Geological events influencing Natural Vegetation in Trinidad

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Introduction

On several occasions, I have listened to talks given by geologists about events pertaining to Trinidad, and have always ended up being confused by the jargon they employ in their presentation. It may be meaningful to their colleagues but to the average layperson it can be very confusing. This article, therefore, is an attempt to describe the geological history of Trinidad and the development of its natural vegetation in a manner that I hope will bridge the gap that often exists between the scientific community and the public when dealing with so-called "scientific material". I trust my effort will prove successful.

To begin, it can be stated that processes like bulldozing and erosion, terms we usually associate with the destructive influence of man, have been employed by nature in a constructive way to produce Trinidad as we now know it. This will become clearer in subsequent sections. Also, differing views on the plate tectonics of the Caribbean prevail (Donnelly 1985, Gose 1985) and the one presented in this article is by no means definitive.

An acceptance of evolution in the broader abiotic sense is necessary to an understanding of events portrayed in this article. To demonstrate how dramatic geologic changes can be, compare the world's distribution pattern of continents today, where clustering of large landmasses occurs in the Northern Hemisphere, with what the planet looked like 430 million years ago in the Silurian Epoch (a geological time period named after a Celtic tribe). During the Silurian, the continents were concentrated in the Southern Hemisphere (Bambach et al. 1980).

Geological changes, albeit on a smaller scale, have been just as dramatic in Trinidad. Before looking at these changes, let's see where Trinidad fits into the geologic time scale (Fig. 1). The oldest rocks in Trinidad date from the Late Jurassic (150 million years before present or mybp). The Jurassic is named after the Jura Mountains in western Europe. By comparison, the oldest known rocks on Earth are found in Canada's Northwest Territories dating 3,960 mybp (Morell 1990); therefore, Trinidad is a geological infant.

Plate Tectonics

To appreciate and understand early geological events influencing Trinidad's development we need to look at the larger picture of plate tectonics and what has happened since Pangaea, the last supercontinent. Figure 2 illustrates what Pangaea looked like during the Triassic (200 mybp). The Triassic is derived from "trias" which refers to the three-fold character of these rocks in

mybp	Epoch	Era
	Holocene	Cenozoic
10,000 (ybp)	Pleistocene	
1.8	Pliocene	
5	Miocene	
22.5	Oligocene	
38	Eocene	
54	Paleocene	
65	Cretaceous	Mesozoic
136	* Jurassic	
190	Triassic	
225	Permian	Paleozoic
280	Carboniferous	
345	Devonian	
395	Silurian	
430	Ordovician	
500	Cambrian	
570	Precambrian	

Figure 1 The geologic time scale. The asterisk (*) denotes the oldest rocks in Trinidad.

Europe. During this geological epoch there was no Atlantic Ocean or Caribbean Sea.

As Pangaea started to break apart during the Early Jurassic (180 mybp), a "proto-Caribbean" plate developed. The Caribbean Plate at this time was just west of the North American Plate in the eastern Pacific Ocean. By the Early Cretaceous (135 mybp; Cretaceous is derived from the Latin word "creta", meaning chalk) the North Atlantic Ocean was opening, and by the end of the Cretaceous, and the Mesozoic Era (65 mybp), most of the North Atlantic and all of the South Atlantic were fully opened (Fig. 3). As these events were taking place, the Caribbean Plate was replacing the proto-Caribbean by shifting eastwards, relative to the separated North and South American Plates which were moving westwards. Then, about 800,000 years ago, a land-bridge formed between North and South America creating what is now Central America.

The Greater Antilles (Cuba, Hispaniola, Puerto Rico, Jamaica) probably represent an earlier attempt at forming a land-bridge between the two American continents. As the Caribbean Plate moved eastward, it broke up the land-bridge into the large islands which now border the northern Caribbean Sea.

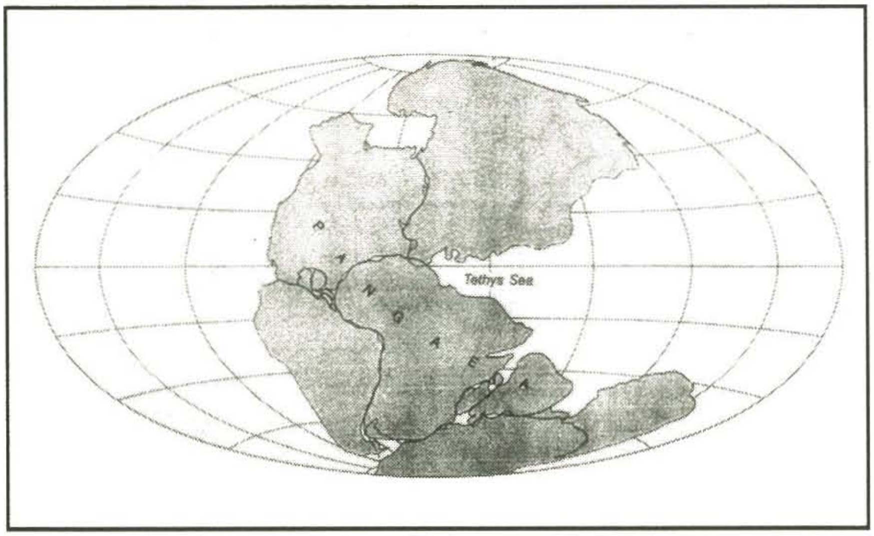

Figure 2.
The supercontinent of Pangaea during the Triassic (200 mybp).
(After Robert S. Dietz and John C. Holden. Journal of Geophysical Research 75: 4943. 1970. Copyright by American Geophysical Union)

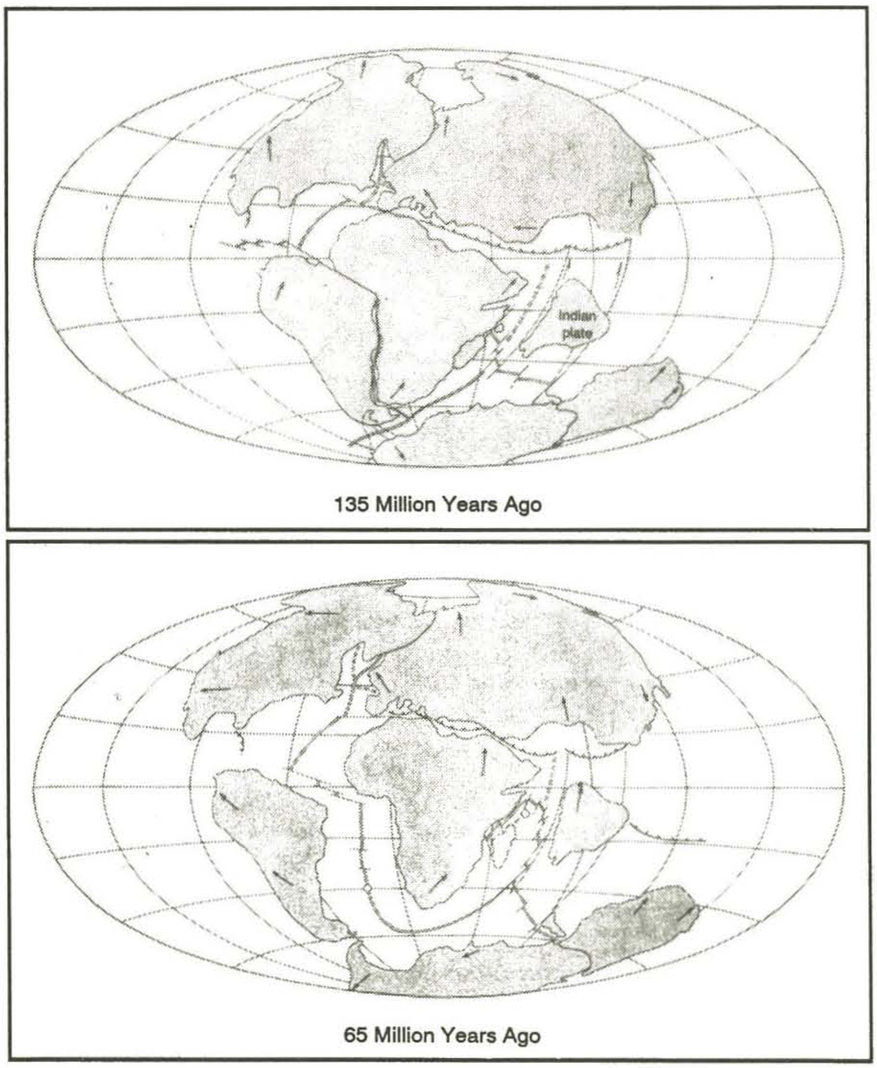

Figure 3.
The opening of the North Atlantic by the Early Cretaceous (135 mybp) and the South Atlantic at the end of the Cretaceous (65 mybp).
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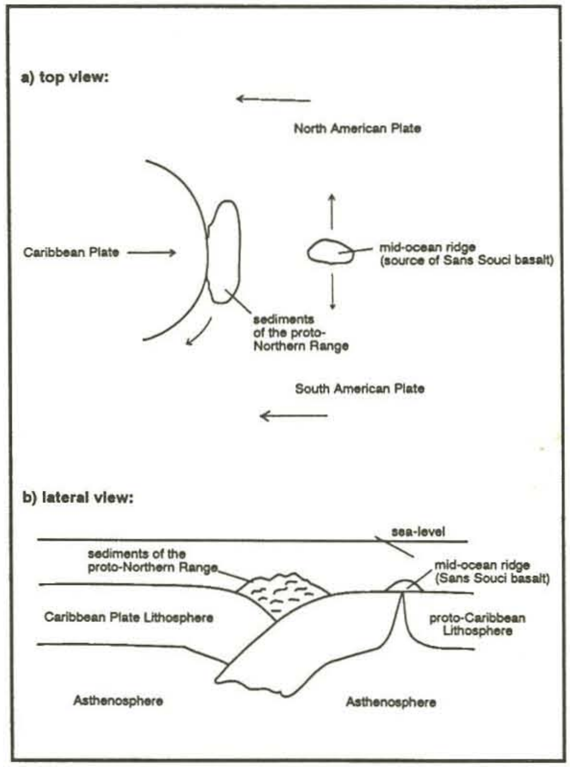


Figure 4. The beginning of the Northern Range.

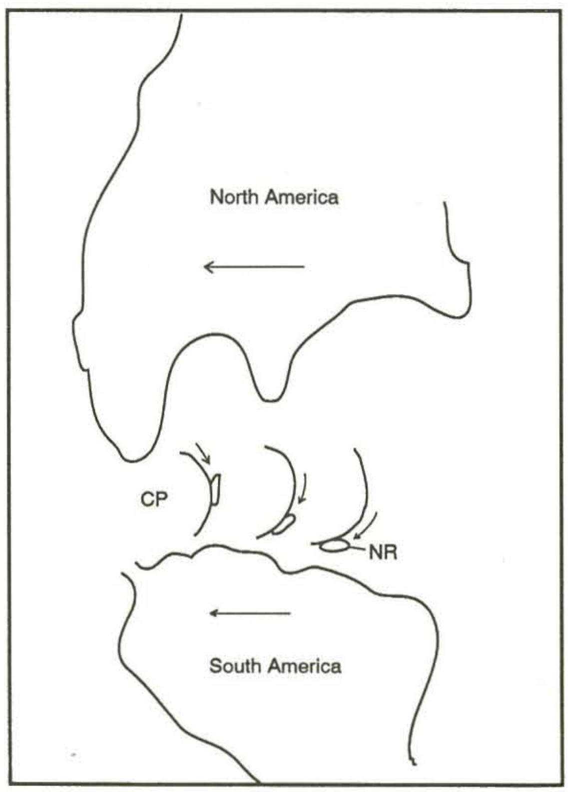


Figure 5. Movement of the proto-Northern Range. (CP = Caribbean Plate; NR = Northern Range)

The Beginnings of Trinidad

Geological events related to Trinidad date back to the Late Jurrasic (about 150 mybp) in the Mesozoic Era (Table 1). Around this time, ammonites, which are indicative of a deep-water marine environment, were being deposited in sediments (which were to help form Trinidad) in the vicinity of the Caribbean Plate which was still west of North and South America. Evidence for this deposition is based on ammonites found at Hollis Reservoir and in the Plaisance Conglomerate at Pointe-à-Pierre (J. Frampton pers. comm.). Subsequent to this, shallow marine conditions prevailed as the gap opened between the North and South American Plates around the Late Jurassic and Early Cretaceous (136 mybp). In these shallow waters, evaporites (associated with salt-pans) were deposited, which today can be seen in the northern Gulf of Paria and around St. Joseph.

As the gap widened betweened the North and South American Plates during the Cretaceous, deeper marine conditions developed where sediments, today associated with Trinidad, were being deposited.

As these varying marine conditions with respect to water depth unfolded, the Caribbean Plate continued to move eastward, relative to the westward moving North and South American Plates, acting like a bulldozer as it pushed sediments along its leading edge, sediments which were to become the precursor of the Northern Range (Fig. 4).

Meanwhile, a mid-ocean ridge in the proto-Caribbean between the North American & South American plates and eastward of the advancing Caribbean Plate, was welling up molten rock that is the source material of the Sans Souci Basalt which dates from 87 mybp (Cretaceous). This material was later to be incorporated or mixed in with the sediments being pushed eastward by the advancing Caribbean Plate (Fig. 4). The Lesser Antilles, on the other hand, represent an island arc system developing along a subduction zone where the Caribbean Plate is colliding with the Atlantic Ocean portion of the North American Plate, and as such these islands are lithologically different from the Sans Souci material.

It is estimated that the Caribbean Plate is moving eastward at an assumed constant rate of 2 cm/year in the vicinity of present-day Trinidad (Rohr 1990). This is relative to the westward moving North and South American Plates (Fig. 5). During this process, the Mesozoic sediments (Jurassic and Cretaceous), combined with the Sans Souci Basalt (that together were forming the proto-Northern Range), were gradually being moved southward by this eastward moving Caribbean Plate. This caused a great deal of contraction to occur in what is known as the Plate-Boundary Zone, which, in the vicinity of present-day Trinidad, is a zone (between the Caribbean and South American Plates) that varies in width from 250 km near the longitude of Margarita to 185 km at the longitude of Tobago (Rohr 1990). It is estimated that a compressional rate of one km/million years resulted in 50 to 200 km of contraction or narrowing between the Middle Eocene (45 mybp) and the Middle Miocene (14 mybp). By analogy, imagine an eastward moving hand fan (with a Western hinge) that is slowly being folded shut. This compression assisted in the development of Northern Range metamorphic rocks (Fig. 6).

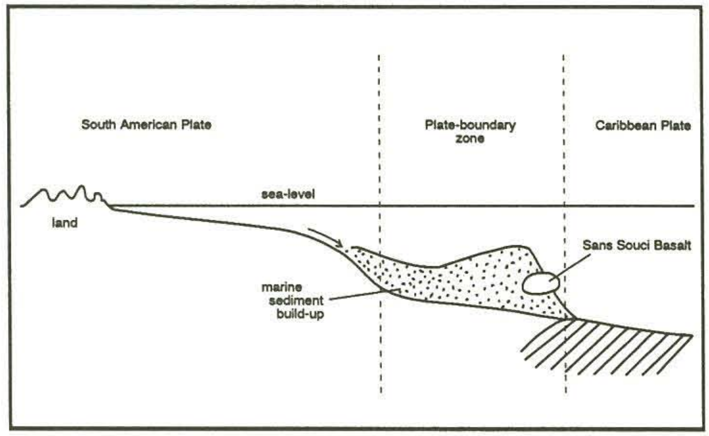


Figure 6. Early development of Northern Range rocks.

The Coalescing of Trinidad

We are now at a stage where we can begin to visualize the early development of Trinidad by referring to paleogeographic maps that illustrate important geological events (Table 1) during the Cenozoic Era. During the Middle Eocene (45 mybp) the main depositional events from the South American landmass, influencing the development of Trinidad, are caused by a great delta and submarine fan complex that stretched from Maracaibo (Venezuela) to Barbados (Fig. 7). Barbados at this time was below water and positioned at an approximate longitude of 64°W rather than its present-day longitude of 59°W. It can be seen from Figure 7 that sediments associated with Trinidad were being deposited along the slope of the continental shelf. At the end of the Eocene (38 mybp) there are indications of some shallow sea regions in proto-Trinidad (eg. San Fernando Formation).

At the Oligocene-Miocene boundary (22 mybp) oblique collision between the Caribbean Plate and the Plate-Boundary Zone is combined with deposition from the Naricual Delta (Fig. 8). This large delta was formed by the confluence of the Rio Caura and Rio Caroni draining from the Guyana Shield. A Northern Landmass

Table I Geologic Events Related To Trinidad.

Era	Geologic Age	mybp		Notable Events
	Holocene	10,000 yrs to present		– near maximum forest cover up to 500 ybp – Orinoco drainage shifts into Gulf of Paria 700 ybp – minor regression and subsequent advance of sea-level 1,500 ybp – optimum post-glacial climatic period 7,000 - 5000 ybp – final land separation between Trinidad and South America 10,000 ybp
	Pleistocene	1.8 m to 10,000 ybp		– earliest Amerindian artifacts (near Biche) 11,000 ybp – ice-sheets started retreating in North America and Europe 14,000 ybp – seas 100 metres lower 18,000 ybp creating a land-bridge to Tobago – Trinity Hills are formed by shear-compression during the Early Pleistocene
	Pliocene 5 - 1.8	*		– Pliocene-Pleistocene tectonic movement becomes predominantly simple shear along major fault lines – Pliocene deposition is especially dominated by the Orinoco Delta 3 mybp
	Miocene 22.5 - 5			– Central Range forms towards the end of the Miocene – muddy sea in what is now south Trinidad during the Late Miocene
			*	– no evidence of thrust-faulting from the end of the Middle Miocene onwards – a well defined shelf-edge transects Trinidad at the position of the Central Range 14 mybp – Northern Range becomes a distinct mountain range in the Miocene (possibly as early as the Middle Oligocene)
	Oligo-Miocene	22		– central Trinidad is on a shelf-slope boundary, southern Trinidad on a lower sea-slope
			*	– oblique collision occurring between the Caribbean Plate and the Plate-Boundary Zone
	Oligocene	38 - 22.5		– open sea persists where Trinidad occurs
	Eocene	54 - 38		– indications of some shallow sea regions in proto-Trinidad at the end of the Eocene (eg. San Fernando Formation) – the main depositional events are caused by a great delta and submarine fan complex from Maracaibo across the Falcon Basin to Barbados 45 mybp
			*	– between the Middle Eocene and the Middle Miocene 50 to 200 km of contraction occurs within the Plate-Boundary Zone.
	Paleocene	65 - 54		– deep water where Trinidad occurs
	Cretaceous	136 - 65		– dinosaurs disappear at the end of the Cretaceous – deep water where Trinidad occurs due to widening gap between North and South American Plates
	Jurassic 190 - 136			– between the Late Jurassic/Early Cretaceous shallow marine conditions owing to narrow gap between North and South American Plates (this is indicated by evaporites found in northern Gulf of Paria and around St. Joseph) – deeper marine conditions elsewhere in the Late Jurassic (evidence based on ammonites found at Hollis Reservoir and in Plaisance Conglomerate at Pointe-à-Pierre)

* Denotes events of major importance.

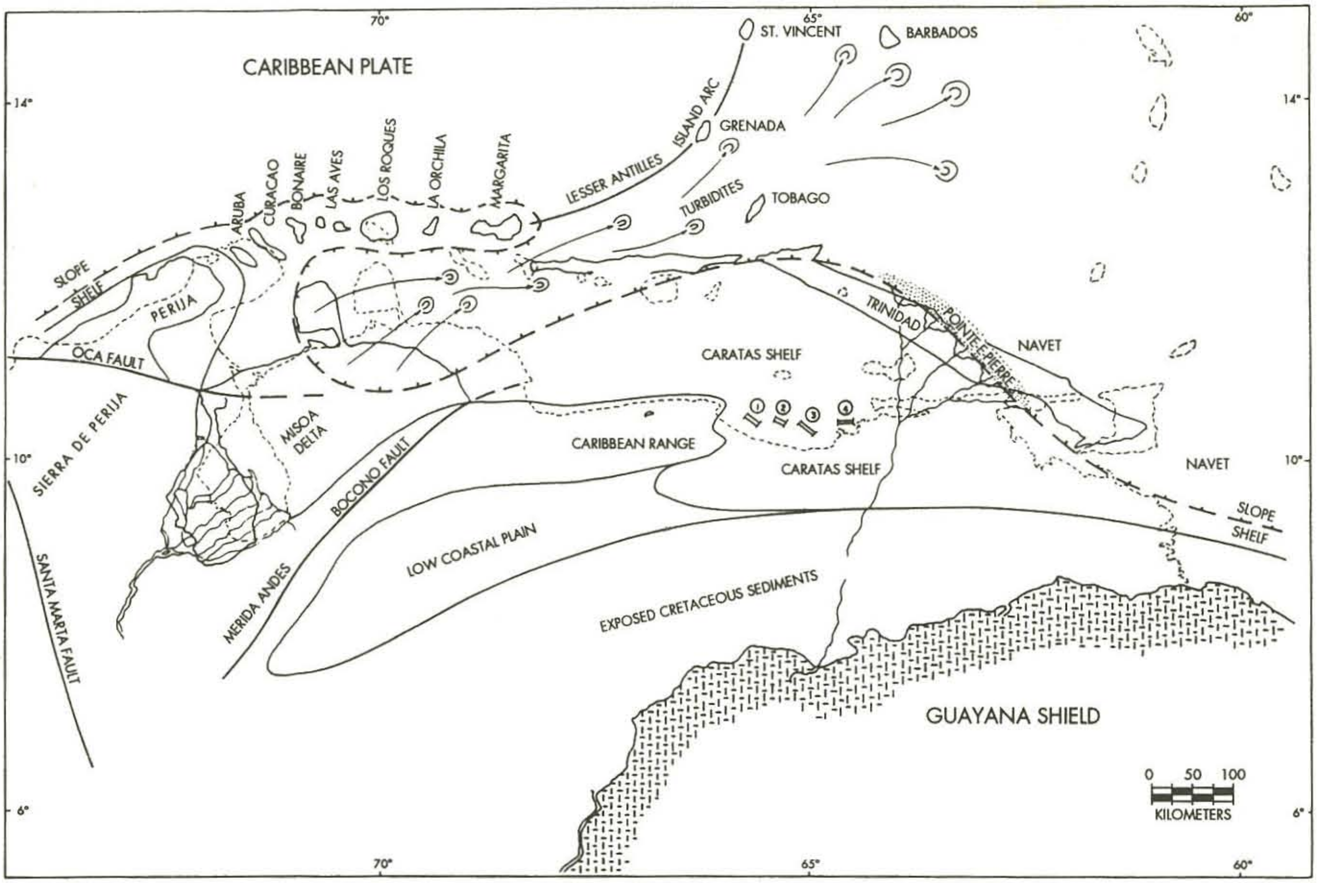
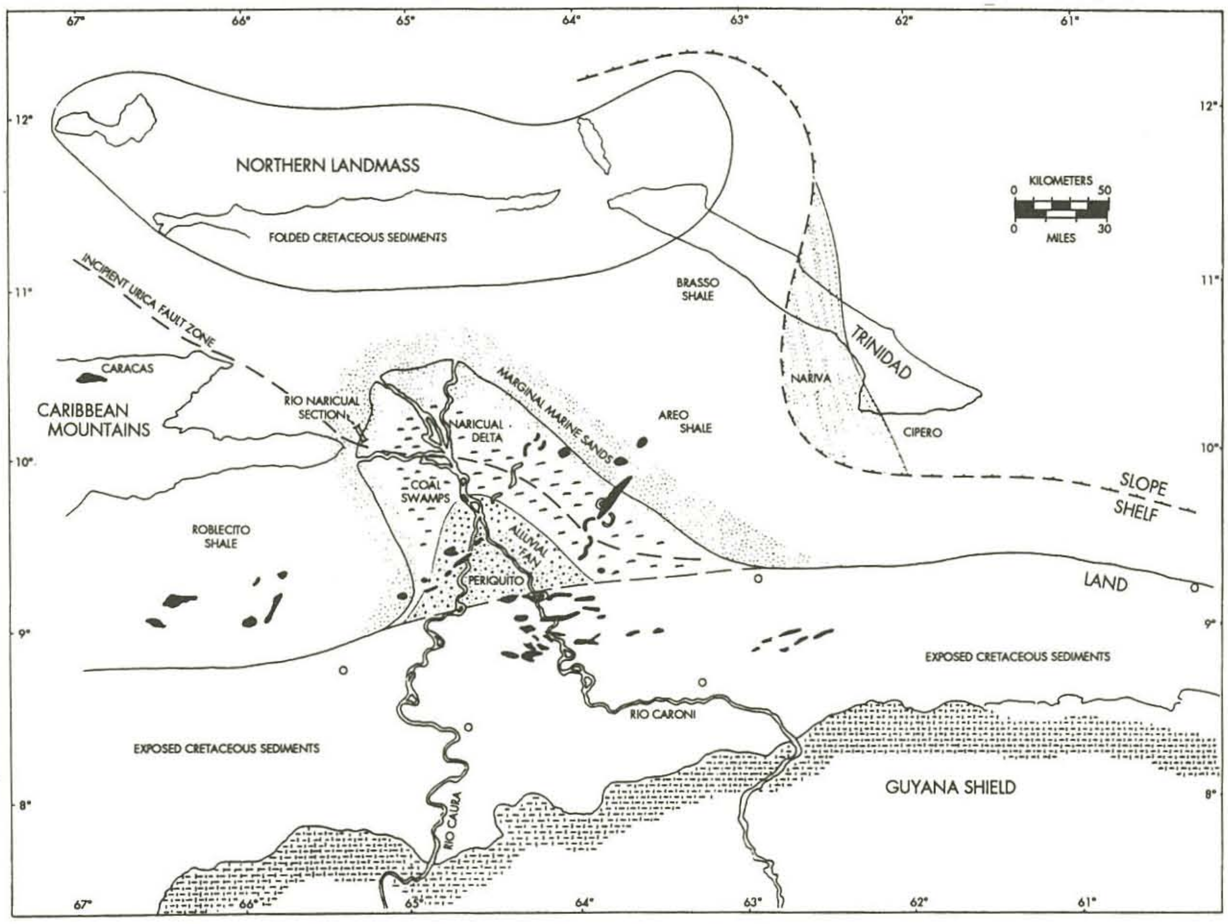


Figure 7 Paleogeographic map of the Middle Eocene (45 mybp). (Source: Rohr 1990)

Figure 8 Paleogeographic map of the Oligocene-Miocene boundary (22 mybp). (Source: Rohr 1990)



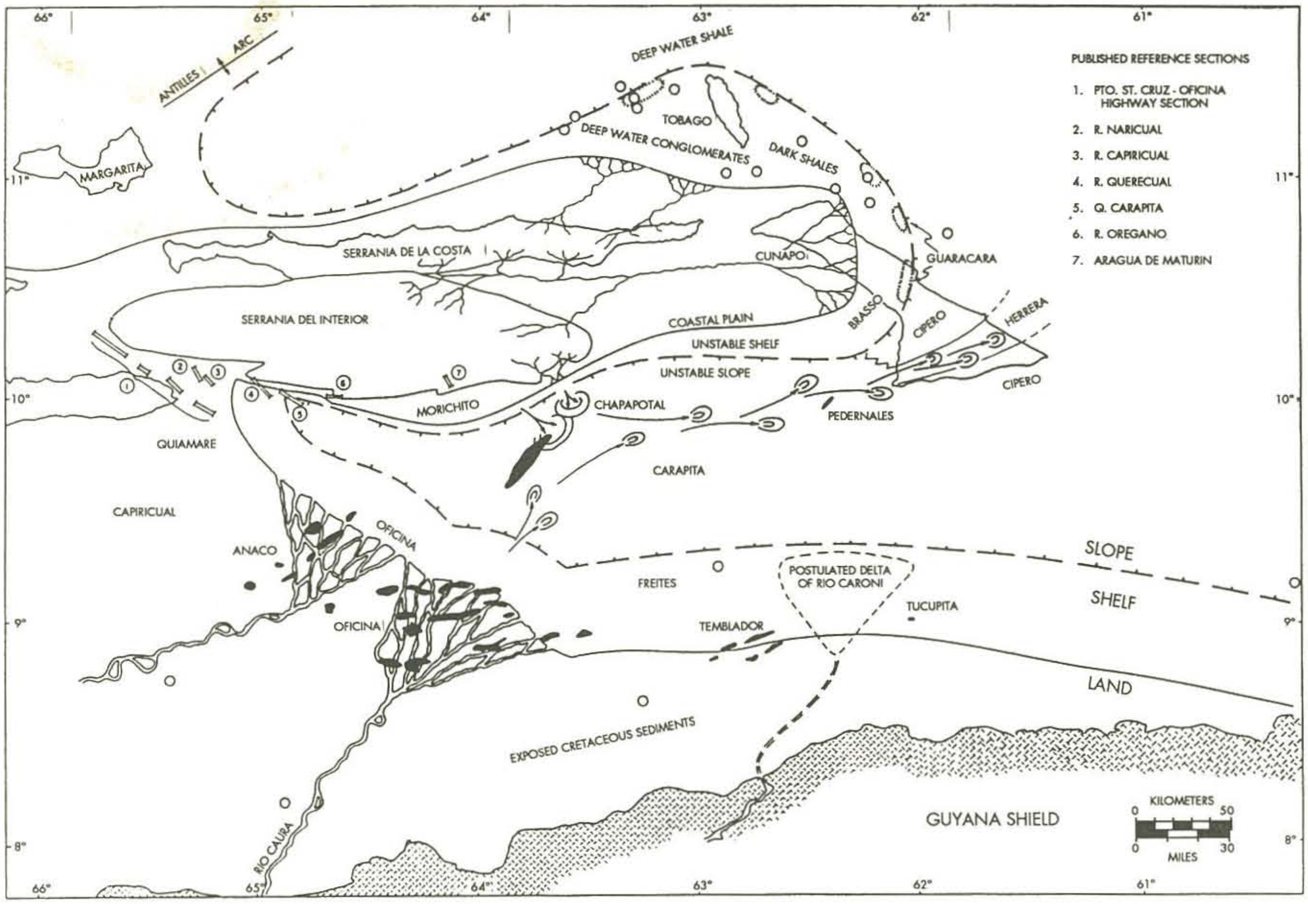
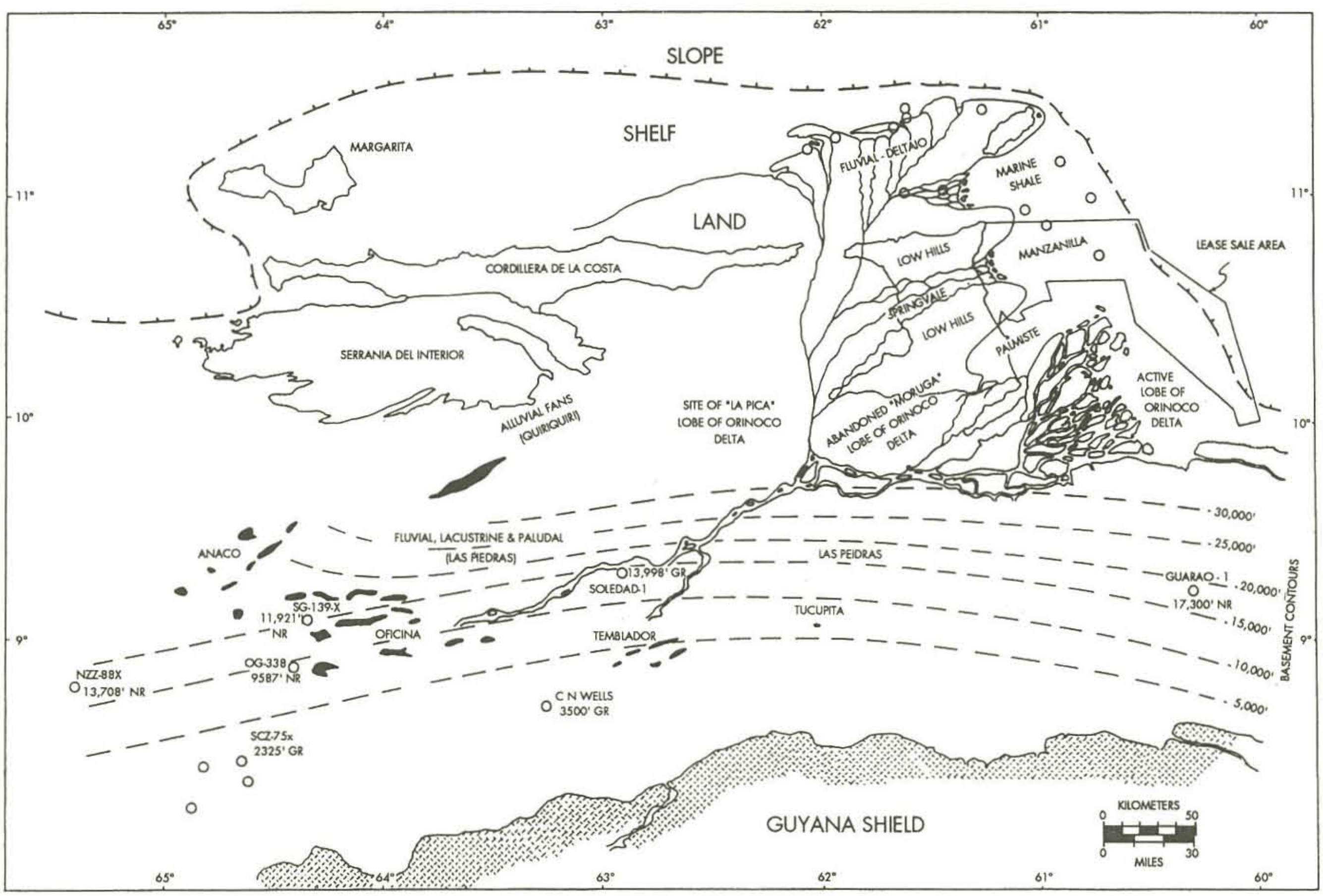


Figure 9 Paleogeographic map of the Middle Miocene (14 mybp). (Source: Rohr 1990)

Figure 10 Paleogeographic map of the Middle Pliocene (3 mybp). (Source: Rohr 1990)



situated about 50 km north of the Naricual Delta, that was either just above or just below sea-level, caused sediments from the delta to be diverted eastward and deposited on the continental shelf and slope. Central Trinidad at this time is on this shelf-slope boundary, while southern Trinidad is on the lower sea-slope.

During the Miocene, the Northern Range certainly becomes a distinct mountain system. It may have formed earlier, the uncertainty arising because it is difficult to date the early conglomerates which were shed off the Northern Range. Conglomerates can indicate a high-energy environment, for example, a rushing stream, where only coarse materials, such as rounded gravel stones, can settle out. The finer sediments including the microfossils are washed away thus removing evidence that could more accurately date the conglomerate. Conglomerates, however, are indicative of an eroding environment, hence the landmass they are associated with, i.e. the Northern Range, is above water at the time the conglomerates were formed. It should be noted here that the Northern Range has probably never been much higher than its present-day 925 m (J. Frampton pers. comm.).

By the Middle Miocene (14 mybp) a well defined shelf-edge transects Trinidad at the position of the Central Range and reefs start to form (the best examples being Biche, Tamana and Guaracara limestones) (Fig. 9). The Central Range today is regarded as being a paleo-shelf-edge (Rohr 1990). There is no evidence of thrust-faulting (northern landmasses over-riding southern ones) from the end of the Middle Miocene onwards. This indicates a cessation of compression in the Plate-Boundary Zone. Muddy seas occur in what is now south Trinidad during the Late Miocene caused by deltaic discharges from the Caroni, Caura, and Orinoco Rivers of Venezuela.

During the Pliocene, deposition of Trinidad sediments is especially dominated by the Orinoco Delta (3 mybp). At this time, the huge delta engulfs all of Trinidad (Fig. 10) with its active lobe positioned to the southeast of the present-day landmass. The Caroni and Caura Rivers (of Venezuela) at this stage have become tributaries of the Orinoco.

Pliocene-Pleistocene tectonic movement in Trinidad now becomes predominantly simple shear along major fault lines. Moving from north to south, there are four of these fault lines running more or less parallel from west to east (Fig. 11). It should be noted that these fault lines have no relationship with east coast resistant headlands, such as Manzanilla and Galeota Points. The southern fault lines (3 and 4) have alignments of mud volcanoes along their courses. Fault 2 is aligned with the El Pilar Fault of Venezuela, while Fault 1 (our El Pilar) separates Northern Range Mesozoic metamorphics from Cretaceous and Cenozoic sediments on the rest of the island.

By the Early Pleistocene (1.8 mybp), the Trinity Hills are formed by shear-compression. At this time, Trinidad's shore-line extended further north and east than today and encompassed Tobago (Fig. 12). Seas were also lower (by approximately 100 m) near the last glacial maximum about 18,000 years ago. Based on maximum sea-depths between Trinidad and Tobago (Fig. 13), Tobago was connected to Trinidad by a land-bridge until at least 14,000 years ago when the ice-sheets started retreating in North America and Europe.

At the start of the Holocene (most recent geologic age, 10,000 years to the present), the final land separation between Trinidad and South America occurred (Fig. 14) and Trinidad assumed the shape that we recognize today.

The Development of Trinidad's Natural Vegetation

How does Trinidad's natural vegetation relate to its geological evolution? Our earliest fossil plant records, that I know of, date from the Late Pliocene, but mainly from the Early Pleistocene (1.8 mybp). These fossil plant leaf-casts were found in south Trinidad, mainly from Porcellanite beds in Siparia (see Table 2), and represent a flora indicative of a moist evergreen forest, similar to our Seasonal Evergreen Forest (Beard 1946) of the present time.Owing to the lack of physical (fossil) evidence prior to the Pleistocene regarding natural vegetation in Trinidad, one can only speculate as to the evolution of the region's flora up to the beginning of this geological period. By following the sequence of geologic events already discussed in the text and illustrated in Figures 7 to 10, it is possible to construct a scenario showing when land first appeared and predict the type of vegetation it may have supported.

One can say with a fair degree of certainty that land in Trinidad occurred above sea-level in the Early Miocene (22 mybp), and may even have appeared as early as the Middle Oligocene (30 mybp). Prior to this, sediments forming Trinidad were entirely below sea-level. This newly exposed land which partly consisted of folded Cretaceous sediments is referred to as a Northern Landmass (Fig. 8) and was located north of the Naricual Delta. It included the Northern Range, Tobago, the Serrania de la Costa of northern Venezuela, and Margarita. This Northern Landmass initially may have been separated from the South American mainland, but by the Middle Miocene (14 mybp) it was firmly attached to the continent. Its early flora, therefore, may have been more oceanic in character until a land-bridge was formed after which it presumably supported vegetation of a continental nature. By the end of the Miocene (5 mybp)

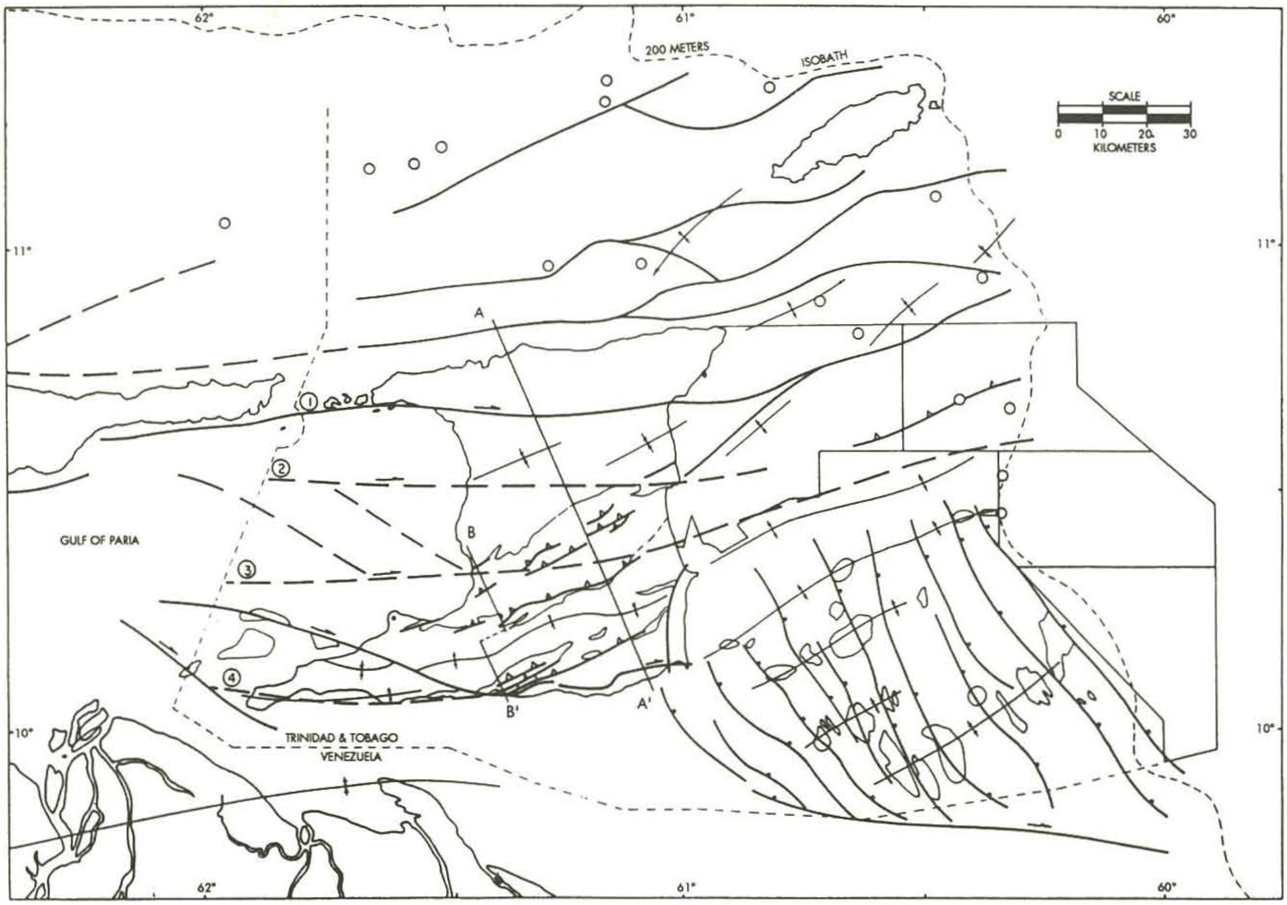


Figure 11. The major fault lines in Trinidad: 1) El Pilar, 2) Chaguanas, 3) Piparo, and 4) Galeota. (Source: Rohr 1990)

the Central Range was above sea-level, and by the Middle Pliocene (3 mybp) all of Trinidad (except the Trinity Hills), as well as Tobago, formed part of or were incorporated in the Orinoco Delta. The Trinity Hills were elevated above sea-level during the Early Pleistocene (1.8 mybp).

Tropical forest trees as we know them today have persisted for at least 30 million years, from the Middle Oligocene, which is also the earliest possible time when land forming Trinidad first appeared above sea-level. Thus, a moist tropical forest flora seems most likely to have persisted in the region up to the start of the Pleistocene (1.8 mybp). There are strong indications, however, that following the beginning of the Pleistocene, fluctuating climate has caused corresponding fluctuations in the type of vegetation cover that occurs in tropical regions like Trinidad. During the last million years, there have been at least eight glacial maxima. It takes about 100,000 years for the ice-advance to reach maximum levels, then the ice-sheets retreat in a few thousand years during periods of warm northern summers. These regular cycles have been correlated with three astronomical cycles: 1) eccentricity of the Earth's orbit, a 100,000 year cycle: 2) precession (wobble) of its spin axis (23,000 years); and 3) tilt of the spin axis, currently 23.5° (41,000 years). These three cycles combine to vary the amount of sunshine reaching high northern latitudes in summer. This allows glacial advance to occur during intervals of cool summers (less melting) and mild winters (more precipitation) (Broecker & Denton 1990).

The ice-ages caused changes in oceanic circulation patterns which altered the transport of heat and moisture and thus affected climate (Lutgens & Tarbuck 1989). Thus, a period wetter than the Holocene (10,000 years to the present) occurred during the major part of the Last Glacial (between 90,000 and 21,000 ybp) while a period drier than the Holocene occurred between 21,000 and 13,000 ybp (Van der Hammen 1974). From 21,000 to 13,000 ybp, the climate was much drier in northern South America. This period corresponded with the time of maximum glaciation. Also, during this time there was about a 3°C temperature drop in tropical lowlands.

Pollen diagrams in the coastal lowlands of Guyana and Surinam show a considerable extension of savannas during glacial maximum periods with low sea-levels (Van der Hammen 1974). By extension, if the same thing happened in Trinidad, then moist seasonal forest cover must have fluctuated with climatic change, and

Table II Fossil Plants Found in Trinidad. (Source: Hollick 1924)

Family	Species	Locality
Palmae	*Palmocarpon bactrioides*	# Porcellanite quarry, Siparia
Musaceae	*Musophyllum trinitense*	" " "
Moraceae	*Ficus porcellanaria*	" " "
	Ficus pseudoeggersii	" " "
	Ficus comparabilis	Bluff just north of Moruga
		Porcellanite quarry, Siparia
	+ *Coussapoa vaningeni*	" " "
Lauraceae	*Ocotea pseudomartinicensis*	" " "
Leguminosae	+ *Inga pseudonobilis*	Bluff just north of Moruga
	Cassia sipariensis	Porcellanite quarry, Siparia
Guttiferae	+ *Clusia vera*	" " "
Myrtaceae	+ *Myrcia peudorostrata*	" " "
	Eugenia comparabilis	" " "
Myrsinaceae	+ *Geissanthus brittoni*	" " "
Apocynaceae	+ *Plumiera alia*	Bluff just north of Moruga
	+ *Cameraria* (?) *incerta*	Porcellanite quarry, Siparia
Bignoniaceae *	+ *Crescentia* (?) *cucurbitinoides*	" " "

+ Exclusively New World
* All except *Crescentia* are new species to science
# Porcellanite dates from the Late Pliocene, but mainly from the Early Pleistocene

Table III Pre-Columbian Forest Types in Trinidad Compared With Today's Forest Cover +

Trinidad's * Forest Types		Approximate Percent Cover 500 ybp	Percent Cover 1989
Seasonal Evergreen:		75	20
Mixed		65	
Mora		10	
Semi-evergreen		10	3
Deciduous		< 1	0.7
Dry Evergreen (Littoral)		< 1	0.1
Lower Montane		10	4.5
Montane (above 760m)	least affected by man	< 1	< 1
Elfin Woodland	least affected by man	< 1	< 1
Seasonal Montane	least affected by man	< 1	0.2
Swamp Forest	least affected by man	< 1	2.7 (Swamp Forest, Palm Swamp, Herbaceous Swamp, Mangrove combined)
Palm Swamp	least affected by man	< 1	
Herbaceous Swamp	least affected by man	< 1	
Mangrove	least affected by man	1	
Marsh Forest	least affected by man	< 1	< 1
Savanna		1	< 1

* Trinidad's total land area is 482,500 hectares.
+ Source: Beard 1946, and The National Forest Resources Plan, Min. Envir. Nat. Ser., June 1989.

during drier periods deciduous forest and climatic savannas spread. A 20% drop in rainfall in the tropics during maximum glaciation would spread aridity into strongly seasonal climatic regions like Trinidad (Colinvaux 1989). If this same climatic change occurred all across northern South America, then there must have been periods of maximum exchange of savanna and xerophytic species from east to west (or vice versa) along the southern Caribbean Coast (Van der Hammen 1974).

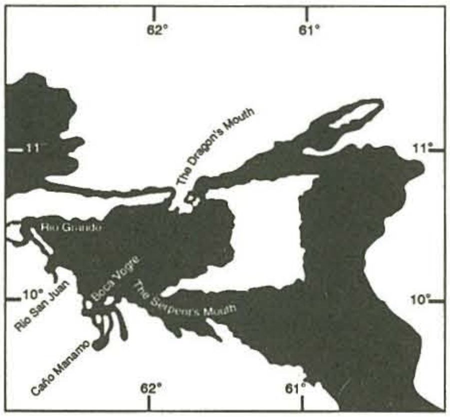


Figure 12. The Early Pleistocene shore-line (1.8 mybp). (Source: Texaco Trinidad Quarterly 1961)

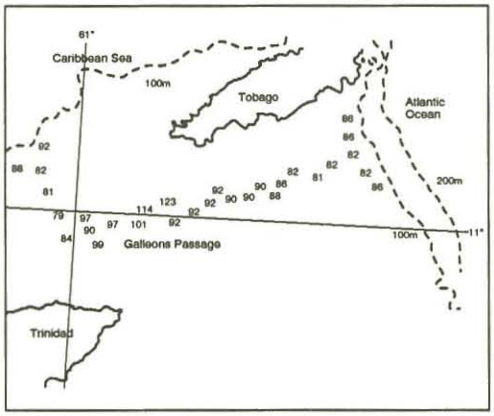


Figure 13. Maximum sea depths in metres between Trinidad and Tobago. (Source: World Geodetic System – 1972 Datum)

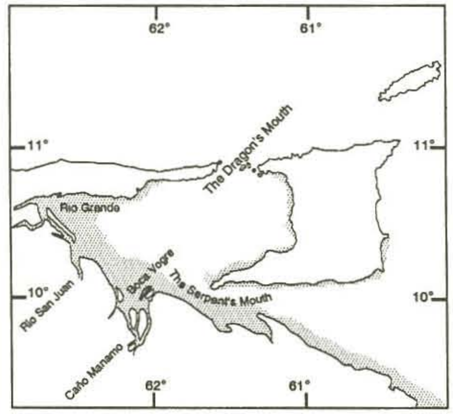


Figure 14 Trinidad shore-line about 10,000 ybp. (Source: Texaco Trinidad Quarterly 1961)

This could have led to the formation of forest refuges temporarily separating populations of forest animals and plants, and leading to speciation in isolation (an increase of endemism).

This scenario can work the other way when moist forest advances with a return to wetter climatic conditions, and savannas and xerophytic habitats retreat. Repeated events like these would help explain some of the disjunct distributions we see in the region today. Also, during the Early Pleistocene when Trinidad's shore-line extended further north and east, edaphic savannas, like Aripo, may have been more widespread in low-lying areas.

Recent maximum forest cover in Trinidad seems to have corresponded with the optimum post-glacial climatic period between 7,000 and 5,000 ybp. The earliest Amerindian artifacts so far known (near Biche) date from 11,000 ybp (P. Harris pers. comm.). It seems unlikely that the Amerindians had much impact on this forest cover as their activities seem to have been confined to coastal areas. With the final land separation between Trinidad and South America occuring 10,000 ybp, this forest remained relatively undisturbed. We can postulate, therefore, that this maximum forest cover of 7,000 to 5,000 ybp more or less persisted until pre-Columbian times (500 ybp). An indication of what the components of this forest cover were can be seen in Table 3. By comparing these pre-Columbian forest types with what exists in Trinidad today we can see the dramatic changes that have taken place in recent times. That, however, is another story.

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