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GEOMORPHIC AND LITHOSTRATIGRAPHIC EVIDENCE OF PLEISTOCENE CLIMATIC CHANGE IN AMAZONIA : NEW DATA FROM THE MIDDLE CAQUETA AREA, COLOMBIA

Témoignages géomorphologiques et lithostratigraphiques de changements climatiques en Amazonie, d'après des nouvelles données de la Moyenne Caquetá, Colombie.

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RÉSUMÉ

Les témoignages de changements climatiques en Amazonie, au cours du Pleistocene sont ici passés en revue, du point de vue lithostratigraphique et géomorphologique, à la lumière d'une étude récente sur le paysage écologique de la région de la Moyenne Caquetá, en Colombie.

Des séquences sédimentaires fluviatiles, des stone-lines et des dépôts colluviaux présentent les arguments plus plausibles pour un changement paléoclimatique. Il en est de même des dépôts éoliens mais ceux-ci ne sont présents que sur les bords, voire à l'extérieure de la région. D'autres phénomènes souvent mentionnés (induration de la plinthite, zone de sables blancs, forte dissection) sont moins convaincantes dans ce domaine.

Les preuves géologiques ou géomorphologiques d'un changement de climat sont toutefois indirectes et sont fondées sur l'hypothèse que la forêt dense s'est transformée en une forêt moins développée et plus ouverte sous l'effet des précipitations réduites et plus saisonnières, correspondant aux périodes glaciaires. Dans la région de la Moyenne Caquetá, il est toutefois invraisemblable que la couverture forestière ait subi des changements aussi importants pendant ces périodes sèches du Pléistocène. Afin d'éliminer l'influence des montagnes andines sur les dépôts sédimentaires, il convient de rechercher les changements climatiques spécifiques de l'Amazonie dans des bassins d'extension plus limitée.

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ABSTRACT

The lithostratigraphic and geomorphic evidence of Pleistocene climatic change in Amazonia is summarized, and discussed against the new information coming from a recent landscape ecological survey of the middle Caquetá area, Colombia.

Fluvial sedimentary sequences, stone-lines and colluvial layers seem to offer the more reliable geoscientific evidence of paleoclimatic change in Amazonia. Eolian deposits offer evidence as well, but these deposits are only found along the margins or even outside Amazonia. Other often mentioned phenomena (hardened plinthite, white sand areas and severe dissection) are less useful or not convincing in providing evidence of climatic changes.

The geoscientific evidence of climatic change is indirect. Most geomorphic and lithostratigraphic phenomena are explained by the assumption that the closed forest vegetation changed in lower and more open cover types. These changes in cover types are believed to be the result of the reduced and more seasonal precipitation during the Pleistocene glacial periods. In the middle Caquetá area, however, it is unlikely that the forest cover has undergone substantial changes during these drier Pleistocene periods. To avoid Andean climatic influence in sedimentary records, more evidence about true Amazionan Pleistocene climatic change must be searched within the depositional sequences of rivers with their catchment restricted to the Amazonian lowlands.

INTRODUCTION

The Pleistocene climatic history of Amazonia is of great importance to understand the origin and the present-day distribution of soils and vegetation as well as of plant and animal taxa. Palynological studies (recent overview in VAN DER HAMMEN, 1991; see also ABSY *et al.*, 1991), have indicated that drier and somewhat cooler climatic conditions prevailed during some periods in the Pleistocene in the Amazon area. Lithostratigraphic and geomorphic evidence for Amazonian climatic change has been reported since the late fifties/early sixties, and has been used particulary to support the so-called Pleistocene forest refuge theory (HAFFER, 1969; PRANCE, 1982; WHITMORE & PRANCE, 1987).

The purpose of this paper is to give a short updated overview of the lithostratigraphic and geomorphic indications of Pleistocene climatic change in Amazonia and to report if these were also observed during the recently carried out landscape ecological survey of the middle Caquetá area of Colombia (DUIVENVOORDEN & LIPS, 1993). In this survey new aerial photographs (scale of 1:20,000 and 1:33,000) were used to map about 700,000 ha of the middle Caquetá basin between Araracuara and the mouth of the Cahuinari River (Fig. 1 and 2). Field data were obtained between 1986 and 1991 (DUIVENVOORDEN & LIPS, 1993; VAN DER HAMMEN *et al*, 1992a, b). Earlier reports of exploratory studies have been given by EDEN *et al.* (1982) and PRORADAM (1979).

Various criteria have been used to determine the boundaries of Amazonia. In the present paper Amazonia is defined as the catchment basin of the Solimoes/Amazon River excluding the elevated zones in the Andes but including some areas outside this basin (parts of Amapá and Pará in Eastern Brazil, the Guianas and the lower Orinoco area - Fig. 1). According to this definition, which is after FITTKAU (1974), Amazonia corresponds roughly to the Hylaea of VON HUMBOLD and to the geographical distribution of the genus *Hevea*.

Recent reviews on the geology, geomorphology and paleoclimate of northern South America have been given by KLAMMER (1984), BIGARELLA and FERREIRA (1985), TRICART (1985), DICKINSON and VIRJI (1987), HAFFER (1987), SALO (1987) and SCHUBERT (1988). In the present paper the geoscientific evidence of climatic change of areas clearly outside Amazonia (although mentioned as 'Amazonian' paleoclimatic evidence in some reviews) is not taken into account (GARNER, 1958, 1966 : Río Caroni; BEIGBEDER, 1959 : upper Río Branco area; TRICART, 1974 : Llanos of the Orinoco River; TRICART, 1985 : Pantanal area, São Francisco valley and Santa Elena area; see all locations Fig. 1). Several repeatedly mentioned lithostratigraphic and geomorphic phenomena can be recognized, which will be discussed shortly below.

PLEISTOCENE PALEOCLIMATIC SIGNIFICANCE OF LITHOSTRATIGRAPHIC AND GEOMORPHIC PHENOMENA IN AMAZONIA

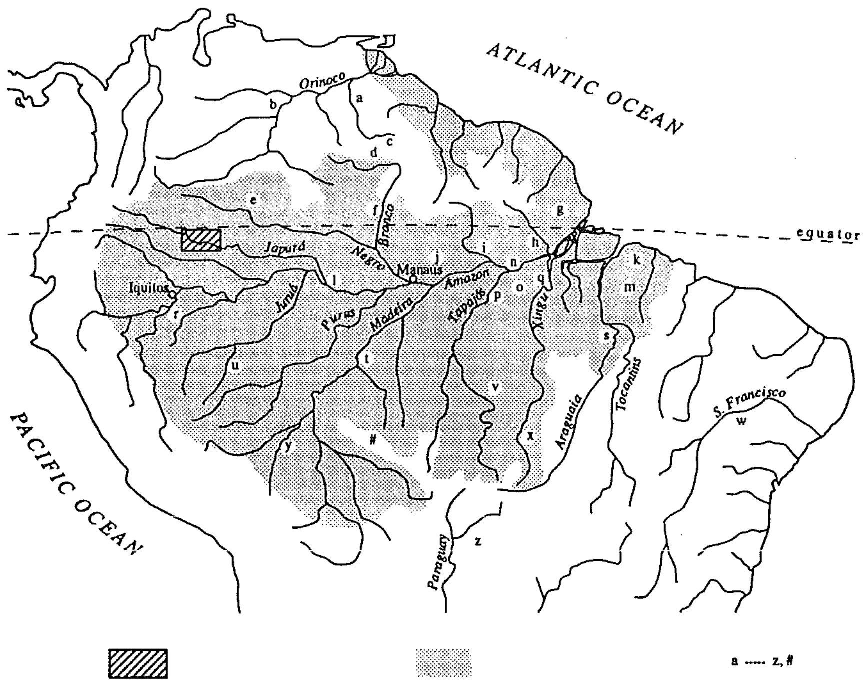
FLUVIAL TERRACES AND MORPHOLOGY OF RIVER PLAINS

Fluvial terraces are generally considered to provide evidence of Pleistocene climatic change in Amazonia. Several quite distinct models of terrace formation may have paleoclimatic significance. In central/eastern Amazonia, and particulary along the Amazon itself, the formation of river terraces is considered a result of channel aggradation at high interglacial sea levels, induced by the continuous supply of detritus from the Andes. Channel incision would have occurred at times of low sea levels during the glacial maxima. Study results supporting this model are based on relative datings and are obtained along the Solimões River Near Tefé and along the Madeira River near Humaitá (TRICART, 1985), along the Trombetas, Urubú and Uatumã rivers (KLAMMER, 1976, 1978), the Guamá-Imperatriz area (SOMBROEK, 1966) and the Tapajós, lower Amazon, Parú and Jarí rivers (KLAMMER, 1971) (Fig. 1 for all locations). SOMBROEK (1966) also mentions that, theoretically, high sea levels and associated high erosion base levels may lead to entrenchment and terrace formation in upstream deposits of glacial periods, above the so-called terrace intersection point of relative small tributaries of the Amazon River in east and central Amazonia. All these terraces are related to glacial-eustatic sea level changes and have thus only an indirect palaeoclimatic significance.

Contrary, in the periphery of Amazonia, where hard rock of the Precambrian shield often form local erosion bases, fluvial terrace formation is generally related to climatic factors (SOMBROEK, 1966; EDEN *et al.*, 1982; KHOBZI *et al.*, 1980; TRICART, 1977, 1985; see also KROOK, 1979). It is assumed that deposition of relatively coarse terrace material (aggradation) took place in drier glacial periods when the reduced vegetation cover and the more torrential precipitation favoured erosion. Valleys became filled up with eroded material that could not be transported sufficiently by the rivers because of their reduced discharge capacity. In more humid interglacial periods phyto-stabilization along slopes reduced the erosion, and rivers cut themselves down into their proper sediments which would lead to channel incision and the formation of terraces. Relatively coarse terrace deposits in comparison with finer present-day flood plain sediments in Amazonia are generally considered to be deposited in drier phases of the Pleistocene (SOMBROEK, 1966; BAKER, 1978). Similarly BIGARELLA and FERREIRA (1985) state that the occasional cross-bedding and the poor sorting of the sandy terrace deposits in the Brazilian Amazon area would indicate that the sediments were "transported by a fluctuating stream regime with a high capacity of transport typical of seasonal climates unlike the present pluvial one". In the view of KLAMMER (1971), however, this poor sorting and cross-bedding might be caused by shifting stream channels, and do not necessarily point at any climatic change.

Only few Amazonian field descriptions and no absolute dating exist to support the climatic model of Amazonian terrace formation. In the Araguaia basin, at the border of Amazonia (Fig. 1) SOMBROEK (1966) mentions a terrace level composed of "very sandy" material and covered by forest, to which he assigns a Pleistocene age. The same author also suggests that extensive areas in the upper Xingu area (Fig. 1) which are mapped as Pleistocene deposits on the 1960 geological map of Brazil, have the same climatic origin. TRICART (1977, 1985) describes terrace sequences along the Muru and Tarauacá rivers, in the upper Juruá basin (Fig. 1) and relates them to a slow regional uplift of the area in combination with alternating phases of channel aggradation and incision that may have been induced by climatic changes.

In a way some parallels exist between the climatic terrace formation model and the model of pediplanation processes in more arid parts of South America (GARNER, 1969; BIGARELLA *et al.*, 1985; see below). Tentatively BIGARELLA and FERREIRA (1985) tried to correlate Amazonian terrace levels to various levels recognized in the



Middle Caquetá area (see fig. 2)

Amazonia (after Fittkau, 1974)

Sites mentioned in this paper

Fig. 1 : Location of Amazonia and of the most important research sites mentioned in the paper (see also fig 2); Explanation of codes : a. Río Caroni (GARNER, 1958, 1966); b. Llanos Orinoco River (TRICART, 1974); c. Sta Elena, Venezuela (TRICART, 1985); d. Upper Río Branco (BEIGBEDER, 1959); e. Eastern part of Colombian Vaupés area (PRORADAM, 1979); f. Catrimani (Río Branco) (TRICART, 1985); g. Amapá area (including Serra do Navio area and Araguari River) (AB'SÁBER, 1982; KROOK, 1979); h. Parú and Jarí basins (KLAMMER, 1971); i. Trombetas River (KLAMMER, 1978); j. Urubú/Uatumã rivers (KLAMMER, 1978); k. Bragançá-Imperatriz area (SOMBROEK, 1963); n. Tapajós and lower Amazon basin (KLAMMER, 1971); o. Interfluvium Tapajós-Xingu rivers (BIGARELLA & FERREIRA, 1985); p. Itaituba area (JOURNAUX, 1975; BIBUS, 1983); q. Altamira (JOURNAUX, 1975); r. Ucayali River basin (DUMONT *et al.*, 1992); s. Araguaia (SOMBROEK, 1966); t. Humaitá area (TRICART, 1985); u. Muru/Tarauacá rivers (TRICART, 1985); v. Serra do Cachimbo area (BIBUS, 1983); w. S. Francisco valley (TRICART, 19485); x. Upper Xingu (mentioned by SOMBROEK, 1966); y. Lowlands Beni River (JORDAN, 1981); z. Pantanal area (TRICART, 1985); #. Chapada dos Parecis area, N-Rondônia (EMMERICH, 1990).

landscape development of (semi-)arid parts of SE and NE Brazil. These authors, however, do not present any supporting terrace data from Amazonia itself.

Recent studies of radiocarbon dated Pleistocene deposits in western Amazonia point at fluvial terrace formation under the influence of relatively humid climatic stages in the Andes. In the middle Caquetá area in Colombian Amazonia (VAN DER HAMMEN *et al.*, 1992a; see below) formation of the low terrace of the Caquetá River is linked to Andean climatic conditions with deposition of terrace materials in the relative humid Middle Pleniglacial period and incision during the relative dry Upper Pleniglacial period. In the Iquitos area along the Andean Ucayali River (Fig. 1), DUMONT and collaborators found two Pleistocene formations of fluvial deposits up to 10 m thick, overlying the Tertiary Pebas formation, and consisting of coarse siliceous pebbles and sands (DUMONT *et al.*, 1992; DUMONT & GARCIA, 1989). Radiocarbon datings of one of these formations (Pumacahua) point at an age between > 40,000 and 32,000 years BP. Recent fluvial deposits in this area are much thicker (up to 25 m), consist of grey to grey-dark sands and silts without any coarse pebbles and show "relatively monotonous sedimentary patterns". According to DUMONT and colaborators the Pleistocene sediments may have been deposited during "high drain-off stages", with violent, probably seasonal, discharges due to climatic conditions that probably occurred in the transition periods between colder and warmer glacial interstages in the Andes.

Finally fossil flood plain morphology has been used as evidence of Pleistocene climatic change. Comparing the form and width of present rivers an cut-off meanders, DUMONT *et al.* (1992) show that the discharge of the Ucayali River might have decreased to 1/10 or 1/7 of its present-day magnitude in a drier period, that may have been around 13,000 years BP.

Cementation with iron of coarse terrace deposits is commonly recorded in central and eastern Amazonia (e.g. KLAMMER, 1971; BIGARELLA & FEREIRA, 1985) According to BIGARELLA and FERREIRA (1985) part of this ferruginous material has been formed by lateritization, which would indicate the presence of a savannah-type of climate in the Pleistocene (see below). KLAMMER (1971) denies a lateritic origin of the ferruginous materials in the terrace deposits. He claims that the iron cementation is caused by a descendant transport of Fe, which would be incompatible with lateritization.

WHITE SAND AREAS

Roughly three categories of white sand deposits in Amazonia can be distinguished : 1. White sands as *in situ* weathering residue from acid, Si-rich hard rock parent material, usually found on sandstone mesetas or on granitic inselbergs. Evidently, these white sands have no paleoclimatic significance. 2. Redeposited white sands by fluvial or eolian processes, exposed at well or poorly drained sites in flood plains or in upland conditions ("tierra firme"). Paleoclimatic conclusions about these white sands can only be deduced from their depositional facies, and not from their bleached appearance. It is therefore not clear why AB'SABER (1982) attributes a paleoclimatic significance to certain channel fills near the Serra do Navio in the Amapá region and to interfluvial white sand deposits in the Bragança area, Pará (see locations in Fig. 1). 3. White sands derived from podzolization. According to KROOK and MULDERS (1971), podzolization might have been induced by the raw humus produced by the savanna vegetation of drier Pleistocene phases. On the other hand, recent studies in various parts of Amazonia (Manaus : BRAVARD & RIGHI, 1989, 1990; Río Negro basin : SCHNÜTGEN & BREMER, 1985; Guyanas : LUCAS *et al.*, 1982; POELS, 1987) have indicated that white sand areas are formed by current podzolization processes, under humid conditions (see also KHOBZI *et al.*, 1980; BRAVARD & RIGHI, 1990).

EOLIAN DEPOSITS

Eolian deposits are generally considered as clear evidence of dry climates at the time of their formation. AB'SABER (1982) mentions intraformational Pleistocene fossil structures in white sand deposits near the Serra do Navio area in Amapá and TRICART (1985; citing TRICART & ALFONSI, 1981) reports deflation structures and sand dunes fossilized by the deposits of the Flandrian transgression near the Orinoco delta. In central Amazonia, BIBUS (1983) reports a presumed drift-sand layer in the Serra do Cachimbo area. The same author even suggests a possibly eolian origin of redeposited Belterra clay near Itaituba. In addition, TRICART (1985) mentions low sand dunes and deflation hollows near Catrimani in the basin of the río Branco, at the border of Amazonia. And finally, JORDAN (1981) describes dune areas in the lowlands of the Beni River in NE Bolivia, but these dunes occur only in the flood plain of the Beni River and have therefore probably no paleoclimatic significance. Other observations of dune fields in northern South America are made in areas outside Amazonia (e.g. TRICART, 1985 : São Francisco valley; TRICART, 1974 : *Llanos* of the Orinoco area; see all locations in Fig. 1).

Geologists of Proradam (1979) claim that Pleistocene eolian sand deposits cover extensive areas in the eastern part of the Colombian Vaupés area (Fig. 1) and in certain locations near La Chorrera, about 100 km south of Araracuara (Fig. 2). All their arguments have been convincingly disproved by KHOBZI *et al.* (1980), who accordingly state that hardly any evidence exists to support an eolian origin of the extensive sand deposits along the border of the Guiana shield in Colombian Amazonia.

STONE-LINES AND COLLUVIAL DEPOSITS

Stone-lines, as defined by AB'SABER (1982), are sub-surface formations composed of fragments of rocks and/or duricrusts. They are formed by local transportation induced by gravity and sheet wash, under conditions of a sparse vegetation cover. Stone-lines represent conclusive evidence of ancient pavements and are therefore often believed to be indicative for drier climatic conditions in the past. They are however also described as the result of animal activities (SOMBROEK, 1966; WIELEMAKER, 1984) or of shrinkage due to chemical weathering in combination with mass flow in saprolites (ALEVA, 1983). Stone-lines usually lack organic inclusions (AB'SABER, 1982) and allow therefore only relative datings. In Amazonian literature, stone-lines are sometimes mentioned as a relict of so-called desert pavements formed by deflation of fine debris and the relative accumulation of coarser rock fragments (SALO, 1987; HAFFER, 1987). It is unlikely that these extreme arid climatic conditions will have played any role in Amazonia during the Pleistocene. Stone-lines should also not be confused with layers of ferruginous concretions related to the hardening of plinthite as part of soil formation (SALO, 1987).

Stone-lines are observed in Central Amazonia along the road between Itaituba and Altamira in the border zone between the Precambrian and Tertiary surface (JOURNAUX, 1975; BIBUS, 1983), in the Serra do Cachimbo area (BIBUS, 1983) and near Manaus (MOUSINHO DE MEIS, 1968, 1971). All these stone-lines are covered by colluvial deposits, which are also related to drier glacial climatic conditions (MOUSINHO DE MEIS, 1968, 1971; BIGARELLA & FERREIRA, 1985; JOURNAUX, 1975). It remains unclear if an hiatus exists between the stone-line and the colluvial layer. Stone-lines are also reported from the Amapá and Pará regions (AB'SABER, 1982, citing VANZOLINI, 1970; SOMBROEK, 1966) in eastern Brazil. The stone-lines and cover layers in the Chapada dos Parecis area in N-Rondônia, mentioned by EMMERICH (1990), are situated just outside Amazonia (see all locations in Fig. 1).

HARDENED PLINTHITE AND EROSIONAL SURFACES

Plinthite is reddish mottled iron-rich soil material formed in intensely weathered soils under the conditions of shallow and fluctuating ground-water or pseudo ground-water levels (BENNEMA, 1982; SOMBROEK, 1966). It becomes hard upon drying due to a lowering of the water table sometimes in combination with a truncation of the profile by erosion. These processes are partially controlled by climatic factors, which explains why hardened plinthite ("laterite") in Amazonia is mentioned in relation to past drier cimates (e.g. BIGARELLA & FERREIRA, 1985). The formation of erosional surfaces is also generally associated with dry climatic conditions, in accordance with the general model of the cyclicity of land forms (e.g. GARNER, 1969; BIGARELLA & FERREIRA, 1985; see also KROONENBERG & MELITZ (1983) who point at the influence of lithology upon the formation of planation surfaces in Surinam).

BIGARELLA and FERREIRA (1985) describe an extensive pediplain ("pd1") developed on Tertiary sediments in the Amazon basin in a period of semi-aridity of presumed late Pliocene to early Pleistocene age. As an example of this surface they mention the flat interfluvium between the Xingu and Tapajós rivers (Fig. 1). Others describe this "Pliocene-early Pleistocene" level as a depositional surface (SOMBROEK, 1966; KLAMMER, 1984). BIGARELLA and FERREIRA (1985) also mention two younger Amazonian pediment levels, but are not able to relate these levels with specific locations. The various planation surfaces recognized on the shield areas in Amazonia, mostly capped by laterites and bauxitic remnants, are believed to be principally of Tertiary age (KROOK, 1979; SOMBROEK, 1966; BIGARELLA & FERREIRA, 1985).

FELDSPAR IN DEPOSITS OFF THE ATLANTIC COAST

DAMUTH and FAIRBRIDGE (1970) studied sediment cores from the deep-sea prodelta of the Amazon River in the Atlantic Ocean. The cores contained arkosic sands with 25-60 % feldspar, whereas recent sands of the Amazon River on the continental shelf contain only 17-20 % feldspar. It was argued that the arkosic sands originated from the Brazilian and Guiana shields and that they were deposited under arid conditions of a Pleistocene glacial when feldspar was supposed to be a relatively stable mineral. The conclusions of DAMUTH and FAIRBRIDGE (1970) were put into doubt by MILLIMAN *et al.* (1975) who studied arkosic sands that occur in a narrow belt on the continental shelf. These authors claimed that both the arkosic sands on the shelf as well as the deep-sea arkosic sands found by DAMUTH and FAIRBRIDGE (1970), might have come all the way from the Andes and deposited during glacial phases with low sea-levels. In addition, IRION (1976) argued that the arkosic sands found by DAMUTH and FAIRBRIDGE (1970) might have been derived from unweathered Tertiary sediments in the Amazon basin, eroded during periods with low sea-levels. In both scenarios there is no need to assume that dry conditions prevailed during the sedimentation of the arkosic sands.

Based on profound mineralogical studies, KROOK (1979) doubts a Guiana shield provenance for the arkosic sands found by DAMUTH and FAIRBRIDGE (1970) but he does not add a new interpretation. KROOK (1979) also rejects the interpretation of IRION (1976). Further on, KROOK (1979) indicates that the narrow belt of arkosic sands on the continental shelf (studied by MILLIMAN *et al.*, 1975) was not deposited by the Amazon River but by the Araguari River in the Amapá area (Fig. 1), possibly during the rise of the sea level after the Last Glacial Maximum, when the river valley of the Amazon River was drowned and very few Amazonian sediments reached the coast. More recently, HAFFER (1987) comes up with supporting evidence for the interpretation of DAMUTH and FAIRBRIDGE (1970), citing various sea bottom core studies from the Caribbean Sea.

DISSECTION

Contradicting opinions exist with respect to the origin of the dense, severely incised topography of humid tropical forested areas. TRICART (1975, 1985) is convinced that the intense dissection of the Barreiras Formation, and the deep, V-shaped valleys along the rivers in central Amazonia, are relict forms of past drier periods with lower, and more open vegetation on the slopes and with a considerable lowering of the erosional base level, related to the sea level lowering during the Last Glacial Maximum. He claims that under the present climatic conditions forested slopes in Amazonia are not being eroded by run-off which restricts the formation of any alluvium. Indeed, the lack of present-day sedimentation in Amazonian flood plains and the very low suspended load in Amazonian rivers is commonly mentioned (e.g. BAKER, 1978). The importance of bed-load transport in these rivers, however, may be underestimated : KLAMMER (1984) reports underwater clouds of sand and gravel in most Amazonian clear waters rivers.

On the other hand GARNER (1969) indicates that dense dissection patterns are developed by vertical stream incision under humid climatic conditions in forested tropical areas. This authors, as well as BREMER (1973) also mention sub-surface solution as an important present-day process in the formation of forested Amazonian valleys.

THE MIDDLE CAQUETA AREA

SETTING

The current climate of the middle Caquetá area can be classified as Afi (KÖPPEN, 1936) : tropical, with mean monthly rainfall exceeding 60 mm, and with a mean daily temperature closely fluctuating around 26° C. The yearly precipitation is

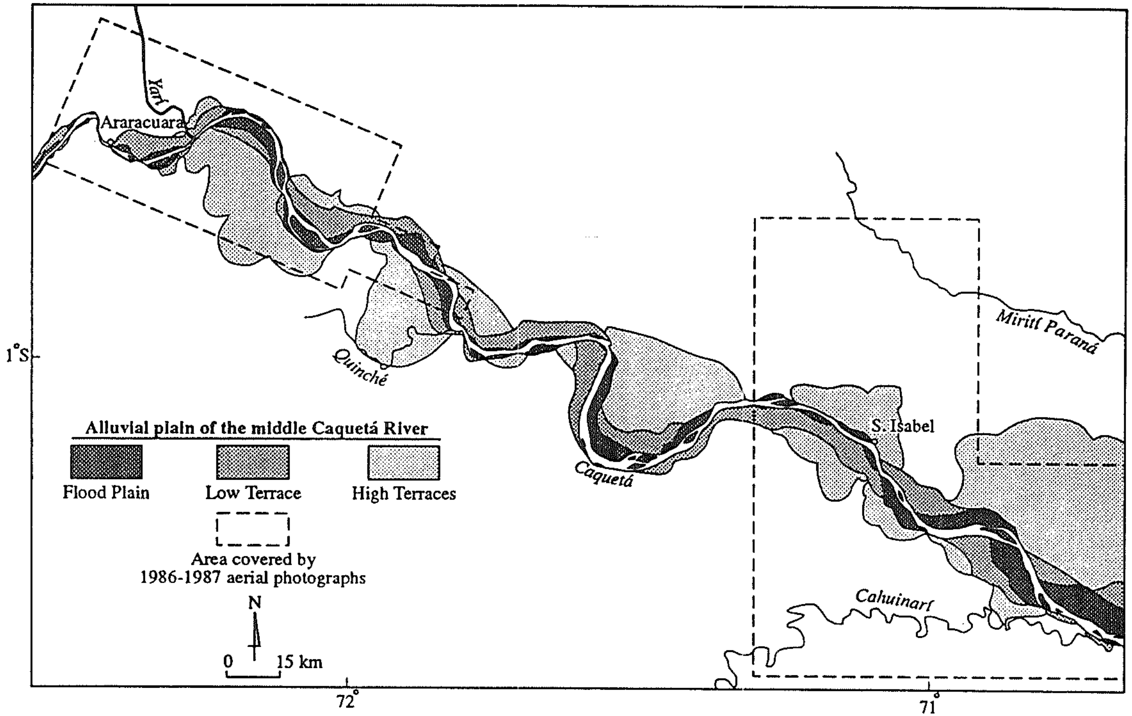


Fig. 2 : The location of the flood plain, the low terrace and the high terraces (various levels combined) of the middle Caquetá River in Colombian Amazonia (see fig. 1; after DUIVENVOORDEN & LIPS, 1992) The position of these land systems in the area not covered by aerial photographs, is derived from 1:200 000 radar images and field observations.

around 3000 mm, and shows a near unimodal distribution, with a decrease in December-February, and highest rainfall in May-July. Average rainfall in the "driest" months is well above 100 mm (DUIVENVOORDEN & LIPS, 1993). The middle Caquetá area belongs therefore to the more humid parts of Amazonia.

The Caquetá River (named Japurá River in Brazil) is a white water river and is one the major tributaries of the Solimões/Amazon River. It is a low sinuosity river and has a anastomosing appearance with stable forested islands. In certain parts it has an almost straight channel, that might be controlled by the underlying Precambrian shield. Precambrian hard rock' outcrops are regularly observed at low water levels (mostly gneisses). The Caquetá River is by far the largest river in the area and the only one with its origin in the Andes. The Amazonian rivers have generally meandering river channels. Important Amazonian rivers are the Yarí, Cahuinarí and Mirití-Paraná rivers (Fig. 2).

The middle Caquetá area is bordered at its western margin by a sandstone plateau of about 300 m a.s.l. (130-150 m above the low waer level of the Caquetá River). The sandstone belongs to the paleozoic Araracuara Formation, and is fine textured and horizontally bedded. The plateau has a flat to slightly undulating topography which is made irregular by deep fissures. Near Santa Isabel exists another NS orientated plateau of Araracuara sandstone but at a lower elevation (approx. 60 m above low river level).

The remainder of the middle Caquetá area consists mostly of non to slightly consolidated, clayey to sandy Tertiary sediments, that form a dissected sedimentary plain of about 250 m a.s.l. (about 70 m above lowest river water levels in the western part of the area to about 40 m in the eastern part). Proradam (1979) describes the landscape of these Tertiary sediments with the somewhat confusing term "denudational plain", indicating, according to BOTERO (1980), that this plain is highly dissected. During the landscape ecological survey no arguments for an erosional origin of the Tertiary plain could be found, and, in agreement with KHOBZI *et al.* (1980), it is considered essentially depositional (DUIVENVOORDEN & LIPS, 1993). The variable height of its level might be related to tectonics, as suggested by BOTERO (1980) and EDEN *et al.* (1982). The drainage pattern of the plain is predominantly dendritic and shows a high density (about 3.1 - 4.7 km/km^2; see below). Valleys are generally between 30-60 m deep with slopes of 10 - 35°. The Tertiary sediments in the area are of Miocene age and are deposited in fluvial and lacustrine environments, the latter with influxes of brackish water (Pebas Formation; HOORN, 1990, 1991). At various locations, a thin layer (about 1 - 2 m) of fluvial deposits (sand with well rounded quartz gravel, resembling the deposits of the high terraces of the Caquetá River; see below) have been found on top of the Tertiary sequence. These deposits are possibly of Pliocene-Pleistocene age.

The flood plains of the Caquetá River and the Amazonian rivers comprise less than 5 % of the area (DUIVENVOORDEN & LIPS, 1993). In the alluvial plain of the Caquetá River two upland fluvial terrace systems were recognized : low terraces and high terraces of respectively 10 - 15 and 25 - 55 m above the low level of the Caquetá River. Occasionaly, on flat and undissected parts of the high terraces of the Caquetá River and the Tertiary sedimentary plain, small to extensive areas with podzolized soils are found (DUIVENVOORDEN & LIPS, 1993). Layers of hardened plinthite have not been encountered in the middle Caquetá area (EDEN *et al.*, 1982; DUIVENVOORDEN & LIPS, 1993).

FLUVIAL TERRACES AND MORPHOLOGY OF THE CAQUETA RIVER PLAIN

During two expeditions at times of very low water levels of the Caquetá River a high number of river bank sections with organic layers were encountered (VAN DER HAMMEN *et al.*, 1992 a and b). Radiocarbon analyses yielded a total of 46 datings, of which 6 were infinite, 9 of Middle Pleniglacial age, 2 of Late-glacial age and 28 of Holocene age. The infinite 14C samples and those of Middle Pleniglacial age, were all obtained from sections belonging to units that were previously recognized as low terraces of the Caquetá River during the landscape ecological survey (DUIVENVOORDEN & LIPS, 1993) (Fig. 2).

The sedimentary sequence of the low terraces of the Caquetá River typically contains coarse deposits with layers of well rounded gravel and yellow sand with cross-bedding in the basal part, and finer deposits in the upper part. In the lower part of the sequence, and most often at the contact zone with the underlying fine-textured Tertiary sediments, the gravel and sand may be cemented with iron, sometimes forming extensive horizontal crusts exposed at the low water level line of the Caquetá River. The gravel contains chert of Andean provenance (KROONENBERG, personal communication), and pebbles of redeposited Tertiary clay which must have been deposited not far from their source. Clay pebbles are also found in other fluvial terrace deposits in western Amazonia (e.g. of the Iça Formation in western Brazil; CPRM, 1977). The layers with organic material, that ranged from dark peaty clays to peats and that included wood fragments and trunks, were found in shallow channel fills in the clayey deposits above the sands.

The depositional sequence of the higher terraces of the Caquetá River resembles that of the low terraces which allows the speculation that the high terraces are of Pleistocene age as well. However, in comparison with the low terraces, the high terraces are generally coarser textured, show much less whitish coloured clays in the upper parts of the sequences, and lack organic deposits. The borders of the high terraces with older geological units (in most cases the Tertiary sedimentary plain) are formed by curved escarpments which seem to indicate that the bends of the Caquetá River had a smaller radius during deposition of the high terraces than at the time of deposition of the low terrace and the present flood plain (Fig. 2). In the eastern part of the middle Caquetá area , high teraces of the Caquetá River at both sides of the river channel have been cut off along rather straight lines which run parallel to the so-called "Caquetá fault" line recognized by the geologists of Proradam (1979). This might point at an influence of fault tectonics upon the Caquetá River plain development, which would have occured before the Middle Pleniglacial deposition of the low terrace material.

The depositional sequences of the fluvial terraces strongly contrast with the current Holocene flood plain sequence of the Caquetá River, which is generally fine-textured, and lack the gravel as well as the sand with cross-bedding (DUIVENVOORDEN & LIPS, 1993; VAN DER HAMMEN *et al.*, 1992b; EDEN *et al.*, 1982). Parallel to the interpretation of the origin of fluvial terrace deposits in the Iquitos area (DUMONT & GARCIA, 1989; DUMONT *et al.*, 1990; see above), VAN DER HAMMEN *et al.* (1992a) suggest that the deposition of the coarse basal low terrace deposits took place during humid periods of the Middle Pleniglacial, when thick fluvial and fluvio-glacial deposits of gravel and sand were deposited in the Andes. Subsequent dissection supposedly occurred during the dry Upper Pleniglacial period.

The ferruginous sand and gravel material in the terrace sequences of the middle Caquetá River is considered a result of lateral and downward movement and subsequent secondary deposition of iron, in line with the interpretations of KLAMMER (1971). Perhaps it might be speculated that the large size of the outcrops of these ferruginous deposits point at local humid climatic conditions during their formation.

WHITE SAND AREAS

White sand areas are found on top of the sandstone plateaus (mesetas) and on top of undissected parts of the high terraces of the Caquetá River and the Tertiary sedimentary plain.

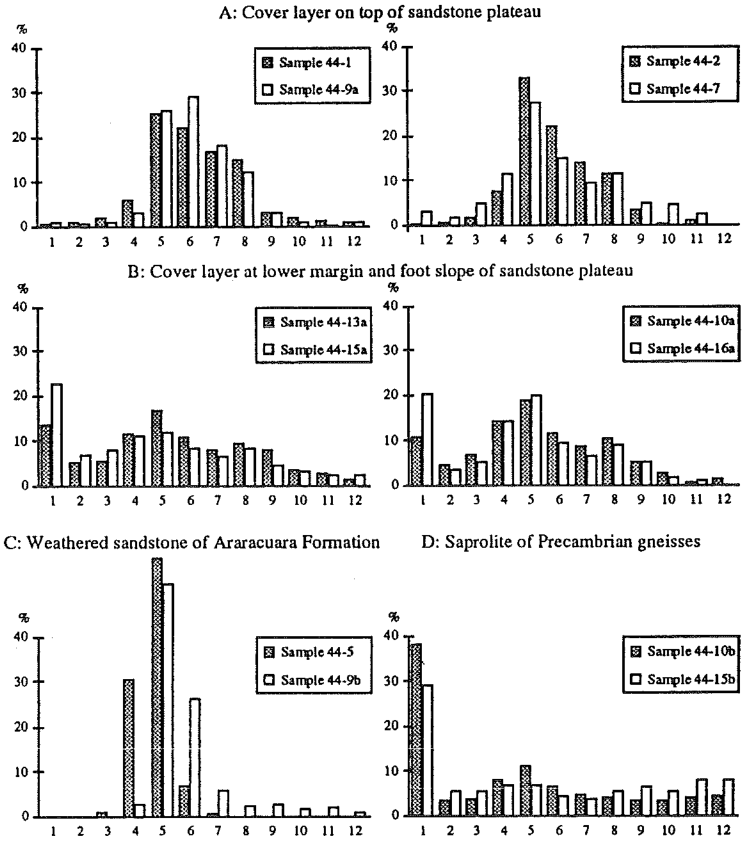
On the sandstone mesetas white sand soils occurs where soil drainage is impeded by the presence of superficial impermeable sandstone hard rock (up to 100 cm from the surface). At sites where this hard rock occurs at a greater depth, soils turn into yellowish coloured, loam textured well drained Ultisols. Grain-size analysis of the sand and silt fractions indicate that these yellowish Ultisols are formed in the same parent material as the poorly drained white sand soils (DUIVENVOORDEN & LIPS, 1993).

On the Caquetá high terraces and the Tertiary sedimentary plain the white "sand" soils have actually a rather silty texture, and are therefore better indicated as podzolized soils. The podzolization seems to have been favoured by an impeded drainage due to the superficial position of an impermeable layer of Tertiary clay, in combination with a slightly concave topography. At sites where the impermeable Tertiary clays appear at greater depth, or where the dense dissection pattern (see below) precludes any superficial water stagnation, most soils are yellowish to reddish coloured, clay to clay loam textured and well drained Ultisols.

It is striking that podzolized soils have not been found on the (upland) low terraces of the Caquetá River. The poorly drained sites on the low terrace have a high water table throughout the year, probably due to the buffered lateral supply from higher geological units, and tend to have soils with peat accumulation. In addition, total chemical analyses have shown that the parent material of the low terraces is somewhat less poor then that of the high terraces, the Tertiary sedimentary plain (except those parts developed in the Pebas Formation) or the sandstone plateaus (KROONENBERG & HOORN, 1990; DUIVENVOORDEN & LIPS, 1993). The occurrence of the white sand areas in the middle Caquetá area can therefore be attributed to soil formation under temporary conditions of impeded drainage, probably in combination with chemically poor parent material. There is no reason to infer any paleoclimatic significance from these areas.

EOLIAN DEPOSITS

Near Araracuara, in concave parts on the surface of the sandstone plateau, along the straight sloping to moderately steep (5 - 15°) long slopes of the plateau and on top of the Tertiary sediments near the foot-slope of the sandstone plateau, a cover layer of about 0.5 - 1.5 m thickness can be traced. The layer shows an orange colour, is loam to clay loam textured and has a rather uniform appearance, which might possibly point at an eolian origin, as suggested by geologists of Proradam (1979; see above). Granulometric analyses of four samples of the material found on top of the plateau, however, shows that the median lies around 90 - 105 μm, which is finer than the



Fractions (µm):

1:	2000-420	5:	150-105	9:	32-16
2:	420-300	6:	105-75	10:	16-8
3:	320-210	7:	75-50	11:	8-4
4:	210-150	8:	50-32	12:	4-2

Fig. 3 : Grain-size distribution of the sand silt fractions of the cover layer sampled on top (A : four samples) and along the lower slopes (B : four samples) of the sanstone plateau, of weathered sandstone of the Araracuara Formation (C : two samples) and of saprolite of Precambrian gneisses (D : two samples), near Araracuara, Colombian Amazonia.

the median size mentioned for most eolian dune deposits (REINECK & SINGH, 1980). In addition, the small but distinct coarse tail in the grain-size distribution and the moderate to poor sorting of these samples (Fig. 3A; the distributions in Fig. 3 are depicted without the clay fraction) also plead against an eolian origin.

The four samples taken below the highest outcrops of the saprolite of the Precambrian gneiss (Fig. 3B) show a peak in the coarsest fraction which is absent in the samples from the higher positions. This peak probably stems from washed down saprolite material (compare Fig. 3B and D) and points at a local colluvial origin of the material on the lower slopes of the sandstone plateau. The higher samples seem to contain washed out material originated from the sandstone of the Araracura Formation (compare Fig 3A and C). They may however also contain some material derived from fluvial deposits containing layers of well rounded fluvial gravel (also with chert of Andean provenance), found at various sites on top of the sandstone plateau. It can be concluded that evidence for a supposedly eolian origin of the cover layer is lacking. The colluvial origin of the down-slope parts of the cover layer seems to point at the existence of periods of a reduced vegetation cover on top and along the slopes of the sandstone plateau. These periods may turn out to coincide with past phases of human settlement and intensive agriculture (MORA *et al.*, 1991), but a climatic origin cannot be discarded.

STONE-LINE

Near Araracuara a gravel-containing, somewhat ill-defined layer occurs below the cover layer on the straight long slopes of the sandstone plateau and on top of the Tertiary sediments near the foot-slope of the sandstone plateau. This stone-line is found at a depth between 0.5 - 1.5 m and has a width of 5 - 50 cm. Near the top of the sandstone plateau it consists of well rounded gravel and angular iron concretions of 0.5 - 2 cm diameter. The gravel is composed mainly of quartz but sometimes also of chert and sandstone. Below the outcrops of saprolite of Precambrian gneiss, some angular quartz fragments are included. Further downwards, below the summit level of the Tertiary hills additional pyrite concretions are encountered in the stone-line.

This stone-line has also been described as part of the AB horizon of a soil in slope deposits along the marginal slope of the sandstone plateau by MOURA and KROONENBERG (1988, 1989). These authors mention the marked geochemical and mineralogical discontinuity in this AB horizon with respect to the more superficial horizons. According to the authors the discontinuities are probably not related to pedoturbation but more likely to the effects of slope wash at times of less effective vegetation cover in drier Pleistocene periods.

Apart form the stone-line along the marginal slopes of the Araracuara sandstone plateau, no other stone-line have been encountered in the landscape ecological survey

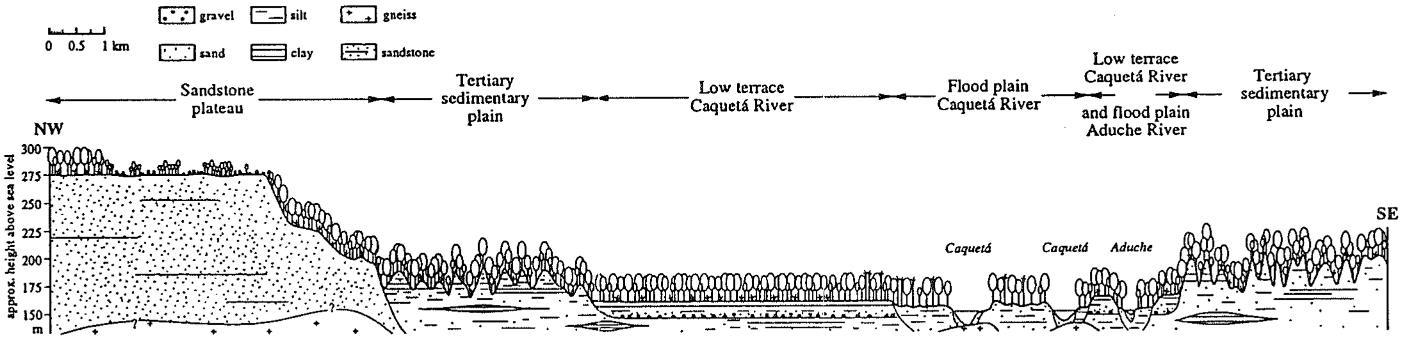


Fig. 4: Cross-section of a part of the Caquetá River basin, Colombian Amazonia, with the flood plain and low terrace of the Caquetá River, the flood plain of the Aduche River (Amazionian origin), the Tertiary sedimentary plain and the sandstone plateau (derived from 1:20 000 aerial photographs). Note the difference in dissection between the low terrace and the Tertiary sedimentary plain.

of the middle Caquetá area. This may be due to the overall severe dissection with steep slopes in most land systems. It may however, also point at very specific conditions favouring erosion, downwash of material and stone-line development along the margins of the sandstone plateau near Araracuara. These conditions include : the vegetation on top of the sandstone plateau may have changed more substantially than in other parts of the Caquetá area at times of Pleistocene dry periods because of the wide distribution of shallow sandy soils; the relatively rapid uplift of the sandstone plateau, which is believed to have taken place since the end of the Tertiary (KHOBZI *et al.*, 1980; EDEN *et al.*, 1982); relative intensive land use by high concentrations of indigenous populations (MORA *et al.*, 1991).

DISSECTION

In the middle Caquetá area, a gradual increase of drainage densities with the age of the deposits can be discerned. It is particulary striking that the low terrace of the Caquetá River, which was exposed as upland during the Last Glacial Maximum (most probably between 20,000 - 13,000 years BP, VAN DER HAMMEN *et al.*, 1992a), shows hardly any dissection (DUIVENVOORDEN & LIPS, 1992 (Fig. 4). On the other hand, the high terraces of the Caquetá River and the Tertiary sedimentary plain, which both consist of loose to slightly consolidated sediments, show increasing drainage densities of 1.9 - 2.9 and 3.1 - 4.8 km/km^2 respectively (Fig. 5). In these land systems most valley are deeply V-shaped, and are formed by moderately steep to steep (10 - 35°) and straight slopes and are separated from each other by rounded interfluvial summits. Valley bottoms are very narrow and consist generally only of a streambed. Higher order streams occasionally flow through narrow flat valley bottoms. Only the larger streams, of which the meandering channels cross several distinct geological units, show a well developed flood plain with point-bar complexes, backswamps, and oxbow lakes.

Most of the Amazonian rivers in the middle Caquetá area have clear or black waters, devoid of suspended load even after heavy rains. The important Cahuinari River however (Fig. 2) which drains a considerable area of the Tertiary clays of the Pebas Formation, does contain suspended load : its waters are even less transparent than the waters of the Caquetá River in some parts of the year (LIPS & DUIVENVOORDEN, 1993). This indicates that present day erosion of the dissected Tertiary catchment area of the Cahuinari River takes place. An initial study of soil erosion under cover types that varied from grassland to forest near Araracuara (McGREGOR, 1980) resulted in intermediate values of sediment yield and runoff in the forest. More important are the common mass movements induced by tree falls along steep slopes where Tertiary clays are in a superficial position and where streamlets have undercut the lower part of the slopes (DUIVENVOORDEN & LIPS , 1993; ETTER & BOTERO, 1990). Despite their frequent and wide occurrence, these mass movements have not lead to deposition in valley bottoms of the lower order rivulets, which implies that current bed load transport must play a significant role.

All the above mentioned processes take place under the present day humid tropical conditions. The poorly developed dissection of the low terrace of the Caquetá River indicates that the more severe dissection of the older geological units stems from before the Last Glacial Maximum, but it is not necessary to assume that this dissection is a relict of drier past climates. A deep incision of the Caquetá River during the Last

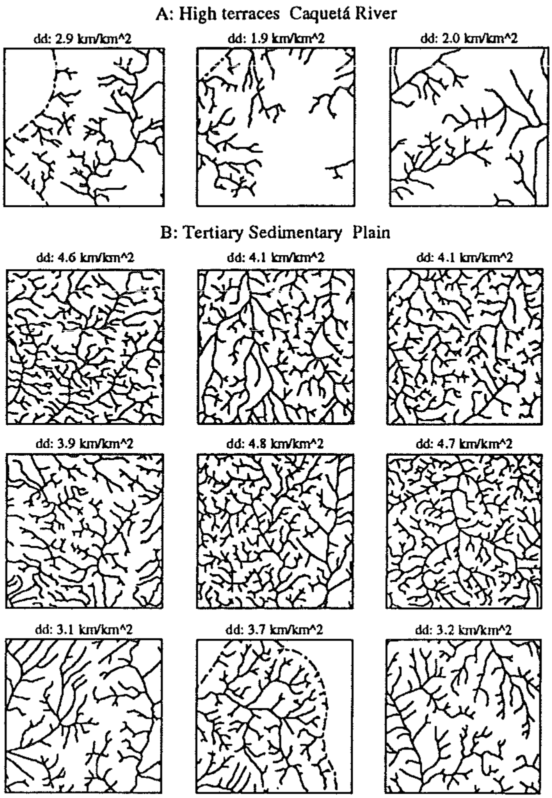


Fig. 5: Drainage densities as seen on 1:20 000 and 1:33 000 aerial photographs of dissected parts of high terraces of the Caquetá River (A) and of the Tertiary sedimentary plain (B). Each square represents 17.6 km^2, dd = drainage density.

Glacial Maximum can be ruled out because of the superficial position of the Precambrian hard rock that outcrops regulary in its channel.

A second argument against linking dissection to vegetation cover is offered by the relatively flat to somewhat undulating topography of the podzolized areas on the high terraces and the sedimentary Tertiary plain. The vegetation in these areas, which at present varies from forest to srub vegetations, would have been relatively open and low in past Pleistocene drier phases. The absence of the severe and dense dissection patterns in these podzolized areas indicate that the dissection is more regulated by the superficial position of resistant and impermeable Tertiary clays than by a changing vegetation cover.

CONCLUSION

Fluvial sedimentary sequences, stone-lines and colluvial layers seem to offer the more reliable geoscientific evidence of paleoclimatic change in Amazonia. Eolian deposits offer evidence as well, but these deposits are only found along the margin or even outside Amazonia (apart from some doubtful records : BIBUS, 1983). Most layers of hardened plinthite ("laterite") occur on Tertiary planation surfaces. In addition, these layers often suffer from difficult chronostratigraphic interpretations and seem therefore less useful to provide evidence of Pleistocene climatic change. The paleoclimatic significance of white sand areas is doubtful. Severe dissection does not offer any convincing arguments to proof climatic change. Various examples of dissection in the middle Caquetá indicate that Amazonian dissection phenomena are probably much more regulated by time, by sub-surface sedimentary structures, by lowering of the erosional base level and possibly by tectonic uplift than by a changing vegetation cover.

The geoscientific evidence of climatic change is indirect. Most geomorphic and lithostratigraphic phenomena are explained by the assumption that the closed forest vegetation changed in lower and more open cover types. These changes in cover types are believed to be the result of the reduced and more seasonal precipitation during the Pleistocene glacial periods. In the middle Caquetá area, however, it is unlikely that the forest cover has undergone substantial changes during these drier Pleistocene periods. Even under a strong scenario of a general reduction of the rainfall with 500 to 1000 mm during a glacial maximum (based on ABSY *et al.*, 1991; VAN DER HAMMEN *et al.*, 1992a), the rainfall in the middle Caquetá area would still be comparable to that of Amazonian areas that are presently covered by seasonal forests. In addition, the soil water retention capacity of most soils, apart form the podzolized soils in the white sand areas, seems sufficiently large to avoid drying out even during the longer dry periods of past glacial maxima (DUIVENVOORDEN & LIPS, 1993). Possibly, as suggested by VAN DER HAMMEN *et al.* (1992a), the forest cover may have shown some reduction around the areas with podzolized soils on the terraces of the Caquetá River and the sedimentary Tertiary plain ("Amazonian caatingas") and on the sandstone plateaus, but this will only have affected a small proportion of the middle Caquetá area. It is therefore no surprise that the landscape ecological survey has not yielded any geomorphic and lithostratigraphic evidence of local Pleistocene climatic change, apart form the possible evidence derived from the locally occurring stone-line and colluvial layers along the margins of the sandstone plateau near Araracuara.

The radiocarbon dated sedimentary sequences of Late-Pleistocene deposits of the Caquetá River (VAN DER HAMMEN *et al.*, 1992a) and the Ucayali River (DUMONT & GARCIA, 1989; DUMONT *et al.*, 1990), indicate that Andean changes in precipitation during the Pleniglacial period influenced depositional processes in the lowlands of western Amazonia. It seems striking that the few additional radiocarbon datings of western Amazonian fluvial terrace deposits are of comparable Middle Pleniglacial age (RÄSÄNEN *et al.*, 1987; CAMPBELL & ROMERO, 1989; LIU & COLINVAUX, 1985; COLINVAUX & LIU, 1987), despite the high variation in river dynamics in western Amazonia related to differences in underlying geological structures. This suggest that a low fluvial terrace of Middle Pleniglacial age is widespread in western Amazonia (VAN DER HAMMEN *et al.*, 1992a) and supports the idea that climatic conditions in the Andes regulate sedimentation in the entire western Amazonia. Unfortunately, these Middle Pleniglacial fluvial terrace sequences do not necessarily point at a local Amazonian climatic change. Therefore, more evidence about true Amazonian Pleistocene climatic change must be searched within the sedimentary sequences of rivers with their catchment restricted to the Amazonian lowlands, in addition to the descriptions of the Muru and Tarauacá river deposits by TRICART (1985) and the terraces along the Araguaia River by SOMBROEK (1966).

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