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SRTM-based morphotectonic analysis of the Poços de Caldas Alkaline Massif, southeastern Brazil

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Abstract

An evaluation of SRTM 03″ data applicability in geomorphology and morphotectonic analysis is proposed, considering the morphometric parameters slope, aspect, surface roughness and isobase surface. The study area, in southeastern Brazil, comprises the Poços de Caldas Alkaline Massif, a 33 km-diameter Late Cretaceous collapsed volcanic caldera. Morphometric indices evaluated showed the correlation of landscape within the massif with NE–SW and NW–SE structures, as well as landforms related with recent tectonic influence. DEM-derived drainage presented satisfactory results when compared to a 1:50,000 topographic map. SRTM 03″ proved to be a good resource for geomorphological analysis, up to the semi-detail scale.

Keywords: SRTM; DEM; Morphometric analysis; Geomorphology; Poços de caldas; Alkaline massif

1. Introduction

Morphometric analysis, or geomorphometry, is the practice of terrain modeling and ground-surface quantification, through applications of earth sciences, mathematics, engineering and computer science (Pike, 2002). Geographic Information Systems (GIS) and Digital Elevation Models (DEMs) allow speed, precision and reproducibility to calculation of morphometric parameters.

The release of Shuttle Radar Topography Mission (SRTM) DEM data (Farr and Kobrick, 2000; van Zyl, 2001; Rabus et al., 2003) brought the possibility of regional geomorphological analysis in a fast and inexpensive way.

In this work, we considered the morphometric parameters slope, aspect, surface roughness and isobase surface to present an evaluation of SRTM 03″ data applicability in geomorphology and morphotectonics. The study area, located in southeastern Brazil, comprises the Poços de Caldas Alkaline Massif, a 33 km-diameter Late Cretaceous collapsed volcanic caldera.

2. Geological and geomorphological context

The Cabo Frio Magmatic Lineament, as defined by Almeida (1991), is a WNW–ESE structural feature, 60 km wide by 1150 km long, developed

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from Jaboticabal (Northern São Paulo State) eastwards, up to the Almirante Saldanha Bank, region of the boundary between continental and oceanic crusts.

Located in the central-western portion of the Cabo Frio Magmatic Lineament, the Poços de Caldas Alkaline Massif (Figs. 1 and 2) is the largest alkaline complex in Brazil with about 800 km^2, composed mainly of nepheline syenites, phonolites, ankaratrites and volcanoclastic rocks (phonolitic tuffs and lapilli-tuffs, volcanic agglomerates and breccias); diabases, carbonatites and ultramafic ultrapotassic biotite lamprophyre dikes occur as subordinated rock types (Ulbrich and Gomes, 1981; Schorscher and Shea, 1992, Alves, 2003). Shea (1992) obtained an Ar–Ar age of 78 ± 3 Ma for the central nepheline syenite body of the caldera, representing one of the earlier stages of its evolution, and an age of 76 ± 2 Ma for a lamprophyre dike related to the final stage of volcanic activity.

The alkaline massif main morphology is a semi-circular plateau with average altitude of 1300 m rising up to 400 m above surrounding flatlands (Poços de Caldas Plateau, Fig. 2), with elevations up to 1500–1600 m in its borders. Original vegetation coverage consisted of *cerrado* (savanna) and now most of the area is covered by pasture (Radambrasil, 1983).

This plateau is a remnant of the South American Planation Surface (King 1956, 1967) and resulted from differential erosion of basement rocks and volcanic ring dikes around the massif at the Late Cretaceous–Paleogene transition. Landforms within the massif are closely linked with contrasts in lithology (Holmes et al., 1992) and with Pleistocenic and Holocenic tectonic structures (Alves, 2004). Contrast between tectonic and lithologic influence on geomorphology favors morphotectonic analysis.

3. Methods

Analysis were carried out with free software GRASS-GIS (Neteler and Mitasova, 2004; GRASS Development Team, 2005) as proposed by Grohmann (2004). Original SRTM data were imported into GRASS, reprojected to UTM coordinate

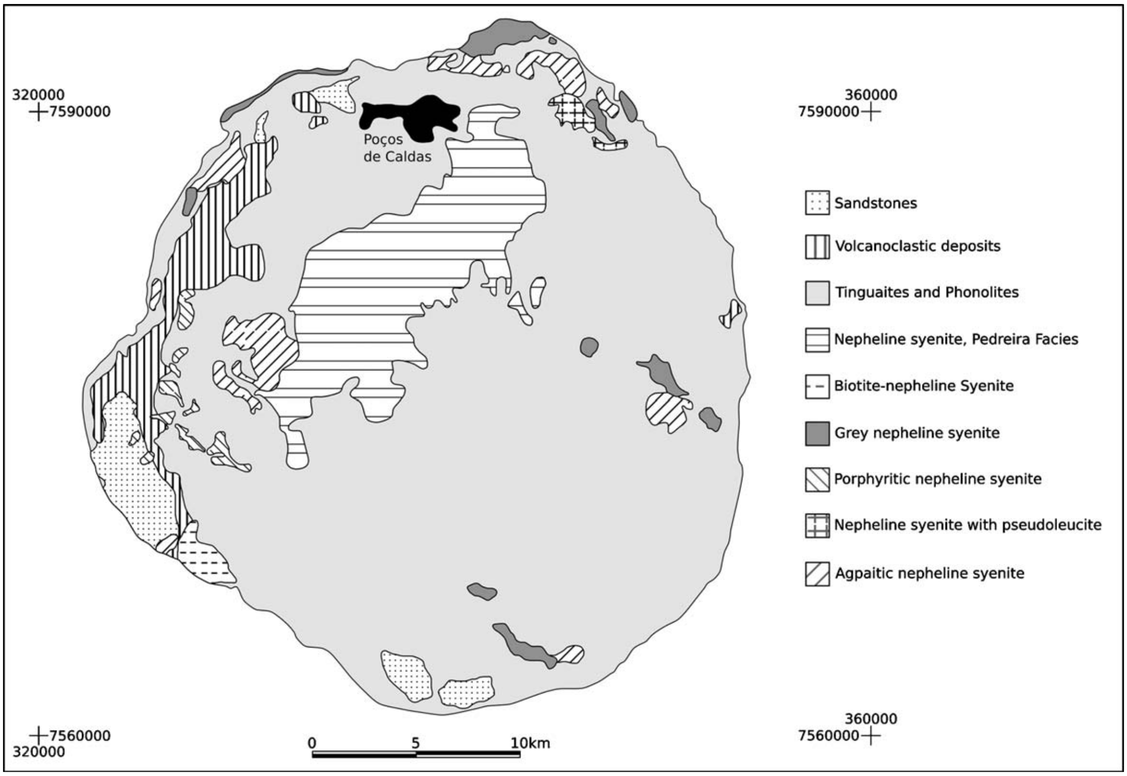


Fig. 1. Simplified geological map of Poços de Caldas Alkaline Massif. After Ruberti et al. (2000). UTM coordinate system, Zone 23, southern hemisphere.

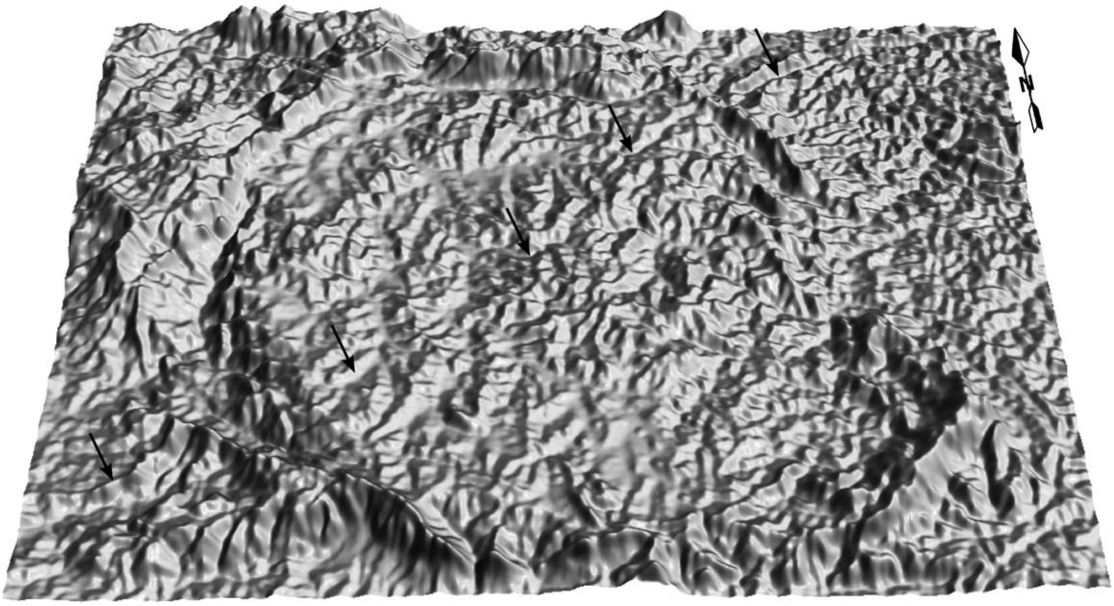


Fig. 2. SRTM DEM 3D Perspective of Poços de Caldas Alkaline Massif, view from south to north, vertical exaggeration of 3.5 ×.

system and resampled by nearest neighbors to a spatial resolution of 50 m, in order to work at a 1:50,000 scale. In the original data only a small void was present, and was filled by interpolation with regularized splines with tension (RST—Mitasova and Hofierta, 1993; Mitasova and Mitas, 1993).

Slope and aspect were calculated with a 3×3 neighborhood operator (Horn, 1981). Aspect was converted from its original output (i.e., counter-clockwise from east) to conventional orientation (clockwise from north) and classified into eight categories, each corresponding to a 45° interval.

Day (1979) describes surface roughness as the expression of non-systematic variability of the topographic surface, and used the dispersion of vector normals to surface plans as a roughness indicator to discriminate tropical karst stiles. Hobson (1972), describes it as the ratio between surface (real) area and flat (plan) area of square cells; in this approach, flat surfaces would present values close to 1, whilst in irregular ones the ratio shows a curvilinear relationship which asymptotically approaches infinity as the real areas increases.

Ferrari et al. (1998) argue that surfaces with distinct characteristics can present the same roughness value, due to the existence of interactions between the number and magnitude of terrain irregularities. Grohmann (2004), considers this method useful for morphological characterization since it is mainly related with the shape of landforms and not its elevation; thus, tectonically tilted areas have their expression shown, while it could be masked in a hypsometric map, as consequence of altimetric variations.

In this work, surface roughness was considered as the ratio between surface and plan area of 1×1 km cells. Surface area of the 1 km cells was achieved by summing up the real area of individual cells (50×50 m, Fig. 4) within a 1×1 km window.

SRTM data can be biased by canopy variations; in areas of dense forest coverage such effect can account for increasing overall DEM height and act as a smooth blanket over terrain, hiding minor details (Valeriano et al., 2006). In the study area, original vegetation was widely removed and replaced by pasture; in its original form it consists of *cerrado*, savanna-like grassland scattered with shrubs and isolated trees (Radambrasil, 1983).

Prior to drainage extraction, the DEM was smoothed with a 7×7 filter that fits quadratic surfaces to elevation values (*r.param.scale* command, Wood, 1996a, b), in order to prevent creation of artifacts (O'Callaghan and Mark, 1984; Garbrecht and Martz, 1999) and to minimize both the effects of noise that SRTM data present in flat areas (Guth, 2006; Huisenga, 2005) and possible canopy variations.

Drainages were calculated using the A^T least-cost search algorithm (*r.watershed* command, Ehlschlaeger, 1989), with a threshold value of 50 cells as

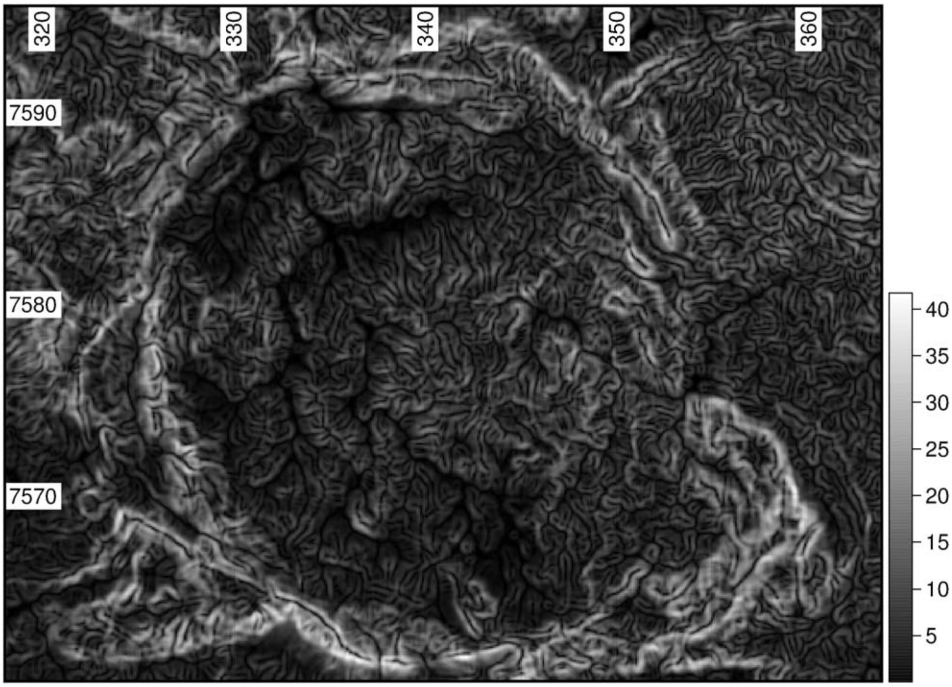
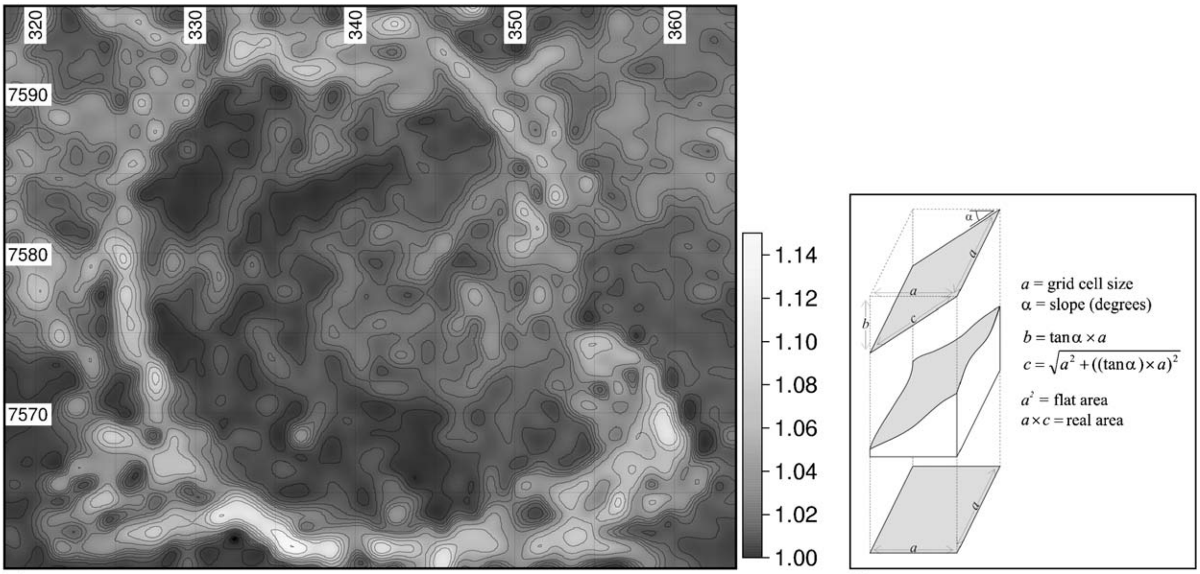


Fig. 3. Slope map. Values in degrees.



(a) (b)

Fig. 4. (a) Surface roughness map, for cells with 1 × 1 km. (b) Geometric relations between regular grid and slope.

minimum watershed size (Fig. 5). DEM-derived drainage can be compared against drainage from a 1:50,000 topographic map in Fig. 6. Raster streams were converted to vectors and manually classified according to Strahler's (1952) drainage order scheme.

The isobase method (Filosofov, 1960; Golts and Rosenthal, 1993), concerns about relations between stream channel order and topography. The stream order refers to the relative position of stream segments in a drainage basin network; within such basin, streams of similar orders relate to similar

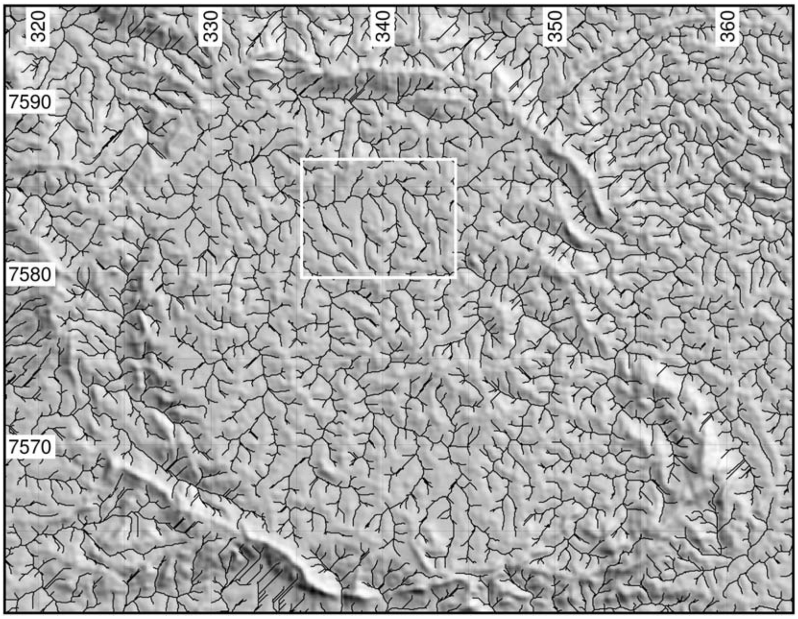


Fig. 5. DEM-derived drainages over shaded relief image. White rectangle area is enlarged in Fig. 6.

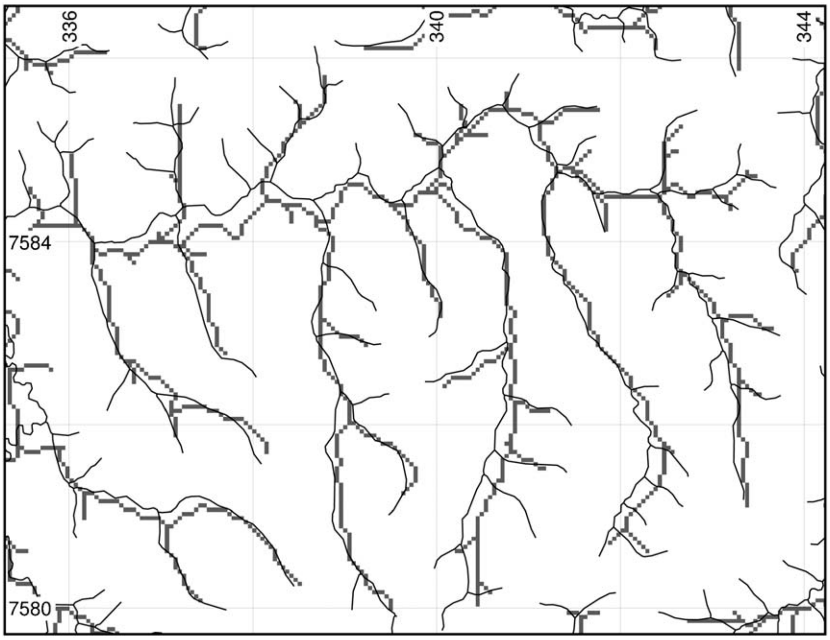


Fig. 6. Vector drainages of 1:50,000 topographic map overlaid on DEM-derived drainages.

geological events and are of similar geological age (Golts and Rosenthal, 1993).

According to Filosofov (1960), isobase is a line that delineates an erosional surface; the isobase surface is formed by connecting stream profiles of similar order and disregarding topography above isobase surface (Fig. 7).

Isobase lines draw erosional surfaces, hence isobase surfaces are related to tectonic-erosional events, mainly the most recent ones. Abrupt

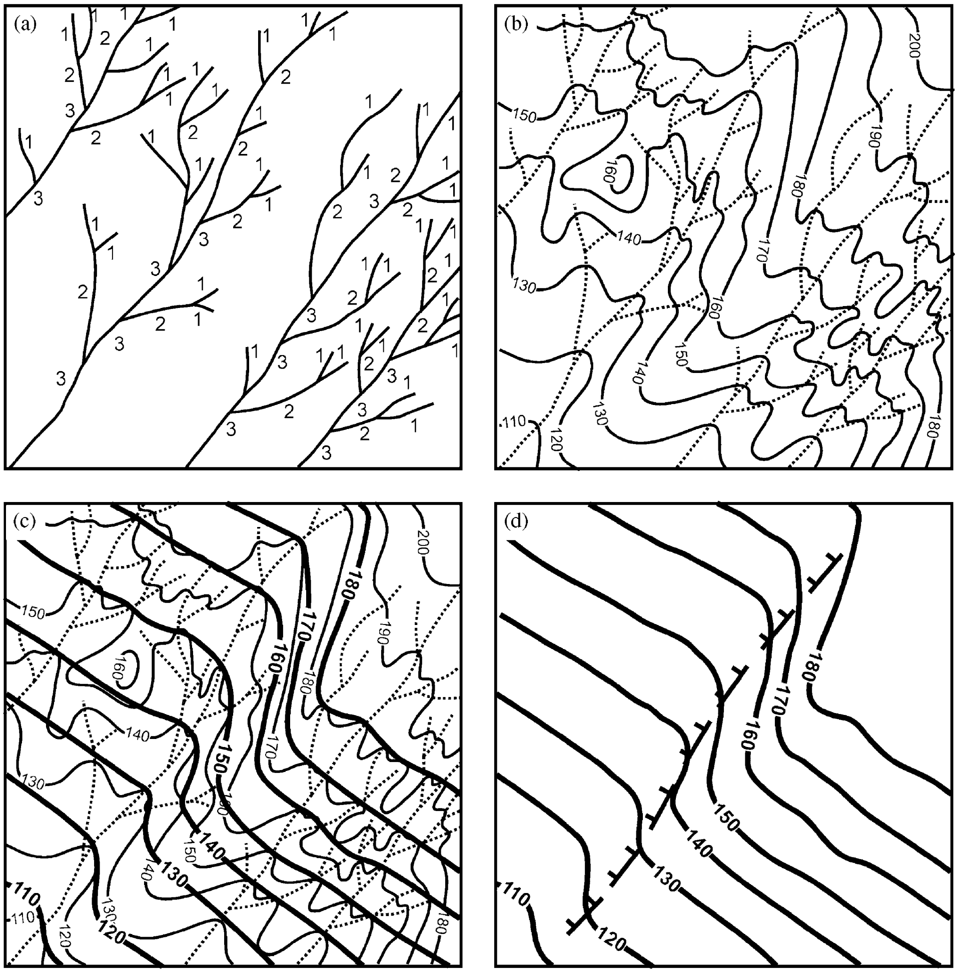


Fig. 7. Development of isobase map. (a) Definition of stream orders. (b) Overlay of drainage network and contours. (c) Isobase lines derived from second and third-order streams. (d) Fault traced according to deviations of isobase lines. Reprinted from Golts and Rosenthal, Geomorphology 7:305–315, Copyright 1993, with permission from Elsevier.

deviations in isobase lines directions may be reflect of tectonic dislocations or severe lithological changes (Golts and Rosenthal, 1993).

The isobase map can be seen as a 'simplified' version of the original topographic surface, from which was removed the 'noise' of the 1st-order streams erosion. The main goal of this method is to be able to identify areas with possible tectonic influence even within lithological uniform domains, what cannot be achieved with 'base-level' maps, usually constructed from elevations of thalwegs in a given area, or with swath profiles (Baulig, 1926; Tricart and Cailleux, 1957) were intersections of contours with equally spaced profile lines are marked within a swath, or band; this kind of profile is useful to provide a broader view of altimetric behavior and help to determine inclination of large topographic features in planaltic regions (Meis et al., 1982).

The isobase map (Fig. 8) was made by RST interpolation of altitude values from intersections of contours with second- and third-order stream channels.

4. Discussion

The Poços de Caldas Alkaline Massif stands as a high plateau in a strongly eroded area, and preserves, in its ring dikes, the remnants of the South American Planation Surface, developed at the Late Cretaceous–Paleogene transition.

Slopes within the massif are small, generally lower than 10° (Poços de Caldas Plateau); higher values, up to 40°, occur mainly in the massif's borders (Fig. 3). Localized areas with high slope values occur within the Plateau, generally aligned NE–SW. The aspect map shows slopes facing mostly NW and SE within the Plateau, controlled by NE–SW lineaments; the volcanic edifice exhibits a radial pattern of aspect distribution.

In the surface roughness map (Fig. 4a) is possible to see some very flat areas, with values close to 1, roughly aligned NE–SW (northern Plateau) and NW–SE (southern Plateau). The expression of the massif borders is marked by the higher values, ranging from 1.07 up to 1.15.

The isobase map (Fig. 8) not only gives a good delimitation of the massif, with higher values, but also presents some typical characteristics of areas that went trough tectonic activities, such as approach, separation and sudden inflection of isobase lines (Golts and Rosenthal, 1993). Isobase lines within the plateau show trends in NE–SW and NW–SE directions, both in areas were lines are close to each other as were they are separated.

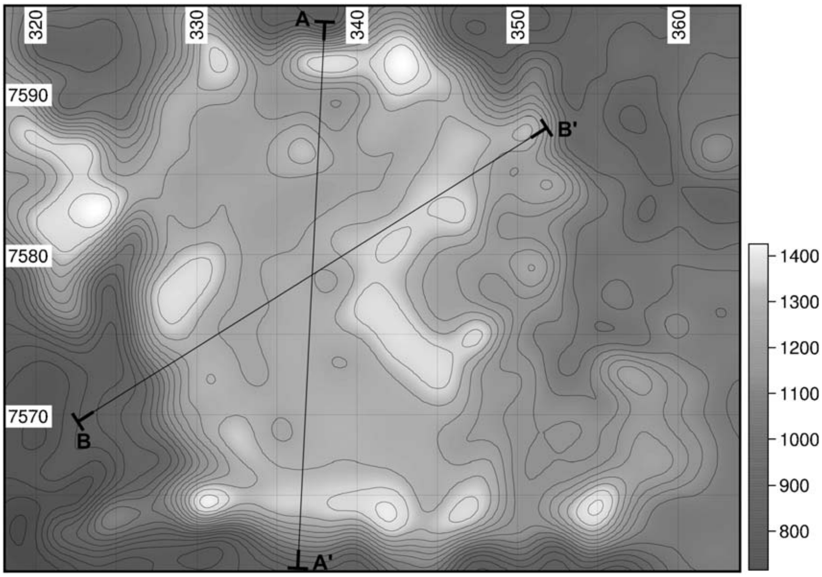


Fig. 8. Isobase map.

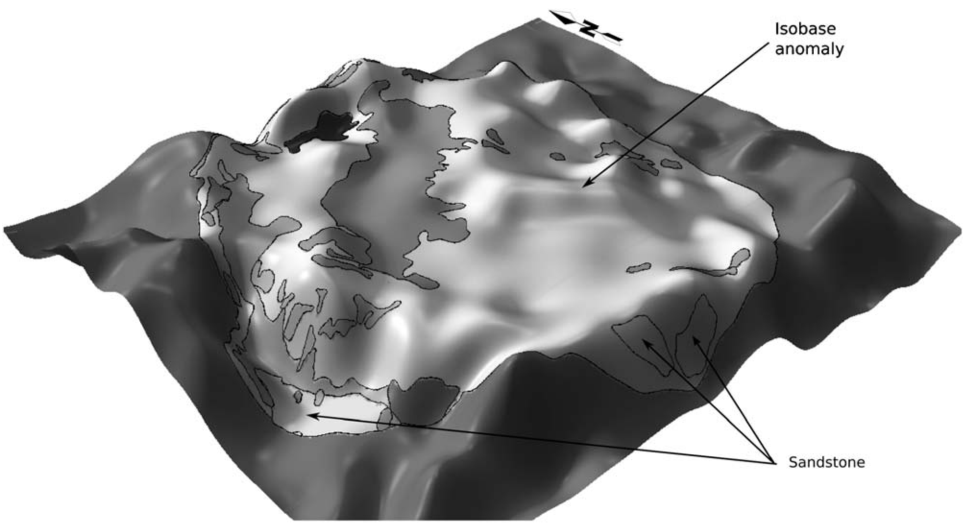


Fig. 9. 3D-view of geology draped over isobase surface, viewed from southwest to northeast. Vertical exaggeration of 10 ×.

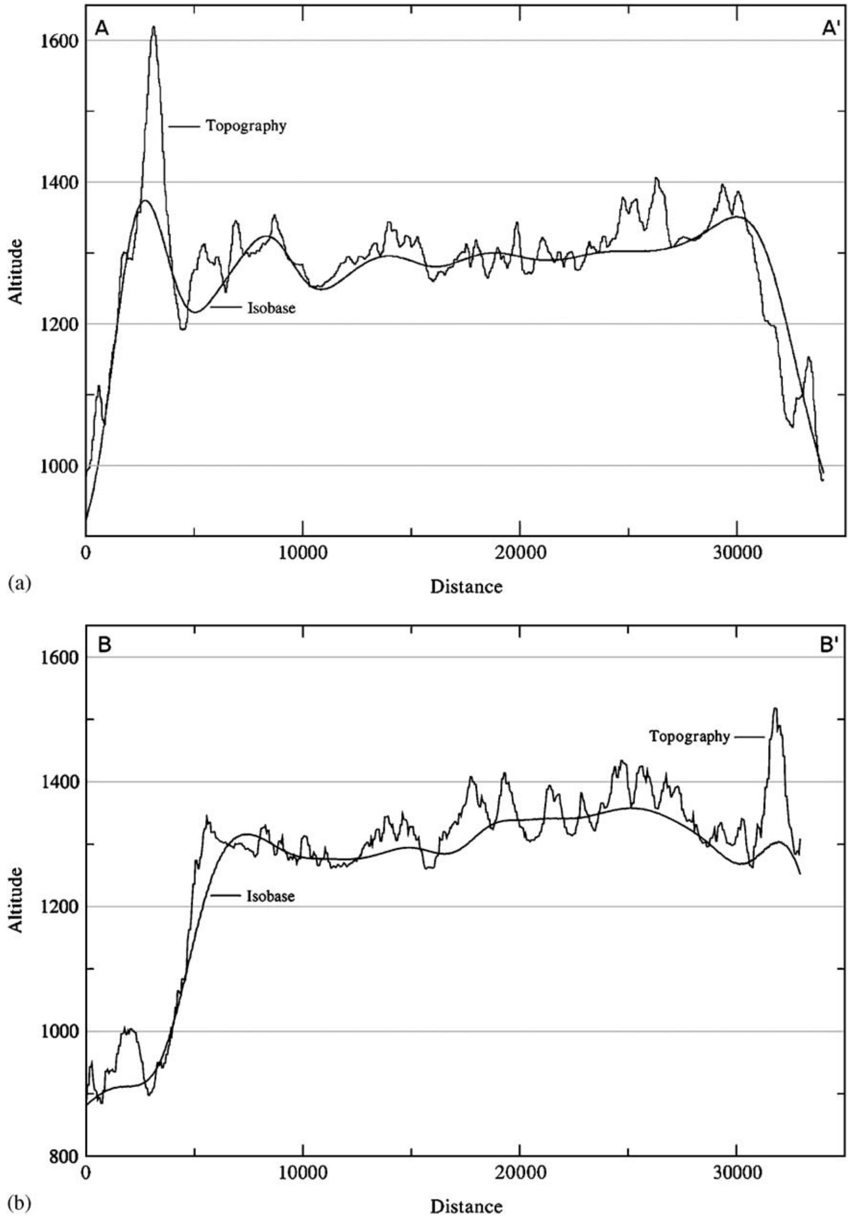


Fig. 10. Morphological profiles across massif showing topography and isobase relations. (a) N–S profile. (b) SW–NE profile.

There is a partial coincidence of a lithologic change in the northeastern portion of the massif and a strong NE–SW isobase anomaly, which turns abruptly to NW–SE in the central area of the plateau, without any associated variation in lithology. This large anomaly is related with a NE–SW fault that cuts throughout the entire massif (Fig. 2), identified by Almeida Filho and Paradella (1977).

Geomorphological settings related to tectonic and lithologic controls can be better seen when the geological map is draped over a 3D model of isobase surface (Fig. 9). Sandstones in the western border of the massif are in a depressed region, while the strong NE–SW isobase anomaly roughly follows the contact of the central nepheline syenite body and turns to a NW–SE direction in a lithological homogene area.

Morphological profiles across the massif in the N–S (Fig. 10a) and SW–NE (Fig. 10b) directions show the relations between topography and isobase.

Although the isobase curve does not pass exactly under the valley bottoms, perhaps due the need of fine adjustments to interpolation parameters, it is possible to see areas where the first-order drainages incision is more prominent, thus more likely to reflect strong differences in weathering resistance of rocks, or recent tectonic activity.

5. Conclusions

The contrast between tectonic and lithologic influence on Poços de Caldas Alkaline Massif's geomorphology favors morphotectonic analysis. Regional geomorphological configuration is a remnant of the Late Cretaceous–Paleogene South American Planation Surface, while landscape within the plateau is controlled by structures trending NE–SW and NW–SE. Isobase analysis allowed discrimination of areas where the dominant geomorphic process is related to differential erosion from areas affected by recent tectonics. Drainage extraction from DEM presented satisfactory results when compared to a 1:50,000 topographic map.

SRTM DEM proved to be a good resource for geomorphological analysis at a semi-detail scale. Availability of data assures that analysis can be carried out in a fast and inexpensive way, even in areas of poor topographic coverage.

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