GEOMORPHOLOGY AND LAND DEVELOPMENT IN THE MARACA AREA OF NORTHERN RORAIMA, BRAZIL.

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SUMMARY

The geomorphological materials and forms of the Maraca area of Roraima, Brazil are described, and their signficance for land development examined. Significant contrasts are noted in areas presently under rainforest and savanna vegetation. Lateritic gravels and extensive sheetwash accumulations in savanna areas contrast with incipient or absent plinthite development, few gravels and limited evidence of colluvium under rainforest. Terrain is in general relatively highly-dissected. Slope profiles are characterised, particularly within the savanna zone, by a relatively steep lower concavity. These contrasts are sharply-demarcated by the present savanna/rainforest boundary, unexpectedly in view of the generally accepted hypothesis of repeated contraction and expansion of Amazonian rainforest throughout the Pleistocene. It is concluded that geomorphological conditions in the Maraca area are not favourable for land development.

INTRODUCTION

The geomorphology of the Federal Territory of Roraima has been reviewed generally at various times (Guerra, 1956; Ruellan, 1957; Barbosa & Ramos, 1959; Beigbeder, 1959; Radambrasil, 1975). These studies have been concerned mainly with general topographic characteristics and long-term landform evolution. The relation of these geomorphological factors to land development has not been examined in detail. This paper sets out to examine the geomorphological materials and forms in part of the Territory adjacent to the present savanna/forest boundary, to seek explanation for their formation, and to assess their significance for land development.

Field investigations were carried out in 1987 in the Maraca area of the Rio Urari coera, a major right bank tributary of the Rio Branco (Fig. 1). The area represents the transition zone between savanna to the east and forest to the west. The climate is humid tropical, with a mean annual temperature of about 26°C and annual precipitation of approximately 1900-2000 mm (RadamBrasil, 1975). The regime is seasonal, with drier conditions commonly extending from September to March.

Geologically, the study area lies on the southern flank of the Guiana Shield, which comprises an ancient complex of crystalline rocks. These are mainly granites, gneisses

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and mica-schists of Pre-Cambrian age, and are locally overlain by Proterozoic sediments of the Roraima Formation. There is recurrent evidence of faulting and other tectonic effects in the vicinity of Maraca. Fault patterns in the area strongly affect local drainage alignments, as in the case of the Furo de Santa Rosa.

Landscapes of the Guiana Shield have undergone polycyclic development, with gently undulating to dissected planation surfaces produced. The most extensive level in the Maraca area is at an elevation of 100-130 m, and is partly covered by Quaternary sediments. An extensive planar surface occurs at approximately 250-400 m in the area to the west of Maraca Island. These units are broadly shown on the morphostructural map of Roraima produced by Projeto Radambrasil (Radambrasil, 1975) (Figure 2).

The savanna/forest boundary in the vicinity of Maraca is roughly coincident with the relief boundary between the lower, end-Tertiary (Plio-Pleistocene) Surface, denoted by Bigarella & Ferreira (1985) as **Pediplane Pd_1**, to the east, and the higher, late-Tertiary (upper Miocene-lower Pliocene) Surface, denoted by Bigarella & Ferreira (1985) as **Pediplane Pd_2**, to the west. These surfaces are recognised in nearby Guyana by McConnel (1968) as the Rupununi and Kaieteur Surfaces respectively. The study area, which is developed over schistose and related rocks of the Guiana Shield, lies at a height of approximately 130 to 140 m on the margin of the Pd_1/Rupununi Surface. Investigations were concentrated on the forested eastern end of Maraca Island, and on the savanna/forest boundary areas to north and south (Figure 3). Considerable local dissection has occurred in the area, giving rise to undulating relief with an amplitude of dissection of 25 to 30 m.

In general, contrasting pedogeomorphic processes may be expected to occur in savanna and rainforest areas. Areas of Amazonia in which savanna appears to have predominated throughout the Quaternary commonly exhibit stripped profiles, with hardened plinthite at or close to the surface in many places. Flat summits, often with associated gravel deposits, and areas of sheetwash accumulation are also common, giving many parts of the savanna a rather angular appearance.

In contrast, areas which appear to have remained under rainforest commonly exhibit a much lower degree of plinthite hardening, reflecting less exposure by stripping. Incipient concretions are found within soil profiles, but indurated layers are infrequently encountered. Summits are usually rounded rather than flat, while overall, slope forms are generally convexo-concave. Sheetwash processes occur, but are less efficient than in the savanna.

However, Quaternary climatic change has been postulated for Amazonia, leading to shifts in the distribution of savanna and rainforest (Haffer, 1969). Is has been argued (for example, Prance, 1982) that as much as 80 percent of existing rainforest was displaced during drier climatic periods. The forest refugia were largely restricted to mountainous slopes receiving orographic rainfall on the eastern side of the Andes and on the Guiana and Brazilian Shields, and to a few relatively small areas elsewhere (Figure 4).

Where rainforest has been temporarily displaced by savanna as a result of climatic change, savanna processes would extend into the area formerly under rainforest. It would be expected, therefore, that relict features of savanna processes, such as lateritic gravels and sheetwash deposits, would persist under the restored rainforest. In the field, however, the authors have found surprisingly marked pedogeomorphic contrasts across the contemporary savanna/forest boundary in the vicinity of Maraca. The environmental significance of this will be discussed.

MATERIALS

The marginal area of the Pd_1/Rupununi Surface in the vicinity of Maraca is a partially-stripped landscape. Unweathered rock outcrops are localized, and are mainly micaceous schist with some granitic material. Tors, with rounded blocks, occupy some off-summit slopes, though large-scale rock residuals are less frequent in this area than is often the case in other parts of the Pd_1/Rupununi Surface. Such features are, of course, more readily observed in savanna areas, but have been encountered under primary rainforest in the study area.

Exposures of **in situ** weathered bedrock are encountered on many flanking slopes in both savanna and rainforest zones. Preliminary analysis of representative slope profiles suggests that such exposures tend to occur closer to summits in savanna areas (Fig. 5). It seems most likely that these materials are associated with a process of etchplanation rather than pediplanation (Eden, 1971), with schists weathering to clays in this area. These clays are mainly kaolinitic, with gibbsite and some traces of illite (Radambrasil, 1975).

In areas to north and south of the eastern end of Maraca Island, marked contrasts exist in surface materials found in areas presently covered by rainforest and savanna vegetation. Representative soil profiles from the margin of the Pd_1/Rupununi Surface, under rainforest and savanna and both underlain by **in situ** weathered rock, indicate the principal differences:

Site 74 - rainforest

Location:	south of Furo do Maracá, c. 4 km south of Fazenda Nova Olinda
Relief:	local summit, slope 0 to 1°.
Parent material:	schist.

0-25 cm	Yellowish red (5YR4/6) sandy clay loam to sandy clay. Occasional fine pisolithic concretions and weathered schist fragments.
25-45 cm	Dark red (2.5YR3/6) clay with few fine pisolithic concretions.
45-150 cm	Dark red (2.5YR3/6) clay with very few medium subangular gravels and fine pisolithic concretions.

150-200 cm Dark red (2.5YR3/6) clay with few fine pisolithic concretions.

Site 91 - savanna

Location: north of Furo de Santa Rosa, c. 1km north of mouth of Igarapé Saúba.
Relief: local summit, slope 0 to 2º
Parent material: schist.

0-25 cm Loose layer of medium to coarse angular to subangular lateritic gravels with few medium to coarse angular to subangular quartz gravels and few fine rounded pisolithic gravels in dark grayish brown (10YR4/2) sandy loam matrix.

25-90 cm Abundant medium to coarse angular to subangular lateritic gravels with few to common medium to coarse subrounded quartz gravels in red(2.5YR5/8) to reddish yellow (7.5YR6/8) sandy clay loam matrix.

In general, evidence of laterization appears to be comparatively slight in rainforest profiles in the study area. Incipient iron concretions are present in most rainforest profiles, but hardened concretions are few, and often limited to occasional small rounded pisoliths in upper horizons. Nortcliff & Robison (1988) note the presence of plinthite under rainforest on Maraca Island, although they do not describe the nature of the plinthite in detail.

In contrast, surface concretionary accumulations are widespread in parts of the savanna. The accumulations characteristically comprise medium to coarse (2 to 5 cm) angular to subangular lateritic gravels with subsidiary medium to coarse (2 to 5 cm) vein quartz gravels and fine (0.5 to 1 cm) rounded to subrounded pisolithic gravels. These gravels frequently form a relatively flat-surfaced capping on local summits, to a depth of at least 1 m.

Other savanna summits, together with adjacent lower ground, are sandy loam to sandy clay loam in texture, and appear to comprise sheetwash accumulations. These savanna topsoils are significantly more compact than rainforest topsoils, bulk densities averaging 1.48 (n = 15) compared with 1.27 (n = 21) from rainforest. In this area, as elsewhere in Amazonia, an increase in topsoil bulk density rapidly follows contemporary rainforest clearance (Eden & McGregor, 1989). Compaction and surface sealing, following climate-induced vegetational changes, will almost invariably lead to increased runoff. This will in turn sustain sheetwash processes and, particularly in upslope locations, lead to residual accumulations of lag gravels. Fines are transported out of the system through the stream channel network.

A representative colluvial soil profile under savanna indicates the principal characteristics:

Site 84 - savanna

Location:	c. 3 km east of Fazenda Patchuli.
Relief:	flat-topped summit.
Parent material:	schist.

0-25 cm	Yellowish brown (10YR5/4) sandy loam.
25-50 cm	Yellowish brown (10YR5/8) sandy loam.
50-75 cm	Brownish yellow (10YR6/6) sandy loam.
75-100 cm	Brownish yellow (10YR6/6) sandy loam with few red (10R5/8) mottles. Few fine subangular and subrounded quartz gravels.

Extensive augering throughout the field area indicates that colluvial slope foot materials are characteristically more extensive in savanna than in the area presently under rainforest. This is a function of greater colluvial activity in savanna in the study area, as evidenced by the widespread presence of sheetwash on savanna sites, and as suggested by the relatively rapid response to contemporary rainforest clearance noted here and elsewhere in Amazonia.

Morphology

Relief patterns

Regional relief contrasts are visible on radar imagery (Radambrasil, 1985). The texture of tonal change on such imagery relates to degree of dissection. Thus, a higher frequency of tonal change corresponds to lesser, but more frequent, vertical incision, while a lower frequency of tonal change corresponds to greater, and presumably more 'mature', incision (Eden **et al**., 1984).

The higher Pd_2/Kaieteur Surface is characterised by relatively high-frequency dissection patterns predominating to the west and southwest of Maraca Island, in areas presently under continuous rainforest. The margin of the Pd_1/Rupununi Surface, partly under rainforest and partly in savanna, is characterised by a more open texture, with fewer tonal changes. This is well-illustrated in the forest zone running approximately north-south through the eastern third of Maraca Island. Further to the east, the Pd_1/ Rupununi Surface is predominantly in savanna, and is characterised on the imagery by a progressively more open texture, corresponding to colluvial/alluvial plains of lower relief.

On Maraca Island, local changes in dissection patterns may be recognised from aerial photographs at a scale of c. 1:70,000. These changes have been mapped (Figure 6), are partly structural in origin, and only partially related to the Pd_1/Pd_2 boundary. Accurate quantitative assessment of dissection differences between areas presently under rainforest and adjacent areas under savanna proved impossible due to the masking effects of the rainforest cover. However, a qualitative assessment of pattern under rainforest and savanna at the margin of the Pd_1/Rupununi Surface suggests that more ridged and narrower summits under rainforest contrast with flatter and wider summits in savanna areas. Summits in rainforest areas appear to show a slightly more linear plan, compared with a slightly more circular plan in savanna areas. In terms of development potential, it is clear from examination of the aerial photographs that much of the study area presently under rainforest is relatively heavily dissected.

Slope profiles

Slope profiles are generally smooth throughout the field area, with the exception of profiles in which rock outcrops are present. Representative surveyed profiles are shown in Figure 5.

Slope profiles are in general similar to those reported elsewhere in Amazonia (for example Young, 1970; Journaux, 1975; Eden **et al**., 1982), more angular savanna profiles contrasting with more rounded profiles under rainforest. It is notable, however, that in many savanna profiles, the lower slope is markedly steeper than that under rainforest (Figure 5). Maximum slope angles in savanna and under rainforest recorded in this survey are not markedly dissimilar ($28^{\circ}20'$ in savanna compared with $26^{\circ}30'$ under rainforest) but angles exceeding 20° were relatively frequent in savanna, and uncommon under rainforest.

Elsewhere in Amazonia, steep lower slopes have been noted under rainforest (Journaux, 1975). These were ascribed by him to a combination of periodic fluvial undercutting and remobilisation of colluvial material during drier climatic conditions in the Pleistocene. While forms identical to the 'demioranges' described by Journaux (1975) have not been identified in the Maraca area, field evidence points to the possibility of slope undercutting, possibly by river erosion or by basal sapping, as a contributory factor in oversteepening of profiles in savanna areas. Wash features are common in the field area, and thicken towards the foot of the slope. Minor gullying and mass movement (terracettes) are commonly present. The sharp break of slope frequently noted just off the summit edge may relate to the armouring of many savanna summits by lateritic gravels.

There are two possibilities. Either the morphological features seen at present under savanna are the result of contemporary processes, or relate to a period or periods of environmental conditions unlike those of the present. One contemporary process which could cause slope undercutting is basal sapping. This was noted in a number of locations, and undoubtedly would contribute to oversteepening of profiles. Local sites of minor mass movement have often developed a 'scalloped' profile, with arcuate zones of minor disturbance on sides of individual hills. These act to concentrate basal sapping though it is not clear whether basal sapping is a significant contributory process in the development of the form, or whether the developing form has caused a concentration of basal sapping.

However, the overall effects of basal sapping are not necessarily significant in this area. If they were, the process would presumably have produced similar forms in the past in areas where rainforest was temporarily replaced by savanna. Such similar forms, either active or relict, were not encountered under rainforest during the present study, though lack of visibility reduces the possibility of recognition.

The second possibility suggested above is that these features may relate to environmental conditions unlike those of the present. To propose a combination of colluvial activity and fluvial undercutting implies less vegetative cover than at present in savanna, but more vigorous stream activity. This suggests a low-frequency, high-magnitude discharge environment, such as semi-arid, not markedly dissimilar to that pertaining during the dry season in savanna areas today. If there was a dry period in the late Pleistocene in this area, such environmental conditions could well have prevailed. It is stressed, however, that such postulated conditions represent a difference of degree, rather than type, compared with present-day conditions in the Roraima savanna, where a dry season of 7 to 8 months is experienced. The basic processes, resulting in production of lateritic gravels and arcuate slope forms, are similar.

DISCUSSION

This is a weathered landscape, apparently associated with etchplain formation. Leached soil parent materials predominate, generally resulting in acid soils containing few exchangeable bases and with clays having low cation exchange capacities. These soil conditions are of course widely recognised by soil scientists and agriculturalists, but it is worth emphasising that their basis lies in the geology and the geomorphological evolution of the landscape. Admittedly, deeply weathered land surfaces have in places already been stripped, as is the case with the margin of the Pd_1/Rupununi Surface at Maraca, but there is still a veneer of decomposed rock in many areas. It is suggested that the weathered layer will be of greater thickness on the older Pd_2/Kaieteur Surface to the west, as this surface has not been subject to etching at the Pd_1/Rupununi level.

Plinthite is generally associated with the more seasonal areas of Amazonia, and is widely present in the study area. In the rainforest zone, plinthite consists of iron-rich incipient concretionary material and few, generally fine, quartz gravels. The current tendency of scientists working in the Amazon Basin is to de-emphasise the significance of plinthite with respect to land development, and certainly the more pessimistic views regarding the dangers of its formation (McNeil, 1964; Goodland & Irwin, 1975) are no longer acceptable. As Cochrane & Sanchez (1982) indicate, the areal extent of soils with subsoil plinthite in Amazonia is limited to only about 4 percent. However, this is equal to a total area of about 21 million ha, and, where plinthite does occur, it is a significant factor in land development.

The other main product of landforming processes in the area is lateritic gravel - a residual product of stripping. In this area, it forms level or gently - sloping surfaces, which usually occupy higher summit in the savanna zone. The wide presence of lateritic gravel in the savanna zone is a severe constraint on land development. The question arises of the extent to which this problem may be exacerbated by clearence of adjacent forest areas for agricultural or pastoral use. Nicholaides **et al**. (1984) indicate that laterization hazard arises "... only when the subsoil is exposed". In their view, "... the key is to prevent the soft plinthite in the subsoil from being exposed by erosin of the topsoil. It is only then that irreversible hardening takes place".

In the study area, topsoil compaction is higher in the savanna zone compared with that under rainforest, and this will be a significant factor in runoff production. Further it has been reported (Eden & McGregor, 1989) that here, bulk densities increase rapidly on conversion of forest to agricultural land, with an apparent increase in runoff and soil loss. Observed rates of colluvial activity elsewhere in Amazonia support this contention (McGregor, 1980). No empirical measurements of erosin rates were attempted in this study, so it remains to be shown whether the observed colluvial accumulations can be accounted for by process rates similar to those presently operating.

These conditions are ideal for the exposure and hardening of plinthite. The question is how much plinthitic material is present within the existing rainforest zone, and whether plinthite hardening would become a problem in the Maraca area on rainforest clearance? The significant amounts of lateritic material encountered in savanna areas adjacent to Maraca Island seem to suggest that widespread laterization would in time follow forest clearance as this is an area of relatively uniform geology (if locally variable), with a relatively limited range of weathering products.

A further consideration in terms of land development is the rather highly-dissected nature of the terrain. The flat plains of the Boa Vista area give way in the vicinity of Maraca to a more dissected terrain on the Pd_1/Rupununi Surface, partly in savanna, partly in rainforest. The frequency of dissection increases within the rainforest zone at the transition from the lower Pd_1/Rupununi Surface to the higher Pd_2/Kaieteur Surface presumably in response to increased potential energy for erosion. Slope profiles are characterised, particularly within the savanna zone, by a relatively steep lower concavity.

In the vicinity of Maraca, the contemporary savanna/rainforest boundary is the focus of land use change, at present principally conversion of forest to pasture. Attention must therefore be drawn to the significantly different surface materials and slope profiles observed either side of that boundary. The savanna areas are partially capped by lateritic gravels, presumed to be derived from the breakup of a hardened plinthite layer, their generally angular nature suggesting relatively little transport from source. These areas are also partially overlain by sandy sheetwash material, which may be partly derived from weathered bedrock residues and partly from hardened plinthite. It seems possible that areas presently under rainforest, and appearing to offer rather better conditions for agriculture, would become geomorphologically similar to the savanna areas, resulting in accelarated erosion rates and, through time, production of hardened plinthite.

CONCLUSION

The Maraca area is of considerable geomorphological interest. There are several questions relating to the nature and effects of Pleistocene climatic change which warrant further study. For example, research elsewhere (McFarlane (1976)) suggests that a reduction in the rainforest cover, such as that induced by a shift to a more arid climate, would increase the degree of laterization. But this does not seem to have been the case here, assuming that rainforest cover was much reduced in this area. The sharp contrasts in surface materials and forms found at the present-day savanna/forest boundary in the Maraca area are not in accord with the 'refugium' concept of Haffer (1969).

This area is not yet in another Quaternary dry period. However, climatic change is only one factor in determining the rates of geomorphological activity. Human interference with the natural system is increasing, and may in time produce land stripping leading to laterization similar to that caused by climatic change. This clearly has implications for land development.

In the Maraca area, neither the forest zone nor the savanna zone adjoining the forest boundary are geomorphologically suited to land development. The presence of lateritic gravels on many savanna summits is a severe limitation on land development. Although forest profiles are generally less lateritic, rates of geomorphic activity are potentially relatively high on conversion of forest to agricultural land. Wash processes are accelerated, and are almost ubiquitous. In addition, nutrient status of rainforest soils in generally low, and declines relatively quickly after initial clearance and burning of forest vegetation (Eden & McGregor, 1989).

The degree of terrain dissection is relatively high in the Maraca area, particularly on the higher Pd_2/Kaieteur Surface to the west, into which clearance will extend. Many of the slopes are relatively steep and, particularly in the savanna zone, often sharply concave at their base. Development of a coherent road transport system would be rendered difficult, if not impracticable in such terrain. Is it concluded that geomorphological conditions in the Maraca area are not favourable for land development.

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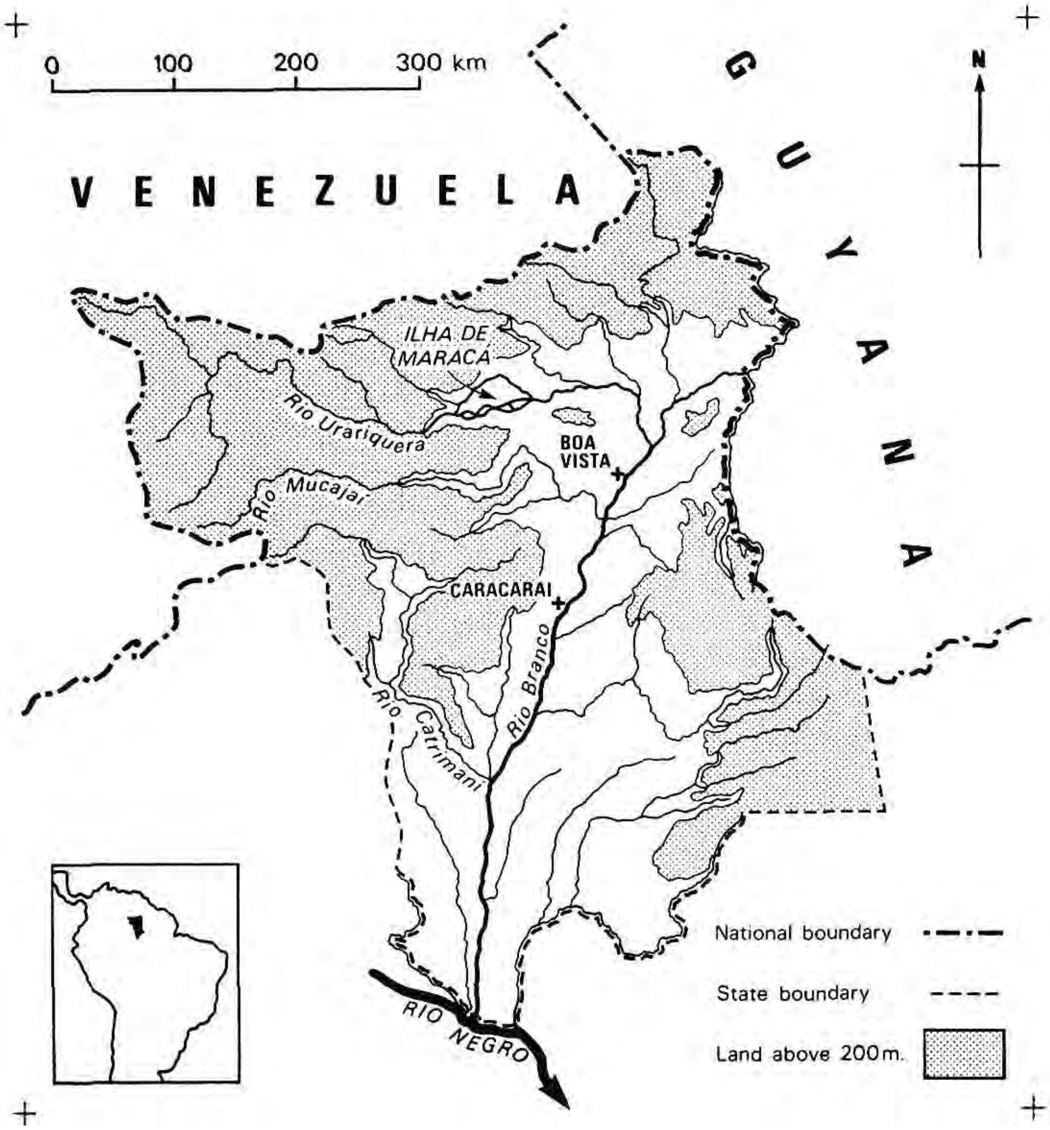

Fig. 1a. Location map - Federal Territory of Roraima and Maracá Island.

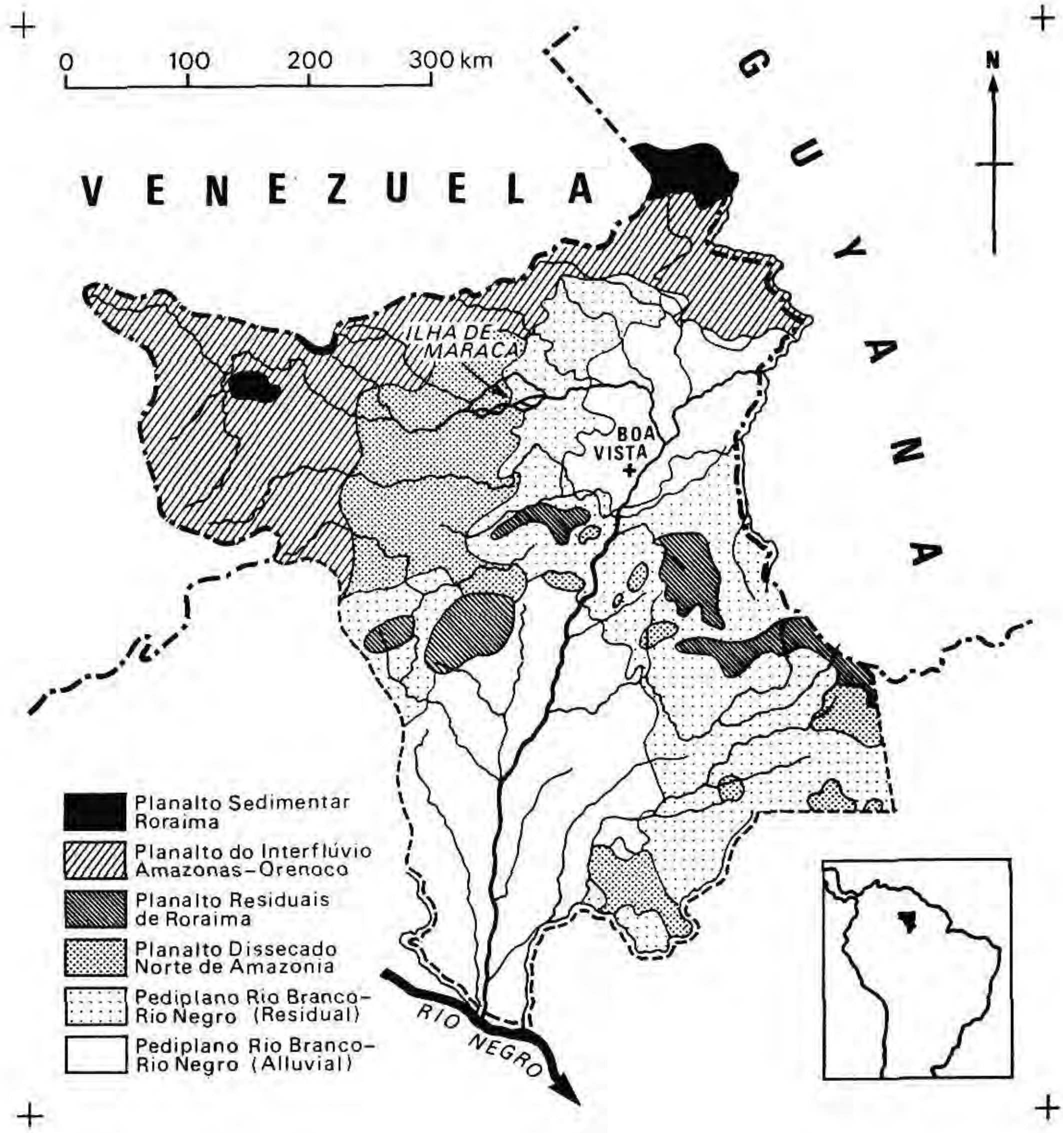

Fig. 1b. Morphostructural units of Federal Territory of Roraima (after Radambrasil 1975, 1976, 1978).

Fig. 2. The field area. Rainforest shown in tone. Site locations marked (see text).

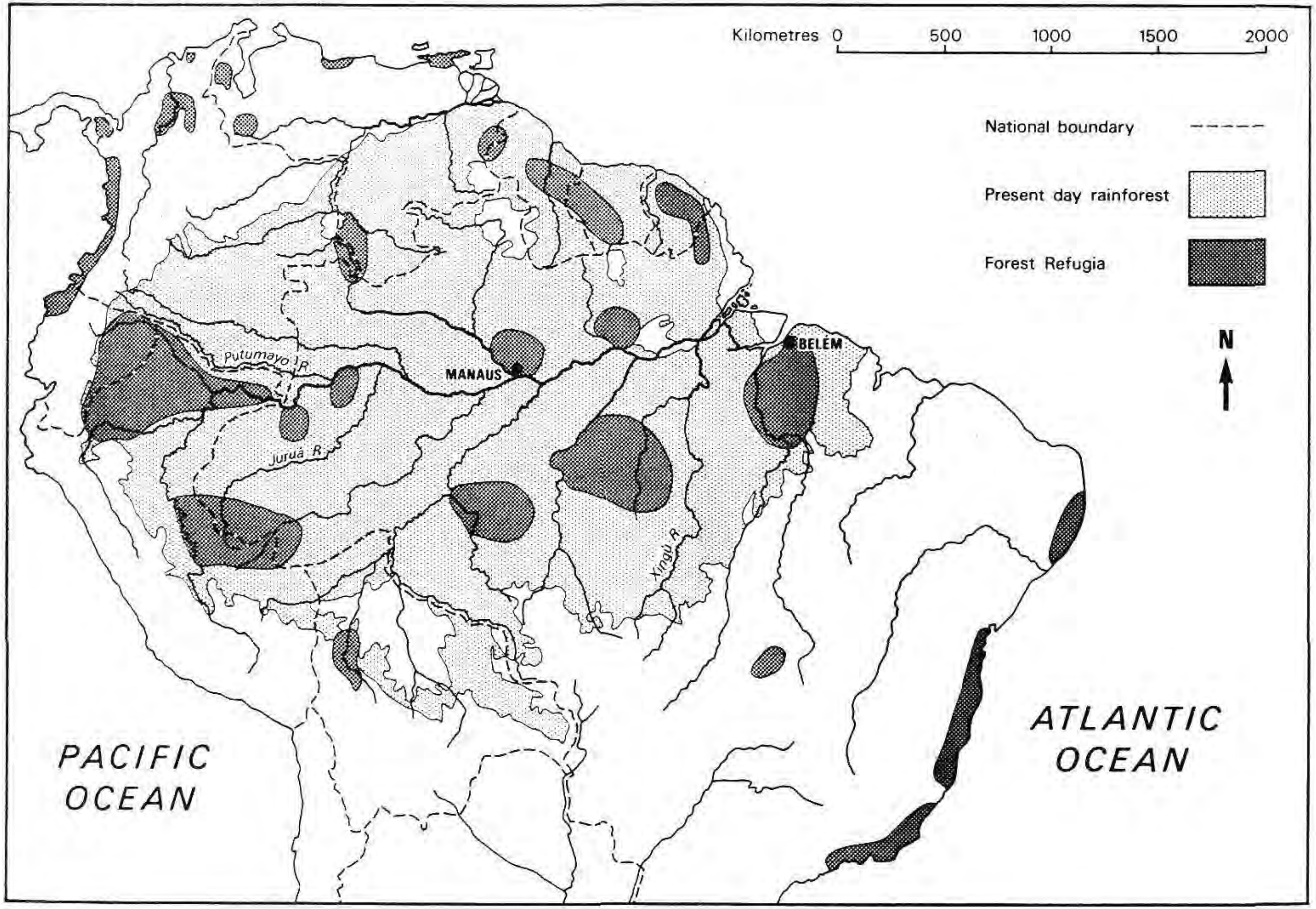

Fig. 3. Extent of rainforest in Amazonia - present-day extent and Pleitocene refugia (after Parnce 1982).

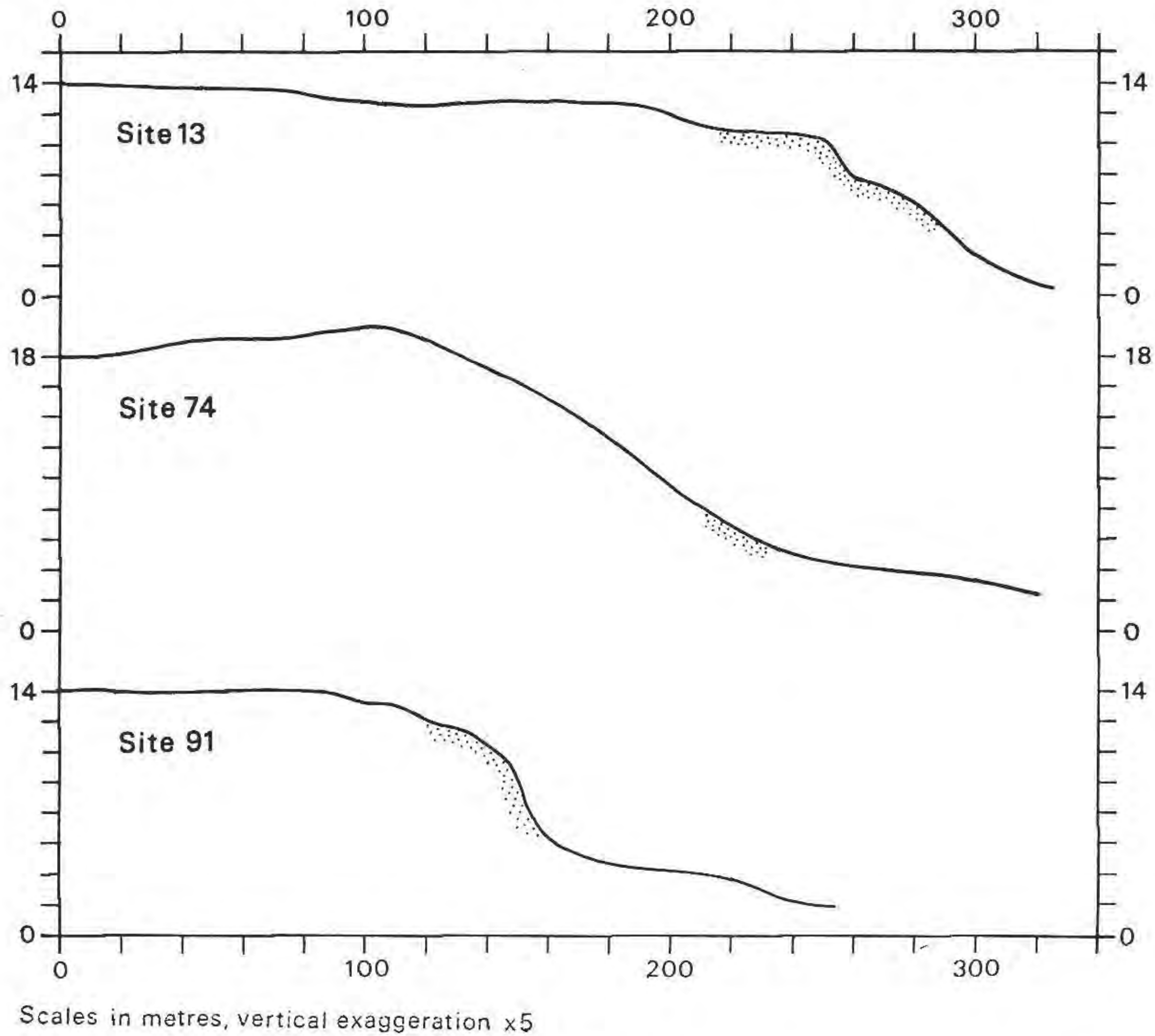

Fig. 4. Representative slope profiles. Stipple indicates outcrop of weathered bedrock.

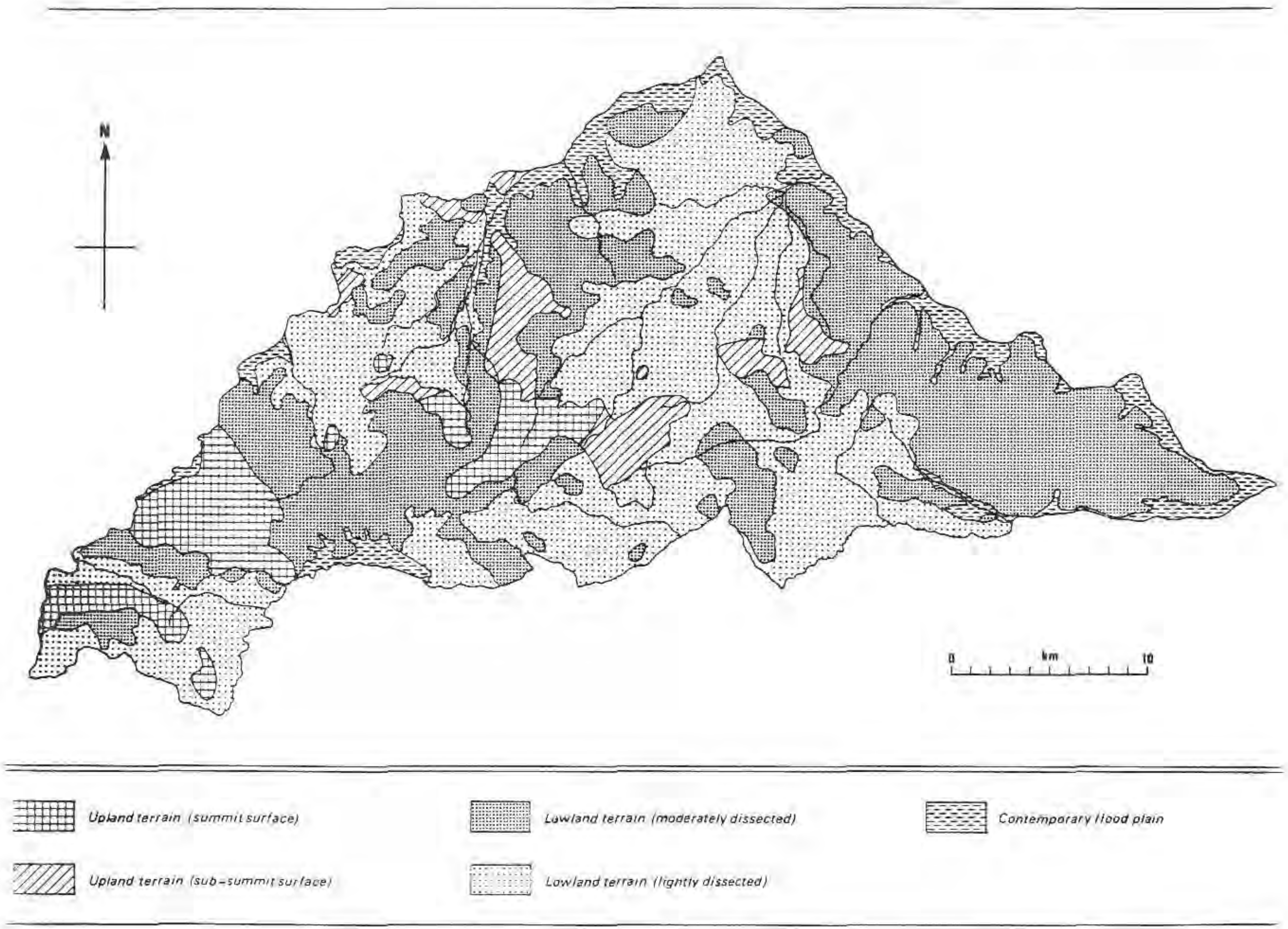

Fig. 5. Maracá Island - dissection patterns interpreted from aerial photographs.

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