

FOURTH INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY - Italy 1997

Session: Tropical Geomorphology

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**KARSTIC-TYPE FORMS AND LANDSCAPE EVOLUTION
IN TAUBATÉ BASIN (SÃO PAULO, BRAZIL)**

ABSTRACT: COLTRINARI L., *Karstic-type forms and landscape evolution in Taubaté basin (São Paulo, Brazil)*. (IT ISSN 0391-9838, 1999).

Morphological mapping of depressions, amphitheatre-like valley-heads and other karstic-type features was performed to demonstrate the extent of landforms of geochemical origin in the upper reaches of Taubaté sedimentary basin. Interpretation of aerial photographs ~1:25.000 surveyed before Presidente Dutra highway opening (probably in the middle '40s) allowed the detection of surface features prior to landform degradation by urban growth and industrialisation. The choice of a morphological key aimed to stress changes in form and direction of slope over the interfluvies and valley slopes in São José dos Campos plateau.

Differences in shape, size and distribution of depressions within the research area are evident. In the SW extremity wide level interfluvies predominate, depressions are isolated or within amphitheatres at valley heads and drainage density is low. In the NE section depressions are more numerous and vary in size, shape and distribution; they may be flooded or present swampy bottoms. Flat concave areas were interpreted as dry depressions related apparently to a former higher level of the water table.

References to the geochemical origin of depressions and karstic-type features appear repeatedly in the literature. Only recently was confirmed that these landforms evolve by vertical exportation of soluble material from the base favoured by lithological or tectonic discontinuities. The dominance of geochemical evolution of landforms and soils allows the adoption of a landscape evolution model homologous to etchplains.

KEY WORDS: Karstic-type landforms, Morphological mapping, Geochemical processes, Landscape evolution, SE Brazil.

INTRODUCTION

Morphogenetical origin related to semi-arid episodes during the Pleistocene ice-ages has been accepted to ex-

plain Cainozoic landform evolution in the Brazilian tropics. Until this decade only geomorphic data -morphology and correlative deposits- were used as a basis for landscape evolution models. (Bigarella & alii, 1961; Bigarella & alii, 1965a, 1965b; and others). Reassessment of Quaternary chronologies and discussions regarding the nature of morphogenetic processes and their relationships with unconsolidated materials covering landforms (Coltrinari, 1992) led to the reconsideration of those models. Results from research on processes acting over and within the soil cover (Castro, 1989; Filizola, 1993; and others) confirmed the dominance of chemical processes in accordance with zonal climatic parameters and allow the proposal of a new hypothesis for landscape evolution in southeastern Brazil (Coltrinari & Filizola, 1993) similar to etchplanation.

In his analysis of landforms in the tropics Thomas (1994) includes channeless headwater valleys or *dambos* (central Africa) in areas of low relief, known also as *vleis* in southern Africa. Those features were previously identified as *Flachmuldentäler* by Louis (1957) and as «wash depressions» (*Spülmulden*) by Büdel (1957, 1965, 1982). In Taubaté basin Coltrinari & Nogueira (1989) described also *dambo*-like forms in sedimentary terrains. In humid tropical areas evidences of etching and chemical denudation of the basement rock below those valleys were mentioned by Thomas & Thorp (1980) so *dambos* could be degradation forms linked to deep soils and surface downwearing by weathering and chemical erosion.

Those «zero-order» basins frequently present an amphitheatre-like valley-head or hillslope hollow. According to Thomas (1994) some studies indicate that slopes in the hollow evolve by mass-wasting due to high water levels in the soil after prolonged rains. Similarities in shape between amphitheatres and closed depressions led Filizola & Boulet (1996) to investigate the process of evolution from depressions to valley-heads. They concluded that depressions sinking by chemical erosion is rapid and their opening is related to lateral flow of perched groundwater through a lower col after heavy rains favouring quick drainage of de-

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This research was partially supported by CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) grant 302012/76-1(RN). We are grateful to the Remote Sensing Laboratory (Departamento de Geografia USP) for the long-term lending of aerial photographs; to Dr. M. De Biasi and M. A. Rocha for technical advice on design and edition of the original morphological map; to P. Rosa that re-drew maps for this paper, and to Instituto de Pesquisas Tecnológicas de São Paulo (IPT) for free cession of São José dos Campos mapping survey and plotting of the UTM grid.

pressions, i.e., the outlet results from the internal dynamics of depressions rather than from capture.

Depressions can be found on summits and plateau surfaces without ironcrusts both on siliceous and carbonate rocks. Their origin is related to dissolution of basement rock and the absence of outlets indicates that weathering products are exported predominantly in solution via macropores or through fractures (Filizola, 1993; Filizola & Boulet, 1993). They have been described in Africa (Boulet, 1964; Humbel, 1964; Soubiès, 1974; McFarlane, 1976, among others), in New Caledonia (Trescases, 1975) and in Papua New Guinea (Löffler, 1978) (see also Filizola & Boulet, 1996).

According to Thomas (1994) depressions take part in the general lowering of landscape surface through solution of rock and soil minerals in small areas but their recurrence in all morphological compartments suggests a significant participation in surface downwasting. In the NE sector of the study area depressions in deep latosolic covers appear isolated or intermingled with shallow valleys in complex patterns.

In Brazil these depressions occur in metamorphic rocks as in the *serras* do Mar and Mantiqueira, and in quartz-kaolinitic sedimentary rocks in Taubaté basin. Their origin was associated to geochemical evolution by Ruellan (1943), Ab'Sáber & Bernardes (1958), Raynal (1960), Suguio (1969) and Coltrinari (1975). More recently Coltrinari & Nogueira (1989), Coltrinari & Filizola (1993) and others corroborated the presence of depressions and amphitheatres in interfluves, slopes and floodplains. Depressions may be dry, waterlogged or permanently flooded, closed or with uncertain links with shallow valley-bottoms Amphitheatre-like valley-heads are found in the minor right-margin tributaries of the Paraíba do Sul river in the study area as well as on hillslopes of a low plateau in the opposite margin near Guaratinguetá.

The recent demonstration of geochemical origin of depressions and confirmation of their relationships with the evolution of soil cover, slopes and drainage network by Filizola (1993) and Filizola & Boulet (1993, 1996) suggested that mapping of depressions and associated forms could be an adequate means to demonstrate the extension and diversity of karstic-type forms in the area, and therefore contribute to support a new landscape evolution model for the study area.

MATERIALS AND METHODS

The study area includes the upper section of Taubaté sedimentary basin approximately between the present location of São José dos Campos and Caçapava cities (fig. 1) known as São José dos Campos plateau. The two excerpts included in this paper (figs. 2 and 3) were selected from the original morphological map presented in the Conference to represent landforms within a land strip that follows nearly the interface between the hills on Tertiary rocks and the Quaternary floodplain of Paraíba do Sul river.

Geological and geomorphological background

Depressions and associated karstic-type landforms were studied in the upper middle section of Paraíba do Sul river basin (fig. 1). One of the basins located in the Atlantic Plateau in São Paulo, Taubaté basin is part of the Paraíba graben, a 220 km long depression partially filled by Tertiary and Quaternary fluvial deposits. Landforms were identified in rocks of the middle and upper sedimentary sequences – Taubaté (Upper Oligocene) and Pindamonhangaba (Miocene) – that fills the graben (Campanha, 1994). Those deposits are predominantly quartz-kaolinitic sediments (mudrocks and claystones), interbedded with and capped by coarser layers (sandstones and pebble layers).

The fault-line escarpments of *serras* da Mantiqueira (NW) and do Mar (SE) are the boundaries of the tectonic trough. Karstic-type landforms were identified on hilltops, slopes and valley bottoms in São José dos Campos plateau. High level summits (630 to 700 m) in the SW section of the basin and along the NE slope of Serra do Mar are the best preserved areas of a Middle-Upper Tertiary planation surface. Narrower and lower interfluves (610 to 630 m) appear downstream where fluvial dissection and a higher number of depressions contribute to the break-up of ancient landforms (Coltrinari, 1989). Deep oxisols and underlying ferrallitic weathering of sedimentary rocks predominate in this upper step of Neogene Surface (de Martonne, 1940). High percentages of kaolinite in oxisols and weathering profiles point to a high-leaching, humid or sub-humid environment with the coincidence of warm period and rainy season (Maignien, 1966).

Construction of the morphological map

The morphological maps (figs. 2 and 3) intend to represent depressions and their «basins», i.e., the land surface from which water and solid materials run into the doline-shaped concavities as well as features originated either by surficial water flows or groundwater circulation. Another purpose is to establish the location and type of breaks and changes of slope as well as the form and direction of true slope over the surface of interfluves, slopes and valley-bottoms before the opening of Presidente Dutra highway between Rio de Janeiro and São Paulo (around the middle forties) (fig. 1) and the uncontrolled growth of cities and industrialisation (ca. 1970). The basis for this essay on palaeogeomorphology was an aerial survey (calculated scale ~1: 25,300) taken by the Brazilian Army probably around 1945 and deposited in the Remote Sensing Laboratory of the Department of Geography (São Paulo University) since the decade of 1960. From the original collection of 54 vertical photographs only 40 are presently available, many of them seriously damaged because of inadequate storage and conservation. The sequence where the study area (14 photos) is included is complete with only with minor damages along the borders.

A Zeiss pocket stereoscope was employed for photoanalysis and a mirror stereoscope for the complete vision of each stereo pair. Field descriptions, maps and photographs

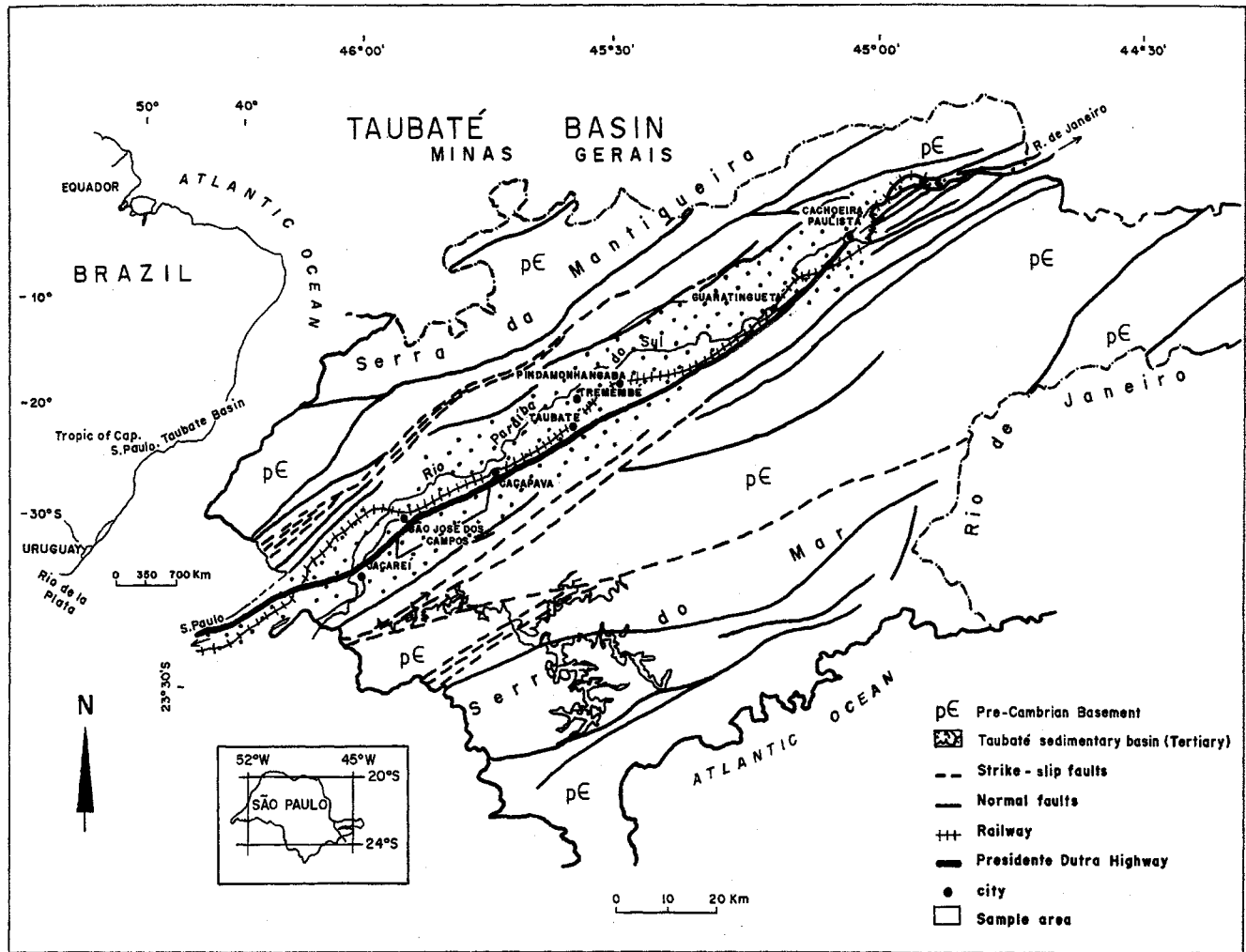


FIG. 1 - Taubaté basin and surrounding area (after Hasui & *alii*, 1978).

helped to complete or define interpretation where flaws in aerial photographs made it difficult. Overlays on Regma-phane polyester paper were first transferred to a horizontal planimetric map and for the final version they were adjusted to a UTM grid. The legend (fig. 4) was partially adapted from St.-Onge (1968), Doornkamp & King (1971) and Demek (1972).

RESULTS

The morphological map of São José dos Campos plateau depicts landforms presently destroyed or obliterated in the SW extremity of Taubaté basin, and confirms karstic-type landforms as typical landscape features in the study area. Considering mainly the morphology of inter-fluves and in a larger scale form, size and distribution of depressions and associated forms two different parts may

be distinguished. The first is located in the south-western part of the area approximately in the south and northeast quadrants around São José dos Campos, and the second near Caçapava extending to south and south west from the city. Details of those sectors are represented respectively in figs. 2 and 3.

In the SW sector (fig. 2) dry, flooded, waterlogged, and vegetated depressions were identified on the wide flat hilltops. The doline-shaped forms may be circular or elongated as in the upper part of Lavapés river valley, or arranged along an axis like those on the right margin of Alambari river. Actually they are located within amphitheatres-like forms as indicated by convex changes of slope above depressions. This is the case also with depressions in the upper part of Lavapés valley and around humid bottoms in the SW and NE areas. Around dry depressions evidences of former slope hollows are generally ill-defined, fragmentary, or absent except in the NW and

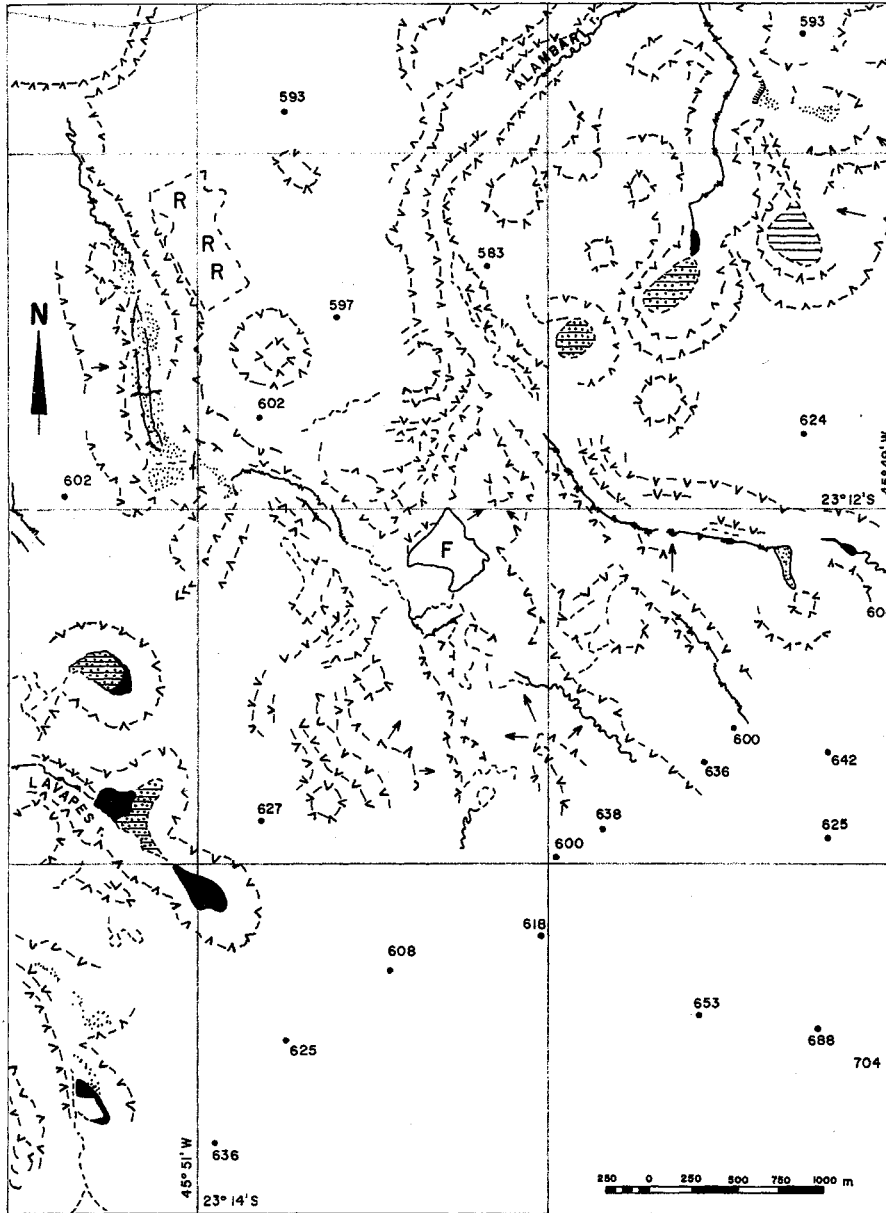


FIG. 2 - São José dos Campos plateau - SW sector.

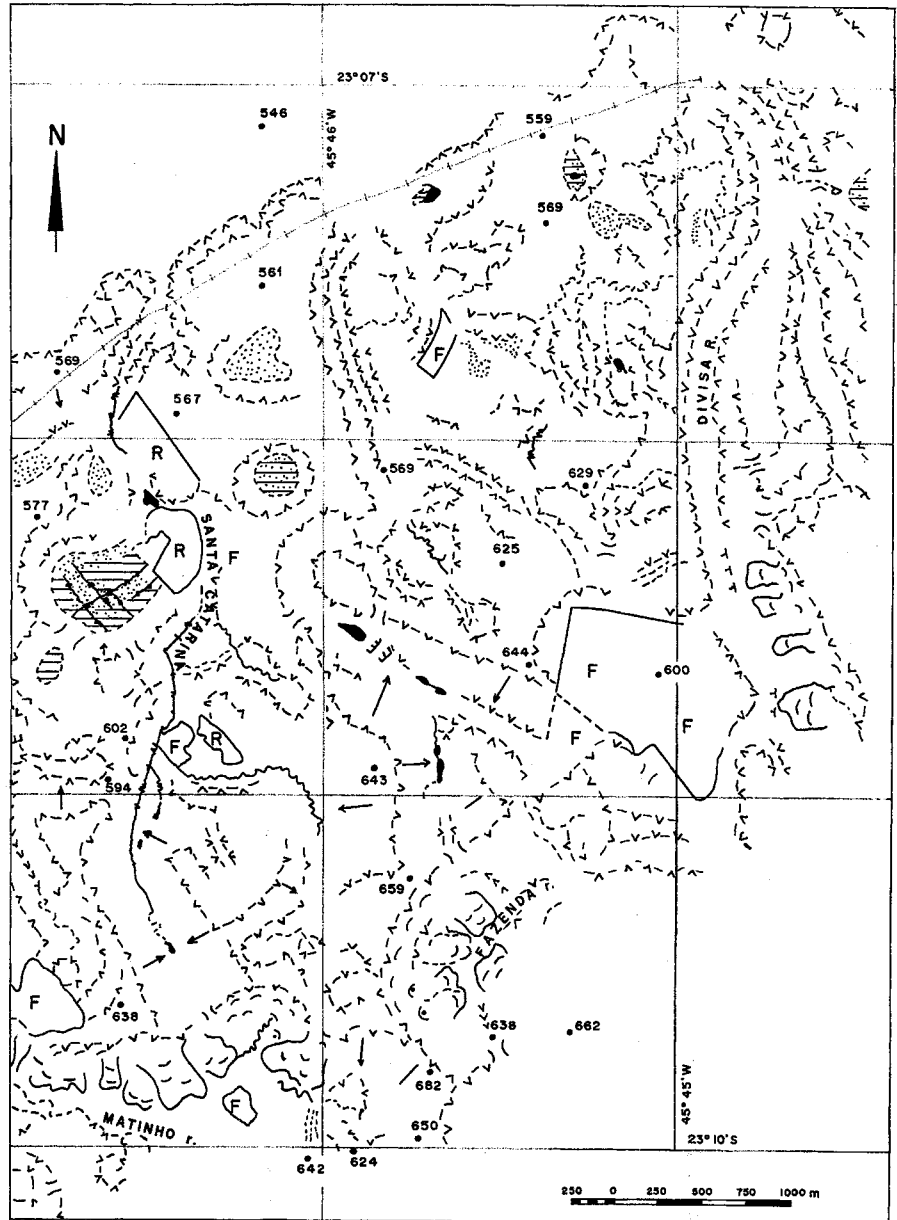
central areas of fig. 2. At the epoch of the aerial survey dry (inactive) depressions, segments of shallow dry valleys and traces of former concentrated flow were located roughly above 600 m in coincidence with Pindamonhangaba Formation exposures.

Depressions may be drained by a ditch excavated in concave valley bottoms or present traces of a former outlet. Diameter may be 250 m or more long but dry depressions are generally smaller and shallower than the functional ones. Traces of concentrated flow are also visible over the interfluvies isolated or within shallow elongated concavities, perhaps the remnants of former valleys. They appear also intercalated with short sections of tortuous

meandering channels along shallow bottoms with uncertain boundaries, as in the central part of fig. 2, indicating a low streambed gradient. Patches of waterlogged soil were identified along valley-bottoms and shallow concavities.

Towards Caçapava (fig. 3) interfluvies are narrower and lower than in the SW sector. Some small rivers as the Santa Catarina flow along open big depressions and swampy areas. Those depressions are sometimes linked upstream to smaller ones by a col while natural or artificial outlets communicate them with streambeds where canal cuts generally concentrate water within ill-defined valley bottoms. They are located mainly in the lower interfluvies around 560 - 600 m. There are also isolated depressions, circular or el-

FIG. 3 - São José dos Campos plateau - NE sector.



liptical, and segments of dry shallow streambeds. Dry depressions are scarce. Traces of concentrated flow are numerous either within dry streambeds or isolated over the interfluves.

Many cols cut narrow convex ridges or link hilltops to slopes. They may show evidences of concentrated flow from top to slope or appear immediately above flow scars on slopes. Sometimes those traces are related to springs located in high-gradient slopes within amphitheatres. Together with fissures, landslip scars and deposits those springs appear mainly along Matinho, Fazenda, and Divisa rivers and indicate an important participation of mass-wasting processes in slope evolution within the area.

DISCUSSION

Analysis of results suggest comments and inferences on the meaning behind landforms in the middle upper section of Taubaté basin up to the decade of 1940.

The opening of President Dutra highway was the first regional-scale intervention in the area and attracted industrial developments that provoked accelerated urban growth and drastic modifications in regional landscapes. So it is possible to consider that the geomorphological maps extracted from the aerial survey taken around 1945 include quasi-original landforms, i.e., submitted only to modifications by surficial processes and local anthropo-

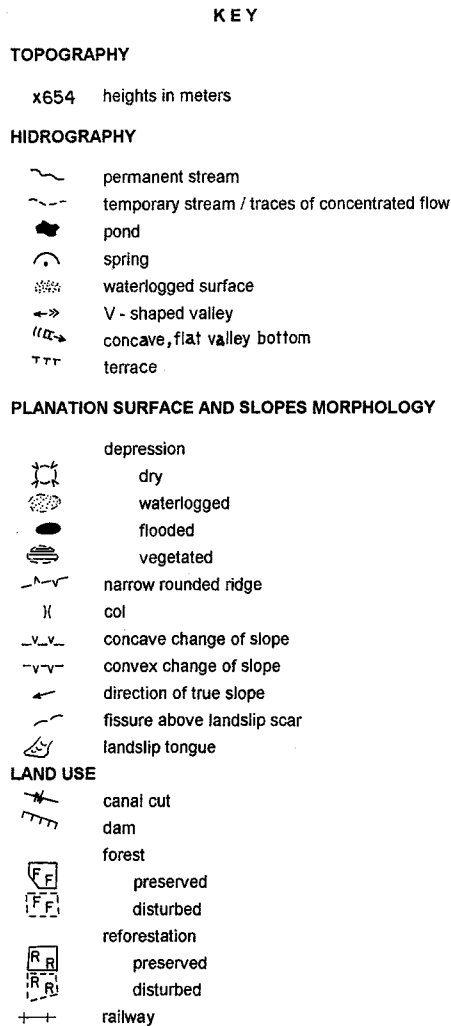


FIG. 4 - Key to the morphological maps (adapted from St.-Onge, 1968; Doornkamp & King, 1971, and Demek, 1972).

genic interventions that did not modify or obliterate their original morphology, distribution and relationships.

Depressions are significant features in the study area; together with amphitheatre-like valley-heads, dry shallow valleys and poorly defined streambeds they demonstrate landforms in a humid tropical landscape mantled by deep soil covers. Differences among depressions may be related to form, distribution, density and present state.

They may be elongated, circular or elliptical, especially in the SW sector over the higher remnants of the Neogene surface. When compared with the NE area frequency of depressions is lower as well as the number of active (flooded, swampy/waterlogged and vegetated) depressions. As to distribution or arrangement they may be isolated or linked to other depressions through cols and to streambeds by outlets as it happens in the NE area.

Some of those differences may be related to the geological and tectonic history of the research area. To explain

depressions evolution by vertical water loss following fault breccia as well as their location and density Filizola (1993) and Filizola & Boulet (1993, 1996) evoked a dense system of lineaments and the predominance of Pindamonhangaba Formation rocks around Caçapava.

By the same criteria the lower number of depressions in the SW sector can be related with a lesser number of tectonic discontinuities and more restricted exposures of Pindamonhangaba Formation beds near São José dos Campos. Nevertheless tectonic control is evident in the elongated depressions in the upper Lavapés valley and the arrangement of doline-shape forms on the right margin of Alambari river. According to the geological map in Campanha (1994) sites of depressions in this area coincide with exposures of Pindamonhangaba permeable rocks within Alambari basin, and isolated strips and patches over Taubaté Sequence rocks, as it is the case with Lavapés depressions. Perhaps the high clay/sand relation in Taubaté Sequence rocks could also contribute to explain the low number of solution forms in the higher hilltops due to low permeability of sedimentary beds.

Depressions and waterlogged/swampy areas are also good indicators of present water table position within each area and of geochemical activity as well. In the SW sector at the epoch of the aerial survey dry (inactive) depressions, segments of shallow dry valleys and traces of former concentrated flow were located roughly above 600 m in coincidence with Pindamonhangaba Formation exposures. The effaced convex changes of slope above some depressions indicate probably changes in surficial processes due to increasing lack of water within depressions. When swampy or flooded areas began to shrink geochemical sinking processes and increase of slope gradient were progressively substituted by colluviation (Filizola, 1993). Bottom aggradation probably induced progressive stability upslope that modified ancient changes and breaks of slope.

In the SW sector dry depressions and other non-functional forms related to a higher groundwater table level are more numerous than those near the present level while in the NE sector karstic-type active forms indicate that geochemical processes are still active. Though colluvia are found within depressions geochemical processes are still efficient as it is confirmed by present chemical weathering under depressions bottoms (Filizola & Boulet, 1996). Other demonstration of geochemical processes activity in the area is given by landslide scars and deposits within huge amphitheatres, a consequence of slope evolution by mass-wasting processes implying in a deep pedologic cover prior to mass movements. On the other hand an accurate explanation on the origin of these landforms should include instabilisation of slopes materials by tectonic adjustments along lineaments (Carneiro, 1977).

CONCLUSIONS

1) Regional extension of depressions and other karstic-type forms indicate the significance of geochemical processes in the study area.

2) Attributes of these landforms (form, distribution, present state – active/inactive – and relationships among them) reveal both endogenetic and exogenetic influences in their origin and evolution.

3) Progressive lowering of interfluvial and increasing number of depressions and slope hollows from SW to NE may indicate the degradation of the Neogene planation surface from Caçapava to the SW extremity of Taubaté basin. Degradation processes are probably linked to water table lowering to a regional base-level associated to Precambrian exposures cutting Tertiary sediments around Caçapava. Dry depressions, evidences of amphitheatre-like headvalleys, cols and dry shallow valleys demonstrate geochemical processes and surficial water circulation associated to a higher level of the water table.

4) Predominance of solution processes and restricted evidences of colluviation indicate that landscape evolution in São José dos Campos plateau has been related to geochemical processes and not to mechanical morphogenesis as suggested by evolution models presently accepted. Therefore humid tropical climate has been predominant in the area at least during the Upper Cainozoic.

5) We propose the substitution of those models and the application of etchplanation principles (Wayland, 1934; Willis, 1936; Büdel, 1957) i.e., the consideration of geochemical exports/material loss from the weathering front (Filizola, 1993) or basal weathering surface where etching progresses.

6) On the other hand evolution of the upper (soil/landforms) surface in São José dos Campos plateau does not seem to follow Büdel's (1957) model, i.e., the surface is not submitted to processes related to surficial water circulation. Evidences (Filizola, 1993; Filizola & Boulet, 1996, and others) indicate that material loss occur within the whole pedologic cover and geochemical erosion provokes the increase of slopes gradient, linked to base level lowering in depressions and valleys. Those data seem to corroborate de Martonne's (1943/1944) hypothesis on slope evolution in the study area by solution of rocks minerals.

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