Morphology of scarps and piedmonts on the equatorial passive margin of northeast Brazil: Neogene to present evolution and its factors

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Introduction

Steep slopes form the marginal scarp of the semi-arid northern Brazilian “Nordeste” and bound inner residual plateaus and ridges rising up to 800-1,200 m. They overlook a low pediplain merging seaward with a well developed coastal erosional-gradational piedmont. Only a few of them coincide with geological contacts and/or fault zones. Their location, their straight or sinuous outlines, and the presence or lack of residual landforms in front of them give indications on their origin and evolution. Dissected pediments and sparse debris fans visible at the base of some escarpments suggest recent erosive activity and possible slope retreat, although most of these forms are decoupled from major valleys. In order to understand scarp morphology and evolution in a context where various factors (lithology, neotectonics, climatic and eustatic changes) can be considered, we describe the morphostructural patterns of chosen escarpments, as well as the present and past morphodynamic conditions of their evolution, especially during the Neogene. We discuss their implications on origins and conditions of shaping, evolution, preservation or reworking of scarps and piedmonts on a passive margin.

Study area, hypotheses and methodological remarks

The study area is part of the Brazilian Equatorial continental margin, formed in Aptian times [1]. Onshore, a Precambrian basement is organized around NE-SW shear zones, some of which were reactivated by pre-opening rifting (Cariri-Potiguar rift zone) and then intersected by the transform passive margin (Potiguar basin area). A thin dissected layer of Cenozoic sediments (Barreiras Group) is preserved over a 10 to 80 km wide coastal strip, forming low-lying plateaus or "tabuleiros" (10-60 m) at the foot of two offset segments of a discontinuous "Great Escarpment". The slightly dissected coastal lowlands merge inwards with vast corridors and plains (the Sertaneja surface) that extend far into the semi-arid interior between flat or rugged plateaus and ridges of moderate altitudes, shaped into a wide flexural uplift zone (800-1,200 m).

The two segments of the marginal escarpment respectively intersect the NW rift shoulder of the Cariri-Potiguar rift zone, and the eroded remnants of the southern Potiguar rift shoulder (fig. 1). The offset zone partly corresponds to a post-rift subsidence area (Potiguar basin). However, no direct tectonic control of scarp outlines is observed. Erosional retreat and shaping from remote structures, fault zones or marginal flexure, must be considered in most cases.

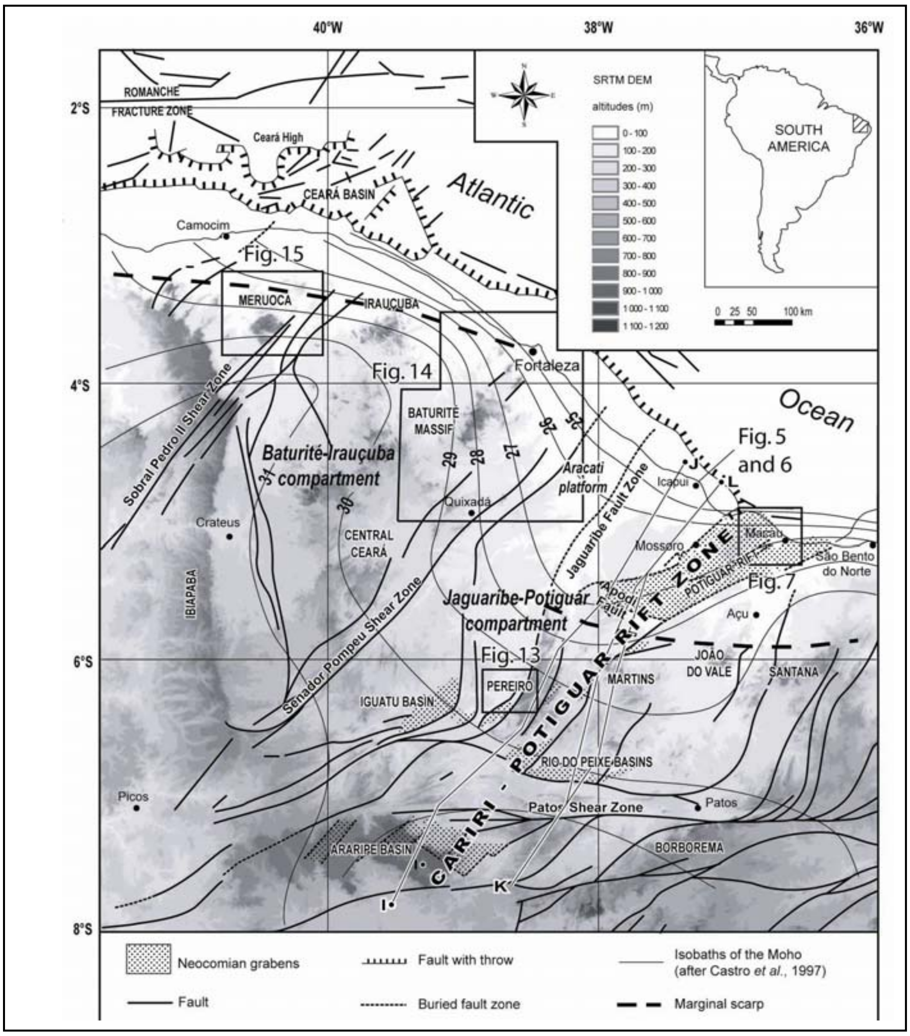

Fig. 1. Location map of the study area. Boxes refer to figures in [2].

The slopes of the marginal and inner scarps, and of inselbergs are steep. Sharp basal knicks or short concavities link them to narrow pediments or slightly dissected or rolling surfaces, parts of the Sertaneja surface. A few marks of active dissection and mass wasting are observed in some of them, in spite of general disconnection between the slopes, incised by gullies or short valleys, and the main river trunks, incised on 20 to 50 m into the piedmonts and the coastal “tabuleiros”, 5 to 30 km from the scarps. Therefore, the question arises of their age, origin and evolution, and of the durations and factors that can explain slope retreat and/or piedmont downwearing outside the main drainage axes, i.e. a fundamental issue in the understanding of planation processes in tropical areas. In order to get a representative set of morphostructural contexts and of controls on the geomorphic evolution, we analyse several examples belonging to the marginal as well as to inner scarps.

Geomorphic data

Morphostructural typology

Our study bears on scarps previously chosen for a study of possible neotectonics controls on recent evolution [2]. Additional observations were made on other escarpments more clearly explained by differential erosion:

- 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 straight SE scarp of the Meruoca granitic massif, 600m high, overlooking the Acarau River corridor hollowed along the Sobral-Pedro II shear zone.
- the discontinuous basement scarp, topped by sandstone tables, that forms the northern edge of aligned spurs and buttes south of the Potiguar basin (e.g. Serra do Martins). It overlooks the Chapada do Apodi, a low surface bevelling Turonian limestones, beyond a wide depression underlain by the exhumed basement. It corresponds to a residual fault scarp which has retreated from remote rift structures (Carnaubais and Apodi faults), mainly before the deposition of the post-rift cover that they slightly deform [2].
- the 500-600 m high escarpment that forms the eastern edge of the Baturité and Aratanha massifs, south of Fortaleza, deprived of clear structural control. Most peaks, culminating ridges, and outstanding escarpments are shaped into the folded quartzite layers which form the skeletal structure of the massif. No fault line is identified along the sinuous scarp and its multiple embayments, located 50 km NW from the NE-SW Senador Pompeu shear zone and from the Choró river. Even along the straight eastern scarp of the Aratanha massif, to the north, we consider the outlines as erosional.
- the granitic Uruburetama massif, to the west, where sinuous outlines of the promontories, inselbergs and embayments show local controls by contacts between granite and host rocks, and by excavated fracture and other weakness zones. The scarps are steeper, with sharper knicks, on the western, dry side, than on the more humid eastern and northern sides. No master fault is identified between the tabuleiros and the massif, a residual relief shaped into the flexural zone of marginal uplift.

In the first two examples, the coincidence with intrusive contacts suggests a contribution of differential erosion associated to the preservation of residual mountains above the low surface. Both scarps are separated from the main valleys entrenched along their master fault zones (Jaguaribe and Acarau rivers) by 5 to 15 km wide pediments. In spite of the local presence of perched valleys and triangular facets similar to those of fresh fault scarps, outstanding erosive remnants are found on the opposite blocks, suggesting that these scarps are mainly differential erosion features.

In the last cases, important scarp retreat took place, helped by post-rift marginal flexuration which reduced the thickness of the rock slice to be eroded. Together with an early initiation of scarp formation deduced from the identification of Cretaceous or pre-Neogene paleosurfaces in distal parts of the Sertaneja surface [3], this situation explains the high sinuosity and the development of wide embayments, frequently controlled at small scale by lithological contacts and tectonic weakness zones.

Morphodynamic data : Present

Whereas most granitic escarpments display steep and bare walls, frequently shaped into rounded domes or sharp needles (Pereiro, Uruburetama), or steep facets with straight profiles (Aratanha, Meruoca SE), the wall morphology is more irregular in the sinuous scarps shaped into metamorphic rocks (Baturité). However, minor, non coalescent alluvial fans are found at the base of both types of scarps, below short and steep valleys or gullies. In several locations, mainly in the driest and least vegetated parts of granitic massifs (western part of the Uruburetama massif, northern Meruoca walls), we found fresh forms and deposits of debris flows, probably formed after heavy rains of recent active rain seasons (2003, for instance). Their sparse distribution reflects that of fracture zones or benches where significant volumes of saprolite (mainly grus and blocks) can have been temporarily retained in otherwise steep walls before being removed.

Only few scarp gullies and deposits are connected to the drainage system of the surrounding pediplains, since the entrenchment of lower river segments is observed at distance from the scarps. Most alluvial fans are built or preserved on non-dissected pediment roots. However, some mountain valleys are continued through dissected remnants of pediments, mainly along sinuous scarps, even far from the coast (80 to 120 km: Baturité, Serra do Martins, Ibiapaba glint), showing that slight vertical incision could occur in some proximal parts of the piedmonts, after late pedimentation stages.

Older correlative deposits : the Neogene legacy

Remnants of older waste deposits were mapped on parts of the Sertaneja surface, at distance from the scarps. Deposits of argillaceous, often ferruginous, sands and gravels of alluvial to colluvial origins were mapped on slightly dissected pediplains at low altitudes, e.g. on proximal parts of the Jaguaribe pediplain and of the coastal piedmont, around the Baturité massif. Sparse deposits of coarse quartz and quartzite pebbles and gravels, several meters thick, are also found in proximal and even distal locations, on dissected fans and pediments, and high fluvial terraces, in the same areas as well as south of the Potiguar basin. All of them reflect the occurrence of periods of active slope erosion and alluvial fan construction on proximal parts of the low surfaces. A slight entrenchment of valleys now places these deposits on interfluves, 20 to 30 m above the present valley floors and cuts them from their source areas, scarps and inselberg slopes located up to 20 or 30 km away. This dissection, similar to that of the Barreiras sediments, may suggest a stratigraphic relationship between both sets of deposits.

The Barreiras sediments overlie the weathered basement of the coastal piedmont, but also unconformably cover Late Cretaceous sediments in the Potiguar Basin. Reduced to dissected remnants disconnected from source areas, these deposits of Miocene to Pliocene age [4] and of limited thickness (10-80 m) slightly dip seaward. Inland, layers of reddish to white argillaceous sands contain minor amounts of quartz gravel, and more clay beds at depth. Several sea cliff outcrops also expose coarse deposits, mainly in the vicinity of present river mouths and of mountains approaching the coast.

These deposits belong to a piedmont system whose inner, eroded parts are exposed almost in the same plane. Their substrate is well identified at the coast and along shallow valleys incised down to the basement. Generally flat, it is locally irregular, with low rounded hills and inselbergs protruding through the cover. Its buried distal parts as well as exposed proximal elements intersect each other at low angles (fig. 1) and locally comprise dissected surfaces. Both buried and exposed parts, the final shaping of which probably provided the Barreiras deposits, are diachronous in age. Such a piedmont geometry implies some kind of non-cyclic evolution during the Neogene, such as described in distal parts of uplifting areas, in wide flexural zones where interplay between moderate uplift and variations of the base level remain insufficient for triggering stages of deep river entrenchment until the final dissection.

Interpretation and discussion

Clastic rocks as correlative deposits of the last stages of scarp and piedmont evolution

The Barreiras sediments are part of a large clastic wedge that is found onshore and offshore along the Brazilian margin. As measured on a synthetic profile in the Potiguar basin area, the mean thickness of this Late Miocene and younger wedge (about 150 m at most on a 100 km wide strip) would represent at most 50 m of vertical erosion on a 300 km wide inland zone (*i.e*. the mean width of the Sertaneja surface). The eroded slice is probably thinner in the less uplifted coastal areas. Such moderate figures, also suggested by the identification of pre-Barreiras to pre-Cenomanian paleosurfaces on parts of the low surface, are comparable to average values measured from stratigraphy on the post-Cretaceous times [2]. They do not imply any Neogene acceleration of erosion and uplift, neither does an investigation of possible neotectonic movements outside coastal sites.

However, transient increases of erosion phenomena, recorded by the clastic facies of the Neogene sedimentation, were controlled by climatic, tectonic or eustatic factors. Climatic changes induced numerous short term fluctuations since the Miocene [5], essential for the regradation of low surfaces by etchplanation and their inward extension [3]. The identification of coarse alluvial fans on dissected pediments, below high mountain slopes bearing marks of deep denudation and of strong demolition of rock ledges, and the presence of thick gravel terraces along middle or lower river courses probably reflect the occurrence of periods favourable to widespread stripping of deep soil horizons and even to erosion of bare rock slopes and surfaces, leading to generalized, yet moderate downwearing, and local backwearing.

Conditions of recent evolution of escarpments and piedmonts

Such events may have taken place in dry conditions with discontinuous vegetation cover, allowing the occurrence of debris flows and torrential floods, and they were followed by dissection stages in periods of more humid climate and/or of lower sea level. The diversity of sequence combinations, already suspected in the origin of the Barreiras and Tibau deposits, reflects a complex Late Cenozoic environmental history. Although the repeated Pleistocene sea level falls probably explain the final dissection of the piedmonts, this complexity and the short duration of climatic and eustatic events were not favourable to continuous regressive erosion towards the scarps, explaining the frequent disconnection of the main river trunks from the scarps, even those bearing sparse marks of active erosion, especially in the widest coastal and inner piedmonts.

As shown by the position of deposits of various ages on pediments and exhumed surfaces close to the scarps, backwearing was also limited on the same period, even at the head or at the knick-points of the scarce gorges connected to the parts of the drainage system entrenched into the low surface. The main stages of retreat from master tectonic structures had to occur before, suggesting that most scarps, straight or sinuous, controlled or not by local structures, are mainly inherited landforms, initiated during the

Cretaceous rifting or later, in response to post-break-up marginal uplift. The distribution of paleosurfaces on piedmonts, especially in coastal areas, is explained by morphotectonic conditions (weak uplift), favourable to limited post-rift dissection and scarp retreat, and to phenomena of morphological resistance.

Conclusion

Only a few scarps retained in our study show strong structural control. It could not be determined in all cases whether they are residual or active fault scarps, or fault-line scarps. Most of them, straight or sinuous, controlled or not by local structures, are mainly inherited landforms, initiated during the Cretaceous rifting (south of the Potiguar basin) or later. However, dissected pediments and sparse debris fans visible at the base of many escarpments suggest recent erosive activity and possible slope retreat, although most of them are decoupled from major valleys. The Neogene clastic sedimentation on the piedmonts and on coastal areas probably reflect the occurrence of dry periods inducing widespread stripping of deep soil horizons and erosion of bare rock slopes and surfaces, even without tectonic forcing. Dissection stages occurred in periods of more humid climate and/or low sea level. Only slight or local backwearing of slopes occurred, associated with downwearing on pediments, probably in diachronic ways. The moderate volumes of Neogene clastic sediments imply overall low uplift and erosion rates until the Present, still to be more precisely quantified, and favourable to morphological and lithological resistance effects in the landscapes.

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