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# Landforms and Neotectonics in the Equatorial Passive Margin of Brazil

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**Abstract**

Neotectonic movements have been proposed in the literature in order to explain some landforms of the equatorial passive margin of northeastern Brazil. Its seismo-tectonic activity is concentrated in a few sectors located on or near the coast. Active or recently active structures are mainly identified in Neogene deposits. Identifying a contribution of neotectonics to the morphogeny is difficult in a context where most major morphostructural patterns are explained by Cretaceous tectonics related to oceanic opening and by differential erosion induced by Tertiary epeirogenic uplift. We aim to assess the nature of features considered as possibly neotectonic in origin. Seismogenic faults are not related to significant topographic breaks, except on the coast, where they usually reach only a few meters in height. A study of landforms located near zones of seismo-tectonic activity indicates a possible, probably weak, contribution of neotectonics to the formation of a few high scarps. These scarps occur along or near fault zones reactivated in Cretaceous times. We conclude that neotectonic movements are the result of ongoing deformation along predominantly strike-slip fault zones, with long term deformation rates similar to those recorded by dated landmarks (0.01 $mm.yr^{-1}$). Despite reported deformation rates that can amount in places to 0.4 $mm.yr^{-1}$, neotectonic rates are lower than erosion rates. The consequence is that major structural landforms in the region mainly originated in Cretaceous to early Tertiary events.



*Keywords:* fault scarp, neotectonics, passive margin, seismicity, differential erosion

## 1. Introduction

As intraplate domains, passive margins are classically regarded as being characterized by weak tectonic and seismic activity [1]. Yet it is widely recognized that plate-driving forces, as well as local sources of deformation, such as extension resulting from flexural bending and spreading at the coast may result in significant seismo-tectonic activity [2]. Rare but violent earthquakes are known to have occurred in some passive margins, either characterized by a thick sedimentary wedge (Libya, 1851, M=7.1; South Carolina, 1886, M=7.6; Exmouth, Western Australia, 1906, M=7.6) or not (Lisbon, 1858, M=7.1; Nice, 1963, M=6.0) [3]. Therefore, the question arises regarding the role of neotectonic movement in the morphology (including mountain escarpments) of margins characterized by such activity.

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The study area is located mainly in the states of Ceará and Rio Grande do Norte (Fig. 1) and is part of the continental margin of northern Brazil, formed after the transform opening of the Equatorial Atlantic in Aptian times [4]. As in other parts of Brazil [5], neotectonics has been invoked in explanation of some structures and morphological patterns, especially in coastal areas [6][7]. East of the study area, around Natal (Rio Grande do Norte), several NE- to SE-trending faults delimit grabens and horsts that form the coastal structural framework [7]. Several regional indications suggest that Precambrian shear zones and Cretaceous fault zones were reactivated and that new faults were generated long after the break-up.

Such neotectonic events are suggested by analyses of fault controls in the deposition of Neogene sedimentary deposits

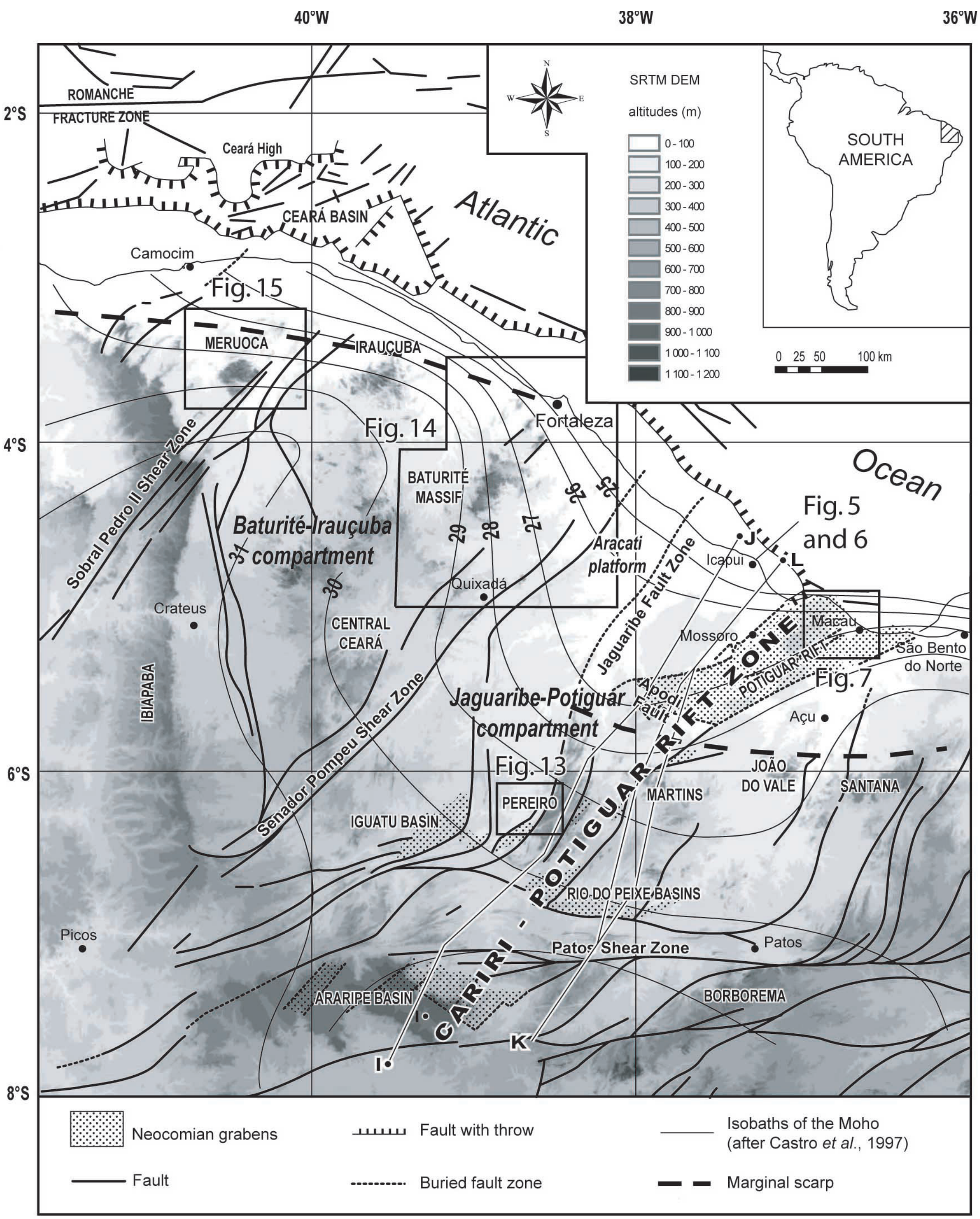



Figure 1. Location map of the study area, showing relationships between topographic patterns, Early Cretaceous rift structures and crust-mantle inferface relief in the study area. Topography from the SRTM DEM; isobaths of the Moho after Castro *et al.* (1997).

in some coastal areas and by the historical and instrumental seismic record. This evidence indicates a higher level of seismicity in NE Brazil than in any other part of the country

This hypothesis of neotectonic influence in landform evolution has been expanded to also encompass early Cenozoic (Paleogene) events. More generally, early Cenozoic tectonics and magmatism in the adjoining oceanic area have been considered as possible controls in the morphostructural evolution of offshore and onshore domains. This occurs in particular along the continental continuation of oceanic transform faults and chains of seamounts [8].

Although the role of faults has been accepted as contributing to landscape evolution in the region, no work thus far has investigated the relationship between geomorphic features and neotectonics. Furthermore, the occurrence of a well-defined and widespread set of tectonic events in the Cenozoic is not clearly demonstrated. What is needed here is (1) a clear definition of the neotectonics that is commonly referred to in publications, (2) a quantification of tectonic vs. erosion rates, and (3) the assessment of the actual contribution of neotectonics to landforms. We reconsider features described as neotectonic in origin, especially the correspondence between these features, the distribution and characteristics of seismic activity, and the local morphology (fault scarps, hydrographic markers). We also question neotectonic interpretations that have been proposed in the literature for some landforms located outside seismic areas. Our objective is to form a preliminary assessment of the morphological effects of neotectonics in the study area by distinguishing them, if possible, from those of long-term morphotectonic evolution, i.e., since the Cretaceous.

## 2. Methodological remarks

### *2.1. Common geomorphic criteria of neotectonic activity*

Neotectonics were previously considered as a process of tectonic deformation restricted to Late Cenozoic times [9] [10] [11]. Increasingly, however, the term has been used to describe processes and structures that develop in the current tectonic regime. This would imply that these processes and structures propagated or were reactivated in a stress/strain field that has persisted without significant change of orientation until the present day [12]. According to these authors, neotectonics need not be regarded as synonymous with Holocene, Quaternary, or Neogene-Quaternary tectonics.

In addition, the study of neotectonics is relevant to understanding many landforms in all areas where tectonic rates may exceed erosion rates [12] [13] [14]. In mostcases, the geomorphic features that are expected to result from seismic activity are surface ruptures in the form of coseismic fault scarps, sag-basins, pressure ridges, and other small-scale landforms on which measures of direction, length, throw, dip, and pitch can be made. However, some ruptures may occur at depth, without apparent surface rupture, resulting only in localized or regional vertical movements (for instance, after the violent 1811-1812 earthquakes in the « Lake County uplift », New Madrid, Mississippi: [15]).

Along faults with predominant vertical motion, relevant criteria are the height and continuity of related scarps, a constant attitude of significant length, a weak sinuosity, and the presence of well-identified coseismic scarps [12] [13] [16]. Along strike-slip faults, relevant criteria are a strong topographic and structural linearity (erosive trough, aligned scarps with alternate aspect), the presence of horizontally offset elements (streams, fluvial terraces), and captures that are not explained by non-tectonic causes.

One difficulty in the assessment of neotectonic activity as a morphogenetic process lies in the rapid alteration of coseismic landforms, especially if they were formed in soft rocks [13]. Such forms may remain apparent for a long time if erosion is negligible or very slow - in arid regions, for example - or slower than deformation.

Some of these criteria have already been identified in northeastern Brazil, where the neotectonic period is considered to have begun with widespread faulting that took place in the Miocene-Pliocene and allowed deposition of the Barreiras Formation in fault-controlled troughs [7] [17]. Nevertheless, most of the criteria are somewhat applicable for areas characterized by strongly active tectonics.

### *2.2. Evaluating the possible role of neotectonics in landforms of passive margins*

The use of common identification criteria of active tectonics, especially in contexts of moderate tectonic activity, is difficult in the absence of conspicuous and continuous escarpments related to well-recognized fault structures [18]. A more promising method may be to compare the distribution of seismic activity to that of recognized tectonic structures along which recent movements might be involved in the formation of nearby escarpments. This approach must take into account the possible distribution of deformation on poorly identified splay faults, such as faults with small throw similar to those found on granitic plateaus in the Natal area (Rio Grande do Norte [2]). Possible clues of recent activity along these structures must also be analyzed. In such a region, where slip rates are low and where earthquake recurrence intervals are probably long, coseismic landforms are expected to be preserved and to cumulate in outstanding escarpments only in areas underlain by resistant rocks and in areas located outside zones of intense erosion (transverse or oblique valleys, or zones of active excavation).

In most cases, the use of common identification criteria of fault activity is difficult in such a context because the expected rates of tectonic movements, if any, are probably comparable or lower than erosion rates [18]. Therefore, long-term movements along faults may be inferred from the analysis of medium-scale (hectometric to kilometric) landforms, which integrate the cumulated effects of numerous seismo-tectonic events. These landforms generally include stratigraphic or geomorphic landmarks that can be dated - such as deformed deformed or offset stratigraphic levels, planation surfaces, fluvial terraces - allowing a quantification of movements over long periods. The difficulty of this approach lies in the reconstruction of corresponding medium or long-term evolution because of the superimposition of deformational stages. Part of these

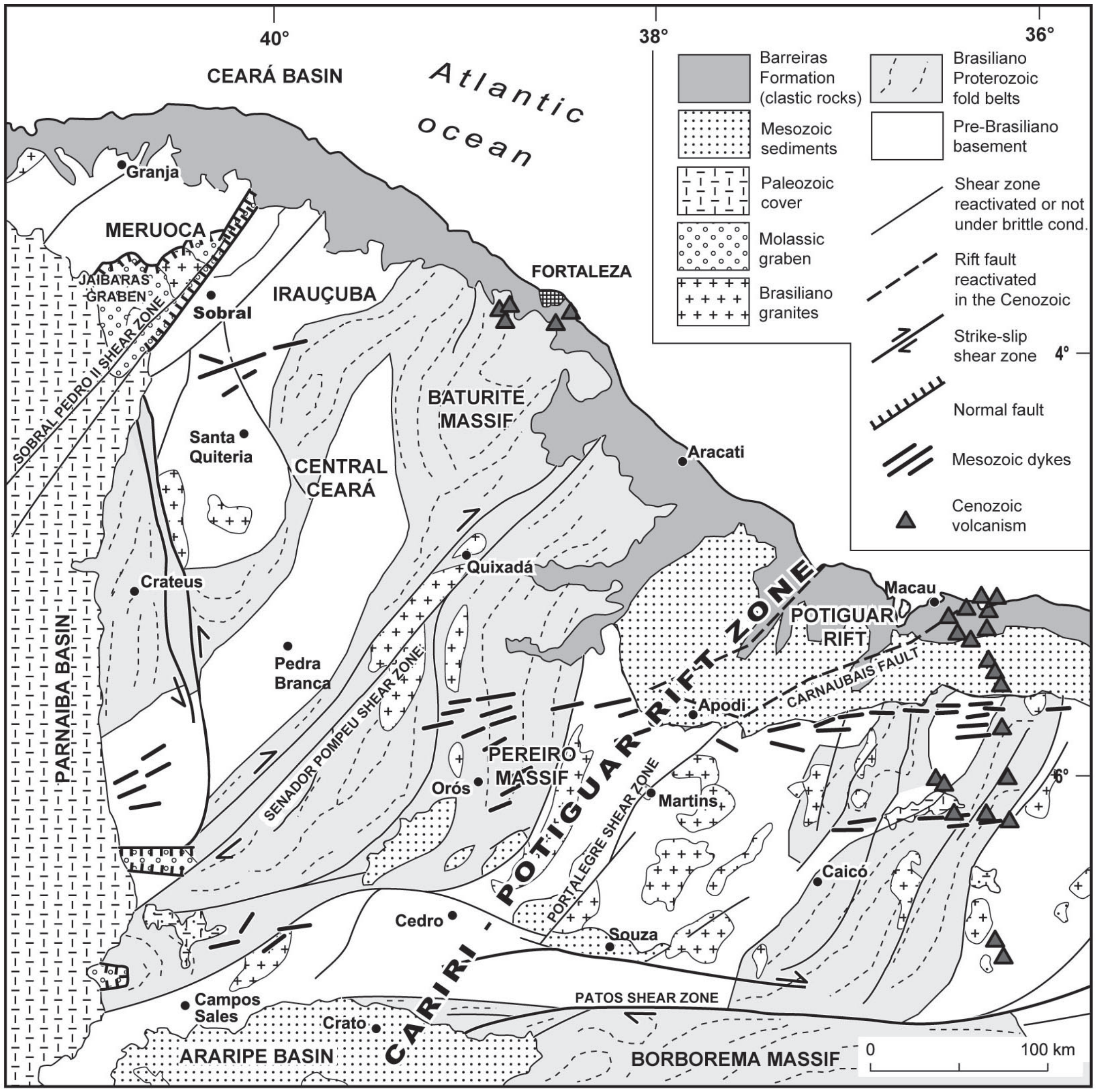



Figure 2. Sketch geological map of the study area. Compiled from Brito Neves *et al.* (2000) [20], Carneiro *et al.*, (1989) [50], and Caby *et al.* (1995) [19].

stages may be very old and may correlate with different stress regimes. Other drawbacks are linked to the intervention of erosion phenomena, reduction of slope or planation, scarp retreat, or differential erosion, which may result in landforms whose location and geometry do not reflect those of the faults (residual fault scarps, fault line scarps [13]).

Continued deformation (faulting, epeirogenic warping, tilting) over periods of millions of years is likely to have a profound effect on drainage systems, so that the study of drainage patterns may also be useful [11] [15].

## 3. Morphotectonic context of the study area

### *3.1. Morphostructural setting*

The study area belongs to the northern part of the Brazilian north-east (*Nordeste*), between 3°15' and 7°30' S and between 37° and 41°W (560 x 520 km) (Fig. 1). This eastern segment of the Brazilian Equatorial margin is a transform passive margin [4]. The western and southern limits coincide with high plateaus, Serra da Ibiapaba and Chapada do Araripe (*ca* 1,000 m), respectively. To the southeast and east, the Borborema massif (1,200 m) separates it from the lower São Francisco valley and from the plateaus and lowlands of the east coast.

This set of plateaus and highlands, characterized by modest and regular summit altitudes (1,000-1,100 m) overlooks wide coastal and inland plains. Two discontinuous and offset EW alignments of mountain slopes and plateau edges form a highly dissected marginal scarp along the northern oceanic front. They lie roughly parallel to corresponding segments of the continental margin (Fortaleza – Parnaiba, Aracati – Macau) intersecting inland systems of highlands and plains (Fig. 1). The inland area *(sertão)* is arranged in two concentric half-rings of highlands around the lower Jaguaribe plain (Jaguaribe-Piranhas hemicycle). This plain coincides with the scarp offset area. It opens onto the Aracati Platform, the Potiguar Basin, and a SE-trending segment of the continental margin (Fortaleza -Potiguar).

The Brazilian Equatorial continental margin was formed after the Equatorial Atlantic opening in Aptian times [4]. Onshore, a Precambrian basement area, the Borborema structural province [19] [20], is subdivided into several domains by large Late Proterozoic shear zones (Fig. 2). The structural pattern is organized around the 500 km-long intracratonic Cariri-Potiguar rift zone, a discontinuous NE-SW set of basins and half grabens. These Mesozoic rift structures, overlain by remains of post-rift sedimentary covers (Araripe and Potiguar basins), are intersected in the Potiguar Basin area by the transform margin [21]. Remnants of a pre-rift cover are preserved either outside these structures (Parnaíba Basin, to the west) or along the rift zone (Araripe Basin in southern Ceará). A thin, dissected layer of Cenozoic clastic sedimentary rocks (Barreiras Formation) is preserved on a coastal strip, forming the low-lying tablelands (*tabuleiros*) between the marginal scarp and the shallow continental shelf. Only a few elements of the morphology – such as fault scarps and deformed structural surfaces - directly reflect the tectonic structure [22].

The present relief is a juxtaposition of landforms of various ages. Many features are inherited from the most significant events of the tectonic history: (1) Neocomian intracontinental rifting, followed in the Albian by (2) post-rift subsidence of rift structures and oceanic opening, and finally (3) formation of the transform passive margin, with differentiated tectonic evolution of compartments inherited from rifting patterns. In spite of significant differential erosion along various weakness zones, the regional hemicycle pattern widely reflects the effects of these tectonic events. The marginal scarp is made of two types of rift shoulders, respectively related to (1) continental rifting, south of the Potiguar basin, and (2) transtensional opening of basins before the formation of the Equatorial Atlantic ocean, from Fortaleza westward [4]. Their subsequent evolution is related to almost continuous subsidence and deposition in the offshore Potiguar basin and to the complex evolution of the Ceará basin, characterized by weak and discontinuous Tertiary sedimentation. In both cases, the scarp is mainly inherited from Cretaceous tectonics and uplift, even if local backwearing probably occurred later [22].

### *3.2. Landforms and tectonic heritage*

There are two main stepped sets of planation surfaces in the regional relief. The highest level is composed of dissected surfaces at slightly different altitudes (700-800 m). The lowest level represents the Sertaneja surface (0-300 m), which is made of interior depressions and corridors all merging seaward in a wide coastal piedmont plain partly buried by Late Cenozoic sediments and then slightly dissected. This pattern suggests a simple but spatially differentiated evolution [22]. However, as shown by the gently and uniform seaward-sloping profile of the Sertaneja surface, the corresponding planation processes were generally sufficient to balance the effects of the monoclinal uplift throughout the study area, despite the preservation of numerous remnants of the uplifted volumes.

The main tectonic controls on large-scale landforms are found in patterns created during the post-rift and oceanic opening stages rather than in continental rift structures, which control smaller units (rift shoulders, basins, horsts, fault scarps) [23]. At the centre of the Jaguaribe-Piranhas hemicycle (Fig. 1), the offset zone between the two contrasting parts of the marginal escarpment coincides with the post-rift Potiguar synform. Intersected by the transform zone of oceanic opening, this structure is both the result of thermal post-rift detumescence of the Potiguar rift and of the subsidence of the passive margin [4] [24]. This area (Jaguaribe-Potiguar compartment: Fig. 1) later underwent a wide and gentle flexural movement that allowed the preservation of paleosurfaces of Cretaceous age in the hinge line, at the foot of residual fault scarps [22]. The outlines of this compartment geographically fit with those of the crustal thinning zone detected by Castro *et al.* [25] and defined as coinciding with the Potiguar basin (Fig. 1). The SSW-trending axis of this thinning zone corresponds to an ESE-WNW extension, that of the Neocomian-Barremian continental rifting.

The opposite compartment (Baturité-Irauçuba compartment) presents higher summits next to the coast. A comparison with the preservation of Cretaceous paleoescarpments south of the Potiguar basin may suggest that this contrast (materialized by the eastern escarpment of the Central Ceará mountains; Fig. 1) is also a direct heritage of higher pre-breakup altitudes or differentiated shoulder uplift during the breakup process [26]. However, stronger uplift might also occur in later times, related to steeper flexural deformation of the margin west of Fortaleza. Such a contrast may be related to difference in the elastic thickness of the lithosphere [27] and to a greater proximity of the oceanic opening zone. Decoupling between both compartments is suspected to have occurred along the Senador Pompeu fault zone (Fig. 2).

## 4. Available data

### *4.1. Seismo-tectonic activity and neotectonics: evidence and uncertainties*

The seismic activity in the study area has been investigated with the help of instrumental, historical, and paleoseismic data. A significant instrumental seismicity has been known in the study area since the 1960s and occurs within the first 1-12 km of the upper crust [28]. The heightened seismicity is characterized by moderate intensities (observed maximum: VII MM) and magnitudes mostly $\leq 5.0$. It is mainly concentrated in a few areas of the coastal strip, specifically the Potiguar basin, its southern border and the Aracati platform (Cascavel-Pacajus area), and in the Fortaleza-Baturité area, close to the Senador Pompeu shear zone and related faults. A few earthquakes also occurred in the Sobral-Irauçuba area [6][28] (Fig. 3). Other earthquakes of low magnitude ($m_b$<5.2) are recorded in slightly inner regions, with epicenters located close to Precambrian shear zones (Jaguaribe and Portalegre fault zones) reactivated in the Cretaceous and later (Figs. 1 and 3).

The historical seismicity is known since 1808, when an earthquake of estimated magnitude $m_b$ = 4.0 and intensity

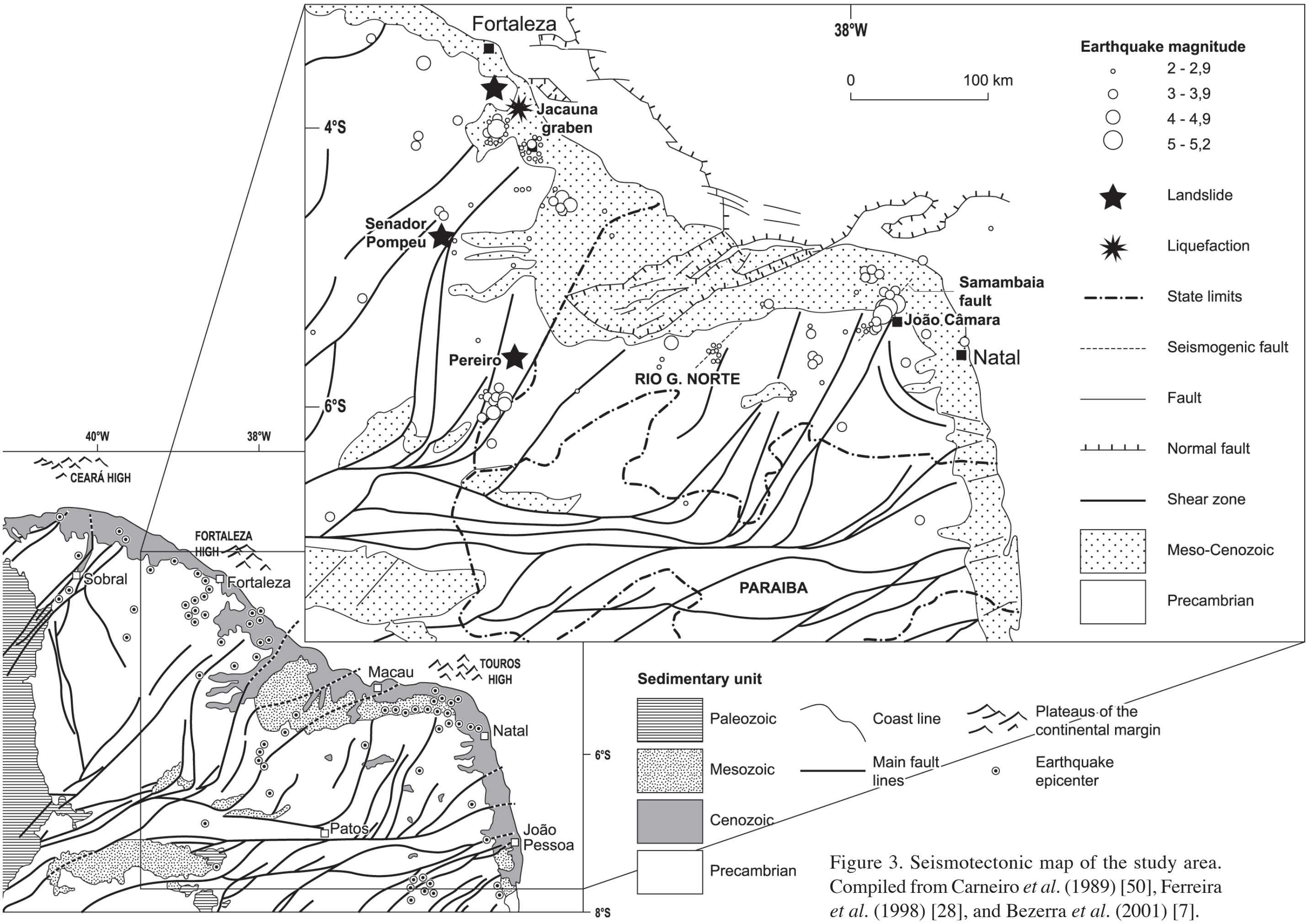



Figure 3. Seismotectonic map of the study area. Compiled from Carneiro *et al*. (1989) [50], Ferreira *et al*. (1998) [28], and Bezerra *et al*. (2001) [7].

MM>VI occurred near Açu (Fig. 1). No coseismic surface rupture has hitherto been reported in northern Brazil [29], even by the most violent earthquake ever recorded in NE Brazil (Pacajus, November 20, 1980, 5.2 $m_b$) [28] or by the João Camara earthquake swarm in the period 1986-89, in which an individual event reached 5.1 $m_b$ [30].

Only a few phenomena of soil collapse and boulder falls from steep slopes were observed. The first soil collapse occurred after the Aracaticum earthquake swarm in March and April 1979, and the others occurred during the Pereiro earthquake of January 2, 1968, and the Senador Pompeu earthquake of February 23, 1968. This seismicity merely shows poor correlation with mapped faults [28].

Paleoseismic investigations have been increasingly common in the study area. In coastal areas, limited data on slip rates along active faults were obtained from measurements on late Cenozoic, mainly Holocene, deposits. Along the Carnaubais fault (Figs. 2 and 3), the base of the Pliocene sequence is down-faulted by about 60 m southwest of São Bento [2], suggesting that the minimum average slip rate might be 0.01 mm.$y^{-1}$. Seismic-induced liquefaction features have been found in the study area. They include dikes, pillars, and pockets, which occur in once-water-saturated Quaternary alluvial gravels in the Açu and Jaguaribe River valleys [31]. These features are evidence of earthquakes of 5.5 $M_L$ and 5.6 $M_S$ or greater, which would have occurred on the region as recently as 4,860-4,570 yr B.P. [7]. They are also visible in cliffs and shore platforms of the east coast of Ceará (Fig. 4), especially in those of the Ponta-Grossa-Peroba area (Icapui), where they have been interpreted as neotectonic since the deformed sediments are considered as belonging to the Barreiras Formation (Fig. 5). The liquefaction structures represent secondary features associated with the reactivation of strike slip fault zones [31].

### *4.2. Stress*

Analysis of focal mechanism indicates EW- to NW-SE-oriented maximum compression, parallel to the coastline, and NS to NE-SW-oriented extension [28]. Since the Pliocene, these orientations roughly correspond to the direction of movement of the South American plate, which meets strong resistance on its western border (Andes), and to the flexural movement located in the coastal area [28] [29]. In the study area, this activity is in keeping with several tectonic pulses that have caused the development of strike-slip and normal faulting in coastal areas since the Cretaceous.

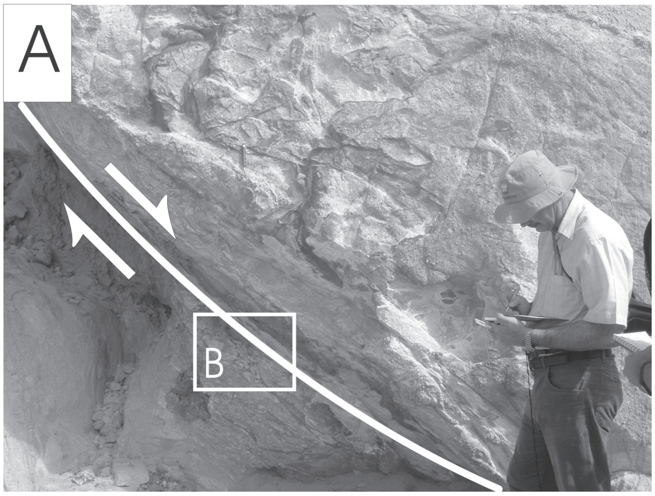




Figure 4. Syn-sedimentary fault at a seacliff on the east coast of Ceará (Icapui, Redonda; see Fig. 1 for location): (A) normal fault affecting post-Turonian fluvial sandstone; (B) detail of (A). Note that the footwall present soft-sediment deformation related to faulting.

### 4.3. Fault scarps along the coast

Active faults are suspected to control a well-developed horst and graben morphology and the drainage, alluvial, and coastal patterns in eastern Rio Grande do Norte between Natal and João Pessoa [7]. However, the only scarp related to an active fault in the study area was recognized on the coast of the Potiguar basin near São Bento (Fig. 3). It forms cliffs up to 7 m high southeast of the Carnaubais fault, in a marine bioclastic grainstone that interfingers with the Barreiras Formation. The base of this sequence is downfaulted by about 60 m southwest of São Bento [2]. Other indications of possible neotectonic movements were obtained from the analysis of the geometry of Tertiary and Quaternary fluvial and marine depocenters in the Açu River delta near Macau (Fig. 3), where NW- and NE-trending normal fault movements cut across marine and fluvial sediments dated to 30,190+/- 370 yr BP with offsets of 30 m [32]. Neotectonic movements are also inferred from the identification in the Barreiras Formation sedimentary rocks of small normal faults trending N40° - 60° and from clastic dikes NW of the Potiguar basin (Fazenda Retirinho) [33] and in NW Ceará (Camocim) [6].

In most cases, active faults recognized in the study area do not present topographic expression, which should be implied in small throws and/or erosion rates higher than tectonic rates. Moreover, they mostly occur along the coast, in sediments of the Barreiras Formation and alluvial deposits whose weak resistance to erosion is not favorable to preservation of tectonic landforms. The study area lacks equivalents of the grabens of the eastern coast (Rio Grande do Norte and Paraíba), along which river erosion has allowed a moderate topographic expression of the most outstanding faults [7]. However, linear (fluvial) erosion along some fault structures of the Macau region, mainly during the Pleistocene periods of low sea levels, may have exaggerated the depth of the downfaulted compartments and contributed to controlling further sedimentation (Fig. 6). Last, the main reason for the absence of recognized neotectonic landforms probably lies in the focal mechanisms in northeastern Brazil, indicating that the current faulting regime is strike slip [2]. This does not favor high scarps or significant relief expression of neotectonic movements.

### 4.4. Lack of reliable data on neotectonics inland

No similar observations are reported inland, where only indirect geomorphic arguments may provide evidence of tectonic activity, as most studies have focused on the Potiguar basin and its southern border. The presence of remnants of relatively thick covers of Cenozoic sediments in the Potiguar basin, where they cap late Cretaceous rocks in the graben area (Fig. 2), probably reflects the role of Cenozoic deformations (subsidence), superimposed on the general flexure.

To the south of the Potiguar basin, recent uplift was postulated to explain how the fluvial sediments at Martins (Fig.2) may cap high mesas 600-700 m above the low-lying Lajes depression and Chapada do Apodi (Fig. 7) [8]. By analyzing drainage orientations around the Serra de Santana, Menezes *et al*. [34] and Barros *et al*. [35] looked for evidence of recent deformations in and around this plateau. Few drainage anomalies were found, suggesting that this mesa belongs to a wider tectonic compartment in which no neotectonic activity is reported, except for a few fractures of NE, NW, and NS trends. Indeed, according to some authors, this altitude might result from uplift and slight southward tilting along the so-called Lajes lineament at the southern border of the Potiguar basin (Fig. 2) [35]. Such a structure would reflect regional flexure caused by sedimentary overload on the continental margin [8]. Drainage orientations and possible anomalies were also studied with the purpose of detecting neotectonic activity in SE Ceará and W Paraiba, around Chapada do Araripe, without any significant result [36].

## 5. Results of the morphotectonic study

### 5.1. Scarps and seismic areas

#### 5.1.1. Distribution

Major neotectonic faults do not show significant topographic expression in the study area. Many of the scarps produced by neotectonic faults in the Potiguar basin are too small, less than 5 m high, to be identified on regional topographic maps. Along the coast, several fault-bounded valleys are characterized by topographic breaks 20-40 m high between Cretaceous or late Tertiary rocks and Quaternary sediments (Fig. 6).

These fault scarps are faint and degraded and have been attacked by weathering and erosional processes. Colluvium has accumulated, and debris slopes have grown due to fault scarp retreat. Free faces are uncommon or absent because most fault scarps are capped by debris, vegetation, and soil, indicating that most have not been active recently, despite their late Tertiary to Quaternary age.

We present below the best example of seismogenic faulting in Brazil [30], the Samambaia fault, and its related topographic features. No topographic contrast occurs along this fault (Fig. 8).

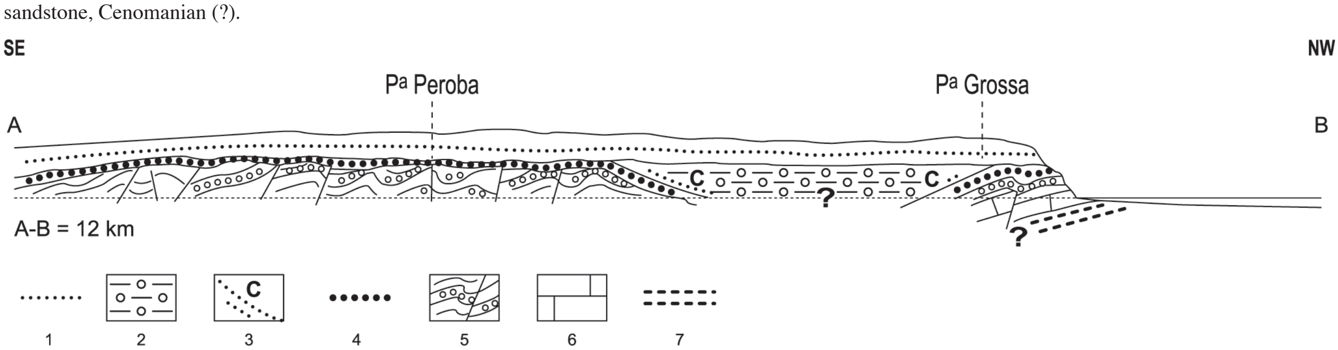
Marks of seismic activity are also recognized along the NE continuation of the Portalegre shear zone, called Carnaubais fault zone in the Potiguar basin (Fig. 2). The Carnaubais fault zone deforms both the Açu and Jandaira formations [37] and seems to have been reactivated from the late Tertiary to the Quaternary, since it has controlled the sedimentation during this period. Along the coast, east of Macau, it forms the boundary between the Barreiras Formation and Quaternary coastal sediments composed mainly of sand dunes and tidal flats. Inland, the lithological boundary between the Jandaira and the Barreiras formations to the SW of São Bento is roughly parallel to the Carnaubais fault. Coseismic uplift is reported to have occurred to the east of the fault, where rapid emergence of at least 4 m occurred ca. 4,080-2,790 cal. yr BP [2]. However, the topographic contrast between these lithological units is only about 5 m in the former site, and about 15 m in the latter (Fig. 9).

The NW-trending Afonso Bezerra and Queimado Lake faults control Quaternary sedimentation and drainage patterns in the central part of the Potiguar Basin (Fig. 6). The Afonso Bezerra fault has controlled the Gangora River and Vargem de Cima Lake. The Queimado Lake fault influences the shapes

Figure 5. Deformed post-Turonian sediments and unconformable deposits (allochtonous laterite, paleodunes) at Ponta Peroba (Icapui).

A. Folds beveled and sealed by an allochtonous laterite and by paleodune sands.

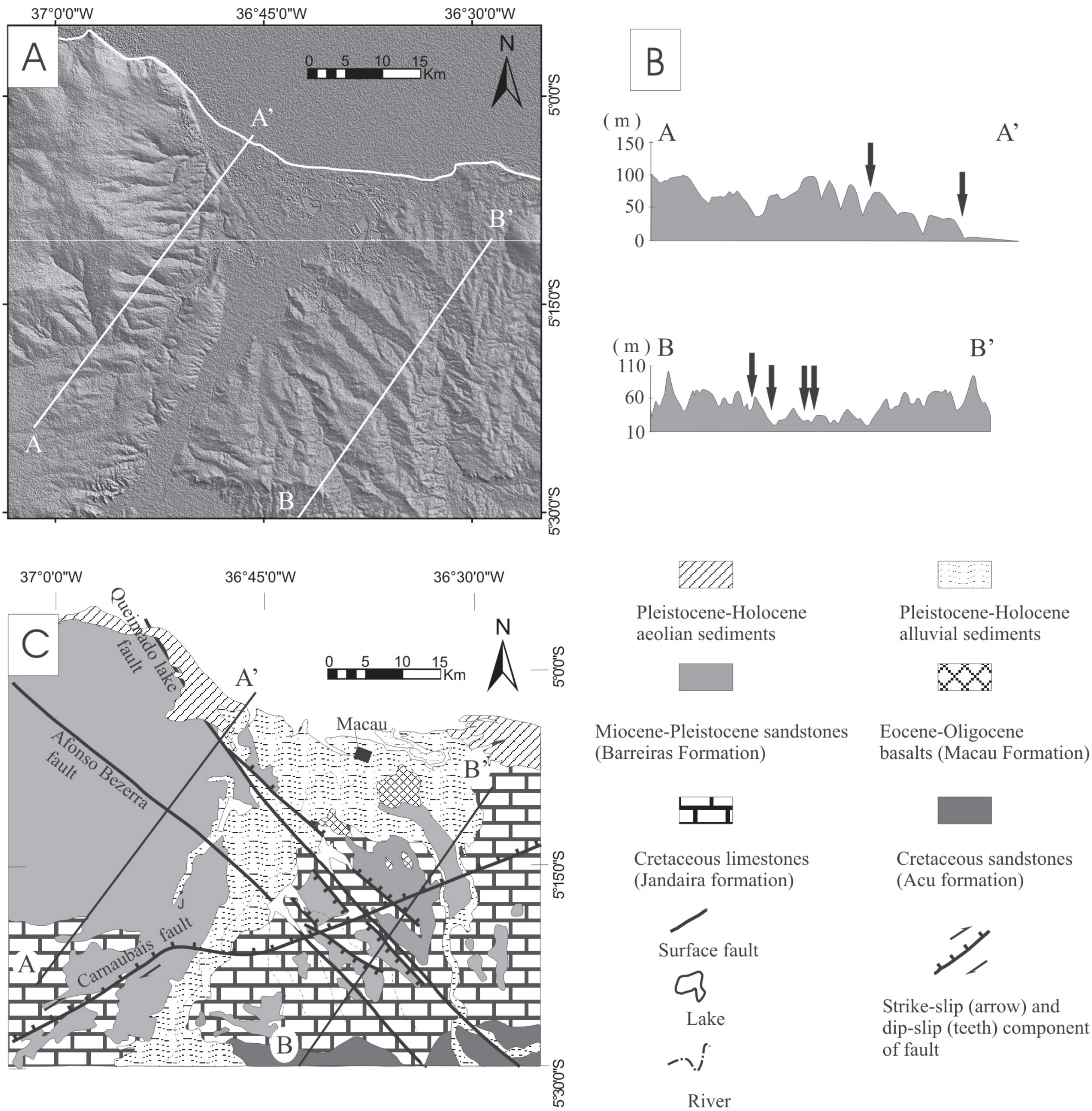
B. Sketch profile, out of scale (approximate height: 20-30 m), after Peulvast and Claudino Sales (2004) [22]. 1: Palaeodunes; 2: horizontal layers of reddish argillaceous sand (Barreiras sediments of possible fluvial origin); 3: slope deposits on the flanks of the Redonda buried depression (palaeovalley ?); 4: allochtonous laterite; 5: strongly deformed (faulted and folded) and lateritized sandstones and conglomerates; 6: Jandaira limestone (Turonian-Campanian); 7: Açu sandstone, Cenomanian (?).



of Queimado Lake, Cavalos River and Conchas River, and forms much of the boundary between the Barreiras Formation and Quaternary coastal sediments. Kinematic indicators obtained along straight faults recognized across more than 100 km in the central part of the Potiguar basin indicate an important strike-slip component of movement. These faults were reactivated in the Cenozoic, producing 30-35 m high degraded fault scarps. On the contrary, no similar topographic expression is known along the EW- and NNW -trending faults, which were the locus of seismic activity since 1980 on the western border of the Potiguar basin (Fig. 3) [28].

Inland, most faults along or near which recent seismotectonic activity is recorded control important features of the regional relief, at least locally. Many of these features are oblique or perpendicular to the coastline. They correspond to Precambrian shear zones already reactivated during the Cretaceous rifting: Sobral-Pedro II, Senador Pompeu, Jaguaribe, and Portalegre shear zones (Fig. 2). Some of these shear zones (Sobral-Pedro II and Senador Pompeu) have played major roles in decoupling between crustal compartments of the passive margin that have undergone different post-breakup tectonic evolutions [21] [25].

Figure 6. Topographic and geologic signatures of strike-slip faults in the central part of the Potiguar basin: (A) SRTM topography illuminated from NE; (B) topographic cross-sections; arrows indicate trace of faults on surface; (C) simplified geologic map.



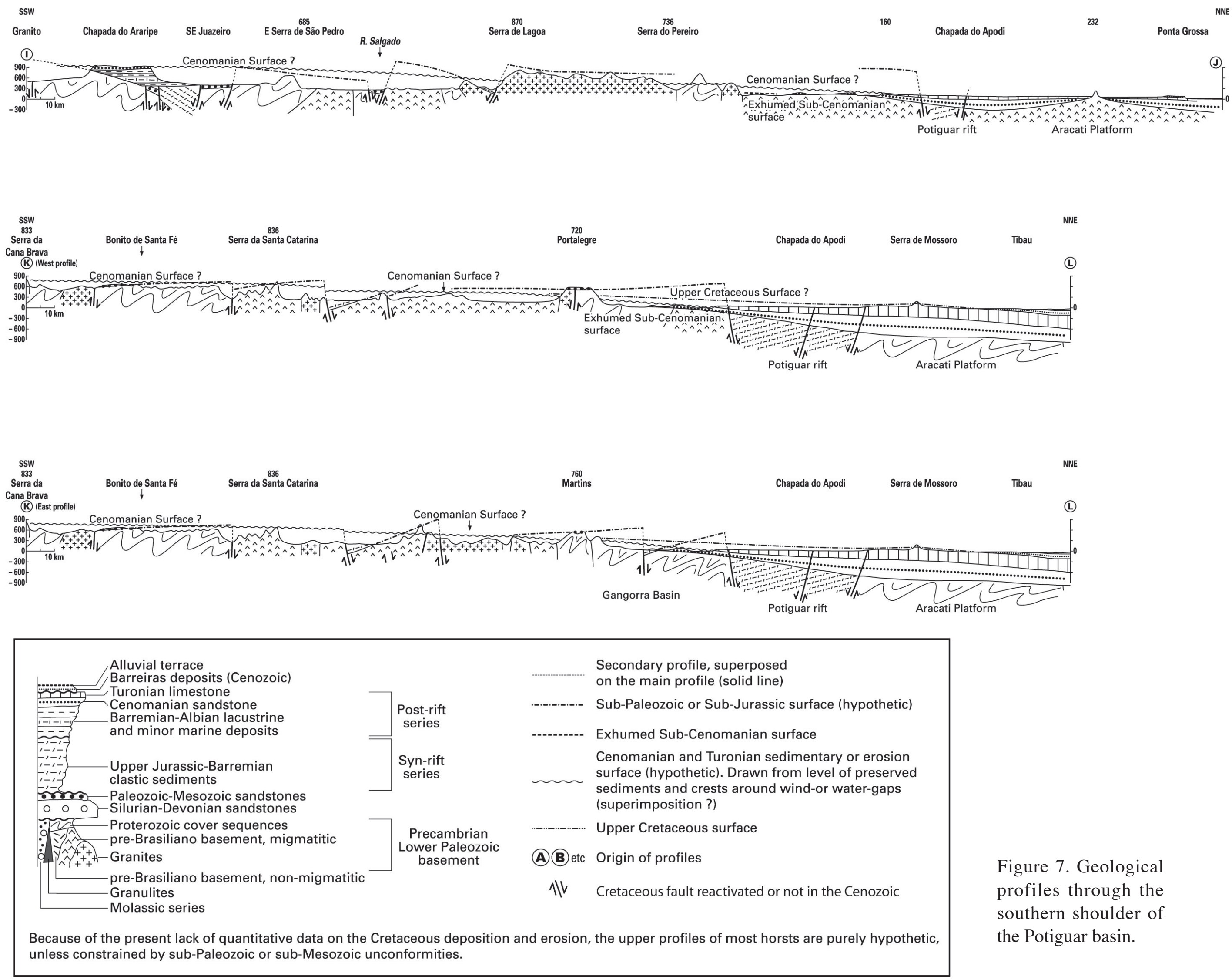



Figure 7. Geological profiles through the southern shoulder of the Potiguar basin.

According to the distribution of seismic zones, the main scarps and other landforms whose existence or shapes might be partly or completely explained by neotectonics are the following (Fig. 1):

• the discontinuous basement scarp, topped by sandstone tables, that forms the northern edge of the aligned spurs and buttes of Pereiro, Portalegre, Martins, João do Vale, and Santana. It overlooks the Chapada do Apodi (i.e., the low surface that bevels the limestones lying at the top of the Cretaceous layers of the Potiguar basin), beyond the wide Apodi-Lages depression under which lies the exhumed basement.

• the eastern edge of the Baturité and Aratanha massifs, south of Fortaleza, the highest scarp in the study area and the most enigmatic because of the lack of control by known nearby faults or lithological contacts.

• the western edge of the granitic Pereiro massif, a 120 km long, 400-500 m high, straight and continuous scarp overlooking the slightly dissected floor of the low Jaguaribe depression (Fig. 1).

• the SE scarp of the Meruoca granitic massif above the Acarau River corridor, hollowed along the Sobral-Pedro II shear zone, in NW Ceará (Fig. 1).

The first of these landforms is the only part of the discontinuous marginal escarpment where an intervention of neotectonics has been proposed [35] [8]. No lithological feature explains its position [23]. The same problem arises for parts of the eastern scarp of the Baturité-Aratanha massif. On the contrary, in the last two examples, the coincidence with intrusive contacts suggests a contribution of differential erosion associated to the preservation of residual mountains above the low planation surface. But this should be addressed by further investigation.

### *5.1.2. The marginal escarpment to the south of the Potiguar basin*

The eastern part of the marginal escarpment is a fault scarp that has retreated from the Carnaubais fault and from the Apodi transfer fault, mainly before the deposition of the unconformable Açu sandstones or in relation to it, as shown by the preservation of sandstone outliers at the foot of the northern spurs of the Pereiro massif (Figs. 2 and 7). The pre-Cenomanian planation of the rift structures strongly suggest the

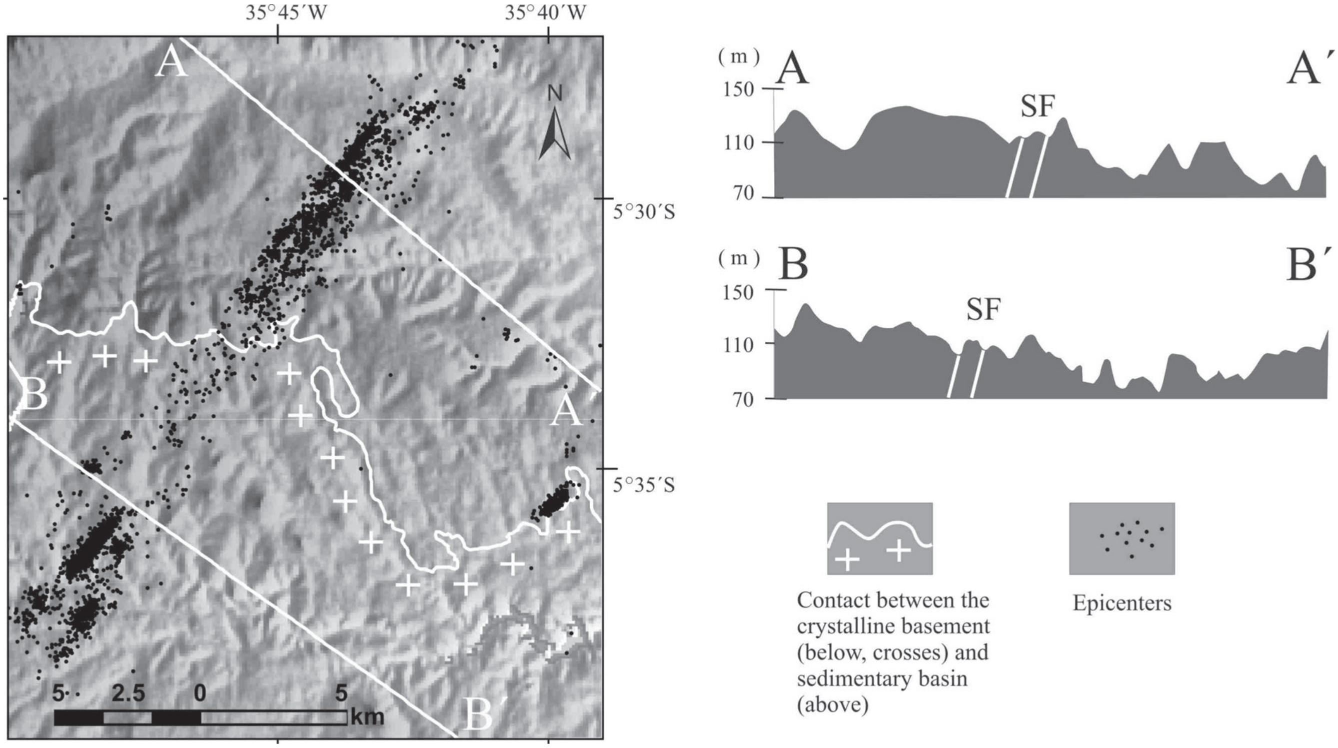



Figure 8. The Samambaia fault and related topography derived from SRTM digital model. Note in cross-sections A-A´ and B-B´ that crustal blocks across the fault do not show significant topographic changes. Epicenters from Takeya *et al*. [48].

old age and the erosional origin of these escarpments. These age and origin are also indicated by the fact that rift structures are mostly buried below the unconformable post-rift series – followed, however, in the Potiguar basin by reactivations of the Carnaubais fault zone until at least the Tertiary [37]– and by the lack of any important parallel fault or flexure zone between these rift structures and the northernmost edge of the Borborema uplands (Portalegre, Martins, João do Vale, and Santana plateaus). We consider these escarpments as residual fault scarps that retreated ~ 30-50 km from the master faults (Fig. 10). Moreover, the historic seismic activity is concentrated around fault zones that obliquely intersect the so-called Lajes lineament, mainly the Portalegre shear zone [2], and other fault zones located to the east (Fig. 3). Although important at regional scale and in spite of the Cretaceous reactivation of at least one of them (Portalegre shear zone) [38], these faults do not control important morphological features at the scarp or below, except for the water gap through which the Piranhas River crosses the EW alignment of buttes (Fig. 11).

*5.1.3. The Pereiro scarp and the Jaguaribe fault zone*

The most conspicuous escarpment related to one of the reactivated fault zones is the western edge of the Pereiro granitic massif, which in turn is related to the ENE-trending Jaguaribe shear zone across more than 100 km (Figs. 2 and 12). Except for a wide embayment in the south, its southern half is a straight or en echelon granitic wall, dissected by only a few short and steep valleys that contrast with the shallow depressions of the plateau overlooking the Icó half-graben, 2-5 km east of its master fault line (Fig. 13).

Macroseismic data indicate that the seismic activity is concentrated in the west part of the granitic massif [39]. It may be related to fault segments in the plateau area to the NE of Icó, where the escarpment splits into minor crests on both sides of the fault zone (Figs. 3 and 13). Here, and to the north, it appears as a residual fault scarp controlled by the intrusive contact parallel to the fault zone, but having undergone some erosional retreat in relation to the development of a narrow strip (1-5 km) of rugged pediments and alluvial fans. The presence of residual basement hills and crests on the hanging wall also suggests that exhumation and downwearing of the metamorphic rocks of this compartment may also have contributed to the scarp formation. Similarities of differential erosion features (fault line valleys and scarps, hogbacks) with tectonic features prevented any identification of recent fault scarps.

Such a situation probably also occurred to the north, where the escarpment and the extremity of the Pereiro massif are subdivided into parallel gneissic and granitic ridges or elongated domes between branches of the shear zone, with sharp knicks or short concavities at the contact with the surrounding Sertaneja surface. The tectonic controls are more complex than in the south, on both sides of this narrow-range extremity, between the Jaguaribe and Apodi depressions (Fig.1) [23]. The digitated outlines of the Pereiro massif are assumed to be those of a residual horst or half-horst system. Its present topographic rims would correspond to the outer contacts of resistant granitic intrusions, 5-40 km from the nearest master faults, one or several branches of the Orós-Jaguaribe fault system to the west, and the buried Apodi transfer fault to the NE, respectively (Figs. 7 and 13).

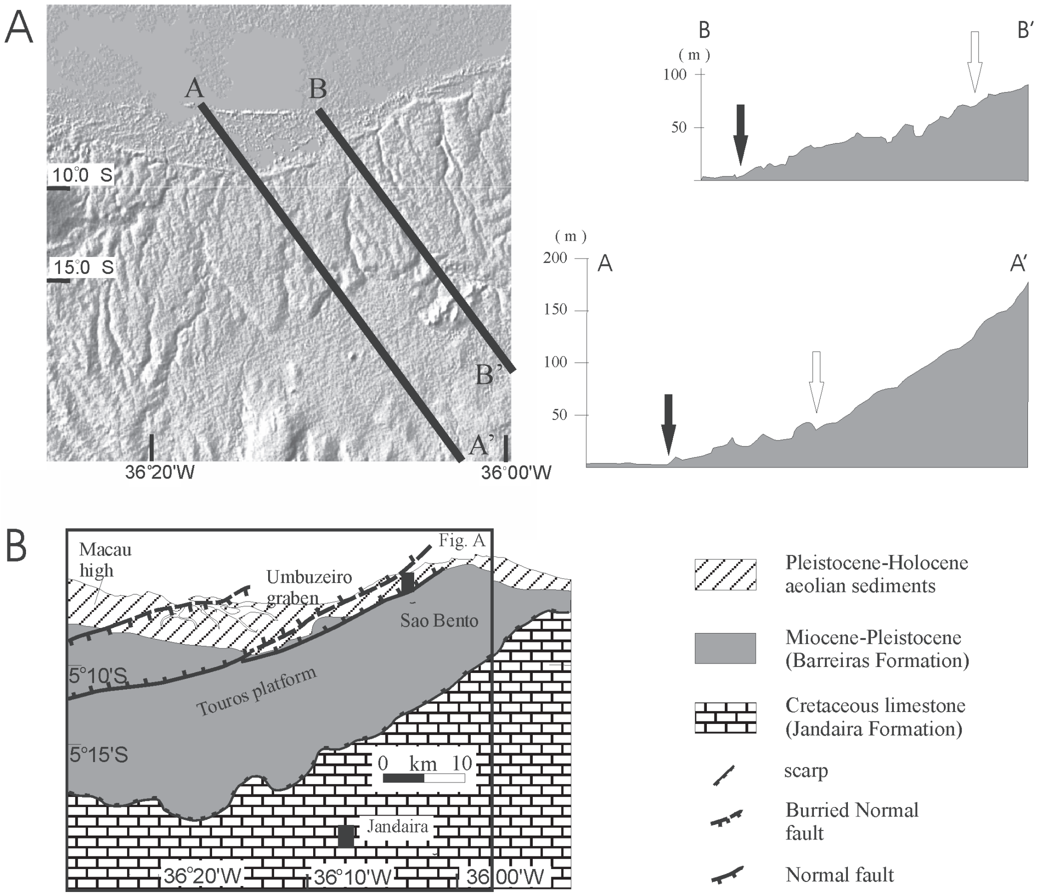



Figure 9. Relationship between morphology and fault scarps: (A) SRTM topography of the São Bento area and topographic cross sections. Black arrow indicates fault-scarp boundary between Quaternary and Miocene-Pleistocene sediments; white arrow indicate erosional scarp between Cretaceous rocks and Miocene-Pleistocene sediments; (B) Simplified geological map of study area, including fault and erosional scarps. In both cases, the topographic contract is less than 15 m.

### *5.1.4. The Baturité-Aratanha scarp and the Senador Pompeu shear zone*

From Quixadá to the coastal area, structural controls on the outlines of the eastern escarpment of the central Ceará highlands are much less clear. This occurs especially on the eastern side of the lithologically complex Baturité massif, which turns NNE, reaching the southern outskirts of Fortaleza (Fig. 1). Although this mountain resembles an uplifted block slightly tilted eastward, no fault scarp is clearly identified along its borders. To the east, more than 50 km northwest of the Senador Pompeu shear zone, no fault line is mapped or even visible on radar images [40]. Nor is one found between this shear zone and the sinuous escarpment that overlooks the Sertaneja pediplain (even along the shallow parallel valley of the Choró River), or along the foot of the escarpment (Fig. 14).

The Baturité massif *sensu stricto*, in the south, is mostly shaped into supracrustal rocks of the Independência and Canindé Formations of the Ceará Complex [40]. From Capistrano to Redenção, several features suggest the erosive origin of the eastern border of the Baturité massif: (1) the irregular and sinuous outlines of this 500-600 m high escarpment, including short and steep valleys opening on five large embayments; (2) the presence of a long NE-trending promontory; (3) the local lithological controls on the shapes and position of the hillslopes (abrupt flanks of domes shaped into massive gneissic layers, marble and dolomite crests and pinnacles, quartzitic hogbacks); and (4) the presence of several high inselbergs in front of it (Pedra Aguda, Fig. 14).

Although large parts of the Baturité massif are underlain by the same metamorphic rocks (Canindé Formation) that form the surrounding pediplains, most peaks, culminating ridges, and outstanding escarpments are shaped into the folded quartzite layers of the Independência Formation, which form the skeletal structure of the massif (Fig. 14). Therefore, the outlines may be considered as erosional. However, the absence of residual reliefs on the opposite side of the Senador Pompeu shear zone might suggest that the eastern scarp would have retreated into the uplifted compartment during or after the Cretaceous rifting. To the northeast, both compartments are bevelled by the same surface that disappears below the Cenozoic sediments of the coastal area and that truncates the buried rift structures of the margin (offshore Potiguar rift, Jacaúna, and Messejana grabens: Fig. 3). This would rule out any significant movements in a neotectonic period. In fact, the outer tectonic limits of the eroded compartment may be those of the Aracati platform (Fig. 2). The dissected pediments that form the floor of the embayments and merge with the slightly undulating Sertaneja pediplain to the southeast do not display any topographic break that might indicate significant movements close to the massif.

A more local tectonic control may be suspected north of Redenção, on the eastern side of the Serra da Aratanha. This is one of the northern outliers of the Baturité massif shaped into a thick migmatitic and granitic nappe, which is also partly planated to the southwest of Fortaleza. NW of Pacatuba, its straight outlines and steep rectilinear profile look like those of a high fault scarp [22]. But here again, the escarpment is not located on the lithological contact with the underlying

Figure 10. The north edge of the Serra do Martins, a residual fault escarpement, as seen to the east. Knick, marble buttresses (foreground), inselbergs at the contact with the Sertaneja surface (which derives from the exhumed pre-Cenomanian surface). In the distance, to the ESE: the Serra João do Vale, another remnant of the south shoulder of the Potiguar rift. Located 30-40 km to the north (i.e. to the left) in the Potiguar basin, the master faults are not visible in the area represented here since the pediment only appears over 5-10 km wide in the picture. Photography J.P. Peulvast.

gneisses. It lies 3 km to the west of a N20°-trending fault line that controls the shallow upper Cocó River valley, south of Fortaleza (Fig. 14). In the case where post-Paleozoic tectonic activity might have occurred, this fault, as other minor faults in the vicinity, might belong to an en échelons system connected to the Senador Pompeu shear zone (Figs. 1 and 2).

#### *5.1.5. The Meruoca scarp and the Sobral-Pedro II shear zone*

Significant neotectonic movement may also be suspected in the seismic area of Sobral-Irauçuba. The quadrangular Meruoca plateau (23x28 km and 1,020 m high) directly overlooks the Sertaneja pediplain to the east (Fig. 15). This high granitic massif is strongly dissected by an orthogonal pattern of shallow hanging valleys. It turns straight and abrupt escarpments respectively toward the Jaibaras graben and its clastic, volcanoclastic and volcanic rocks (SE); the scattered monoclinal ridges and inselbergs of the metamorphic Senador Sá uplands (NE); and the digitated embayments of the Sertaneja surface that are shaped into the molassic rocks of the Ubajara basin, to the NW and SW. The bases of all these escarpments coincide with orthogonal fault lines along which the Meruoca granite was intruded in the Late Cambrian or Early Ordovician [41] (Fig. 15).

The highest escarpment (SE wall) coincides with the Sobral-Pedro II dextral shear zone, along which the conglomerates of the basal deposits of the Jaibaras graben are partially verticalized. The granitic massif presents triangular facets that look like those of a fresh fault scarp, especially in its northeast portion (Figs. 1 and 16). This tectonic interpretation is also suggested by the low sinuosity of its outlines and by the presence of a few steep and short valleys between the facets. However, according to Teixeira *et al.* [42], only subhorizontal striae were found on fault planes along contacts of the granite with the sediments. In addition, the downfaulting of Paleozoic sediments along this shear zone near Santana do Acarau appears to be mainly transtensional [43], without indication of generalized post-Paleozoic vertical movements. Here again, no distinction could be established between features of differential erosion, inherited tectonic landforms, and possible results of recent faulting. For example, a small fault line scarp shaped into conglomerates faces the main escarpment for over 2 km, west of Sobral. Both escarpments are separated from each other by a short corridor eroded into a zone of strong cataclasis and hydrothermal alteration along the contact between the Meruoca granite and the Jaibaras graben rocks [42] (Figs. 1 and 16).

The reasons for possible similarities between tectonic and differential erosion landforms are (1) the probability of a prolonged continuity in tectonic regimes, and (2) the intensity of the erosional shaping after exhumation from the Paleozoic cover [26]. All the other escarpments face depressions and high quartzitic residual ridges whose preservation suggests that differential erosion between the granite and the surrounding host rocks of the Ubajara basin is responsible for their formation (Fig. 2). Therefore, these escarpments may be defined as fault line scarps.

Finally, only small-scale features related to neotectonic activity in late Cenozoic deposits have been recognized in this context of passive margin, where tectonic activity remains moderate [2]. At larger scales, only effects of long-lasting movements and long-term evolutions may be accurately measured, on the basis of morphostratigraphic arguments.

### *5.2. Asymmetry of drainage basins: the middle Jaguaribe basin*

The drainage pattern of the study area strongly reflects the Cretaceous tectonic heritage, since the main rivers either follow well-identified Neocomian rift structures or flow toward them from their shoulders, as in Leeder and Gawthorpe's models [44]. For example, it may explain the strong asymmetry of the middle Jaguaribe basin, where the main river trunk, downstream from Orós, receives only a short tributary (Figueiredo River) on its right (eastern) side, whereas on the opposite side it receives long rivers draining the northwest

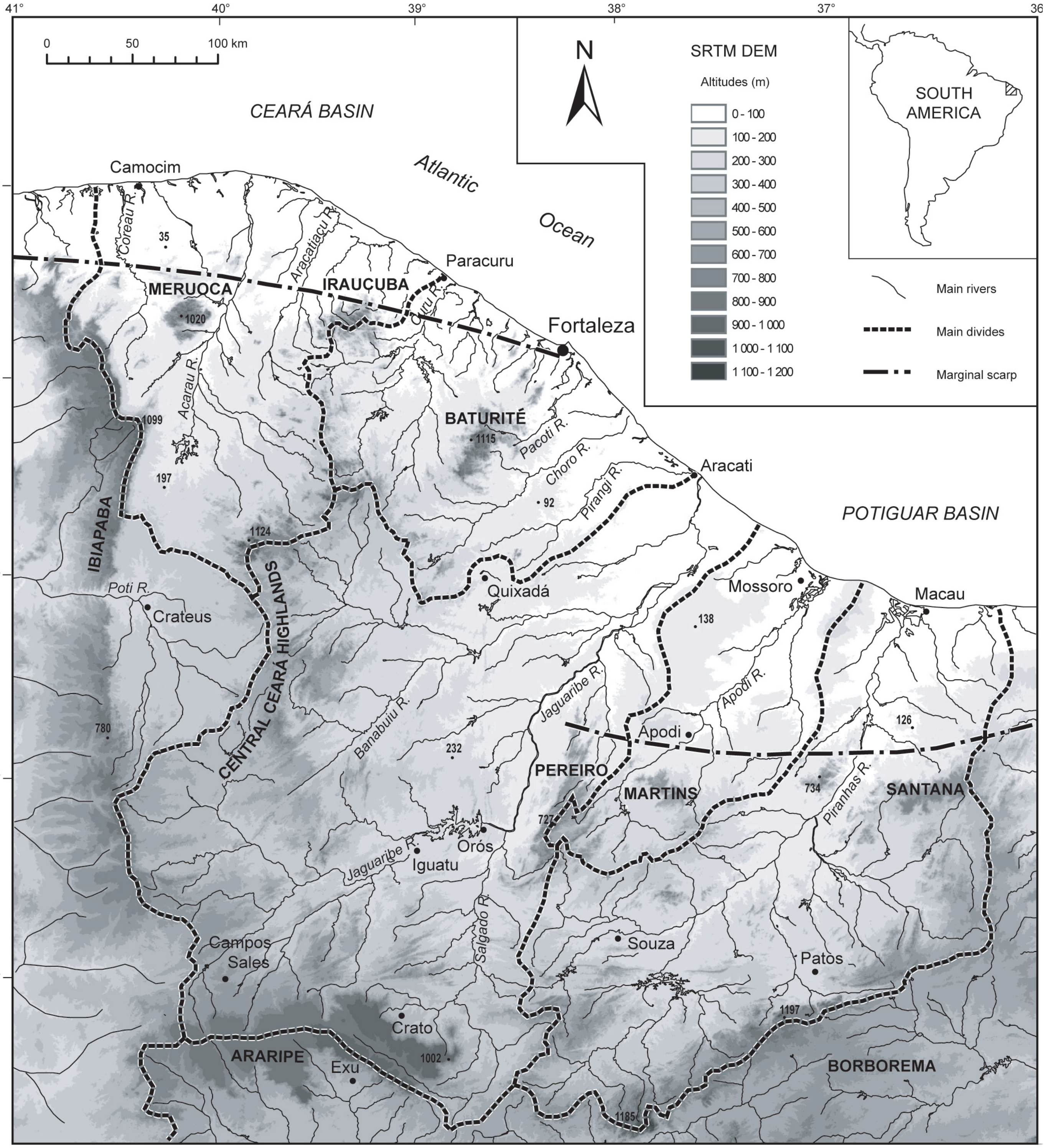



Figure 11. Topography (from the SRTM DEM) and drainage patterns of the study area. Strong asymmetry of the middle Jaguaribe basin, where the main river trunk, downstream of Orós, receives only a short tributary on its right (eastern) side (Rio Figueiredo), whereas on the opposite side it receives long rivers draining the north-west shoulder of the Potiguar rift.

shoulder of the Potiguar rift, reflecting a former hanging/foot wall slope opposition related to the Jaguaribe fault system. Thus, downstream of the confluence with Salgado River, the Asymmetry Factor [45] of the watershed is (27,400 $km^2$:8,130 $km^2$).100 = 337 (Fig. 11).

However, this pattern may also reflect an eastward attraction related to the post-rift and possibly recent subsidence of the Potiguar basin. This is suggested by the trend of the Banabuiú River, which turns east and leaves the shallow corridor excavated along the Senador Pompeu shear zone. It crosses the Orós-Serra

Figure 12. The Pereiro fault scarp, seen to SE from the BR 116 road between Icó and Jaguaribe. Photography J.P. Peulvast. Note the weak sinuosity of the escarpment, which coincides with the outer limit of a syn-orogenic granitic intrusion. Presence of short steep and hanging valleys, with small alluvial fans. Gneissic pediment in the foreground.

do Felix ridge rather than continuing NE toward the Piranji River – this river being the only important one in Ceará that is not fed by sources located in the highlands. A former Banabuiú-Piranji River could have been captured by tributaries of the lower Jaguaribe River, presently the lower Banabuiú and Sitia rivers, more easily deepened owing to its regional dip toward the Potiguar basin and the weak resistance of its sediments.

## 6. Discussion

### *6.1. Poorly characterized neotectonic movements*

Precise stratigraphic indications on the amplitude and rates of tectonic movements were only obtained SE of the Senador Pompeu shear zone and in south Ceará. In spite of their potential interest, observations on neotectonic movements gave more limited results. All of them were obtained in coastal areas, from measurements on Holocene, Pleistocene, and late Cenozoic deposits. Along the Carnaubais fault, the minimum average slip rate might be 0.01 $mm.y^{-1}$. Higher rates may be locally recorded in Pleistocene marine deposits, with fault throws as high as 10-12 m, as shown by the uplift of the youngest Pleistocene marine terrace around Touros (oxygene-isotope substage 5e, 117-110 ka BP) [46], yielding rates up to 0.4 $mm.y^{-1}$. Inland, slip rates are probably much lower. Recurrence intervals of earthquakes responsible for coseismic deformations are not known.

The generally low post-rift deformation rates observed in most cases are comparable with long-term uplift and denudation rates obtained by morphostratigraphic methods in the Jaguaribe-Piranhas hemicycle, at most 10 $mm.ka^{-1}$ in southern Ceará, and much less in the weakly uplifted coastal area of the Jaguaribe-Potiguar compartment [26]. Cenozoic tectonics and magmatism related to the evolution of the adjoining oceanic area have been considered as possible controls in the morphostructural evolution of offshore and onshore domains [8]. The strong increase in the proportion of clastic sedimentation recorded in the offshore Potiguar basin since the Miocene is interpreted as a result of such a Cenozoic uplift [47]. Actually, it does not reflect a strongly increased erosion rate, since the mean thickness of the Late Miocene and younger clastic Barreiras and Tibau sediments (about 150 m at most on a 100 km-wide strip, measured on profiles of the Potiguar basin) would represent at most 50 m of vertical erosion on a 300 km wide inland zone, i.e., a rate <10 $mm.ka^{-1}$, similar to the average rate obtained for the post-Cenomanian times [26]. In such conditions, no accelerated uplift stage is recorded regionally.

Although local movements are possible, no significant escarpment is expected to have been formed by neotectonic activity, unless exaggerated by shore or fluvial erosion in coastal areas [7]. Together with the limited magnitude of this tectonic activity, long recurrence intervals between seismotectonic events probably explain why the morphological expression of faults is often faint or ambiguous in such a context of low slip rates. Moreover, strike-slip components of movement prevail in the whole area [28]. Therefore, the occurrence of expressive tectonic landforms related to neotectonic movements seems unlikely on this passive margin, where possible confusions between these and differential erosion landforms of various ages obscure their identification.

### *6.2. Predominance of paleolandforms and differential erosion features*

Although no clear evidence of recent tectonic movement is identified along outstanding geomorphic features, most faults along or near which recent seismo-tectonic activity

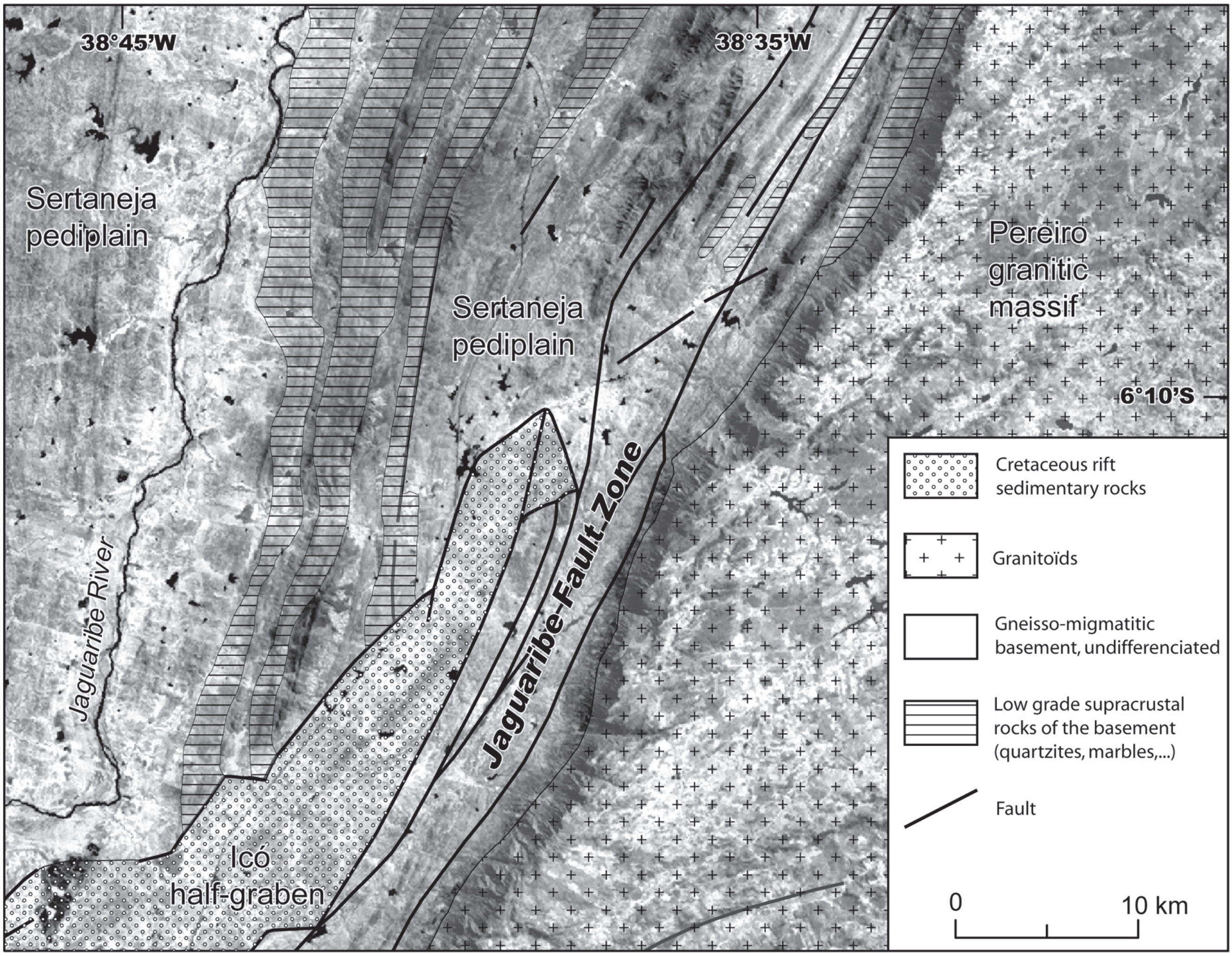



Fig. 13. Geological map [40] superposed on a Landsat picture of the Pereiro fault scarp (location: see Fig. 1). Note the coincidence between the escarpment, a major fault, and the contact between granite and gneiss, that may account for tectonic as well as lithological (differential erosion) origin.

is recorded control at least some important features of the regional relief. Many of them are oblique or perpendicular to the coastline and correspond to Precambrian shear zones reactivated during the Cretaceous rifting: Sobral-Pedro II, Senador Pompeu, Jaguaribe, and Portalegre shear zones (Fig. 2). Some of these (Sobral-Pedro II and Senador Pompeu) are suspected to play major roles in massive decoupling between compartments of the margin that seem to have undergone different post-breakup tectonic evolutions. Marks of seismic activity are also recognized near the offshore Jacauna graben and in the NE continuation of the Portalegre shear zone, along the Carnaubais fault zone in the Potiguar basin. But in these cases, no important escarpment may be related to these structures.

Only a few scarps overlooking the low surfaces are controlled by clearly identified structures. It could not be determined in all cases whether they are residual or even active fault scarps, or fault line scarps formed by differential erosion. Two high and straight scarps are conspicuously controlled by both major fault lines and lithological contacts, along the granitic intrusions of Pereiro and Meruoca (Figs. 13 and 16). In both cases, the presence of strong lithological contrasts with host rocks and the possible role of (1) differential erosion associated with excavation of these rocks, (2) zones of strong cataclasis and hydrothermal alteration along the contacts, or (3) former syn- and post-rift sediments (Pereiro escarpment) makes their interpretation uncertain. The Pereiro escarpment seems to be a fault scarp whose outlines are also approximately controlled by the intrusive contact parallel to the fault zone. However, the presence of residual basement hills on the hanging wall also suggests that exhumation and downwearing of the opposite compartment may have contributed to scarp formation. Even in the SE escarpment of the Meruoca massif, which coincides with one of the faults of the Sobral-Pedro II shear zone and presents several triangular facets that resemble those of a fresh fault scarp, no distinction has been established between features of differential erosion, old tectonic patterns, and possible effects of neotectonic faulting. This lack of distinction occurs because of the probable continuity in tectonic deformation for a long period and of strong erosive shaping.

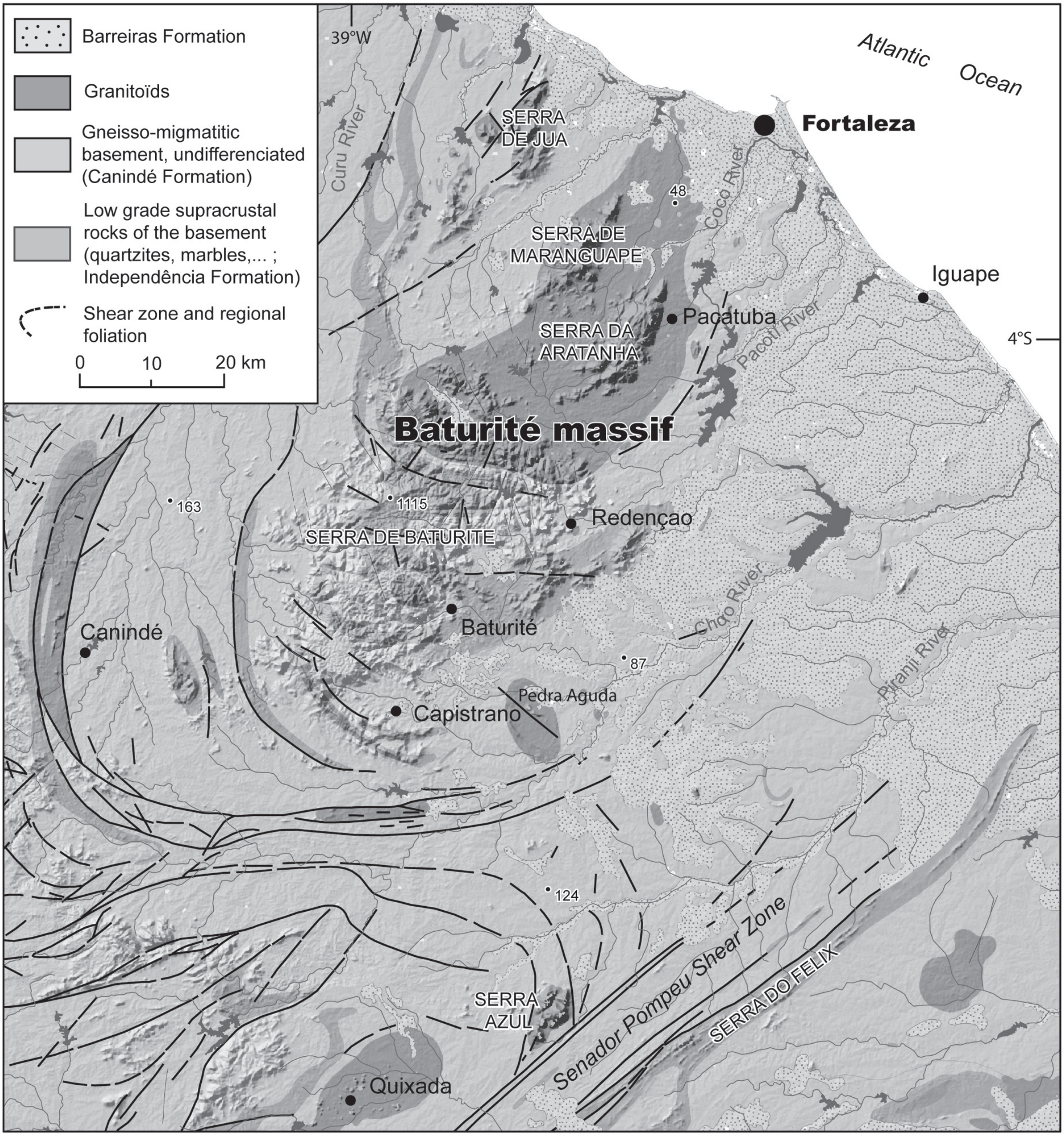



Figure 14. Geological map [40] superposed on the SRTM DEM of the Baturité area (location: see fig. 1). Note the lack of mapped fault zone that might control the outlines of the Baturité massif and its satellites, even the rectilinear eastern scarp of the Aratanha ridge, the origin of which remains uncertain.

The systematic presence of steep or hanging valleys in the major escarpments along which seismo-tectonic activity is reported (Meruoca, Baturité, Pereiro) may be an argument for a possible role of recent uplift in their evolution. However, differences in resistance between the bedrock of the mountains and the surrounding rocks may also explain a slower vertical erosion in these massifs. This is suggested by the identification of similar landforms in scarps that have no tectonic explanation: for example the quartzitic western scarp of the Baturité massif. The context might be that of transient accelerations of erosion rates, until the Neogene (Barreiras Formation sedimentation), controlled by climatic as well as tectonic or eustatic factors [26].

The identification of coarse alluvial fans on dissected pediments below high mountain slopes that bear marks of

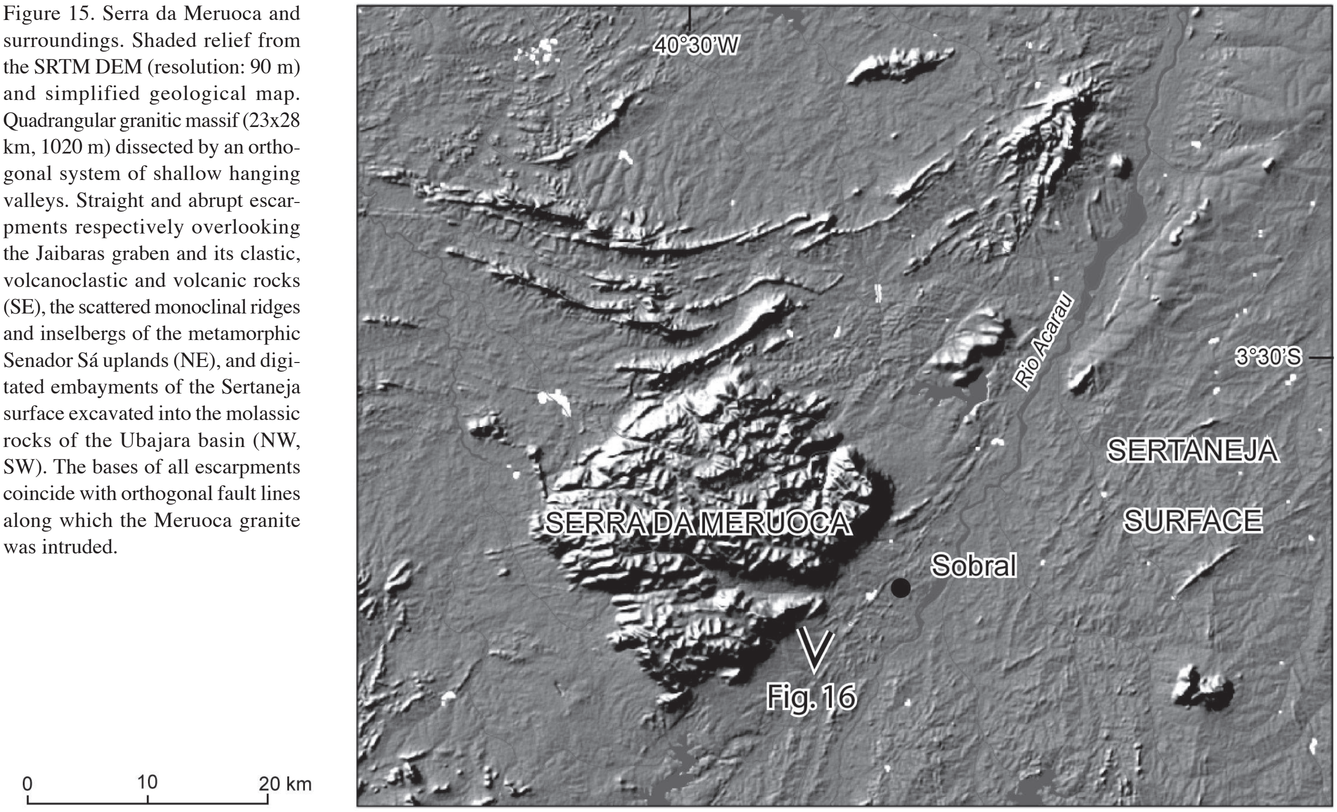



Figure 15. Serra da Meruoca and surroundings. Shaded relief from the SRTM DEM (resolution: 90 m) and simplified geological map. Quadrangular granitic massif (23x28 km, 1020 m) dissected by an orthogonal system of shallow hanging valleys. Straight and abrupt escarpments respectively overlooking the Jaibaras graben and its clastic, volcanoclastic and volcanic rocks (SE), the scattered monoclinal ridges and inselbergs of the metamorphic Senador Sá uplands (NE), and digitated embayments of the Sertaneja surface excavated into the molassic rocks of the Ubajara basin (NW, SW). The bases of all escarpments coincide with orthogonal fault lines along which the Meruoca granite was intruded.

deep denudation or demolition of rock ledges (Serra de Santana) [48], and the presence of thick gravel terraces along the middle or lower courses of major rivers (Acaraú, Curu, Jaguaribe-Banabuiú), probably reflect widespread stripping of deep soil horizons and even erosion of bare rock slopes and surfaces, which would induce steepening or exaggeration of the escarpments. Such events may have taken place in relation to dry conditions and discontinuous vegetation cover, allowing the occurrence of debris flows and torrential floods, without any tectonic forcing [49]. These events were followed by dissection stages in periods of more humid climate and/or lower sea level.

The most frequent case is that of "residual" fault scarps (i.e., those that have undergone erosional retreat), often deprived of lithological control. On the east side of the Baturité massif, no fault line is identified along the sinuous scarp, located 50 km NW from the Senador Pompeu shear zone (Fig. 14). The lack of inselbergs or other residual hills on the opposite side of the shear zone might suggest that it is a fault scarp that would have retreated from this fault during or after the Cretaceous rifting. A more local tectonic control is even suspected on the eastern side of the migmatitic-granitic Serra da Aratanha, which is the only straight scarp, where no clear lithological control is found (Fig. 14). Records of the historic seismic activity in this area

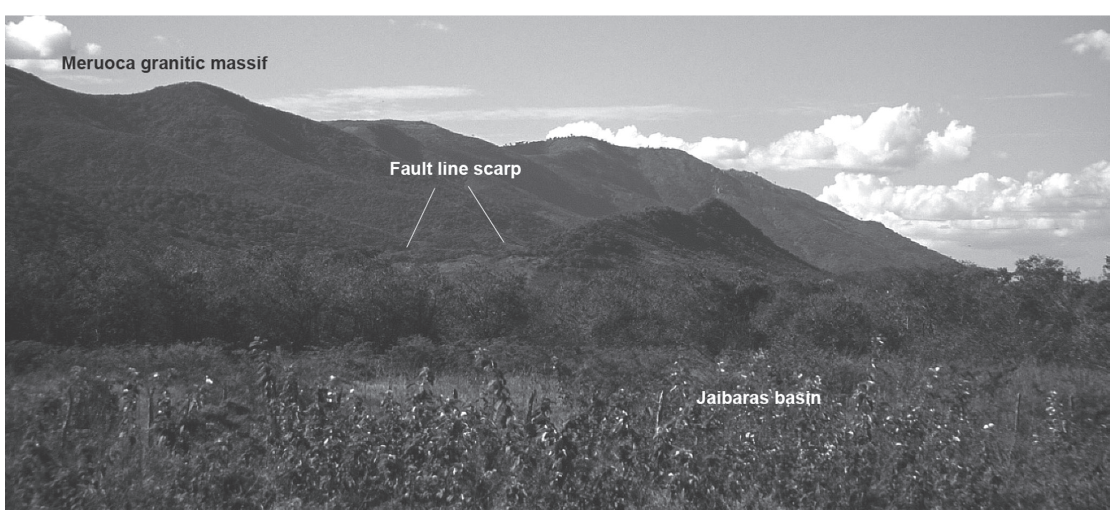
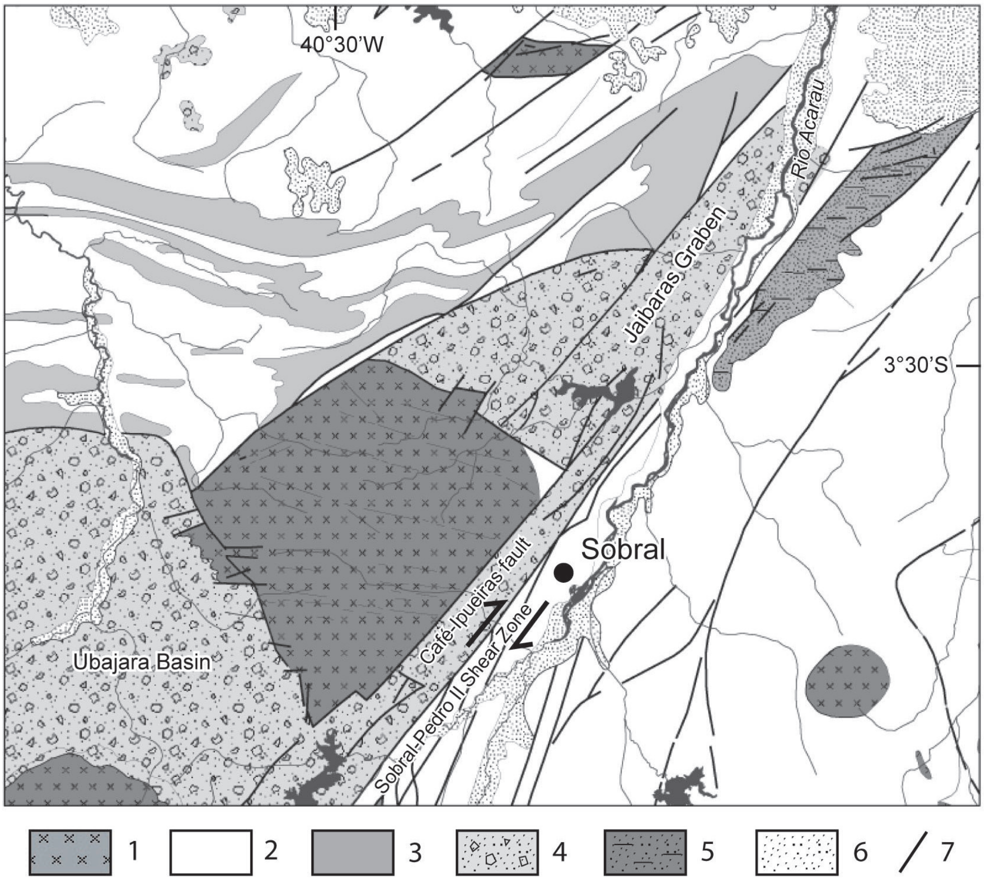



Figure 16. The SE fault or fault line scarp of the Serra da Meruoca. The slope angle of the facets (25-30°) is slightly weaker than on active fault line scarps, whereas the low sinuosity and the location of the scarp on the fault line may be explained by strong lithological control as well as by neotectonics. The presence of a short fault line corridor between the conglomerate ridge visible in front of the main scarp (middle) suggests a decisive role of differential erosion, at least in the formation of the basal part of the scarp.




[6] suggest a possible influence of moderate neotectonic movements along minor faults connected to the Senador Pompeu shear zone. However, the respective rhythms of erosive shaping (downwearing and backwearing in the uplifted block) and of uplift are not known, making ambiguous the exact significance of this scarp. On the contrary, the Potiguar basin is clearly bounded to the south by a residual fault scarp that has retreated from the Carnaubais and Apodi faults.

In both cases, important backwearing – probably associated with downwearing – took place, helped by post-rift flexure that reduced the thickness of the rock slice to be eroded. This situation is probably that of all the borders of inner and coastal surfaces forming the Sertaneja surface. It explains the generally high sinuosity of the escarpments and the development of wide embayments, frequently controlled at small scale by lithological contacts and tectonic weakness zones. It implies old ages (Cretaceous to Tertiary) for most of these landforms.

## 7. Conclusions

In this study, we consider neotectonics the period during and after the deposition of the Barreiras Formation of Miocene-Pliocene age. This period presents a major kinematic pattern for faults that is related to a continuous stress field up to the present day. Many difficulties, however, arise in the study area for identifying specific effects of neotectonics in the landforms, mainly because of the stability of stress regimes over long periods, of deformation rates of 0.01 mm.yr$^{-1}$, and of prevailing strike-slip components of movement recorded along seismogenic faults.

Analyzing landforms located close to zones of seismo-tectonic activity indicates a possible, but probably weak contribution of neotectonics to the formation of high scarps related to fault zones reactivated during the Cretaceous rifting, more hypothetic on the eastern edge of the central Ceará highlands. The influence of neotectonics on major landforms of the Potiguar basin and its surroundings is minor, in spite of strong seismic activity that occurs due to a predominance of weak vertical throw faults, often in poorly resistant rocks. Identified in a few sites in the coastal strip, neotectonic contribution seems to be lacking in the formation of the marginal escarpment to the south of the Potiguar basin, a residual fault scarp whose location and main outlines were already established in the late Cretaceous.

At a regional scale, the main morphostructural units were formed during the Cretaceous rift stage and continental break-up, and many structural landforms of smaller scale have been shaped by later dissection, differential erosion and partial planation related to Tertiary epeirogenic movements. In the less uplifted yet more seismic coastal areas, deformation rates generally remained low enough to be compensated for by erosion, although mean erosion rates have been moderate for long periods and have allowed the preservation of many paleolandforms on resistant bedrock in the area. In such conditions, the use of common neotectonic criteria on passive margins is delicate because confusions is possible between young or old tectonic landforms and the effects of mere differential erosion. On the basis of the present knowledge, only the effects of long-term movement and evolution may be more accurately measured in investigations such as those of morphostratigraphic principles.

**Acknowledgements**

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