MAPPING COASTAL EROSION IN SOUTHERN PARAÍBA, BRAZIL FROM RADARSAT-1

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ABSTRACT

In the southern coast of Paraiba in northeast Brazil coastal erosion is a severe problem with serious damage to coastal settlements and sensitive ecosystems. Assessing the effects of sea level rise and global climate change in these coastal areas requires detail knowledge of the geological controls, and an accurate and simple method to measure shoreline changes. Using local 1:100 000 topographic maps from 1971 and a 1996 RADARSAT-1 image, we estimate that the shoreline has retreated between 150-300meters in 25 years. The image was also used to update existing drainage, geomorphological and geological maps. In this area, the resistance of coastal sedimentary units, and the degree of fracturing along the coastline control coastal erosion. Weak and fractured Quaternary sediments characterize areas of severe erosion, and sandstone cliffs, protected by reefs characterize the stable areas.

INTRODUCTION

Coastal erosion is a serious international problem with long term economic and social consequences. In northeast Brazil, coastal erosion has caused serious property damage in coastal communities, and threatens sensitive wetlands and estuaries. The erosion is most intensive during the rainy season, during high tide periods. Recently, shoreline erosion has been intensified, partly because the natural reefs are also destroyed.

Historically, the US War Department has studied the coastal erosion problems in this region since 1939. In this study, we focus on the geological and geomorphological controls to coastal erosion by using a RADARSAT-1 image to update existing maps, measure shoreline changes, and analyse the regional geology and tectonics. Similar approaches have been used by Singhroy (1996), Singhroy and Barbosa (1998), and the USGS (1996).

A RADARSAT-1 S7 (45-49 degrees) image was used to map areas coastal erosion, and update the geological and geomorphological maps of coastal areas. The choice of the S7 was based on the fact that the larger angles are more suitable to delineate the land water boundaries and therefore facilitate mapping shoreline geomorphology. In addition, other optical images such as SPOT and LANDSAT were not useful because of the permanent cloud cover in these coastal areas.

THE STUDY AREA

The study area extends for about 29 km to the south of João Pessoa (Figure 1). The climate is sub-tropical, hot and humid. The original tropical forest was cleared for agriculture and settlements. The local economy is based on plantation agriculture- sugar cane and coconuts and fishing.

Coastal sediments are Mesozoic, Tertiary and Quaternary in age. The units include, marine and river sediments, fine sandstone with silt and clay, and a sandy limestone. The geomorphology is characterized by sandstone cliffs, flat marine and river sediments with mangroves, and spits (Radambrasil,1981)

RESULTS

Three maps (drainage, geomorphology and geology) were produced from the interpretation of the RADARSAT-1 data. The interpretation of the images was based on the identification of the SAR texture and drainage patterns, which correspond to the geological and geomorphic units. Field checks also supported the precise delineation of these units.

The drainage map (Fig. 2) was produced using the 1971 topographic map and the RADARSAT-1 image. The drainage is characterized by high medium and low density dendritic patterns, which assisted in mapping the lineaments in the region. The geomorphological map (Fig. 3) shows two geomorphologic units: accumulation areas (A) and tablelands (S). This last unit was divided in 8 sub-units (S_{1-8}), based on the RADARSAT-1 interpretation as shown in Table1. The geological map (Fig. 4) is an revised version of the RADAMBRASIL 1981 Geological Map, using the new information from RADARSAT-1.

Lineaments interpreted from the RADARSAT-1 data are shown on the geological map as lines and rose diagrams (Fig. 4a). The eight interpreted lineament directions EW±5^0, NS±5^0, N20^0E ±5^0, N40^0E±5^0, N60^0E ±5^0, N25^0W±5^0, N35^0W±5^0, N60^0W±5^0 show a very good correlation with existing Precambrian and Cretaceous geological structure directions in the interior of the State of Paraiba (Tables 2 & 3). The Patos and NW lineaments shown in Figure 4b, are Precambrian structures. They control the interior and coastal sedimentary basins. Our lineament direction analysis (Fig. 4) confirms that the coastline is structurally controlled with lineament directions trending NS±5^0, N40^0E±5^0 and N25^0W±5^0.

Mapping Coastal changes.

To map the changes of the coastline over the past 25 years, the RADARSAT-1 1996 image was superimposed in the 1971, 1:100 000 topographic map of the southern coast of Paraíba (Fig. 5) Although the topographic map was published in 1986, the aerial photographs used were acquired in 1971. Geometric correction and registration of the RADARSAT-1 image was not difficult since the coastal areas are relatively flat. We noted that shoreline changes were not consistent along the coast. Some areas were more vulnerable to erosion than others, based on local geomorphological and geological controls. Areas with low coastal erosion are characterized by resistant sandstone cliffs, barrier reefs and low fracture densities. Areas with extreme erosion are characterized by weak sediments and high density fractures.

As an example, the Gramame and Abiai river estuaries (Fig. 5) are characterized by weak Quaternary sediments, and are the most vulnerable to erosion. According to the local population, the mouth of the Gramame River (Photo 1) continuously changes. During the higher tides, the ocean destroys the spit and floods the mangrove areas. The largest changes are shown on the RADARSAT-1 image (Fig. 5) at the mouth of the Abiai and Gramame rivers. In 1971 the mouth of the Abiai River flows north, now it flows to the south (Photo 2).

The estimated change in the shoreline over a 25-year period (1971-1996) is between 150-300 meters. The area of sandstone, a more resistant rock shows a change of about 150 meters, and the weak Quaternary sediments show changes of 300 meters. These areas are also highly fractured which adds to their erodibility. For example, there is an increase in lineaments at directions N25^0E±5^0, N20^0W±5^0 and N35^0W±5^0 , and a decrease at directions N40^0E±5^0 and N60^0W±5^0

(Table 4, Fig. 4a). These directions are related to Patos and interior NW lineament system, which suggest that the tectonic systems in the interior are reflected in the coastal areas.

CONCLUSIONS

The following brief conclusion result from this study:

- The shoreline of southern Paraiba is structurally controlled. There is a good correlation between the radar-interpreted lineaments in the coastal areas and the Precambrian and Cretaceous structures in the interior areas.
- Coastal erosion is controlled by lithology and regional and local fracture systems.
- The most severe coastal erosion occurs where the shoreline sediments are weak and fractured.
- Fractured marine and alluvial sediments are easily eroded (300 meters in 25 years). Sandstone cliffs are more resistant (150 meters in 25 years).
- RADARSAT-1 S7 image was useful to measure the shoreline changes, and to map the structures, lithology and drainage systems in the coastal areas.

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TABLE 1 - GEORMORPHOLOGICAL PHOTO-INTERPRETED UNITS'S CHARACTERISTICS

UNIT		Altimetric Level	Dissection Degree	Drainage Deepeneing	Erosive Steep Slope	Cliff	RELIEF		DRAINAGE			Texture
							Pattern	Dissection	Pattern	Density	Uniformity	
A		l	vl	vwe	a	a	f	vl	tree	vl	h	fi
S	S_1	d	l	vwe	p	p	ft	vl	tree	vl	h	fi/m
	S_2	d	l	we	p	a	f to wt	l	tree	l	h	m/fi
	S_3	d	l	vwe/we	p	p	hft	vl	tree	vl	h	fi
	S_4	d	l	we	p	a	f to wt	l/m	tree	l/m	h	m/fi
	S_5	d	l/m	we/m	p	p	w to f	m/h	tree	m/h	h	c/m
	S_6	d	l	we	p	p	hft to hwt	l/m	tree	l/m	h	m/c
	S_7	d	m	m	p	p	w to sw	m/h	tree	m/h	h	c/m
	S_8	d	m/h	m/h	p	a	sw	h	tree	h	h	c

S_{1-8}: S sub-units. a: absent; c: coarse; d: different; f: flat; fi: fine; h: high; l: low; m: medium; p: present; s: strongly; t: top; v: very; w: wavy; we: weak.

TABLE 2 - PRE-CAMBRIAN AND POST-CRETACEOUS LINEAR GEOLOGICAL STRUCUTURES' DIRECTIONS OF THE STATE OF PARAÍBA

A - Patos lineament (A great dextral lineament, with general direction W-E , Figure 4b)	**B - NW sinestral strip slip fault system** (Barbosa (1993), Barbosa and Guedes (1993) and Barbosa and Silva Neto (1994).
• $N\approx25^0E\pm5^0$ high deep angle reverse or thrust faults	• NS ±5° high deep angle reverse or thrust faults
• $N\approx60^0E\pm5^0$ dextral strip slip faults*	• N≈40°E±5° dextral strip slip fault*
• $EW \pm5^0$ dextral strip slip faults*	• N≈65°E±5° normal faults
• N≈20°W±5° sinestral strip slip faults*	• N≈35°W±5° sinestral strip slip faults*
• N≈35°W±5° normal faults	• N≈60°W±5° sinestral strip slip faults*
* all strip slip faults in the region are conjugated with normal (gravitational) faults	

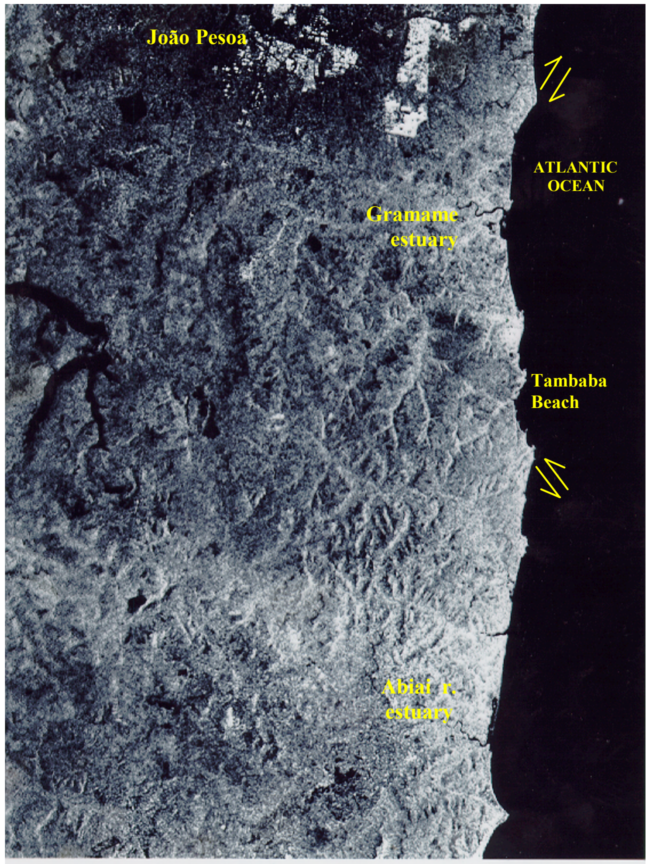
TABLE 3. CORRELATION BETWEEN GEOLOGICAL LINEAMENT DIRECTIONS OF THE INTERIOR PARTS OF THE STATE OF PARAÍBA, WITH RADARSAT PHOTO-INTERPRETED LINEAMENTS' DIRECTIONS AND FIELD DATA. SOUTHERN COASTAL ZONE OF THE STATE

	QUANTITY OF FRACTURES							FREQUENCY (%)						
AZIMUTH	SOUTHERN COAST		PRE-CAMBRIAN		MESOZOIC SEDIMENT. BASINS [2]			SOUTHERN COAST		PRE-CAMBRIAN		MESOZOIC SEDIMENT. BASINS[2]		
	Sedimentary Rocks		"S"[1]	"W"[2]	Ante Nor Navarro	Souza	Pombal	Sedimentary Rocks		"S"[1]	"W"[2]	Ante Nor Navarro	"S"	Pombal
	RADAR SAT	Field data	Field data	Field data	Field data	Field data	Field data	RADAR SAT	Field data	Field data	Field data	Field data	Field data	Field data
NS±5°	42	50	444	139	11	36	25	11.96	8.82	13.74	9.90	2.60	4.20	5.80
EW±5°	21	34	530	254	13	60	47	5.98	6.00	16.40	18.20	3.10	7.00	10.90
N25°E±5°	29	77	608	176	51	94	43	8.26	13.58	18.80	12.60	12.20	10.90	9.90
N40°E±5°	75	92	345	112	41	132	91	21.36	16.22	10.68	8.00	9.80	15.40	20.4
N60°E±5°	39	72	474	106	45	130	41	11.11	12.70	14.67	7.60	16.80	10.00	9.50
N20°W±5°	41	76	443	295	45	130	85	11.70	13.40	13.71	21.10	10.80	15.20	18.30
N35°W±5°	58	91	92	83	97	167	70	16.52	16.05	2.80	5.90	23.40	19.50	16.20
N60°W±5°	46	75	358	234	114	153	39	13.11	13.23	11.08	16.70	27.30	17.80	9.00
TOTAL	351	567	4,194	1,399	417	858	441	100	100	100	100	100	100	100

[1] Barbosa & Silva Neto, 1994; [2] Barbosa & Guedes, 1993

TABLE 4 - GEOLOGICAL LINEAMENT DIRECTIONS IN SOUTHERN COAST OF STATE OF PARAÍBA (FIELD DATA)

	QUANTITY OF FRACTURES				FREQUENCY (%)			
AZIMUTH	Total Area	"N" (Gramame river)	CENTRE (Tambaba beach)	"S" (Abiaí river)	Total Area	"N" (Gramame river)	CENTRE (Tambaba beach)	"S" (Abiaí river)
NS±5°	50	29	6	15	8.82	7.74	5.26	19.23
EW±5°	34	25	5	4	6.00	6.67	4.38	5.13
N25°E±5°	77	58	4	15	13.58	15.46	3.51	19.23
N40°E±5°	92	50	34	8	16.22	13.33	29.82	10.25
N60°E±5°	72	38	29	5	12.70	10.14	25.45	6.42
N20°W±5°	76	48	12	16	13.40	12.8	10.52	20.51
N35°W±5°	91	75	5	11	16.05	20.0	4.40	14.10
N60°W±5°	75	52	19	4	13.23	13.86	16.66	5.13
TOTAL	567	375	114	78	100	100	100	100



RADARSAT-1 C-HH image

- Data: March 29, 1996
- Orbit: 2083, descending, west look
- Mode: Standard 5
- Incidence angle: 36^0 - 42^0
- Resolution: 12.5 m X 12.5 m

Figure 1- RADARSAT image of the study area:

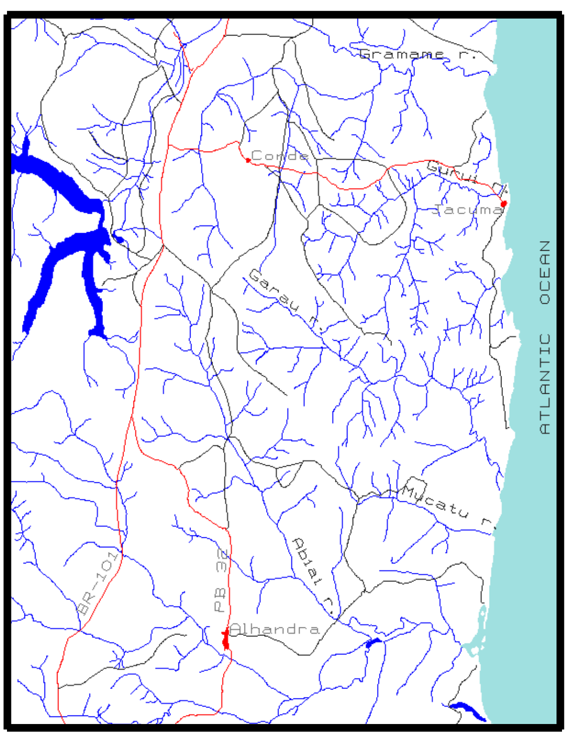


Figure 2: Drainage Map.

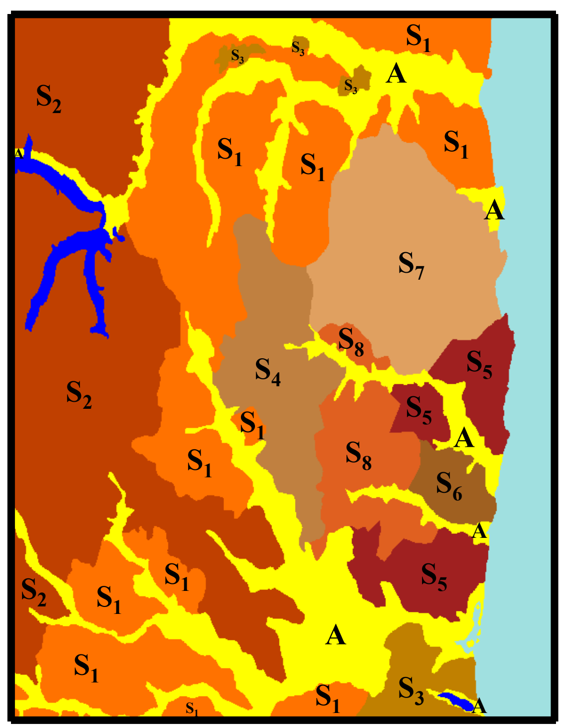


Figure 3: Map of Geomorphological units.

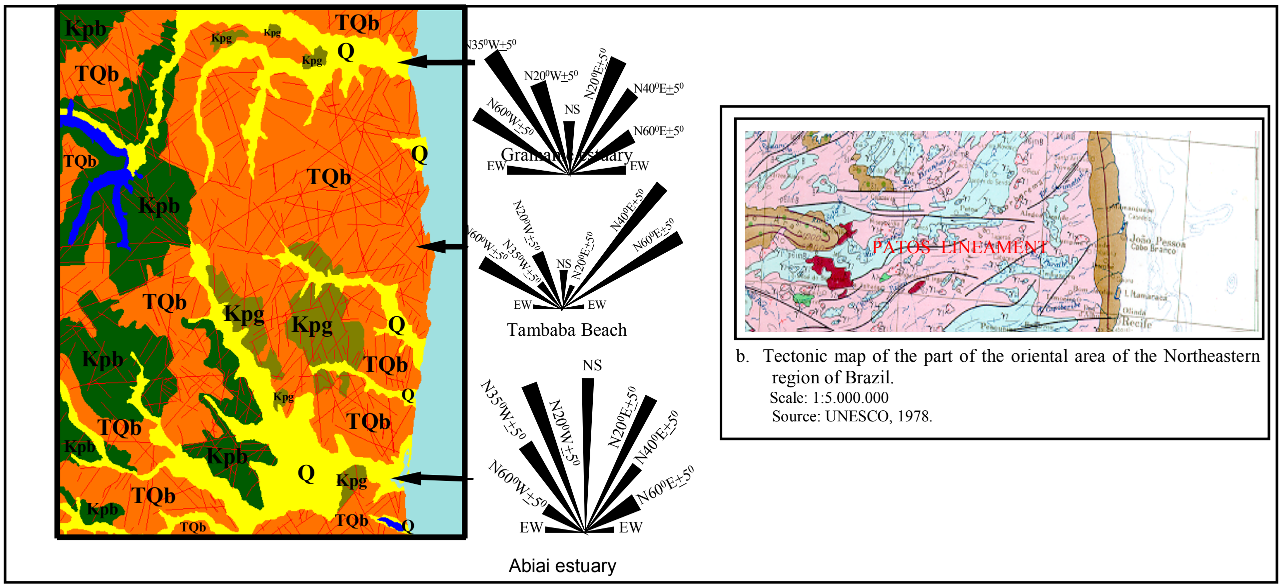


Figure 4. Map of geological units and lineaments

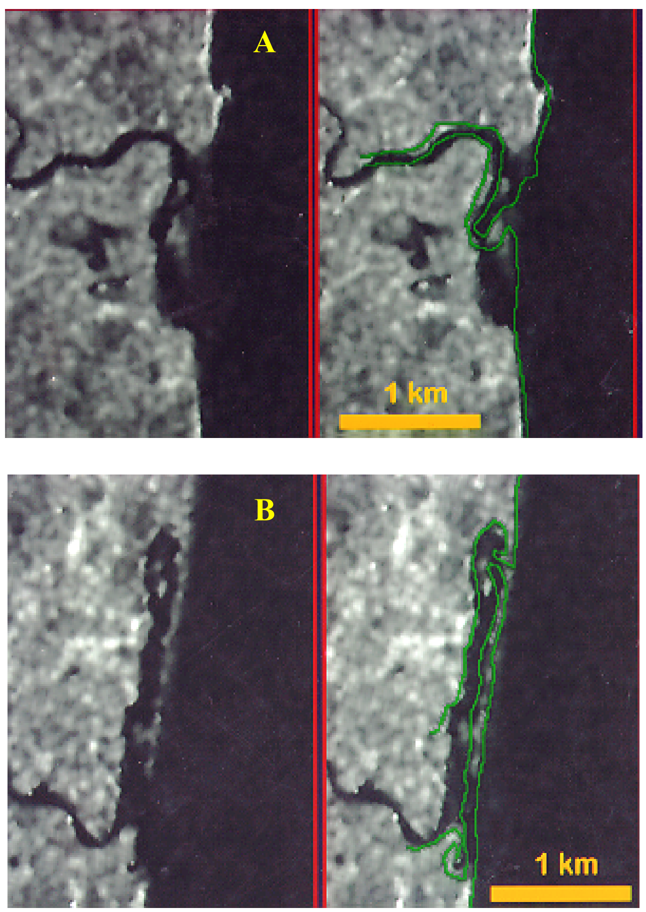


Figure 5. Estuary of the Gramame (A) and Abiai (B) rivers with vectors from the 1971 topographic map (green lines).

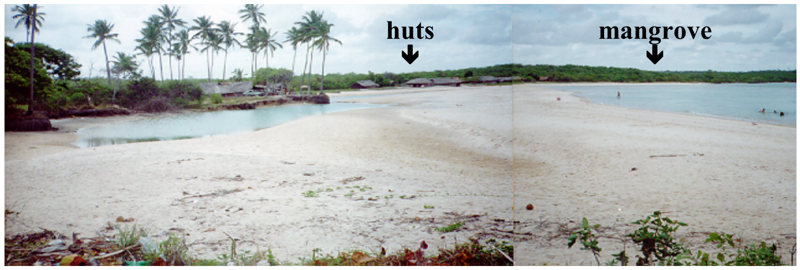


Photo 1. Gramame river estuary, South part.

Photo 2 - Abiaí Estuary - panoramic view (low tide).