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# GEOMORPHOLOGY OF THE PACAÁS NOVOS RANGE, SOUTHWESTWERN AMAZONIA, BRAZIL: ONE EXAMPLE ON THE IMPORTANCE OF GEOMORPHOLOGICAL EVIDENCES TO THE RECONSTRUCTION OF QUATERNARY PALEOENVIRONMENTAL SCENARIOS IN AMAZONIA

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**ABSTRACT** The geomorphology of the Pacaás Novos Range was surveyed. The study area is situated in the State of Rôndonia, southwestern Amazonia, near the Brazil - Bolivia border. The range is formed by sedimentary Precambrian rocks and the piedmont area by Precambrian crystalline rocks of the Guaporé Shield. The occurrence of a thick saprolite mantle, detrital talus, pediments, duricrust formation, dissection and alluvial fans provide strong evidence that the morphogenetic systems changed drastically in this part of Amazonia during the Quaternary.

Keywords: south-western Amazonia, Quaternary, geomorphology, palaeoclimates

**INTRODUCTION** Geomorphological evidence is currently used in the tropics for the interpretation of paleoclimatic fluctuations and to evince variations in the Quaternary environment. A fair amount of the present information on the Quaternary evolution of humid tropical African and Asiatic rainforests is provided by geomorphological evidences (De Ploey 1964; data review in Thomas 1994, Kadomura and Hori 1990, Thomas and Thorpe 1985, 1992, Runge 1992, 1995, and many others). On the contrary the Amazon is characterized by the lack of such information. During the last 30 years, studies concerning the geomorphology of the Brazilian Amazon Basin focused principally on some aspects of fluvial geomorphology, soil development and weathering (Ab Saber 1967, 1982, Chauvel *et al.* 1987, Iriondo 1982, Iriondo and Latrubesse 1994, Journaux 1975, Costa 1991, Klammer 1971, 1984, Lucas *et al.* 1987, 1988, Meis 1968, Mertes *et al.* 1996, Tricart 1977, 1885, and others). Data on the Quaternary are provided basically by the study of fluvial and lacustrine deposits, palinology and vertebrate paleontology (among others, Absy *et al.* 1991, Latrubesse and Franzinelli 1998, Latrubesse and Ramonell 1994, Latrubesse and Rancy 1998, Rancy 1993, Rasanen *et al.* 1992, Van der Hammen and Absy 1994).

Our aim here is to evaluate the potential of the geomorphological record from some areas of Brazilian Amazonia and to determine paleoenvironmental indicators. We present results from the Pacaás Novos Range area, Rondônia State, Brazil.

This region is situated on the Brazil - Bolivia border, to the east of the Madeira-Mamoré River ($65^0$ 20'W; $10^0$ 44' S) (Fig.1) and is covered by tropical rainforest. The climate of this area is humid tropical with a dry season of tree month duration, average temperature of $24^0$ C, and rainfall between 2000 and 2250 mm/year (Nimer 1989).


*Figure 1 - Location map indicating the study area*

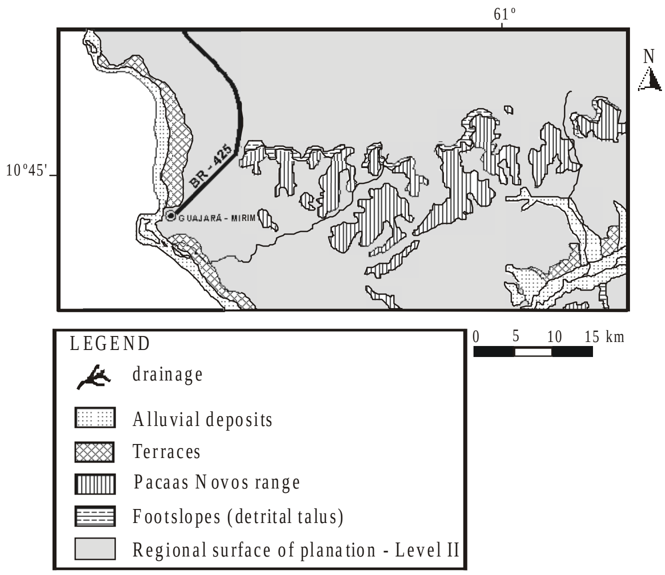


*Figure 2 - Geomorphological scheme of the western portion of the Pacaás Novos Range*

**METHODS** Analysis of radar mosaics (SLAR), LANDSAT images and aerial photographs, before and during the fieldwork, aided in the identification of the geomorphologic features. Intensive fieldwork was carried out in 1996 and in 1997. Slope and morphometric measurements of landforms were performed in the field by theodolite.

Grain size of the sediments was obtained during the laboratory stage. Mineralogical determinations were obtained using X-ray diffraction and petrographic microscopy. X-ray diffraction was done on the total sedimentary fraction after triturating. Geochemical determinations were performed by X-ray fluorescence. Absolute dating was performed by thermoluminescence on the quartz particles of the sediments.

**GEOLOGICAL BACKGROUND** The main geological unit outcropping in the area is the Guaporé Shield, which is composed of igneous and metamorphic rocks of the Xingu Complex, Lower Precambrian in age. This unit is defined in the area as a Regional Surface of Planation of Rondonia and identified as Level II (less than 300-m. a.s.l). The Pacaás Novos Formation rests on the rocks of the crystalline basement in the area of the northern piedmont (Fig. 2), where it is possible to observe the contact between the range escarpment formed by the sedimentary rocks of the Pacaás Novos

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Formation and the granitic rocks of the Guaporé shield. The Pacaás Novos Range is composed of arkosic sandstones and conglomerates about 400 meters thick of the Pacaás Novos Formation, of Precambrian age (Radambrasil 1978) and the maximum heights reach 900-m a.s.l. The range is a testimony of a broad and old eroded synclinal with an approximately E-W axis. The abrupt northern flank was related to compressive neotectonic activity, which produced faulting in a NW-SE direction and a W-E secondary set of fractures (Scandolara 1999). The sedimentary rocks have low dip, reaching a maximum of $40^0$ (Radambrasil 1978). Detailed studies on the western end of the Pacaás Novos Range, near the city of Guajará Mirim were undertaken (Fig. 3). In this area the range appears as a set of isolated blocks, elongated in the N-S direction and with a northern flank controlled by an E-W lineament. Dip measurements in the strata and fractures are presented on figure 4. The beds dip gently and predominantly to the south. The blocks show a conspicuous asymmetry with an abrupt northern flank and a gentler southern flank. The maximum heights are 362-m a.s.l.

**THE PIEDMONT AREA** In the northern piedmont there is contact between the range escarpment formed by the sedimentary rocks of the Pacaás Novos Formation and the granitic rocks of the Guaporé Shield. The rocks of the shield are strongly weathered, forming saprolite. Residual weathered blocks of granite can be found inside the saprolite mass. The thickness of the saprolite mantle is unknown because the deep base is not apparent in the outcrops.

On the northern flank of the range, the horizontal to sub-horizontal strata of the Pacaás Novos Range form an abrupt front 150 m in height on the piedmont level, with a free face of 70-80 m. On the foot slope of this free face are found thick and coalescing talus of detritus. Talus thickness is variable, reaching up to 75 m, the slope reaches $34^0$. The talus is continuously present along the piedmont area; its base is in relation with the smoothly dissected pediment surface that extends on large parts of the northern piedmont (Fig. 3). The pediment developed on the weathered granitic rocks of the Guaporé Shield. The pediment surface is very gentle, with angles of $5^0$ in the proximal area, decreasing to $1^0$ away from the range. In some sectors of the piedmont, numerous outcrops can be found of the saprolite on which the pediment developed. Also granitic blocks and tors are frequent, randomly scattered.

The *in transit* alluvium on the pediment surface is very thin, no more than 40 cm thick, and formed by conglomerate with gravels of variable size. The best-rounded gravels were reworked from the conglomerates of the Pacaás Novos Formation. However, an angular population of quartz pebbles comes from the residual products of the saprolite. The thin alluvial *in transit* sediments of the pediment suffered lateritization, which resulted in duricrust formation during a sub-humid climate (Fig. 5). The conglomerate on the pediment was eroded and is present as a dismantled ferricrete or duricrust. This crust was dissected and for this reason is discontinuous, forming isolated accumulations of blocks on the pediment surface.

The installation of a drainage network on the pediment surface produced dissection. Alluvial and colluvial sediments were deposited in the valleys. This alluvial/colluvial unit is formed principally by gray to brown fine sediments, with some ochre tones and mottling by lateritization. The unit is situated on a lower level than the pediment and, in general, has higher declivity. We could not determine in the outcrops the total thickness of the sediments. However we found in a gully a 2.6-m thick profile composed of silty sandy sediments, brown gray, highly bioturbated, porous, forming vertical banks. Occasionally were recorded cross stratification in sandy sediments and lamination in finer sediments. Lenses of gravel formed by quartz particles, 5-20 cm in maximum thickness are found sporadically. In general, piping develops gullies. In the western end of the northern piedmont the unit is formed by alluvial fans that cut the detrital talus and the pediment. The fan slopes are up to $10^0$ in the apex area and $3^0$ in the middle/distal area. The most important fan lobes are found in the first 50-m from the piedmont angle. The coarsest sediments (blocks and boulders) form them. Thermoluminescence dating was performed on fan sediments in the laboratories of the University of Peking, China, indicating an

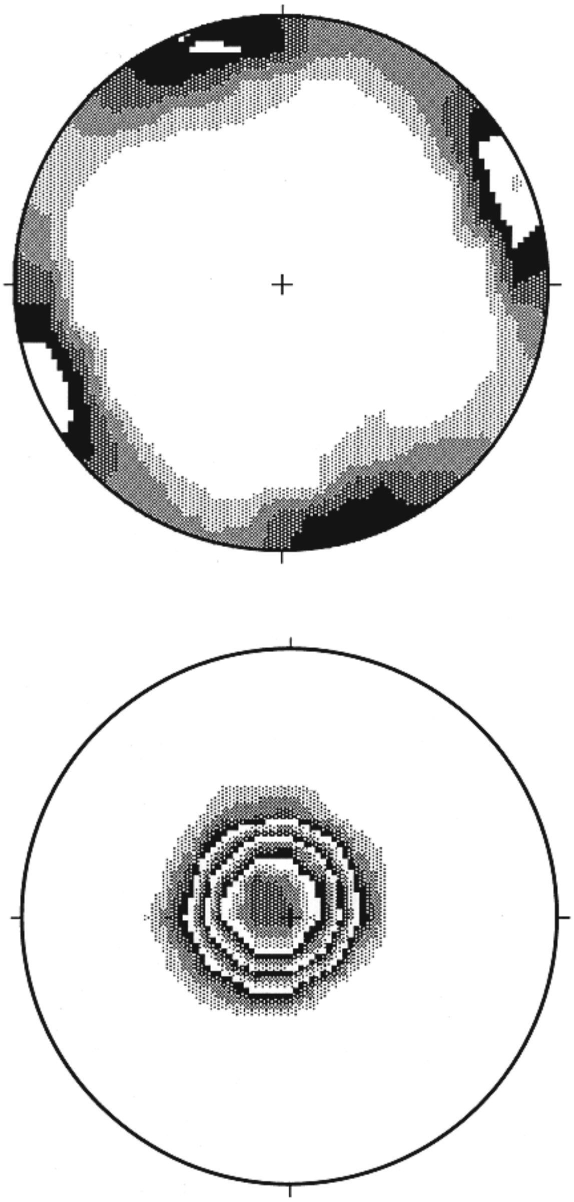

*Figure 3 – **a** - Fracture strike measurements. **b** - Strata dip measurements. Method of Kamb (1959).*

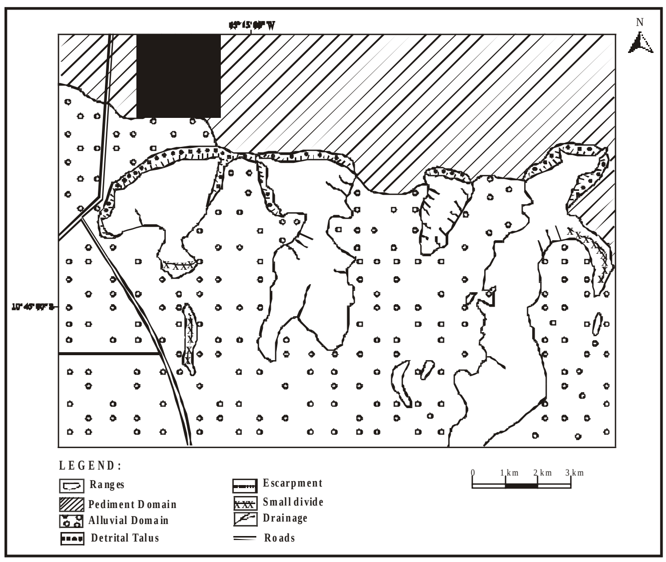


*Figure 4 - Main geomorphological domains in the Pacaás Novos Range, close to Guajará Mirim.*

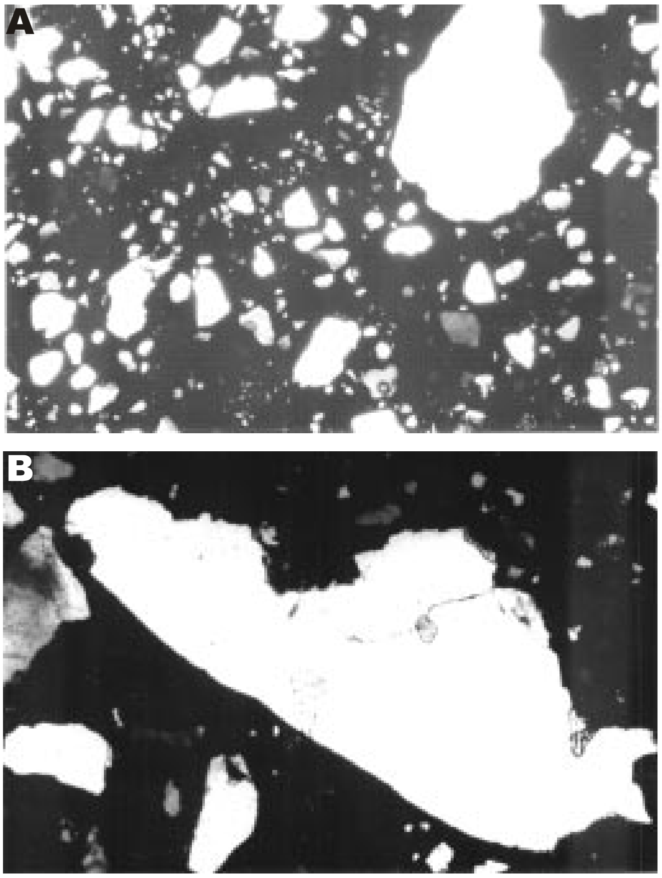


*Figure 5 – Thin section showing the composition of the ferruginous duricrust developed on the pediment surface. a) Clast heterogranularity with iron oxide cement. Dimension: 3.0 X 2.0 mm. X Nicols b) quartz particles corroded by iron oxide cement. Dimension: 1.2 X 0.8 mm, X nicols*

Upper Holocene age for these deposits. The ages obtained were 1.58 +/- 0.2 ka BP (sample ST 120) e 2.88 +/- 0.4 (sample ST 121). The samples were collected on the western end of the northern piedmont of the Pacaás Novos range ($10^0$ 43.332 S and $65^0$ 016.368 W). At present this unit is being eroded by the reactivation of the drainage network.

The southern flank of the range is gentler and the drainage network is better hierarchized than on the northern flank. The creeks have a torrential dynamics. The longitudinal profile of the watercourses is frequently broken by the presence of hard levels in the sedimentary rocks. In the southern piedmont there is aggradation, with a strong and rapid grain size selection of the sediments. The alluvial/colluvial domain is the more important geomorphological unit on the southern piedmont (Fig, 3).

**ANALYTICAL RESULTS: THE REGIONAL SURFACE OF PLANATION, LEVEL II** Mineralogical and geochemical analysis were performed to determine the type and intensity of chemical weathering on the granitic rocks of the Regional Surface of Planation, Level II. The pediment domain developed on that regional surface.

This surface extends on the western and northwestern part of the state of Rondônia and was developed mainly on Precambrian rocks. At present it is partially covered by undifferentiated Neogene deposits. Its surface, less than 300m a. s. l. in height shows a relatively flat landscape with the presence of inselbergs, tors, and half orange-like hills. Nevertheless there are no systematic data on the thickness of the weathering mantle; it was possible to observe in some points a thickness of 10-20m. Geochemical analyses were performed on saprolite, on fresh granite and on weathered blocks of granite in the northern piedmont of the Pacaás Novos Range (pediment domain)

The pediment domain of the Pacaás Novos Range can be considered part of the Regional Surface of Planation, Level II that is widespread on the western and northwestern corners of Rondônia (Fig. 2).

*Table 1 - Chemical composition determined by X ray fluorescence on the total fraction of the samples*

| Oxides % | Saprolite | Residual block in the saprolite | Fresh granite |
|---|---|---|---|
| $SiO_2$ | 49.39 | 53.25 | 73.57 |
| $TiO_2$ | 0.52 | 0.47 | 0.26 |
| $Al_2Fe_3$ | 32.34 | 26.65 | 13.12 |
| $Fe_2O_3$ tot. | 4.79 | 9.86 | 2.19 |
| MnO | 0.08 | 0.09 | 0.09 |
| MgO | 0.26 | 0.26 | 0.54 |
| CaO | 0.01 | 0.01 | 0.96 |
| $Na_2O$ | 0.00 | 0.02 | 3.66 |
| $K_2O$ | 0.36 | 0.21 | 4.69 |
| $P_2O_5$ | 0.06 | 0.05 | 0.09 |
| L.O.I. | 12.18 | 9.13 | 0.83 |

*Table 2 - Mineralogical qualitative or semi-quantitative composition of saprolite and residual granitic block immersed in the saprolite, determined by X-ray diffraction D = Dominant; I = Important; S = Scarce; T = Trace*

| Unit | Quartz | Feldspar | Ill/Mi | Kaol | Chlorite | Gibbsite | Hemat-Goeth |
|---|---|---|---|---|---|---|---|
| Saprolite | D | S | T | S | - | I | S |
| Residual block | I | T | S | S | T | S | S |

Table 1 shows results of chemical analyses of samples of the saprolite, of the residual weathered granitic blocks immersed in the saprolite, and of fresh granite.

The results indicate the progressive evolution of chemical weathering on granitic rocks. As shown, the progressive decreasing of $SiO_2$ is proportional to the increase of $Al_2O_3$, which is an important component of kaolinite and gibbsite (Table 2). $Al_2O_3$ from the saprolite is in large part used in the composition of the kaolinite and considerable part of $Si_2O$ is also used in kaolinite formation.

The alkaline original compounds of feldspar ($Na_2O$ and $K_2O$) are quickly leached, and thus missing in the saprolite, or carried away by water. The total $Fe_2O_3$ increases in the saprolite in a variable manner.

The complexity of deposits and landforms that compose the Regional Surface of Planation, Level II, suggests the participation of etch-planation processes in its genesis. The presence of pediments, surface sedimentary deposits, a deep weathering mantle, tors, inselbergs, laterites, half orange-like hills, indicate a polygenetic origin for this unit, supporting the hypothesis of etch-planation process during the elaboration of the surface, comprising considerable geological time for its evolution.

**DISCUSSION** Traditionally the Amazonian landscape has been described from a static point of view, accepting that minor and not drastic changes in its morphodynamics happened along the Quaternary. However, the geomorphological data of the Pacaás Novos region show strong evidence that the morphogenetic systems in Western Amazonia changed during the Quaternary.

Our evolutionary scheme starts with the development of the thick saprolite on the unaltered rocks of the Guaporé Shield (Fig. 6a). The formation of coalescent detrital talus along the northern piedmont and the pediment indicates climatic deterioration in this region. The climate was markedly more arid than the present one, permitting the development of the widespread erosional surface (Fig. 6b).

Afterward, the *in transit* alluvium on the pediment was laterized, forming a duricrust on the pediment surface. The morphogenetic episode can be related to sub-humid conditions (Fig. 6c).

A new climatic change is recorded at the time a drainage network dissected the pediment surface, dismantling the ferruginous crust (Fig. 6d). The alluvial fans and the alluvial/colluvial sediments were deposited by sheet wash and creeks during more arid conditions than the present (semiarid?) (Fig. 6e). At present, rainforest covers the landscape and mask these landforms. The scarcely developed present day drainage network might be in an incipient state of vertical incision (Fig. 6f).

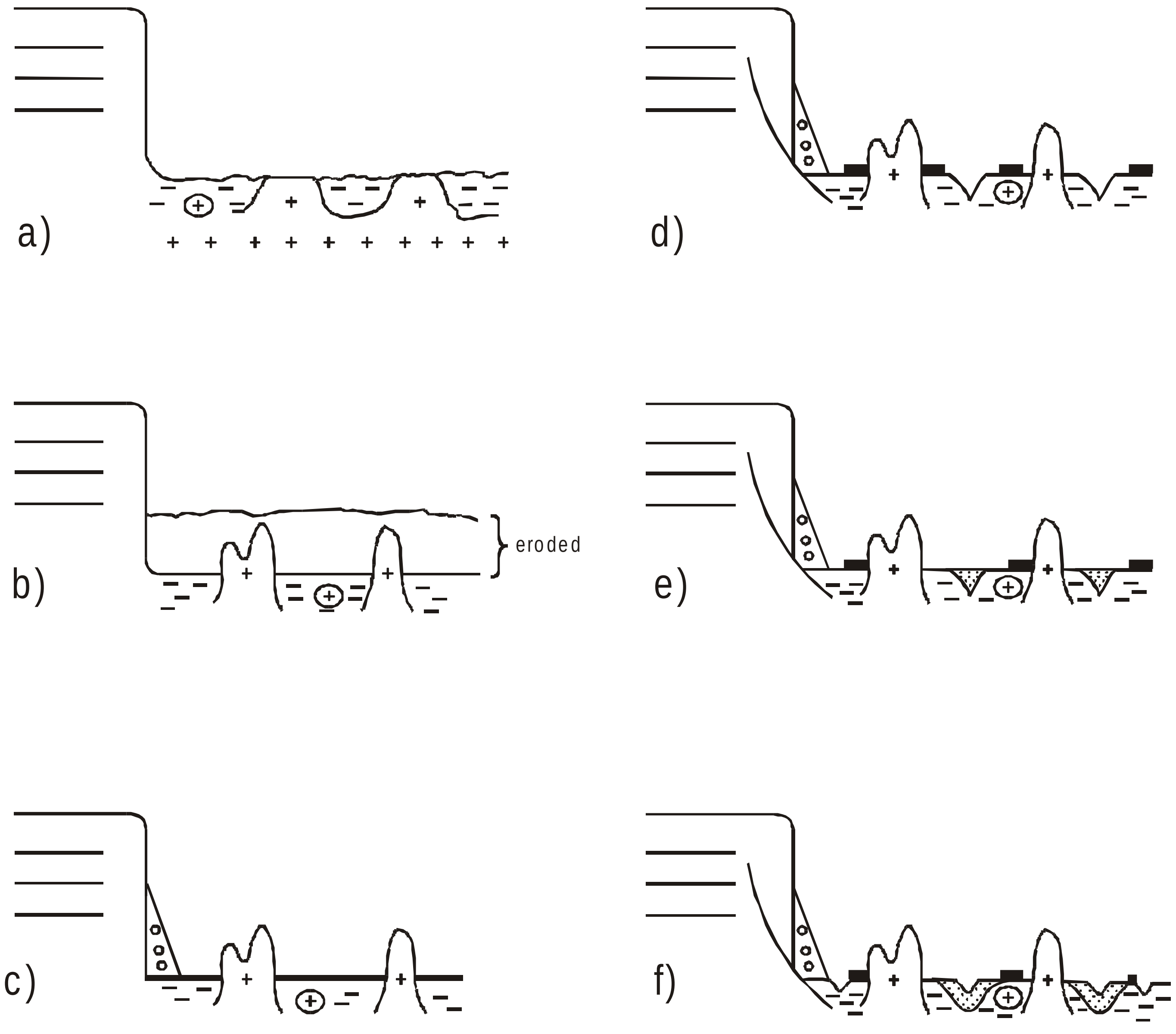


*Figure 6 - Evolutive geomorphological sequence in the Pacaás Novos area.*

**CONCLUSION** The geomorphologic data of the Pacaás Novos presented here are unequivocal evidences of climatic changes in this part of Amazonia during the Quaternary.

However we do not have a good chronology of the morphogenetic episodes that can permit us to correlate them to the Quaternary general climatic changes.

The complex geomorphological sequence in the Pacaás Novos Range permits us to claim that it is necessary and possible to find new kinds of paleoenvironmental and paleoclimatic indicators in Amazonia, that permit to go back to some periods of the Quaternary which are almost totally unknown to us, as happens with a large part of the Pleistocene. Thus, the geomorphological research becomes a need to reconstruct the past, as currently demonstrated by results of different authors in other tropical rainforest of the world. As exemplified in this paper, the ways indicated by early research pioneers in Amazonia, and successively forgotten, need to be retaken.

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