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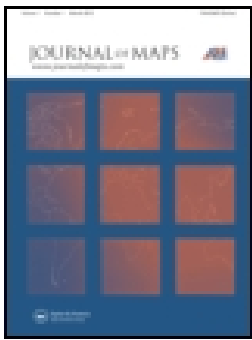
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SCIENCE

Morphostructure of the Serra Do Mar, Paraná State, Brazil

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ABSTRACT

The morphostructural map of the Serra do Mar in Paraná was (Main Map) made of geologic and geomorphologic data obtained from fieldwork, satellite images, topographic data and information from previous studies. Six important escarpments limited by geologic structures, eight morphostructural units and four morphostructural domains were mapped. Kinematic data and the directions of the main families of faults, interpreted using digital elevation models, permitted us to characterize morphostructures that were generated by Cenozoic deformation events superimposed over older tectonic events. In many cases, we could also identify and map neotectonic features.

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1. Introduction

The Serra do Mar (SM) is characterized by a mountain range extending more than 1200 km from the south of the state of Bahia to the south of the state of Santa Catarina, and has a northeast–southwest general direction. In the state of Paraná, the mass that forms the SM delimits the ‘first plateau and the coastal plain’ (Bigarella, Becker, Matos, & Werner, 1978) and is a ‘step’ in the form of an escarpment that matches topographic heights with orographic attributes defined in detail by Maack (1972). The geomorphic subdivisions are prominent mountain ranges, consisting of granitic massifs, intruded into the paleoproterozoic basement (Figure 1), called from the south to the north, Serra do Piraí, Serra do Iquererim, Serra do Marumbi, Serra do Ibitiraquire, Serra da Virgem Maria, Serra da Igreja, Serra das Canavieiras and Serra do Capivari Grande. The Serra da Graciosa and the Farinha Seca are high relief features with steep slopes (Figure 2).

The most prominent mountain subdivision in Paraná state has average altitudes between 1300 and 1800 m and the highest altitude is the Pico Paraná (1877 m), in the Serra do Ibitiraquire. Between the highest peaks there are inter-mountain hills with elevations between 300 and 1000 m that form a pediment surface (Figures 3 and 4).

Initial studies on the SM relief in Paraná are those of Maack (1942, 1947), who addressed their geomorphology and those of Ab’saber and Bigarella (1961) and Bigarella et al. (1978), who attribute an important role to the erosive events in the Tertiary in the development of planed surfaces. Remnants of paleosurfaces, currently widespread on the landscape of SM, were named by Bigarella et al. (1978) as Pd3 (correlated to the Purunã surface), Pd2 (correlated to the Alto Iguaçu surface)

and Pd1 (equivalent to the Curitiba surface) corresponding, respectively, to the Sulamericana, Velhas and Paraguaçu paleosurfaces, defined by King (1956).

The drainage network is a major component of the landscape in areas with morphostructural control. Drainage is one of the first features in the landscape to adapt to changes in tectonic base level, or control by the structure of substrate exposed by the exhumation of overlying rocks. Among the anomalous features identified in the drainage network of the study area are displaced terraces and inflexions of rivers (Rockwell, Keller, & Dembroff, 1988), changes of direction in the water flow (Deffontaines & Chorowicz, 1991; Howard, 1967; Ouchi, 1985), hanging valleys, abrupt changes in valley profiles and in the profiles of river terraces (Bishop, 1995; Summerfield, 1991), asymmetric valleys (Cox, 1994) and river catchments (Bishop, 1995) and knickpoints (Hack, 1973).

The aim of this work is to represent cartographically the main morphostructures that allow the identification of the morphostructural framework in the geomorphological evolution of SM in Paraná State at a regional scale, supported by field data and digital image analysis of relief.

This will supplement the limited existing work on this geomorphic unit which ‘represents the most important center of the meridional sector of the scarps which are the main alignment of the SM in Southeast Brazil’ (Ab’saber & Bigarella, 1961, p. 105).

2. Methods

The large spatial extent of the area required the use of data from multiple sources, including altimetric and hydrographic data at a scale of 1:25,000 from the

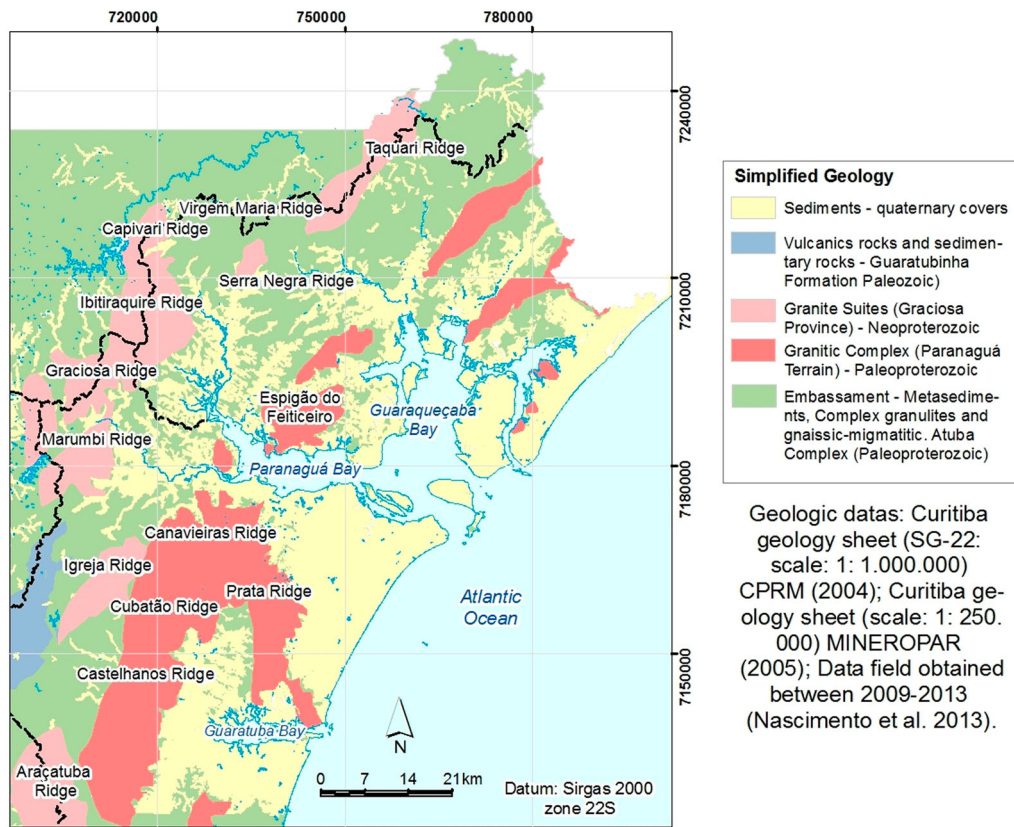


Figure 1. Simplified geology of the study area.

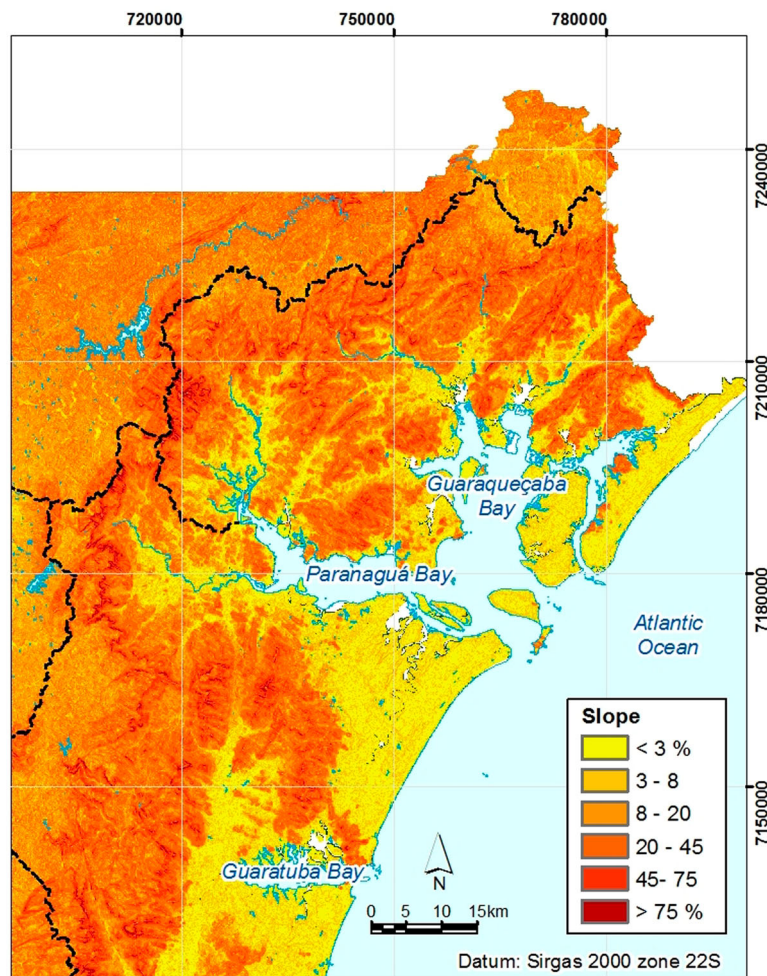


Figure 2. Slope map of the study area.

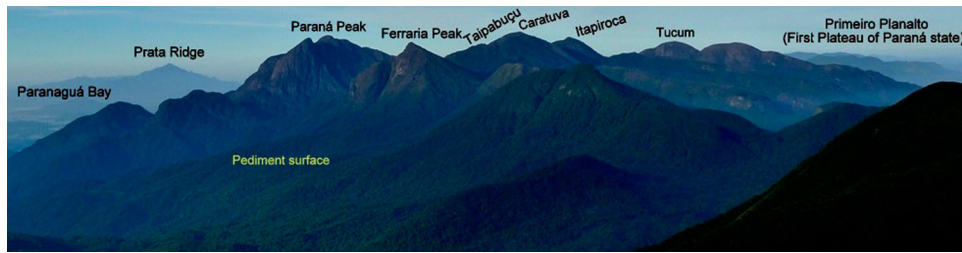


Figure 3. Partial view of the Serra do Ibitiraquire – Pico Paraná (1877 m), Pico do Ferraria (1734 m), Pico Caratuva (1856 m), Pico Itapiroca (1754 m), Morro do Tucum (1741 m).

topographic maps shown in Figure 5 (Pró-Atlântica, 2005); geological and structural data at a scale of 1:250,000 provided by Mineropar (2005); TOPODATA project data (Valeriano & Rossetti, 2008); Landsat ETM+ images and, finally, high-resolution images provided by Google Earth[®].

We determined the axes of paleotension on fault planes from data on slickensides and steps found in the field. For this, we used the right-dihedral method, present in the WinTensor software (Delvaux, 2011) and described in Kipata, Delvaux, Sebagenzi, Cailteux, and Sintubin (2013). The geometric analysis of strike-slip faults was related to the direction of paleotension vectors identified in adjacent areas affected by Neogene tectonic activity (Paranaguá Graben, Sete Barras

Graben, Curitiba Basin). Of the 174 points described in the field, we highlight those of adjacent structures with six tectonic lineaments that define structural scarps. These were analyzed using the software SIGMAS, Stereo32 and also in WinTensor. The Main Map was compiled in ArcGis 10.1.

2.1. Knickpoints

To identify knickpoints, we used the 'slope-length relationship' index relative slope-extension (RDE) proposed by Etchebehere, Saad, Perinotto, and Fulfaro (2004), derived from the Hack Index (1973). Because of the length of time required to use the RDE in large areas an electronic routine was developed,

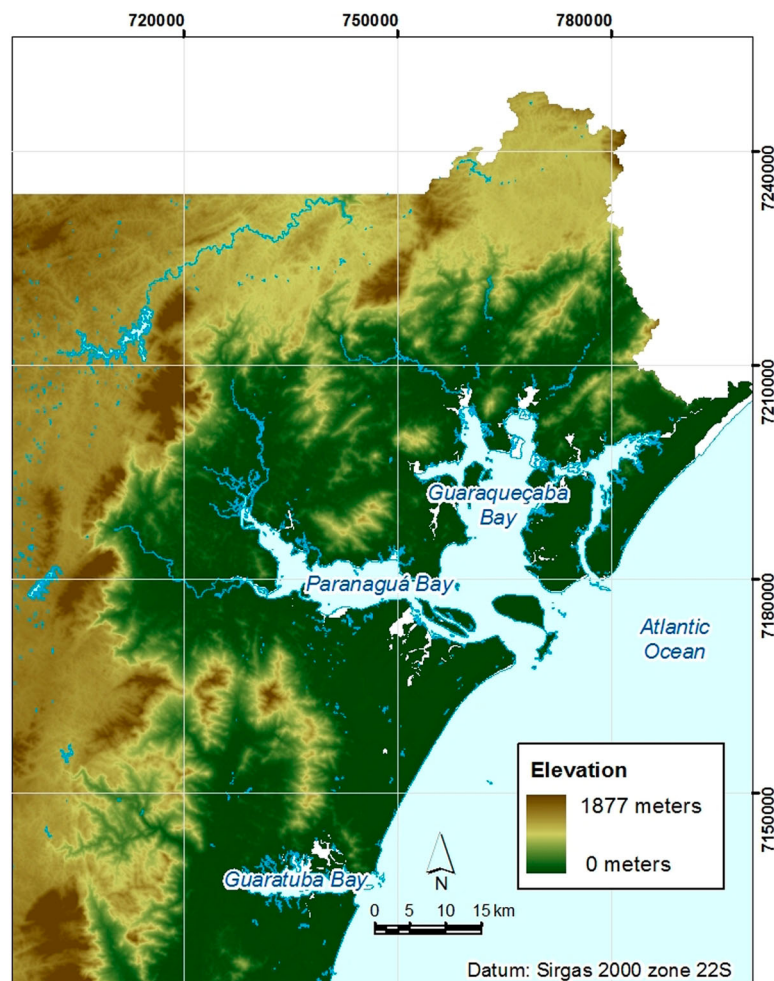


Figure 4. Hypsometric map of the study area.

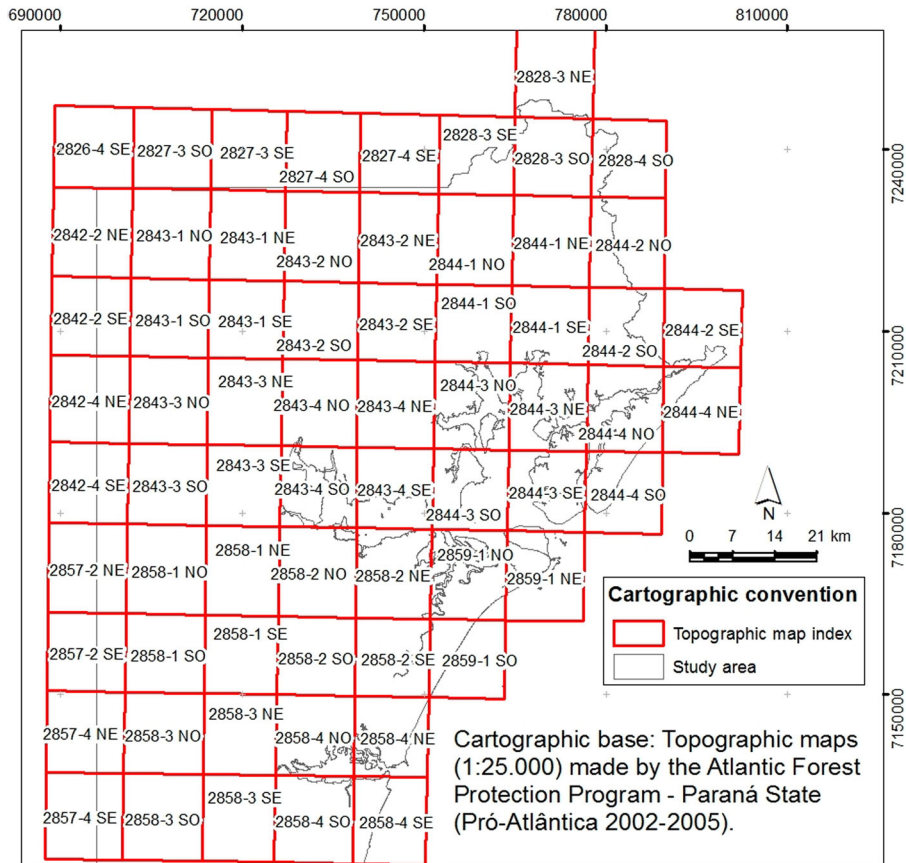


Figure 5. Cartographic base (Pró-Atlântica 2002–2005).

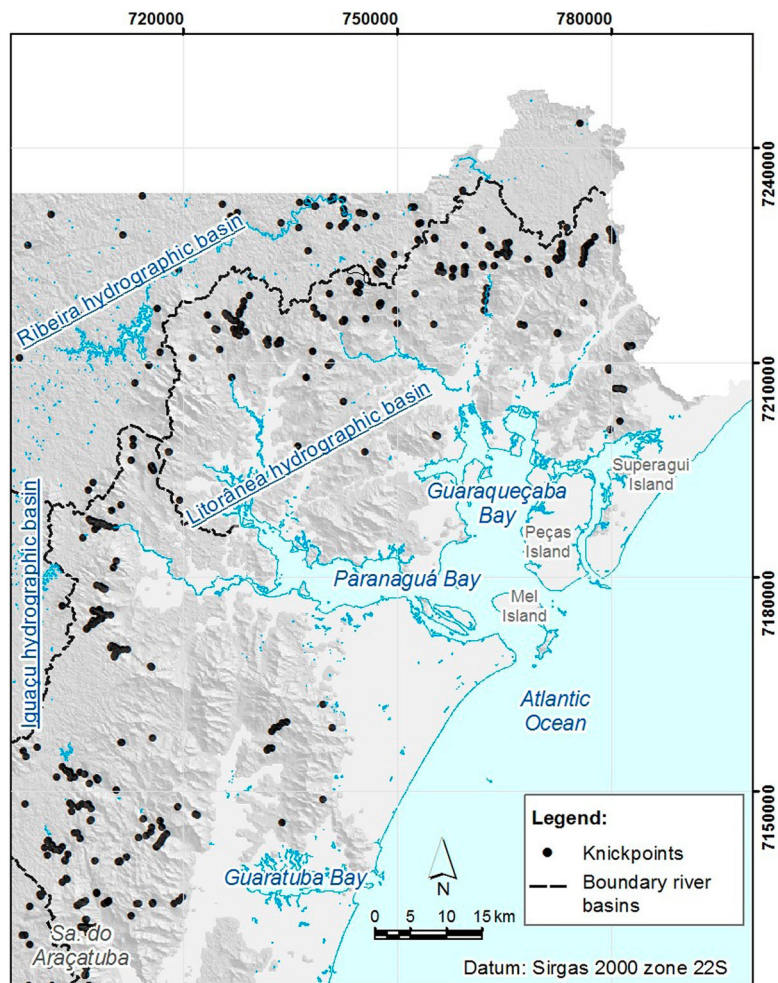


Figure 6. Map of knickpoints identified in the study area.

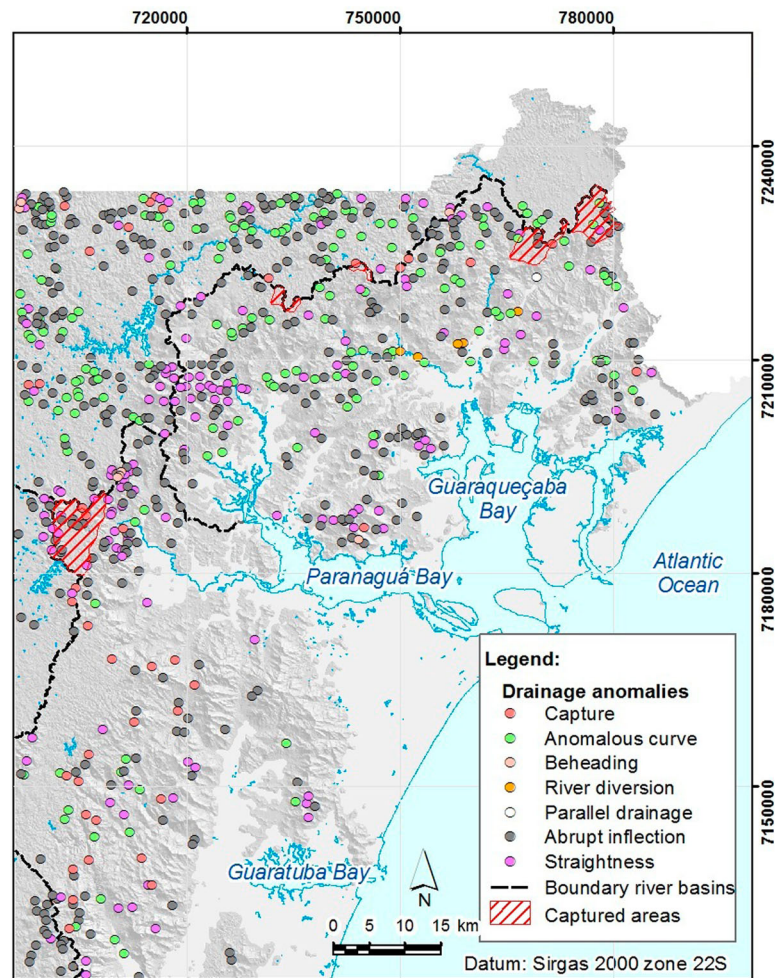


Figure 7. Map of drainage anomalies identified in the study area.

programmed in the Python language, for use in Esri ArcGIS (available at: <http://www.neotectonica.ufpr.br>). This routine uses a matrix image with altimetry data to extract the drainage network. It then automatically identifies knickpoints (Figure 6).

2.2. Drainage anomalies

Drainage anomalies are features that differ from those expected of the regional drainage network, or the existence of atypical stretches in river channels draining a given watershed. De Blieux (1949) calls the expected drainage standard 'normal', and their deviations 'anomalies' which, according to Howard (1967), are connected to geological structures.

Drainage anomalies compared with regional geomorphological and geological features were identified in the field and on satellite images at a scale of 1:130,000 (Figure 7).

2.3. Structural lineaments

Geomorphic features such as the edges of raised areas or crests of ridges, drainage lines, coastlines, geological contacts and aligned valleys are relief expressions

commonly associated with geological structures such as faults, fractures, joints and foliation (Sabins, 1978). The definition of the structural lineaments of interest in this study was based on the regional expression of scarps associated with fault planes using satellite images and multiscale topographic data. Six lineament systems were identified: the Paranaguá Bay in the north, the Piraquara-Ferraria lineament, the Morretes lineament, the Palmital shear zone, Cubatãozinho shear zone and Alexandra shear zone, as well as four morphostructural domains.

2.4. Morphostructural domains

Four morphostructural domains were defined from the presence and identification of geological structures with associated structural escarpments, mainly through the interpretation of a magnetic image provided by the Research Laboratory of Applied Geophysics of Federal University of Paraná (UFPR). The four defined morphostructural domains are: (1) Antonina Morphostructural Domain; (2) Morretes Morphostructural Domain; (3) Guaratuba Morphostructural Domain and (4) Guaraqueçaba Morphostructural Domain.

Table 1. Summary of the main features of lineaments and morphostructural domains.

Lineament(s)	Morphostructural domain	Morphostructural and main anomalies of the drainage network
<i>Northern Paranaguá Bay</i> Morphostructural units: Dissected plateau of the upper and middle Ribeira river and SM II	Guaraqueçaba and Antonina	<ol style="list-style-type: none"> (1) Knickpoints determined by E-W structures, especially the Salto Morato (Municipality of Guaraqueçaba-PR), where the scarp fault has triangular facets and discontinuous alluvial deposit (limited by the escarpment, with deposition upstream and downstream of the scarp) (2) Alignment of the rivers that flow into Paranaguá Bay following the NNE direction and presence of extensive alluvial plains that extend from the bay to the foot of the SM (3) Drainage anomalies distributed throughout the area, especially the abrupt inflections, captured areas and anomalous bends (Figure 7)
<i>Lineament Piraquara-Ferraria</i> Morphostructural units: Dissected plateau of the upper and middle Ribeira river, Curitiba plateau SM I and SM II	Antonina	<ol style="list-style-type: none"> (1) Main mountain front of the extreme northwest portion of the SM (likely NE-SW fault reactivated in the Quaternary) (2) knickpoints, anomalous features in the drainage network and a large colluvial deposit east of Morro do Guaricana (3) Rivers eroded in lineaments of NE direction and anomalous features (anomalous curves or sharp inflections) in both the granitic substrate and the Atuba Complex lithotypes (4) Predominant angular, rectangular drainage pattern in the granite area, and influence of the direction of the dikes and parallel structures to the lineament Piraquara-Ferraria
<i>Lineament Morretes</i> Morphostructural units: Coastal plain; Depositional ramps; Isolated hills and Inter-plane Elongated crests; Dissected plateau of the upper and middle Ribeira river; Curitiba plateau; SM I and SM II.	Morretes and Antonina	<ol style="list-style-type: none"> (1) knickpoints on recent colluvial sediments and the Neoproterozoic granites (2) Large area recently captured from the watershed of the upper Iguaçú river (Figure 7) (3) Angular and rectangular predominant drainage patterns and shaped like chandeliers in the granite areas and sub-dendritic in lower portions on the Atuba Complex (4) Several remnants of paleosurfaces (Main Map) (5) Rivers of first and second orders controlled by NE lineaments
<i>Palmital Shearing Zone</i> Morphostructural units: Coastal plain; Depositional ramps; Curitiba Plateau; Isolated hills and SM II	Morretes	<ol style="list-style-type: none"> (1) knickpoints aligned according to the direction N40–45W (2) Geomorphological expression from the First Paraná Plateau (altitude 800 m) to the bay of Babitonga-SC (altitude 0 m) (3) Rivers cross the SM and drain the Tijucas Sedimentary Basin (Cenozoic), where there is a series of drainage anomalies and dividers of tenuous waters (early stage) between the coastal basin and the Iguaçú river (4) Several remnants of paleosurfaces (Main Map) (5) Typical geomorphological features of conditioned tectonic zones (triangular facets, structural escarpment and rivers with drainage anomalies)
<i>Shearing Zones Alexandra and Cubatãozinho</i> Morphostructural units: Coastal plain; Depositional ramps; Isolated hills and Inter-plane Elongated crests; Isolated hills; SM I and SM II	The Shearing Zone Alexandra – Morphostructural domain Morretes The Shearing Zone Cubatãozinho – limits the morphostructural dominions Morretes and Guaratuba	<ol style="list-style-type: none"> (1) The occurrence of knickpoints on granites in valleys without the sediment deposits in the regions nearby the two shearing zones (2) They mark the tectonic markings of the Paranaguá Land with the microplates Luiz Alves and Curitiba and feature Cenozoic reactivation (3) The Shearing Zone of Cubatãozinho presents the south of the Serra das Canavieiras best defined structural escarpment of the Paraná SM, with a wide alluvial plain (4) The structural lineaments near the direction N70E and N60W control the directions of the rivers and alluvial deposits, suspended basins and remnants of the South American paleo-surface

2.5. Morphostructural units

Eight mapped morphostructural units were derived from the joint analysis of the structural and geomorphological data collected in the field, from topographic maps and satellite images, as well as data derived from altimetry such as relief distribution, slope, hillshade and roughness concentration index (Sampaio & Augustin, 2014). The morphostructural units are described on the map and are presented as follows: (1) Coastal plain; (2) Depositional ramps; (3) Isolated hills and inter-plane elongated crests; (4) Dissected plateau of the upper and middle Ribeira river; (5) Curitiba plateau; (6) Isolated hills; (7) Serra do Mar I and (8) Serra do Mar II.

3. Results

From the visual and digital analysis of satellite image data, geomorphometric data extracted from digital elevation model (DEM) and geological–structural data obtained in the field, six lineaments, four morphostructural domains with regional coverage in the SM, as well as morphostructural units with different geomorphological characteristics, were defined (Table 1).

4. Conclusions

Morphostructural mapping of the SM in Paraná State allowed the identification of six structural lineament directions that determine the main features of the regional relief. In addition to these regional elements, we mapped local evidence for neotectonics, such as minor structural scarps, knickpoints aligned following the direction of important structures, alluvial deposits segmented by knickpoints, drainage anomalies, suspended hydrographic basins and other landscape features that allow us to recognize recent tectonic deformations in the formation of the landscape.

From the mapping of the morphostructures of the SM it is expected that we can contribute not only to expanding geological and structural knowledge of the area, but also improve the understanding of the risks involved in the occupation of the region, especially those related to geotechnical issues that have caused significant economic and social problems in the region.

Software

The strike-slip fault data were analyzed using the software SIGMAS, Stereo32 and also in WinTensor. The map was produced using Esri ArcGis 10.1.

Disclosure statement

No potential conflict of interest was reported by the authors.

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