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Geomorphology 43 (2002) 257–271

GEOMORPHOLOGY

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# Morphotectonics of a high plateau on the northwestern flank of the Continental Rift of southeastern Brazil

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Received 12 January 2001; received in revised form 16 July 2001; accepted 10 August 2001

**Abstract**

Integration of landform and structural analysis allowed the identification of Late Pleistocene–Holocene pulses of tectonic activity in the Campos do Jordão Plateau with ages and regimes similar to the ones from the continental rift. Fault reactivation along Precambrian shear zones give rise to a series of conspicuous morphotectonic features, determine the formation of stream piracy phenomena, and divide the plateau into smaller blocks. Recognition of these tectonic pulses as well as of their effects in landform development—particularly clear on the Campos de São Francisco at the highest area of the SE edge of the plateau—show that besides the climate-related Quaternary environmental changes significant neotectonic instability should be considered in the geomorphic evolution of the Campos do Jordão Plateau. 

*Keywords:* Southeastern Brazil; Quaternary; Morphotectonics; Tropical plateau; Hillslope evolution

## 1. Introduction

The Campos do Jordão Plateau is part of the faulted and tilted façade of Southeastern Brazil, a classic relief type of passive continental margins with Great Escarpments (Ollier, 1985; Thomas, 1994). In spite of being defined as "passive", these continental margins are not without activity (Ollier, 1985) and may be subject to slow but continuous tectonism (Battiau-Queney, 1991). Much of their geomorphological evolution depends on the complex tectonic/structural heritage. Influence of residual seismicity may be inferred from the plateau location within the Cunha Seismogenic Zone (Hasui et al., 1982; Mioto, 1993), which presents the greatest number of recorded epicentres in southeastern Brazil, with seism magnitudes up to 4.3 mb.

The relief of southeastern Brazil clearly shows the heritage of the Cenozoic tectonic processes that followed the Mesozoic–Cenozoic Reactivation and the opening of the south Atlantic Ocean basin. During the Paleogene (Eocene–Late Oligocene), normal reactivation of old Brasiliano/PanAfrican shear zones brought about a striking tectonic feature, the Continental Rift of southeastern Brazil (Riccomini, 1989), initially named Serra do Mar Rift System (Almeida, 1976). This rift extends in an ENE direction for about

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PII: S0169-555X(01)00137-4

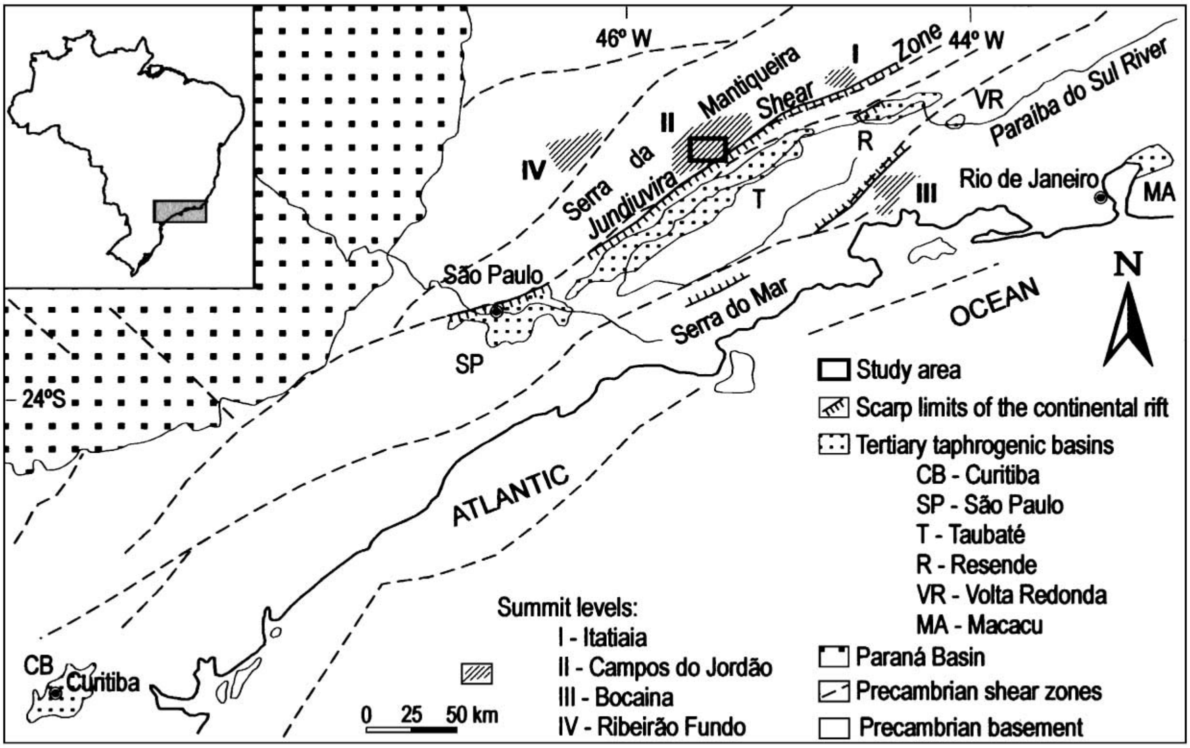


Fig. 1. Summit levels of southeastern Brazil and the Paraiba do Sul rift valley (modified after Melo et al., 1985).

1000 km and comprises six main Cenozoic basins (Fig. 1) — Curitiba, São Paulo, Taubaté, Resende, Volta Redonda and Macacu, of which the Taubaté basin is the most important — and smaller depressions, such as the Itaboraí and Barra de São João sedimentary basins and the grabens of Sete Barras and Guanabara. In eastern São Paulo state, the continental rift is topographically expressed by the Serra do Mar and Serra da Mantiqueira as raised geomorphic units and the Taubaté Basin as downthrown unit. Further uplift of probable Miocene/pre-Pleistocene age would have accentuated differences in altitude between compartments.

More recent data on fission track analysis of apatites indicate a gradual uplift and erosion of approximately 8 km at the Serra da Mantiqueira and neighbouring areas, from the Early Cretaceous to the present (Gallagher et al., 1995; Hackspacher et al., 1999). The thermal history of the Serra da Mantiqueira (Hackspacher et al., 1999) shows two outstanding phases of cooling, which indicate the accentuation of uplift rates in the Cretaceous and Pleistocene, the later from one million years ago to the present.

## 2. The Campos do Jordão Plateau

At the SE end of the main block of the Serra da Mantiqueira, the Campos do Jordão Plateau (1950–2050 m) is bounded by two large NE-trending strike-slip faults of Precambrian and Early Paleozoic age, reactivated during the Early Tertiary: the Jundiuvira Fault (IPT, 1978) near the plateau scarps and the Paiol Grande (IPT, 1978) or São Bento do Sapucai Fault (DNPM, 1979) on its northern flank. The plateau consists of rocks of the Brasiliano cycle as well as reworked older rocks. The main lithotypes are Proterozoic gneisses, granites, migmatites, schists and quartzites, and metasediments of a small Neoproterozoic sedimentary basin (IPT, 1978; DNPM, 1979; Morais et al., 1998; Hiruma, 1999) (Fig. 2).

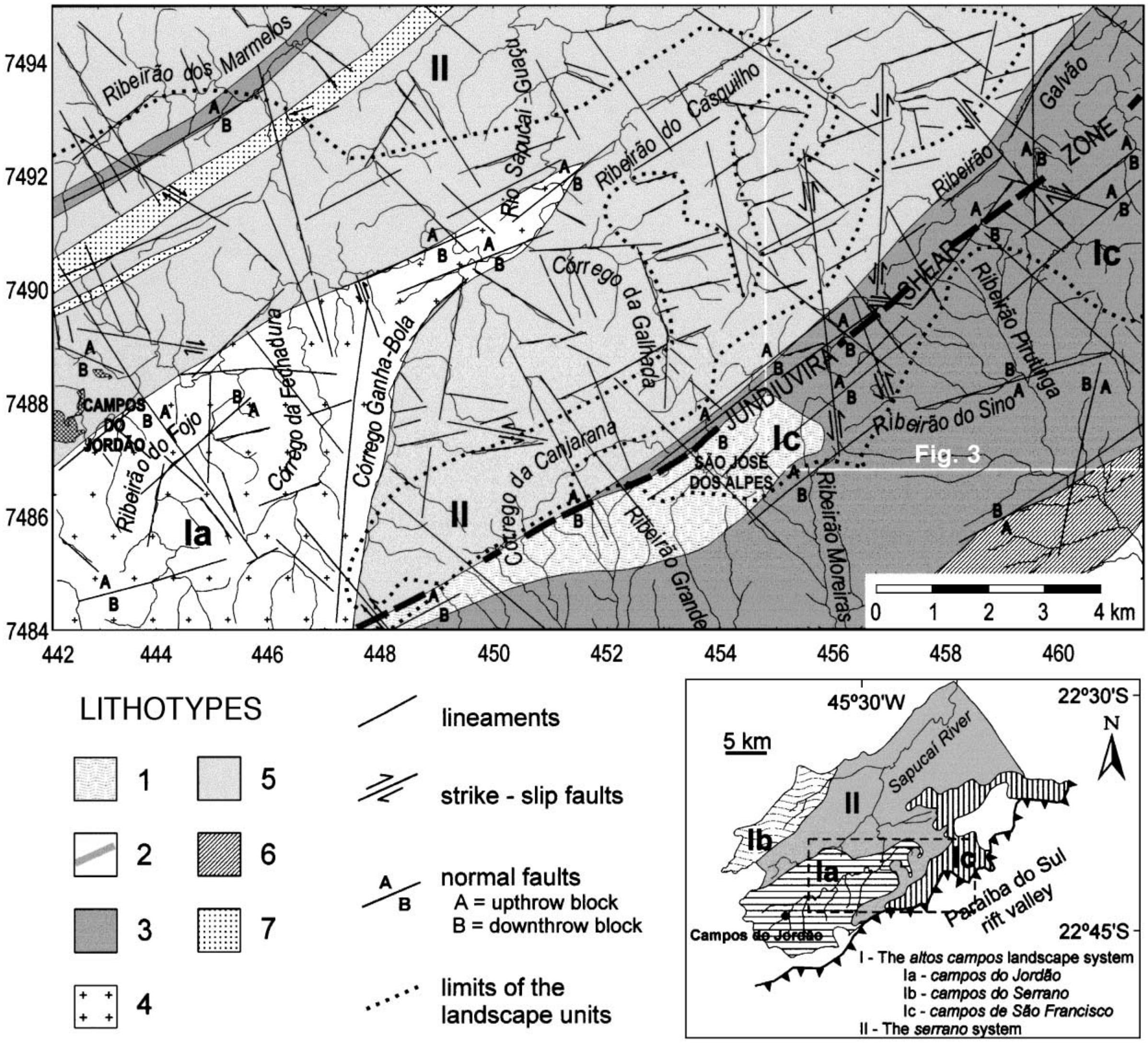


Fig. 2. Landscape systems of the Campos do Jordão Plateau (after Modenesi, 1988a). Geological map of the studied area (after Hiruma, 1999). Main lithotypes: (1) polymictic metaconglomerates, arkosean metasandstones, and metasiltstones; (2) ultramylonites in Precambrian shear zone; (3) mylonitic gneisses; (4) biotite granites; (5) banded biotite gneisses; (6) porphyroblastic biotite gneisses and biotite schists; (7) muscovite quatzites, locally mylonitic.

Remnants of the oldest planation surface of southeastern Brazil, the *campos surface* (De Martonne, 1940; Ab'Saber and Bernardes, 1958; Almeida, 1964), would have been preserved in the Campos do Jordão Plateau as accordant summits (Modenesi, 1988a).

During the Quaternary, reworking of the old surface by morphogenetic systems operating in high altitude conditions — colder and more humid climates — developed the *altos campos* (high grasslands) landscape system (Modenesi, 1988a) in the higher areas of the plateau above local base levels in the subsequent streams. This tropical montane landscape is characterized by a grassland–forest mosaic clearly adjusted to the landforms and to the distribution of surficial materials (Modenesi, 1983, 1988a,b):

rounded hilltops and convex slopes with shallow and highly weathered materials are covered by grass, forests occupy the rectilinear slopes and amphitheaters where deeper and less weathered materials occur. Small variations in the lithology and degree of relief dissection allow the recognition of three altos campos areas locally known as Campos do Jordão proper, Campos de São Francisco, and Campos do Serrano (Fig. 2).

The altos campos slope evolution has been characterized by a succession of phases of increasing and decreasing morphogenetic activity (Modenesi, 1980, 1983, 1988a,b). Phases of intense slope erosion (deep slump-slides) gave origin to three generations of erosion amphitheaters and associated coarse terrace deposits. These last were considered equivalent to the Middle and Late Pleistocene terraces recognized by Bigarella et al. (1965) all over southern and southeastern Brazil. Phases of lesser denudation gave origin to colluvium deposits. The basal part of soils developed over colluvia has been dated at ca. 8630 and 9250 years BP (Hiruma, 1999). On the lower hillslopes at Vila Nova Suiça, sequences of up to three colluvium beds may occur intercalated with paleosols. The oldest paleosol was dated ca. 37,000 years BP (Modenesi-Gauttieri, 2000).

On the altos campos hilltops and convex slopes, the contact colluvium-weathered bedrock is usually marked by *stone lines*. These compact residual accumulations of coarse clasts form a regional paleopavement that has been attributed to the widespread aridity of the last glacial maximum, ca. 13,000–23,000 years BP, (Ab'Saber 1962, 1969; Bigarella et al., 1965; Thomas, 1994).

The cyclic character of the plateau evolution, with alternate phases of higher and lower morphodynamic activity on hillslopes, suggests climatic control under montane subtropical conditions, now humid and hot, now relatively drier and colder. On the other hand, probable neotectonic activity can be inferred from morphological evidence found along structural lineaments of the Campos do Jordão Plateau (Modenesi, 1988a,b; Hiruma, 1999) — deep asymmetric valleys with rectilinear slopes (Córrego do Ganha-Bola) and hanging valleys or amphitheaters with trapezoidal and triangular facets (Ribeirão do Fojo and Morro da Pedra de Fogo). In the Campos de São Francisco area, drainage anomalies and stream piracy phenomena along the Mantiqueira divide offer additional evidence. Recurrent pulses of tectonic displacement, showing evidence of Pleistocene and Holocene activity, have been recognized in the neighboring Paraiba valley, within the Taubaté basin, usually following older structural discontinuities (Riccomini et al., 1989; Salvador and Riccomini, 1995; Gontijo, 1999; Riccomini and Assumpção, 1999).

Few neotectonic studies have been made in the Precambrian shield areas along the continental rift, most of them in the taphrogenic basins (among others, Riccomini, 1989; Melo et al., 1985; Mancini, 1995; Salvador and Riccomini, 1995; Gontijo, 1999) where sedimentary records are significant and well preserved. On the high plateaus bordering the rift, such studies are scarse (Saadi, 1991; Gontijo, 1999; Hiruma, 1999; Santos, 1999), discontinuity and thinness of sedimentation make more difficult recognition of the chronology of neotectonic events. Despite the importance of landform evidence to the study of neotectonics, only two of the studies cited have a morphotectonic approach (Gontijo, 1999; Hiruma, 1999).

The present study aims specifically at describing geomorphological evidence of recent tectonism, characterizing the neotectonic framework of the plateau, and recognizing its relationships to regional structures. In a broad perspective, the morphotectonic approach will probably help to extricate the role played by climate and neotectonics in the geomorphological evolution of the Campos do Jordão Plateau.

## 3. Methodology

The term neotectonics is used here as defined by the INQUA Neotectonic Commission (Mörner, 1988). Morphological and structural analyses were integrated. Analysis of the relationships between structures and landforms was mainly concentrated on medium-scale features equivalent to the fifth and sixth orders of the Cailleux–Tricart Taxonomic Classification (Tricart, 1965). In these units, the influence of tectonic movements is no longer direct, and landform characteristics depend mostly on the morphogenetic systems.

Morphotectonic analysis was concentrated on the Campos de São Francisco along lineaments of the

Jundiuvira Fault where the morphological expression of faulting is more marked.

*Shaded relief maps* obtained from the digital terrain model, LANDSAT images (1:100,000) and aerial photos (1:60,000) were used to trace lineaments (Liu, 1987; Riccomini and Crósta, 1988). The following morphometric documents were elaborated in order to help the identification of descontinuities and anomalies that might suggest neotectonic control of the relief (Deffontaines, 1989): maps of isobase (Filosofov, 1960 cited in Golts and Rosenthal, 1993), hydraulic gradients (Rodriguez, 1993), drainage density (Horton, 1945), and lineament density, at the scales of 1:10,000 and 1:50,000.

Geomorphological mapping based on aerophotointerpretation (1:60,000 and 1:25,000) and combined field work provided geologic and geomorphic data on the relief compartments, Quaternary deposits and neotectonic structures. Structural analysis was done along the structural alignments of greater morphological expression, evinced by the morphometric analyses and detailed geomorphic mapping. The brittle faults identified within the study area were treated by graphic methods (Angelier and Mechler, 1977; Angelier, 1994) in order to identify the Quaternary stress regimes. The direction of fault movements was determined by kinematic indicators (Petit, 1987; Angelier, 1994; Doblas et al., 1997). Characterization of the joint families followed the Hancock and Engelder (1989) classification, which has been used in previous work in the rift region (Salvador and Riccomini, 1995; Hiruma, 1999).

Radiocarbon dating of soils and palaeosols developed upon colluvia and cut by brittle structures made it possible to establish the chronology of the neotectonic events.

## 4. Structures and morphological features of the Campos de São Francisco area

Campos de São Francisco (Figs. 2 and 3) is the highest (1900–2009 m), elongated *campos* area on the SE border of the plateau. Its NW limits are marked by a conspicuous NE-trending fault zone; the SE edge is part of the scarp of the large Mantiqueira fault block. This altos campos area is characterized by low relief (40–50 m), deep weathering, generalized hill-slope convexities, shallow slope depressions, and relatively broad flood plains filled with peaty sediments. The erosion amphitheaters, typical of the Campos do Jordão, are here less common, smaller, and usually concentrated along the more conspicuous lineaments.

Morphostructural lineaments indicate the following main trends: NE–SW, coherent with the old metamorphic foliation and strike-slip faultings, N–S and NW–SE (Figs. 2 and 3). Morphometric analyses show relatively low values of the hydraulic gradient ($<0.1$) and slope angle ($<10°$) and well-spaced isobase lines, defining a little dissected relief. The Campos de São Francisco also corresponds to an anomalous high-density drainage area, attaining values greater than 6 km/km$^2$ in the intersection of NE–SW, NW–SE, and N–S faults (Hiruma, 1999).

### 4.1. Structures

Three main types of brittle structures (faults and shear joints) were identified along the Precambrian Jundiuvira Fault from detailed structural analyses (Hiruma, 1999). The first is represented by subvertical reactivation faults exhibiting an orthogonal pattern with ENE/WNW and NNW trending and right and left lateral displacements, respectively, besides normal components in both directions (Fig. 4a). This association of structures indicates a NW direction for $\sigma_1$; the subvertical dip and the presence of a predominant strike-slip component imply a tectonic regime with a vertical orientation for $\sigma_2$, thus leading to a general strike-slip regime. These faults are in accordance with a right-lateral transcurrent binary of E–W direction, with a NW–SE compressive regime (Fig. 4a) similar to that seen in the rift, of probable Late Pleistocene to Holocene age (Riccomini, 1989). Such faults cut the stone-lines found on top of the weathered bedrock, which correspond to the regional paleopavement (Modenesi, 1988a), dating probably from the end of the Pleistocene (Fig. 5).

The second type of structures is a set of NE–SW, ENE–WSW and N–S normal faults with centimetric to decimetric vertical displacements (Fig. 4b). The NE–SW and ENE–WSW faults are roughly parallel to the Jundiuvira fault zone and develop along the planes of weakness represented by the metamorphic foliations of the Precambrian rocks. Sets of sub-

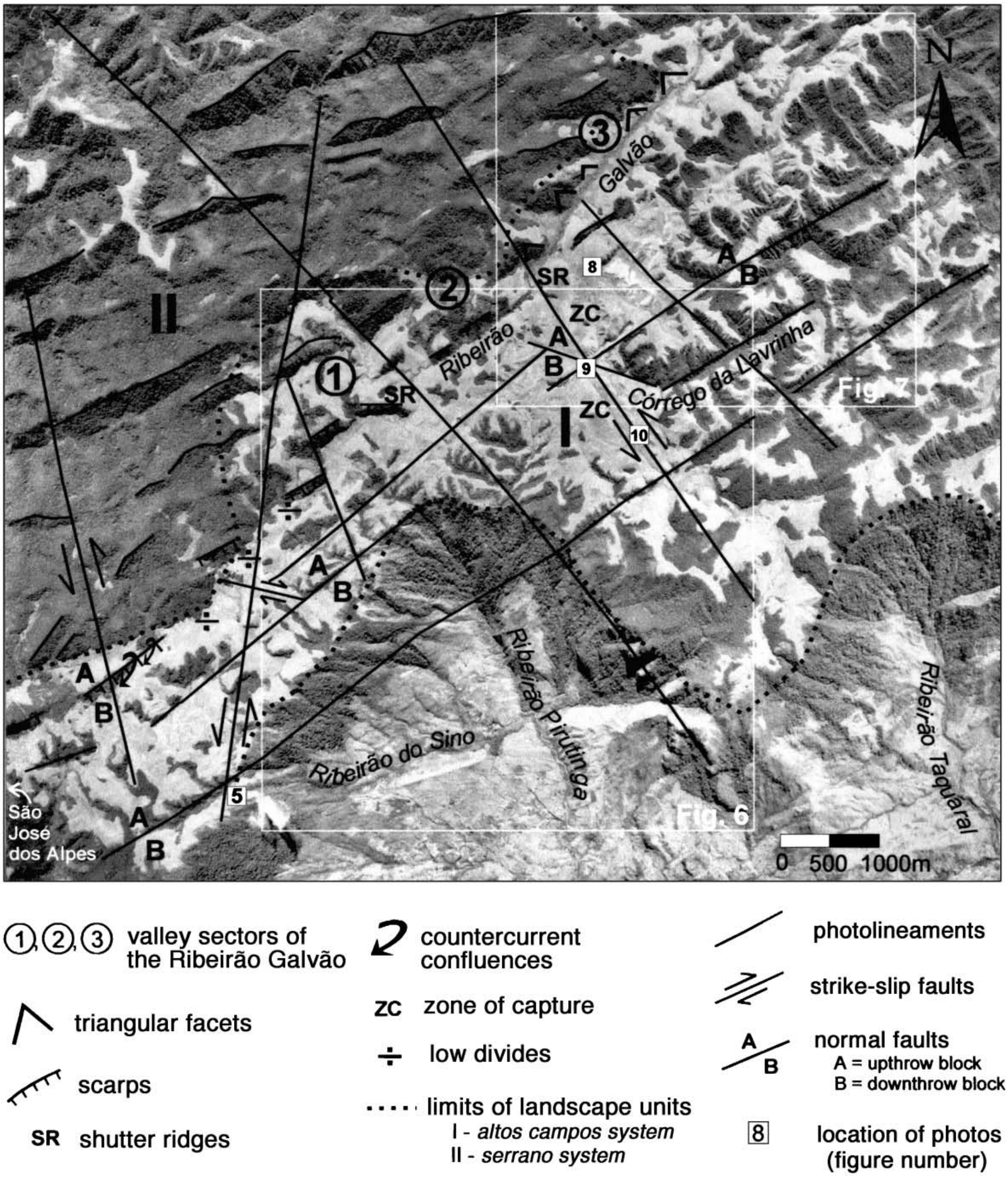


Fig. 3. Main structures and morphotectonic features in the Campos de São Francisco area along the Jundiuvira Fault alignment (1:60,000 vertical aerial photo).

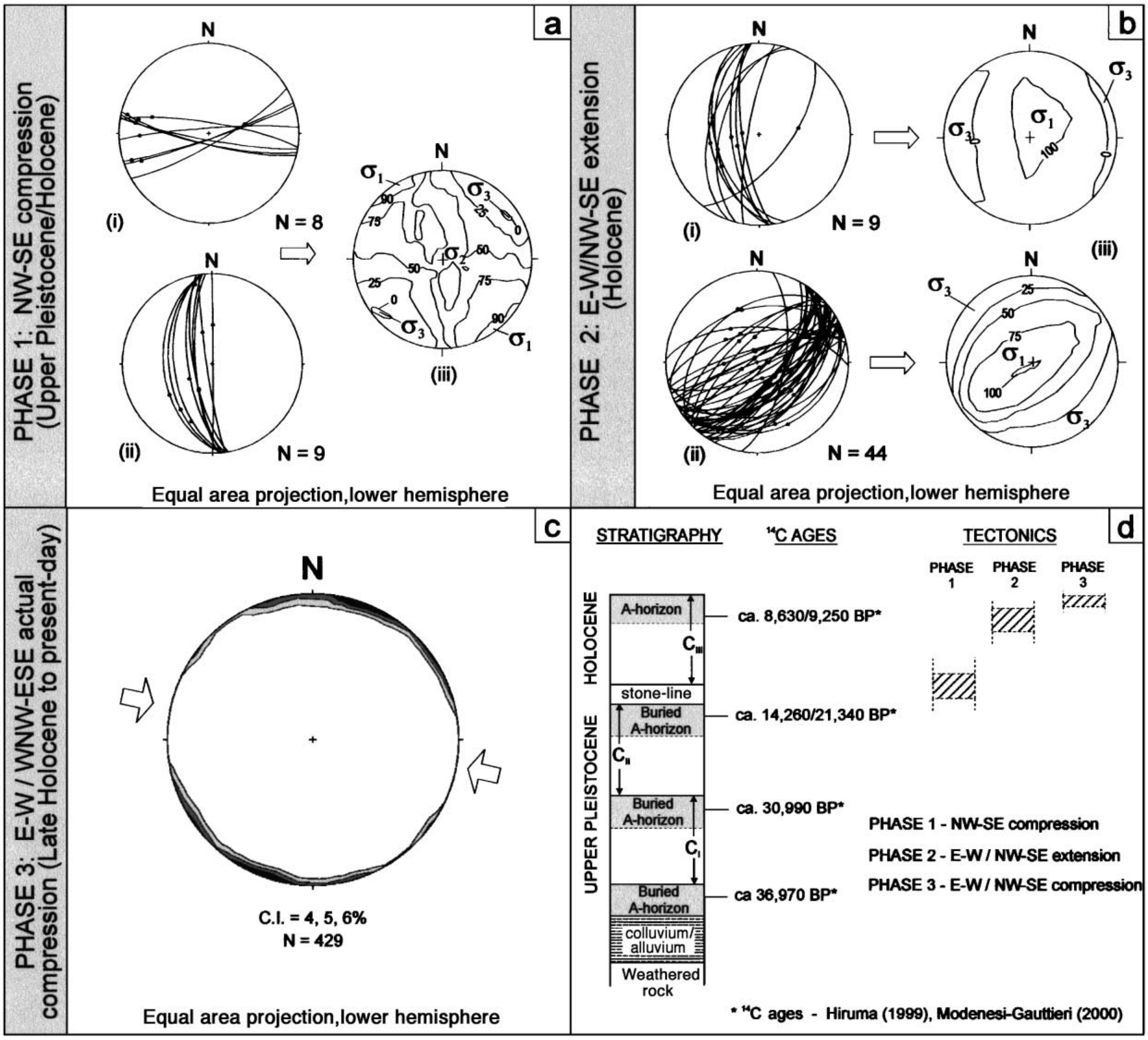


Fig. 4. (a) Faults related to the E–W transcurrent binary (NW–SE compression): (i) ENE–WSW/WNW–ESE right-lateral strike-slip faults (great circles) and striae (dots); (ii) NNW–SSE left-lateral strike-slip faults (great circles) and striae (dots); (iii) results of application of the method of Angelier and Mechler (1977) for the fault population, where the higher and lower isoline values (in %) indicate, respectively, the higher and lower probability fields for the maximum ($\sigma_1$) and minimum ($\sigma_3$) stress axes. (b) Faults related to the E–W/NW–SE extension: (i) N–S normal faults (great circles) and striae (dots); (ii) NE–SW normal faults (great circles) and striae (dots); (iii) results of application of the method of Angelier and Mechler (1977). (c) Families of joints related to the NW–SE compression that cut colluvium ($C_{III}$) and surficial humic horizons. C.I. = contour interval from the center of the diagram; arrows indicate the maximum stress axes ($\sigma_1$). (d) Tentative relationship between tectonics and Quaternary sedimentation in the Campos do Jordão Plateau (Vila Nova Suiça sequence); stratigraphy of Quaternary deposits after Modenesi (1988a,b).

parallel fault planes with decimetric spacing may be identified at outcrop scale. These faults are compatible with an E–W to NW–SE extension regime (Fig. 4b) similar to the one observed in the rift. The normal faults, more recent than the strike-slip faults of the previous phase, cut the stone lines and the basal part of present thick dark soils dated ca. 9250 and 8630 years BP (Hiruma, 1999).

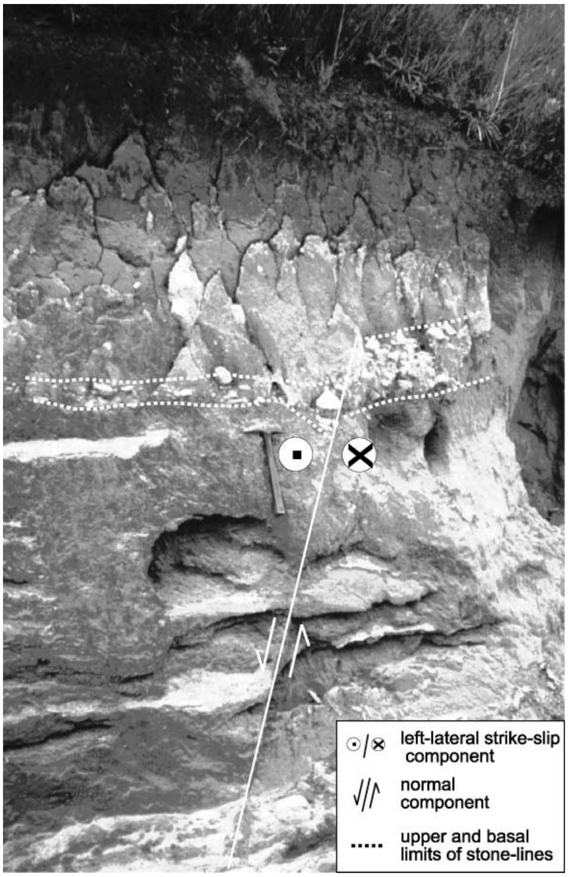


Fig. 5. Late Pleistocene strike-slip fault with normal component displacing stone lines. Vertical offset of about 20 cm due to the main strike-slip component. Notice the difference in stone line thickness at both sides of the fault.

The more recent brittle structures would be represented by probable neotectonic joints (in the sense of Hancock and Engelder, 1989), which cut the more recent colluvia from top to bottom. These shear joints show decimetric to metric spacing and subvertical dips determining diedral angles $< 45°$ (horizontal $\sigma_1$ situated in the bisectrix of the acute angle). Neotectonic joints could be differentiated from the subangular or prismatic pedological structures of the Campos do Jordão soils (Comissão Nacional de Solos, 1960) by their penetrating character (in some profiles, joints go down to the bedrock), great lateral continuity and, mainly, by the persistence of strikes and dips. Joint arrangement suggest a E–W to NW–SE compressive stress regime compatible with the directions of the present maximum horizontal stress (Fig. 4c) identified in the SE of Brazil from geophysical data (e.g. Assumpção, 1992).

A tentative correlation between sedimentation and tectonics in the Campos do Jordão Plateau is shown in Fig. 4d.

### 4.2. Morphotectonic features

Intersection of NE- and NNW-trending faults divide the plateau into rectangular blocks — confirming previous hypothesis (Ruellan, 1952; Modenesi, 1988a) — and play a major role in the geomorphic compartmentalization of the region.

Over a distance of approximately 12 km, between São José dos Alpes and the end of the meandering sector of the Ribeirão Galvão — where it leaves the *altos campos* to initiate the descent of the Mantiqueira escarpment — the Jundiuvira fault has a continuous and clear topographical expression. Relief adjustment to the general NE trend results in the alignment of asymmetric valleys with straight SE-facing scarps (Figs. 3, 6 and 7).

In the first 6 km, an almost continuous scarp, 30–70 m in height, with frequent rock outcrops follows the short subsequent courses of the Ribeirão Grande and Ribeirão do Sino, both from the Paraiba do Sul drainage basin. Their headwaters are separated by low divides that coincide with the NNW-trending transcurrent faults (Fig. 3). Along the Ribeirão dos Sinos, structural control is expressed by geomorphic features such as countercurrent confluences and hanging valleys (Fig. 3).

The Jundiuvira lineament continues to the NE in the Ribeirão Galvão valley, which may be divided into three distinct sectors (Fig. 3) characterized by specific geomorphic features. Knickpoints separating these valley sectors are located at the crossing of NE- and NNW-trending faults (Fig. 3), in areas of uniform lithology (milonite-gneisses). The two upper sectors correspond to the river's subsequent course, adjusted to the general NE–SW direction of the old structures; in the third sector, the valley turns to the NNE, cutting a series of parallel ridges at approximately 45° (Fig. 7).

The first valley sector (Fig. 6) is U-shaped with a 250-m-wide flood plain bounded by continuous SE-facing scarps up to 70 m in height; bedrock outcrops at different levels in hillslopes. Valley asymmetry is

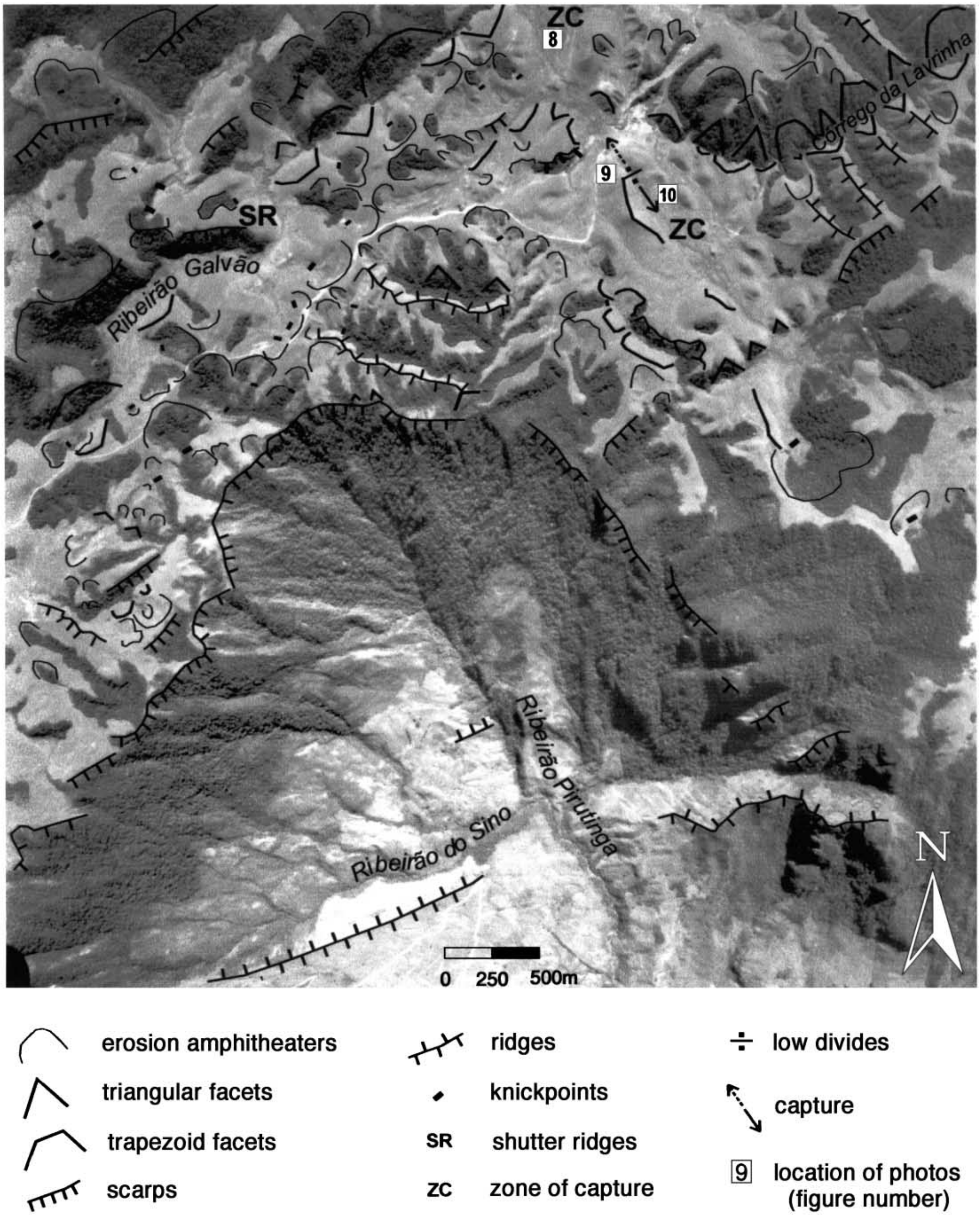


Fig. 6. Erosion amphitheaters and morphotectonic features in the first and second valley sectors of the Ribeirão Galvão (1:25,000 vertical aerial photo).

accentuated by the contrast of hillslope forms: NW-facing slopes are more convex and have poorly developed amphitheaters; triangular facets may appear on the rectilinear sector of lower slopes. There are no terraces or evidence of fluvial incision. Transition to the downstream sector (Figs. 3 and 6) occurs at the

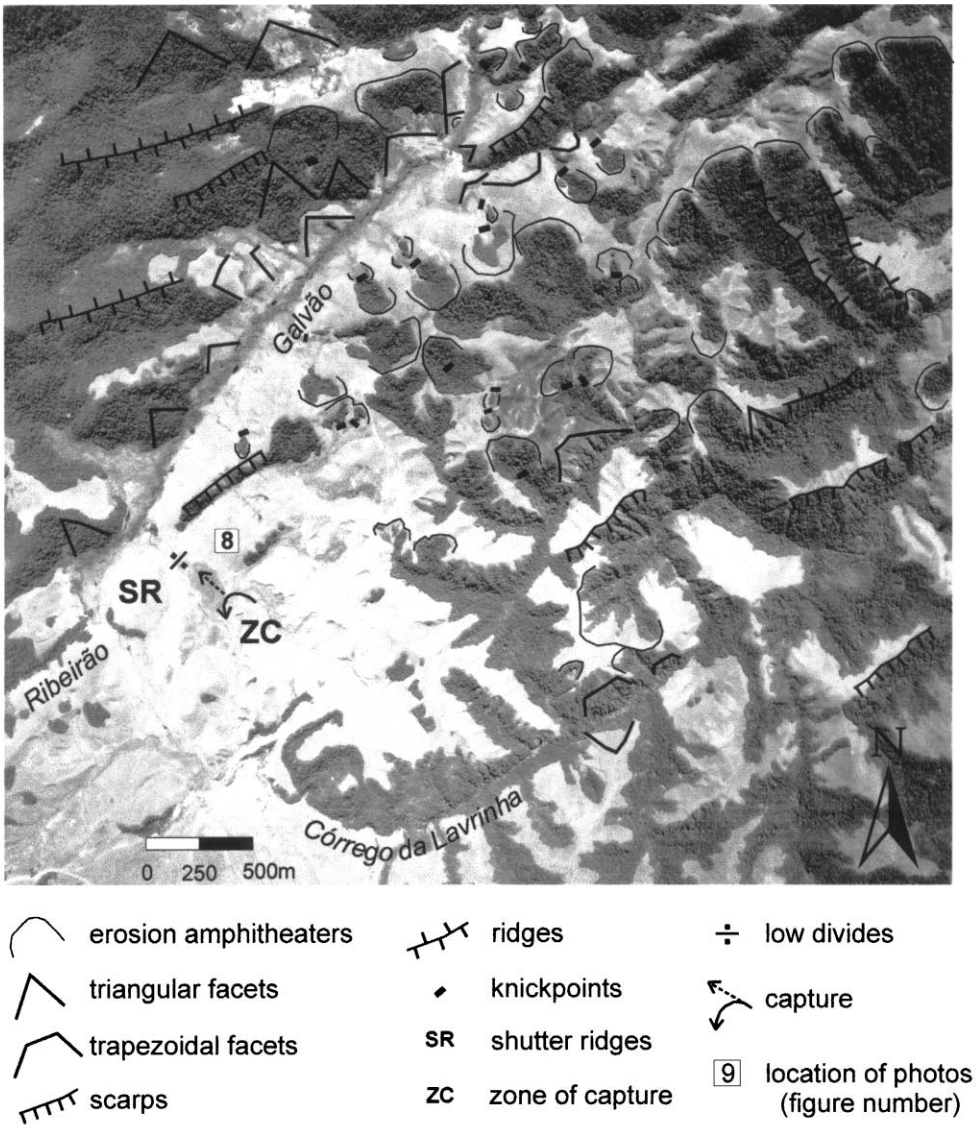


Fig. 7. Erosion amphitheaters and morphotectonic features in the third valley sector of the Ribeirão Galvão (1:25,000 vertical aerial photo).

intersection of the ENE structures with a NNW-trending strike-slip fault being marked by probable shutter ridge. This fault segment is evident on the plateau's escarpment in the high slope gradients and hanging triangular facets of the deep embayment around the headwaters of the Ribeirão Pirutinga (Fig. 6).

In the second sector (Figs. 3 and 6), S-facing scarps are rectilinear and continuous, averaging 30–50 m in height. N-facing slopes are more complex and may present triangular facets and two generations of amphitheaters. In this valley sector, the river meanders in a narrow plain without terraces. Transition to the downstream sector, with probable shutter ridges and a *complex zone of capture*, also occurs in an area of intersection of the general NE trend with a NNW strike-slip fault (Figs. 3 and 7).

In the third valley sector (Figs. 3 and 7), the river meanders in a larger flood plain, from 75 to 120–

Fig. 8. Broad swampy alluvial plain developed at the intersection of NE- and NNW-trending faults in the northern part of the *complex zone of capture* where the Galvão and Lavrinha basins are separated by a 6–7-m divide. Tilted block in the background.

150 m wide, with oxbow lakes aligned on both sides of the channel. Local relief is about 80 m. Remnants of triangular facets persist in the S-facing hillslopes; the more recent ones show scars of mass movements. At the N-facing hillslopes, two amphitheater generations are conspicuous; older amphitheaters occur hanging at upper slopes. The more recent ones are related to the transition between gentle convex upper slopes and abrupt lower ones (Fig. 7); rocky ramps of about 15° covered with quartz angular clasts extend from the base of amphitheaters to the flood plain. Low gravel terrace deposits reworked by colluvia appear only at the end of the third valley sector where the valley widens forming a small basin (*alvéolo*), but equivalent topographic levels may be recognized on the north-facing hillslopes.

Knickpoints, poorly marked divides, and probable shutter ridges always occur where NE normal faults intersect NNW-trending transcurrent faults (Fig. 3). Such intersections would also favor the capture of subsequent courses by streams of the Mantiqueira scarp (Fig. 6).

In the Galvão–Pirutinga–Lavrinha watershed on the plateau's edge, a series of piracy phenomena have modified the drainage network, defining a complex zone of captures (Figs. 3, 6 and 7) that can be divided into two parts. At its northern part, the Galvão and Lavrinha headwaters are separated by a poorly marked divide, 6–7 m in height; probable shutter ridges, elbows of capture, and a large swampy flood plain (Figs. 7 and 8) suggest capture of tributaries of the Ribeirão Galvão by the Córrego da Lavrinha. In the southern part of the zone of capture, the Lavrinha and Pirutinga headwaters are separated by an 8-m divide (Fig. 9). The "mature" relief that characterizes this area (Fig. 10)—low relief, extremely convex hills, and relatively large valley sectors in contrast with the present drainage—would be a heritage, landforms would probably be related to the paleovalley existing prior to the captures. Active hillslope erosion features and incipient sand fans (Fig. 10, insert) indicate the post-capture resumption of erosion.

## 5. Neotectonics and morphogenesis

Faults identified in the Campos do Jordão Plateau may be grouped in three main neotectonic stress regimes: (i) a compressive NW–SE regime, well characterized by strike-slip faults in accordance with

Fig. 9. Eight-meter divide separating the Lavrinha from the Pirutinga basin.

an E–W right-lateral transcurrent binary, probably terminal Pleistocene, or younger, judging from the age attributed to the stone-lines displaced by faults; (ii) an E–W/NW–SE extension regime evinced by normal faults cutting the base of Holocene colluvia dated ca. 9000 BP; (iii) a final E–W/NW–SE compressional phase characterized by the system of neotectonic joints cutting the present soil profiles from top to bottom. All three reactivations are younger than the Late Pleistocene since faults from the three systems cut the *regional paleopavement* buried by colluvia.

These neotectonic phases are also registered with similar characteristics and age in the Paraiba valley in accordance with the tectonic regional model established for the Continental Rift of southeastern Brazil (Riccomini, 1989). The rapid change of stress fields


Fig. 10. The *altos campos* in the southern part of the *complex zone of capture*. Relief of approximately 15 m and extremely convex hillslopes are probably relictual, related to the morphology of a paleovalley prior to stream captures by the Paraiba basin. Incipient sand fans (insert) indicate post-capture resumption of hillslope erosion.

observed during the Late Pleistocene and the Holocene in the plateau is probably related to the surface relaxation and normal faulting within a regional compressive stress regime in southeastern Brazil, as indicated by geological and geophysical data (Riccomini and Assumpção, 1999).

The relief of the Campos de São Francisco retains clear geomorphic evidence of neotectonic activity along the Jundiuvira shear zone, where conspicuous morphotectonic features occur superimposed upon the main fault systems of three Pleistocene–Holocene reactivation phases. However, it is not always possible to establish a direct relation between neotectonic structures and landforms.

Many of the morphotectonic features found in the *altos campos* predate paleopavement formation. For instance, rectilinear scarps, triangular facets (except for the most recent ones) and hanging valleys are most probably related to previous phases of the geomorphic evolution of the plateau. In the case of scarps, the recent age and centimetric to decimetric displacements of reactivation faults make it difficult to associate a relief of tens to hundreds meters with the structures. It is probable that the actual scarp height corresponds to the sum of individual displacements of normal faults in successive tectonic reactivations. However, identification and dating of these reactivations is hindered by the lack of deposits older than the Late Pleistocene.

On the other hand, some landforms and drainage anomalies could be related to the postpaleopavement reactivations. Knickpoints and shutter ridges separating the Galvão valley as well as low divides at the headwaters of the Ribeirão do Sino and Ribeirão Pirutinga (Fig. 3) seem to be related to the first of the three neotectonic reactivations, since they always occur where NNW-trending strike-slip faults cut the NE trends. The differentiated patterns of drainage and terrace distribution shown in each of the Galvão valley sectors would thus correspond to variations in river slope imposed by the right-lateral transcurrent tectonic activity of the first phase. The poorly marked divides separating the Galvão–Lavrinha–Pirutinga headwaters (complex zone of captures, Figs. 6 and 7) that occur in the valley flat, below the level of gravel terraces, give an indication of their recentness; these divides would also be related to the first neotectonic phase. The most recent triangular facets may be associated with the normal faults of the second phase.

As shown by the location of captures always at the intersection of reactivation faults (Fig. 3), piracy phenomena in the Campos de São Francisco seem to be related to factors other than the more rapid headward erosion of streams with a steeper gradient close to the Mantiqueira scarps.

Formation of erosion amphitheaters in the Campos do Jordão area has been explained by the triggering of successive phases of intense mass movements on hillslopes. The cyclic character of this evolution suggests changes in the bioclimatic conditions involving episodes of rainfall concentration and vegetation thinning (Modenesi, 1988a,b). The hypothesis of recent tectonic influence raised previously is now reinforced by structural data. Alignment of erosion amphitheaters along reactivated faults, often with faceted-spurs separating successive amphitheater generations, points to interference of neotectonic activity in the geomorphological evolution. Pleistocene phases of enhanced denudation on hillslopes were probably due not only to climate-related Quaternary environmental changes but also to neotectonics.

## 6. Conclusions

Relief and landscape patterns of the Campos do Jordão Plateau reflect the evolution of a tropical block mountain submitted to the combined effects of tectonic factors inherent to its passive continental margin setting and Quaternary climatic oscillations.

In southeastern Brazil, fault displacements associated with the Mesozoic and Cenozoic tectonic events—opening of the south Atlantic (Early Cretaceous) and formation of taphrogenic basins such as the Taubaté basin (Paleogene)—are recorded as tectonic reactivations along older discontinuities. Recognition of this pattern in the Campos do Jordão Plateau evinces the importance of structural heritage in the neotectonic framework and geomorphic evolution of the plateau. Recurrent uplift and alternation from strike-slip to normal faulting have led to relief rejuvenation. The incision of the plateau by narrow, steep-sided valleys indicates rapid tectonic uplift.

The three Late Pleistocene to Holocene tectonic reactivations identified in Campos do Jordão are in accordance with the contemporaneous fault systems of the neighbouring rift and seem to have a regional character. Absence of sediments older than the Late Pleistocene hinders identification of previous tectonic pulses in the plateau and explains the great Precambrian–Late Pleistocene hiatus in the evidence for reactivation. The only available evidence for this interval is morphological, since hillslope deposits showing brittle structures are all younger than the Late Pleistocene.

Effects of tectonics on landform development can be seen both regionally and at the local scale. In the Campos de São Francisco, normal and strike-slip reactivation of the Precambrian faults gave origin to morphotectonic features such as rectilinear scarps, triangular and trapezoidal facets, hanging valleys, and shutter ridges. Intersection of NNW strike-slip faults with the NE trends divided the plateau into rectangular blocks thus separating the *altos campos* and the Ribeirão Galvão into distinct compartments. These intersections also had a strong influence upon the present drainage, being preferential sites for the stream piracy phenomena observed in headwaters along the Mantiqueira divide.

Persistence of tectonic landforms despite the action of the humid tropical processes of the *altos campos* landscape system could in itself be an indication of the recency of the tectonic activity.

Whether originally climatic or tectonic, the formation of amphitheaters in the Campos do Jordão Plateau remains dubious. The geomorphic evolution of the *altos campos* most probably results from the interaction of tectonic and climatic controls (Modenesi-Gauttieri, 2000). Neotectonic influence can be recognized in the geomorphic compartmentalization of the plateau, in recent changes in the drainage pattern and in some landforms. Imprints of the climate-controlled processes of weathering and pedogenesis and of transportation on hillslopes are evident in the montane tropical landscape system and well expressed by the vegetation mosaic. However, the integration of neotectonics and morphoclimatic influences in the evolution of the *altos campos* is still not completely understood.

## Acknowledgements

This research was partially supported by the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP). We wish to thank the two referees for their constructive criticism and Paulo Emilio Vanzolini for improving the English text.

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