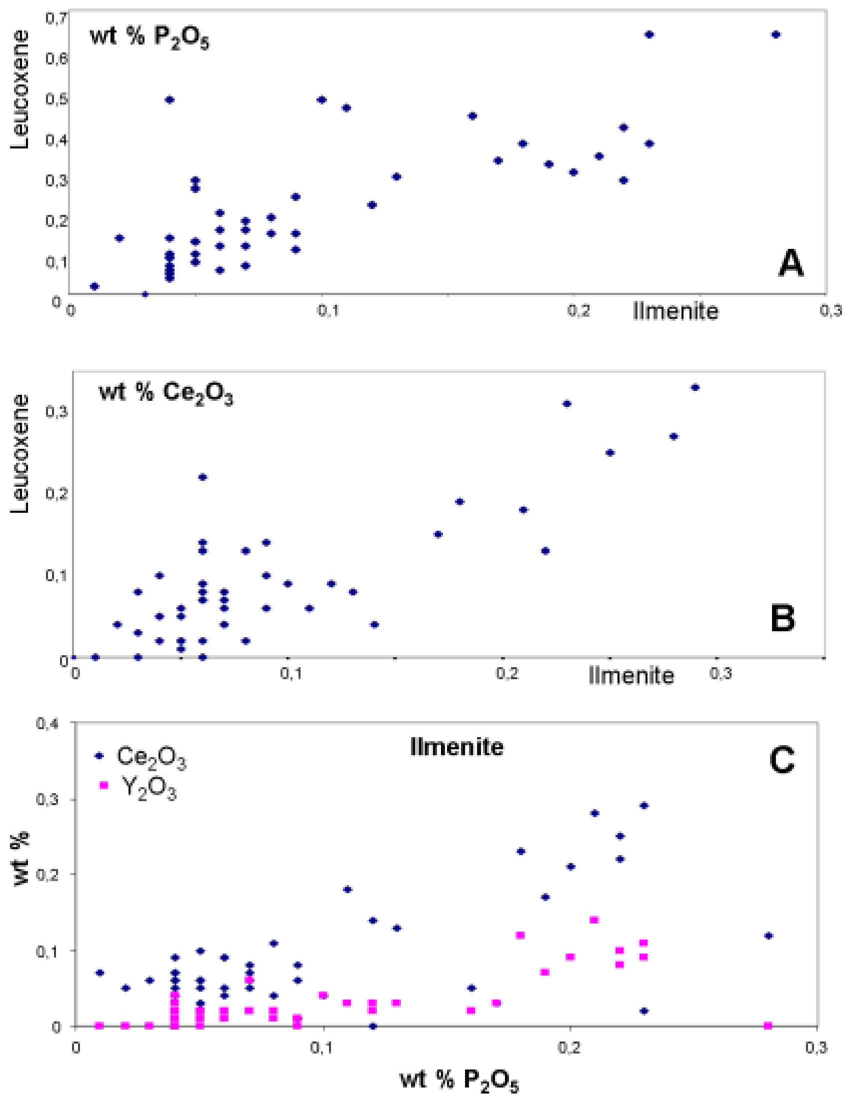


Figure 41 Phosphorus and Rare Earth Elements in ilmenite and leucoxene.
A) P_2O_5 in leucoxene versus P_2O_5 in ilmenite. Each point represents a sample.
B) Ce_2O_3 in leucoxene versus Ce_2O_3 in ilm. Each point represents a sample.
C) Ce_2O_3 and Y_2O_3 versus P_2O_5 in ilmenite.

4. Rio Do Campo area

Investigations conducted in the Rio Do Campo area south of Salvador (3 on Figure 43) by the local authorities indicated the existence of about 266 million tons of mineralised sands with average heavy mineral content of 3.09%. (Dominguez, 2010). The authorities (Company Bahia Mineral Research – CBPM) promoted the deposit to be mined and have done quite a bit of work to document the reserves and find a way to solve possible future environmental issues, and the following is based on the work conducted by the Brazil authorities and a field-visit in May 2011.

4.1 Introduction to the Pratiga deposit

Mineral exploration in the coastal area in this part of the Bahia state was in the early 1980'ties focused on peat. However, these investigations showed that there was also a considerable heavy mineral resource in the area. Consequently, a consortium of companies *"Consortium MKS",* was formed in the late 1980'ies by Multiquartz Mining Ltd., Kawatetsu and Sumitomo Mining Co. Ltd. In a bidding process, the Consortium MKS won the mining rights in a small part of the area with heavy mineral accumulation and the Consortium MKS signed a "Protocol" with Company Bahia Mineral Research – (CBPM) in 1990 concerning exploration in the area. CBPM was then conducting heavy mineral research in the area during the following years aiming at defining the heavy mineral resources and they came up with calculations indicating the existence of about 266 million tons of mineralised sands with average heavy mineral content of 3.09%. (Dominguez, 2010).

In the late 1990'ies environmental protection of some of these coastal areas became an issue, and the mineral resource was blocked for heavy mineral exploitation because of restrictions imposed by the ecologic-economic zoning of the Pratigi Environmental Protection Area. To be able to solve the conflict between the different stakeholders, the Government of Bahia initiated an interdisciplinary study in 1998 with the aim of integrating geological characterization of the heavy mineral deposits, their genesis, and the environmental restrictions imposed by the ecologic-economic zoning of the Pratigi Environmental Protection Area. Based on the results obtained, Dominguez (2010) proposed a new zonation, focused on sustainability principles and maintenance of biodiversity and preservation of the several remnants of the regional biomes present in the area (open scrubland "restinga", wood scrubland "restinga" and mangroves).

The idea is that the area could function as a bank of species to rehabilitate areas impacted by fires, deforestation, garbage disposal and future interventions as well. The belief of Dominguez (2010) is that this new proposal represents a model for the use of the natural resources present in the study area, harmonizing regional development and sustainability. If this new zoning proposal is eventually approved by the state's environmental agencies and councils, it would unblock to mineral exploitation a total of 236 million tons of ore sand comprising 7,5 million tons of heavy minerals. A total of 29,5 million tons of ore sands would be permanently blocked out to mineral exploitation because of environmental restrictions that would persist, even under the new zoning proposal.

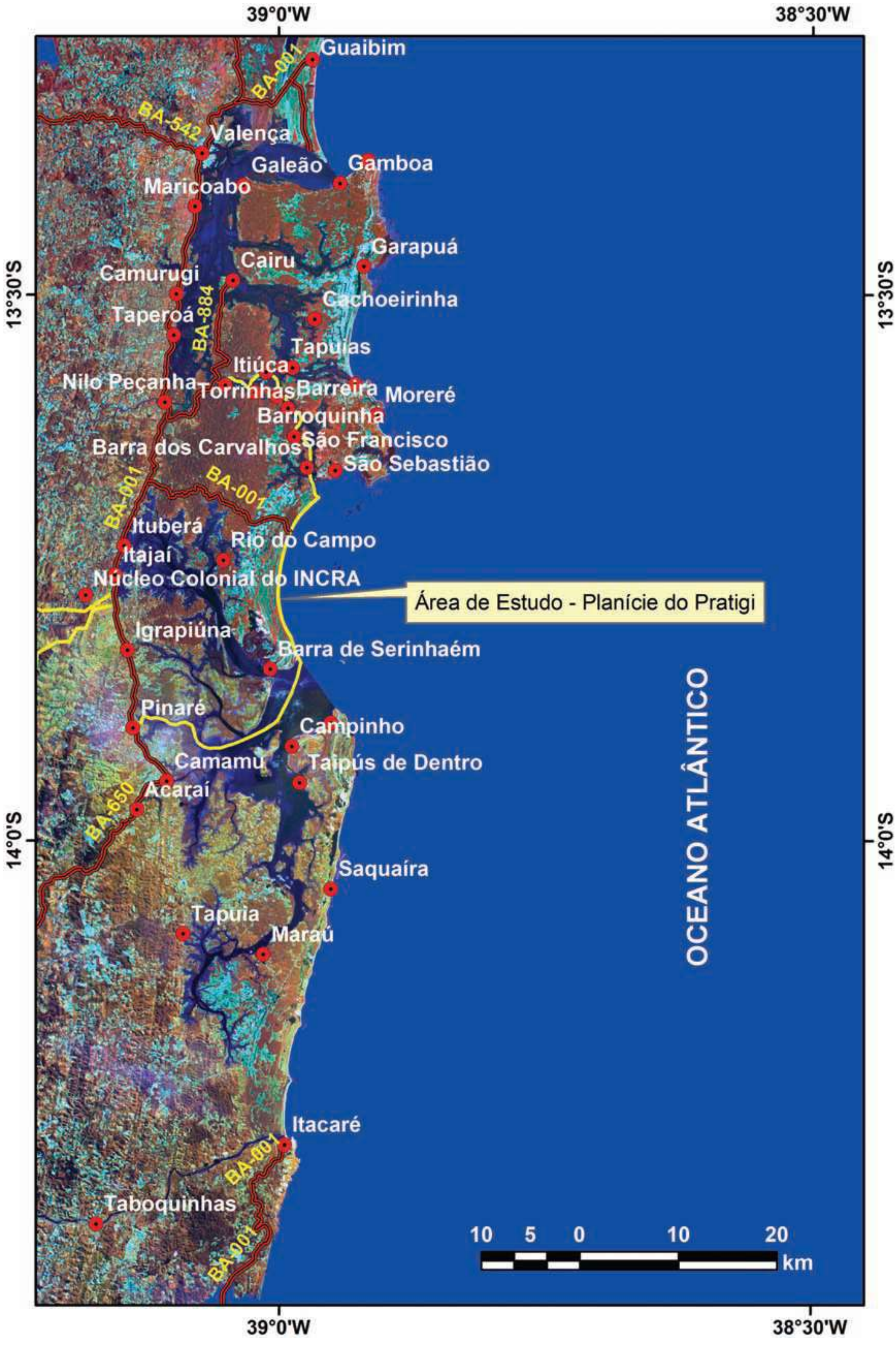
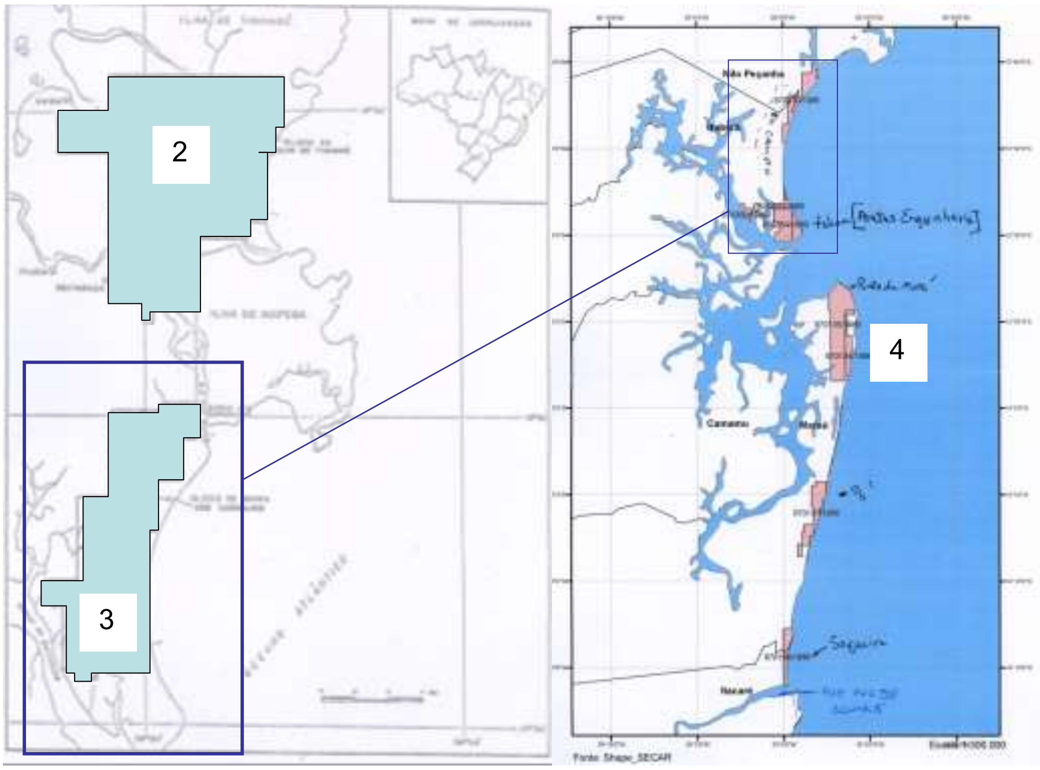


Figure 42 *Location map of study area from Dominguez (2010).*

4.2 Mineral rights

The situation concerning the mineral rights is a bit confusing as there seems to be three different groups of owners in the area. The largest part of the mineral rights is owned by Company and Mineral Resources Research – CPRM – which is the federal Geological Survey linked to the Federal Government (left on Figure 43). The second biggest owner of mineral rights (right on Figure 39) is Company Bahia Mineral Research CBPM (Geological Survey linked to the Bahia State).



CPRM's ownership CBPM's ownership

Figure 43 *CPRM (Federal) and CBPM (Bahia State) ownership of the mineral rights. Ilha de Tinharé deposit is # 2 on the map, Pratiga deposit is # 3 on the map and Punta do Mota deposit is # 4 on the map.*

As far as we understand the mineral rights owned by CBPM was open for potential staking i 2012. And interested parties would have to bid for the claims as follows:

- Direct a letter of interest to Alexandre Brust
- 45-60 days later an auction is announced
- Submit bid and some time after, the winning bid enters a 24 mo. contract with CBPM for evaluation
- After the geostudy of (3), an environmental and permit study

4.3 General geology of the Rio Campo area

The segment of the Bahian coast where there are heavy mineral deposits is shown on Figure 44 as C & D (in the legend). The area is characterised by Precambrian basement to the west, covered by down faulted Mesozoic sediments – mainly sandstones of the Camamu Sedimentary Basin. The occurrences of heavy mineral deposits are tied to coastal Pleistocene and Holocene marine terraces.

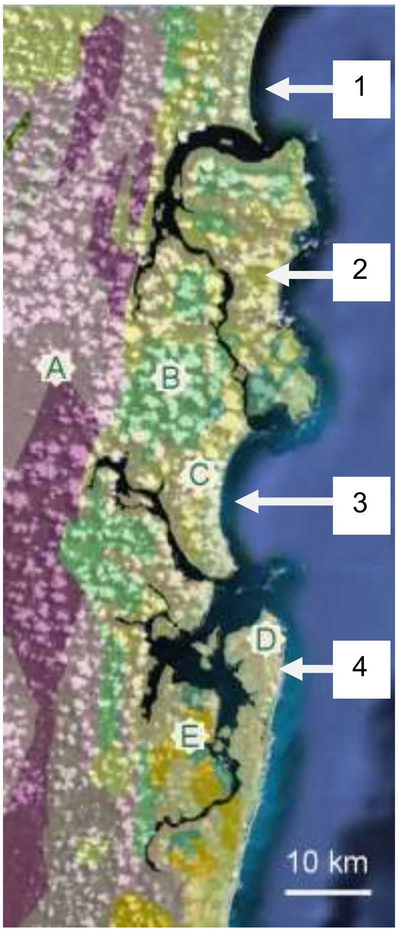


Figure 44 *Geological map of the coast of Bahia between Guaibim and Itacaré.*

A. Basement consisting of tonalite, dacite, rhyolite and gabbro of Archaean and Paleoproterozoic age (Pink colours)

.

B. Camamu Sedimentary Basin Mesozoic sediments of the Sprout Group (Sergi, Alliance and Taipus-Mirim Formations).
These sediments accumulated in this sedimentary basin that formed during fragmentation of South America and Africa (Green).

C. Quaternary beach deposits of Pleistocene age (Yellow).

D. Quaternary beach deposits of Holocene age (Buff).

E. Mangrove (Orange).

1. Guabim deposit
2. Tinharé deposit,
3. Pratiga deposit
4. Punta do Mota deposit

Marine terraces

The Pleistocene marine terraces are ca.10 meters above sea-level. The origin of this terrace is related the progradation of the shoreline after the Maximum the Penultimate Transgression (120,000 years A.P.) when the mean sea level stood about 10 meters above the present level (Martin et al 1980). This terrace consists of fine- to medium-grained, well sorted white sand. The Pleistocene Marine Terrace occupies an area of approximately 19km^2.

At the maximum of the last (Holocene) transgression about 5,100 years BP, the relative sea level stood about 5 meters above the present level (Martin et al, 1979). During this event, a terrace with a flat surface with standlines/ridges was formed (Figure 45),

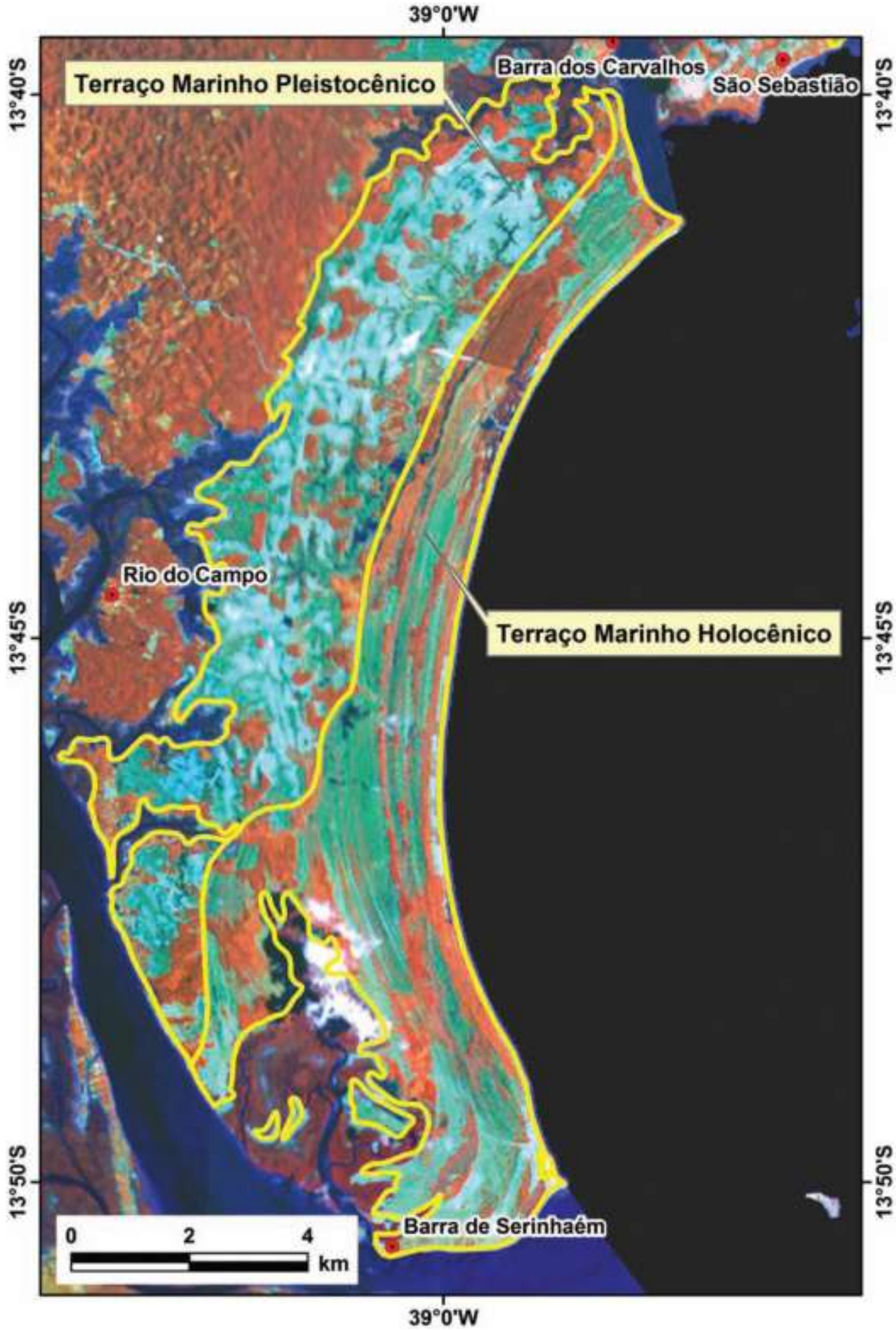


Figure 45 *Landsat TM7 image (from Domingues 2010). Light blue colour is Pleistocene raised beach deposits, the green colour is the Holocene beach deposits and the red colour is trees.*

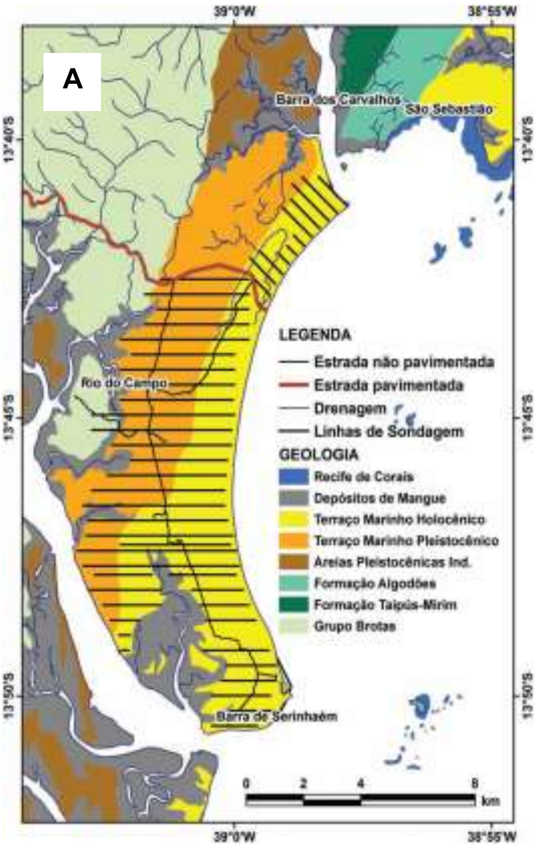


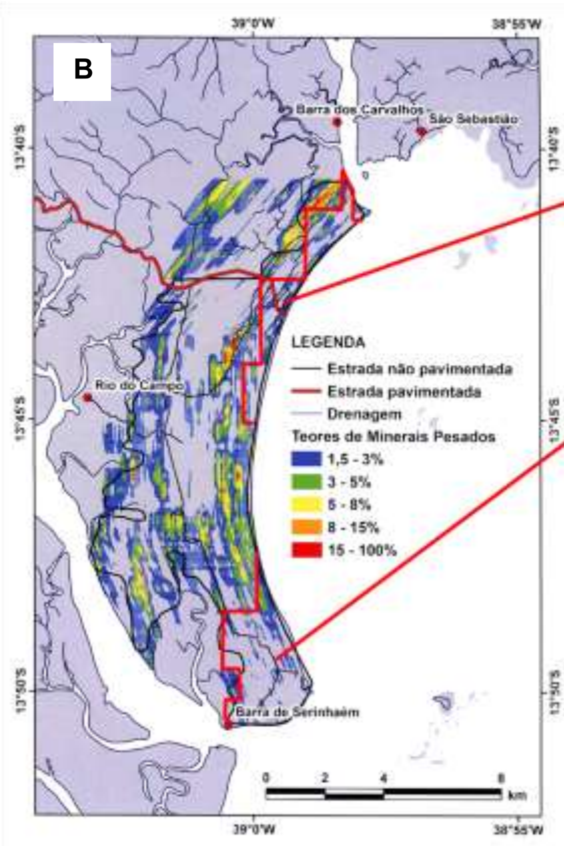
Figure 46

A *Distribution of lines where drilling was conducted. A total of 154 km of line was investigated by 2746 drill holes (spacing between lines ca 250 m and between drill holes in the lines ca 50 m).*

B *Spatial distribution of heavy mineral grades (average drill hole).*

C *Location of CBPM (Bahia State) mineral rights.*

It can be noticed that the major part of the reserves is located outside the CBPM (Bahia State) property which has been subject to a tender procedure and within the CPRM (Federal) property.



The heavy mineral deposit

The heavy mineral accumulations are located in the uppermost 4 meters of the deposit. As can be seen on Figure 42 B, the mineralized sands are arranged in bands parallel to the coast and the strandlines. It can further be seen that the highest concentrations (Figure 36 B) are located at the boundary between Pleistocene and Holocene accumulations. This is probably an effect of reworking of the Pleistocene sands during the Holocene transgression resulting in accumulation of heavy minerals at the base of the Holocene sand.

According to CBPM there is 236 mill ton of ore with 7.4 mill. ton of heavy minerals (average 3.1 %) with a cut off at 1,5 % HM. A lower cut off would yield total reserves at 690 million tons, with 11 million tons of heavy minerals (average 1.6%).

Table 2 TiO_2 content in titanium minerals in Pratiga deposit

GEUS no	%TiO_2 ilmenite	%TiO_2 ilm + leuc.	%TiO_2 ilm + leuc.+rut
512301	61,3	63,5	67,2
512302	63,8	67,2	70,0
512303	58,6	61,9	63,2
512304	58,4	61,0	61,5
512305	58,8	61,6	63,4
512306	59,1	62,3	63,6
512307	58,1	60,5	61,6
512308	59,6	64,2	66,1
512309	64,8	71,7	81,6
512310	63,5	67,6	77,2
512311	65,3	70,7	79,2
512312	64,0	67,8	70,6
512313	64,3	74,4	81,8
512315	64,2	66,2	68,1
Mean	61,7	65,4	69,1

Data from CCSEM analysis of samples collected by Knudsen and McLimans 2011.

.

Table 3 Average content minerals in Pratiga deposit (Domingues, 2010)

Mineral	% of HM	% HM in ground
Ilmenite & leucoxene	75.1 %	2,40
Staurolite	9. 3 %	0,30
Zircon	4.8 %	0,15
Kyanite	4,3 %	0,14
Sillimanite	1.6 %	0,05
Rutile	0.4 %	0,01

Average grade of the ilmenite is 61,3 % TiO_2 (Domingues, 2010) which is very similar to the results of analysis of the 14 samples collected in 2011 and analysed using CCSEM 61,7 % TiO_2 (Table 2). The average TiO_2 in the titanium minerals in the Pratiga deposit is 69.1 % (Table 2).

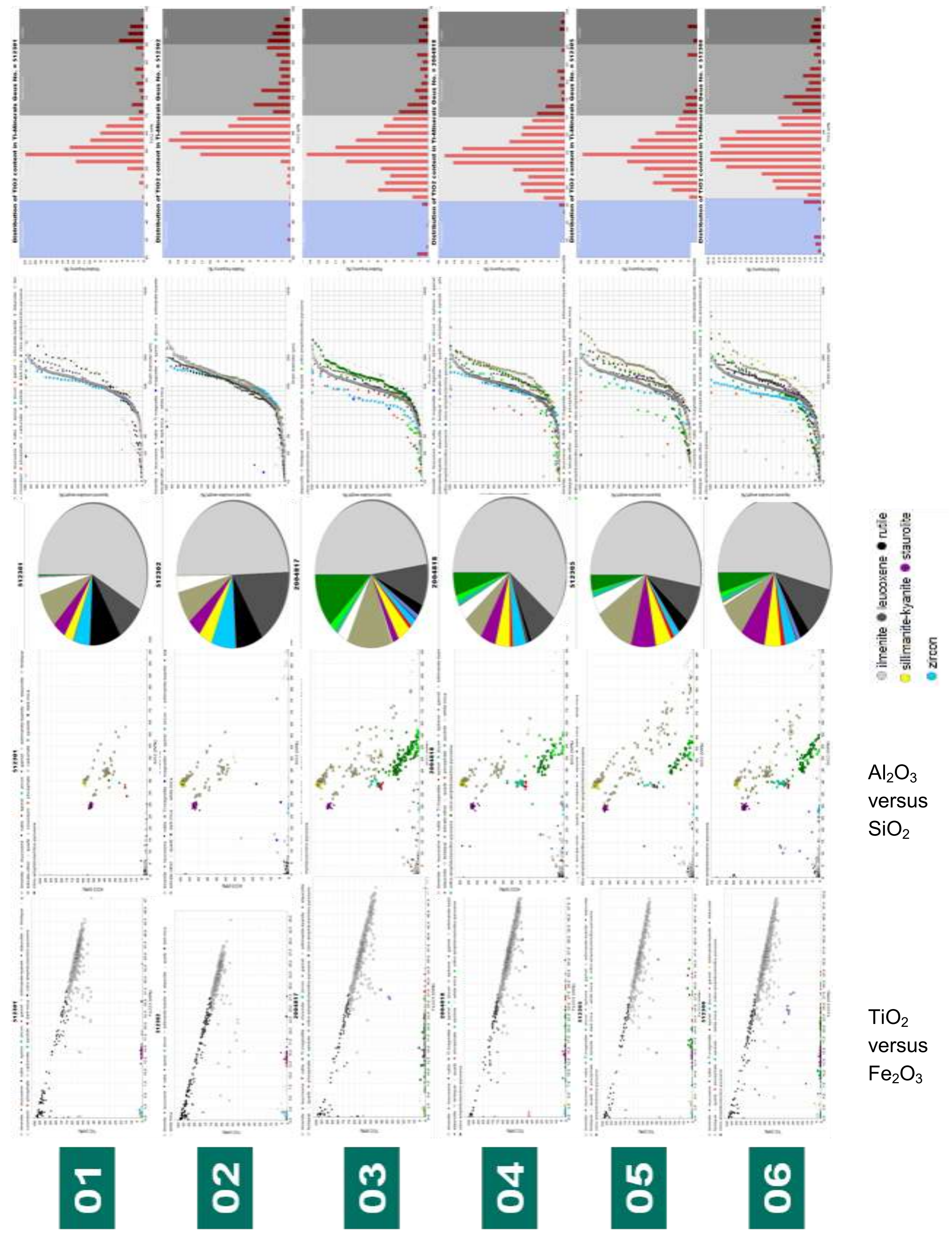


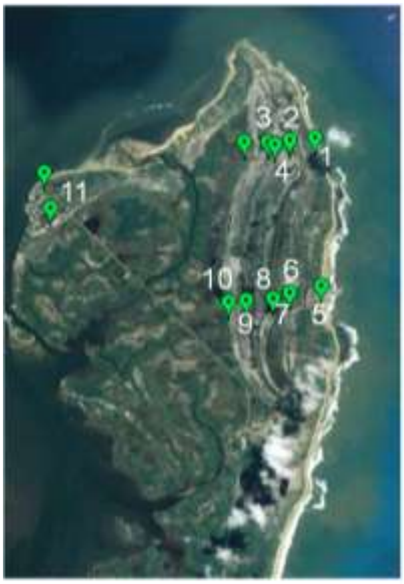
Figure 47 *Mineralogical composition and grain-size of the Pratiga deposit.*

Table 4 Composition of the ilmenite in Pratiga deposit

	TiO2	Fe2O3	MgO	MnO	Cr2O3	Nb2O5	Al2O3	SiO2	Na2O	K2O	P2O5
512301	61,3	34,13	0,29	1,29	0,07	0,28	0,5	1,3	0,02	0,05	0,08
512302	63,81	31,69	0,33	0,95	0,09	0,37	0,5	1,14	0	0,05	0,1
512303	58,59	36,79	0,36	1,2	0,08	0,26	0,88	1,07	0,01	0,04	0,08
512304	58,36	37,61	0,33	1,31	0,08	0,23	0,67	0,72	0	0,04	0,07
512305	58,84	36,51	0,35	1,18	0,08	0,27	0,75	1,19	0,02	0,05	0,06
512306	59,07	36,25	0,34	1,19	0,08	0,27	0,69	1,32	0,01	0,05	0,05
512307	58,05	36,76	0,35	1,13	0,09	0,27	1,13	1,41	0,01	0,07	0,06
512308	59,61	36,24	0,31	1,27	0,07	0,24	0,43	1,09	0	0,04	0,05
512309	64,8	29,09	0,46	0,86	0,12	0,47	0,79	1,58	0,03	0,06	0,07
512310	63,5	30,83	0,35	1,02	0,09	0,35	1,08	1,76	0	0,06	0,07
512311	65,26	29,43	0,45	0,91	0,13	0,32	0,87	0,8	0	0,07	0,07
512312	63,96	31,01	0,3	1,07	0,09	0,33	0,45	1,77	0,04	0,05	0,06
512313	64,32	29,23	0,36	0,78	0,09	0,46	0,82	2,67	0,01	0,07	0,07
512315	64,19	29,55	0,17	1,12	0,08	0,32	1,96	1,61	0,02	0,05	0,07
Mean	61,7	33,22	0,34	1,09	0,09	0,32	0,82	1,39	0,01	0,05	0,07

Data from CCSEM analysis of the samples collected by Knudsen and McLimans 2011.

The sand in the Pratiga deposit is fine- to medium grained and grain-size (d50) of the heavy minerals varies from 100 to 130 μ (Figure 47).



	TiO_2 Ilmenite	TiO_2 Ilmenite + leucoxene	TiO_2 Ilm. + leuc. + rutile	% HM in raw sand
1	54,1	59,6	62,3	0,91
2	55,8	57,4	58,1	4,82
3	59,1	60,4	61,4	3,38
4	55,5	57,6	58,5	2,01
5	54,0	57,4	59,2	2,45
6	56,6	60,1	61,5	1,30
7	55,5	58	58,9	1,18
8	56,9	58,5	59,2	0,76
9	56,3	58,1	59,7	4,75
10	56,1	59,4	60,7	0,56
11	56,1	61,7	64,2	0,57
Mean	56,1	58,7	60,0	2,1

Figure 48 *Sample sites and titanium mineral composition from the Punta do Mota deposit. The peninsula is ca. 6 km across and the deposit is ca 2 km wide and 6 km long.*

Punta do Mota deposit

The Punta do Mota deposit (Figure 48) is located to the south of the Pratiga deposit but it consists a part of the claims owned by CBPM (Bahia State) property (Figure 46 C).

The setting of the deposit is very similar to the Pratiga deposit just not with the upper Pleistocene part but only consisting of Holocene beach sands in a landscape with a very low relief (Figure 49).

The modal composition of the heavy mineral fraction is somewhat similar to the Pratiga deposit (Figure 50) but with less altered ilmenite with a lower grade of the ilmenite of 56,1 % TiO_2 and with of 60 % TiO_2 in the combined titanium minerals (Figure 42).

Figure 49 Pictures from the Punta do Mota deposit (by Jeppe Kristiansen).

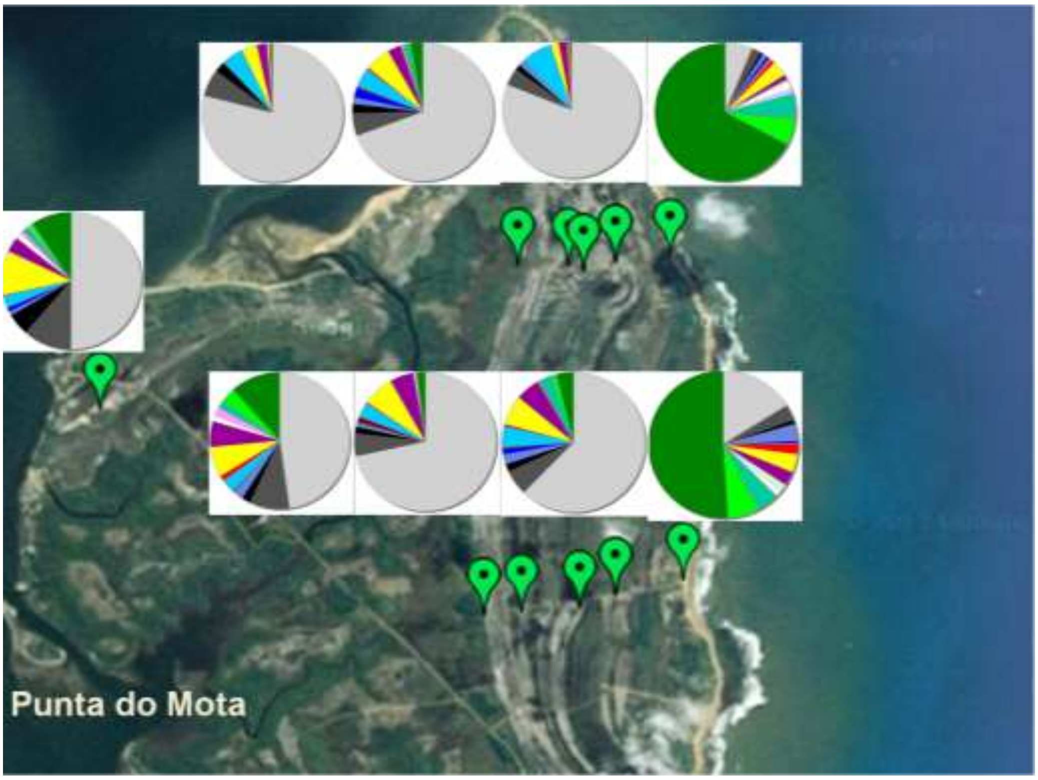


Figure 50 *Composition of the heavy mineral fraction of the Punta do Mota deposit. The recent beaches (east) contain mafic silicates indicating that the minerals here has not yet been affected by leaching.*

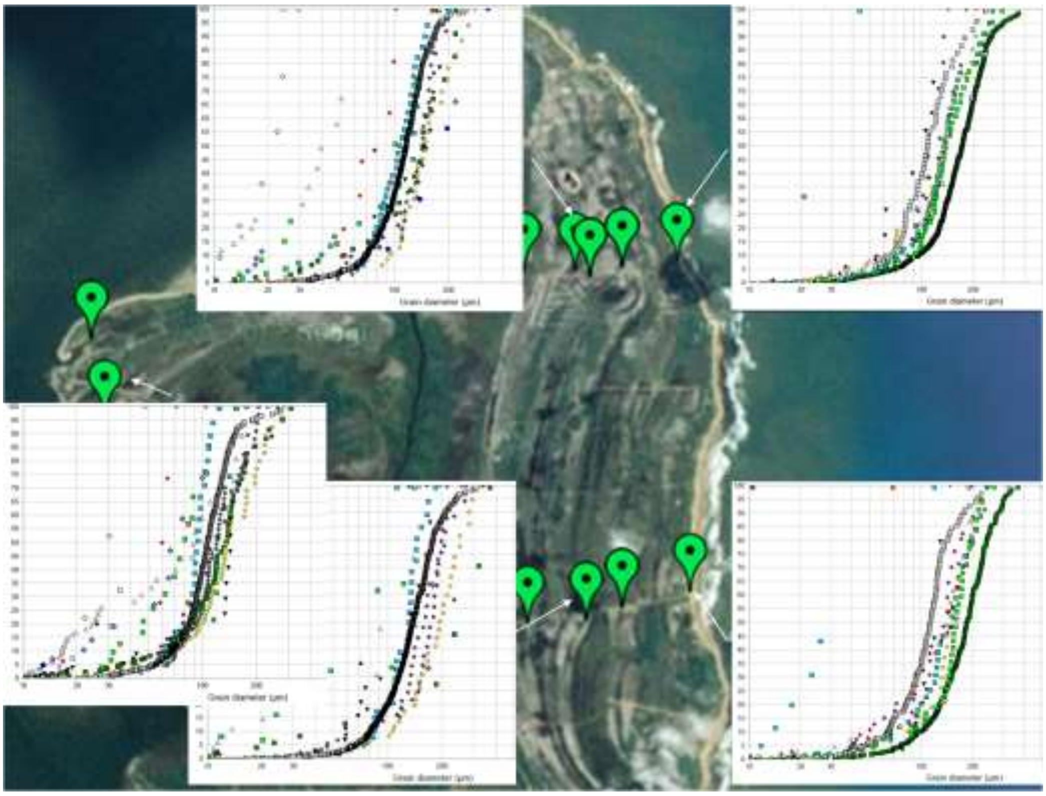


Figure 51 *Grain-size distributions of the heavy minerals in the Punta do Mota deposit.*

Environmental issues in Pratiga and Punta do Mota deposits

The reserves of heavy minerals considered this report are contained in the Pratigi conservation unit created by Decree State No. 7272 of April 2, 1998. On November 24, 2000 was approved by CEPR through Resolution No. 2533, Zoning Ecological-Economic Pratigi APA containing explicit prohibitions and restrictions to the activity mineral extraction in the APA which, if maintained, make it impossible to extract heavy minerals.

Figure 52 *Vegetation map of the Pratigi strand plain (from Domingues 2010) with pictures of the different vegetation types.*

The state of Bahia initiated work to try to solve the conflict between the mineral interests and the environmental issues. This is presented in Domingues (2010) which is an interdisciplinary approach to the problem, integrating geological characterization of these deposits, their genesis, and the environmental restrictions imposed by the ecologic-economic zoning of the Pratigi Environmental Protection Area (Figure 53). Based on the results obtained, a new zoning proposal, focused on sustainability principles and maintenance of biodiversity is presented.

The proposal by Domingues (2010) aim at integral preservation of the several remnants of the regional biotopes such as open scrubland "restinga", wood scrubland "restinga" and mangroves. This area would function as an in situ genetic biodiversity preservation unit, which in the case of human intervention in neighboring areas, would function as a wildlife refuge for fauna and flora.

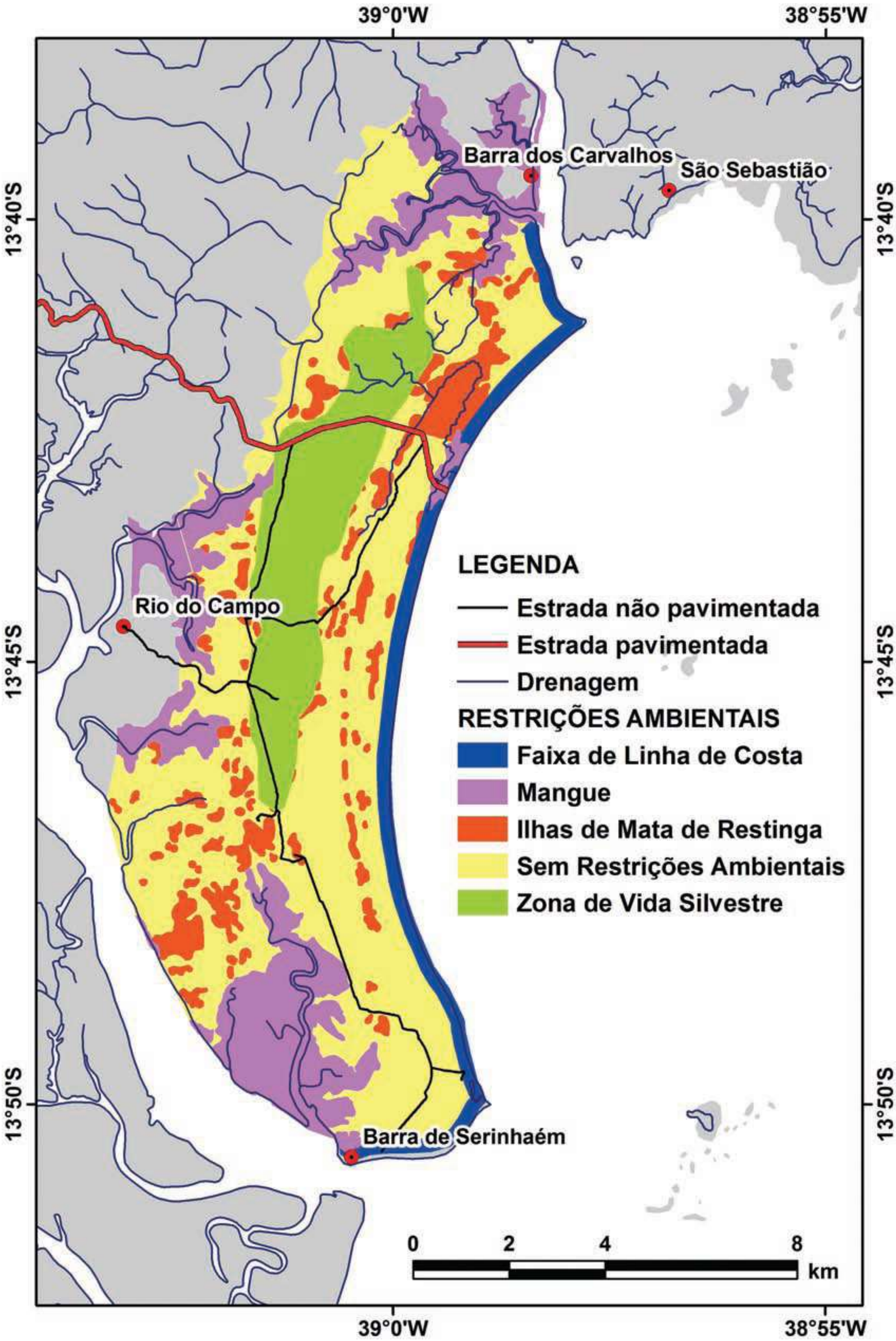


Figure 53 *Map showing environmental restrictions incorporating the zoning proposal by Domingues (2010).*

5. Other possibilities in Brazil

5.1 Byproduct from kaolin production and kaolin tailings

The kaolin deposits in Brazil contain an attractive heavy mineral suite, and the tailings from the kaolin mines constitute a potential titanium resource.

There are 15 identified deposits, 3 in operation:

Cadam (Caulin da Amazonia SA), Rio Jari
PPSA (Para Pigmentos SA), Capim
RCC (Rio Capim Caulim SA, Imerys), Capim

Total kaolin production in Brazil scheduled to be 3 MM tons annually.

The RCC mine is located in Cretaceous rocks in the eastern margin of the Cametá Subbasin where Albian/Cenomanian deposits are cut by a kaolinized Upper Cretaceous unit referred as the Ipixuna Formation. This unit is well exposed in the Rio Capim Kaolin area, where it shows thickness of nearly 40 m and consists of kaolinized mudstones and sandstones. The heavy mineral assemblage in kaolin deposits is mature to super mature dominated by ilmenite, zircon and tourmaline, and subordinately rutile, kyanite and staurolite (Goes et al. 2007).

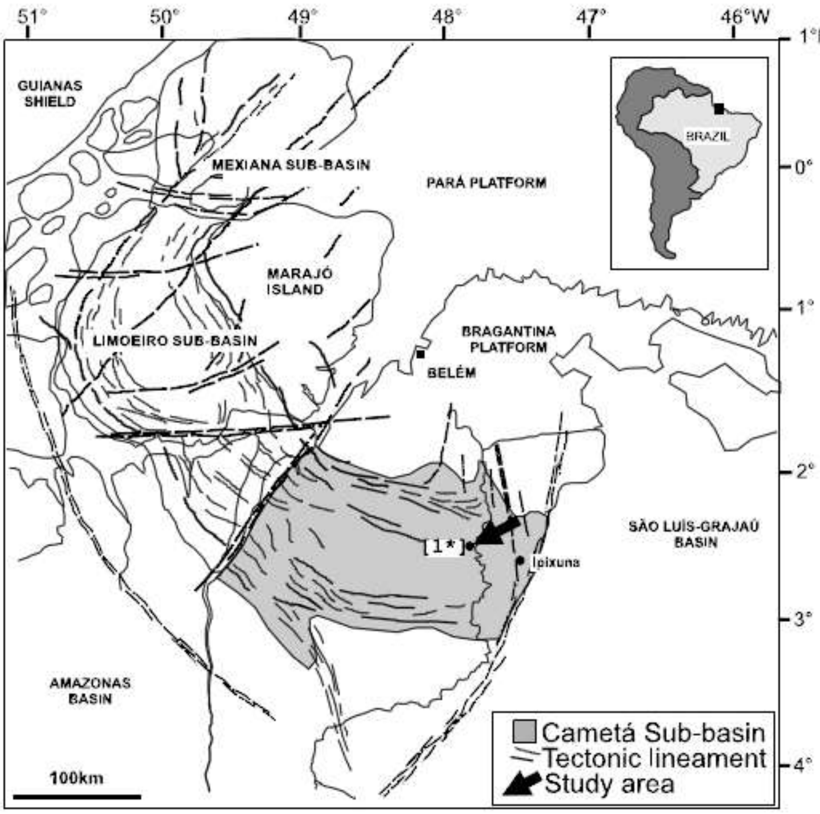


Figure 54 *Location of the Imerys mine in the Cametá Sub-basin.*

Figure 55 *Imerys mine site.*

Table 5

Effluent from cyclone at the mine site	
r.o.m. grade -	1.5 % TiO_2
% of kaolin -	10 %
HM % -	13.34 %
HM grade -	4.4 % TiO_2
Ilmenite grade –	64 – 66 % TiO_2
Zircon % in HM -	8 – 10 %
Concentrate grade	66 – 70 % TiO_2
TiO_2 recovery -	70 %

Content of HM suite:
43% Ilmenite @ 60-65% TiO_2
20% Leucoxene @ >75% TiO_2
5% Rutile @ >94% TiO_2
14% Zircon
18% Other HM

Current HM byproduct production at Imerys mine: 30,000 t/yr.
Possible TiO_2 concentrate from above: 70% TiO_2
Tailing Ponds: 1-2 million tons to be reprocessed (poss. 100-200K tons TiO_2).

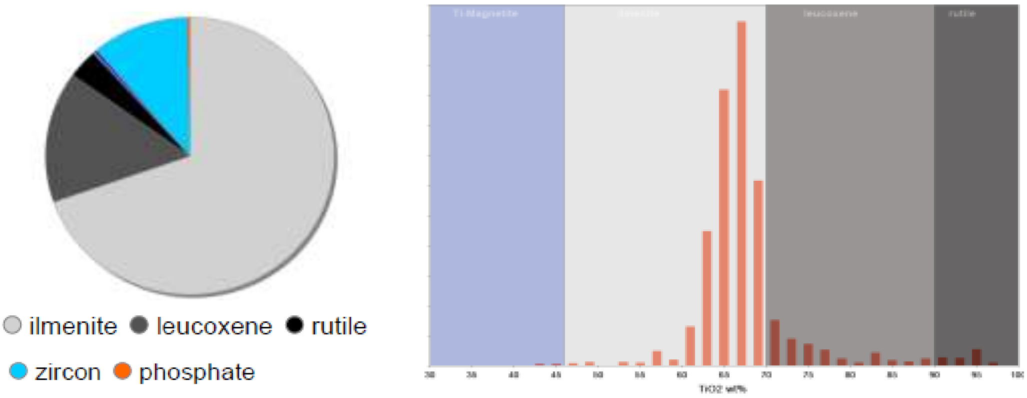


Figure 56 *Content of HM suite and distribution of TiO_2 in Ti-minerals*

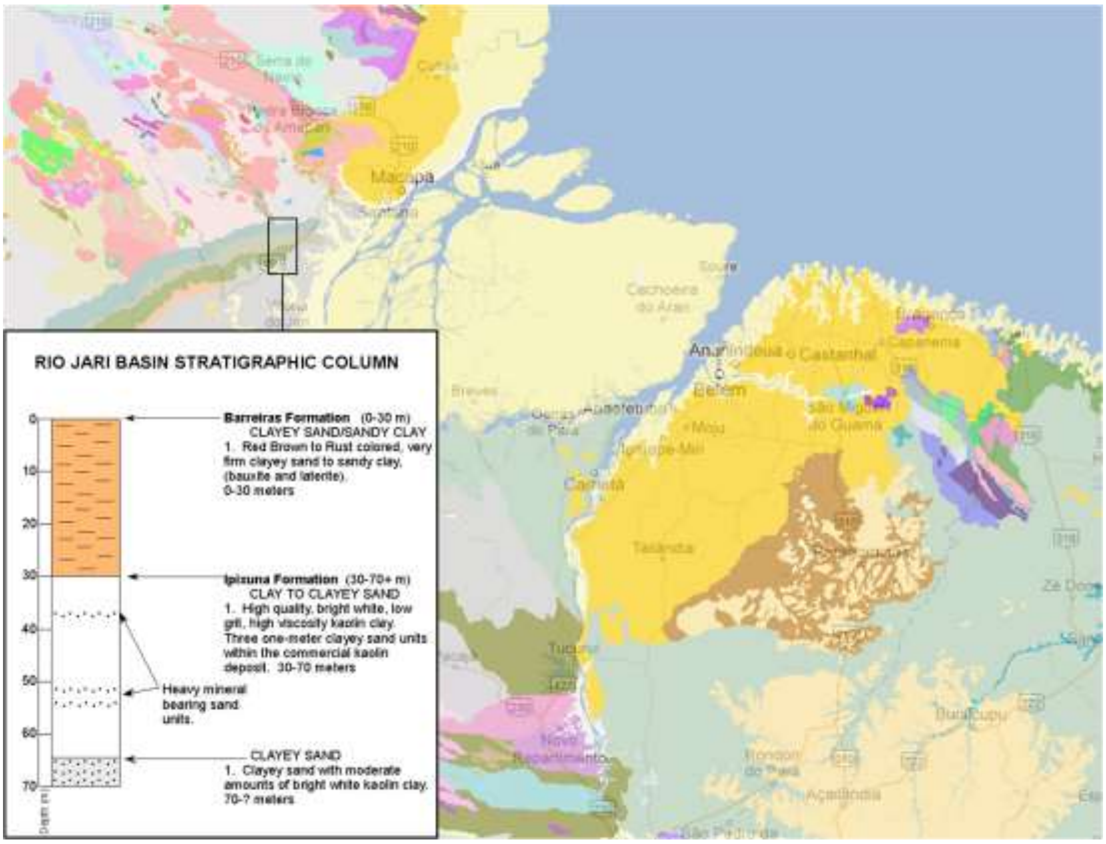


Figure 57 *Location of kaolinite rich sediments, Ipixuna Formation in the Rio Jari Basin.*

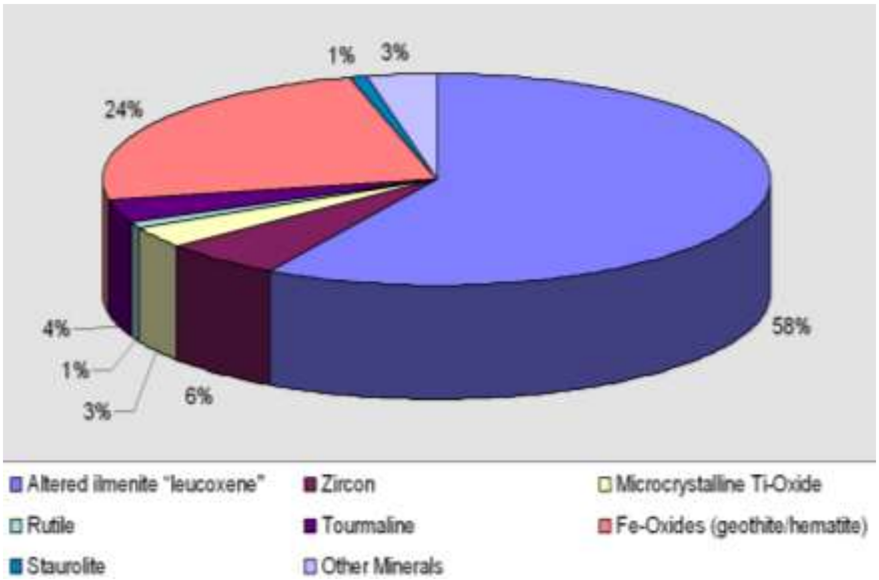


Figure 58 *Composition of the heavy mineral suite in the Rio Jari Basin.*

Kaolin ore reserves in this region of Brazil = 500 MM tons. (2-6 million tons TiO_2 minerals).

5.2 Bujuru

Dillenburg et al (2004) demonstrates the link between the evolution of a coastal barrier in southern Brazil during the Late Holocene and the formation of a large volume of aeolian disseminated heavy mineral deposits at Bujuru formed in three steps:

1. Recycling of coastal plain deposits during the Postglacial Marine Transgression, this ended at 5.6 ka when heavy minerals were incorporated into beach and wash over facies of a transgressive barrier.
2. Shoreward retreat of the barrier, under a slow and small sea-level fall, during the last 5.6 ka. This second step eroded and recycled sediments from the Pleistocene substrate, which acted as an extra source of heavy minerals. Heavy minerals were concentrated in backshore deposits by wave action during barrier recession.
3. Erosion and transport of backshore sands by onshore winds into an inter-barrier depression in the form of transgressive dune deposits. These deposits contain ca. 4.7 % heavy minerals (1494 samples). This aeolian placer deposit has started to form 1 ka ago and is still under formation.

It is suggested that the Bujuru area is visited to collect samples to test the quality of the ilmenite.

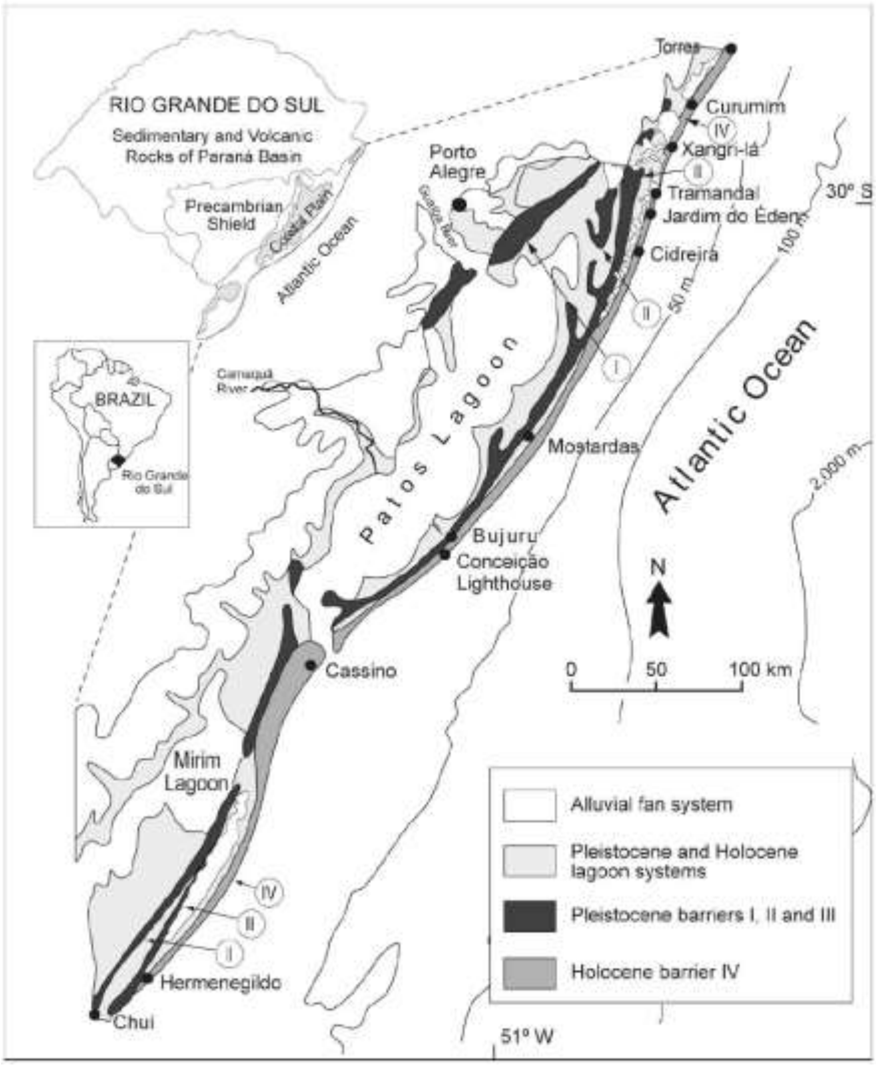


Figure 59

The very large areas with marine placers with potential for heavy mineral accumulations of which at least one at Bujuru is known.

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