ATLANTIC ZONE PROGRAMME

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CARIBBEAN COAST DEVELOPMENT OF COSTA RICA AFTER THE EEMIAN PERIOD

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CENTRO AGRONOMICO TROPICAL DE INVESTIGACION Y ENSEÑANZA - CATIE

AGRICULTURAL UNIVERSITY WAGENINGEN - AUW

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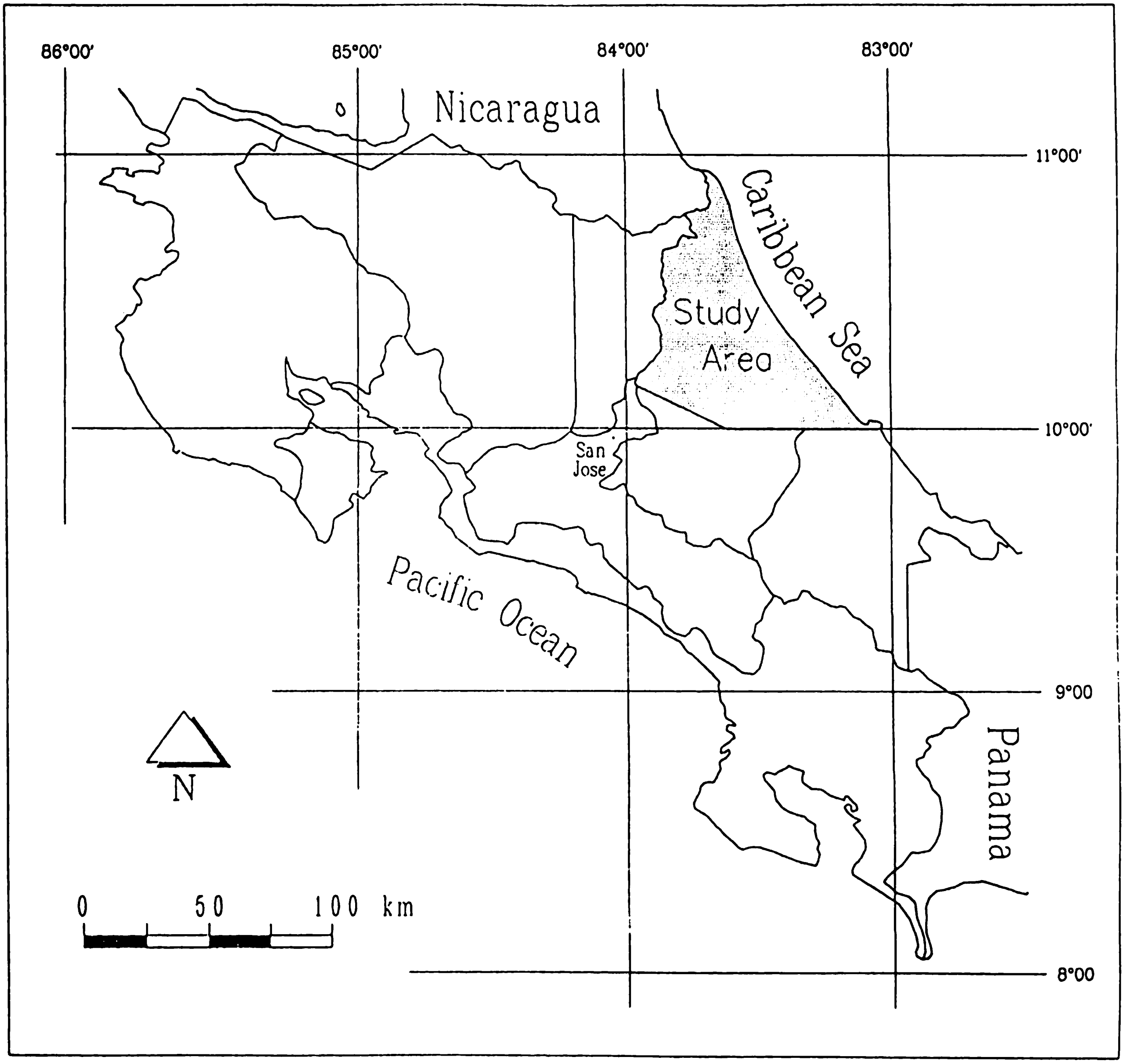

86°00'
85°00'
84°00'
83°00'
Nicaragua
11°00'
Caribbean Sea
Study Area
10°00'
San Jose
Pacific Ocean
9°00'
Panama
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PREFACE

General description of the research programme on sustainable Landuse.

The research programme is based on the document "elaboration of the VF research programme in Costa Rica" prepared by the Working Group Costa Rica (WCR) in 1990. The document can be summarized as follows:
To develop a methodology to analyze ecologicaly sustainable and economically feasible land use, three hierarchical levels of analysis can be distinguished.
1. The Land Use System (LUS) analyses the relations between soil type and crops as well as technology and yield.
2. The Farm System (FS) analyses the decisions made at the farm household regarding the generation of income and on farm activities.
3. The Regional System (RS) analyses the agroecological and socio-economic boundary conditions and the incentives presented by development oriented activities.

Ecological aspects of the analysis comprise comparison of the effects of different crops and production techniques on the soil as ecological resource. For this comparision the chemical and physical qualities of the soil are examined as well as the polution by agrochemicals. Evaluation of the groundwater condition is included in the ecological approach. Criterions for sustainability have a relative character. The question of what is in time a more sustainable land use will be answered on the three different levels for three major soil groups and nine important land use types.

Combinations of crops and soils

	Maiz	Yuca	Platano	Piña	Palmito	Pasto	Forestal I II III
Soil I	x	x	x		x	x	x
Soil II						x	x
Soil III	x			x	x	x	x

As landuse is realized in the socio-economic context of the farm or region, feasibility criterions at corresponding levels are to be taken in consideration. MGP models on farm scale and regional scale are developed to evaluate the different ecological criterions in economical terms or visa-versa.

Different scenarios will be tested in close cooperation with the counter parts.

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.

PREFACE

The MSc research project in geology and hydrogeology, which I performed in Costa Rica, was my last instruction to finish my study on the Agricultural University in Wageningen. My decision to go to Costa Rica was for the first instance that a research combination of a geological- and hydrogeological component was possible. The second reason was that it would be the first time that I went to a humid tropical country. The research combination failed due to broken down of the geo-electrical equipment.

During the period from January till July 1993 in Costa Rica, many people helped me during the fieldwork and the writing of my report. First of all I would thanks my supervisors Prof. dr Salle Kroonenberg and Ir Andre Nieuwenhuyse for their geological indications and recommendations in Wageningen after the period. Salle provided my stage in Costa Rica and Andre helped me during the fieldwork.

I would thanks Marieke and Sam who helped me with my fieldwork. During the breaks we went to Doña Mayra for coffee or for a 'fresco' to a 'Soda'. With John, and with him the pub 'Bar Monte Carlo', I lived together for about three months. Remco, where I had a visa trip with to Panama and Anna who cut my hair a few times. With Gytha I will never forget the special moments in Cahuita. Finally I would thanks my fellow students who drunk a Pilzen or Imperial with me in the 'Tucan Bar' and 'Bar Charlies' and made the period in Costa Rica to a pleasant one.

Ted de Jong
Renkum, August 1993

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ABSTRACT

In this report a reproduction of the Caribbean coastal development, in Costa Rica, after the Eemian glacial is given. This study was carried out to get more insight in the morphological coast changes caused by sea level changes.

In a coastal peat area, near Cerro Coronel, a transect is made. Peat samples are taken just above a transition clay/peat which reduced the influence of peat compaction. The samples are dated by ^{14}C method to estimate sea level rise during the last 6000 years.
Deposit information in the "Lomas de Sierpe" area, with a depth of about 30 to 60 m, is used to understand the vertical and lateral succession. Samples are taken to determine age and probable marine influence.

Present Pleistocene alluvial plain remnants, probably of Eemian age, are a result of erosion during stadials and glacial. The infill between these remnants results of a transgressive sea. Depending on age of the Pleistocene remnants different periods of indentation could be recognized. Calculated with depth and age of different deposits and different assumed rates of subsidence an approximation is made if subsidence or uplift occurred. After the Eemian a eastward shifting shoreline existed, alternated by tidal lagoons due to a transgressive sea.
The dated peat samples suggest a prograding shoreline after 6 ka B.P. during the Holocene. This indicate a turn over point of a transgressive to a regressive sea.

1 INTRODUCTION

The present study was carried out to obtain a deeper insight in the morphological changes, caused by sea level changes during the last 10000 years in the northern Atlantic Zone of Costa Rica. A transect in a Holocene peat area, deposited against Pleistocene hills, was studied in an effort to determine rate of sea level rise during the late Holocene.

In chapter 2 the geological setting of Central America and Costa Rica are described. The materials and methods of the research are discussed in chapter 3. In chapter 4 the results are given. Finally in chapter 5 the development of the Caribbean coastal area of Costa Rica is discussed.

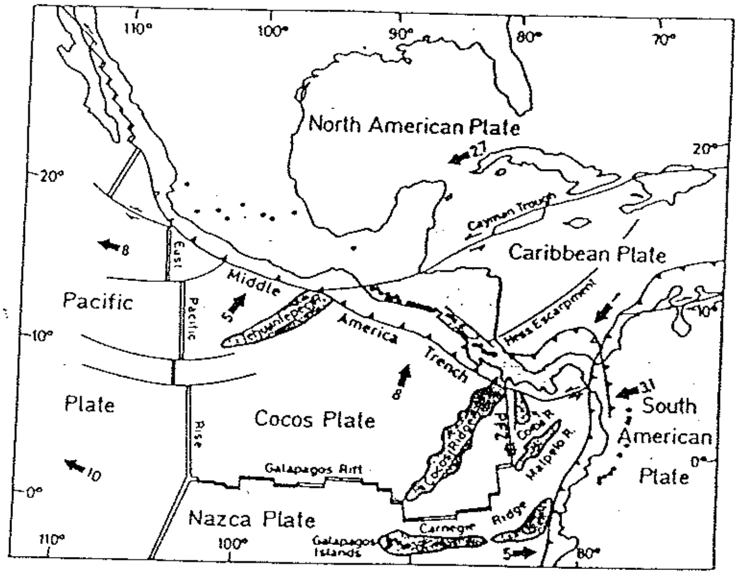


Figure 1 : Tectonic setting of Central America. Black arrows indicate drift directions; numbers represent absolute movement in cm • yr^{-1}, black dots are active volcanoes (Seyfried et al, 1991).

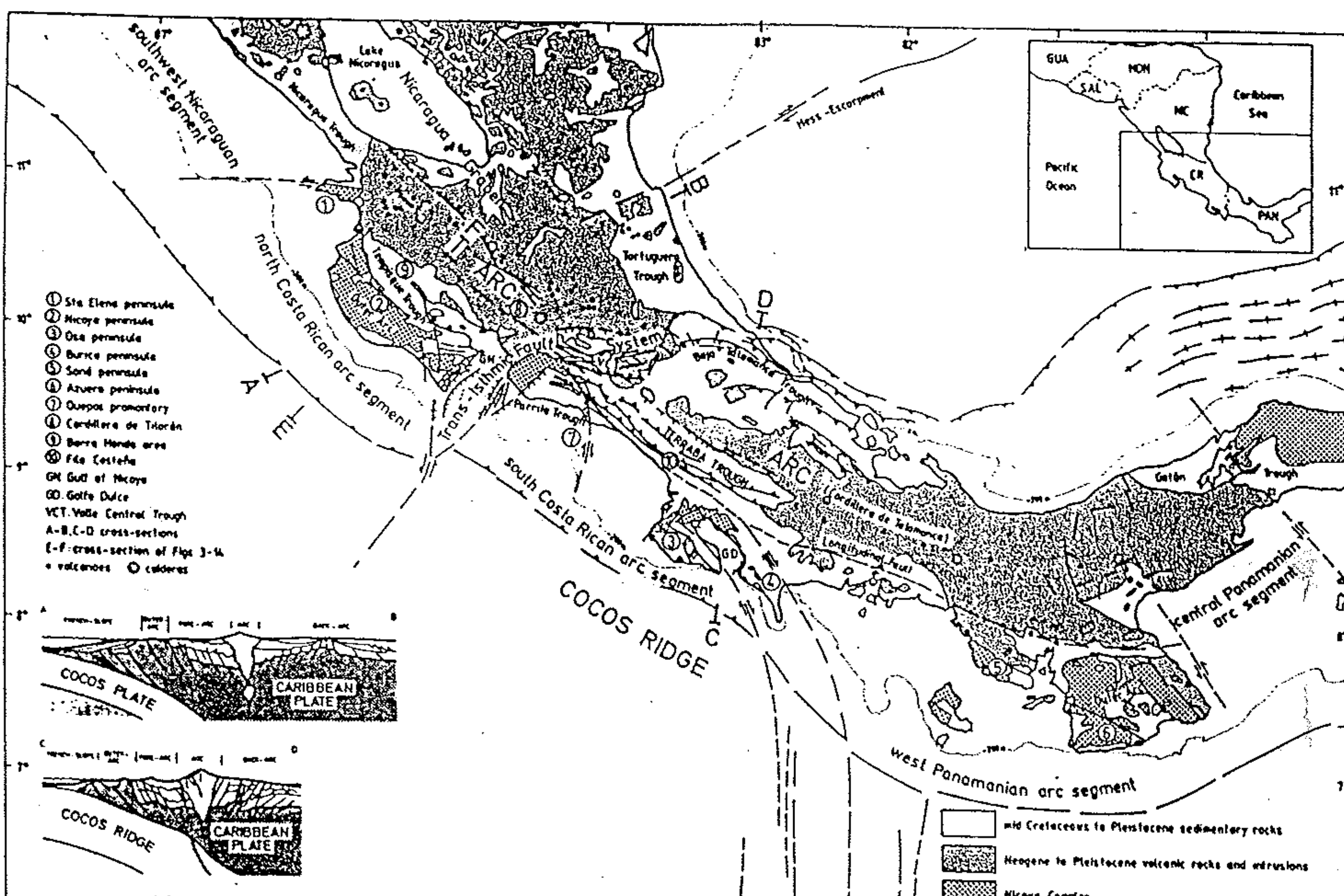


Figure 2 : Structural map of southern Central America, showing major tectonic elements; main tectonostratigraphic units and sedimentary basins (Seyfried et al, 1991).

2 GEOLOGICAL SETTING

Geological setting of Central America

Central America is situated at the western margin of the Caribbean plate near the triple junction of the Cocos, Nazca and Caribbean plates (fig.1). Along the Middle American Trench, the Cocos plate is currently being subducted beneath the North American and Caribbean plates. The southern part of the Central American isthmus is the product of island-arc volcanism (Seyfried et al, 1991). An island-arc is a chain of stratovolcanoes formed by the melting of the crust material of the subducted plate beneath the overriding plate.
Southern Central America, which consists of Costa Rica and Panama, is fundamentally different in its geological development than northern Central America (Weyl, 1980). The oldest deposits are of Cretaceous age and consist of oceanic sediments and volcanic rocks. This basement is overlain in different troughs by deposits of chiefly marine Tertiair sediments. These sediments are only slightly deformed but are permeated by large quantities of volcanic and plutonic rocks which exhibit signs of a gradual transition from a basic oceanic volcanism to an intermediate to saliac island-arc magmatism. Violent uplifting during the late Tertiary and Quaternary caused the isthmus to rise up to form the present mountainous countries with their active volcanism (fig.2), and the arcuate course was determined by various plate movements and transform faults.

Geomorphological units of Costa Rica

Costa Rica can be divided into three main morphological regions (Weyl, 1980):
- a central mountain range;
- a Pacific coastal region;
- a northeastern Atlantic-Caribbean Lowland (Cuenca de Limon);

The central mountain range, striking from northwest to southeast, consist of the Cordillera de Guanacaste, the Cordillera de Tilarán, the Cordillera Central, the Valle Central, the Cordillera de Talamanca, the Valle del General and the Fila Costena (fig.3). The northwestern part is composed of Quaternary volcanic or of Tertiairy magmatic rocks while the southeastern part compromising the Cordillera the Talamanca and the Fila Costena consist of volcanic, plutonic sedimentary rocks of Tertiairy age.

The Pacific coast of Costa Rica is extremely broken by peninsulas, bays and islands. This fore-arc area is formed by the uplift in the Late Mesozoic of the Caribbean plate, through the subducted Cocos plate, at altitudes up to 1000 m. The uplifted plate is broken up in smaller parts like the Nicoya- and the Osa peninsula (fig.3).

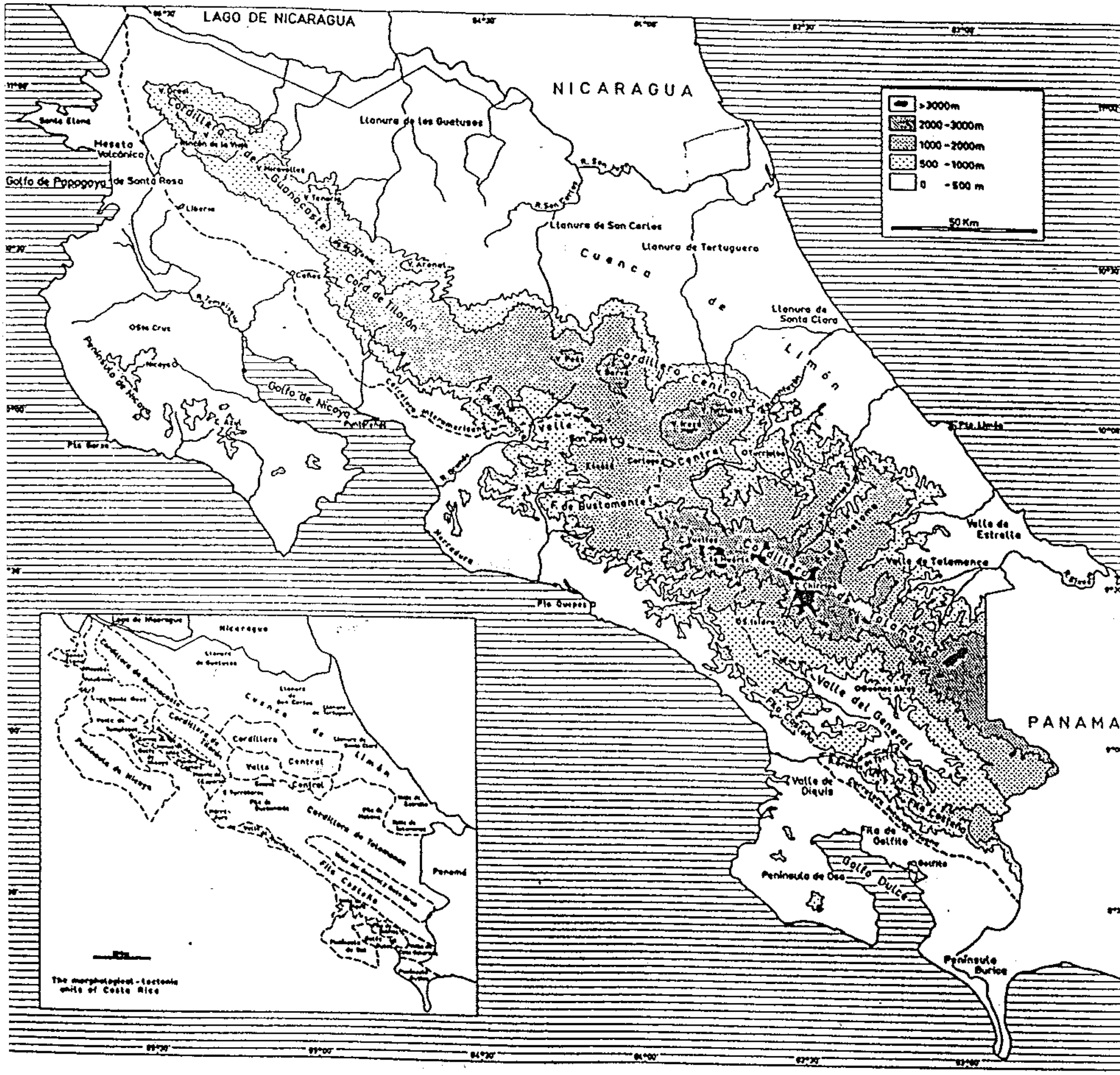


Figure 3 : Morphological map of Costa Rica (Weyl, 1980).

The Atlantic-Caribbean Lowland or the Limon Basin is situated in the back-arc area. A back-arc basin is formed by crustal thinning behind the island-arc, initiated by tensional stress in the overriding plate due to a faster rate of sinking of the subducting plate than the forward motion of the overriding plate. Since the early Tertiairy uplifting of the island-arc has caused the formation of this sedimentation basin. It is filled up with fluvio-volcanic sediments. Small basaltic volcanism occurred due to crust tensions. Cerro del Tortuguero, Cerro Coronel and Lomas De Sierpe are examples of this feature, with an age of 1.2 million years and a heigth of about maximally 300 m above present sea level.

The continuous subsidence of the basin and a rather stable sea level results in older deposits covered by younger ones. At some places the thickness of the Tertiairy and Quaternary sediments is more than 10000 m and the thickness of the Quaternary deposits only are 500 m in the eastern part of the basin. This indicate an average subsidence rate of 0.25 $mm \bullet yr^{-1}$ during this periods. Three main superficial Holocene geomorphological units are distinguished (Nieuwenhuyse, pers. com., 1993):

- Alluvial fans

The alluvial fans cover an area of about 420 km^2. The largest alluvial fan, with an area of 300km^2, is formed by the river Toro Amarillo and the river Sucio fan. Fans are situated in the footslope of the Cordilleras. The upper part of the Toro Amarillo/Sucio fan is dissected as a result of the uplifting of the Cordillera Central and therefore inactive. Also the east side of the river Toro Amarillo fan has become inactive, due to a lava flow from the Turrialba volcano which changed the stream direction of the river Toro Amarillo (Seeters, 1992).

- Alluvial plains

More seaward, the alluvial fans grade into alluvial plains which occupy a total area of about 2400 km^2. The plains can be divided into active and inactive. The latter are never flooded. In this part of the plains river terraces can be found. In the active plains a levee-backswamp landscape occur with on many places remnants of dissected Pleistocene terraces (red hills). Between the red hills infilling with Holocene sediments took place after the last glacial period. These sediments consist mainly of fine textured sediments. Sand deposits are also found in the form of sand sheets.

- Coastal plain

Wave action at the coast has thrown up sandy sediments to form beach ridges, with a total area of 690 km^2. With a transgres-sive sea in the Holocene, the succession of the beach ridges during the late Holocene was in upward and seaward direction as a result of a higher sedimentation rate than the rate of sea level rise. Wetlands have formed behind them as a result of the very low gradient of the distal part of the watersheds. In many of these marshes (topogenous) peat growth occurs as a result of persistent waterlogging and the low sediment supply (Driessen, 1989).

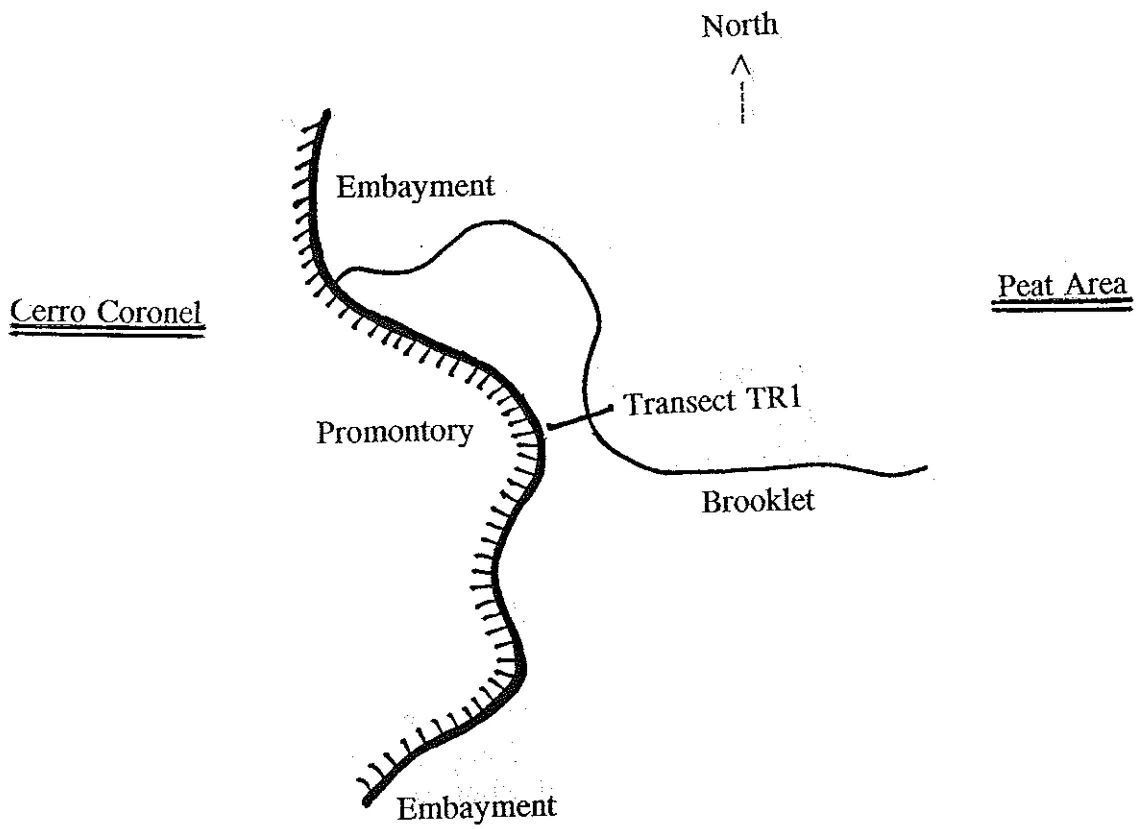


Figure 4 : Site location of transect TR1

3 MATERIALS AND METHODS

In order to study sea level rise, an area was selected in the Northeastern part of the Atlantic Zone of Costa Rica near the rivers San Juan and Colorado and east of the basaltic hills Cerro Coronel, with latitude 10°42' and longitude 83°38'.
This area was chosen because of the presence of ombrogenous peat, which grows against the hills. These hills are covered with a weathered clay layer which makes the transition peat-hill relative easy to recognize. The contact level has a downward gradient perpendicular on the hill.

The exact place of the research area in the peat area was chosen using 1:80000 airphotos. Special attention was paid to the shape of the hill relative to the peat. A site in front of a promontory and between brooklets which drain embayments was chosen, because of the supposed lower influence of the sedimentation by these brooklets (fig.4).

A transect (TR1) was made to find the depth of the contact level and first trial borings were carried out with an open gouge and a piston auger. The sediment characteristics with their thickness and depth and the distance between the sample points were noted. With the knowledge of the depth of the peat just above the contact level the peat samples were taken with a Dachnovsky sampler. Roots and wood were removed in the field as much as possible and only leaves, twigs and branches were analyzed. Sampling was carried out in a line perpendicular on the hillslope, with increasing sampling depth of about one meter.

About 25 km south-southeast of Cerro Coronel the basaltic hills Lomas de Sierpe occur (fig.5). West of these hills near Milloncito the banana plantation Lomas de Sierpe is located with latitude 10°25' and longitude 83°36' (map of figure 8).
In the spring of 1993 deep bore holes for water supply were made. The machine-made drillings were done by a punch and pulse system. This results in a mixing of deposits during punching and consequently missing of some information. During drilling the employee laid different deposits aside, while a geologist made notition of that later. The drillings were carried out on top of the Pleistocene terrace remnants and between these terrace remnants, with depths between 30 to 60 m. The depositional information so obtained is not very detailed but is used here to get more insight in the succession and lateral distribution of sediments.

The author was present at the drilling of one deep bore hole. Two mud samples with shell remnants were taken at a depth of about 24 m (LS1) and 26 m (LS2) because of suspected marine influence. This is about 5 and 7 m below present sea level. Both samples were analyzed on texture and only sample LS1 was dated by ^{14}C on age.

From transect TR2, east of Cerro Coronel in the coastal region, three peat samples, COR1, COR2 and COR3 were taken with a Dachnovsky sampler at the transition peat-sea sand (fig.5). An other 2.5 km transect (TR3) is situated south of Tortuguero village perpendicular to the coast, where peat sample COR4 is taken (Nieuwenhuyse and Kroonenberg, 1993). The age of the samples are established by ^{14}C dating (Heijnis, 1991).

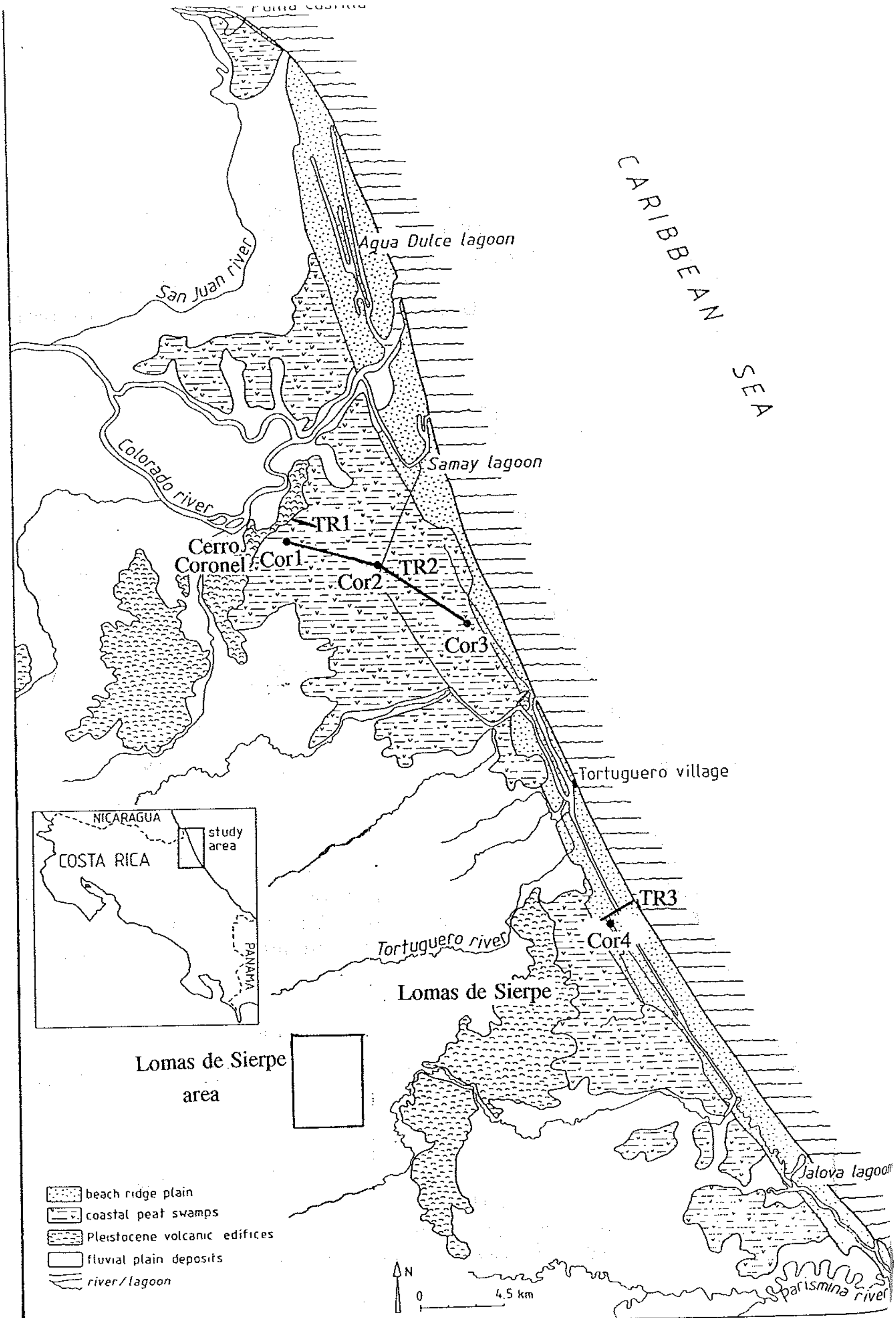
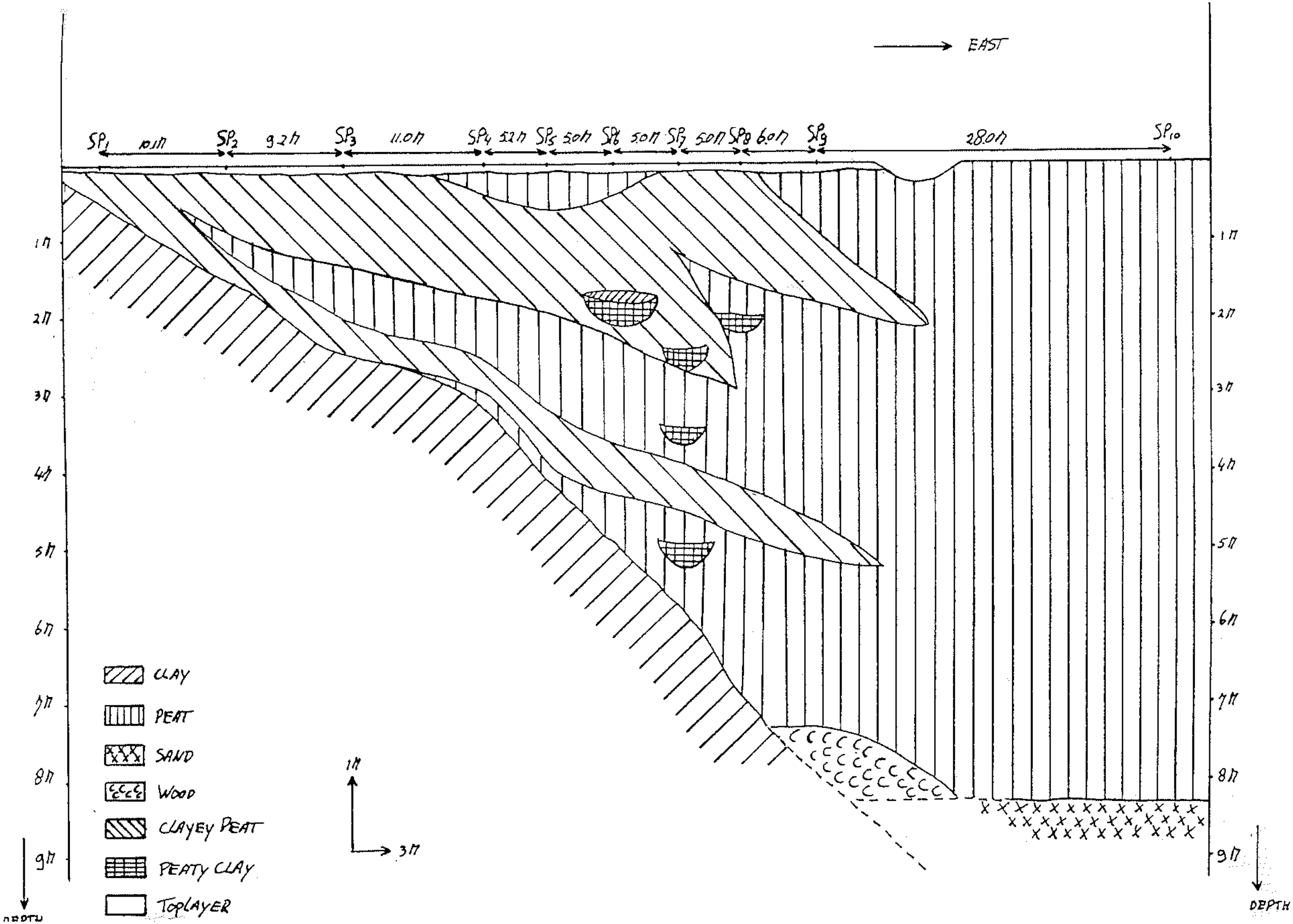


Figure 5 : Part of Caribbean coast of Costa Rica with location of points 1, 2, 3 and 4; as well as three transects.

Figure 6 : Transsection at the footslope of Cerro Coronel.



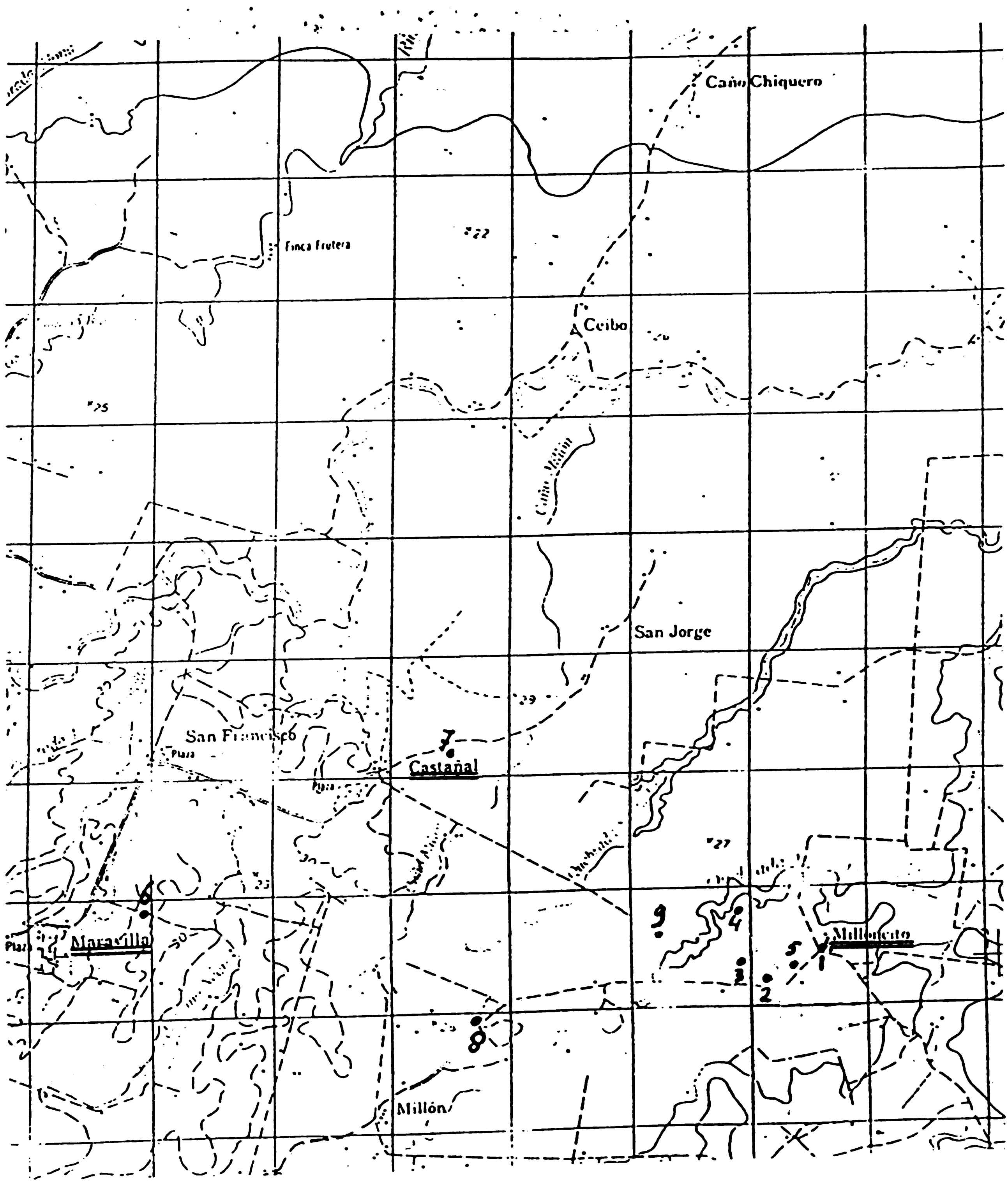
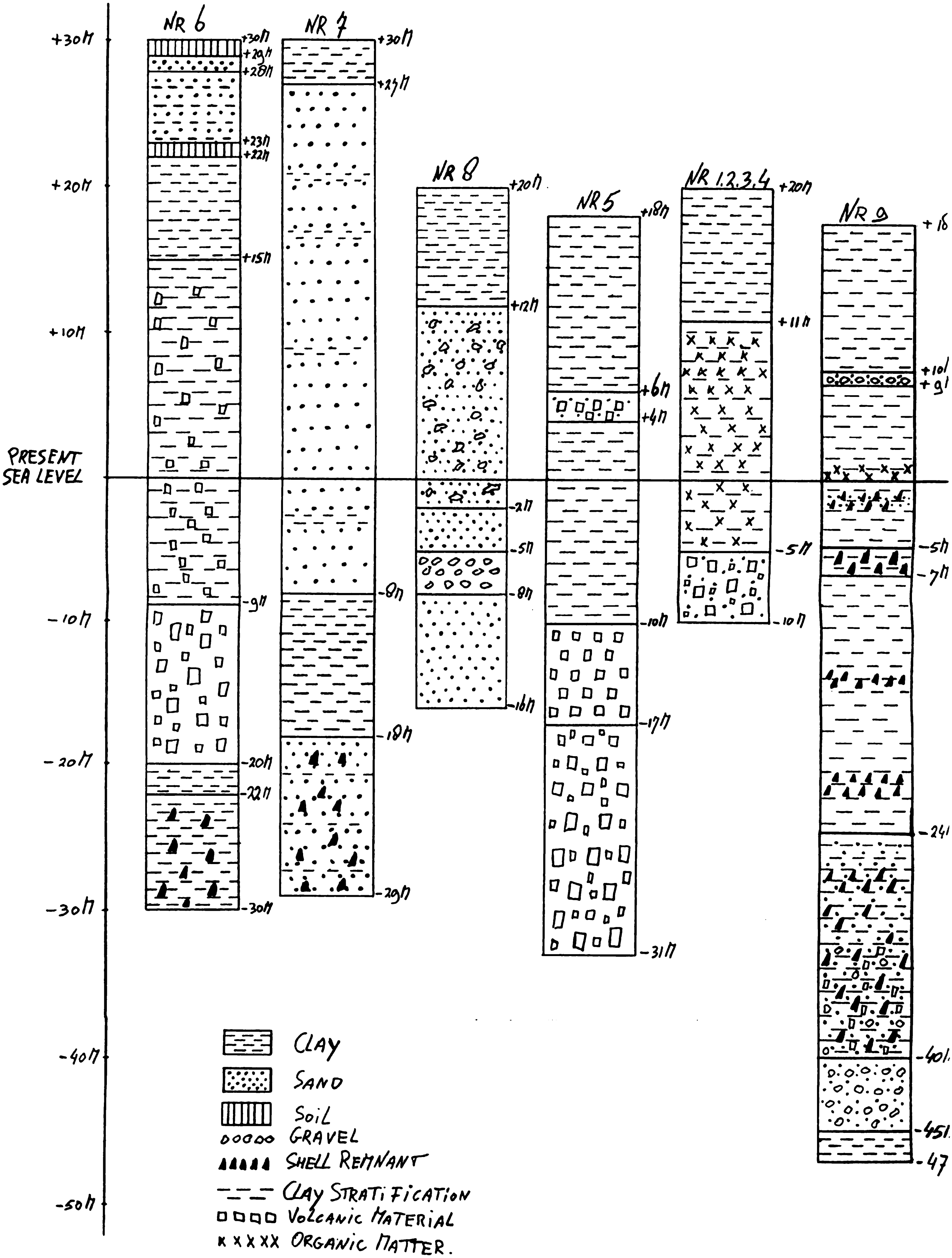


Figure 8 : Depositional succession of profile numbers according the enclosed map (1:50000) of the area near Lomas de Sierpe.



NR 6
NR 7
NR 8
NR 5
NR 1.2.3.4
NR 9
+30M
+20M
+10M
PRESENT SEA LEVEL
-10M
-20M
-30M
-40M
-50M
CLAY
SAND
SOIL
GRAVEL
SHELL REMNANT
CLAY STRATIFICATION
VOLCANIC MATERIAL
ORGANIC MATTER.

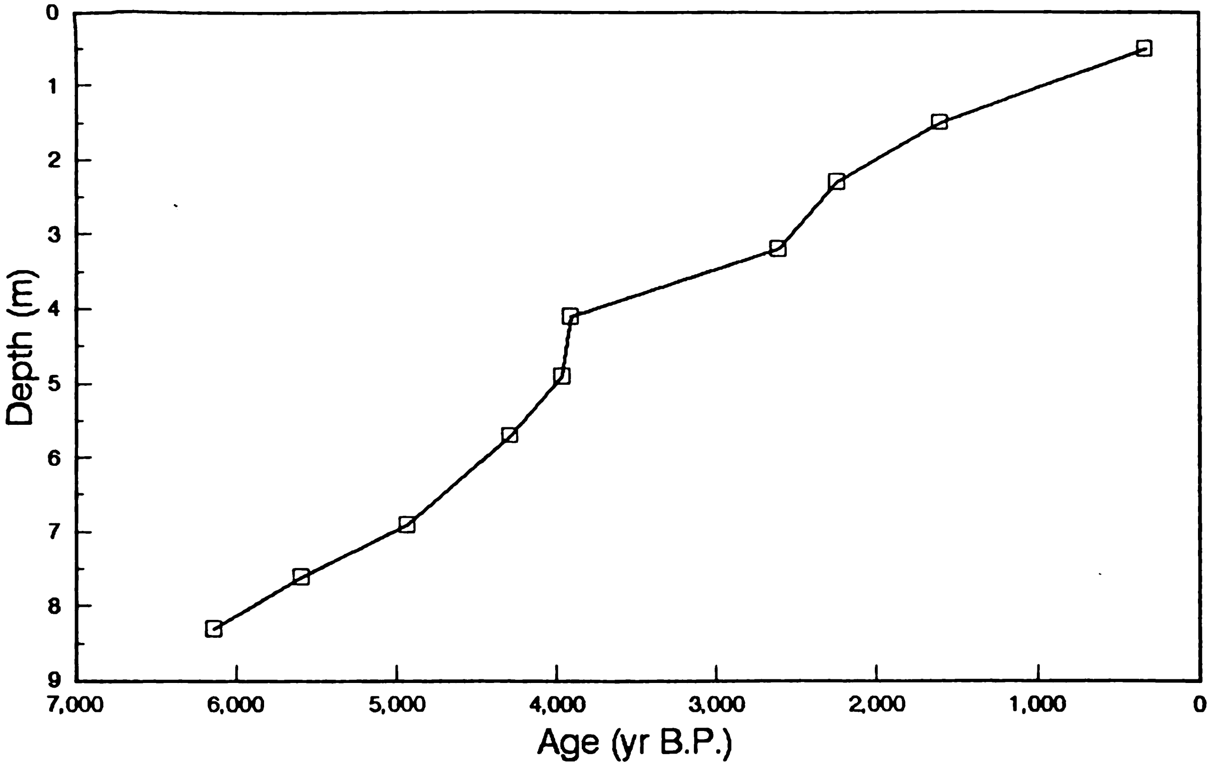


Figure 7 : Curve of TR1 peat sample ages compared with depth.

4 RESULTS

Coronel Transect (TR1)

A brooklet crosses the area at about 70 m from the foot of the hill and drains part of the hill and swamp. Normally the brooklet is 0.2-0.5 m deep and about 2-3 m wide. With heavy rainfall parts of the peat area are inundated, while the stream velocity stay low ($<0.5\ m \bullet sec^{-1}$). Slope erosion occurs, evidenced by washed out tree roots and little alluvial fans at the footslope.

In figure 6 the deposits found in transect TR1 are shown. The contact level between hill and peat was recognizable by the red weathered clay except for sample point SP9 where wood prevented further penetration.
At the first sample point (SP1) the transition of clay/peat was found at a depth of 0.5 m, while at the last sample point (SP10) a transition of fine, well sorted, grey to blackish sand/peat was found at a depth of 8.3 m. Total section length was 84.5 m. No further borings were carried out since setting of the sandy subsoil may obscure the true former sea level and Nieuwenhuyse and Kroonenberg (1993) found that the sand depth remains about the same for more than 500 m, (sample COR1 from transect TR2, fig.5). Several tongue shaped clayey peat depositions in the peat were found with a increasing depth and distance perpendicular to the hill. Peaty clay was also found as lens shaped depositions, interpreted as deposits by small brooklets. Above one lens shaped deposition, reddish clay was found.
The TR1 peat samples results are given in table 1 and figure 7.

Table 1, ages (yr B.P.) and depth (m) of the peat samples of transect TR1.

Sample	Depth(m)	Age(yr B.P.)
C0.5	0.5	330 ± 50
C1.5	1.5	1600 ± 40
C2.3	2.3	2240 ± 40
C3.2	3.2	2610 ± 40
C4.1	4.1	3920 ± 50
C4.9	4.9	3970 ± 40
C5.7	5.7	4300 ± 30
C6.9	6.9	4940 ± 40
C7.6	7.6	5600 ± 40
C8.3	8.3	6140 ± 50

DEPOSITIONAL SUCCESSION

Profile 1, 2, 3, 4:
0 - 9 m : Red colored, deep weathered clay
9 - 25 m : Black colored, organic matter rich clay with sulphurious smell
25 - 30 m : Coarse textured sediments of volcanic origin

Profile 5 :
0 - 12 m : Black colored clay
12 - 14 m : Coarse textured sediments of volcanic origin
14 - 28 m : Black colored muddy to clayey sediment
28 - 35 m : Coarse textured sediments of volcanic origin
35 - 51 m : Coarse textured sediments of volcanic origin with pebbles and boulders

Profile 6 :
0 - 1 m : Soil
1 - 2 m : Fine sandy sediments
2 - 7 m : Clayey sand
7 - 8 m : Soil
8 - 15 m : Clay sediments
15 - 39 m : Clayey sediments with tuff remnants of gravel texture
39 - 50 m : Tuff sediments (> 2 cm)
50 - 52 m : Clay sediments
52 - 60 m : Muddy sediments with shell remnants

Profile 7 :
0 - 3 m : Clayey sediments
3 - 38 m : Grey to blackish colored sandy sediments with stratified layers of clay
38 - 48 m : Clayey sediments
48 - 59 m : Grey to blackish colored sandy sediments with clay and shell remnants

Profile 8 :
0 - 8 m : Clayey sediments with gravel fragments
8 - 22 m : Muddy sediments with grey colored sand and gravel remnants
22 - 25 m : Black colored, fine sand (<2 mm)
25 - 28 m : Muddy sediments with grey colored sand and gravel remnants
28 - 36 m : Black colored, fine homogeneous sand, probably of marine origin

Profile 9 :
0 - 10 m : Black colored clayey sediments
10 - 11 m : Sandy sediments with gravel remnants
11 - 23 m : Black colored clayey sediments with organic matter and shell remnants
23 - 25 m : Black colored clayey sediments with shells
25 - 42 m : Black colored clayey sediments with stratified shell remnants
42 - 58 m : Clayey sand sediments with shell remnants and gravel of volcanic origin
58 - 63 m : Gravel of volcanic origin with sand
63 - 65 m : Black colored clayey sediments

Lomas de Sierpe area

The "Lomas de Sierpe" area exist of the banana plantation Lomas de Sierpe and adjacent areas (fig.5). The samples LS1 and LS2 were taken from a deep bore hole with a depth of 65 m, grey to black clay with shell remnants was found till 58 m, while from 58-63 m grey to blackish sand and gravel occur. At depths of 32-42 m and 50-58 m an accumulation of shells was found (profile 9 of figure 8).
All shell remnants are found in grey to black colored loamy to sandy sediments and above these sediments no Pleistocene red colored clay is found.
Samples LS1 and LS2 were analyzed on texture and the results are given as percentage of dry weight per fraction:

Sample	depth	$<63\mu$	$63\text{-}150\mu$	$151\text{-}595\mu$	$>595\mu$
LS1	±24 m	82	2	13	3
LS2	±26 m	74	2	8	16

The age of sample LS1 was dated at 34 ka ± 1.4-1.7 ka B.P.
The following components were defined:
- about 60% volcanic material, ash and mineral pellets (plagioclase, olivine). Most of the pellets are not or scarcely rounded off. In the coarse fraction of LS2 a stone kernel of hardened ash of a bivalve shell was found.
- about 35% remainder of wood and plant material.
- about 5% shell fragments, mainly in the coarse fraction.
- other additional components were some fish remnants, pyrite (FeS_2) and a few foraminifera (Ammonia parkinsoniana:d'Orbigny).

The succession of the Pleistocene deposits near the banana plantation "Lomas de Sierpe" consists of about a 10 m thick deep weathered, red colored clayey sediment (profile 1, 2, 3 and 4 of figure 8). Underneath this deposit a organic matter rich, grey to blackish clayey sediment occur. The latter sediment smells sulphuric and is about 15 m thick. Finally coarse grained sediments were found of volcanic origin.
Between the terrace remnants younger deposits are found existing of grey to black muddy sediments, which contain sometimes broken and dissolved shell remnants at various depth and/or occasionally gravel, probably of volcanic origin (profile 5 of figure 8).
Near Maravilla and Castanal shell remnants are found in grey to blackish sand at a depth of about 50 to 60 m (profile 6 and 7 of figure 8), while near the banana plantation Mata de Limon at some sites fine well sorted grey to blackish sand is found at a depth of about 20 to 30 m probably of fluvio-marine origin (profile 8 of figure 8). South-southeast of the hills Lomas de Sierpe also shell remnants are found at a depth of 20 m and 42 m.
The results of peat samples of the transects TR2 and TR3 (fig.5) are given in table 2.

Table 2, depth (m), distance (km) to the shoreline and age (yr B.P.) of the peat samples of transect TR2 and TR3.

Sample	Depth(m)	Distance(km)	Age(yr B.P.)
COR1	9.8	11	6285 ± 45
COR2	2.5	5	3460 ± 60
COR3	0.65	1.15	1065 ± 65
COR4	1.6	1.75	1830 ± 75

5 COASTAL DEVELOPMENT

Pleistocene development

The oldest deposits at the surface of the Atlantic lowland are the small basaltic hills, which were dated at 1.2 ± 0.4 ma (Bellon and Tournon, 1978).
The dissected Pleistocene terrace remnants are older than 50 ka (Nieuwenhuyse, pers. com., 1993) and are the highest morphological units of the alluvial plain. Their sediments are of fluvial origin and are deeply weathered (Van Ruitenbeek, 1992). Close to the volcanoes also lahar deposits may be found. Figure 9 shows locations of some of these mainly fluvial remnants. It seems likely that the red hill deposits near the "Lomas de Sierpe" area are of fluvial origin.
The organic matter rich sediments, found below the red colored terrace remnants in the "Lomas de Sierpe" area (profile 1, 2, 3 and 4 of figure 8) must have been formed in a marsh environment. The sulphurous smell could result from pyrite oxidation or is due to sulphate rich sediments probably derived from the volcanoes. Pyrite suggests a tidal marsh environment. Unfortunately it is not known if and how these deposits are stratified, which could give more clues about their deposition.
If sedimentation of these deposits occurred in an environment with tidal influence, sea level must have been higher than at present. This implies a warmer climate. An interstadial occurred about 70 ka B.P. and the Eemian interglacial occurred from about 140-120 ka B.P. (Komar, 1976). According Zagwijn (1983) only during the Eemian an about 8 m higher sea level than at present occurred and the 70 ka B.P. sea level was somewhat lower (Komar, 1976).
The actual seaward gradient of the Tortuguero river near the "Lomas de Sierpe" area is about $0.8\ m \bullet km^{-1}$ in the coastal area and about $1.25\ m \bullet km^{-1}$ at the alluvial plain (Van Seeters, 1992). With a total width of about 13 km respectively 8 km, of above mentioned geomorphological units, this indicates that the "Lomas de Sierpe" area is at about 20 m above present sea level.

During the Eemian the shoreline was probably more landwards and it seems likely that the present Pleistocene terrace remnants were part of a coastal plain then with an altitude of about 5 m to 10 m above the Eemian sea level according the present river gradient at that time. Compared with the present sea level, the present Pleistocene alluvial plain should have an altitude of about 13 m to 18 m not including subsidence or uplifting. The present altitude is about 25 m which implies an uplift. A higher river gradient during the Eemian could exist because of a shorter distance to the footslopes of the mountain range. This could explain the elevation difference. With a subsidence of about $0.25\ mm \bullet yr^{-1}$ (chapter 2) after the Eemian period a subsidence should have occurred of about 30 m. This is not likely because it implies about a 30 m higher sea level then. An average subsidence, for example, of $0.15\ mm \bullet yr^{-1}$ or $0.05\ mm \bullet yr^{-1}$ would result in a subsidence of about 18 m respectively 6 m.

The latter rate of subsidence appears more likely. Compared the Eemian sea level, a subsidence of about 0.05 mm • yr^{-1}, the present sea level and the altitude of the present Pleistocene alluvial plain and during the Eemian an upward elevation difference of about 13 m to 18 m exist. This could be a result of a higher sedimentation rate probably caused by larger volcanic activities during the Eemian or by uplift after the Eemian.

During Weichselien stadials before 34 ka B.P. erosion probably prevailed in the "Lomas de Sierpe" area. The organic matter rich deposit under the red colored Pleistocene sediments could have been preserved probably due to protection of the weathered clay which maintained an anaerobic situation.

Shell remnants found near Maravilla and Castanal (profile 6, 7 of figure 8) could be older than the shell remnants dated at 34 ka B.P. in profile 9 (fig.8), because of elevation differences as compared to present sea level. Assuming an altitude of about 30 m above present sea level near Maravilla and Castanal, the shells remnants, at about 20-30 m below present sea level, could have been deposited about 70 ka B.P. in a coastal environment. This would imply that the Pleistocene terrace remnants are older and were sedimented before or during the Eemian period. If this is correct than the basaltic hills and Pleistocene terrace remnants were islands in a open sea during the about 70 ka B.P. interstadial. If the Pleistocene alluvial plain was deposited 70 ka ago than the shell remnants are probably between 34 ka and 70 ka old.

The samples LS1 and LS2 contain relatively much fine textured material, while coarser grains were not or hardly rounded. This suggest hydrodynamically calm circumstances during sedimentation and/or short transport distances. The high organic matter content is an indication for vegetation rich circumstances and due to high rate of peat formation under anaerobic circumstances. Fish remnants and pyrite suggest a reduced sedimentary environment with tidal influence. Ammonia parkinsoniana is a characteristic species for brackish environments.
Al these observations suggest that during the about 34 ka B.P. interstadial (Komar, 1976), (Bartlett et al, 1973) a transgressive sea submerged parts of an earlier eroded alluvial plain. The environment in the "Lomas de Sierpe" study area, in which LS1 and LS2 samples were deposited was a tidal basin or brackish water lagoon dotted with little islands of terrace remnants.

According recent topographic measurements the altitude of the profile 9 sample site location is about 18 m above sea level (fig.8). Given the depth at which dated shells were found and a presumed subsidence of 0.05 mm • yr^{-1}, sea level, 34 ka ago, must have been lower than at present (fig.10). This corresponds with dates from Milleman and Emery (1968) of the Atlantic continental shelf of the United States (Bartlett et al, 1973). Dreimanis et al. (1966) found evidences that in the period of 48 to 28-24 ka B.P. stadials and interstadials occurred in the Lake Erie region (Bartlett et al, 1973). Dansgaard et al (1969) give interstadial evidences of a variation study in oxygen-isotope composition of ice from the Greenland ice cap. The atnosphere, during the period from 35 to 29 ka B.P., has a relative high ^{18}O amount, which indicates higher temperatures as compared to glacial periods (Bartlett et al, 1973).

During the last intense glaciation from 24 to 18 ka B.P., (Komar, 1976), sea level fell down to about 140 m below the present one (fig.10). The much faster rate of erosion base lowering as compared to probable basin subsidence, caused seaward shifting of the shoreline and dissection of the alluvial plain. Deposition in the alluvial and coastal plain occurred further seawards than today.
Assuming that the Pleistocene terrace remnants were deposited during the Eemian three phases of dissection during the Weichselien glacial can be distinguished:
- after the Eemian interglacial and before the 70 ka B.P. interstadial.
- after 70 ka B.P. and before the 34 ka B.P. interstadial.
- after the 34 ka B.P. interstadial, during 24-14 ka B.P. in the Late Pleistocene.

Holocene development

After 18-14 ka B.P. sea level began to rise rapidly until about 7-6 ka B.P. with a maximum rate of 1 cm • yr^{-1} (fig.10). During this transgression period the rate of sea level rise was higher than the sedimentation rate. Readjustments to sea level rise resulted in coastal erosion and offshore deposition (fig.11). Former beach ridges were eroded and their sediments together with sediment supply from rivers, were probably mainly deposited offshore.
This period ended at about 7-6 ka B.P. when sea level rise began to slow down. In a high energy sedimentation environment only well sorted sand is deposited. Point SP10 of transect TR1 contain well sorted sand at a depth of 8.3 m. During 7-6 ka B.P. the shoreline was probably at the east footslope of the basaltic hills Cerro Coronel.
When the erosion base rose, dissection of the Pleistocene alluvial plain stopped and infilling of the eroded valleys with Holocene fluvial volcanic sediments began.

After 7-6 ka B.P. the rate of sea level rise gradually decreased to about 0.5 mm • yr^{-1} during the past 2000 years (fig.12), (Van der Valk, 1992). The Caribbean coast of Costa Rica prograded seawards due to respectively higher sedimentation rate relative to the difference between rate of sea level rise and possible subsidence. Upward beach ridge progradation is due to continuous rise of sea level and/or possible subsidence (fig.13).
Sand may be supplied by cross-shore processes, which means that wave action cause a landward supply of continental shelf sediments. Tidal energy is low due to tidal range of about 0.6 m (Nieuwenhuyse, pers. com., 1993). By long-shore processes, river sediments are transported parallel to the shoreline by wave action. Prevailing northeastern trade winds cause longshore drift which transport and throw sediment up in mainly southeast direction. This situation caused formation of a sandy beach ridge plain.

The morphological shape of Cerro Coronel is something like a open arc towards the sea, with its northern end located near the rivers San Juan and Colorado. It is likely that this morphology already existed about 7-6 ka B.P.. Beach ridge formation may have started at the northern end of Cerro Coronel as a spit, which was tied at the hill and free at the other (Komar, 1976). Depending on the energy content of river water with its sediment supply relative to wave energy a spit can result in a ridge. Separated by a beach ridge, possible with river outlets, a tidal basin existed in front of Cerro Coronel.

This would explain the rather homogeneous depth at which sand is found in front of Cerro Coronel. Sooner or later the tidal basin became closed and changed into a rain water accumulation basin where peat growth started.

According peat samples of transect TR2 (fig.5) the shoreline prograded between point COR1 and COR2 about 2.1 m • yr^{-1}, and sea level rose about 2.5 mm • yr^{-1}. Between point COR2 and COR3 this was respectively 1.6 m • yr^{-1} and about 0.8 mm • yr^{-1}. Decreasing rates of sea level rise data of Van der Valk (1992) conclude that a subsidence of 0.03 mm • yr^{-1} could occur according data of point COR2 and COR3.
This rate of shoreline progradation between point COR1 and COR2 during 6285-3460 yrs B.P. is not likely because of the supposed existence of a tidal lagoon closed by beach ridges. This suggest that the coast extending was not only due to beach ridge aggregation but also by closed lagoons.
Transect TR1 (fig.6) shows that no fluvial sediments are found with increasing distance to the hill and that the tongue shaped peaty clay sediments must be eroded hill sediments.

The ages of the TR1 peat samples shows a rather linear connection with depth, but during the late Holocene it shows a little decrease (fig.7). This suggest a decrease of sea level rise during the late Holocene which corresponds with data of Van der Valk (1992).
The ages of samples C4.1 and C4.9 are more or less equal. This could be due to ^{14}C concentration differences of the atmosphere. It could suggest that during peat formation at a depth of 4.1 m an almost egual ^{14}C concentration of the atmosphere exist compared with peat formation at 4.9 m depth. According Pearson et al (1986) wiggels of ^{14}C concentration of the atmosphere occurred. This could imply the inveracious age of sample C4.1.
Peat compaction is of subordinate issue because sampling occurred just above the transition clay/peat. Samples C4.1 and C4.9 could have been taken from the tongue shaped clayey peat deposit according figure 6.
The ages of transect TR2 sample COR1 and transect TR1 sample C8.3 (fig.5) are almost equal and conclude that the transection sand/peat has a little or no gradient and that it could have been a former tidal basin. The depth differences of these samples could be due to ombrogenous peat formation.

The oldest peat samples were taken at a depth of 8.3 m to 9.8 m and are about 6 to 6.5 ka old. It means that at this time a transition of a transgressive to a regressive sea occurred. These data are similar with data of sea level changes in the Netherlands of Van der Plassche (1982), which is an evidence of global sea level rise decrease after 6000 years B.P..

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