ATLANTIC ZONE PROGRAMME

Report Nr. 5
Field Report 73

GEOMORPHOLOGY AND SOILS OF THE AREA LIMON - CAHUITA, ATLANTIC ZONE OF COSTA RICA

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February 1992

CENTRO AGRONOMICO TROPICAL DE
INVESTIGACION Y ENSEÑANZA - CATIE

AGRICULTURAL UNIVERSITY
WAGENINGEN - AUW

MINISTERIO DE AGRICULTURA Y
GANADERIA - MAG

The Atlantic Zone Programme (CATIE-AUW-MAG) is the result of an agreement for technical cooperation between the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Agricultural University Wageningen (AUW). The Netherlands and the Ministerio de Agricultura y Ganadería (MAG) of Costa Rica. The Programme, that was started in April 1986, has a long-term objective multidisciplinary research aimed at rational use of the natural resources in the Atlantic Zone of Costa Rica with emphasis on the small landowner.

Location of the study area.

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PREFACE

The work presented in this report was carried out within the context of the Atlantic Zone Programme. This multidisciplinary research programme started in 1986 with as central theme of the investigations sustained forms of land use. Therefore, a study of the soils and their caracteristics is an important part of the research.

When working in a virtually unknown area like the part of the Atlantic zone where this study was carried out, a geomorphological study is essential as a first step of a soil reconnaissance. Therefore, it was decided that a team of two students would carry out a combined investigation on both soils and geomorpholgy, and that results were to be presented in one single report.

The fieldwork was carried out in the first half of 1988, and first drafts were prepared shortly after by both students. Due to several drawbacks the final report was not finished. However, the information in it is considered so valuable that more than three years after the fieldwork period a final report was prepared and published. The work was supervised by Dr. S.B. Kroonenberg and Dr. W.G. Wielemaker of the Department of Soil Science and Geology of the Wageningen Agricultural University. The final report was prepared by A. Nieuwenhuyse, soil scientist of the Programme.

1. SUMMARY

This report is the result of a geomorphological and soil study of the area between Limón and Cahuita within the Atlantic Zone of Costa Rica.

Hardly anything is known about the geomorphology and the soils of the study area; this study was carried out as a first reconnaissance. A geomorphological map, scale 1:100.000, has been drawn based on aerial photograph interpretation and field work. Using the acquired information of the geomorphology and the soils, some statements concerning the genesis of the landscape are made.

The report starts with some general information about the study area, and a brief outline of the geology of Costa Rica. Next, a short description of the working method is given (Chapter 4). The major part of this report consists of a detailed description of the legend (Chapter 5) and some ideas concerning the genesis of the landscape (Chapter 6). Finally a description of the soil types in relation to their geomorphological position is given (Chapter 7).

2. GENERAL INFORMATION

2.1 Study area

Location

The study area forms a part of the Atlantic Lowland of Costa Rica, and covers an area of about 55000 ha. It is situated north of Cahuita up to Limón. The area is bound by latitudes 9º 37'S and 10º 01'S and by longitudes 82º 52'W and 83º 13'W. It can be found on the following sheets of the topographical map, 1: 50.000 (1968) : 3545\1, 3545\2, 3546\2, 3644\4, 3645\3, and 3645\4.

Physiography

The area covers a part of the foot slopes of the Talamanca mountain range and the adjacent coastal plain.

The coastal plain varies in width of 2 to 4 kilometers, and is built up of Holocene deposits. It is intersected by various rivers, the most important of which are the Río Estrella and Río Banano.
Within the study area, the elevation of the Talamanca mountain range does not exceed 1500m. Several intramontane basins are found, characterized by a flat topography and built up of alluvial deposits. The largest of these basins is the Valle de Estrella .

Climate

The climate of the study area can be characterized as a humid tropical climate without a real dry season. The area has an abundant rainfall during the whole year. Average annual rainfall at meteorological stations varies from 2400 to 3900 mm. There is a tendency of decreasing rainfall along the coast from north to south. However, annual variation is large, and no stations are located in the much more rainy area in the hills and mountains. It is estimated that at heights of 500 m or more rainfall may reach 7000 mm/year.
The average annual temperature is about 26 - 27 C at sea level. Seasonal variation is very small, about 2º a 3º C. No information is available for higher elevations.

Vegetation an land use

The natural vegetation of the main part of the area is tropical rainforest. The coastal area forms an exception. The vegetation close to the see mainly consists of coconut palmtree, and also the coastal swamps know a rather uniform vegetation. In these permanent wet areas the Yolillo palmtree dominates. At the mouth of the Estrella River, Estero Negro, mangrove can be found. Occupation by man is concentrated along the coast and on the well drained areas at the transition of the hilly land the coastal plain: the "pie de monte". Cacao and plantain form the main

crops. Also the intermontane basins (e.g. Valle de la Estrella, Valle Limoncito) are intensively used for bananas or coconuts. More and more, man also invades the hill and mountains as well as the coastal swamps.
The removal of the natural vegetation of the slopes results in an intensified erosion and the occurrence of many landslides.

2.2 Physiography of COSTA RICA

Costa Rica can be divided into three main regions (Fig 2.1) :

- The Central Cordillera
- The Atlantic lowland
- The Pacific coastal region

Morphological map of Costa Rica.

Figure 2.1 : Physiography of Costa Rica

The central mountain range

This mountain range, which crosses the country from northwest to southeast, is composed of several regions. The northwestern part, the Cordillera de Guanacaste, is build up of a series of Quaternary volcanoes. This area reaches a height up to 2000 m. above sea level.
To the southeast follows a mountain range made up of Late Tertiary volcanic rocks; the Cordillera de Tilarán. Eastward it passes into the Cordillera Central, composed of several Quaternary volcanoes, various of which are active. The highest volcano, the Irazú, rises up to more than 3400 m. above sea level.
The largest and highest mountain range of Costa Rica is the Cordillera de Talamanca. It forms the southernmost part of the central mountain range and continues into Panama. Large parts of the Cordillera de Talamanca are yet unexplored. Its geological structure is rather complex: it is built up of folded Tertiary marine sediments, with intercalated volcanic and Middle Miocene plutonic rocks. The highest peaks (Chirripó: 3820 m. and Kamuk: 3554 m.) have been glaciated during the Late Ice Age (Weyl, 1956).

Within the central mountain range two extensive intermontane basins are located.
The Valle Central runs south of the Cordillera Central at 600 to 1500 m above sea level. The basement of this valley is built up of slightly folded marine sediments which are overlain by Cenozoic volcanic and alluvial deposits.
The Valle del General, southwest of the Cordillera de Talamanca, extends at a height of 100 to 1000m. above sea level. This depression is filled up with thick accumulations of Pliocene and Pleistocene gravel and volcaniclastic rocks, in which the rivers have formed terraces.

The Atlantic lowland.

This extensive lowland region is the southeastern continuation of the Nicaragua Depression and like this, it is a sedimentation basin dating back to the Early Tertiary. Its surface is covered with alluvial deposits. At the transition of the mountainous area and this lowland extensive alluvial fans and mud flows are found. In the northeastern part some small Plio-Pleistocene alkaline volcanic cones are found (Bellon & Tournon, 1978). The coastal area north of Limon is characterized by a straight coastline, consisting of elongated beach ridges, along which extensive coastal swamps and lagoons are found. South of Limón this straight coastline is broken at several places where elevated Pleistocene coral reefs and Miocene rocks reaches up to the sea to form cliffs.

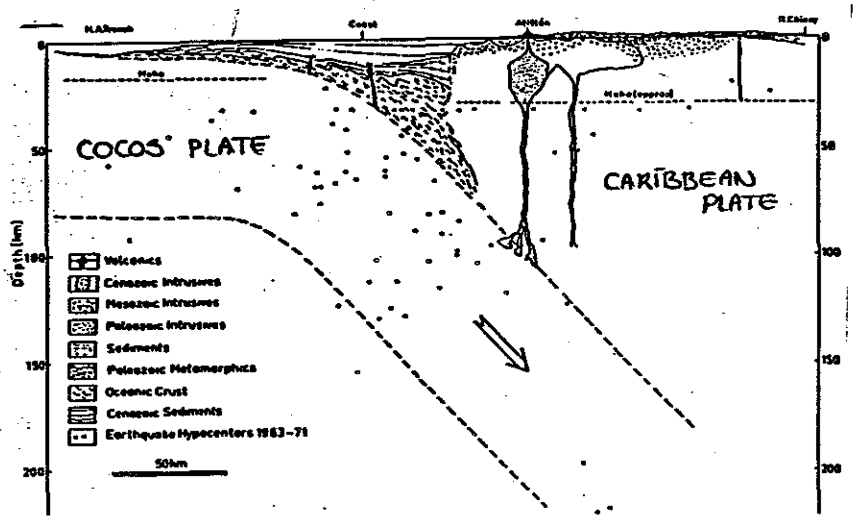
The Pacific coastal region.

This area is of a complex morphology. It is composed of mountainous country, peninsulas consisting of Cretaceous to Tertiary rocks, depressions filled up with alluvial and volcaniclastic sediments and coastal plains built up of alluvial deposits.

3. GEOLOGY

3.1 Geological history\ tectonics

Until the beginning of the Cenozoic, North America and South America where separated by a sea, although a temporary land link existed at the end of the Cretaceous. The forming of the land bridge between the American subcontinents is the result of plate tectonics, which started in the Upper Cretaceous. The magmatism triggered by this subduction, gave rise to the formation of an isthmic island chain. (Fig 3.1).



Geological cross-section through Guatemala and the Middle America Trench illustrating the subduction of the Cocos Plate under the Caribbean Plate. (Redrawn from SEELY et al. 1974, Fig. 12).

Figure 3.1: from Weyl 1980

During the Tertiary, the ocean basins bordering the island arc were filled up with large masses of marine as well as volcaniclastic sediments (see par. 3.2). Further development was characterized by the ascent of violent volcanism of increasingly sialic character and with quartz-dioritic to granodioritic and granitic plutonism. From the Upper Miocene onwards, vigorous magmatic activity throughout the region of the present Cordillera of the Talamanca in the form of intrusions and energetic uplift caused the isthmus to rise up to form the present mountainous country.
According to Rivier (1985), the uplift caused an enormous slide of the sediment cover from the north-east flank of the Talamanca mountain range to the lower parts. In these lower parts Tertiary sediments accumulated, deformed by folds overthrusts and reverse faults (gravitative tectonics). These processes continued into the Plio-Pleistocene. Even the youngest formation (Suretka Formation) has been affected by these pressure movements. (Fig 3.2).

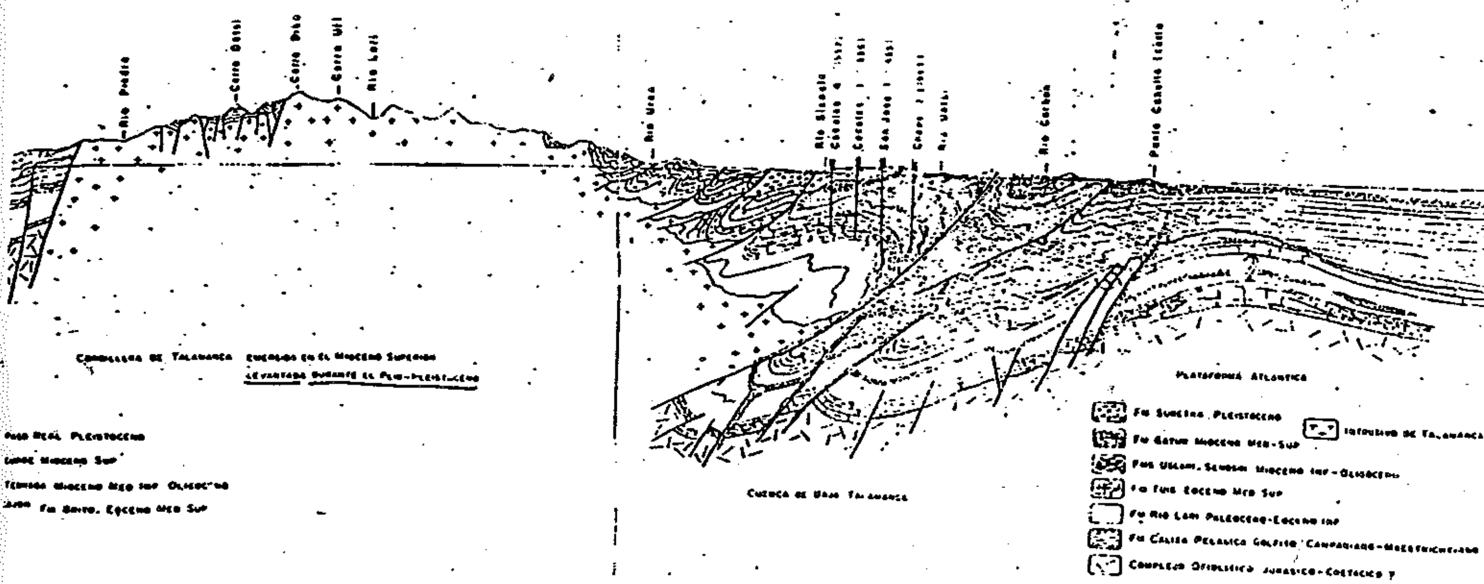


Figure 3.2: Geological cross section through Costa Rica from Pacific to Atlantic ocean (from Rivier Sutter 1985)

The geological structure of the study area can be understood in the light of these enormous gravitative slides. On the geological map (Fig 3.3) a pressure belt can be recognized, in which anticlines and reverse faults or overtrusts run paralel to each other with a general strike NW-SE. This pressure belt is intersected by a number of transcurrent faults, with a strike approximately NE-SW. The main river courses of the area (Rio Banano, Rio Bananito and Rio Estrella), coincide with the location of these faults. The influence of Pleistocene volcanism is not clear.

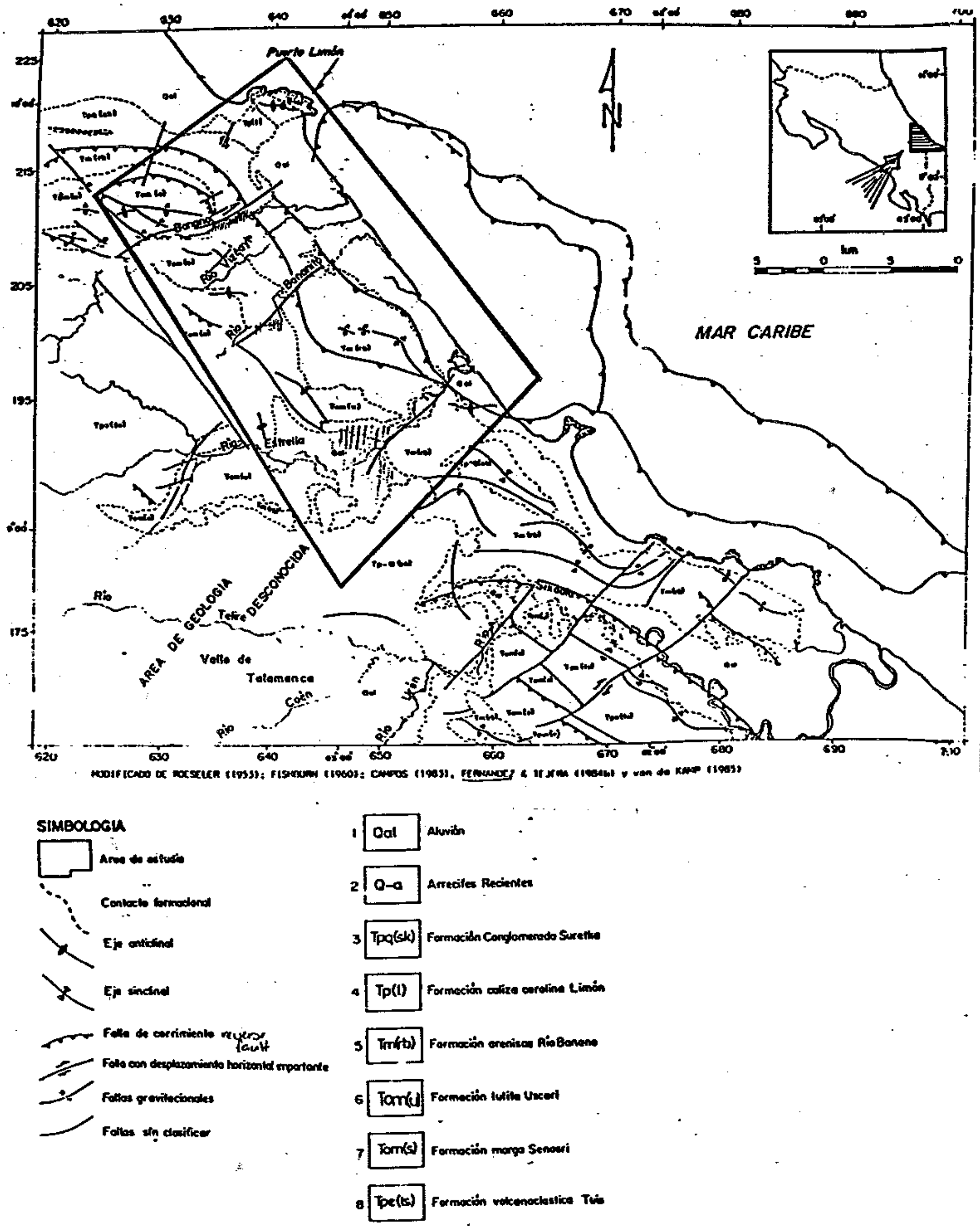
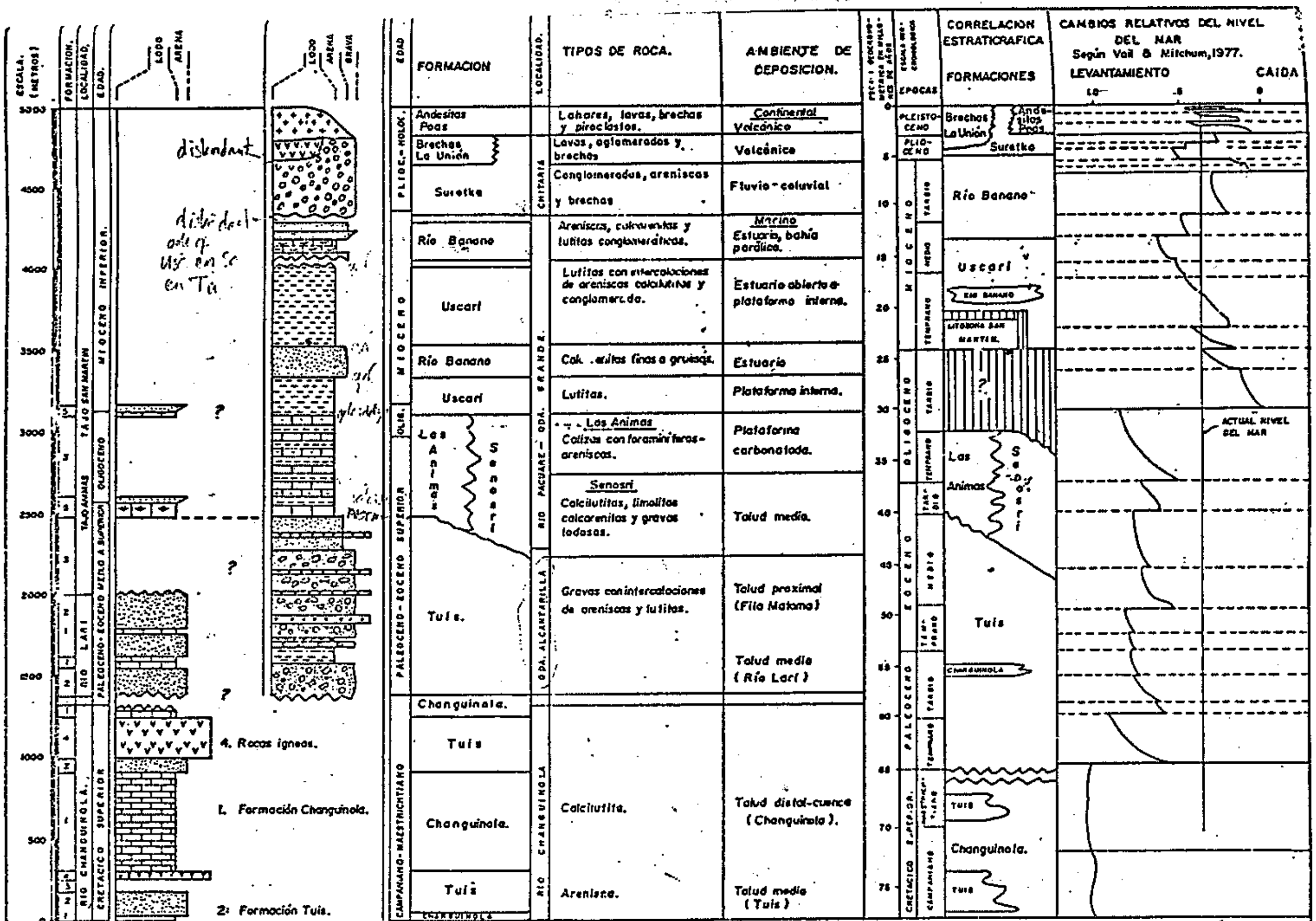


Figure 3.3: Geological map from Campos Bejarano 1987.

Figure 3.4



COLUMNA ESTRATIGRAFICA GENERALIZADA
CUENCA LIMON- BOCAS DEL TORO.

FIG. 50

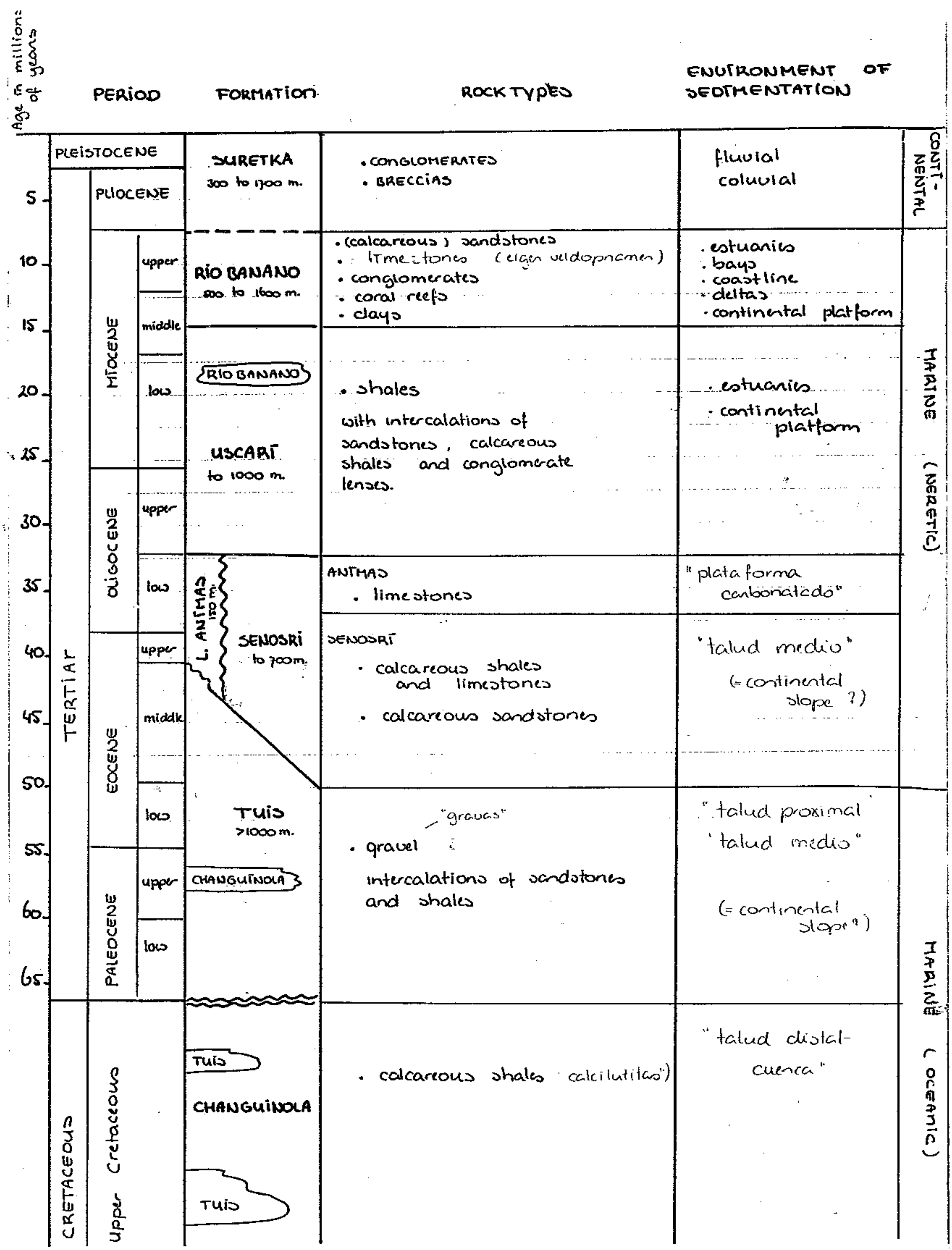

Age in millions of years
PERIOD
FORMATION
ROCK TYPES
ENVIRONMENT OF SEDIMENTATION
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
TERTIAR
CRETACEOUS
Upper Cretaceous
upper
middle
low
SURETKA
300 to 1700 m.
RIO BANANO
800 to 1600 m.
USCARI
to 1000 m.
L. ANTHAS
SENOSRI
to 700m.
TUIS
>1000 m.
CHANGUINOLA
· CONGLOMERATES
· BRECCIAS
· (calcareous) sandstones
· limestones
· conglomerates
· coral reefs
· clays
· shales
with intercalations of sandstones, calcareous shales and conglomerate lenses.
ANTHAS
· limestones
SENOSRI
· calcareous shales and limestones
· calcareous sandstones
"gravas"
· gravel
intercalations of sandstones and shales
· calcareous shales calcilutitas")
fluvial
coluvial
· estuaries
· bays
· coastline
· deltas
· continental platform
estuaries
· continental platform
" plata forma carbonatada"
"talud medio"
(= continental slope ?)
" talud proximal
" talud medio"
(= continental slope?)
" talud distal-cuenca"
CONTI-NENTAL
MARINE (NERETIC)
MARINE (OCEANIC)

Figure 3.5

RECONSTRUCCION ESQUEMATICA DE RELACIONES INTERFORMACIONALES CUENCA LIMON SUR.

(Fernández, J.A., 1987).

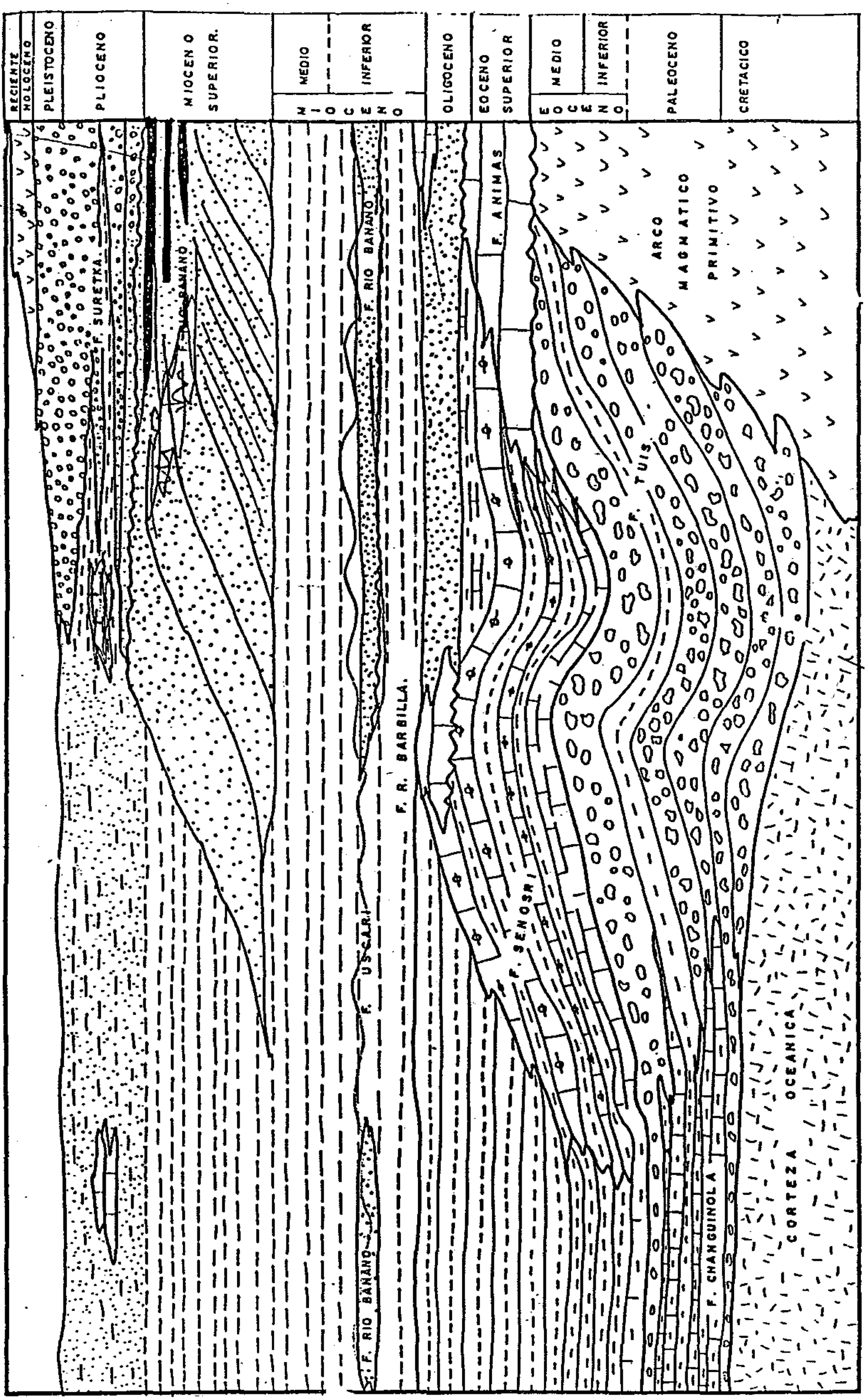


Figure 3.6

3.2 Stratigraphic sequence

The stratigraphy of the southern Limón Basin has been described by different authors. However, knowledge of the different formations is still very scarce, and large parts of the area are virtually unexplored.

In this paragraph a short summary of the different formations will be given with the help of the lithostratigraphic sequence according to Fernandez (1987). Only the formations which are essential to the study area will be discussed in more detail. The classification of the stratigraphic units is based on the nomenclature recommended by Sprechmann (1984) (Fig.3.4, 3.5 and 3.6).

Stratigraphy

The oldest known formation which covers the oceanic basement is the Upper Cretaceous Changuinola Formation (Fisher and Pessagno, 1965), which is composed of mainly calcareous shales (calcilutitas) and some volcaniclastic sediments and lava flows.

From the early Tertiary until the Middle to Upper Eocene mainly volcaniclastic sediments were deposited in the form of unsorted gravel and coarse sand (gravas desorganizadas, arenas guijarrosas desorganizadas), up to more than 1000 m; the TUIS FORMATION (Fernández 1987).

The ANIMAS FORMATION (Fernández, 1987) is built up of mainly limestones (calizas), with some intercalated volcanic deposits. dating from the middle Eocene up to the Oligocene. The estimated thickness is 150 m at most.

The SENOSRI FORMATION (Fernández, 1987) consists on mainly calcareous shales and limestones (calcilutitas y limolitas), rhythmically alternating with frequent intercalations of calcareous sandstones (calcarenitas), and mudflows (gravas fangosas desorganizadas). This formation dates from the Middle Eocene to the Lower Oligocene, and has a thickness of approximately 700 m. The continental slope formed the sedimentary environment (sedimentos de talud).

The USCARI FORMATION (Taylor, 1975) is dating from the Upper Oligocene to the Middle Miocene and consists of "arcillolitas", mudstones, limestones and shales (limolitas, lutitas) showing a homogeneous stratification, enclosing intercalation of fine grained sandstones, calcareous shales (calcilutitas) and conglomerate lenses. The sedimentary environment was the continental platform or shelf. The estimated thickness of this formation is about 1000 m. The Uscari formation alternates vertically with facies of the subsequent Río Banano formation.

The RIO BANANO FORMATION (Taylor, 1975) is characterized by a great lithological variety and can be defined as a series of clastic facies deposited in a shallow marine environment, and coral reefs.
Five facies can be distinguished. The major part consists of fine-grained sandstone, often with a clear stratification. The colour is grey in fresh rocks, whereas weathered rocks turn to grayish-orange. There are indications of bioturbation and also crossbedding and current ripple-marks have been found. Rhythmically interstratified within these sandstone, conglomerates can be found, consisting of pebbles embedded in a coarse sand matrix.
Especially in the upper part of this formation intercalations of shallow water limestones and reefs occur. In the surroundings of Limón these reeds are covered by a well sorted sandstone, with a coffee-yellowish color, named as "arenas Pueblo Nuevo".
Friable, grey to green-colored clays, "miembro arcillas de Moín", in which sedimentary structures can be discovered, form the upper part of this formation, also located in the surroundings of Limón.
The Río Banano formation dates from the Middle/Upper Miocene up to the Pliocene or Lower Pleistocene, and reaches a thickness of 500 to 1600 m.
The sedimentary environment was formed by estuaries, bays, deltas, the coastline and the continental platform.
An unconformity exists between the Río Banano formation and the subsequent Suretka formation.

The SURETKA FORMATION (Fernández, 1987) is built up of fluvial and colluvial deposits of conglomerates and breccias, which can be seen as the erosion products originating from the energetic uplift of the Cordillera the Talamanca since the Middle Miocene. This material has been deposited in the form of enormous alluvial fans and mudflows (molasse-depositions).
The conglomerates and breccias consist of mainly volcaniclastic components of different sizes, mostly unsorted, sometimes showing sedimentary structures. They are weakly consolidated to strongly cemented.
It is difficult to give an exact dating of this formation. The estimations of the authors vary considerable, ranging from the Miocene to the Pliocene (Dengo, 1962), Pliocene to Pleistocene (Paris, 1963) and Late Pleistocene to the present (Taylor, 1975).

4. WORKING METHOD

This geomorphological survey can be divided into three phases:
- preparation
- fieldwork
- reporting

Preparation

During two weeks the study area was explored by means of field excursions guided by Dr. Salomon Kroonenberg and Dr. Wim Wielemaker, in order to get acquainted with the different rock types and landforms. Another two weeks were spend studying the literature concerning the geology of the area and with an interpretation of aerial photos. On the photos geomorphological units were distinguished on base of differences in relief, drainage pattern and vegetation.

Fieldwork

During three months of fieldwork, as many as possible data were gathered to come to a characterization of the units distinguished on the aerial photos. Within the coastal plain data could be gathered with the help of soil augerings. Normally the perforations reach a depth of 1.20 m. Sometimes extension pieces have been used to reach depths up to 4 m. At some places draining ditches gave much information. The greatest part of the hilly and mountainous area is covered with tropical rainforest. Outcrops are restricted to places where streams incise in the bedrock and roadcuts.

A description was made of every observation point. The following items were considered :
- photonumber\name location\character of the exposure
- physiographic position
- topography of the surroundings\height observation point
- landform\ drainage pattern
- rock type \ azimuth and dip
- soil
- vegetation\ land use

The aerial photos and topographical maps (1 :50.000, 1978) were used for orientation. Other materials which were used during the fieldwork; a car, geological hammer, geological compass, stereoscope, altimeter. auger and extension pieces, FAO-guidelines for soil descriptions, color chart, hydrochloric acid, sandruler, and machete.
The first photo interpretation appeared to be too rough, and not until the end the fieldwork period an ultimate geomorphological map could be drawn.

Reporting

With the help of a sketchmaster the photo interpretation (scale 1:80.000) could be transferred to a topographical base map (scale 1:100.000).
Discussions with Sr. Fernández (RECOPE, San José) and Sr. Madrigal (Universidad de Costa Rica) contributed to further understanding of the geological structure of the area.

5. THE GEOMORPHOLOGICAL MAP

5.1 Legend construction

On the first level a distinction has been made on base of morphology, resulting in 6 physiographic units:

- coastal plain
- alluvial fans
- interior basins
- valley fills
- hills
- mountains

The coastal plain, alluvial fans, interior basins and valley fills are the result of sedimentary processes, whereas the hills and mountains are shaped by erosion. In other words, differences in genesis, coupled to tectonical structure and lithology underlie this division.

On a second level a further division is made, again on base of morphology. Differences in lithology (e.g. resistant or non-resistant rocks) or differences in age (dissected or non-dissected) form the basis of this distinction.

The third level presents the differences in lithology.

5.2 Map unit description

LLANURA COSTERA / COASTAL PLAIN

Lba: BARRAS DE ARENA / BEACH RIDGES

Relief-morphology:
Elongated parallel ridges, of a height of about 1.5 a 2 meters, and widths to 50 meters.

Material:
Marine sand; well sorted in fine horizontal layers. The composing minerals are pyroxene (median-value: 420-600 um), magnetite (median-value: 210-300 um) and feldspar.

Vegetation, land use:
Mainly coconut-trees on the higher parts, cultivation on the lower parts.

Soils and their setting:
50% typic Tropopsamment on the younger ridges close to the sea, up to 5 m above sea level; deep, somewhat excessively drained dark sands.
50% typic Eutropept on the lower ridges; moderately deep, moderately well drained dark sands:

10-20 cm dark brown (10 YR 3/3) sandy loam over
20-60 cm dark yellowish brown (10 YR 3/4) sand to loamy sand over
60+ dark sand.

Lpt: PANTANOS TURBOSOS / PEAT SWAMPS

Relief-landform:
Coastal marshes located just behind the beach ridges. In this depressions water stagnates to above the groundlevel.

Material:
Thick layers of peat up to more than 4 meters.

Vegetation, land use:
Mainly a dense vegetation of palm (Yolillo) and mangrove trees.

Soils and their setting:
hydric & fluvaquentic Tropofibrist
shallow, very poorly drained peat soils.

Lpa: PANTANOS ARCILLOSOS / CLAY SWAMPS

Relief-landform:
Flat depressions: coastal marshes or fluvial backswamps. The water stagnates or concentrates in little water courses which assemble in one big creek that drains into the sea.

Material:
Thick deposits of non ripened to half ripened, totally reduced clay, rich in organic material. Now and then a peat layer. At some places fossil beach ridges are found under these clay deposits.

Vegetation land use:
Besides yolillo-palmtrees other kinds of trees appear. Some parts are deforested and used as pasture.

Soils and their setting:
Typic Hydraquent
shallow, half ripened, poorly to very poorly drained clay soils.

Laq: LLANURA ALUVIAL DE LOS RIOS GRANDES / ALLUVIAL PLAIN OF MAYOR RIVERS

Relief-landform:
Elevated natural levees alternating with flat depressions (backswamps). It was not possible to map out individual levees or backswamps. The elevated parts are well drained, depressions are poorly drained. On the aerial photos cut-off channels can be recognised.

Material:
The sediments of the levees (sand to loam) show a clear stratification with a fining upwards sequence. The backswamps

consist of fine textured sediments (loam to clay).

Vegetation-landuse:
The levees are used for pasture and cultivation. The backswamps are used for pasture or, when artificially drained, to cultivate bananas. However, the main part is still under forest.

Soils and their setting:
fluventic Eutropept
moderately deep to deep, imperfectly to moderately well drained loam to clay soils
5-15 cm dark yellowish brown (10YR 3/4 & 4/4) loam to clay over
15-115 cm brown (10YR 5/3) to yellowish brown (10YR 5/6) loam to clay.

<u>LAM: LLANURAS ALUVIALES DE RIOS MENORES / ALLUVIAL PLAINS OF MINOR RIVERS</u>

Relief-landform:
A flat and mainly poorly drained area, differentiated from Lpa because of the scarcity of natural levees.

Material:
Mainly thick clay and clay-loam layers, deposited by some small rivers which intersect the area. In one part close to the hills, fossil beach ridges have been found under these sediments (1.5-2 meter below the surface). In the directions of the coast, the clay deposits grow thicker (to at least 3.5 meters), in which halfripened and ripened layers alternate.

Vegetation land use:
pasture and cultivation of bananas.

Soils and their setting:
50% aeric Tropaquept
Shallow to moderately deep, imperfectly drained clay soils in the higher parts.
10-30 cm dark brown (10YR 3/3 & 4/3) to very dark grayish brown (10YR 3/2) clay (loam) over grayish almost ripened clay.
50% tropic Fluvaquent
Shallow, poorly to very poorly drained, half to almost ripened clay and clay-loam soils in the lower parts.
10-20 cm very dark grayish brown (10YR 2/2) clay over grey clay.

ABANICOS ALUVIALES

<u>Anf: ABANICOS NO-DISECTADOS, SEDIMENTOS MEZCLADOS/ALLUVIAL FANS, NON-DISSECTED, MIXED SEDIMENTS</u>

Relief-landform:
One single fan, on the number of coalescing fans, with a slightly undalating topography, weakly inclined (upper parts of the fans: 3-4% lower parts: 1-2%).

At places where rivers, coming from the hills, discharge into the coastal plain, distinct fan shapes can be distinguished (active fans), indicated on the map.

Material:
A clear alternation of fine, medium and coarse sediments. Especially at places where relatively big rivers discharge into the plain, coarse sediments can be found: gravelbeds with pebbles and boulders up to 25 cm in cross-section, both unsorted and rounded.
Sometimes imbrication is clearly visible. The gravel is composed mainly of andesites, sandstones and siltstones. The matrix consists of coarse sand. The sources of this coarse sediment are the conglomerates, sands and siltstones of the formations Suretka and Rio Banano. However rivers draining soft easily weathering rocks (soft limestones or shales), supply much finer sediments at the foot of the mountains; thick loam and clay layers alternate with coarse sand. The drainage is good.
On the whole, the deposits on the lower parts of the fans are finer and less well drained. The coalescing alluvial fans, reach their greatest development at places where there are many rivers leaving the hills.

Vegetation, land use:
Especially the upper parts of the fans (inclination:3-4%) are used to cultivate cocoa; the cultivation of bananas is of much less importance. In the lower parts the natural vegetation still exists.

Soils and their setting:
andic & fluvaquentic Eutropepts + fluvaquentic Dystropept shallow to moderately deep, moderately well to well drained loamy soils.
10-20 cm dark brown (10YR 4/3 & 3/3) sandy loam to clay loam
over
20-70 cm dark yellowish brown (10YR 3/4 & 4/4) sand to silty clay loam.

<u>Adm: ABANICOS DISECTADOS, SEDIMENTOS MEZCLADOS / ALLUVIAL FAN, DISSECTED, MIXED SEDIMENTS</u>

Relief-landform:
Alluvial fan at the transition from the hills to the lowland, very weakly inclined (less than 2%). The course of the river within this unit is more or less braided. In the past the river have formed terraces.

Material:
A distinct alternation of clay, sand as well as gravel deposits. Towards the lower parts of the alluvial fan the sediments become finer.

Vegetation, land use:
The greatest part is used for pasture.
Soils and their setting:

fluvaquentic Eutropept + fluvaquentic Dystropept
for description see unit Anm.

Adq: ABANICOS DISECTADOS, SEDIMENTOS GRUESOS / DISSECTED ALLUVIAL FAN, COARSE SEDIMENTS

Relief-landform:
An extensive alluvial fan in the Valle de Estrella, almost flat to gently undulating, weakly inclined (3-4%). The Rio Surey has formed different terrace-levels in it.
The fan has been cut off in its lower parts by the Rio Estrella; therefore it ends in the form of a terrace-threshold.

Material:
Alternating, more or less horizontal layers of weakly cemented sands and stones varying in diameter from 1 to 50 cm; mainly andesites, sandstones and calcareous siltstones embedded in a loose sandy matrix. The sorting within the stony layers varies; some deposits are well sorted, others moderately well, whereas in the upper levels at the lower part of the fan a completely unsorted, strongly weathered deposit occurs in which the pebbles and boulders don't touch each other, which is probably a mud-flow.

Vegetation, land use:
Large parts of this alluvial fan are used as pasture, the rest for bamboo cultivation.

Soils and their setting:
typic & epiaquic Tropudult
deep, moderately well to well drained clayey soils.
10-20 cm yellowish & dark yellowish brown (10YR 4/6, 4/4 & 3/4) moderate subangular blocky loam to clay loam.
20-45 cm brownish yellow (10YR 6/6) to red (2.5YR 5/6 & 5/8) weak angular blocky clay loam to clay over rotten rock

Up to the surface strongly weatheders boulders occur.

COLINAS / HILLS

Csl: COLINAS, RELIEVE SUAVE: LUTITAS, LIMOTITAS BLANDAS / HILLS, LANDSCAPE IN SOFT ROCKS: SHALES, SOFT LIMESTONES

Relief, landform:
Hilly landscape with a relief intensity up to 50 meter, and slopes varying from 10-20°. Strongly dissected. Many landslides.

Material:
Light-grey calcareous, finely layered shales, and soft, light coloured siltstones. Notable is the occurrence of scattered angular stones of calcareous micro-crystalline rock (hard siltstone) in the shales. These shales belong to the Uscari Formation.

Vegetation, land use:
Mainly forest. Large scale deforestation occurs, which is accompanied by the appearance of many slumps.

Soils and their setting:
30% typic Eutropept
moderately deep to deep, well drained clay soils on top of hills.
10-20 cm very dark brown (10YR 2/3) to dark yellowish brown (10YR 4/4) weak to moderate subangular blocky clay over
30-80 cm yellowish brown (10YR 5/8) to yellow (10YR 7/8) weak angular blocky clay over structureless clay or shale.

70% typic Eutropept
shallow to moderately deep, moderately well to well drained clay soils on slopes of usually more than 20%.
10-20 cm dark yellowish brown (10YR 3/4 & 4/4) moderate subangular blocky clay over
20-30 cm yellowish brown (10YR 5/4 & 5/8) weak angular blocky clay over structureless clay or shale.

Csa: COLINAS, RELIEVE SUAVE: ARENISCAS, LUTITAS, / HILLS, LANDSCAPE IN SOFT ROCKS: SANDSTONES, SHALES

Relief, landscape:
Hilly landscape with a relief intensity up to 50 meters, slopes for the greater part up to 20°, a few up 30°. The landscape is strongly dissected and many landslides occur.

Material:
In the deeply weathered exposures only sandstones were found, but taking into account the relatively low relief intensity and the occurrence of many slumps, it can be assumed that also soft rocks (e.g. shales), form an important part of lithology. Presumably inclined layers of shales and sandstones alternate.
The fine sandstone is well sorted and it shows a very fine stratification. It is moderately cemented, somewhat clayey, probably as a result of weathering. Also this map-unit belongs to the Uscari Formation.

Vegetation, land use:
Tropical rainforest and pasture.

Soils and their setting:
see unit csl

Csm: COLINAS, RELIEVE SUAVE, CAPAS OBLICUAS ALTERNADAS DE LIMOLITAS, BLANDAS, LUTITAS, ARENISCAS Y CONGLOMERADAS FINAS / HILLS, LANDSCAPE IN SOFT ROCKS, ALTERNATING INCLINED LAYERS OF SOFT SILSTONES, SHALES, SANDSTONES AND FINE CONGLOMERATES

Relief, landscape:
A landscape with a relief intensity up to up 40 meters and slopes of 10-20° (a few up to 30°), not exceeding the contourline of 150 meters. On the whole the landforms are rounded and landslides can

be noticed, but some small, sharp ridges occur, indicating inclined layers of more resistant rocks.
The landscape is strongly dissected, and especially the bigger rivers form broad valleys.

Material:
The rounded landform and the landslides are underlain by shales and soft, light grey siltstones containing some clay.
Inclined layers of resistant sandstones and conglomerates determine the sharp relief forms. The siltstones overlie at some places a fine blue sandstone, well sorted, moderately cemented but very compact. Next to a grey, fine sandstone, originally calcareous, strongly cemented and with a fine stratification, also a medium to coarse sandstone has been found. This sandstone shows a clear stratification, and also thin layers of a fine grained (diameter of mainly andesitic and sedimentary pebbles varies from 0.5 to 4 cm) conglomerate are intercalated. Finally a coarser conglomerate has been found, with pebbles and boulders up to 25 cm in size, unsorted and of volcanic and sedimentary origin. The matrix varies in sorting and grainsize. These rocks belong to the Rio Banano Formation.

Vegetation, land use:
pasture, cultivation of ornamental plants and tropical rainforest.

Soils and their setting:
70% typic Eutropept
shallow to moderately deep, moderately well to well drained clayey soils on slopes of usually more than 20%
5-20 cm dark yellowish brown (10YR 4/4) moderate subangular blocky clay loam clay over
20-50 cm yellowish brown (10YR 5/8) weak angular blocky clay over structureless clay.

30% typic Trupodult
moderately deep to deep, well drained reddish clay soils on top of hills
10-30 cm dark brown (7.5YR 4/3 & 4/4) moderate subangular blocky clay over
40-80 cm red (2.5YR 5/8) to strong brown (7.5YR 4/6) weak angular blocky clay over massive porous clay.

CPm: COLINAS, RELIEVE PRONUNCIADO: CAPAS OBLICUAS, ALTERNADAS DE ARENISCAS LIMOLITAS DURAS CONGLOMERADOS LIMOLITAS BLANDAS Y LUTITAS/ HILLS, LANDSFORMS IN RESISTANT ROCKS: ALTERNATING INCLINED LAYERS OF SANDSTONES, HARD SILSTONES, CONGLOMERATES, SOFT SILSTONES AND SHALES

Relief, landform:
The landscape is determined by the alternation of resistant and non-resistant inclined rock layers, which produces cuesta-like landforms; longdrawn parallel watersheds, with to one side an escarpment (slopes up to 60° or more), the other side shows a

less steep slope (20°-30°).
The rivers often run parallel to the watersheds (subsequent rivers) and form asymmetrical valleys. The rivers running in the direction of the dislope form sharp V-valleys in the resistant rock layers. At places where non-resistant rocks are exposed (shales, soft siltstones), many landslides occur.

Material:
Among the resistant rocks the sandstones are the most abundant. These sandstones are often fine grained, well sorted, strongly cemented and show a fine stratification. They are often calcareous and rich in shell remains. Also less well sorted, medium to coarse sandstones can be found. Conglomerate layers are interstratificated within the sandstones. The pebbles are up to 10 cm in diameter, rounded, well sorted and mainly of volcanic origin.
Also a dark grey, strongly cemented, often calcareous siltstone, rich in shellrests, is quite resistant.
Non-resistant rocks are fine layered shales and soft, light grey siltstones.
These rocks belong to the Rio Banano Formation.

Vegetation and land use:
Mainly tropical rainforest, some pasture.

Soils and their setting:
70% typic & lithic Eutropept
shallow to moderately deep, moderately well to well drained loamy soils.
10-20 cm dark yellowish brown (10YR 3/4 & 4/1) moderate subangular blocky loam to clay loam over
30-40 cm yellowish to dark yellowish brown (10YR 4/6 & 5/5) weak angular blocky loam to clay over structureless loam to clay.

30% typic Tropudult
very deep, well drained red clay soils on tops of hills
20-30 cm dark reddish brown (5YR 3/2) to reddish brown(5YR 4/4) moderate fine & very fine subangular & angular blocky clay over
40-80 cm yellowisch red (5YR 4/6 & 5/6) moderate very fine angular blocky clay over structureless silty clay loam

<u>Cpc: COLINAS, RELIEVE PRONUNCIADO, CONGLOMERADOS GRUESOS / HILLS, LANDSCAPES IN RESISTANT ROCKS, COURSE CONGLOMERATES</u>

Relief, landform:
This unit is characterized by a rather sharp relief up to 300 meter: moderately steep to very steep slopes in which numerous rivers formed sharp V-valleys, sometimes with almost vertical valley slopes (quebradas). The drainage pattern is mainly dendritic to sub-dendritic which indicates a rather uniform material. Where rivers cut into less resistant rocks, broad

valleys have been formed.

Material:
Next to the strongly cemented sandstones, especially the cemented coarse conglomerates are responsible for the sharp relief forms. They contain unsorted boulders of 20-30 cm in diameter of mainly volcanic origin. The matrix is medium to coarse sand.
In the lower parts of this unit, sandstones have been found. Both fine grained, well sorted, finely stratified sandstones and coarse grained, poorly sorted sandstones without a clear stratification occur. Both sandstones are strongly cemented. These sandstones are interstratificated with conglomerate layers consisting of small pebbles (0.5-4 cm in diameter) in a coarse sand matrix. Also black colored treestumps are enclosed. Also, layers of strongly cemented conglomerates, with boulders up to 20 cm in diameter, well rounded and of volcanic origin have been found. Finally a coarse, unsorted conglomeratic sandstone was encountered, enclosing pebbles, rounded as well as angular, concentrated in small layers. The whole is strongly cemented.
At some places non- resistant rocks are exposed: fine layered shales enclosing many leaves, and soft light-colored siltstones. The rocks mentioned above belong to the Río Banano formation.

Vegetation, land use:
Tropical rainforest and pasture.

Soils and their setting:
80% Typic Eutropept & typic Humitropept
shallow to moderately deep, well drained sandy soils on slopes of usually more than 20%

15-40 cm	dark brown to dark yellowish brown (10YR 3/2 & 3/3, 3/4 & 4/4) moderate to strong subangular blocky sandy clay loam to clay over
40+ cm	yellowish brown (10YR 5/6) weak to moderate angular blocky sandy clay loam to clay over rotten rock.

20 % typic Tropudult
deep, well drained reddish clay soils on tops of hills

10-30 cm	dark brown (7.5YR 3/2 & 3/3) moderate subangular blocky clay over
30-120 cm	yellowisch red (5YR 5/6) to red (2.5YR 4/8) weak to moderate angular blocky clay over silty clay loam

<u>Ckc: COLINAS, PAISAJE DE KARST, ARRECIFES DE CORAL LEVANTADO Y ARENISCAS/ HILLS, KARST LANDSCAPE, LIFTED CORAL REEF AND SANDSTONE</u>

Relief,landscape:
This unit occurs in the Limón Peninsula. The area is bordered by faults and uplifted as a whole. A great part of the landscape possesses a typical karst relief with conical hills and many closed rounded depressions, several tens of meters in diameter. The relief intensity varies from 15 to 40 meters, with slopes of 10° to 30°.

Material:
Through the whole unit coral has been found, in the form of angular blocks in a clayish matrix. The blocks vary in size. It is unclear if the whole unit consists of these erosion products or if also massive coral reef occur. According to Castillo (1984). this coral layer can reach a thickness of 40 meters. The coral is covered by sand/sandstones or clay. West of Limon well sorted, yellow colored, somewhat clayish sand has been found, according to Sprechman (1984) named as "arenas Pueblo nuevo". The clays are light colored and often finely red-layered. At some places fine- to medium-grained sandstones and calcareous light-colored siltstones are exposed.

Vegetation, land use:
Tropical rainforest and intensive human settlement:

Soils and their setting:
80% typic Tropudult
shallow to deep, moderately well to well drained reddish clay soils formed on sandstones.

15-30 cm dark yellowish brown (10YR 3/4 & 4/6) to dark & strong brown (7.5YR 3/3, 4/4 & 5/6) strong subangular blocky clay over.
40-90 cm yellowish red (5YR 5/8) to reddish yellow (5YR 6/6) moderate angular blocky clay over massive porous clay.

20 % typic Eutropept
moderately deep to deep, well drained heavy montmorillonitic clay soils formed on coral rock

15-30 cm very dark grayish brown (10YR 3/2) to dark yellowish brown (10YR 3/4) strong subangular blocky clay over
30-90 cm dark yellowish brown (10YR 4/6) to brownish yellow (10YR 6/8) moderate to strong angular blocky clay over rock (weakly weathered coral debris).

MONTAÑAS/MONTAINS

Mpc : MONTAÑAS, RELIEVE PRONUNCIADO, CONGLOMERADOS GRUESOS ARENISCAS/ MOUNTAINS. LANDSCAPE IN REISTANT ROCKS, COARSE CONGLOMERATES, SANDSTONES

Relief, landscape:
A steeply dissected to mountainous landscape with a high relief intensity, steep slopes and sharp V-valleys. Higher up in this unit the watersheds form sharp ridges and also clear hogbacks and deep escarpments occur.

Material:
Inclined layers of coarse conglomerates and conglomeratic sandstones determine the landscape within this unit. The sandstones are strongly cemented, the boulders are well rounded,

up to a diameter of 25 cm and are mainly of volcanic origin. They are embedded in an unsorted coarse grained sandy matrix. Often the boulders are not touching each other, and in some exposures rounded as well as angular boulders are scattered in a muddy matrix: mud flows.
The conglomeratic sandstones consist of a coarse grained matrix containing less than 20% pebbles and boulders. The pebbles and boulders are unsorted with a diameter up to 15 cm, and are mainly of volcanic origin. These conglomeratic sandstones are strongly cemented.
These poorly sorted coarse deposits, cemented to a hard rock belong to the Suretka Formation.
At some places large boulders (diameter up to 2 meter) were observed in pastures, probably deposited there by mudflows.
Besides these conglomerates, also inclined dark grey, calcareous siltstone layers and sandstone layers of various texture are found. The coarse sandstones are unsorted, sharp and vaguely stratified, the fine grained sandstones are calcareous and finely stratified. These rock types, all strongly cemented, probably belong to the Rio Banano formation, underlaying the Suretka Formation.

Vegetation, land use:
Impenetrable rainforest and pasture.

Soils and their setting:
see unit Cpc

Mpa: MONTAÑAS, RELIEVE PRONUNCIADO, ARENISCAS CALCAREAS, LIMOLITAS DURAS CALCAREAS/ MOUNTAINS, LANDSCAPE IN RESISTANT ROCKS. CALCAREOUS SANDSTONES, CALCAREOUS HARD SILTSTONES

Relief, landscape:
A mountainous landscape, relief intesity of more than 300 meters, steep slopes (30°-40°). The watersheds are separated by sharp ridges. The rivers form sharp V-valleys, with slopes up to 60° and sometimes even vertical.

Material:
Inclined layers of very resistant, fine to very fine calcareous sandstones, grayish-blue to grayish-green, alternating with hard, dark grey, calcareous siltstones. The gravel brought down by the rivers contain also calcareous breccies and intrusive rocks (granodiorite).

Vegetation, land use:
The slopes of the mountains are covered with impenetrable rainforest. At a very small scale river terraces are used for indian cultivation.

Soils and their setting:
lithic Eutropept
shallow, well drained loam to silty clay loam soils
0-10 cm very dark grayish brown (10YR 3/2) to dark yellowish

brown (10YR 4/6) moderate subangular blocky silty clay loam over 20 cm yellowish brown (10YR 5/4 & 5/6) weak angular blocky loam to clay over weathered rock.

BASINES ALUVIALES INTERIORES

Baa: VALLE RELLENADO, SEDIMENTOS FINOS/ VALLEY-FILL, FINE SEDIMENTS

Relief, landscape:
Intramontane basin, filled up with sediments. The topography is flat to almost flat. The rivers are incised to about 5 meters below the surface.

Material:
Mainly fine fluviatile sediments and thick fluviatile (or lacustrine) loam and clay deposits. Also sandy sediments and gravel layers are found. The pebbles are well rounded, and clearly show imbrication.

Vegetation, land use:
Extensive banano plantations or cultivation of coconuts.

Soils and their setting:
typic Eutropept & typic Dystropept
deep, moderately well to well drained loamy to clay soils
5-10 cm dark yellowish brown (10YR 4/4) massive porous to moderate subangular blocky sandy loam to clay over
>120 cm dark yellowish brown (10YR 4/6) to yellowish brown, (10YR 5/4) massive porous to weak angular blocky sandy loam to clay.

Vtq: VALLE, CAUCE Y TERRAZAS JOVENES, SEDIMENTOS MEZCLADOS, VALLEY, RIVER BED AND YOUNG TERRACES, MIXED SEDIMENTS

Relief, landscape:
Active and abandoned riversbeds and young terraces up to several meters above the valley bottom. The topography is flat to almost flat.

Material:
In the active and abandoned riverbeds, medium to coarse textured sediments are deposited; sand, gravel, boulders.
The sediments of the terraces vary depending on the hydrological regime of the river and age of the deposit.

Vegetation, land use:
The terraces are mostly in use for annual crops or for pasture.

Soils and their setting:
typic Dystropept and Eutropept
deep, moderately well to well drained clay loam to clay on the terraces.

6. MORPHOGENESIS OF THE LANDSCAPE

In this chapter the present landscape will be related to the geological structure and the geomorohological processes, in order to come to an outline of the morphogenesis of the landscape.

The study area can be subdivided into two main geomorphological units:

1: The coastal plain, with its flat to almost flat topography, consists of holocene fluvial and marine deposits. The main actual process is that of sedimentation.

2: The hilly mountainous areas which covers a part of the footslopes of the Talamanca mountain range consists of inclined. Tertiary sedimentary rocks. When the relief intensity does not exceed 300 m. the landscape is called hilly. The term mountainous is reserved for a landscape with a relief intensity of more than 300 m. The present landforms have been shaped mainly by fluvial processes.

THE COASTAL PLAIN

1.1 The beach ridges

The recent beach ridges form a long straight coastline, which is only interrupted to allow rivers to enter the sea. These beach ridges are fed by sand from offshore and by beach drift.
The direction of this littoral current is probably NW-SE. An indication for this assumption is found in the accretion of the beach ridge complexes at the NW-bank of the rivermouths. The complex of adjacent ridges bordering the coastal reaches a width of approximately 200 meters. In the north of the study area the beach ridges are interrupted by the peninsula of Limón.

1.2 The coastal swamps

The coastal swamps are situated behind the beach ridges and can be recognized immediately on aerial photographs by their vegetation. The dominant species is the Yolillo (Raphia taedigera) palm tree. At places where peat alternates with clay layers, Yolillo as well as other species are found. If clay is absent within the peat layer, the Yolillo palmtree is the predominant tree species. These poorly drained areas are the result of ponding of the small rivers that do not have enough force to break through the beach ridges by themselves. They assemble in the lower parts behind these ridges and form broad river mouths influenced by the tides, along which mangrove can be found.

Under the peat layers, marine sand can be found. This sand is composed of the same minerals as the more recent beach ridges bordering the coast. Another indication that the swamps are underlain by buried beach ridges is provided by the rectilinear drainage pattern in the surroundings of the mouth of the Río Viscaya (Fig. 6.1).

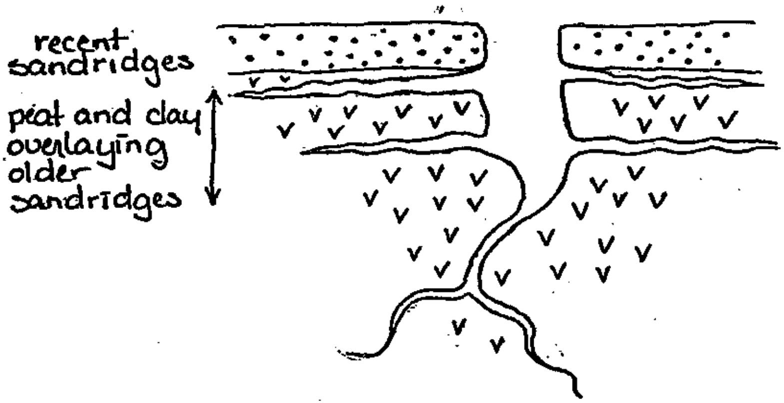


Figure 6.1: mouth Río Viscaya

The buried beach ridges are covered with peat or clay. In the depressions between two adjacent sandridge complex, water accumulates which results in this specific drainage pattern.

1.3 The alluvial plain

The alluvial plain, varying in width from 2 to 4 kilometers consist of mainly fine textured Holocene fluvial deposits. The area is intersected by some major rivers (Río Banano, Río Bananito, Río Estrella). Because of the very low gradient and the predominantly suspended load of these rivers, they form meandering channels on broad flood plains. These meandering systems are quite dynamic. The rivers often change their course, witnessed by the many cut-off meanders which can still be recognized on the aerial photos. Because of the scale of the map, it was not possible to map out the individual landform within these meanderbelts (the natural levees and backswamps).

These major rivers possess enough force to break through the beach ridges, although sometimes they have to run parallel to the beach ridges complex over quite a distance before they eventually break through. (e.q. Río Bananito).
Besides by the major rivers, the alluvial plain is intersected by numerous smaller watercourses which mainly carry very fine sediments. Especially in the north-western part of the alluvial plain extensive clayish deposits can be found.
At a distance of more than 3 kilometers from the present-day coastline, and at an altitude of approximately 20 m above present sealevel, fossil beach ridges are found, overlain by a clayish cover with a thickness of about 2 meters. A few beach ridges could clearly be distinguished on the basis of their form and composing minerals.

1.4 Genesis of the coastal landscape

The fossil sandridges 20 m. above present sea level, form an indication of a relative sea level fall. This relative sea level fall is probably the result of tectonic uplift of the land during the Pleistocene and the Holocene. The Sangamon interglacial sea level high was about 8 m than the actual level, which indicates that deposition during a former sea level high seems a rather unrealistic explaination. This uplift involves a lowering of the base level. The result is an intensified erosion; a deepening of the valleys and formation of terraces. At places where the rivers are leaving the hills the erosion products are deposited in the form of alluvial fans or deltas, gradually building forward, resulting in a prograding of the coast (deltaic progradation) (Fig.6.2).

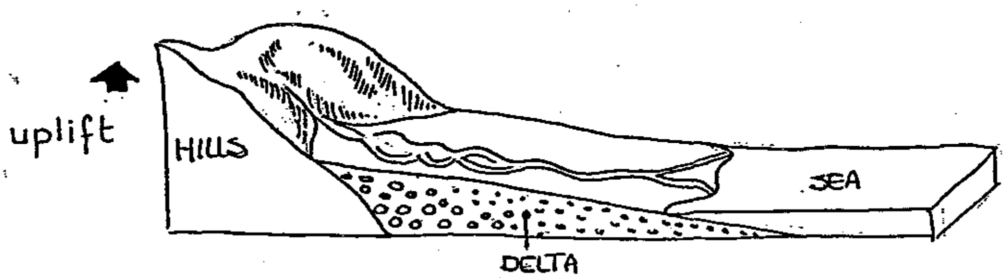


Figure 6.2: prograding coast

At places were shoreline processes dominate over fluvial process, multiple beach ridge complex record the seaward migration of the shoreline (Fig.6.3).

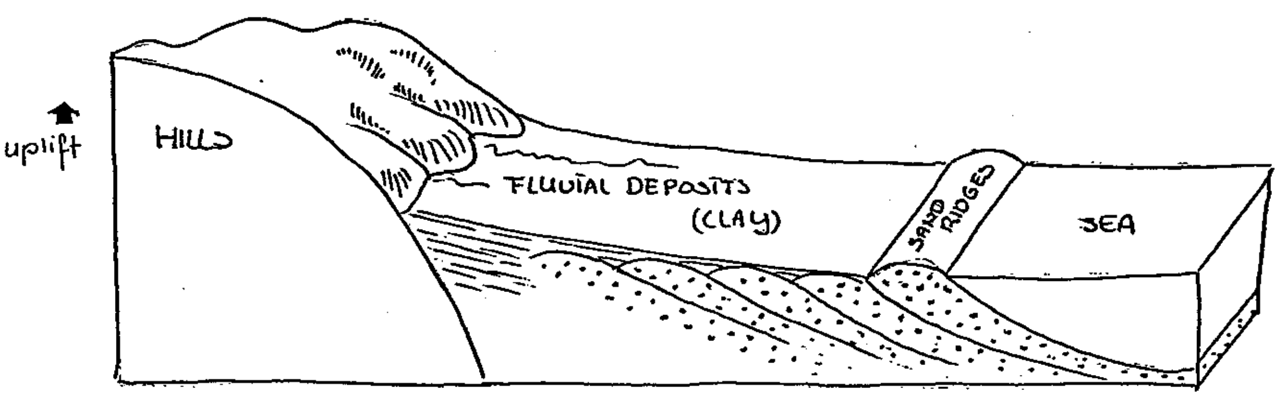


Figure 6.3: formation sandriges relative sealevel fall

On the contrary, the genesis of the landscape just behind the present day beach ridges can be explained with the assumption of a relative sea level rise. At this moment no extending deltas are formed. Therefore, the shoreline is straight. Behind the recent beach ridges extensive coastal swamps are found. The mouths of the smaller rivers which assemble in these swamps, can be regarded as estuaries. The older beach ridges underlying these swamps, are the result of a seaward growth of the shoreline under condition of a slowly rising sealevel or a lowering of the land.(Fig.6.4).

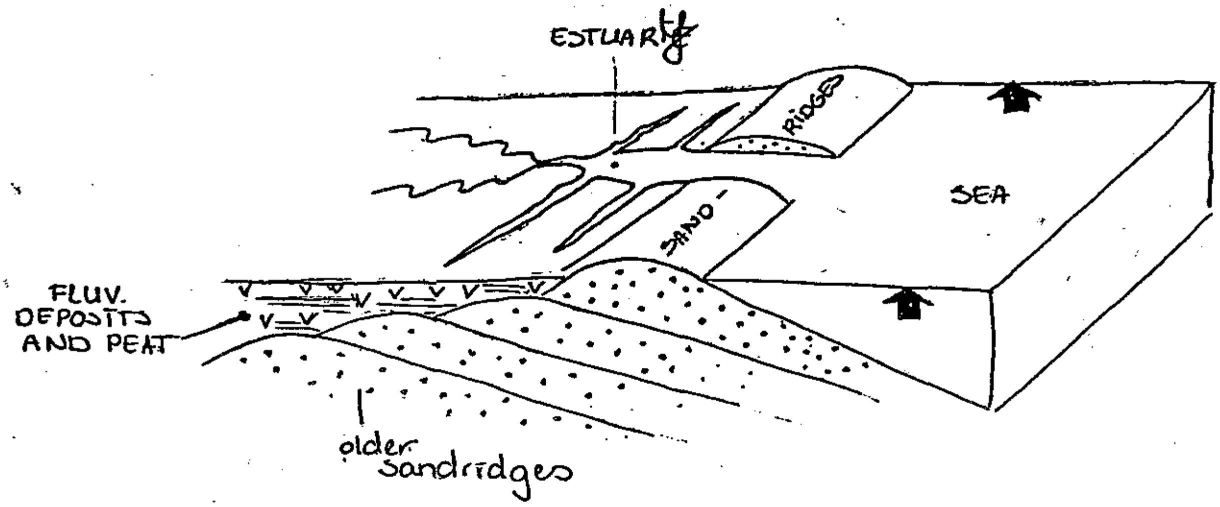


Figure 6.4 : formation sandridges by slowly rising sea level.

Near the airport of Limon the beach ridges directly underlying thin peat or clay layers, are lacking. There is an abrupt transition of the more recent beach ridge-complex to a peat swamp. Within the peat, no clay deposits have been noticed. Not until a depth of 3 m marine sand is found. This abrupt transition is probably the result of former erosion. The erosion could have been caused by a rupture in the barrier of sandridges due to storm surges. The sea carried off sand, clay and peat and created a lagoon. When the opening was closed by the sea, some deposition of fine sediments occurred. The thin clay layer which is overlying the relicts of the older sandridges, is probably a lagoonal deposit. Subsequently, peat grow started (Fig. 6.5 and 6.6).

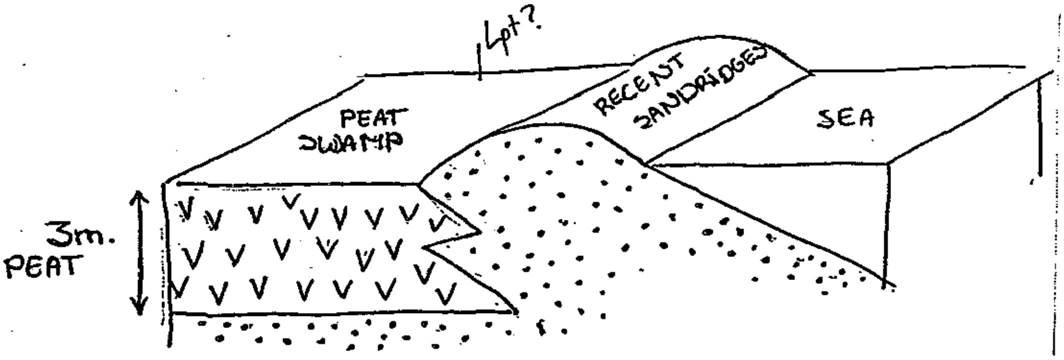


Figure 6.5: abrupt transition sandridge - peatowamp

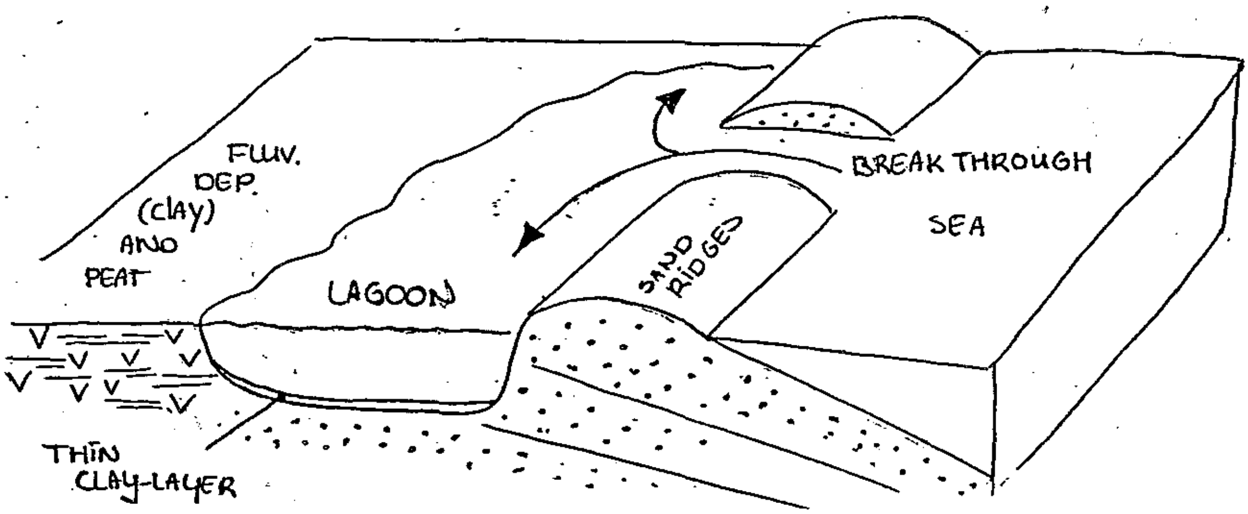


Figure 6.6: Lagoon

Other areas, characterized by thick peat layers with no, or little, clay deposits (code Lpt on the map), could be explained by similar processes.

The coast of the study area can be classified as a prograding coast, predominantly shaped by marine deposition (formation of beach ridges). The older marine deposits are overlain by fluvial sediments and peat. The coastal plain has been affected by the uplift of the land well as the post glacial rise of the sealevel.

THE HILLY/MOUNTAINOUS AREA

2.1 Introduction

Within this area three main geomorphological subunits can be distinguished (Fig. 6.7 and 6.8):

- the hills, bordering the coastal plain, in which the range of elevation does not exceed 300 m. They mainly consist of folded rocks belonging to the Río Banano Formation.
- a zone where soft shales of the Uscari Formation crop out, and in which the intramontane basins are found. The range of elevation of this area usually does not exceed 150m.
- the mountains, with a range of elevation of more than 300m. built up of mainly calcareous sandstones and siltstones of the Senosri Formation.

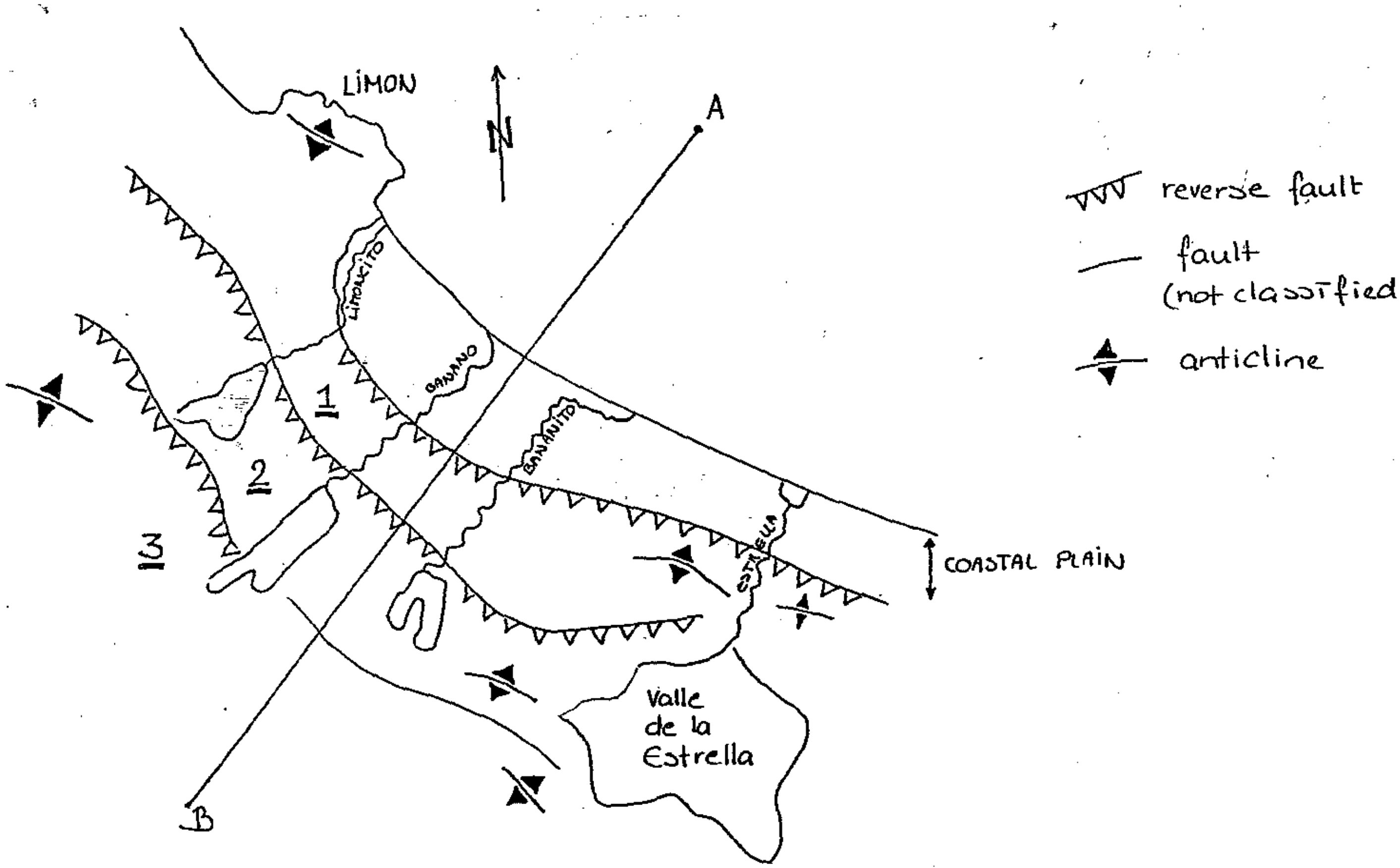


Figure 6.7: 3 geomorfological subunits

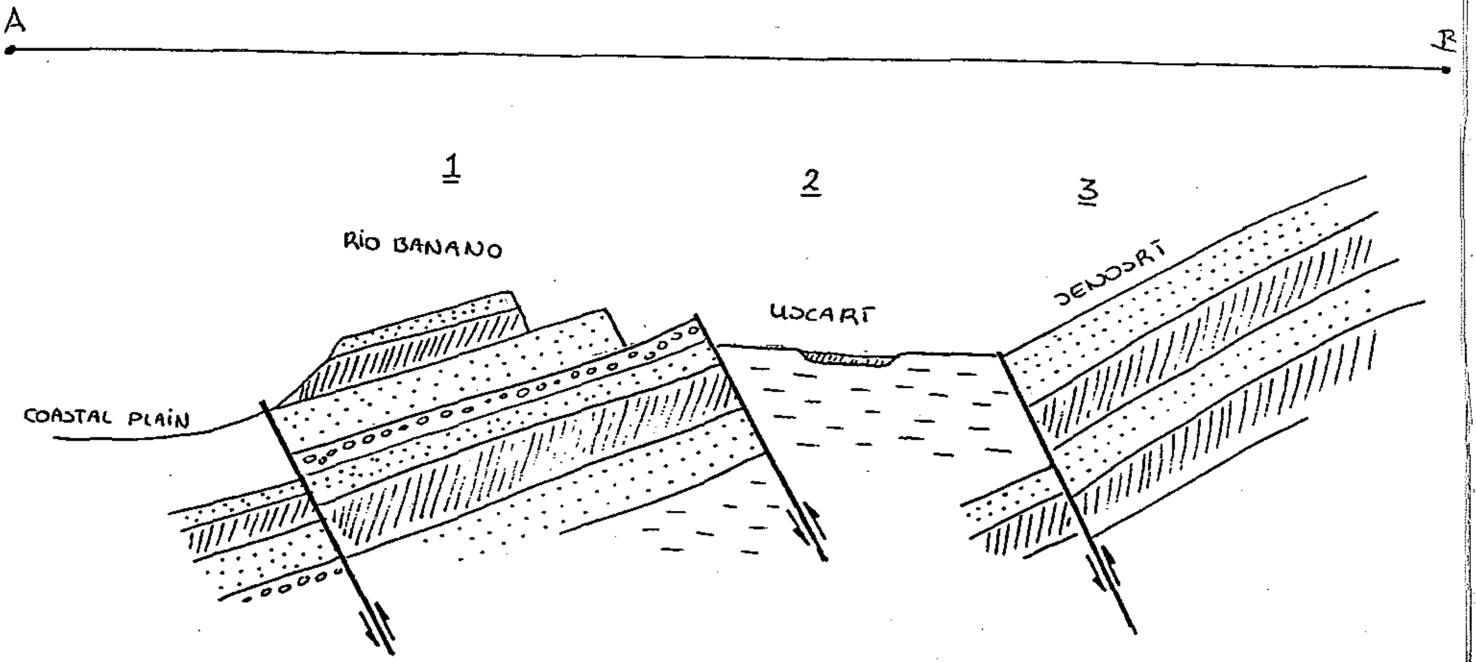


Figure 6.8: Geological cross section

Differences in elevation are caused by two principal factors: tectonics and lithology.

<u>tectonics</u>

The main tectonical structures within the study area, such as reverse faults and anticlines, are the result of pressure, originating from enormous gravitative slides. These slides started with the uplift of the Talamanca mountainrange in the Middle Miocene, and continued into the Plio-Pleistocene (see 2.3.1).
This is why most of these structures possess nearly the same strike and why the three geormorphological subunits as described before, show a zonation which coincide with this strike (see fig 7 and 8).

<u>lithology</u>

Differences in lithology and hence in resistance to weathering explain part of the variation in elevation.
- The hills bordering the coastal plain, are built up of alternating resistant and non-resistant inclined layers. When easily weatherable rocks, such as soft silstones, weakly cemented sandstones or shales crop out, a softening of the relief is noted.
-the next zone consists of mainly soft shales. Shales are very impermeable, are quickly saturated with water and thus are liable to extensive slope movements. Therefore, no high elevation can be expected, compared to the hills bordering the coastal plain.
- In the mountainous area, strongly cemented calcareous sandstones and limestones, or thick layers of strongly consolidated conglomerates predominate. These resistant rocks produce a sharp relief and the range of elevation easily surpasses 300 m.

The different landform which are found in the three subunits will be described successively.

2.2 The hill bordering the coastal plain

Within this area the elongated ridges which can easily be recognized on the aerial photos, form cuestas. These landforms are structurally controlled. Inclined resistant layers, overlying non-resistant rock, form typical asymmetric ridges. The dip slope (20°-30°) is often formed by strongly cemented sandstones or siltstones (Fig.6.9). At the cuesta front strong erosion of the underlying soft siltstones or shales results in an undermining of these resistant layers, so the front remains steep (>40°).

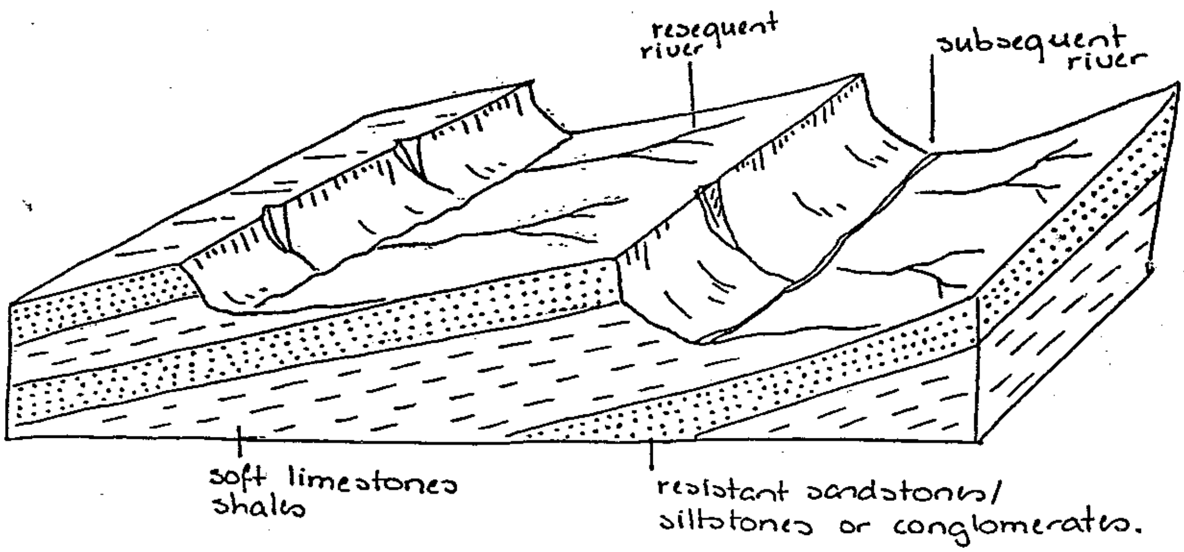


Figure 6.9 : Cuestas (from bloom)

A trellis drainage pattern can easily be recognized on the aerial photos. The subsequent rivers often form broad valleys, of which the walls show many landslides\slumps. On the contrary, the resequent rivers, intersecting the resistent rock layer, form straight, narrow V-valleys. The course of the consequent rivers (e.q Río Banano, Río Bananito, Río Estrella) all coincide with faults (see geological map).
At the north-western side of the Río Estrella, many outcrops of the Río Banano Formation have been found. However, this area does not show the typical pattern of elongated ridges. The drainage pattern can be classified as dendritic to subdendritic. Such a pattern will develop in an area built up of uniform material. Probably, the Río Banano Formation is overlain by a relatively thin, homogeneous cap of coarse conglomerates belonging to the Suretka Formation. The fact that the streams intersecting this area bring down numerous boulders of coarse, strongly cemented conglomerate seems to affirm this conclusion.

According to the geological map the tectonical structure is that of an anticline. A geological cross section based on these data is given in Fig.6.10.

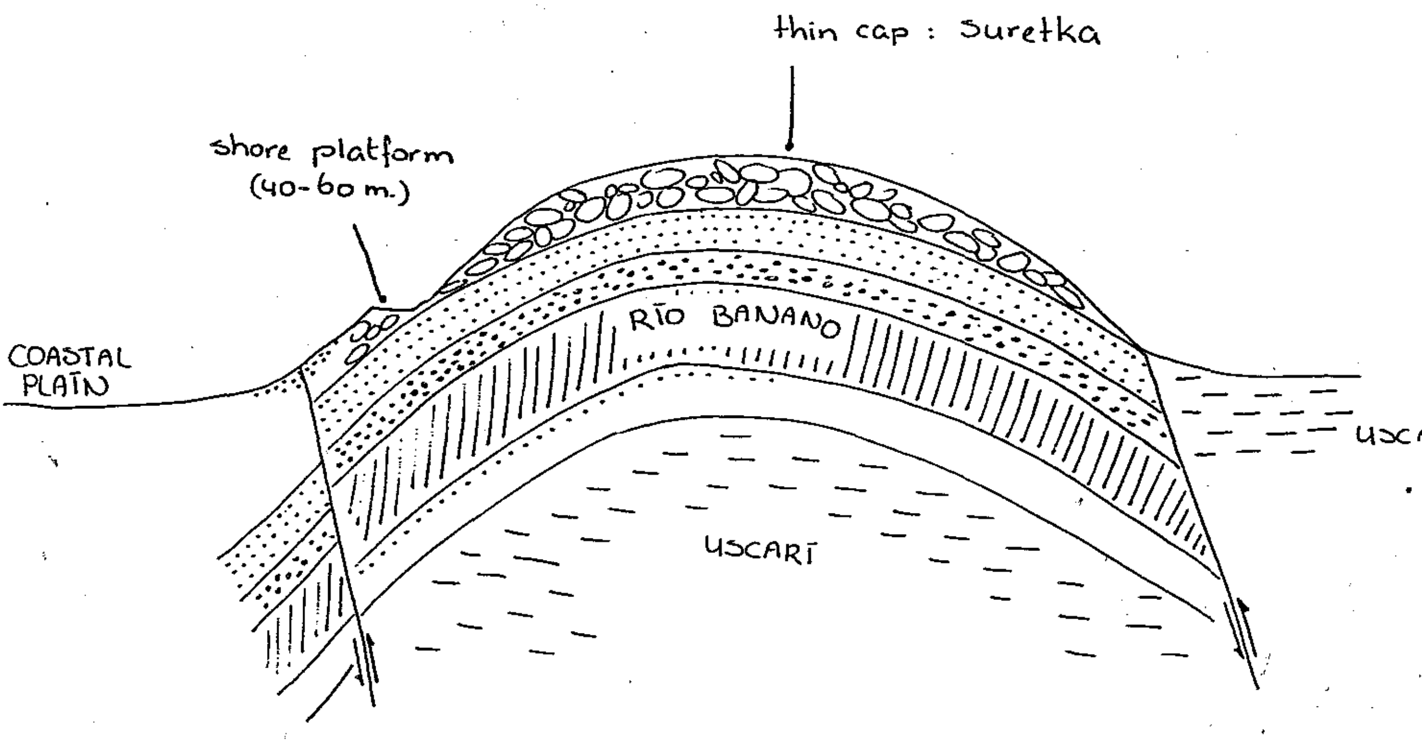


Figure 6.10: Geological cross section

The area is characterized by a sharp relief; moderately to steep slopes, whereas some rivers even have formed canyons. However, at the side of the anticline bordering the coastal plain, some landforms with an almost flat topography, all in one line, 40 to 60 m, above sea level, can be recognized on the aerial photos. Fieldwork did not yield clear evidence, but they are supposed to be relicts of old shore platforms.
Another anticline is found at the north-east side of the Rio Estrella. An enlargement of this part of the geomorphological map (Fig.6.11) shows two cuestas with opposite dips, between which the river eroded a broad valley, filled up with alluvial sediments in the form of the terraces.

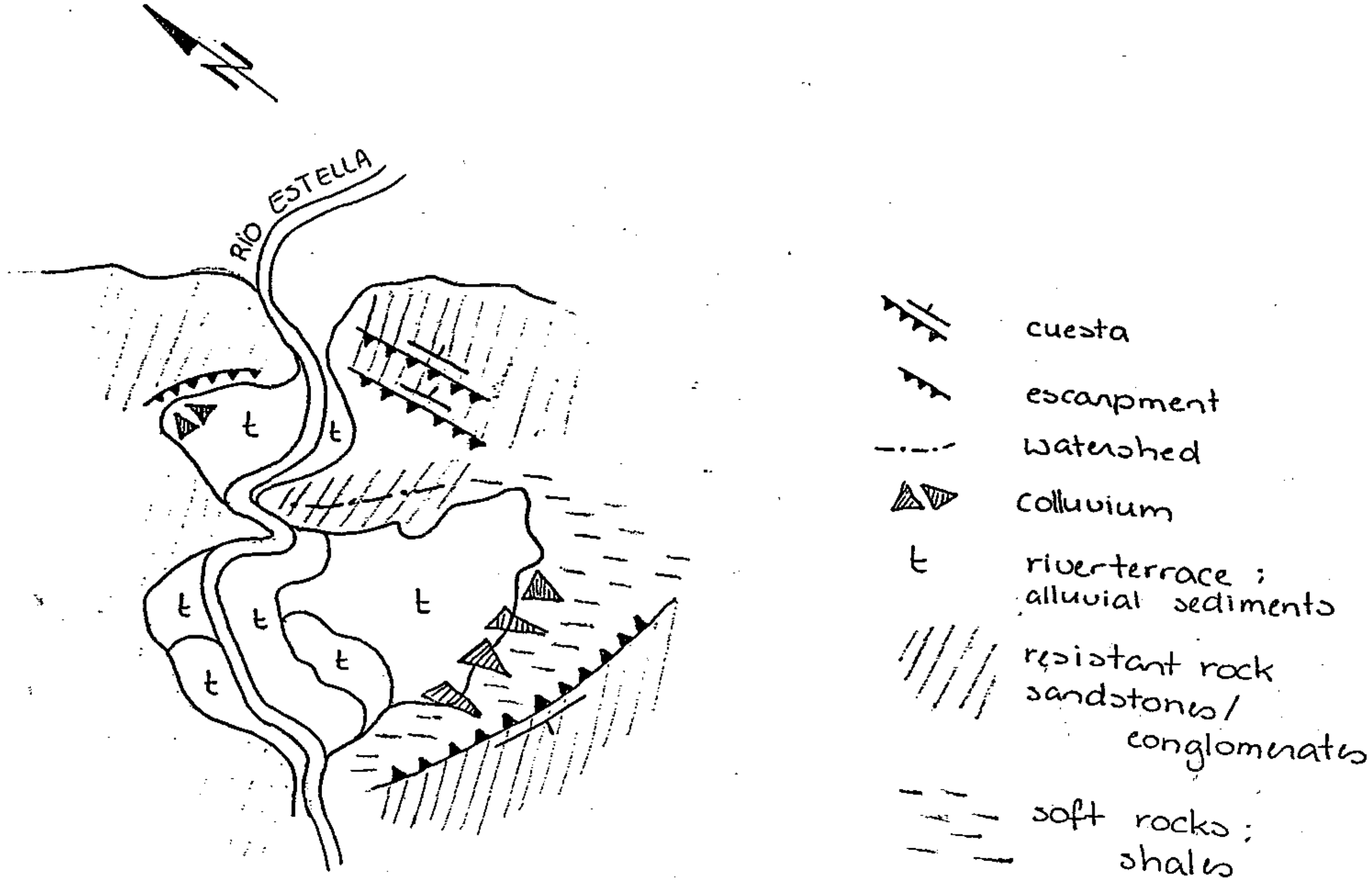


Figure 6.11: part of the geomorfological map (see apendix)

The dipslopes of both cuestas, which probably form the sides of the anticline, consist of resistant sandstones and conglomerates of the Rio Banano Formation. At the frontslope of the cuesta dipping to the south, shales crop out. As a result of constant erosion by downslope movement of material (colluvium), this escarpment remains steep. These shales probably form the inner layers of the anticline.
This landscape reflects differential weathering. Where the river encounters resistant rocks it can only create a narrow passage with steep slopes. However, within the easily weatherable rocks the river can widen its valley. Within these valleys the river forms terraces.
In the north-western part of the study area, the hilly landscape reaches up to the coast and forms the peninsula of Limon. According to Castillo (1984), this area has been lifted along a great fault; "Falla Asunción". The strike of this fault is NW-SE; an orientation perpendicular on the general strike of most of the faults and anticlines within the study area (Fig.6.12).

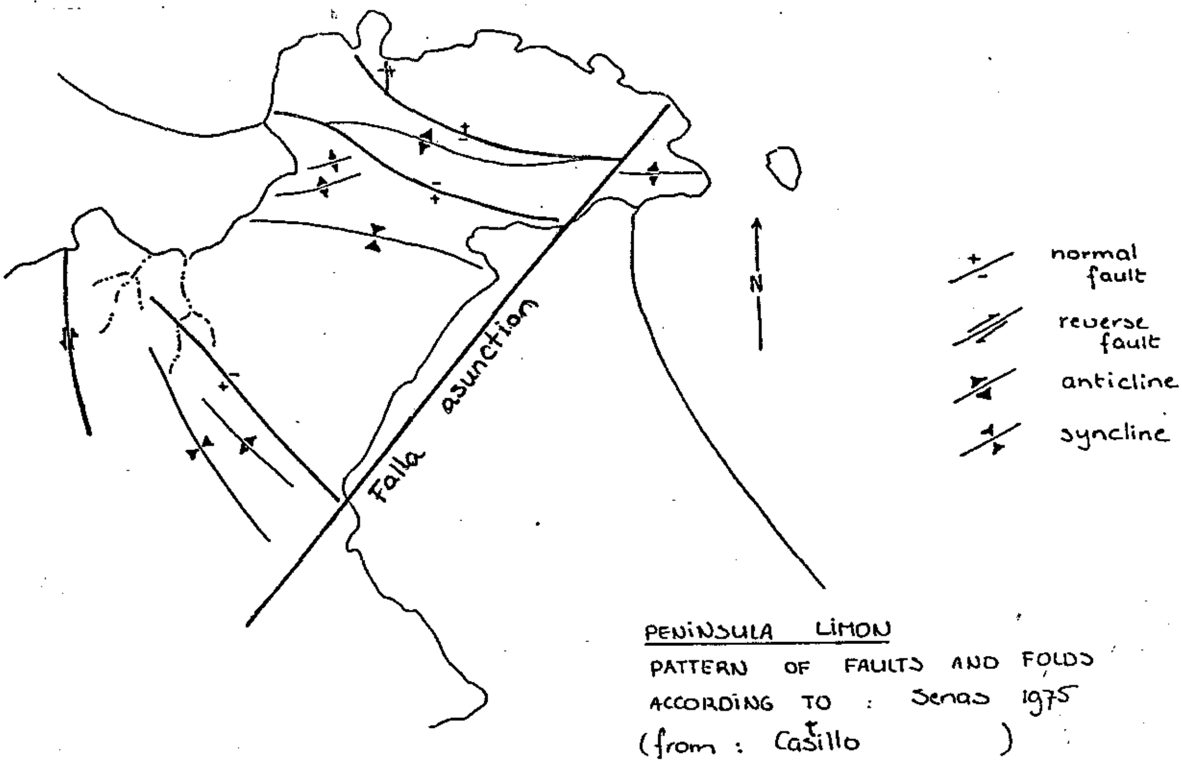


Figure 6.12

The main geological structure within this peninsula is that of an anticline with a strike NW-SE. At the top of this anticline sandstone belonging to the Río Banano Formation crop out. The sides of the anticline consist of mainly Tertiary carbonates; coral reefs (massive as well as breccias) and limestones, reaching a thickness of approximately 100m. These rocks also belong to the Rio Banano Formation.
According to the geological profile (Fig.6.13), the Tertiary coral reefs and limestones of the N-E side of the anticline are overlain by "recent reefs".

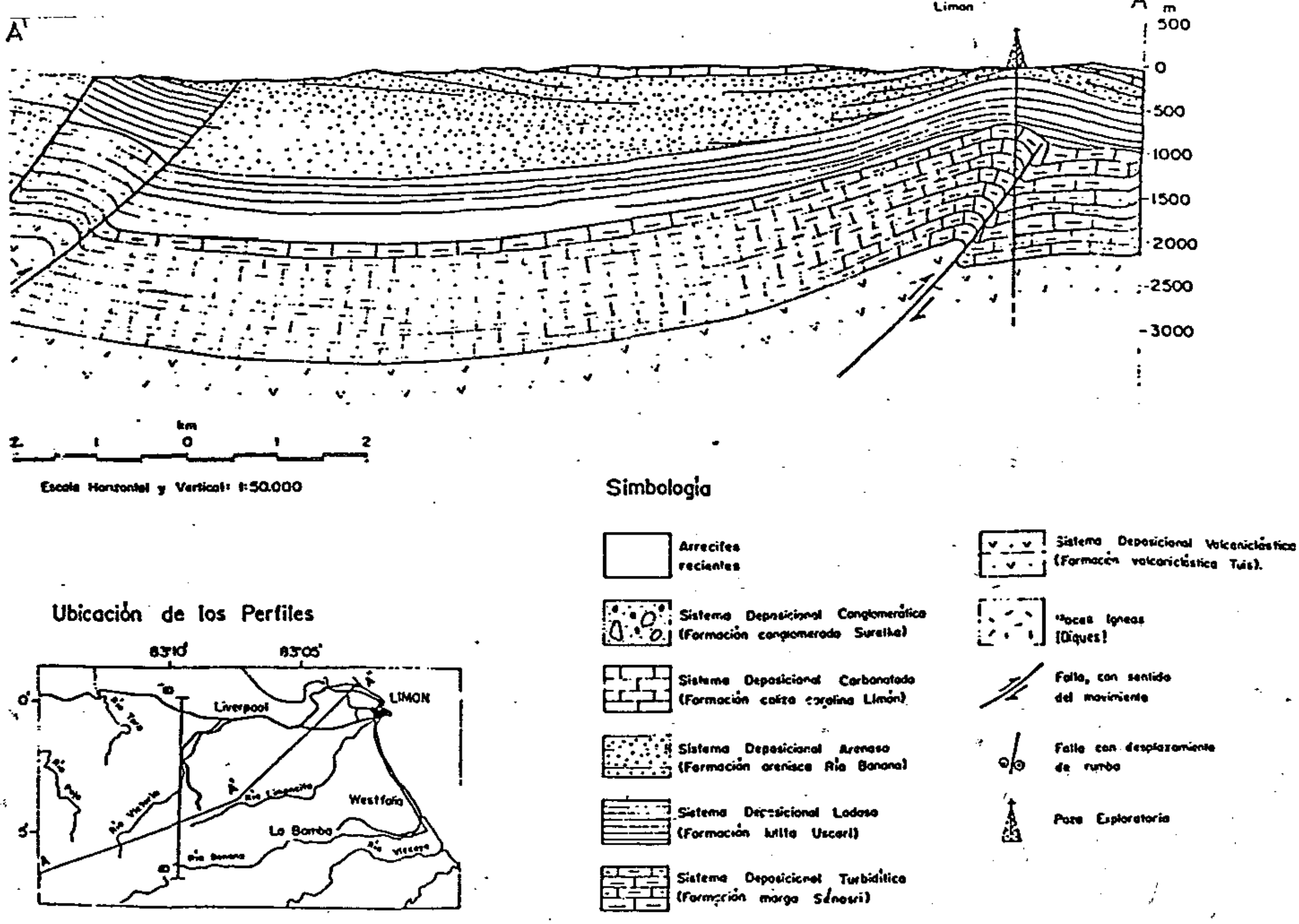


Figure 6.13: geological cross section from campos 1987.

Battistini and Bergoeing (1984), consider these reefs to be of Pleistocene age. However, these lifted coral reefs bordering the coast show a clear inclination, the strike of which coincides with the general strike of the anticline. Since the period of energetic uplift, succeeded by folding and faulting, dates back to the Middle Mionce, it is more likely that these reefs belong to the Tertiary.

On the Peninsula of Limón, solid rock reaches up to the coast forming a headland. Instead of accumulation of material in the form of beach ridges, erosional shore-zone landforms predominate. Within the intertidal zone a shore platform has developed, reaching a maximum width of nearly 100m, near Piuta. This platform is cut in carbonate rocks (Tertiary coral reefs), so besides wave abrasion, also solution processes play a role in the formation of the coast. A similar landform at a somewhat higher level may represent a former higher sealevel or uplift. In the former case, the steep rocks bordering this higher level at the inland side can be regarded as fossil cliffs (Fig.6.14).

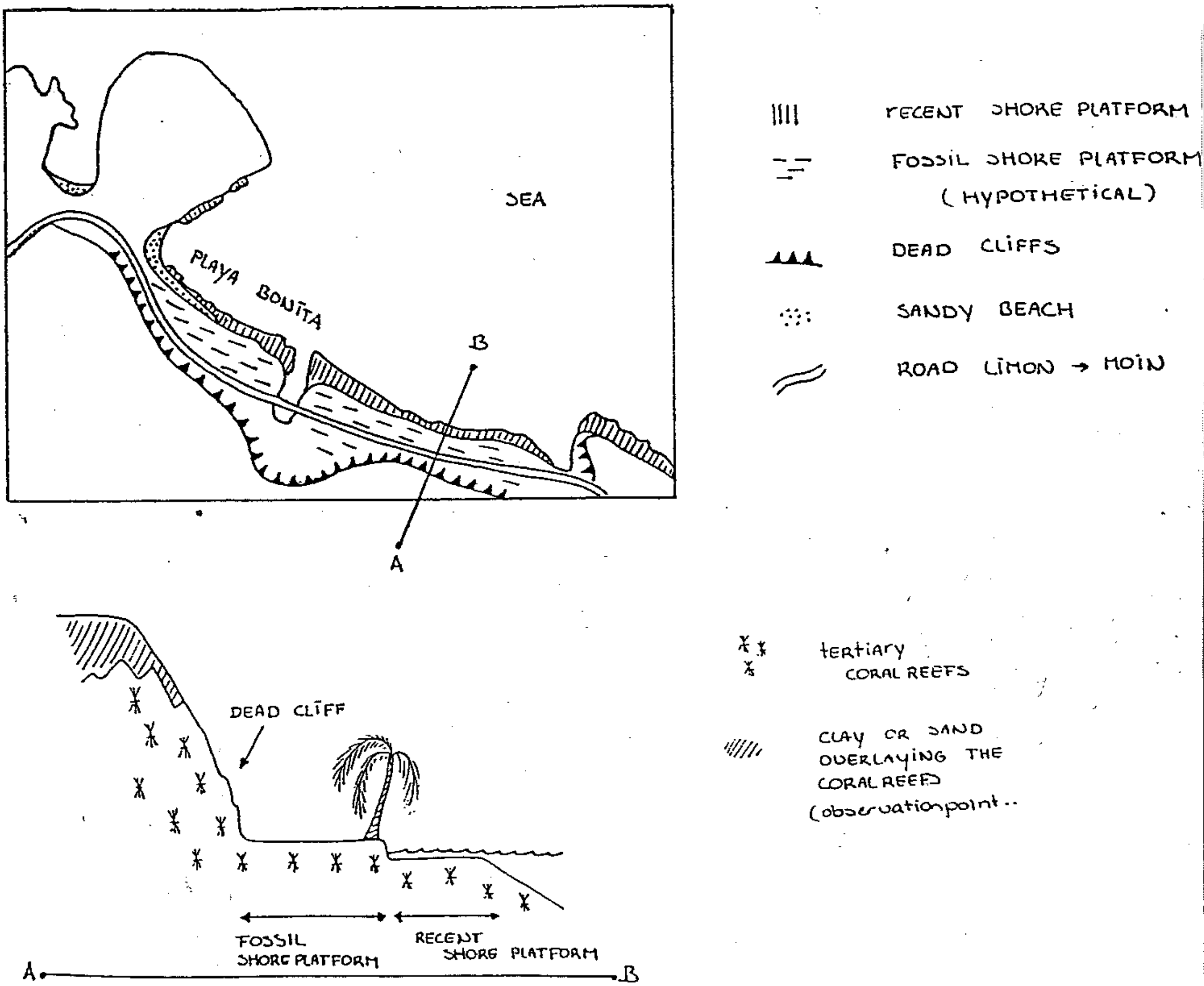


Figure 6.14: cross sectioncoastal area peninsula Limón (from Battistíní, Bergoeing 1984).

In the hills in the surroundings of Limon, staircase-like structures can be recognized on aerial photos. Horizontal zones with a more or less flat topography situated above each other (levels at 70m, 60m, 40-45m and 15-20m above present sea level). Possibly these structures are the result of parallel faulting and uplift, and\or of erosion at different levels. In case this erosion pattern is the result of sea level changes, these landform present marine terraces. However, there are insufficient data to confirm this assertion.

The high solubility of coral limestones and other carbonate rocks, under the prevailing climatic conditions give rise to karst formation. Due to joint control or differential solubility, localized areas of karst terrain are lowered more rapidly than the surrounding area and form closed, circular depressions; dolines. The landscape, therefore, is characterized by a very irregular relief. The drainage is for the greater part underground.

The dolines are up to a 100 meters in diameter and 30 meters in depth. Some of them contain water in case the passage is blocked by impenetrable material (soil, vegetation) which prevents water to drain. At the SW-side of the anticline an extensive Karst-plateau can be recognized, elevated about 20 to 40m. above the surrounding area. This abrupt difference in height is due to faults bordering this plateau and probably also the result of differences in permeability of the rocks. At the border of the plateau where the underlying sandstones crop out, the slope remains steep as a result of undermining of the highly permeable limestones by erosion of these less permeable sandstones (Fig 6.15).

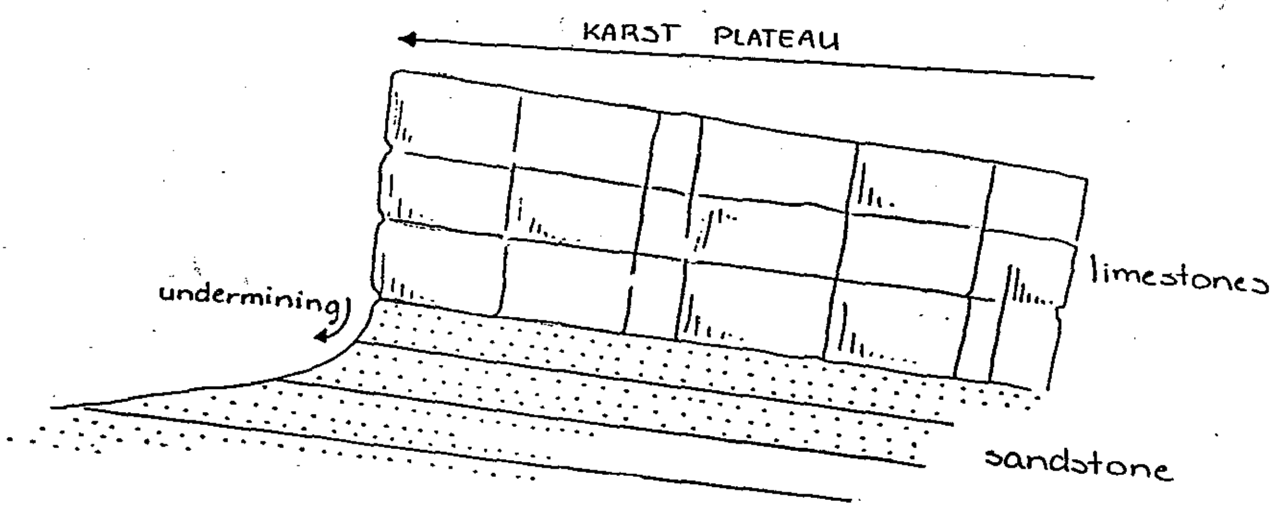


Figure 6.15 : border karst plateau

Further to the South-East of this area, the inclined sandstone and siltstone layers of the Río Banano Formation give rise to the same landform as discussed earlier: cuestas (Fig.6.16).

the same landforms as discussed earlier: cuestas (see fig. 6.16)

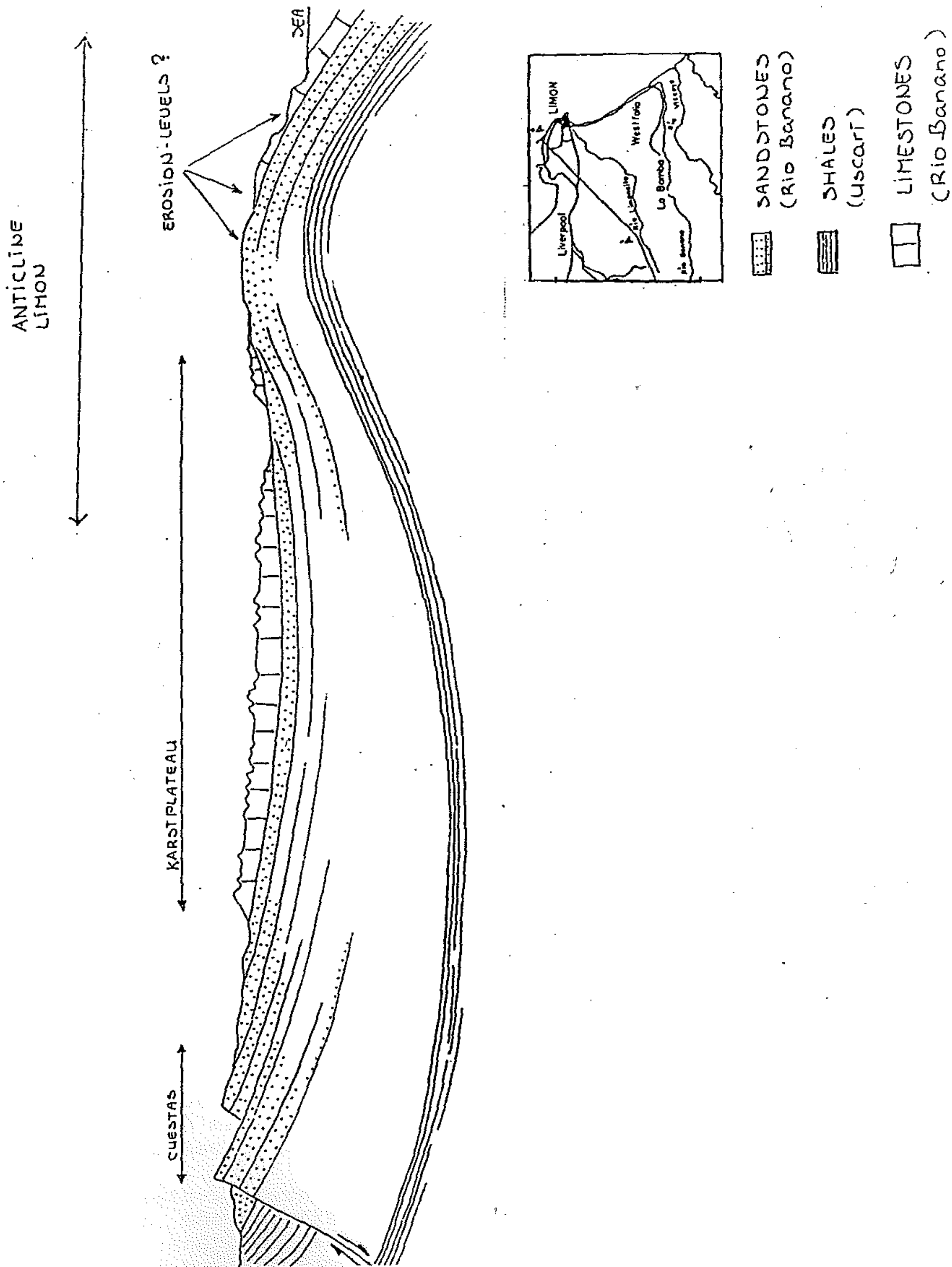


Figure 6.16: geological cross section with different landforms (from L.Campos B. 1987).

2.3 The zone in which shales of the Uscari Formation crop out.

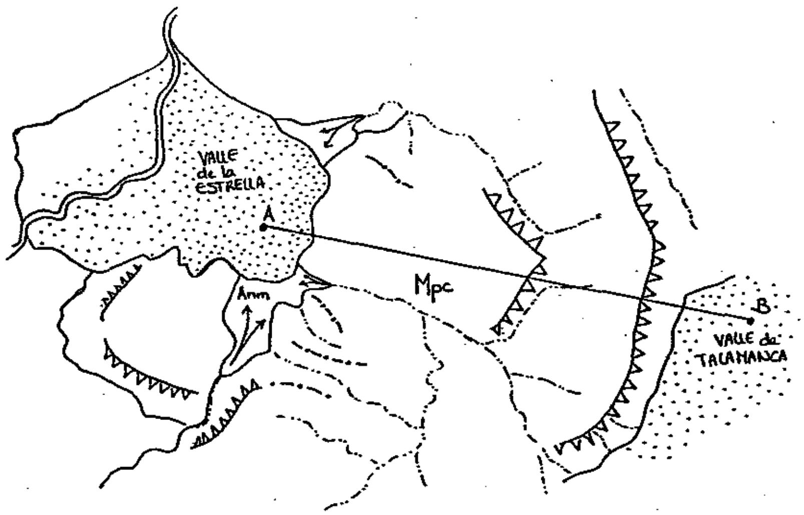
The second geomorphological subunit within the hilly mountainous area is mainly built up of shales, belonging to the Uscari formation. These impermeable rocks are very liable to slope movements. Slumps determine the character of the landscape. The relief intensity is low, usually not exceeding 150m. Locally , the relief intensity exceeds 150m. due to the occurrence of sandstone layers, interstratified with the shales.

In this zone the main rivers have widened their valleys and a series of intramontane basins are found, situated in one line just behind the hilly area which borders the coastal plain, indicating a tectonic origin. The largest basin is the Valle de la Estrella. The topography is flat to almost flat, and inundations occur frequently. The course of the rivers intersecting this area is meandering. These rivers have incised to about 5m, below the surface. Soil augerings and studies of drainage channels, altogether to a depth of about 4 meters showed that main sediments of the upper layer\part consists of fine material; clay, siltloam and very fine sand, showing a fine horizontal stratification. At one observation point sand and gravel have been noticed. The pebbles of the gravel layer are well rounded 0.5-10cm, in diameter, and clearly show imbrication. Thick layers of fine deposits indicate a sedimentation in a quiet environment, like that of a lake (lacustrine sediments). The deposits of sand, gravel, and especially the observed sedimentation structure (imbrication) indicate fluvial sedimentation. While the observations only concern the upper 4 meters of the sediment it is rather difficult to give an opinion on the genesis of the landscape. Presumably the shales of the Uscari formation underlie these sediments. In this soft rock the former rivers have shaped broad valleys and the relief was flattened as a result of the continuous occurrence of landslides. Temporarily lakes may have formed, in which silt and clay was deposited.
Similar alluvial basins of a somewhat smaller dimension can be found along the Rio Banano and the Rio Limoncito. Like the Valle de la Estrella, these basins are characterized by thick layers of very fine deposit, so similar processes will probably underlie the formation of these basins.

2.4 The mountainous area

The term mountainous has been reserved in case the relief intensity largely exceeds 300m. This coincides with outcrops of the Senosri Formation and the Suretka Formation. In the resistant rocks, rivers erode deep V-valleys and resulted in a steeply dissected landscape with sharp crests up to a height of 1800 m.

In the south-western part of the study area, next to many outcrops of the Suretka Formation, inclined layers of resistant siltstones and sandstones have been found. Presumably, these rocks belong to the Rio Banano Formation, and are overlain by thick layers of conglomerates and breccias (Suretka Formation) (Fig.6.17).



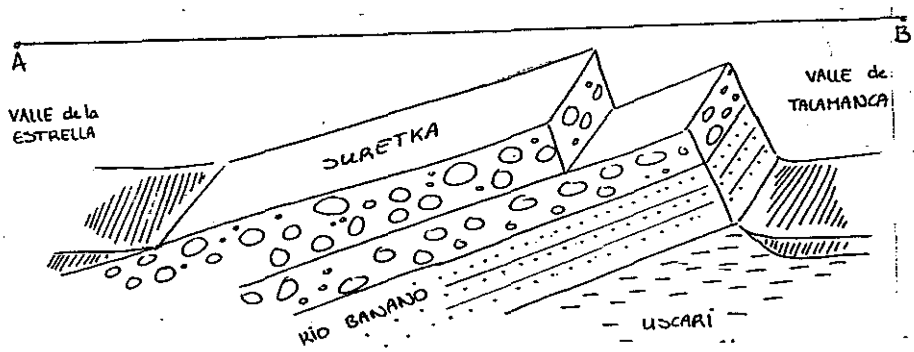


Figure 6.17: geological cross section

These conglomerates and breccias are composed of poorly sorted gravel, boulders and blocks in a sandy to clayish matrix, often without any organization. These deposits are the result of mass movements, for example mud-flows. Because of the inaccessibility of this terrain, the observation points were only made along the limits of the area. A description of the landscape is only possible with the help of an interpretation of the aerial photographs. These photos show some cuestas/ hogbacks, of which the dipslopes probably consists of the coarse conglomerates and breccias of the Suretka Formation. The frontslopes are supposed to be accompanied by faults.
The remaining part of the mountainous area is built up of inclined layers of calcareous siltstones and sandstones of the Senosri formation. Further to the south-west (going inland), rocks of the Tuis Formation (volcaniclastic deposits) crop out, as witnessed by the great contribution of volcaniclastic material in the sediment load of the rivers. Also this area is for the greater part unknown because of its inaccessibility.

2.5 Alluvial fans

An abrupt decline in the gradient of a river will result in sedimentation of a part of the bedload to form an alluvial fan. Usually, the coarse components will be deposited first. Further on the fine-grained elements are deposited.

Within the study area, these alluvial fans are found at the transition of the hilly area to the coastal plain (A) as well as at places where high-gradient tributary mountain streams enter into the intramontane basins (B).

A. At the transition of the hilly area to the coastal plain a weakly inclined "pie de monte" exists. This pie de monte is built up of coalescing fans, and its extent varies with the size of the drainage basins in the hinterland.
The fans are still active. A number of clearly cone-shaped forms can be recognized on the aerial photos as well as in the field.
The alluvial fans are built up of Holocene, rather finely grained sediments: thick layers of clay and silt alternate with thin layers of coarse sand or gravel. Coarse deposits in the form of gravel beds and boulders have been found, but scarcely.

In contrast to the smaller streams, the major rivers enter the coastal plain with hardly any change in gradient. Within the hilly area their valleys are broad and their courses more or less meandering. The velocity of the stream is low. Nowadays, these major rivers do not form alluvial fans.
Nevertheless, a fanshaped, slightly inclined landform can be distinguished where the Río Banano enters the coastal plain. Within this area the course of the rivers is more or less braided (gravelbeds). The sediments of which this alluvial fan is built up vary from coarse gravel at the top, to very fine clayish deposits at the distal part of the fan. This alluvial fan in not active anymore. The Río Banano has incised in its own sediments to form terraces at different levels (Fig.6.18).

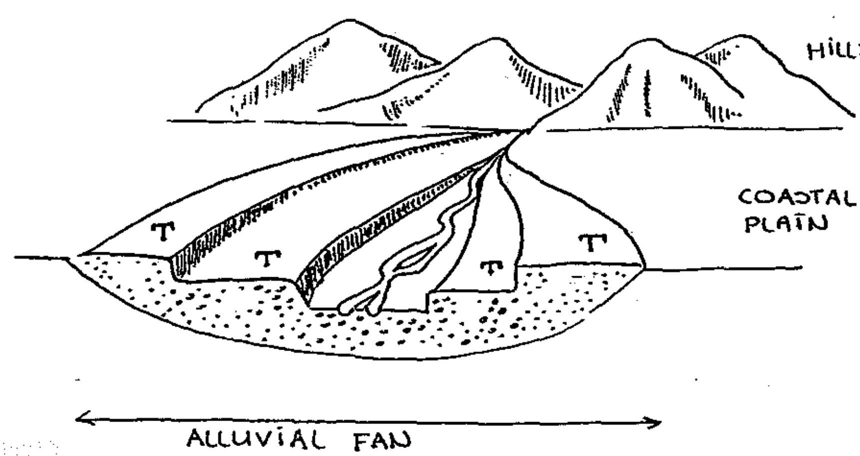


Figure 6.18 : dissected alluvial fan Río Banano

So, in the course of time the river has changed its character. A period in which sedimentation, maybe influenced by mud flows, was the main process (formation alluvial fan) has been followed by one in which erosion predominates (incision and forming of terraces).
Probably this alluvial fan dates from the late Pleistocene. The glacials coincide with drier periods, a rather open vegetation and an intensified superficial erosion; rivers carried large amounts of coarse elements. Where the Rio Banano entered the costal plain a great part of this bedload was dropped to form the alluvial fan. During the Holocene the climate changed. The vegetation closed and superficial erosion became less important. Therefore, the composition of the sediment load became finer, and the river started to incise to form terraces. However, the question remains, why, if this theory is correct, these fans were not formed by the Estrella and Bananito rivers.

B. Also in the hilly\mountainous area alluvial fans can be recognized. Where high gradient streams leave the mountains to enter the intramontane basin (Valle de la Estrella), the abrupt change of the gradient causes the deposition of a part of the bed load. These areas have not been checked in the field. Probably these fans are still active. Sedimentation will be limited to periods of intensified erosion upstream, for example during heavy rainfall or after earthquake triggered landslides.

An extensive fan at the entrance of the Rio Suruy is not active anymore. After a period of sedimentation in which the fan was built up, erosion started and river incised in its own alluvium. Terraces can be found at a height of 40 meters above the present riverbed. Here also mudflow activity might have been important (fig.6.19).

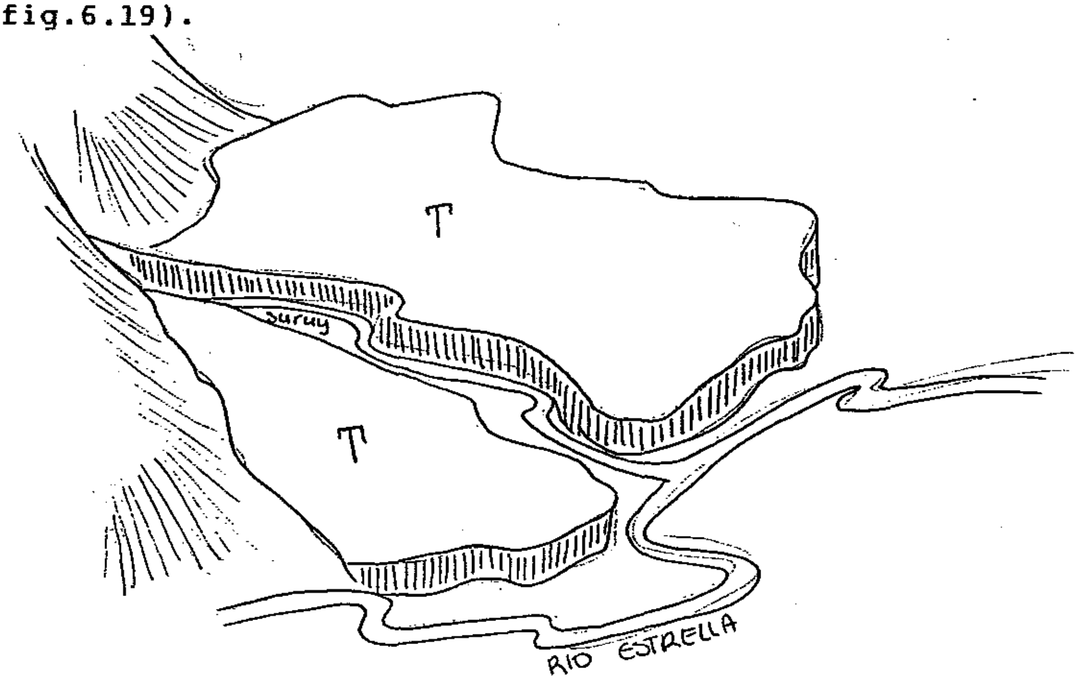


Figure 6.19: dissected alluvial fan Río Suruy

The front of this alluvial fan is cut off by the earlier course of the Río Estrella. So this threshold can be seen as a terrace border as well.
The sediments of this fan consist mainly of boulders, pebbles and sand, deposited in thick separated layers, showing a horizontal stratification. At the foot of the fan coarse, mudflow-like deposits have been found: boulders of all sizes, up to a diameter of 50 cm, embedded in loose matrix (sandy-loam) without touching each other and without any organization.
This alluvial fan is supposed to be far older than those described before, since incision to more than 40m probably requires quite a long period. Besides, within the sand and conglomerate-layers, the process of lithification seems to have started. (On first acquaintance during the fieldwork, these layers were defined as very weakly cemented sandstones and very weakly cemented conglomerates).

Other slightly sloping landforms with a more or less flat topography can be recognized where the Río Bananito and a nearby nameless river leave the mountainous area. Further examination revealed alluvial deposits in the form of coarse gravel and boulders at the top, overlain by layers of fine sediments downslope.
Within these deposits no sedimentary structures were observed. No typical fanshape can be recognized. The alluvial deposits have been confined within the already existing form of two valleys (Fig.6.20). Although these landforms do not really meet the definition of alluvial fan, they are named as such in view of similarities concerning the underlying process as well as the composition.

In the surrounding area, mainly outcrops of a very weakly cemented conglomerate have been found. Gravel and boulders up to 20cm in diameter are bedded in a loose, somewhat clayish matrix, without showing any organization, typical for a mudflow deposit. The components are derived from the bedrock of the hinterland: calcareous sandstones and calcareous siltstones of the Senosri Formation. These deposits do not resemble the conglomerates of the Río Banano Formation or the Suretka Formation. There exists a similarity with the deposits of the extensive alluvial fan of the Río Suruy. Nevertheless, the typical fan form is totally missing. Therefore, this hypothetical fan is probably of a very old age and intersected by many streams. The main river (Río Goban) succeeded to carry off most of the sedimentload, whereas the smaller streams experienced a period of deposition and filled their own stream beds. The fan may correspond in age with the Río Suruy fan.

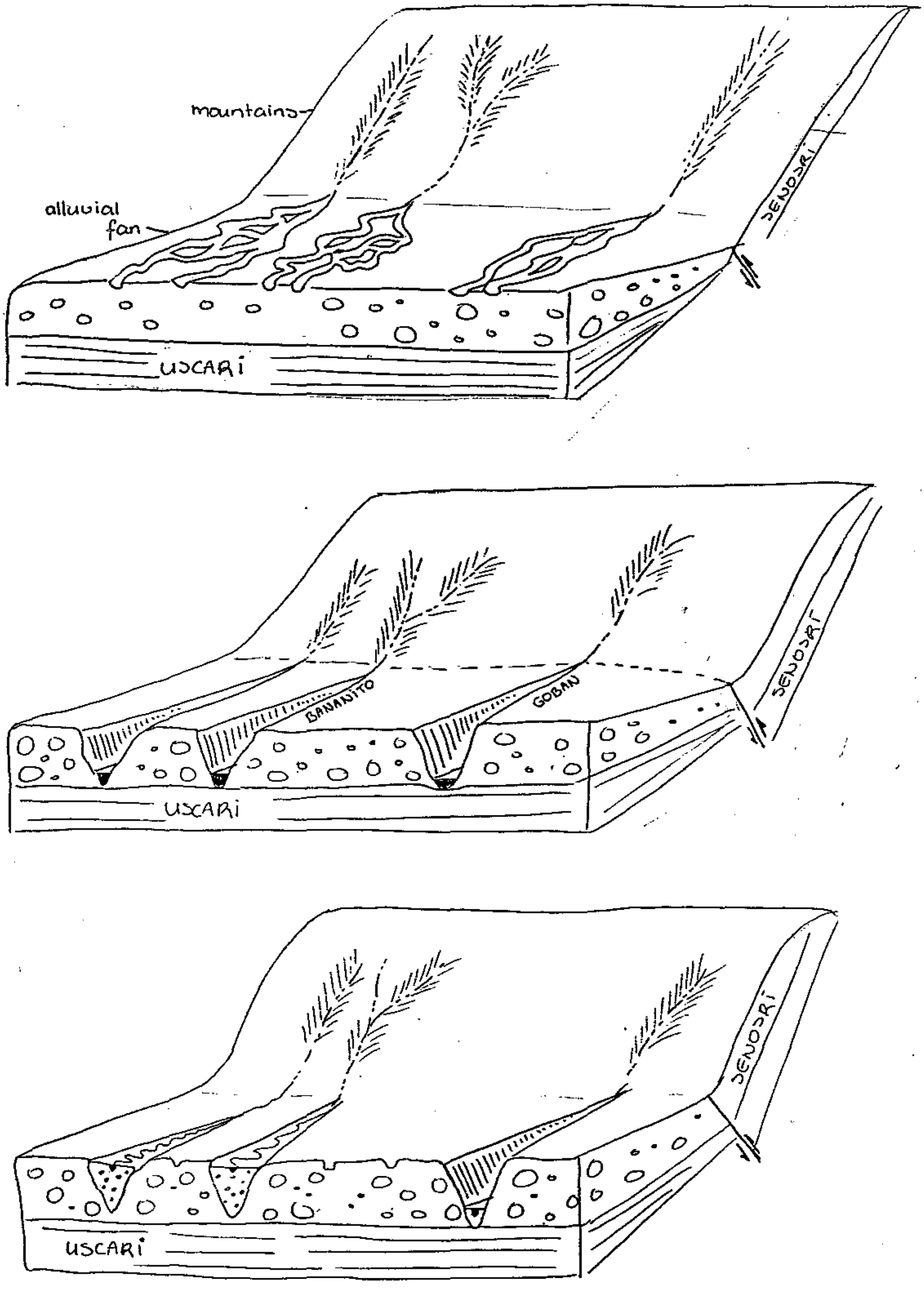


Figure 6.20: hypothetical genesis

2.6 Terraces

Along the main rivers intersecting the hilly to mountainous area terraces can be found. Terraces up to 10 meters above the present riverbed are considered Holocene terraces. The higher terraces are probably of older age.

Pleistocene terraces

Along the Río Banano, the Río Niney and the Río Estrella, terrace remnants can be found at different levels above the present riverbed (20m-40m, 60m-80m, and 100m terraces) (Fig.6.21).

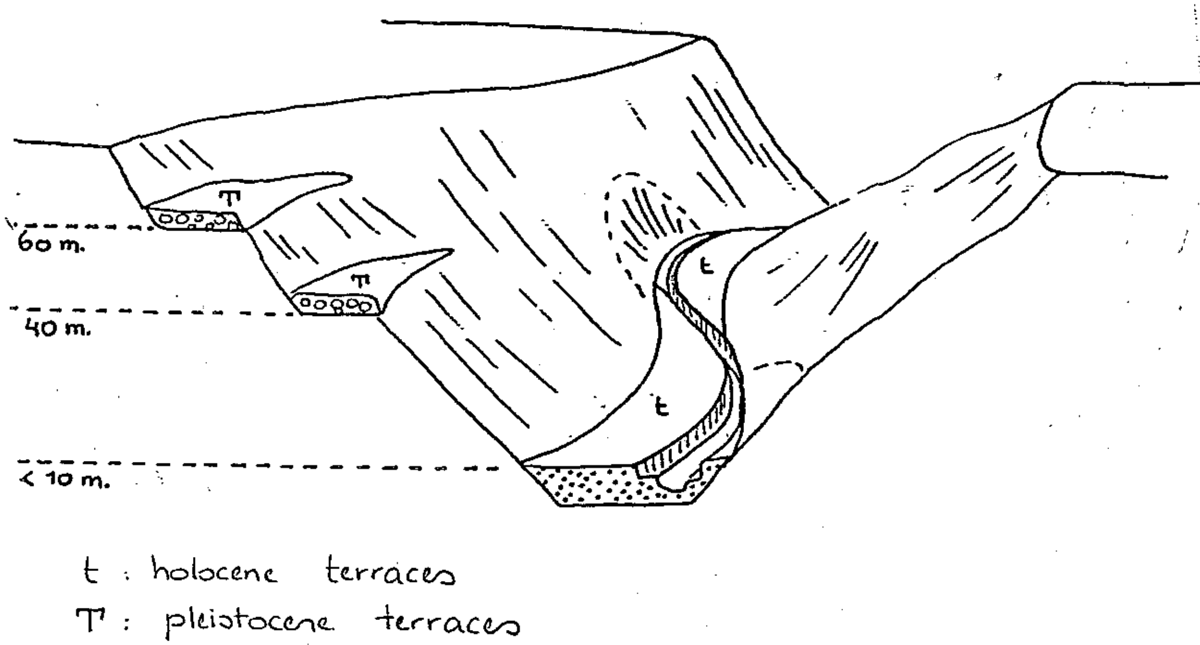


Figure 6.21: Holocene terraces and rests of pleistocene terraces along the Río Banano

Most of the terraces were identified only on the aerial photos; only a few have been visited during the fieldwork to examine their sediment cover. The older terraces consist of rounded pebbles and boulders varying in size from a few centimeters up to 1.5 meters in diameter. Most of these deposits are derivates of Pliocene rocks (Suretka Formation). So, incision and formation of terraces must have happened afterwards, probably during the Pleistocene. In comparison to the sediments of many of the Holocene terraces (sand, silt and clay), these older terraces are covered with coarse material. Climatic conditions during the Pleistocene where quite different. The glacial periods may have influenced this area as well . The formation of these terraces may coincide with the alternation of glacials and interglacials. During the glacial (relatively dry periods), rivers carried large masses of coarse sediments. They filled up their riverbeds (accumulation) whereas during the interglacials (relatively warm periods) these riverbeds where dissected to form terraces. When several glacial and interglacial succeeded each other, a series of terraces of decreasing height developed. However, earthquake triggered landslides may also have provided sediments. It is not possible to correlate the different terraces. A 60m-terraces in sandstones may be not of the same age as a 60m-terrace dissected in soft siltstones. The rate of incision may vary with the resistance of the bedrock.

The extent of the incision (at some places more than 100 meters) is an indication of epirogenetic uplift. So next to changing climatic conditions, also tectonical movements control the process of terrace formation.

Holocene terraces

The Holocene terraces within the hilly area, are built up of mainly fine sediments (sand, silt and clay) indicating a different climatic condition than during the Pleistocene. A warmer and more humid climate promotes deep chemical weathering and a closed vegetation cover prevents superficial erosion. Terraces can be found especially at places where a river encounters soft rocks. At these places the river can widen its valley and deposit its sediments, while in a period in which erosion dominates, terraces are formed. Repetition of this process results in a series of terraces situated above each other. Probably, changes of the climatic conditions (though less pronounced as during the late Pleistocene) underlie these alternation of sedimentation and erosion. When the river meets resistant rocks gorges develop.
It was not possible to examine these terraces in detail. An attempt to correlate the terraces was hampered by a lack of data concerning sedimentological features and the exact heights of the terraces.

7 SOILS

7.1 Processes

According to the stage of soil development, the area can be subdivided as follows (Table 1):

A: recent soils in the coastal plain,

B: recent, but more developed soils in fluvial deposits,

C: the most developed soils in the area of residual rock.

Table 1: soil types on great group level according to physiographic position and stage of soil development.

SOILTYPE	STAGE	POSITION
Tropopsamment	A	beachridge
Tropofibrist	A	coastal peat swamp
Hydraquent	A	coastal swamp
Fluvaquent	A	fluvial basin
Tropaquept	A	fluvial basin
Eutropept	B, C	terraces, alluvial fans, slopes, fluvial basin, tops
Dystropept	B, C	terraces, alluvial fans, tops
Humitropept	C	slopes
Tropodult	C	tops,alluvial fans

7.2 Soil development related to position and materials

A: Recent soils in the coastal plain

Soil formation in the coastal plain is mainly in a initial phase. Due to the young age, soil formation on the beach ridges is limited. Wind erosion might also hamper weathering only on the very youngest ridges, since inmediately behind the beach vegetation prevents erosion. These soils are classified as Tropopsaments.
In the coastal swamps behind the beach ridges soils are saturated with water during most or all of the year, which reduces soil formation strongly. Soil formation is restricted to ripening of

loose, water saturated materials. In the parts where sedimentation by the rivers is almost neglectable, organic material accumulates. Soils here are classified as Tropofibrists. In the parts where fluvial deposition is dominant (LPa), the mainly unripened sediments are classified as Hydraquents. Both soil types have an extremely loose consistence.
Where drainage is slightly better, profiles are more developed. These parts consist of clayey sediments and soils are classified as Fluvaquents. The water table is low during during some time of the year. An A-horizon which shows structure has been formed; a B horizon did not yet develop.

B: More developed soils in fluvial deposits

These soils are situated in a more stable position in the landscape, where actually no sedimentation takes place. The watertable is below the surface for longer periods. Soil structure has been formed. On the oldest Pleistocene terraces clay eluviation toke place. Next to an A- horizon, also a brown sub-horizon developed in which a structure has formed (cambic-B horizon). Therefore, these soils are classified as Inceptisols. The least developed Inceptisols can be found in the coastal plain and are classified as Tropaquepts. In comparison to the Fluvaquents they still have drainage problems but in the upper 50 cm they have a stronger soil structure and a brown B-horizon.
In better drained situations, these young soils are classified as Eutropepts or Dystropepts because of their better drainage and complete ripening throughout the profile. The Eutropepts are rich in bases, have a pH value between 5 and 6 and show high biological activity. They have a well developed soil structured. These soils are very young and have been formed in materials with a high content of easily weatherable minerals, often calcareous, in general sandy or loamy deposits.

With time, these soils loose their high base content by leaching, and the pH value drops to values between 4 and 5. The biological activity decreases and there is a loss of soil structure, which becomes weak. Then, these soils can be classified as Dystropepts. They have developed in older sediments or in young sediments with a low content of weatherable minerals, in general clayey deposits. These materials were already weathered to a high degree when they were deposited. In that case leaching resulted quickly in the loss of bases and a drop in pH, because the low content of weatherable minerals could not buffer this process sufficiently. Therefore, Eutropepts and Dystropepts are found in the same units as a complex on short distance. Eutropepts in the sandy deposits and Dystropepts in the clayey deposits.

The difference in development between Eutropepts and Dystropepts is very well reflected in the differences between the lower and higher young terraces. On the lower terraces, both Eutropepts and Dystropepts can be found. On the higher terraces, only Dystropepts can be found, because of their higher age. Both soil types are also found in the fluvial fans, where the often show

some andic properties, due to the fact that the materials are partly of volcanic origin.
After the stage of the Dystropept, prolonged clay illuviation may lead to the formation of an argillic B horizon so that a Dystropept may become a Tropudult. The pH may drop to values between 3 and 4, and structure is moderate. The oldest terraces have these acid clay soils. On the well drained sites, their color is reddish (hues of 5YR), on the less well drained sites their color is yellowish (hues of 10YR). On subgroup level this is reflected in being a typic Tropudult for the reddish soils and being an epiaquic Tropudult for the yellowish soils.

C: Most developed soils in the area of residual rock

Two processes determine the stage of development of soils formed on weathered rock: the weathering rate of the parent material and the rate of removal of soil material by erosion. Only when the rate of removal is slow in comparison to rate of weathering, a well developed soil can be formed. When rate of removal is fast in comparison to rate of weathering, only a poorly developed soiltype can be found. The balance between rate of weathering and rate of removal is related to both geomorphological processes and parent material. Therefore, this balance depends on the position in the landscape. Two types of balance can be distinguished. When slopes on which profiles are situated not exeed about 20%, rate of weathering exceeds rate of removal. Second, when slopes are steeper than 20 %, rate of removal processes exceeds weathering rate.
In valley bottoms a third situation exists: rate of deposition of colluvium is so fast that no well developed soil are found.

1: soil formation where weathering exceeds removal

This situation occurs where slope transport is slow, in general on tops of hills, with slopes ranging from 0 to 20%. Independent of the rock type in which the soils are formed, a very deep red clay soil is found. Because of the heavy rainfall and free drainage on these sites, the profiles on calcareous rocks show complete loss of $CaCO_3$ down to deep into the rotten rock, which may be 5 meters or more. Therefore, leaching must be strong. Although weathering processes are expected to proceed quickly as well, all weathering products are removed by leaching so the pH shows values between 3 and 5. Under these conditions of low pH and a net downward flow of water, clay illuviation takes place and an argillic B horizon is formed. The identification of the argillic horizon in the field is very difficult because the whole profile consists of clay, which is expected to be kaolinitic. The properties are not clear, but because of the occurrence of red colors, low pH, moderate, blocky structures and clear, continuous cutans of clay on ped surfaces all over the B horizon, we should consider this horizon as an argillic B horizon, or at least the upper parts of it. Beneath 50-100 cm its structure is weak and also cutans are discontinuous. That part probably does not meet the requirements for an argillic horizon.

Soils have mainly reddish colors. In some cases, slightly grayish mottling in the lower parts of the B horizon or transition to the C horizon can be noticed, indicating internal drainage problems, or weathering features. Yet, the main color is red throughout the profile, up to deep into the C horizon.
All these soils can be classified as typic Tropudults. Where the parent material consists of rotten rock derived from the Suretka Formation, the A horizon is thicker and darker than in soils other rock types, indicating that more organic matter is accumulated. Due to the mainly volcanic origin of the Suretka materials they may still contain some amorphous clay minerals, which may complex organic material and cause the darker colors.

2: soil formation where removal exceeds weathering

This situation occurs where slopes exceed 20% and also on level summits. In this situation no well developed soils can be found. In these regions, the development never passes the stage of the Inceptisol.
On tops of hills formed in shales and sandstones of the Uscari formation, removal is obviously very rapid because no argillic horizon has been formed and soil material can be calcareous below 50 cm, which indicates that weathering and leaching are very low. In these units the total soil is not deep, generally there is a lithic contact within one meter below the soil surface. Base saturation is high so these soils are classified as Eutropepts. In unit Csa soils are a bit further developed. Deeper soils and slight red colors (7.5YR) indicate a different balance between removal and weathering, due to the difference in parent material. Here, soils were classified as Dystropepts. In unit Csa more sandstones are found, where unit CSl consists of shales.
On slopes of all mountains and hills, there is besides removal also a large throughflow of water containing leached bases from higher positions (the area of the Tropudults and Tropohumults). In those soils leaching is of no importance and pH values seldom are less than 5. Generally, pH values in these soils vary between 5 and 6, they have a cambic horizon and they are thin to moderately deep. They can be classified as typic and lithic Eutropepts. Their colors may be red, but this depends on the rock type, not on the stage of development. The rocks of the Rio Banano formation sometimes show very red colors in the rotten rock. Hence Eutropepts in units CPm and CSm can have very red colors. In the units CPc and MPc again dark topsoils are found so besides Eutropepts also lithic and typic Humitropepts occur, but it is not clear to which extent.
When the rocks consist of pure limestone of the Senosri Formation (unit MPa), montmorillonitic clay has formed. In the field this was indicated by high plasticity and stickiness. This only occurs where the rock consists of pure limestone. On calcaric sandstones no montmorillonitic clay was found. All soils found in this unit were classified as lithic Eutropepts.

On coral debris of the Rio Banano formation (unit CKc), circumstances are comparable, but because of the different landform deeper soils have been formed. Here, deep clay soils are found which were classified as Eutropepts.