HILLSLOPE DEPOSITS AND THE QUATERNARY EVOLUTION OF THE *ALTOS CAMPOS* - SERRA DA MANTIQUEIRA, FROM CAMPOS DO JORDÃO TO THE ITATIAIA MASSIF.

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ABSTRACT This contribution is an attempt to integrate results of 20 years of geomorphological investigation with new morphotectonic data and ^{14}C ages of colluvia and peat-rich sediments. The Quaternary evolution of the *altos campos* landscape, in the highest summits of the Serra da Mantiqueira, between the crystalline plateau of Campos do Jordão and the alkaline massif of Itatiaia, has a cyclic character, characterized by intensive episodes of hillslope degradation, by mass movements, and by stability intervals. Mass movement processes differ in each plateau according to environmental conditions. In Itatiaia, 500m higher than the Campos do Jordão Plateau, interference of geocryogenic activities was stronger. Since approximately 37,000 years BP, erosive and depositional events took place in the *altos campos* hillslopes, at Campos do Jordão (three colluvia with four intercalated soils) and Itatiaia (two colluvia over older scree deposits). The last and widespread colluviation episode is Holocene, with similar ages in both plateaus. The new data confirm the interference of Quaternary neotectonics in the landscape evolution of the *altos campos*, but the triggering of instability phases, whether tectonic or climatic, still remains to be clarified.

Keywords: Quaternary, hillslope evolution, weathering, colluvium, mass movements, geocryogenic processes, ^{14}C.

INTRODUCTION The relief of southeastern Brazil's Atlantic façade is closely related to its complex regional tectonic evolution. Senonian uplift, enhanced in the Paleogene by normal reactivation of old Brasiliano-Panafrican shear zones, gave origin to the continental rift of southeastern Brazil (Almeida 1976, Asmus & Ferrari 1978, Riccomini 1989) and to parallel northeast-trending relief features, horst-like uplands, semi-grabens and associated taphrogenic basins. Further Neogene and Quaternary uplift (Almeida 1976, Riccomini 1989, Almeida & Carneiro 1998) enhanced differences in altitude between the *rift* valley and adjacent raised units. These features are very conspicuous between São Paulo and Rio de Janeiro (Fig. 1) where the steep escarpments of Serra da Mantiqueira dominate the Paraiba valley from altitudes of more than 2,000m. The Mantiqueira highlands are one of the oldest drainage divides of the Brazilian plateaus (Ab'Sáber 1954), a starting point of relief evolution in southeast Brazil (Ab'Sáber & Bernardes 1958).

Remnants of the oldest regional erosion surface, the *campos surface,* were recognized by De Martonne (1940) on both sides of the Paraiba graben, in the high summits of the Serra da Mantiqueira, on the left flank of the rift, and on the right flank, in the Serra da Bocaina (Fig.1). The age of this surface is controversial. Freitas (1951) and Almeida (1976) believe it to be the result of Oligocene deformation of the Eocene *Japi surface*; Almeida & Carneiro (1998) based on recent tectonic, sedimentological and palynological evidence move back this age to the end of the Senonian. Ab'Sáber (1954) agrees with De Martonne's (1940) proposition, considering the *campos surface* as an independent erosion surface, older than the *cristas médias* (*Japi surface).*

Little of the original *campos surface* survives; where it occurs it is sub-levelled, dissected and degraded, being recognizable by accordance of summits. Probable remnants of the old surface would

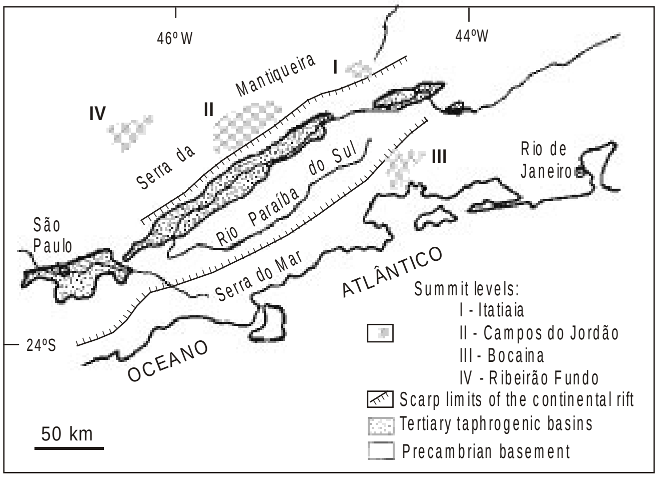

Figure 1 – Summit levels of southeastern Brazil and the Paraiba do Sul rift valley

only persist in the highest part of the Campos do Jordão Plateau, at the Mantiqueira divide, circumscribed by local base levels. Elsewhere, step-like erosion levels may occur below the summital surface. The three topographical levels mapped in Campos do Jordão between Morro do Itapeva and Vila Capivari (Modenesi 1983, 1988a) occur within the same block and do not present evidence of structural interferences; differential erosion has influenced the altitude limits of the levels and their preservation.

Absence of correlative deposits impeded interpretation of the summital surface. In the Campos do Jordão Plateau, remnants of alumino-ferruginous laterites and red latosols found above 1,800m (Modenesi 1980, 1983) allowed correlation of the *campos surface* with Early Tertiary hot humid or, more probably, hot subhumid ferralitic weathering processes. These processes contrast with the present tropical montane conditions and would have been active at lower altitudes, prior, at least, to the accentuation of the plateau's uplift. Levels below 1,800m have less weathered bedrock and are related to more recent phenomena, probably Pleistocene in age.

The Campos do Jordão and Itatiaia highlands are examples of structurally differentiated tropical mountains on the northwest flank of the Paraiba graben. The first named is a crystalline block mountain with an area of about 810km^2 and maximum altitude of 2,050m. Its rectilinear scarps, with twice the altitude of those of the Serra do Mar, rise 1500m above the middle Paraiba valley, forming the second major escarpment of eastern Brazil. Itatiaia is an alkaline massif with ringed structures (Fig.2), covering an area of about 220 km^2 and rising up to 2,778 m (Agulhas Negras). In the central part of the massif, the small and topographically lower area (2,300/ 2,500m) called *planalto* is nonetheless the highest of the southeastern Brazilian highlands, standing 500m higher than the neighboring Campos do Jordão Plateau.

The altitude and geographical position of the eastern Mantiqueira highlands in the humid tropics on the Atlantic façade of the continent determine a particular climatic regime, characterized by complex atmospheric dynamics, with the interaction of equatorial, tropical and polar air masses (Monteiro 1973; Conti, 1975) over a relief of considerable altitude and varied geomorphic compartition (Modenesi 1988a; Modenesi-Gauttieri & Nunes 1998). Cooler temperatures (mean annual temperatures of *ca.* 11.5ºC in Itatiaia and 14.3ºC in Campos do Jordão), higher and better distributed rainfall (2,400 mm and 1,800 mm, respectively) and the importance of polar fronts in defining weather patterns give a subtropical character to the *altos campos* (high *campos*) climate. The lowest temperatures in southeastern Brazil are recorded in Itatiaia; frost may occur all over the year, except January-February, with up to 101 events/year (1938). In Campos do Jordão, frost events are concentrated in winter, between May and August, with a maximum of 70 events/year (1968). El Niño-related disturbances in the rainfall regime are observed in the present at Campos do Jordão but not Itatiaia (Modenesi-Gauttieri & Nunes 1998).

In spite of the relatively low temperatures of the tropical montane climate, surficial materials show a lateritic type of weathering with kaolinization and gibbsitization (Modenesi 1980, 1983; Modenesi & Toledo 1993; Modenesi-Gauttieri & Toledo 1996). In Itatiaia this

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weathering trend is favored by the low silica content of the alkaline bedrock.

Vegetation composition stresses the importance of the Mantiqueira highlands within the phytogeographic framework of southeastern Brazil (Azevedo 1965). The *altos campos* flora comprises elements from the Andes and from southernmost South America (Rambo 1953, apud Azevedo 1965, Brade 1956) and from Central Brazil (Hueck 1957). Spatial distribution of vegetation results in a typical grassland-forest mosaic organized according to the variations in environmental conditions within each different landform compartment (Modenesi 1980, 1983).

The *altos campos* landscape system (Modenesi 1988a) developed in fragments of the old Paleogene surface on both sides of the Paraiba rift, in the Serra da Mantiqueira (Campos do Jordão, Itatiaia and Campos do Ribeirão Fundo) and in the Serra da Bocaina, with similar landform patterns and distribution of surficial materials. Erosion amphitheaters of diverse form and age occur hanging over the present thalwegs. Deeper deposits are restricted to midslope benches and to footslope ramps, usually within amphitheaters; other interfluve sectors display shallow soils, in Campos do Jordão, or bedrock outcrops, in Itatiaia. Local changes in lithology, depth of weathering, relief dissection and vegetation characteristics bring about small variations in the physyognomy of the *altos campos* (Modenesi 1988b, Modenesi-Gauttieri & Toledo 1996).

Detailed geomorphological investigations in Campos do Jordão (Modenesi 1983, 1988a, 1988b; Modenesi-Gauttieri *et al*. MS.) and Itatiaia (Modenesi 1989, 1992; Modenesi-Gauttieri & Toledo 1996), specially aiming at the study of hillslope deposits and weathering-morphogenesis relationships, allowed some conclusions on the hillslope processes and on the Quaternary evolution of the *altos campos*.

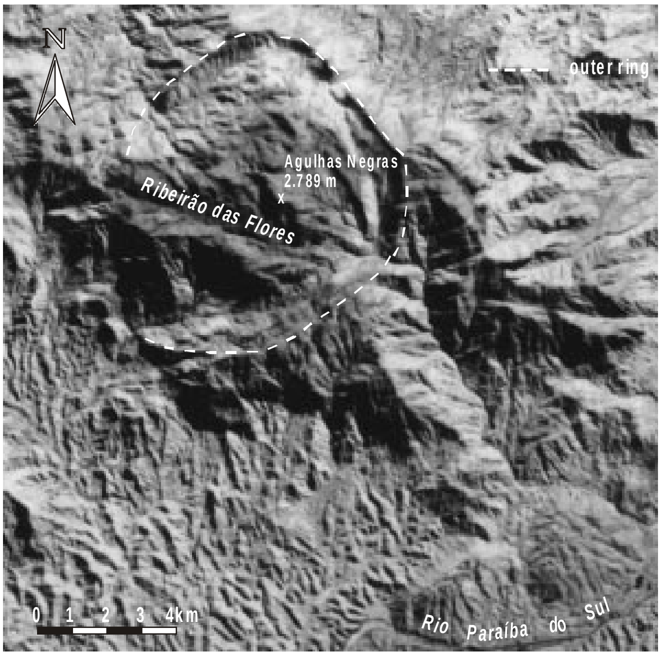

Figure 2 – The alkaline intrusion of Itatiaia and the surrounding crystalline basement (gneiss). The limits of the intrusion, the great outer ring and the Ribeirão das Flores W-WNW lineament appear very conspicuously in the satellite images (Landsat TM, 1:250,000).

Interference of periglacial and glacial phenomena in the Quaternary evolution of the Mantiqueira high plateaus was suggested by De Martonne (1940) and accepted by many authors (Silveira 1942, Raynal 1957, Ab'Sáber & Bernardes 1958, Ebert 1960 among others) mainly in the *plateau* of Itatiaia, where recently Modenesi (1989,1992), Clapperton (1993) and Modenesi-Gauttieri & Toledo (1996) recognized the importance of geocryogenic processes in the formation of hillslope deposits. Evidence of periglacial activity, if lesser, has also been reported in the Campos do Jordão Plateau (Raynal 1957, Lehman 1960, Modenesi 1988a).

The present paper is an attempt to integrate, on one side, results of geomorphological investigations carried out in the Serra da Mantiqueira during the last 20 years, and preliminary peat palynology (Modenesi & Melhem 1986, 1992), on the other, new morpho-neotectonic (Modenesi-Gauttieri *et al*. 1997; Hiruma 1999; Modenesi-Gauttieri *et al*. MS.) and palynological data (Behling 1997), as well as new ^{14}C ages of colluvia and peat-rich sediments.

LANDFORMS AND HILLSLOPE DEPOSITS OF THE CAMPOS DO JORDÃO PLATEAU Campos do Jordão is the largest and most characteristic of the *altos campos* areas (Fig.3). Rounded hilltops and *lombas* (convex slopes covered with grass) with shallow and highly weathered reworked products contrast with the dissected sectors of slopes and erosion amphitheaters where deeper and less weathered materials occur (Modenesi 1980,1983). These characteristics are important in the organization of a forest-grassland mosaic marked by strong physiognomic contrast between large convex interfluves, covered by *campos*, and lower hillslope rectilinear sectors and deep hollows, occupied by *Araucaria* and *Podocarpus* forests. Three slightly different *campos* landscapes may be distinguished within the plateau: the campos do Jordão proper, Serrano and São Francisco (Fig. 4).

Hillslope forms and deposits evince the importance of mass movements in the Quaternary slope evolution of the plateau. Pre-quaternary deep regoliths - evinced by remnants of alumino-ferruginous laterites and reworked latosols (Modenesi 1980, 1983) - were moved during the Pleistocene by a sequence of mass movements, probably slump-slides, forming at least three generations of erosion amphitheaters and three coarse terrace correlative deposits. These processes reworked both the superficial and the less weathered profile zones, bringing considerable changes to the mineralogical characteristics of amphitheater deposits (Modenesi 1980, 1983). A slight decrease in the degree of weathering is indicated by the presence of kaolinite and by an increase in mica (mainly illite) content; weathering relations with upslope materials lessen. The thick, massive, unstructured and conglomeratic (with pebbles,cobbles and boulders) deposits within amphitheaters show normal weathering sequences due either to hillslope process characteristics (slump-slides) or, in older deposits, to post-depositional weathering.

The formation of amphitheaters in the Campos do Jordão Plateau was explained (Modenesi 1988b) by successive phases of mobilization of deep and intensively weathered regoliths, probably by slump-slides. The great number of amphitheaters of different ages and types, showing different phases of mass movements, suggests permanence of this type of evolution probably all over the Pleistocene. Association of the last three amphiteater generations with coarse terrace deposits equivalent to the ones recognized in southeastern Brazil by Bigarella *et al.* (1965) made it possible to relate these events to the instability of climatic conditions, with episodes of rainfall concentration and reduction of plant cover, that would have prevailed during the wet-dry transitions of the Middle and Late Pleistocene.

The upper part of the *lombas* is usually covered by just one colluvial layer, but lower slope sequences (Fig.5) may show up to three superposed colluvium beds (C_I, C_{II}, C_{III}) separated by dark humic A-horizons (IIA_1, $IIIA_1$). Colluvia are usually thinner than amphitheater deposits, have a relatively homogeneous matrix with a better sorted sand fraction, and a much smaller number and size of clasts (usually under 7cm). C_{III} presents well developed A and B-horizons, C_{II} and C_I show dark humic A-horizons on top of sediments only slightly affected by pedogenic processes.

The shallow processes that reworked the loose, more superficial and weathered hillslope materials have slightly modified their mineralogy; characteristics and degree of weathering of colluvial deposits are similar to those of upslope materials. Gibbsite prevails above 1,800m, kaolinite, below. Inverse or disordered weathering sequences are typical of the thicker profiles. With lesser erosive capacity, colluvial events were only capable of modifying the lower slope profiles and filling up floodplains and depressions at the base of amphitheaters with relatively fine sediments.

Colluvial deposits of the Campos do Jordão Plateau have been considered Holocene (Modenesi 1988a, 1988b) but radiometric dating of paleosols in the hillslope sedimentary sequence of Vila Nova Suiça (Table 1) has shown that colluvium deposition in the plateau hillslopes began during the Late Pleistocene, probably after ca. 37,000 BP, alternating with intervals of soil formation. The two first colluvium generations (C_I and C_{II}) were deposited over buried A-horizons of, respectively, ca. 36,970 BP (IVA_1) and 30,990 BP ($IIIA_1$). The more recent colluvia (C_{III}) lie over a buried horizon (IIA_1) of ca. 18,580 BP. Elsewhere in the plateau, IIA_1 horizons may show different ages, *e.g.* ca. 14,260 BP, at the limits of Campos do Jordão and Campos do Serrano, and ca. 21,340 BP, in the southeast border of the plateau. The basal part of the present dark A-horizons in soil profiles of the Campos de São Francisco area show ages of ca. 8,630 and 9,250 BP.

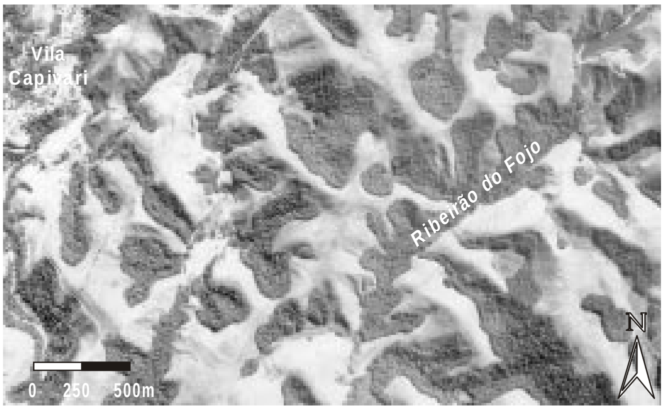

Figure 3 – A very typical area of altos campos, east of Vila Capivarí (Campos do Jordão). The landscape system is here marked by a strong physiognomic contrast between rounded hilltops and lombas, both grass-covered, and rectilinear slope sectors and deep hollows, occupied by forests.

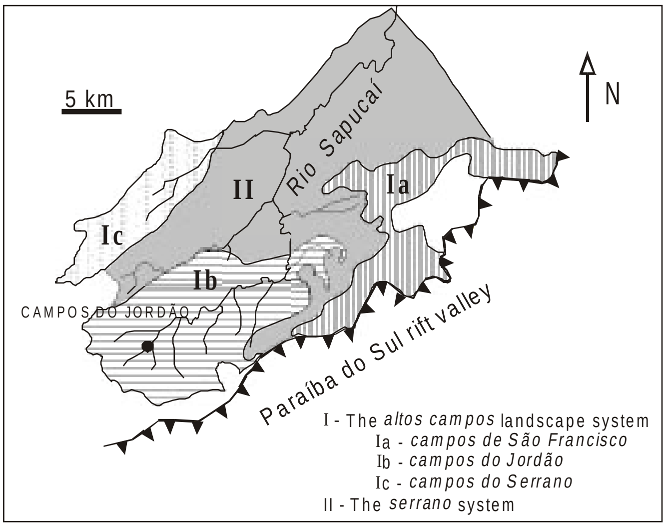

Figure 4 – Landscape systems of the Campos do Jordão Plateau

Peat-rich deposits *ca.* 3m thick, interrupted by sporadic lenses or layers of sand, are usually found inside and at the front of erosion amphitheaters. The basal layers of these deposits have been dated (Table 1) up to 22,450 BP (Modenesi-Gauttieri 1996), in a second generation amphitheater, and up to 4,550 BP (Modenesi & Melhem 1992), in a third generation one. In this latter, three organic horizons of ca. 1,240 BP, 1,020 BP and 340 BP occur intercalated within the C_{III} colluvia, at the margin of the peat basin. Valley peat bogs are rare and only occur in the *altos campos* highest areas.

It should be remembered that morphotectonic features along Precambrian lineaments and drainage anomalies have been recognized in the Campos do Jordão Plateau. These evidences and the generalized drowning of the basal sectors of third generation amphitheaters (lacustrine paleodepressions) have permitted the raising of hypoteses on the interference of neotectonics in the evolution of the *altos campos* (Modenesi 1988a, 1988b). Particularly in the Campos de São Francisco area, where brittle structures may occur in colluvia and stone lines, recurrent tectonic reactivations were identified (Modenesi-Gauttieri, *et al.* 1997, Hiruma 1999) with three superposed neotectonic regimes: an initial E-W righ-lateral transcurrent binary, followed by E-W extension and final E-W compression. Radiocarbon dates of colluvia and soils with evidence of faulting (Hiruma 1999) indicate Late Pleistocene, Early and Late Holocene ages for these events. Faults compatible with the neotectonic regimes are responsible for conspicuous morphotectonic features, such as straight scarps, triangular facets, hanging valleys, shutter ridges, low divides, pull-apart basins, countercurrent confluence and stream piracy. Intersection of transcurrent NE-NNE and NW-NNW trending faults divided the plateau into smaller blocks.

Palynological data from Campos do Jordão are scarse and preliminary, still insuficient for a reliable paleoclimatic interpretation. Besides a pioneer analysis of Holocene peat, from the central part of the *altos campos* (Modenesi & Melhem 1992), there is only a late Quaternary pollen record from Morro do Itapeva, at the limits of the plateau, near its southeastern scarps (Behling 1997). This latter suggests a cold and dry climate in the last glacial period (*ca.* 35,000 – 10,000yr. BP) with slightly warmer and moister conditions prevailing after 17,000yr. BP only at lower elevations, probably between 500 and 1,000m, thus outside the plateau. The highlands would have remained too dry to support a more dense *Araucaria* and *Podocarpus* forest until the late Holocene.

LANDFORMS AND HILLSLOPE DEPOSITS OF THE ITATIAIA *PLATEAU* Bedrock exposition and marked structural control characterizes the intensely dissected erosional relief of the Itatiaia *plateau* (Fig. 6), hillslope form and steepness usually depending on the strikes and dips of the alkalines. Bare rock formations such as tor-like hilltops, freefaces with systems of grooves (*caneluras*) and rocky slopes have often been compared with landforms of cold climate areas. Less contrasting hillslope forms and the vegetation characteristics alter the physiognomy of the *altos campos* in Itatiaia: a smaller number of shallow erosion amphitheaters,

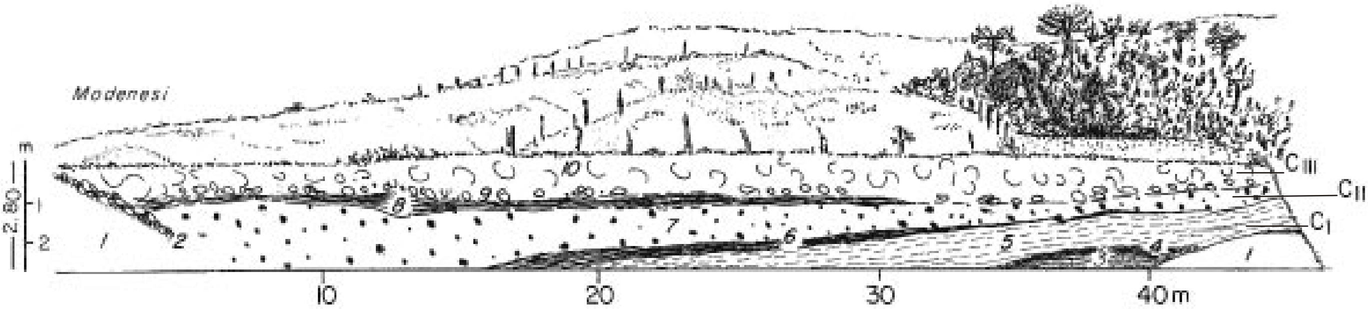

Figure 5 – Sketch of the most complete lower slope colluvium sequence in the Campos do Jordão Plateau, with ^{14}C dates. Local relief inversion due to partial filling of erosion amphitheater. (1) Weathered bedrock. (2) Massive stone-line with clasts of quartzite and quartz, usually up to 3cm maximum diameter, nodules of gibbsite and ferruginous clay. (3) Alternate thin beds of white sand and black peat mudballs. (4) Buried dark friable A-horizon ($IV A_1$); 3% of organic matter (O.M.); 36,970 +/- 650 BP. (5) Yellowish argillaceous and relatively homogeneous colluvium (C_I); little pedogenic weathering. (6) Darkest and most evolved buried A-horizon ($IIIA_1$), 7% O.M.; 30,990 +/- 350 BP. (7) Compact, hard, reddish clayey-sandy colluvium (C_{II}), with granules and small pebbles; little pedogenetic weathering. (8) Buried dark-brown, clayey-sandy A-horizon (IIA_1); 18% O.M.; 18,580 +/- 140 BP. (9) Discontinuous stone-line of quartzite and quartz pebbles (3cm maximm diameter), gibbsite and clay nodules. (10) Yellowish-brown sandy friable colluvium (C_{III}); well developed A and B horizons.

Table 1 – ^{14}C ages of paleosols and peat-rich deposits in the Campos do Jordão Plateau

Sample number	*material*	*depth cm*	*laboratory number*	*age (^{14}C yr BP)*
CJ231b	paleosol II A_1, buried by C_{III} colluvia	103	Beta Analytic 128 173	18 580 +/- 140
CJ231c	paleosol III A_1, buried by C_{II} colluvia	175	Beta Analytic 128 174	30 990 +/- 350
CJ205d	paleosol IV A_1, buried by C_I colluvia	150	Beta Analytic 128 172	36 970 +/- 650
CJ244SE	paleosol II A_1, buried by C_{III} colluvia	195	Beta Analytic 126 077	14 260 +/- 70
CJ111A	paleosol II A_1, buried by C_{III} colluvia	130	Beta Analytic 128 168	21 340 +/- 230
CJ245	C_{III} colluvia, base of the soil profile	205	Beta Analytic 128 171	8 630 +/- 80
CJ10A	C_{III} colluvia, base of the soil profile	150	Beta Analytic 128 170	9 250 +/- 170
CJVS4	organic sediment from the basal layer of a peat bog, in a 2nd generation amphitheater	331	Bondy Lab.	19 560 +2 890/ - 2 130
CJ224 (1.2, 1.4, 1.5, 2.2)	organic sediments from a peat bog in a 3rd generation amphitheather	78	Bondy Lab. 491	290 +/- 240
		118	Bondy Lab. 484	370 +270/-260
		140	Bondy Lab. 483	1 050 +600/-570
		265	Bondy Lab. 492	4 170 +380/-360
JPV (2, 4, 8A)	paleosols within C_{III} colluvia	45	Bondy Lab.	340 +/- 70
		76	Bondy Lab.	1 020 +/- 70
		126	Bondy Lab.	1 240 +/- 230

without the pronounced scars that characterize similar features in Campos do Jordão, only support shrubs or dwarf forest.

Deposits are restricted to the middle and lower slope sectors of shallow amphitheaters, where very coarse sediments and two generations of colluvia (Fig. 7) bear witness to phases of enhanced slope degradation. Both in situ and reworked surficial materials show lateritic weathering, but no evidence of pre-Quaternary aluminoferruginous laterites was found in the Itatiaia *plateau*.

Talus cones and stone streams of subangular and little weathered cobbles and boulders (up to 12m in diameter) occur hanging over the present floodplains, sparsely covered by vegetation. The latter have been considered very similar to those of the Falkland Islands and other areas of Quaternary periglacial activity (Clapperton 1993). Deposits of smaller, more weathered and rounded cobbles and boulders may be found buried under the talus cones. Mountain screes of loose flat angular pebbles and cobbles, with incipient bedding and lacking matrix, may occur hanging over the present floodplains, beneath the more recent colluvia; these screes evince rockfall processes probably associated to past frost conditions more important than present ones.

All the very coarse hillslope deposits are relict features. Gravity (rockfall) and cold-humid climate processes, including a large range of frost weathering processes, would have been effective in detaching the coarse debris from the intensely jointed freefaces of the *plateau* (Modenesi 1992, Modenesi-Gauttieri & Toledo 1996). During the last glaciation, frequent temperature cycles around 0°C and moisture conditions probably coexisted, favored by the position of Itatiaia on the eastern margin of the continent, near the Atlantic coast and under the direct impact of southern and southeastern humid air masses (Modenesi-Gauttieri & Toledo 1996, Modenesi-Gauttieri & Nunes 1998). However, in spite of the hypotheses of a local montane glatiation in Itatiaia (De Martonne 1940, Ab'Sáber & Bernardes 1958, Ebert 1960, among others), no actual evidence of glacial action has been found (Modenesi 1992, Clapperton 1993, Modenesi-Gauttieri 1996). The coarse weathered materials lying under the taluses witness previous mass movements, probably mudflows, released in warmer and humid conditions (Modenesi 1992).

Itatiaia slope evolution has most probably neotectonic implications. Penalva (1974) gave an almost exclusively tectonic interpretation to the *plateau*'s geomorphic evolution. Actually, besides landform evidences many hillslope deposits are structurally controlled (Modenesi 1992). Production and location of coarse rock debris on slopes follow the directions of the alkaline bedrock jointing systems. Size and abundance of boulders in talus and stone streams suggest influence of seismicity in detaching the huge boulders found on hillslopes; Itatiaia belongs to the seismogenic zone (Hasui et al. 1982) with the greatest number of epicentres in southeastern Brazil. Moreover, recognition of Pleistocene and Holocene reactivations in the neighboring areas of Campos do Jordão (Modenesi *et al.* 1997; Hiruma 1999) and Paraiba Valley (Riccomini 1989) as well as in the Serra da Bocaina region (Gontijo 1999), at the south margin of the rift, reinforce these interpretations.

Less coarse hillslope materials document two more recent colluviation episodes on the lower slopes of the *plateau* (Fig. 7). Mineralogy of colluvia shows similar residual and supergene minerals (Modenesi-Gauttieri & Toledo 1993, 1996); gibbsite is present in all samples, kaolinite and small amounts of 2:1 clay minerals, mainly in C_I; oxy-hydroxides are not common. The older C_I colluvia lie over the weathered bedrock, are shallower (less than 100cm), massive, compact and heterometric, being constituted by pebbles (average content of 25%), cobbles and boulders from the bedrock scattered in a yellowish clayey matrix; in spite of being intensely weathered, they show little pedogenetic evolution. The transition between C_I and C_{II} is abrupt and occasionally marked by a stone line. C_{II} vary in thickness (up to 260cm), has fewer (up to 8%), smaller and less weathered clasts, and is characterized by a stony aspect and strong color contrast between the dark matrix and numerous differently colored bedrock pebbles and granules. Concentrations of these angular to subangular clasts on several levels of the thickest profiles, as well as variations in color and texture, show superposition of different materials rather than subdivision of a same humic horizon; discontinuities within profiles imply disturbance of pedogenesis and superposition of A-horizons.

Micromorphological analysis (Modenesi-Gauttieri & Toledo 1993, 1996) has shown that both colluvia consist of a mixture of materials at different degrees of weathering but C_{II} has smaller and more evolved skeleton grains, less common rock and weathering relicts, and more conspicuous aglomeroplasmic pattern, presenting a greater degree of pedogenesis than C_I.

Sedimentological, mineralogical and micromorphological characteristics of colluvia evince changes in hillslope geomorphic processes. C_I colluvia would have origin in mass movements reaching less weathered profile zones, whereas C_{II} results from shallow colluviation processes that reworked initially more evolved materials; mudflows or slow mass movements of solifluxion type eroded only the upper soil horizons including in its way downslope poorly weathered small rock fragments from bare rock surfaces.

In the Itatiaia *plateau*, floodplain sectors intercalated between entrenched stream segments (Fig. 6) are filled with tropical montane peat bogs (maximum observed thickness 260cm). As in Campos do Jordão, strong acidity, important mineral fraction, presence of partially decayed plant remains and contents of organic matter insuficient to define real peats are characteristic. C_{II} colluvia and flodplain organic sediments are contemporaneous (Table 2) and intercalated having been deposited, respectivelly, after ca. 8,000 (Modenesi-Gauttieri & Toledo 1996) and 8,500 years BP (Modenesi 1992).

QUATERNARY EVOLUTION OF THE *ALTOS CAMPOS* OF THE SERRA DA MANTIQUEIRA The Quaternary evolution of the Campos do Jordão and Itatiaia plateaus comprises a succession of

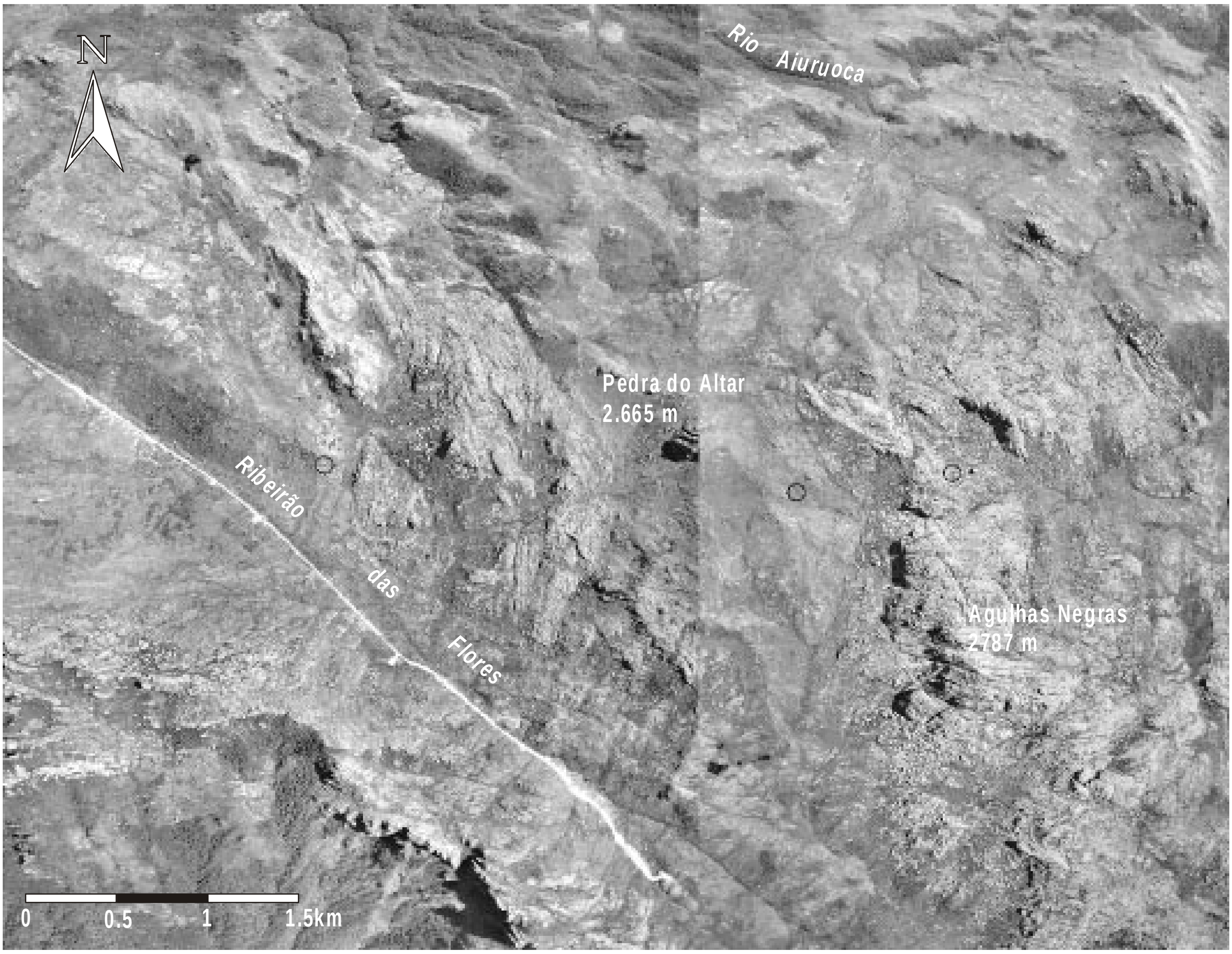

Figure 6 – The area locally known as planalto, developed over quartz-syenites, in the central part of the massif. Ridges and drainage follow fragments of arched structures found inside the outer ring.

episodes of hillslope degradation by mass movements and stability intervals. The latter are evinced by peat-rich deposits and dark A-horizons intercalated in the colluvial sequences. The older Pleistocene degradation episodes had a more effective morphogenetic action in both plateaus; widespread mass movements mobilized larger masses of surficial materials leading to the formation of erosion amphitheaters and coarse to very coarse hillslope deposits.

In spite of the similar general hillslope evolution, processes may differ in each plateau according to variations in the depth of weathering. The amphitheaters of Campos do Jordão were formed by slump-slides mobilizing thick and intensely weathered regoliths. Itatiaia's shallow rocky amphitheaters as well as hillslope coarse deposits probably result from a combination of gravity (rockfall) and cold-humid climate processes, which could explain the detachment of boulders and rock fragments from freefaces.

Decrease in morphodynamic activity and change in hillslope processes is observed during the Late Pleistocene and the Holocene. The processes responsible for transportation and deposition of successive waves of colluvia on the hillslopes of both plateaus seem to have been similar. Relatively shallow colluvial processes, with low erosive capacity (probably mudflows or slow movements of solifluxion type), evince reduction of hillslope denudation. In the Campos do Jordão hillslopes, up to three colluvium layers occur on top of buried A-horizons of the Late Pleistocene (ca. 36,970 BP, ca. 30,990 BP and 21,340 BP to 14,200 BP); colluvia overlying the more recent of these paleosoils are Holocene (ca. 8,630 to 9,250 BP). In the two colluvium generations of the Itatiaia *plateau* a tendency towards reduction of hillslope denudational activities is clear. The older colluvium generation, probably Pleistocene, rich in coarse weathered bedrock clasts, would have been deposited by mudflows reaching less weathered profile zones. Holocene colluvia (ca. 8,050 BP) were most likely deposited by shallow processes that reworked superficial and initially more evolved materials; levels of gravelly materials found inside these materials would result from phases of more intense gelifraction in the Itatiaia slopes.

In the lower slopes of the Campos do Jordão Plateau deposition of each new colluvial layer buried previous A-horizons, which persist truncated; new soil profiles, with A_1 and A_3 or B_1-horizons, developed upon the new colluvial materials. On the other hand, Itatiaia's Holocene colluvial sequences consist of thick A-horizons formed by the continued addition of highly evolved surficial materials over partially eroded A-horizons. In this case, colluvial sequences would correspond to a slow and continuous superposition process and not to a succession of erosion and deposition phases, with interruption of pedogenesis, as in Campos do Jordão.

These facts suggest that Holocene denudation events were relatively more important in Campos do Jordão, and are confirmed by the peat bog sedimentary sequences of both plateaus: with frequent sand layer intercalations in Campos do Jordão, while in Itatiaia, they are pratically uninterrupted in the last 8,500 years.

It should be noted that the interference of geocryogenic processes has been different in both plateaus. In Itatiaia, the lower temperatures and greater permanence of moist conditions related to its higher altitude and isolated position, facing humid air masses of diverse origin, would have favored geocryogenic activities during Pleistocene cold phases and smaller Holocene events. In Campos do Jordão, 500m

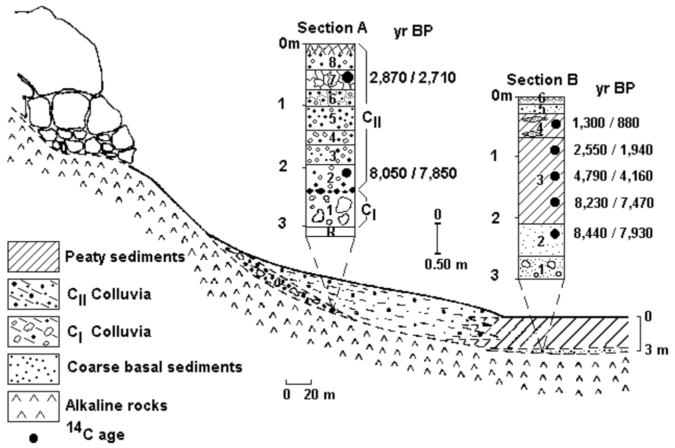

Figure 7 –Lower hillslope and floodplain deposits on the Itatiaia plateau. ^{14}C dates. Section A: (R) - weathered bedrock. (1) - Massive, compact and heterometric C_I colluvium, with boulders from the bedrock (up to 50cm) and weathered feldspar granules and ferruginous nodules scattered in a yellowish-brown sandy-silty-clay matrix. (2) - Less compact C_{II} colluvium; black clayey-silty-sandy matrix with few clasts, mainly granules; 5% O.M. (3 to 6) - Beds of dark massive unsorted materials rich in pebbles and granules, concentrated at several levels of the profile; dark clayey sand to sandy clay matrix. (7) - Less heterometric; strong blocky to subangular blocky structure; 19% O.M. (8) - Increase in the number of pebbles and granules; weak subangular blocky structure; 28% O.M.; abundant roots in the upper 25cm (A horizon). Section B: (1) - Sand with granules and pebbles from the weathered bedrock. 2 - Black clayey sand with 7% O.M. 3 - Black clay (total absence of sand) with 20 to 30% of highly humified O.M. 4 - Black silty clay with sporadic lenses of fine sand; 9% O. M. 5 - Yellowish silty sand with granules and small pebbles; 0.1% O. M. 6 - Black clayey sand with granules; 0.3% O. M. (A horizon).

below, geocryogenic evidence is rare. This seems to indicate a former threshold for intense geocryogenic activity in the Mantiqueira highlands at *ca*. 2,000m, as suggested by Clapperton (1993).

The widespread and cyclic character of erosion amphitheaters in the Campos do Jordão Plateau suggests a climatic control in triggering phases of intense slope degradation. Correlation of the amphitheater generations with coarse deposits of terraces make it possible to attribute them to erosive and depositional phenomena that took place during the wet-dry climate transitions of the Middle and Late Pleistocene (Modenesi 1988b), recognized in southern and southeastern Brazil by Bigarella *et al.* (1965).

Reconstruction of Quaternary climates, based on the analysis of one peat profile in the Campos do Jordão Plateau (Behling 1997), indicates continuous cold and dry conditions from 35,000 to 10,000BP. Besides dating problems, it is in contrast with geomorphic, sedimentological and pedogenetic evidences gathered from the analysis of hillslope materials (Modenesi 1983, 1988a, 1988b). During the mentioned period three erosive/depositional events (colluvia) and four intercalated pedogenetic phases (paleosols) occurred over the *altos campos*, indicating changes in the intensity of morphodynamic activities and in hillslope processes. Paleosols interbedded with colluvia are indicative of an alternance of phases of slope stability and slope degradation, implying changes in the bioclimatic conditions (vegetation cover and rainfall seasonality and/or intensity). The apparent continuity of climatic conditions deduced from this vegetation reconstruction conflicts with the instability suggested by the characteristics of surficial formations.

Otherwise, the identification of three neotectonic pulses in the *campos de São Francisco* area (Modenesi *et al.* 1997, Hiruma 1999) reinforces former hypotheses on the tectonic implications of hillslope instability phases. The last of these pulses, of Late Holocene age, however, needs further investigation.

The many morphological evidences of recent reactivation and drainage anomalies found in Campos do Jordão (Modenesi 1988a, 1988b; Modenesi-Gauttieri *et al.* 1997, Hiruma 1999) have also been recorded in the depressed compartments of the Brazilian Plateau, nearby, such as the Paraiba valley (Riccomini 1989, Salvador & Riccomini 1995) and the region of crystalline hills of Bananal (Gontijo 1999), or distant, as the valley of the Rio Doce (Mello 1997). Although opinions differ as to the establishment of the Quaternary stress regimes, these data confirm the influence of neotectonics in the geomorphic evolution of southeastern Brazil.

The present state of geomorphological knowledge of Mantiqueira uplands allows for a clearer understanding of its Quaternary evolution, confirming the interaction of neotectonics and climatic oscillations in the landscape evolution of the *altos campos*. The change in hillslope geomorphic processes and the decrease in morphodynamic activity observed in the Late Pleistocene and Holocene seem to point to a less marked neotectonic influence and to relatively sTable environmental conditions, probably with only short range fluctuations. Holocene climatic variations would have been characterized by wider oscillations of temperature in Itatiaia and of moisture in Campos do Jordão (Modenesi-Gauttieri & Toledo 1996). The lower temperatures and longer permanence of humid conditions might explain the intensity of periglacial processes in the Itatiaia *plateau*.

Radiometric ages of paleosols and peat deposits now avaiable make necessary some adjustments in time in the evolution of the Campos do Jordão Plateau, since the dating of erosive and sedimentary events in the previous evolutive model was only based on relative chronology (Modenesi 1988a, 1988b). In both plateaus, colluviation processes were not limited to the Holocene, but also occurred during the Late Pleistocene. Only the last and widespread colluviation episode is Holocene, with similar ages in both plateaus.

But many questions still remain to be answered such as, for instance, the effective role played by Quaternary uplift and climate changes in the landscape evolution of the *altos campos*, principally in triggering the conspicuous hillslope instability phases of both plateaus. This is the aim of investigations still going on at Campos do Jordão.

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Table 2 – ^{14}C ages of peat-rich deposits and C_{II} colluvia in the Itatiaia plateau (Ribeirão das Flores valley)

Sample number	*material*	*depth cm*	*Laboratory / sample number*	*Age (^{14}C yr BP)*
IT VG7.3	organic sediments from a valley peat bog	50	Bondy Lab. 178	1 090 +/- 210
IT VG7.4		90	Bondy Lab. 177	2 240 +310/-300
IT VG7.5		130	Bondy Lab. 174	4 470 +320/-310
ITVG7.6		175	Bondy Lab. 169	7 840 +390/-370
ITVG7.7		230	Bondy Lab. 166	8 200 +280/-270
ITVG6.3	C_{II} colluvia, complex humic A-horizon	60	Beta Analytic 59 285	2 790 +/- 80
ITVG6.8		220	Beta Analytic 59 286	7 950 +/- 100

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