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THE TECTONIC EVOLUTION OF THE NORTH CENTRAL CARIBBEAN PLATE MARGIN

by

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1984

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Certified by: ....
Thesis Supervisor.

WHOI - 1984

Accepted by: ....
Chairman, Joint Oceanographic Comittee
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Institute of Technology - Woods Hole
Oceanographic Institution.

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Submitted to the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography on January 10th. 1981 in partial fulfilment of the requirements for the degree of Doctor of Science.

ABSTRACT

The results of a detailed geophysical survey are used in conjunction with all available information in a study of the tectonic development of the Cayman Trough and the Greater Antilles Ridge. This development is connected with the relative motions of the North and South Americas' and the eastern Pacific plates. Thus, the pre-Tertiary history of the region is one of simple convergence. This contrasts with the complex tectonism of primary translation, with secondary convergence and divergence during the Tertiary. The ancestral Greater Antillean Arc suffered fracturing during collision with the Bahamas stable platform in the Late Cretaceous. Oblique convergence re-established itself across the remnant fragments of the ancestral arc in the Tertiary, producing a sheared welt partially decoupled from both the North American and Caribbean plates. Pronounced temporal and structural heterogeneity occurs within this Plate Boundary Zone. Along its northern margin secondary convergence with the North American plate formed the massive subduction complex of the Cuchillas Uplift and the Sierra Septentrional. Convergence between the Plate Boundary Zone and the Caribbean plate resulted in the triple virgation of the fold belts extending westward from the Los Muertos Trough to Oriente Province (Cuba), the Cayman Trough and the Nicaraguan Rise. Tectonism along these fold belts youngs southwestward preserving the stratigraphy of the Caribbean Basin at the time of their formation during the early, middle, and late Tertiary. The Caribbean/North American Plate boundary occured along the zones of major strain accomodation within the Plate Boundary Zone. The Cayman Trough was produced during a period of divergence between the Nicaraguan Rise and the North American plates during the Miocene. Since the Pliocene, the shear boundary within the Cayman Trough occurs along the Oriente Deep proceeding via the

Windward Passage Deep and the Valle del Cibao to the Puerto Rico Trench. Convergence and shear predominate the present tectonic framework of the Plate Boundary Zone.

Thesis Supervisor: Dr. Elazar Uchupi
Title: Senior Scientist

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The relationships of all those people and events that influenced me during this period appear to be like a spiders web in the early morning dew. They are too delicate to capture. By acknowledging only the complexity and recursion of the structure can I hope to thank all those who helped and hindered me. These include ships, computers, labourers, teachers, friends, artists, authors, poets, philosophers, arguments, oceans, emptiness and silence.

Elazar Uchupi, John Sclater, Henry Dick, Hans Schouten, Kevin Burke and Hartley Hoskins require special mention. I humbly thank them. Henry will long be remembered for his honesty.

In so much that life is a footnote in the evolution of the volatiles of the Universe, I acknowledge those organic components, and the paths that energy, space-time and chance took to assemble them.

My final thanks go to my family. Their quality and intelligence burn brightly in a dark world.

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CHAPTER 1

INTRODUCTION

This study is intended to resolve the present and past geometry of the northern Caribbean plate boundary in the region extending roughly from Jamaica to the Puerto Rico Trench (Figure 1). Comparitively little subaerial exposure of the major geologic and structural elements occurs in this region. Elements along this boundary include the Old Bahama Channel, the Caicos Basin, the Greater Antillean Ridge, the Cayman Ridge, the Cayman Trough, the Nicaraguan Rise, the Colombian Basin, the Beata Ridge, the Venezuelan Basin, and the Puerto Rico Trench (Figures 1, 5). The marine geophysical data base gathered during this study was specifically located to allow the mapping of the inter-relationships occuring between these major structural and stratigraphic entities.

The Caribbean Plate

The Caribbean Plate and adjacent borderlands are shown in Figure 1. The present extent of the Caribbean Plate includes the Colombian and Venezuelan basins, the Beata Ridge, the Aves Swell, the Grenada Trough and the Lesser Antilles. The Nicaraguan Rise, Central America, northwestern South America and portions of the Greater Antilles are commonly included as part of the plate (Figures 1-3; e.g. Molnar and Sykes, 1969; Bowin 1976). The physiography of the Caribbean region is discussed in detail by Uchupi (1975).

Location of the seismicity along the Caribbean borderlands define narrow unambiguous plate margins along the Middle America Trench, the Cayman Trough, the Puerto Rico Trench and the Lesser Antilles (Figures 1-3). The seismicity within the area extending from Jamaica to Puerto Rico, including the island of Hispaniola, is diffuse and fails to identify a unique plate boundary (Figures 1-3). Thus workers in the field have proposed several loci for the northern Caribbean plate boundary in this region including through northern, central or southern Hispaniola (e.g. Molnar and Sykes, 1969; Uchupi, 1975; Bowin, 1976). One of the major quandries surrounding the location of the present plate margin is the apparent dissapearance of the major shear boundary running along the northern Cayman Trough in the region of the Windward Passage (Molnar and Sykes, 1969). The problem is addressed in this study.

Geological evidence from the Caribbean suggests that the dominant tectonic process is translation with subduction with or without volcanism being secondary. Translation and shear.

Figure 1. Principle features in the Caribbean region. Contours on land are at elevations of 200, 1000, 2000, 3000, and 4000 m (Times Atlas of the World, 1957). At sea contours are at depths of 200, 2000, 4000, and 6000 m (Uchupi, 1971; Chase and Menard, 1964). Solid circles are active volcanoes. Inset shows plate boundaries given by Molnar and Sykes (1969, Figure 1). Figure is taken from Bowin (1976, Figure 1).

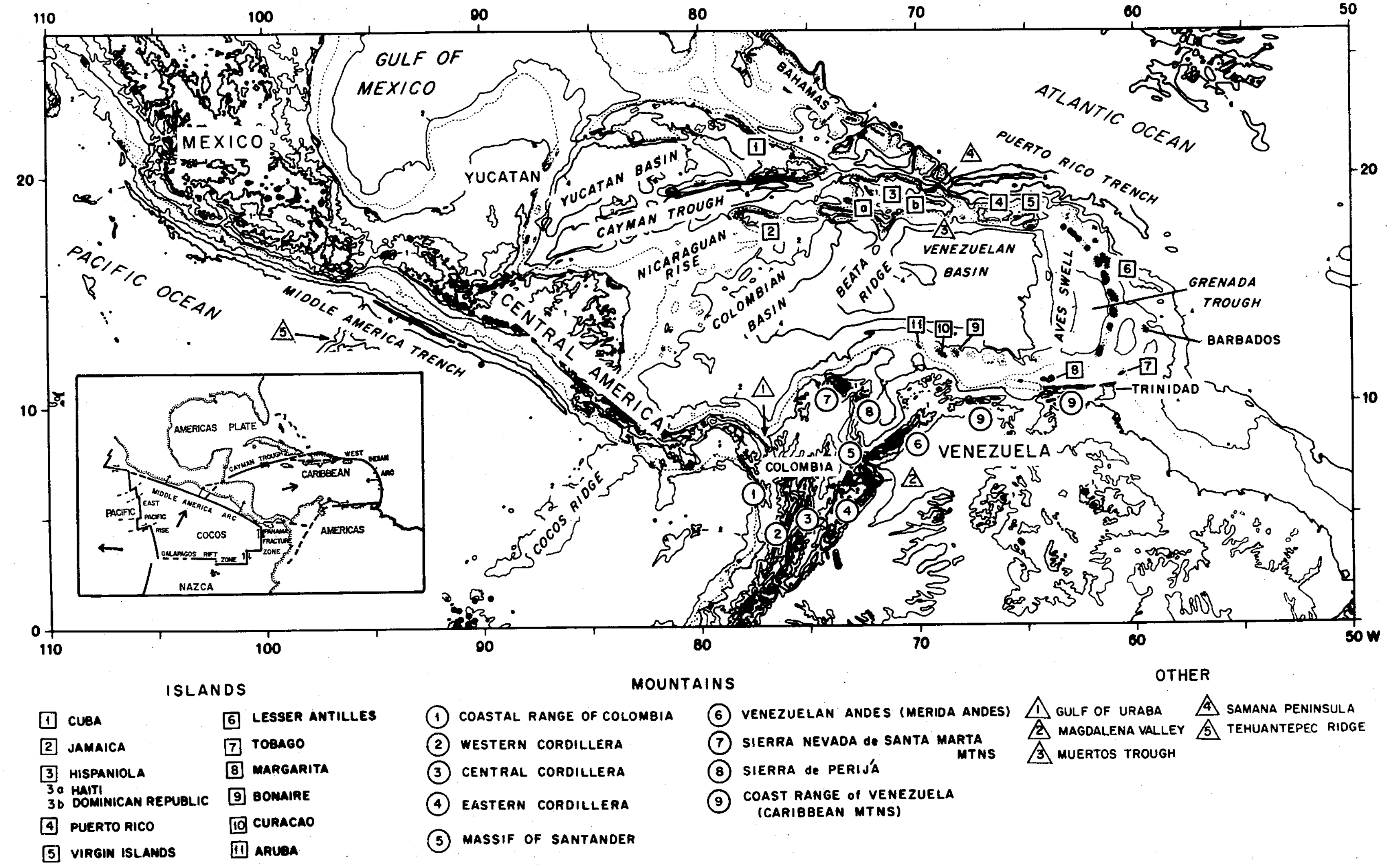

110
100
90
80
70
60
50
50 W
20
10
0
GULF OF MEXICO
ATLANTIC OCEAN
PACIFIC OCEAN
MEXICO
YUCATAN
BAHAMAS
PUERTO RICO TRENCH
YUCATAN BASIN
CAYMAN TROUGH
NICARAGUAN RISE
COLOMBIAN BASIN
BEATA RIDGE
VENEZUELAN BASIN
AVES SWELL
GRENADA TROUGH
BARBADOS
TRINIDAD
MIDDLE AMERICA TRENCH
CENTRAL AMERICA
COCOS RIDGE
COLOMBIA
VENEZUELA
AMERICAS PLATE
CAYMAN TROUGH
CARIBBEAN
WEST INDIAN ARC
MIDDLE AMERICA ARC
EAST PACIFIC RISE
PACIFIC
COCOS
GALAPAGOS RIFT ZONE
PANAMA FRACTURE ZONE
AMERICAS
NAZCA
ISLANDS
1 CUBA
2 JAMAICA
3 HISPANIOLA
3a HAITI
3b DOMINICAN REPUBLIC
4 PUERTO RICO
5 VIRGIN ISLANDS
6 LESSER ANTILLES
7 TOBAGO
8 MARGARITA
9 BONAIRE
10 CURACAO
11 ARUBA
MOUNTAINS
1 COASTAL RANGE OF COLOMBIA
2 WESTERN CORDILLERA
3 CENTRAL CORDILLERA
4 EASTERN CORDILLERA
5 MASSIF OF SANTANDER
6 VENEZUELAN ANDES (MERIDA ANDES)
7 SIERRA NEVADA de SANTA MARTA MTNS
8 SIERRA de PERIJÁ
9 COAST RANGE of VENEZUELA (CARIBBEAN MTNS)
OTHER
1 GULF OF URABA
2 MAGDALENA VALLEY
3 MUERTOS TROUGH
4 SAMANA PENINSULA
5 TEHUANTEPEC RIDGE

Figure 2. Earthquake epicenters in the Caribbean region from 1961 to 1970 as compiled by the U.S. Coast and Geodetic Survey. Figure taken from Bowin (1976, Figure 13)

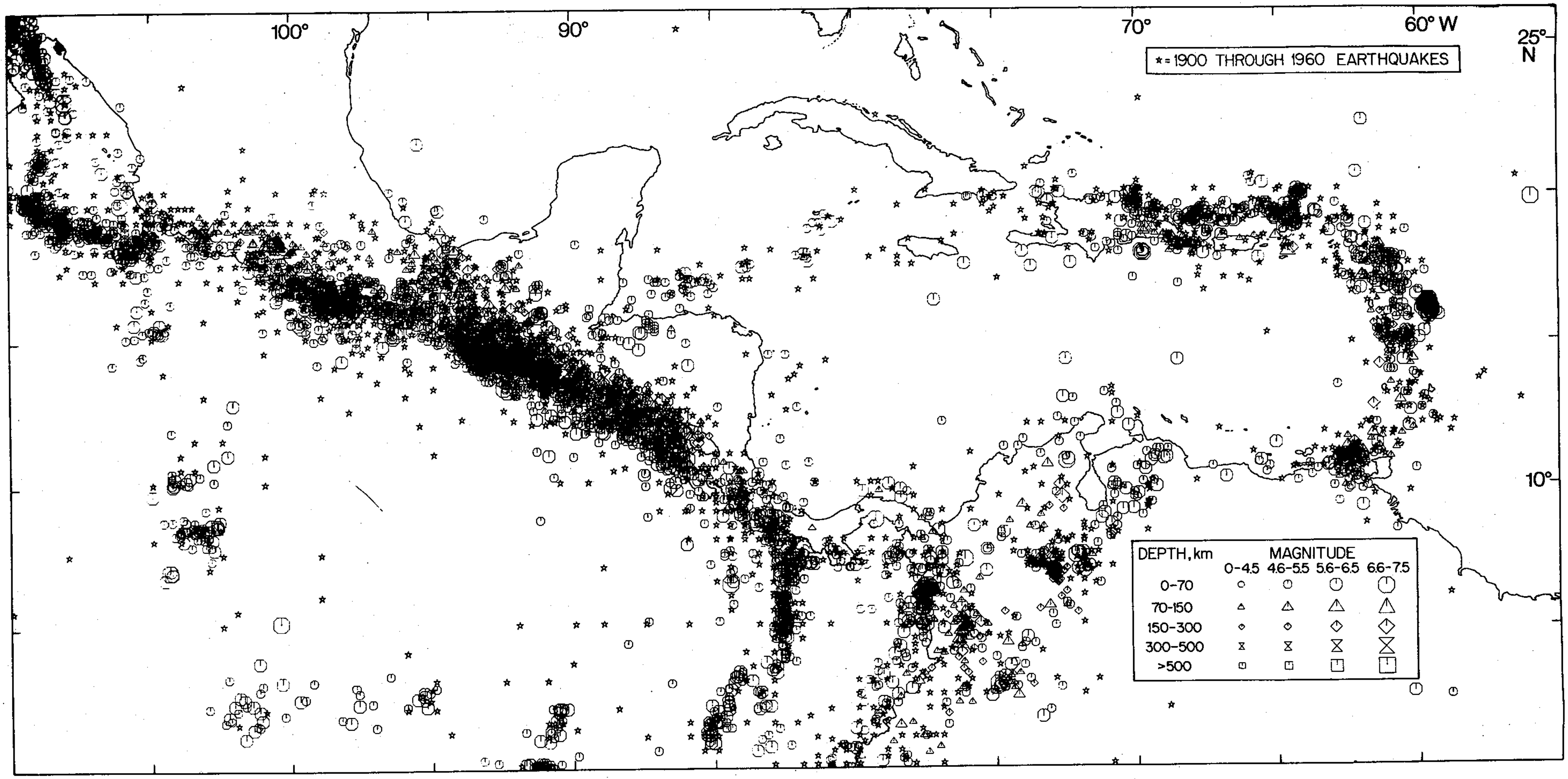
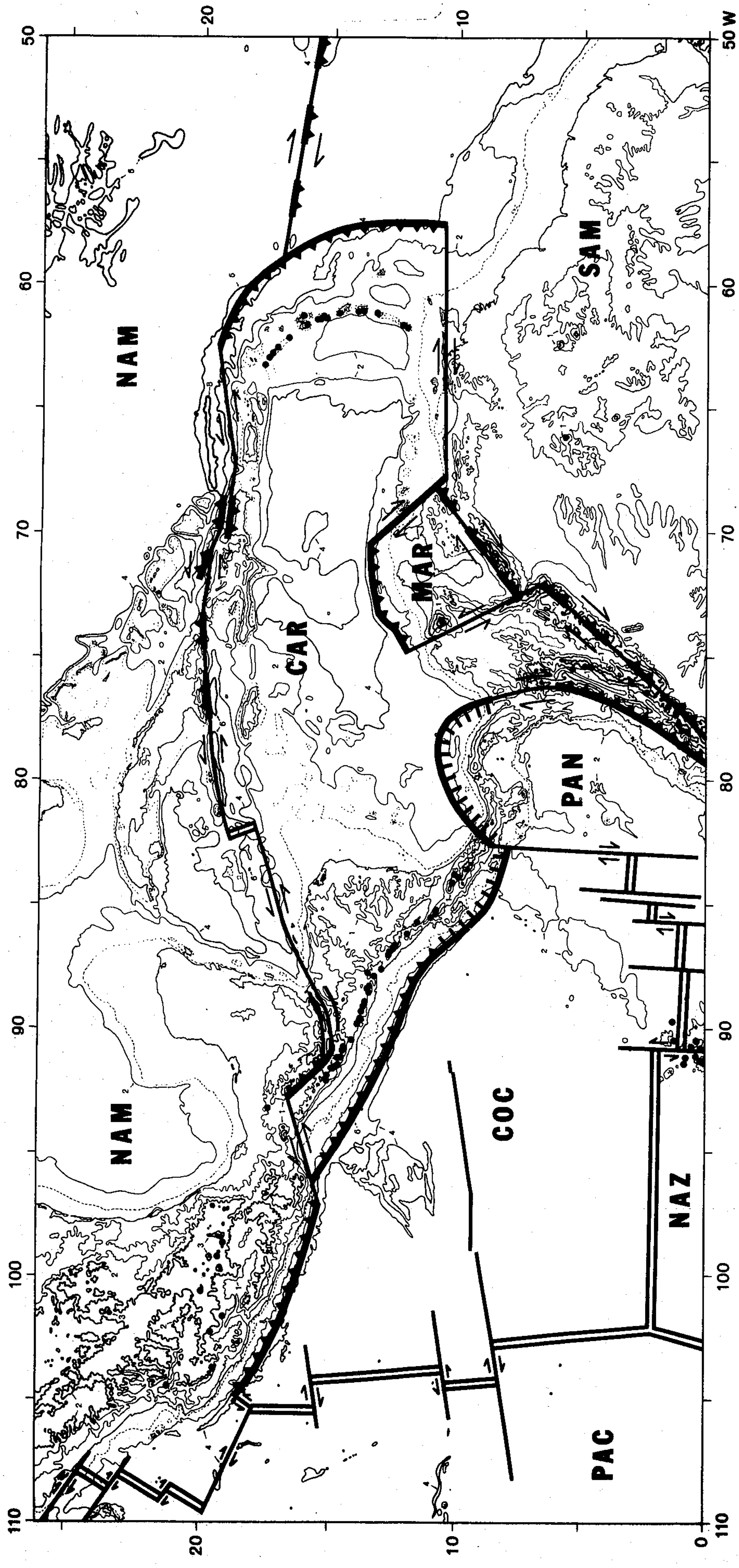

100°
90°
70°
60° W
25° N
10°
* = 1900 THROUGH 1960 EARTHQUAKES
DEPTH, km
MAGNITUDE
0-4.5
4.6-5.5
5.6-6.5
6.6-7.5
0-70
70-150
150-300
300-500
>500

Figure 3. Inferred present plate boundaries in the Caribbean region. Double lines: extensional tectonics. Single thin lines: strike-slip tectonics. Single heavy lines with hatchure: sites of compression. Heavy lines with solid triangles: subductive tectonism. Plates are labled: NAM, North America; SAM, South America; CAR, Caribbean; COC, Cocos; PAC, Pacific; NAZ, Nazca; PAN, Panama block; MAR, Maricaibo block. Contours and solid dots as in Figure 1. Figure taken from Bowin (1976, Figure 16).


NAM
NAM
CAR
MAR
PAN
SAM
COC
NAZ
PAC
50
60
70
80
90
100
110
50 W
110
0
10
20

Data Base

Approximately 3,000 line kms of geophysical data were collected in the Jamaican and Windward Passages during cruise 97, leg 1, of the R/V ATLANTIS II in January and February 1978. The ships tracks are shown in Figure 5. Navigation was by satellite, Omega, Radar (near shore), and dead reckoning.

Bathymetry was measured primarily with a hull mounted twelve element broad-beam, 3.5 kHz transducer, using pulse lengths ranging from 0.2 - 5.0 milliseconds, and recorded on a Hydro Products graphic recorder. The records were digitized at five minute intervals and at every slope break. Depths were corrected for sound velocity using Matthews (1939) tables. These data, supplemented by all other available data from the region, were used to compile the chart in Figure 4. The total geomagnetic field intensity was measured with a Varian proton precession magnetometer towed 250 meters behind the ship. The magnetic anomaly was calculated by subtracting the International Geomagnetic Reference Field (Leaton, 1976).

Gravity measurements were made with a vibrating string accelerometer mounted on a gyro-stabalized table (Bowin, Aldrich, and Folinsbee, 1972). Corrections were applied for the Etvos effect and instrument drift, and free air and Bouguer anomalies were calculated.

Seismic reflection profiles on lines 1 through 3 were made with a 12-channel array, and lines 6 through 28, with two signal summed single channel hydrophone arrays. The sound source consisted of combinations of a 1000 in^3, a 300 in^3, a 120 in^3, an 80 in^3, and a 40 in^3 Bolt air guns. They were fired every 34.0 seconds at an air pressure of 1500 lbs/in^2. Towing speeds varied between 4.5-5.5 knots depending upon the sea state. Signals from the arrays were recorded in real-time analog format on Hewlett Packard X-Y recorders at a 5.0 and 10.0 second sweep. Channel 3 was monitored during the multi-channel profiling. The data also were recorded on magnetic tape in digital format, using a 4.0 millisecond interval, and predominantly a 5.0 second record length. Both single-channel and 12-channel records were deconvolved in single channel format for all water depths of less than 1.0 sec. Interpretation of the records was done by using acetate overlays to trace reflectors. These reflectors were then reduced with proportional dividers and grid onto the bathymetric profiles.

Figure 4. Topography of study area . The contour interval is 200m, (offshore contours are corrected for sound velocity). Solid dots: AII 97/1 track lines; Open circles Ch 47 tracks. Additional bathymetric data were obtained from the Preliminary Bathymetric Map of the Caribbean compiled by Case and Holcombe (1976). The contours for Cuba and Hispaniola were taken from maps compiled by the American Geographical Office (1955).

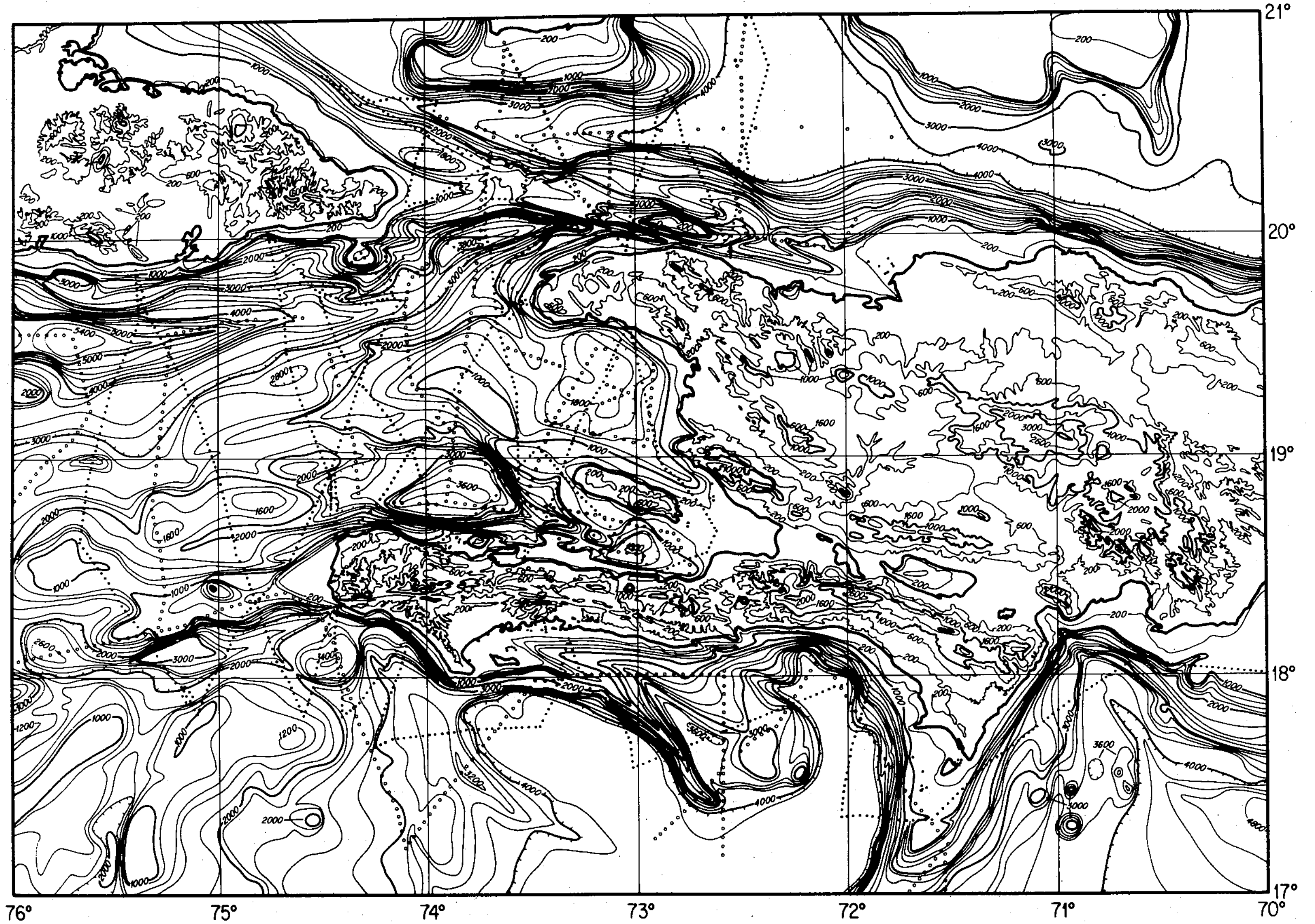
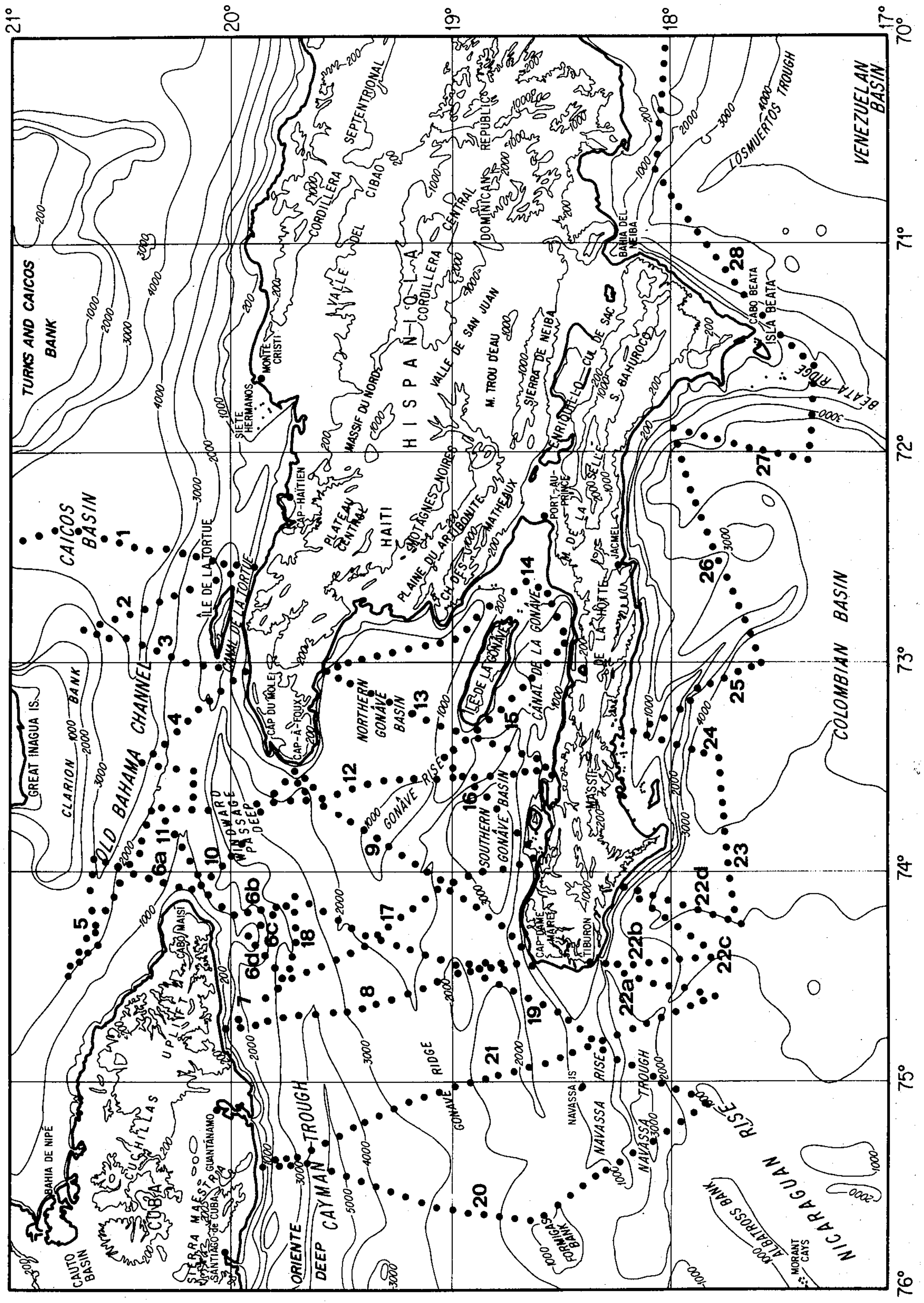

21°
20°
19°
18°
17°
76°
75°
74°
73°
72°
71°
70°

Figure 5. Major Physiographic units in the study area. Contours are in meters. Numbered and dotted lines are ATLANTIS II Cruise 97/leg 1 profiles.


21°
20°
19°
18°
17°
76°
75°
74°
73°
72°
71°
70°
TURKS AND CAICOS BANK
CAICOS BASIN
GREAT INAGUA IS.
CLARION BANK
OLD BAHAMA CHANNEL
WINDWARD PASSAGE DEEP
ILE DE LA TORTUE
CANAL DE LA TORTUE
CAP DU MOLE
CAP-À-FOUX
CAP-HAITIEN
MONTE CRISTI
SIETE HERMANOS
CORDILLERA SEPTENTRIONAL
VALLE DEL CIBAO
CORDILLERA CENTRAL
DOMINICAN REPUBLIC
HISPANIOLA
VALLE DE SAN JUAN
MASSIF DU NORD
PLATEAU CENTRAL
HAITI
MONTAGNES NOIRES
PLAINE DU ARTIBONITE
CH. DES MATHEUX
M. TROU D'EAU
SIERRA DE NEIBA
ENRIQUILLO
CUL DE SAC
S. BAHURUCO
BAHIA DEL NEIBA
CABO BEATA
ISLA BEATA
BEATA RIDGE
LOS MUERTOS TROUGH
VENEZUELAN BASIN
PORT-AU-PRINCE
M. DE LA SELLE
M. DE LA HOTTE
JACMEL
NORTHERN GONÂVE BASIN
ILE DE LA GONÂVE
CANAL DE LA GONÂVE
SOUTHERN GONÂVE BASIN
GONÂVE RISE
MASSIF
TIBURON
CAP DAME MARIE
COLOMBIAN BASIN
NAVASSA IS.
NAVASSA RISE
NAVASSA TROUGH
NICARAGUAN RISE
ALBATROSS BANK
MORANT CAYS
FORMIGAS BANK
GONÂVE RIDGE
ORIENTE DEEP
CAYMAN TROUGH
CUBA
CUCHILLAS
SIERRA MAESTRA
UPLIFT
CABO MAISI
GUANTÁNAMO
SANTIAGO de CUBA
BAHIA DE NIPE
CAUTO BASIN
1
2
3
4
5
6a
6b
6c
6d
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22a
22b
22c
22d
23
24
25
26
27
28
200
1000
2000
3000
4000
5000

CHAPTER II

GEOLOGIC SETTING

It is apparent from the bathymetric map that the study area is marked by considerable physiographic complexity (Figure 4). For simplicity I subdivide the area into a series of morphologically and genetically related basin and rise systems (Figures 5-7). These divisions are based on physiography, stratigraphy and structural relationships.

Old Bahama Channel/Caicos Basin System.

The Caicos Basin is an irregularily shaped depression between the Clarion Bank, the Turks and Caicos Bank, and Hispaniola (Figure 5). Elongated on an east north east trend it has a secondary north south elongation in the central portion (Figure 5). It is continuous with the Puerto Rico Trench to the east, and the Old Bahama Channel to the west. The main portion of the basin lies at depths greater than 4000m, rising to 2900m in the Old Bahama Channel to the west (Figures 4, 5).

Ball et al. (1968), Uchupi et al. (1971), Uchupi (1975), and E. Richardson (personal communication) have described

Figure 6. Major geological units in the region. S = Samana peninsula; SB = Bahia de Samana.

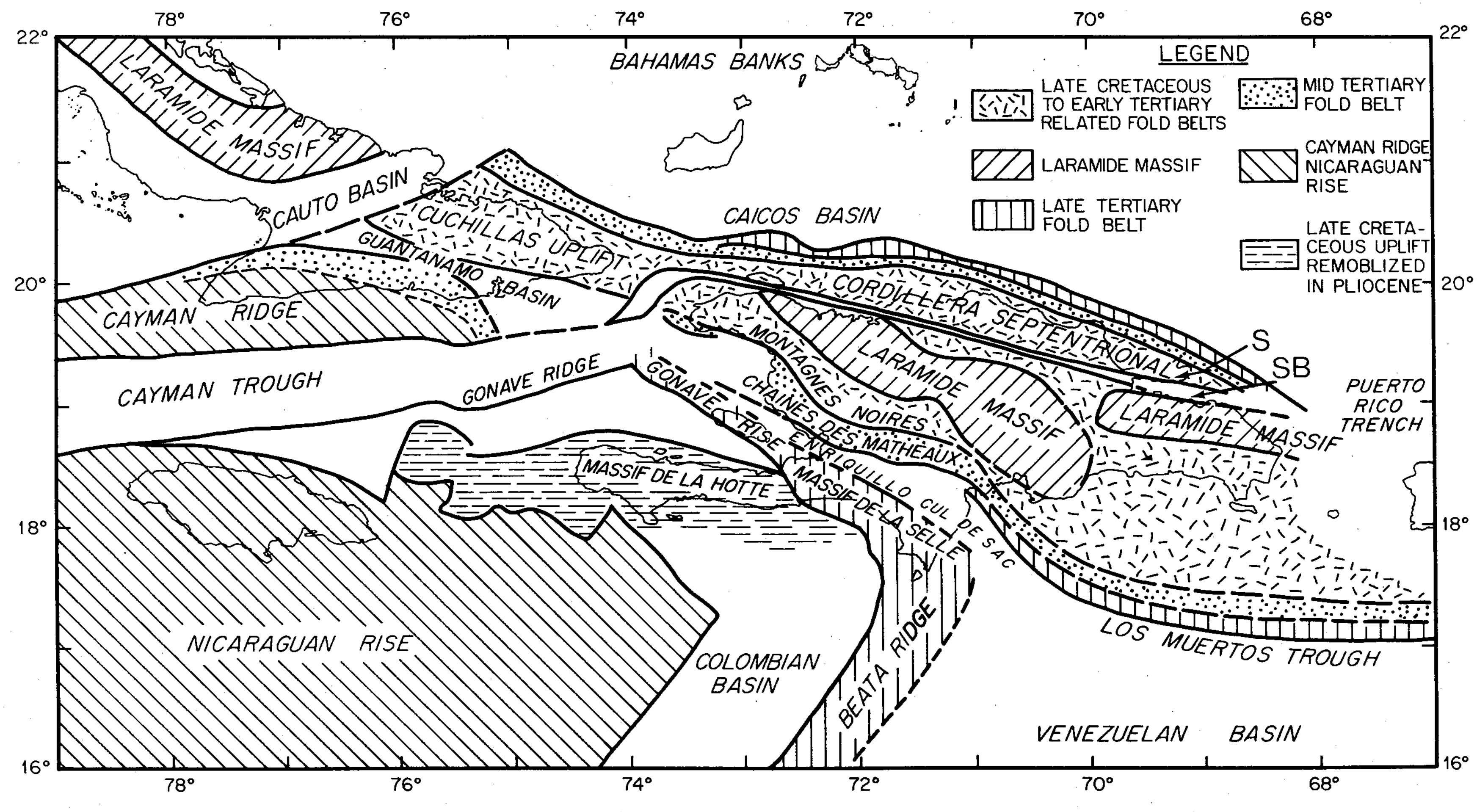
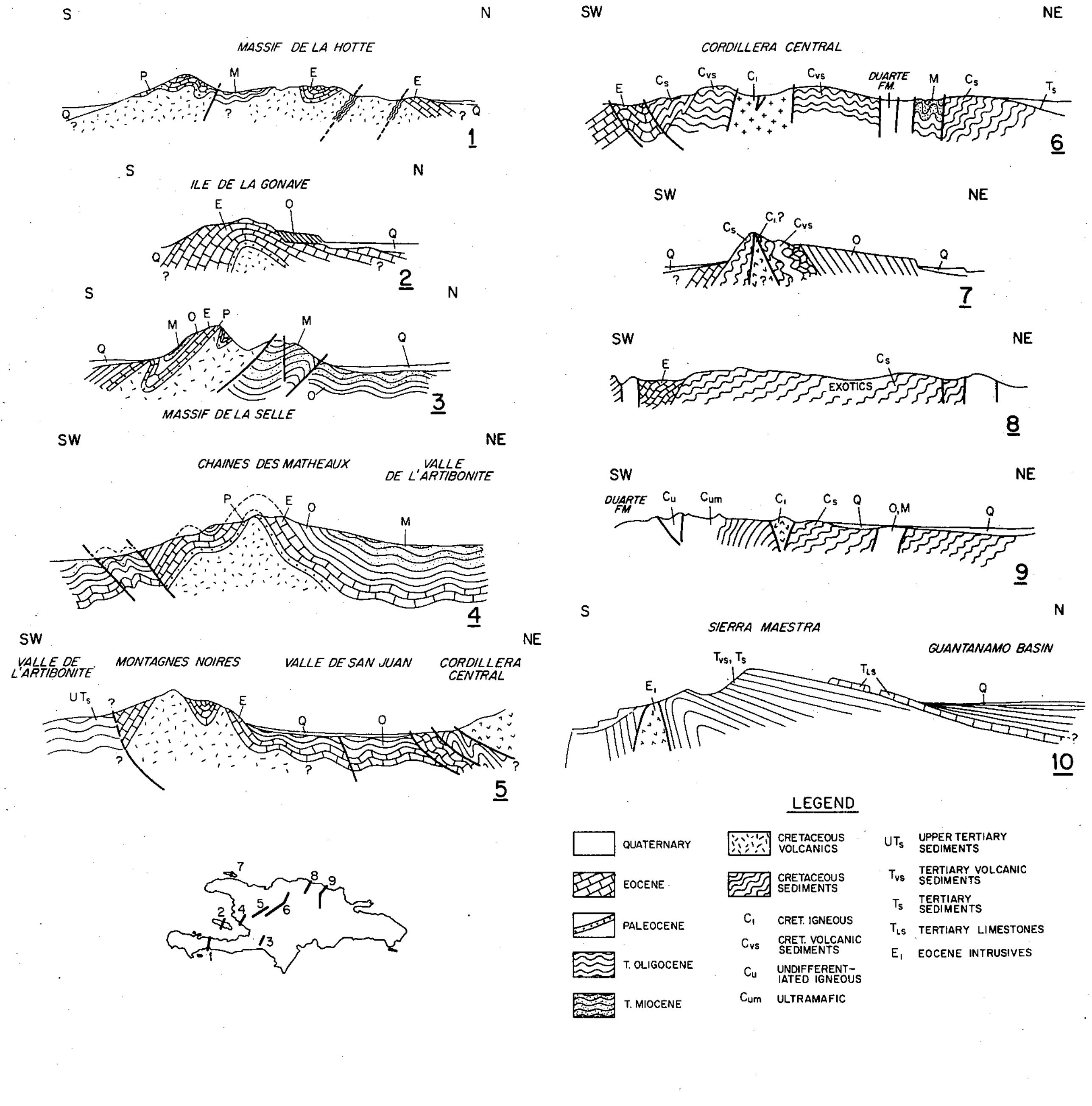

LEGEND
LATE CRETACEOUS TO EARLY TERTIARY RELATED FOLD BELTS
LARAMIDE MASSIF
LATE TERTIARY FOLD BELT
MID TERTIARY FOLD BELT
CAYMAN RIDGE NICARAGUAN RISE
LATE CRETACEOUS UPLIFT REMOBLIZED IN PLIOCENE
BAHAMAS BANKS
CAICOS BASIN
LARAMIDE MASSIF
CAUTO BASIN
CUCHILLAS UPLIFT
GUANTANAMO BASIN
CAYMAN RIDGE
CAYMAN TROUGH
GONAVE RIDGE
CORDILLERA SEPTENTRIONAL
LARAMIDE MASSIF
MONTAGNES NOIRES
CHAINES DES MATHEAUX
GONAVE RISE
ENRIQUILLO CUL DE SAC
MASSIF DE LA SELLE
MASSIF DE LA HOTTE
S
SB
PUERTO RICO TRENCH
LARAMIDE MASSIF
LOS MUERTOS TROUGH
VENEZUELAN BASIN
BEATA RIDGE
COLOMBIAN BASIN
NICARAGUAN RISE
78°
76°
74°
72°
70°
68°
22°
20°
18°
16°

Figure 7. Diagrammatic cross sections over the major physiographic provinces within the study area. Sections 1 through 9 from Weyl (1966) and Bowin (1975). Section 10 is a generalized cross section in south central Oriente Province, Cuba, adapted from Lewis and Straczeck (1955).


S
N
MASSIF DE LA HOTTE
P
M
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Q
1
S
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ILE DE LA GONAVE
E
O
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Q
?
?
2
S
N
M
O
E
P
M
Q
Q
O
MASSIF DE LA SELLE
3
SW
NE
CHAINES DES MATHEAUX
VALLE DE L'ARTIBONITE
P
E
O
M
4
SW
NE
VALLE DE L'ARTIBONITE
MONTAGNES NOIRES
VALLE DE SAN JUAN
CORDILLERA CENTRAL
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5
SW
NE
CORDILLERA CENTRAL
E
Cs
Cvs
Ci
Cvs
DUARTE FM.
M
Cs
Ts
6
SW
NE
Cs
Ci?
Cvs
Q
O
Q
?
?
7
SW
NE
E
Cs
EXOTICS
8
SW
NE
DUARTE FM
Cu
Cum
Ci
Cs
Q
O,M
Q
9
S
N
SIERRA MAESTRA
GUANTANAMO BASIN
Tvs, Ts
Tls
Ei
Q
?
10
7
8
9
5
6
2
4
3
1
LEGEND
QUATERNARY
EOCENE
PALEOCENE
T. OLIGOCENE
T. MIOCENE
CRETACEOUS VOLCANICS
CRETACEOUS SEDIMENTS
Ci CRET. IGNEOUS
Cvs CRET. VOLCANIC SEDIMENTS
Cu UNDIFFERENTIATED IGNEOUS
Cum ULTRAMAFIC
UTs UPPER TERTIARY SEDIMENTS
Tvs TERTIARY VOLCANIC SEDIMENTS
Ts TERTIARY SEDIMENTS
TLs TERTIARY LIMESTONES
Ei EOCENE INTRUSIVES

seismic profiles from the basin. A zone of salt diapirs extends from northern Cuba (Khudoley and Meyerhoff, 1971) down the axis of the Old Bahama Channel, sub-paralleling the southern margin of the Caicos Basin (Uchupi, 1975; Richardson, personal communication). No direct stratigraphic information exists within the basin. However where diapirs have been sampled on the northern coast of Cuba they are cored with Portlandian evaporites and are overlain by massive Cretaceous to Eocene carbonates (Khudoley and Meyerhoff, 1971; Pardo, 1975). Structurally uneventful, the basin has a turbiditic character with minor faulting associated with the evaporite stocks. In the southern portion of the basin the strata are involved in folding along the Greater Antilles Ridge. The basin is aseismic (Molnar and Sykes, 1969; Bowin, 1976). Free air gravity anomalies range from -125 mgals to -225 mgals, indicating a nonisostatic regime (Bowin, 1976).

Cuchillas Uplift/Windward Passage Sill/Ile de la Tortue Rise/Cordillera Septentrional System

The Cuchillas Uplift--Cordillera Septentrional System is physiographically continuous from the Cauto Basin to the Samana peninsula (Figure 7). It is bound to the north by the Old Bahama Channel and the Caicos Basin, to the west by the Cauto Basin and to the south by the Guantanamo Basin, the Windward Passage Deep, the Canal de la Tortue, the Valle de Cibao, and the Bahia de Samana (Figure 6). Along the northern margin depths range from 4000 m to 2800 m below sea level . The crest of the System lies on a W 15° N trend, with elevations ranging from 1300 m below sea level to 1000 m above sea level. At the southern margin elevations vary from 3000 m below sea level to 200 m above sea level (Figure 4). The topography is rugged with a short wave length component subparalleling the major axis.

The Cuchillas Uplift--Cordillera Septentrional System is geologically heterogeneous, containing all the elements associated with a mature subduction complex (Bowin, 1975). Mapping in the Cordillera Septentrional and Peninsula de Samana by Nagle (1966, 1971, 1974), reveal the presence of highly deformed clastics, pyroclastics, and serpentinites (presumed to be of ophiolitic origin) (Sections 7-9, Figure 7). These rocks are typical of accretionary sediment prisms associated with convergent tectonic margins. On Isle de la Tortue, Butterlin (1960), Bowin (1975), and Nagle (personal communication) report the existence of heavily folded and sheared calcareous schists of Eocene/Miocene age. They contain some well rounded cobbles of quartz diorite, dacite, and andesite of Late Cretaceous(?) age (Nagle, personal communication).

Mapping coverage on the Cuchillas Uplift is poor (see

Appendix 1 for discussion of the geology of the uplift). Presumably it is this lack of data which has allowed the Cuchillas Uplift and the Sierra Maestra to be considered as portions of a single geologic entity (e.g. Khudoley and Meyerhoff,1971; Appendix 1).

The stratigraphic units of the Cuchillas Uplift include a basal overturned ophiolitic fragment (Kumpera, 1968), pillow lavas (Lewis and Strazeck, 1955; Boiteau et al, 1972), followed by a thick succession of interbedded clastic, pyroclastic, and bioclastic sediments (Lewis and Strazeck, 1955; Appendix 1). Boiteau et al. (1972a,b) described eclogitic and amphibolitic metamorphic assemblages within the pillow lava sequence along the southern margin of the Uplift (Appendix 1). The stratigraphy of the Chuchillas Uplift suggests a similar age, deformational sequence, and structural trend to that of the Cordillera Septentrional and the Montagnes Noires (Appendix 1).

Free air gravity anomalies over the entire length of the Cuchillas Uplift/Cordillera Septentrional System are roughly +50 mgal (Bowin, 1976). On the order of ten earthquakes of magnitude 5.0-7.0 have occurred along the rise at depths of less than 70 kms (Bowin, 1975; Figure 2). Molnar and Sykes (1969) have calculated an oblique slip thrusting vector from first motion studies of some of these seismic events.

The Windward Passage Deep/Canal de la Tortue/ Valle de Cibao/Bahia de Samana System.

The Windward Passage Deep/Bahia de Samana System is a narrow low extending from the eastern tip of the Cayman Trough through the Canal de la Tortue, the Valle de Cibao, and the Bahia de Samana into the Puerto Rico Trench (Figure 4-6). It is bound to the north by the Cuchillas Uplift/Cordillera Septentrional System, and by the Northwest Haitian peninsula/Massif du Nord/Cordillera Central System and the Sierra del Seibo to the south. Striking predominantly N 75°W from the Bahia de Samana to the northern margin of the Windward Passage Deep it widens into a sigmoidal basin in the deep and joins the eastern Cayman Trough (Figures 4-6). Its width varies from 5 kms in the Canal de la Tortue to 40 kms in the Valle del Cibao. Elevations range from 3800m below sea level in the Windward Passage Deep to 200 m above sea level in the Valle del Cibao.

Bowin (1975) believes the northern and southern flanks of the Valle del Cibao are strike slip fault controlled (Figures 4, 5, 35). The Valle del Cibao itself is a Pliocene feature containing up to 3600m of sediments (Bowin 1975). Bowin (1975) suggests that prior to the Pliocene only gentle down warping occured along the system. By inference the Bahia de Samana and the Canal de la Tortue have a similar tectonic history. It seems reasonable to assume the existence of a Late Cretaceous to Holocene fore arc basin in this region which was dammed by the subduction complex of the Cordillera Septentrional (Figures 4, 35; Bowin, 1975; Nagle, personal communication).

Bowin (1976) found free air gravity anomalies ranging from -175 mgals in the Windward Passage Deep to 0 mgals for the Valle de Cibao. Seismicity appears to be related to underthrusting of the Atlantic Basin (Molnar and Sykes, 1969; Figure 2). Klitgord (personal communication) considers the seismicity along the northern Hispaniolan margin to define a inclined strike slip fault plane dipping south.

The Cordillera Central System.

The Cordillera Central strikes N 70°W and extends as a rugged mountainous terrain from the northwestern tip of the Massif du Nord, to the Coastal Plain of central Hispaniola (Figures 4-6). It varies in width from 30 kms to 60 kms, with elevations ranging from 200 m to over 3000 m above sea level (Figure 4). The highest peaks in the Caribbean exist in this Cordillera. It is bound to the north by the Canal de la Tortue/Valle de Cibao and to the south by the Plateau Central/Valle de San Juan, and varies in width from 30 kms to 60 kms.

The oldest rocks of the Massif du Nord/Cordillera Central System consist of metamorphosed basic volcanics including quartz keratophyres, keratophyres, and waterlain pyroclastics (Bowin, 1960, 1966, 1975; Palmer, 1963; Roobol, personal communication). These are assigned a minimum age of 127 MYBP, the radiometric age of an intrusive body within the basal units (Bowin, 1975). Donnelly (1964) considers similar rock suites on the Virgin Islands to be oceanic in origin, and indicative of the earliest stages of island arc volcanic activity. A fault zone within the basal formations on Hispaniola is interpreted as the trace of a northward dipping subduction zone by Bowin (1975) (Section 6, Figure 7). This implies that the initial stages of island arc volcanism of the ancestral Greater Antilles Ridge were caused by the Pacific (Farallon) plate thrust beneath the North Atlantic plate, a phase lasting only from 160-130 MYBP (Mattson, 1979).

During the Late Mesozoic the direction of subduction reversed (Mattson, 1979; Bowin 1975). The geology of the Cordillera Central indicates prolonged subduction of the North Atlantic basin beneath the Farallon plate along this portion of the ancestral Greater Antilles Ridge at this time (Bowin, 1975; Nagle, 1972). This reversal heralded the rise of the mature island arc volcanic/plutonic complex and associated sedimentary sequences which make up the bulk of the Greater Antilles Ridge

(Bowin, 1975; Mattson, 1979; section 6, Figure 7). Major uplift, deformation and implacement of the major plutonic series throughout the Cordillera Central in the Maastrichtian resulted in large pyroclastic deposits. Concurrent with the uplift, major deposition occured along the northeast and southwest flanks of the Cordillera (Bowin, 1975; Weyl, 1966).

A curious feature of the Cordillera Central, is its abrupt termination against the Tertiary to Quaternary deformed sediments of the Ile de la Tortue high in the northwest and those north of the Los Muertos Trough to the southeast (Bowin, 1975; Ladd and Watkins, 1978; Ladd, personal communication). Clearly mature island arc systems have much greater lateral continuity than is evidenced in this region. Thus these discordant relations indicate:

i) that the ancestral Greater Antilles Ridge was fragmented prior to the establishment of the flanking Tertiary basins.

ii) that the present location and geometry of the Cordillera Central are probably not the same as for the ancestral Greater Antilles Ridge.

iii) that, once disrupted, the present Cordillera Central acted as a "nucleus" for further basin and range formation on its flanks.

Free air gravity anomalies over the Cordillera Central are generally above +100 mgals and range up to +175 mgals (Bowin, 1975). A Bouguer Gravity anomaly high exists in the region with values ranging from +50 mgals to +75 mgals and is flanked by lows of -25 mgals in the basins to the northeast and southwest (Bowin, 1975).

The Cuchillas Uplift/Montagnes Noires/Massif Trou d'Eau, and Plateau Central/ San Juan Basin System.

The Cuchillas/San Juan Basin System includes both the Montagnes Noires highlands and the related Valle de San Juan sedimentary basin to the north east (Figures 4-6). It extends southeastward from the Cuchillas Uplift via the northwestern Haitian peninsula, the Montagnes Noires, the Massif Trou d'Eau to the Coastal Plain of the southwestern Dominican Republic. The associated basin includes the Plateau Central and Valle de San Juan (Figure 4, 5, 6). The Plain de l'Artibonite and Sierra de Neiba flank this System to the southwest and south respectively. Elevations of 600 to 1000 m are common on this province, while those of the Plateau Central and the Valle de San Juan vary from 200 m to sea level. The basin and rise system strikes roughly N 70°W subparalleling the Cordillera Central.

The geology of the southern Cuchillas Uplift is discussed in Appendix 1. Elsewhere along the system the basal unit consists of undifferentiated Cretaceous basalts and dolerites (Butterlin 1954). Their affinity is unknown, but Butterlin (1954) included them with the Cretaceous basalts found in the Chaines des Matheaux, the Massif de la Selle and the Massif de la Hotte. They represent the only recognized volcanics southwest of the Cordillera Central (Butterlin, 1954; Weyl, 1966).

Initial deposition in the region started in the Maastrichtian with the uplift of the Cordillera Central (Bowin, 1975). Sedimentation consisted of pyroclastic material and massive lower Tertiary limestones overlaying the Cretaceous dolerites (Bowin, 1975; Weyl, 1966). These sediments are the youngest deformed units exposed and thus give a maximum age of early Tertiary for the uplift of the Montagnes Noires highland (Section 5, Figure 7). Both lower and upper Tertiary sediments are exposed within the Valle de San Juan basin (Bowin, 1975). Bowin (1975) suggests that there was a progressive emergence of the Cuchillas Uplift/San Juan Basin System until the early to middle Eocene when it became fully emergent and terrestrial deposition became dominant within the Valle de San Juan basin.

Reverse faulting occurs along the contact between the Valle de San Juan basin and the Cordillera Central (Bowin, 1975;

Weyl, 1966) (Section 5, Figure 7). Sediments in the Valle de San Juan basin have been subjected to low amplitude folding affecting even the most recent strata, evidence that diffuse compression continues in the region to the present date (Section 5, Figure 7). The Montagnes Noires highlands are strongly folded and probably overthrust the Plain de l'Artibonite to the southwest (Section 5, Figure 7).

Free air gravity anomalies range from +100 mgals over the highlands to +25 mgals over the Valle de San Juan basin (Bowin, 1975, 1976).

The Cayman Ridge/Sierra Maestra/ Cauto Basin/Guantanamo Basin System.

The Cayman Ridge is one of the major pysiographic features of the northern Caribbean, extending in a broad arc from Central America to the eastern tip of the Sierra Maestra, a distance of roughly 1500 kms (Figures 1, 5, 6). Within the study area only the Sierra Maestra segment of the Ridge is present. This segment is bound by the Cauto and Guantanamo basins to the north and northeast respectively, and by the axial Oriente Deep of the Cayman Trough to the south (Figure 5). Topography of the Sierra is rugged with depths ranging from 5400 m below sea level in the Oriente deep to elevations of greater than 1000 m above sea level on the subaerial portions of the Rise (Figure 4). The topography of the Guantanamo Basin to the north is smooth and has an elevation of roughly 200m above sea level (Figures 4, 5).

Structurally the Sierra Maestra is a sharply assymmetrical homocline (Section 10, Figure 7; Lewis and Strazeck, 1955). Strata are tightly folded along the crest of the Sierra just north of the Cayman Trough. Inland of the topographic divide, the strata dip gently northward plunging under the Tertiary and Quaternary fill of the Cauto and Guantanamo Basins (Section 10, Figure 7). Several major reverse faults lie along the E-W trend of the fold axes. In the eastern section of the Sierra Maestra, structures and outcrops swing to the southwest intersecting the coastline just west of Guantanamo Bay (Figures 4, 5, 35).

Perfit and Heezen (1979) collected seven dredge hauls from the southern flank of the Sierra Maestra. Their samples were predominantly granodiorites, tonolites and basalts showing varying degrees of metamorphism, with some highly sheared and possibly cataclastic samples among the metaplutonic assemblages. A K/Ar^{40} date of 83 ± 2 m.y. was derived from one of the tonalites.

According to Perfit and Heezen (1979), the lithology and stratigraphy of the Cayman Ridge and the Nicaraguan Rise are broadly similar and are composed typically of sedimentary, volcanic and plutonic associations of calc-alkali affinity. These rocks are indicative of an island arc/subductive province that probably dates from the Cretaceous to the mid-Eocene (Appendix 1.).

The Cauto and Guantanamo Basins are broadly synclinal with the strata weakly folded to flat laying. Small domes which may be indicative of deeper structural elements affect the upper strata (Lewis and Straczek, 1955). The nature of the basin and its sedimentary fill is not known. Middle and upper Eocene exposures are largely clastic with biohermal and bedded limestones. The Oligocene and Miocene consists of sandstones, shales, chalks and minor bioclastics. Quaternary deposits are alluvial gravels, sands and silts (Lewis and Straczek, 1955) (Section 10, Figure 7).

Bowin (1976) reports free air gravity anomaly values of approximately +150 over the Sierra Maestra. Pardo (1975) indicates numerous, shallow magnetic sources in the Sierra Maestra and the Cuchillas Uplift, with very deep sources in the Cauto and Guantanamo basins.

The Cayman Trough/Northern Gonave Basin/Plain de l'Artibonite/Chaines des Matheaux/ Sierra Neiba System.

From west to east the Cayman Trough--Sierra Neiba System is bound to the north by the Cayman Ridge, the Sierra Maestra, the Guantanamo Basin, the Cuchillas Uplift, the Windward Passage Deep, the northwestern Haitian peninsula, and the Montagnes Noires System. To the south it is bordered by the Nicaraguan Rise, the Gonave Ridge, Gonave Rise, and the Enriquillo Cul de Sac (Figures 1, 4, 5, 6).

The entire system is a major physiographic and geological feature of the northern Caribbean and extends from Central America to the Los Muertos Trough, a distance of approximately 2000 kms. Within the study area (Figures 4, 5) the Cayman Trough ranges in depth from 5400 m in the Oriente Deep, to 1800 m in the northern Gonave Basin. On Hispaniola elevations in the Plaine du Artibonite tend to be less than 200 m, while those of Chaines des Matheaux, Sierra de Neiba range up to 1600 m above sea level (Figure 4). The topography is rugged on the Chaines des Matheaux and smooth on the Plaine de l'Artibonite and in the Cayman Trough. The Trough is assymetric, deepening to the north (Uchupi, 1975). The strike of this physiographic province changes from east-west in the west of the study area to N 70^{o}W in the east (Figure 1, 2, 3). The Cayman Trough trend is reflected in the structure on the adjacent flanks of the Cayman Ridge and the Nicaraguan Rise (Ballard et al, 1978; Fox and Burke, 1977; Horsfield, 1974; Burke et al, 1980) (Figures 1, 2, 29). These effects are probably due to the sinistral shear strain proposed for the origin of the trough (Molnar and Sykes, 1969; Case, 1975; Case and Holcombe, 1976).

The floor of the Cayman Trough is composed predominantly of the ultramafic suites typical of normal oceanic crust (Perfit and Heezen, 1979). Fresh basaltic rock suites have been recovered from the Mid-Cayman Rise (Holcombe et al., 1971; Ballard et al, 1978).

Perfit and Heezen (1979), describe dredge hauls recovered from the central Cayman Trough midway between Cuba and Jamaica which contain a fine-grain chloritic schist. Land (1979) describes a brown siltstone recovered from a basement high in the mid Cayman Trough which resembles the lower and mid-Eocene pyroclastic unit (the Richmond formation) of Jamaica (Robinson, personal communication). However no stratigraphic information exists for this sample, and carbonates overlaying it are of late Miocene age (Land 1979). Thus the minimum age for this strata is late Miocene. This siltstone horizon represents acoustic basement in seismic profiles taken by Land (1979) and by us (lines 8, 9, 17, 19, 20, 21; Figures 18-21, 24, 25).

No geological information exists for the northern Gonave Basin. The structure of the Plaine de l'Artibonite/Chaines des Matheaux/Sierra de Neiba is similar to that of the Montagnes Noires/Valle de San Juan System (Butterlin, 1954; Bowin, 1956) (Sections 4 and 5, Figure 7). The Chaines des Matheaux and the Sierra Neiba are strongly folded and overthrust to the south and southwest (H. Meyerhoff, personal communication; Weyl, 1966). The Plaine de l'Artibonite is structurally analagous to the Valle de San Juan, being a subsidiary basin developed on the northeast flank of an upthrust foldbelt. Both display the broad deformation affecting the most recent stratigraphic horizons that is indicative of diffuse present day compression (Sections 4 and 5, Figure 7).

Important differences however, occur in the stratigraphic character of either system. Undifferentiated Cretaceous basalts and dolerites occur as the basement in the Chaines des Matheaux (Butterlin, 1954; Bowin, 1975). Overlaying the dolerites are Paleocene and Eocene chalks and limestones, and Oligocene chalky limestones with cherts. These strata are involved in the folded structure of the highlands and give a minimum mid-Tertiary age for tectogenesis of the Chaines des Matheaux/Plaine de l'Artibonite. In contrast, the tectogenesis of the Montagnes Noires/Valle de San Juan is early Tertiary. As has been pointed out by Bowin (1975), there was a progressive emergence of western Hispaniola from the northeast to the southwest over the Tertiary.

A relatively large amount of geophysical data exists in the Cayman Trough (Case, 1975). Over much of the floor of the Trough free air gravity anomaly values indicate it to be near isostatic equilibrium. On the basis of gross similarity, Bowin (1976) suggested that similar tectonic processes were at play in the Cayman Trough, the Red Sea and Gulf of California, with oceanic basement being formed during a rifting episode. However a major narrow low of less than -200 mgals coincides with the Oriente Deep, which led Bowin (1976) to suggest a present day compressive regime across the Trough. Free air gravity anomaly values in the northern Gonave Basin range around 0 mgals increasing to +50 mgals and +100 mgals over the Plaine de l'Artibonite and Chaines des Matheaux/Sierra Neiba respectively.

Seismic refraction measurements reveal a seismic velocity structure typical of oceanic basins in the Cayman Trough, a crustal thickness of approximately 6 kms, and mantle velocities range from 8.0 to 8.3 km/sec (Ewing et al., 1970; Edgar et al., 1971a).

Magnetic anomalies over the eastern Cayman Trough have low amplitudes, and do not have recognizable trends (Case, 1975). However, Gough and Heirtzler (1969) indicate the presence of linear east-west magnetic anomalies paralleling the fracture zone in the Oriente Deep (Figure 3). They have interpreted these anomalies to be due to massive strike slip displacements associated with the Oriente fracture zone.

The Cayman Trough is seismically active along the Oriente Deep (Molnar and Sykes, 1969). On the basis of fault plane solutions which indicate left lateral strike slip tectonics, Molnar and Sykes (1969) have classified the Oriente Deep as a fracture zone forming the present day plate boundary between the North American and Caribbean plates (Figures 1-3).

Heat flow measurements in the Cayman trough are high in the mid-Cayman Rise area ranging from 1.0-3.0 H.F.U. (Ericson et al., 1971; J. Crowe, personal communication). In the eastern portion of the basin a reading of 1.3 H.F.U. has been recorded (Case, 1975).

The Gonave Ridge/Gonave Rise/Massif de la Selle/Sierra Bahoruco/Beata Ridge/ Enriquillo Cul de Sac System.

The Gonave Ridge--Enriquillo cul de Sac System extends from the north-central Nicaraguan Rise via the Gonave Ridge, the Massif de la Selle, the Sierra Bahoruco to the Beata Ridge (Figure 4-6). The Enriquillo Cul de Sac occurs between this system and the Chaines des Matheaux/Sierra Neiba (Figures 4-6). Physiographically variable, depths range from 2000m below sea level along the Gonave and Beata ridges to elevations in excess of 2000m above sea level (Figure 1). The system undergoes a strike change from W 15°S to W 40°N between the Gonave Ridge and Gonave Rise, and again to N 15°E between the Massif de la Selle and the Beata Ridge (Figures 4-6). These various units are interpreted to be parts of a continuous system.

The geology of the Gonave Ridge and Rise west of the Ile de la Gonave is unknown. The Ile de la Gonave is a broadly anticlinal structure of Eocene to Holocene limestones with a presumed core of Cretaceous dolerites (Butterlin, 1956; Weyl, 1966; Bowin, 1975; Section 2, Figure 7). A basement arch of high velocity and high magnetic susceptibility extends from the Ile de la Gonave to the Massif de la Selle (Crux International Inc., personal communication). The Massif de la Selle itself is a complex antiform overthrusting both the Enriquillo Cul de Sac and the Colombian Basin (Weyl, 1966; Section 3, Figure 7).

The basal Cretaceous basalts in western Hispaniola have been correlated by Maurasse et al (1979) with the B" unit in the Venezuelan Basin (Saunders et al, 1973). As discussed in a later section, the stratigraphy of the northern Colombian Basin is assumed to be similar to that of the Venezuelan Basin. Thus the stratigraphy of material preserved within the Gonave Ridge--Enriquillo cul de Sac System is interpreted to be derived from the northern Colombian Basin. On this basis the Cretaceous dolerites mapped by Butterlin (1956) throughout western Hispaniola, which includes those investigated by Maurrasse et al (1979), may either be comparable to, or identical with the dolerites of the sampled in the Venezuelan Basin and also assumed to exist in the Colombian Basin.

Structures in the Massif de la Selle and Sierra de Bahuroco are complex, with block faulting in the west (Maurasse et al., 1979) and extensive compression and thrusting in the central and eastern portions (Weyl, 1966; H. Meyerhoff, personal communication). Where the Massif de la Selle/Sierra de Bahuroco overthrusts the Enriquillo Cul de Sac, deep water upper Miocene marine strata are involved in the folding (H. Meyerhoff, personal communication). The upper Tertiary to Quaternary strata of the Enriquillo Cul de Sac are involved in basinwide folding (H. Meyerhoff, personal communication; K. Burke, personal communication). Thus, the basin is under present day compression, being overthrust along both margins.

The Beata Ridge has a stratigraphy similar to the Venezuelan and Colombian basins (Fox and Heezen, 1975; Case, 1975; Donnelly, 1975). The deformational event giving rise to the Beata Ridge postdates the timing of the Horizon A" event during the mid-Tertiary. The antiquity and tectonic development of the Ridge is debatable. Duque-Caro (1978) suggests it is continuous with a Mesozoic lineament of western South America, while Fox and Heezen (1975) suggest both uplift and subsidence in the Eocene. I suggest that the formation of the Beata Ridge must post-date the mid-Tertiary and pre-date the late Miocene tectonic events that gave rise to the Enriquillo Cul de Sac.

The Beata Ridge is inferred by some workers to reflect a fundamental break in the stratigraphy and structural style of the Venezuelan and Colombian basins (Houtz and Ludwig, 1977; Ludwig et al, 1975; Uchupi, personal communication). Horizon B" forms a planar acoustic basement in the Venezuelan Basin (Case, 1975). In the northern Colombian Basin acoustic basement is a topographically variable and discontinuous surface (Ludwig et al, 1975; Houtz and Ludwig, 1977). However, the supra B" stratigraphy of the Colombian Basin is similar to that of the Venezuelan Basin, with the development of the Carib Beds and Horizon A". Similar seismic velocities for the sub B" units occur within both basins. The debate upon the continuity of the B" horizon and its existance in the Colombian Basin rests entirely upon the difference of structural style in that surface on either side of the Beata Ridge. Clearly the Colombian Basin has represented the interface between the

Caribbean and the Nicaraguan Rise plates in the Cretaceous and mid-Tertiary (Gose and Schwarz 1978). On that basis the difference in structural style is hardly surprising. The distribution of the Cretaceous dolerites on the Massif del la Selle (Maurasse et al, 1978) and the Massif de la Hotte (Butterlin, 1954) indicate derivation from the Colombian Basin (Figure 2). Therefore, it is assumed that the stratigraphic succession of the Colombian and Venezuelan basins are similar, the only variation between them being in structural style.

The Enriquillo Cul de Sac is a late Tertiary to Holocene Basin, with a complex history of sediment accumulation (Bowin, 1975). An enigmatic basin it has been attributed properties from plate margin (Uchupi, 1975) to extensional back arc spreading. It is continuous with the Los Muertos Trough in the east and the northern Gonave Basin in the west. Drilling off the western shore indicated massive carbonate deposits with a Miocene reef occurring at 3000 m (Crux Intl.,personal communication). Marine conditions existed within the basin during the Pleistocene, with coral reefs occurring along the margins of Lago Enriquillo (Bowin, 1975).

Free air gravity anomalies range from +100 mgals over the Gonave Rise to +175 mgals for the Massif de la Selle and Sierra Bahoruco, to +100 mgals for the northern part and 0 mgals for the rest of the Beata Ridge (Bowin, 1975). Bowin (1975) suggests present day isostatic equilibrium over most of the Beata Ridge. Free air gravity anomalies are around 0 mgals for the Enriquillo cul de sac.

Crustal thickness over the Beata Ridge appears to be approximately 15 kms (Edgar et al., 1971; Heezen and Fox, 1975; Ewing, et al., 1960).

The Southern Gonave Basin/Jacmel Basin

The southern Gonave Basin is a triangular low bound by the Gonave Ridge to the west, and Gonave Rise to the northeast, and the Massif de la Hotte, Navassa Rise and Formigas Bank to the south (Figure 5). The eastern basin terminates adjacent to the Jacmel Basin a topographic low marking the juncture between the Massif de la Hotte and the Massif de la Selle (Figure 4, 5). A marked constriction of the basin occurs southwest of the Isle de la Gonave at which point the bottom topography becomes undulatory (Figure 4). In general the basin goes from a depth of 1800 m in the east, to 3600 m in the center, shallowing to 2000 m in the west (Figures 4, 5). At its western end, the basin bifurcates with the southern arm abuting the Formigas Bank, and the northern arm losing its bathymetric identity north of the bank. The region between the bifurcations is a platform less than 1600 m deep (Figure 1, 2). The basin margin against the Massif de la Hotte is marked by laterally continuous undulations associated with folding at the base of the scarp (Figure 1). No geological information exists for the basin to date.

Mercier de Lepinay et al (1979) report compressive tectonism in the valley seperating the Massif de la Hotte and Massif de la Selle with the Massif de la Hotte underthrusting the Massif de la Selle. The youngest rocks involved in the thrusting give a maximum Oligo-Miocene age for the tectonism. A free air gravity anomaly low of approximately -100 mgals occurs over central and eastern portions of the basin (Bowin, 1975).

Formigas Bank/Navassa Rise/Massif de la Hotte System

The Formigas Bank--Massif de la Hotte System extends from Formigas Bank via the Navassa Rise to the subaerial Massif de la Hotte on the Massif du Sud of Haiti (Figures 4-6). Laying on an east-west axis it averages 50 kms in width and 350 kms in length. The system extends into the Colombia Basin southeast of the Massif de la Hotte (Figure 5). Depths range from 1000 m in the west to 3000 m in the southeast and elevations on the Massif de la Hotte exceed 1000 m (Figure 4). An elongate valley extends the length of the Massif de la Hotte from the southern flank of the Navassa Rise to the juncture with the Massif de la Selle (Figure 4). The topography on the Formigas Bank and Navassa Rise is subdued and platform like (Figure 4). Navassa Island is located on the central portion of the Navassa Rise (Figure 5).

Apart from the recent carbonate cover evidenced by the raised modern coral reefs of Navassa Island nothing is known of the geology of the Formigas Bank or the Navassa Rise . Physiographic and inferred geologic continuity with the Massif de la Hotte allows the stratigraphy of the system to be inferred. Unfortunately the Massif de la Hotte also is not thoroughly mapped. The only information available is from the reconnaissance mapping by Butterlin (1956) and (Bowin, 1975).

Upper Cretaceous basaltic and doleritic rocks interbedded with pelagic limestones and radiolarites form the basal unit on the Massif de la Hotte (Section 1, Figure 7). This is a similar unit to that interpreted by Maurasse et al (1979) on the Massif de la Selle to be equivalent to the B" unit. Unconformably above the igneous rocks are massive Upper Cretaceous shallow water limestones (Bowin, 1975). Shallow marine and terrestrial deposition continued to the Holocene. Thus, the system has been a high since the Cretaceous (Bowin, 1975). The post B" stratigraphic succession of the Massif de la Hotte is different to that of the Colombian Basin or the

Massif de la Selle (Section 1, Figure 7). Therein lies an important distinction which will be dealt with in a later section.

Free air gravity anomalies vary from 0 mgals over the Navassa Rise to +150 mgals over the Massif de la Hotte (Bowin, 1975, 1976). Magnetic anomalies from marine portions of the system have the high amplitude short wavelength character common of island arc type areas (Horsfield and Robinson, 1974; Robinson, 1975). A seismic refraction profile by Edgar et al. (1971a) indicated a 10 km crustal thickness for the Navassa Rise.

The Nicaraguan Rise

The Nicaraguan Rise is a broad swell extending northeastward from Central America (Figures 1 and 5). The Cayman Trough, and the Colombian Basin border it to the north and southeast respectively (Figure 1, 4, 5, 6). Topographically the Nicaraguan Rise is extremely variable with elevations ranging from 2500m above sea level to 4200m below (Figure 1, 4, 5). Presently Jamaica marks its uplifted northern margin. Within the study area, the main trend on the Nicaraguan Rise is N45°E, along which several elongate basins and rises are aligned (Figure 4). The Nicaraguan Rise is separated from the Formigas Bank/Navassa Rise/Massif de la Hotte by the Navassa Trough. This low has an elongate east-west axis and is approximately 20 to 30 kms wide. The eastern portion of the trough bifurcates into two basins separated by roughly circular topographic high. The northern limb becomes a narrow basin, apparently continuous with the linear topographic low on the Massif de la Hotte mentioned previously (Figure 4). The southern bifurcation undergoes an axis change to N45^{o}W, and continues into the Colombian Basin (Figures 4, 5).

The northern Nicaraguan Rise consists of a number of east-west ridges of which Jamaica is the northernmost. Those portions of the rise immediately adjacent to the Cayman Trough are involved in the broad regional uplift that typifies the zone surrounding the eastern terminus of the trough (Horsefield, 1974). Indeed in the northern areas of the rise, the Cayman Trough exerts a secondary structural control upon the older tectonic grain of the Nicaraguan Rise (Burke et al., in press).

Geological information for the submerged segment of the Nicaraguan Rise comes from a series of exploratory wells drilled along its crest (Uchupi, 1975; Arden, 1975). The rise is interpreted as a submerged Cretaceous to Eocene island arc, overlain by a considerable thickness of continental and shallow marine formations (e.g. Arden, 1975; Robinson et al., 1970; Case, 1975). Marine successions dominate the northern portions of the system in Jamaica and in the Sierra Maestra (Appendix 1; Perfit and Heezen, 1979).

Two major Tertiary faulting trends exist on Jamaica and along the northern Nicaraguan Rise. They are:

1. The east-west North Coast, Duanvale, Rio Minho/Yallahs/Plantain Garden, and the South Coast fault systems which sub-parallel the main Cayman Trough trend;
2. The NW-SE trend of the Montpelier-Newmarket, Spur Tree, Wagwater Belt, and John Crowe faults (Draper, 1979).

These trends dominate the coastline morphology.

Low grade zeolite, prehnite-pumpellyite and higher grade blueschist assemblages have been described from Jamaica (Draper, 1973; Wadge and Draper, 1979; Draper, 1979). These assemblages are generally considered indicative of subductive tectonics (Miyashiro, 1961, 1972; Coleman, 1972; Draper, 1978). Portions of the inliers exposed along the northern Nicaraguan Rise have been interpreted by Burke et al (1978) to represent fragments derived from the leading edge of of a convergent margin. The geology and structure of the Navassa Trough are not known.

The free air gravity anomaly has a marked E-W trend paralleling the trough of the Navassa Trough. The interpretation suggests that the region is undercompensated (Bowin, 1976). The magnetic anomalies in this region have the high amplitude short wavelength character common of the complex geology of mature island arc systems (Bowin, 1976). A poorly defined NE-SW magnetic anomaly trend contrasts with the mid- and upper-Tertiary E-W and NW-SE structure in the area. This trend is similar to those of the Nicaraguan Rise (Bowin, 1976) and probably represents a relict upper Mesozoic to lower Tertiary tectonic grain dating back to the subductive era that formed the Rise basement. This magnetic signature has been only mildly affected by subsequent tectonic events.

Crustal thickness for Jamaica and the Nicaraguan Rise are roughly 20 kms (Arden, 1975), intermediate between the continental and oceanic regimes (Perfit and Heezen, 1979).

The Colombian Basin.

The Colombian Basin is the westerly basin of the Caribbean Plate. It is bound by the Nicaraguan Rise to the west, the Beata Ridge to the east, and Panamanian Isthmus and Colombian continental margin in the south. Depths in the basin exceed 4200 m (Figure 1, 4, 5). Only the northern section is involved in the study area (Figures 4-6). In this region, the Colombian Basin is divided by the southern extremity of the Massif de la

Hotte into two broad basins, the eastern with a roughly N-S axis, and the western with a N 45°W axis (Figure 4). The margins of the basin are characterized by major topographical breaks over the entire circumference.

No direct geological data exists for the Colombian Basin. Thus, geological information for the Colombian Basin is infered from data derived from the Venezuelan Basin, the Beata Ridge, the Massif de la Selle and the eastern edge of the Nicaraguan Rise. The lateral continuity of acoustic stratigraphy and seismic velocity structure between the Colombian and Venezuelan Basins supports this assumption. The data available is derived from DSDP holes 146/149, 147, 148, 150, 151, 152, 153, 154, described by Saunders et al. (1973).

The deepest stratigraphic units sampled in the Venezuelan Basin were the uppermost of a series of Late Cretaceous dolerite sills. These correspond to the stratigraphic unit below horizon B" (Ewing et al., 1960; Edgar et al., 1971; Heezen and Fox, 1975; Case, 1975; Saunders, et al., 1973). Their thickness is unknown, but throught to be on the order of 1 km (Primoli Silva, personal communication). Processed multichannel records taken by Gulf Oil Company show continuous broadly undulating acoustic reflectors, probably of sedimentary origin, for several seconds below the B" horizon (Eaton and Driver, 1967; Edgar et al., 1971; Saunders, et al., 1973).

This suggests that true basement has not been sampled either by drilling or by acoustic means as suggested by several authors (e.g. Meyerhoff and Kudoley, 1971, Maurasse, 1979). The B" event covers a present day area of greater than 5.0×10^5 km^2 (Donnelly, 1975). Thus, it may represent one of the most extensive penecontemporaneous basaltic events, exceeding the Columbia basalt fields of the western North America. Mattson and Pessagno, (1969), and Maurasse et al, (1979), suggest that this unit is recognized on Puerto Rico, Hispaniola and possibly Colombia. This implies the existance of an even larger basalt field during the Late Cretaceous and early Tertiary. If the Cretaceous basalts and dolerites described by Butterlin (1956) in the central inliers of the Montagnes Noires, the Chaines des Matheaux, the Massif de la Selle, and the Massif de la Hotte is analagous to this unit as is suggested for the Massif de la Selle (Maurasse et al 1979), then the past extent of the field assumes enormous proportion and importance. This also implies a compressive regime had to dominate the northern margin of the Caribbean over the period of their uplift in order that the B" unit be preserved within their basal complexes.

Several authors consider B" to be some form of modified oceanic basement (Ewing, et al., 1960; Edgar et al., 1971; Maurasse et al, 1979). Meyerhoff believes it to be oceanic crust which has undergone a process of "continentalization", especially along its margins (Meyerhoff and Khudoley, 1971). Khudoley suggests exactly the opposite, that Caribbean Plate underwent a process of "oceanization" (Khudoley and Meyerhoff, 1971). Several authors propose it was formed by a back arc spreading process (Le Pichon, 1968; Stainforth, 1969; Dietz and Holden, 1970; Maurasse et al., 1978, 1979; and Mattson, 1979). Others suggest that the basin may be a fragment of Jurassic oceanic crust derived from the eastern Pacific (Farallon Plate) (North, 1965; Mattson, 1966; Wilson, 1966; Edgar et al., 1971; Malfait and Dinkleman, 1971; Goreau, 1979). The subsequent B" basaltic event substantially altered the physical character of the crust in the region. Certainly the question of the B" unit, and the geology and origin of the material below it is one of the major enigmas in the Caribbean.

In summary, the B" unit appears to be an areally important series of basaltic sills (Saunders et al, 1973). The timing of their intrusion coincides almost exactly with the cessation of volcanism along the ancestral Greater Antilles Ridge subductive system (Saunders et al, 1973).

Normal marine pelagic stratigraphy was deposited above the B" interface during the Tertiary (Saunders et al, 1973). Terrigenous sedimentation in the center of the Venezuelan Basin was nonexistant at this time when the mobile belt surrounding the Caribbean basement was experiencing general uplift and presumably extensive erosion (Bowin, 1975; Kudoley and Meyerhoff, 1971). This suggests the existence of effective circum Caribbean topographic sediment traps during the Tertiary. The underthrusting present along the internal margins of the Caribbean (Ladd and Watkins, 1978; Talwani et al, 1978) today, existed throughout the Tertiary. Sediment traps occured within the flanking trenches.

During the mid Eocene to early Miocene pelagic sedimentation was dominated by the sudden appearance of abundant radiolarian ooze. This sedimentation change is indicated by the acoustic reflector A" (Ewing et al., 1960; Edgar et al., 1971; Heezen and Fox, 1975; Case, 1975). Horizon A" is correlated in the DSDP wells with a Tertiary hiatus characterized by abundant chert of possible diagenetic origin (Ewing and Hollister, 1972; Saunders et al, 1973). A" has been sampled directly from the Venezuelan Basin and Beata Ridge, and is detected on seismic reflection profiles throughout the eastern Caribbean (Saunders et al, 1973; Case, 1975).

Radiolarian rich sedimentation continued into the early Miocene when there was a marked input of terrigenous clays derived from the Orinoco River in South America (Saunders et al, 1973). Miocene and Pliocene volcanic sediments are only common close to the Panamanian Isthmus, and are related to the early Pliocene closure of the Panamanian seaway (Saunders et al., 1973). Carbonate sedimentation has dominated the stratigraphic sequences in the Colombian and Venezuelan basin since the Pliocene (Saunders et al, 1973).

Seismic refraction measurements by Officer et al. (1959) indicate the Colombian basin crust is approximately 10 kms thick. Normal oceanic crust in the basin may be depressed by sediment and sill fill exceeding 3 kms thick. Thus, the velocity structure and thickness of the Colombian Basin crust is atypical of normal oceanic crust.

Free air gravity anomalies over the Colombian Basin are very close to 0 mgals indicating general isostacy (Bowin, 1976). Within the study area Bowin (1976, 1975) indicates the existence of free air gravity anomalies of -100 to -120 mgals .

Heat flow measurements range from 1.0 to 1.3 (Epp et al., 1970; Case, 1975). Magnetic anomalies in the Colombian Basin are subdued and indistinct (Case, 1975).

The Venezuelan Basin/Los Muertos Trough System.

Within the study area only the northwestern Venezuelan Basin is involved (Figures 1, 2, 3). The Los Muertos Trough extends from the eastern Enriquillo Cul de Sac to the Anegada-Jungfern Passage southeast of the Virgin Islands along the southern margin of the Greater Antilles Ridge. Depths range from sea level in the west to more than 5600m in the central Los Muertos Trough (Figure 1).

Multichannel profiles described by Ladd and Watkins (1978) show the strata of the Venezuelan Basin dipping into the Los Muertos Trough. The horizon B" continues as a recognizable entity for up to 40 kms beneath the deformed sediments of the southern Dominican Republic margin. Ladd and Watkins (1978) have classified the margin as convergent.

Free air gravity anomalies of -150 mgals to -100 mgals occur in the Los Muertos Trough (Bowin, 1975, 1976).

Southern Dominican Shelf.

The bathymetry of the shelf south of Hispaniola-Puerto Rico has been described by Holcombe and Mathews (1975) and Case and Holcombe (1976). The shelf extends from the northern Enriquillo Cul de Sac to the Anegada Trough, and is bound by the Los Muertos Trough to the south and the Dominican Republic, Mona Passage and Puerto Rico to the north.

No direct geological samples of the southern Dominican shelf are available. Ladd (personal communication) has several multichannel seismic reflection profiles across the western portion. It has the sedimentary and structural features indicative of a well developed subduction complex, with several episodes of fore arc basin formation (Ladd, personal communication). However, no volcanic arc is associated with the system. The extensive coastal plains of the southern Dominican Republic represent the subaerial portions of the basin and contain massive Tertiary to Holocene shallow water carbonate deposits (Bowin, 1975). Little is known about the stratigraphic and structural relationship between the shelf and the Cordillera Central and the Sierra del Seibo. Quaternary carbonates blanket all pre-existing stratigraphy and onlap the Cretaceous massif. The only exposed section occurs to the south of the Cordillera Central and indicates that the shelf has been the site of convergence since the Tertiary. Thus it had a very different history from that of the thrust belts and related basins of western Hispaniola where convergence was limited in space and time, and the structural styles were somewhat different.

CHAPTER III

ACOUSTIC STRATIGRAPHY AND STRUCTURE

Introduction

The coherence of acoustic returns was generally good in the basins and poor on the rises. Where topographic variability is extreme the geometry of the reflecting horizons is rarely optimal. In fact slopes were often beyond the resolution of the array. For such regions the reflectors tended to be of the "choppy" noncontinuous character often associated with highly deformed sedimentary units. The quality of the data was further reduced by excess reverberation in the shallower regions. In several areas laterally continuous reflectors beneath deformed sedimentary units were interpreted to be of tectonic origin, associated with imbricate underthrusting.

The magnetic anomaly variability tended to have a shorter wavelength than the line spacing. Thus, no meaningful contour map could be made with the data (Figure 8).

The Old Bahama Channel/Caicos Basin System.

Lines 1, 2, 3, represent the coverage aquired within the

Old Bahama Channel/Caicos Basin System (Figures 5, 9-11). Diapiric bodies were detected in lines 1 and 2 (L pattern, Figures 9, 10). The structures tend to involve the uppermost sediments (Figures 9-11), indicating present day mobility. The salt involved in these is thought to be of similar age to the Portlandian evaporites from northern Cuba (Khudoley and Meyerhoff, 1971; Pardo, 1975). They represent the basal units of the Bahama Platform province of northern Cuba (Pardo, 1975), and are relict from the restricted marine conditions occuring during the early opening of the North Atlantic.

The sedimentary units above the evaporites thicken southward from 1.0 sec in the north to greater than 4.0 north of Hispaniola. Assuming the geometry of the sedimentary units reflects that of the basement topography, the basement dips southward beneath Hispaniola (e.g. Figure 9). Individual units vary in thickness from 1.0 to 0.3 sec. and merge into the folded sequences on the continental slope off Ile de la Tortue.

Structurally the Caicos Basin is a simple sedimentary low with increasing subsidence to the south. Whatever faulting is present occurs in association with diapiric structures and involves the uppermost strata (Figure 9). Along the southern margin of the basin broad antiformal folding affects the entire sedimentary thickness (Figures 9-11).

Figure 8. The magnetic anomaly map for the study area. The contour interval of 25 gammas. The magnetic anomalies were calculated from the total field measurements by removing the 1975 I.G.R.F. In this region the I.G.R.F. is too high by 400 gammas, a fact reflected in the predominantly negative anomalies.

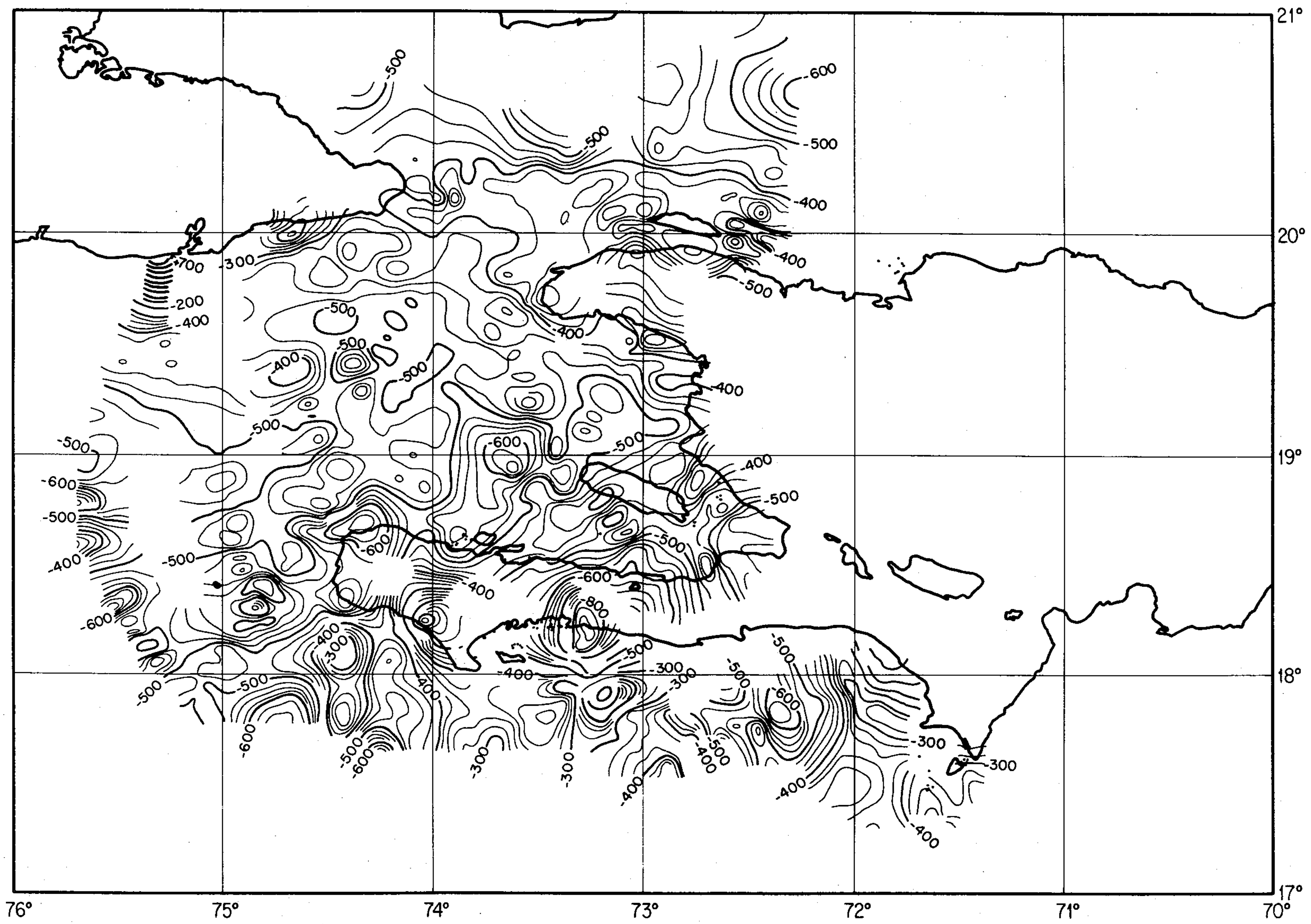

21°
20°
19°
18°
17°
76°
75°
74°
73°
72°
71°
70°
-600
-500
-400
-300
-200
-700
-800

Figure 9. Seismics, gravity, and magnetics along Line 1. Symbols are as follows: M: magnetic anomalies; B: Bouguer gravity anomaly; FA: Free air gravity anomaly; L symbol: diapiric structures. Vertical exaggeration 20:1. For location of profile see figure 5.

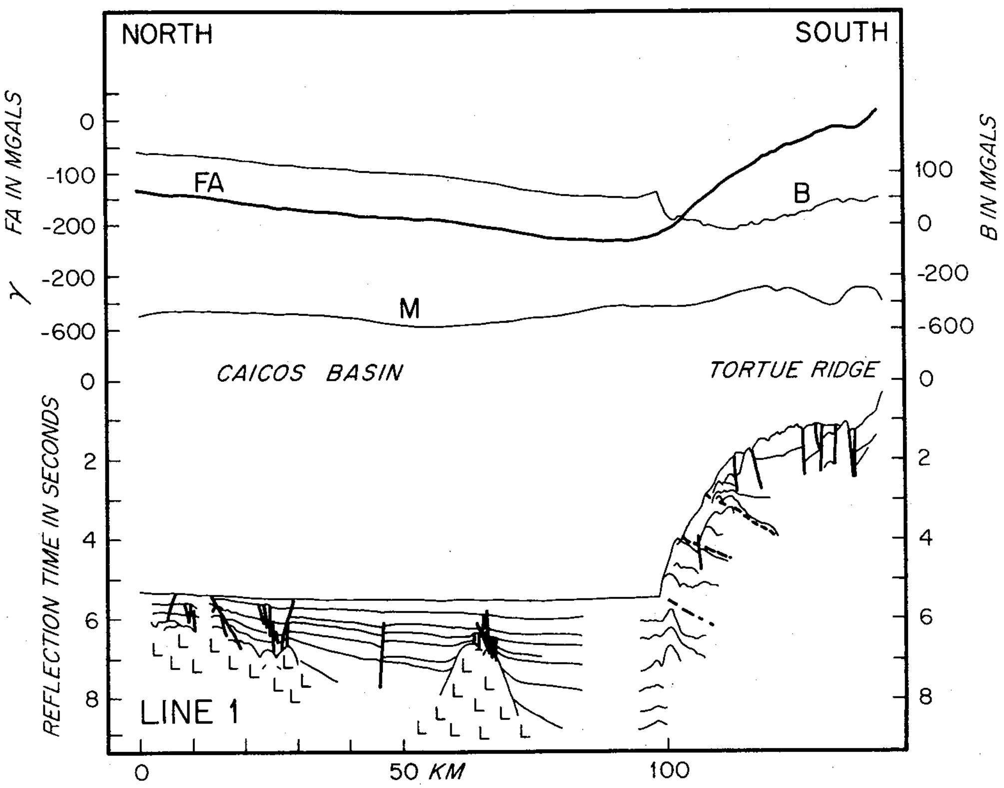

NORTH
SOUTH
FA IN MGALS
B IN MGALS
γ
0
-100
-200
-200
-600
100
0
-200
-600
FA
B
M
CAICOS BASIN
TORTUE RIDGE
REFLECTION TIME IN SECONDS
0
2
4
6
8
LINE 1
0
50 KM
100

Figure 10. Interpretation of seismic profile Line 2, with merged geophysical data. For symbols see figure 9. For location see figure 5

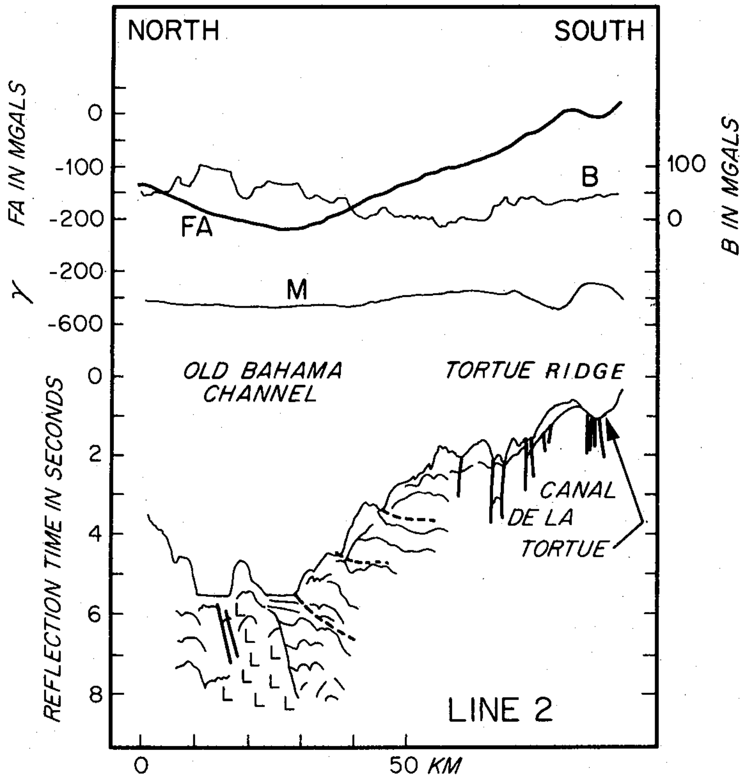
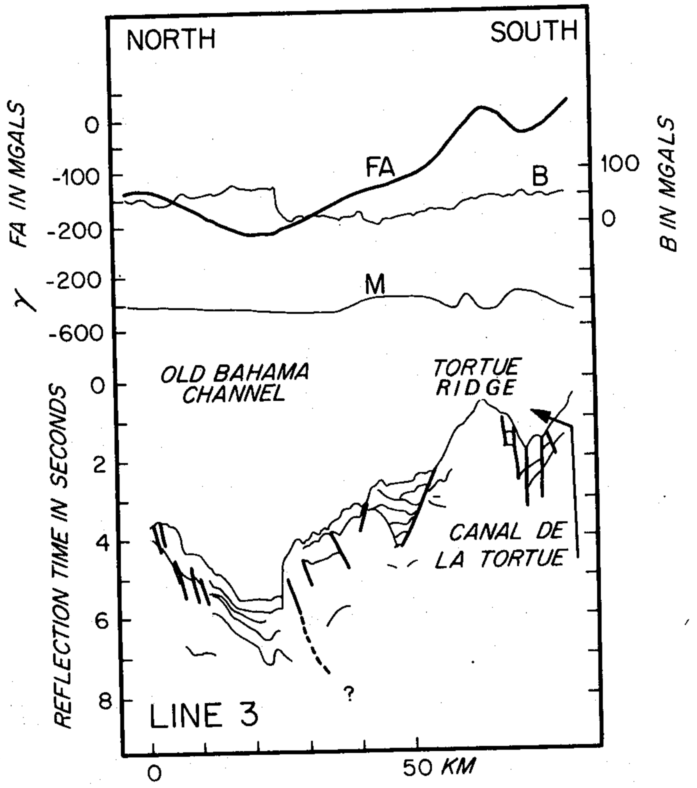

NORTH
SOUTH
FA IN MGALS
0
-100
-200
FA
B
100
0
B IN MGALS
γ
-200
-600
M
REFLECTION TIME IN SECONDS
0
2
4
6
8
OLD BAHAMA CHANNEL
TORTUE RIDGE
CANAL DE LA TORTUE
L
LINE 2
0
50 KM

Figure 11. Interpretation of seismic profile Line 3, with merged geophysical data. For symbols see figure 9 For location see Figure 5.


NORTH
SOUTH
FA IN MGALS
0
-100
-200
FA
B
100
0
B IN MGALS
γ
-200
-600
M
OLD BAHAMA CHANNEL
TORTUE RIDGE
CANAL DE LA TORTUE
REFLECTION TIME IN SECONDS
0
2
4
6
8
?
LINE 3
0
50 KM

Farther west this deformation affects not only the slope but the entire width of the Old Bahama Channel (Figures 10, 11). The basin and channel southern margins are marked by an extreme topographic break which is most pronounced in line 3 (Figure 11). Tectonic styles in this region are strongly reminiscent of those found where subduction occurs in heavily sedimented regions such as the Gulf of Oman (White et al., 1978). This is corroborated by structures on the Haitian margin which are suggestive of an accretionary sediment prism, presumably composed of originally horizontal sediments from the Caicos Basin/Old Bahama Channel System.

The Free air gravity anomalies measured in the Caicos Basin and Old Bahama Channel are less than -200 mgals, with the lowest values occurring just north of the slope break (Figures 9-12). Bouguer gravity anomalies are around 50 mgals for the entire basin and channel, increasing to 100 mgals along their northern edges (Figure 13). The extreme values of these anomalies are suggestive of a present day dynamic regime, with the considerable departures from isostacy due to tectonic mass difficiencies associated with convergent processes (Bowin, 1976). The magnetic signatures over the region are virtually characterless with less than a 30 gamma variation (Figures 8-11).

Figure 12. The Free air gravity anomaly contour map of the study area. Anomalies are in milligals, with a contour interval of 25 mgals. This map was compiled from data obtained during ATLANTIS II Cruise 97/leg 1 (black dots) and data from Bowin (1976).

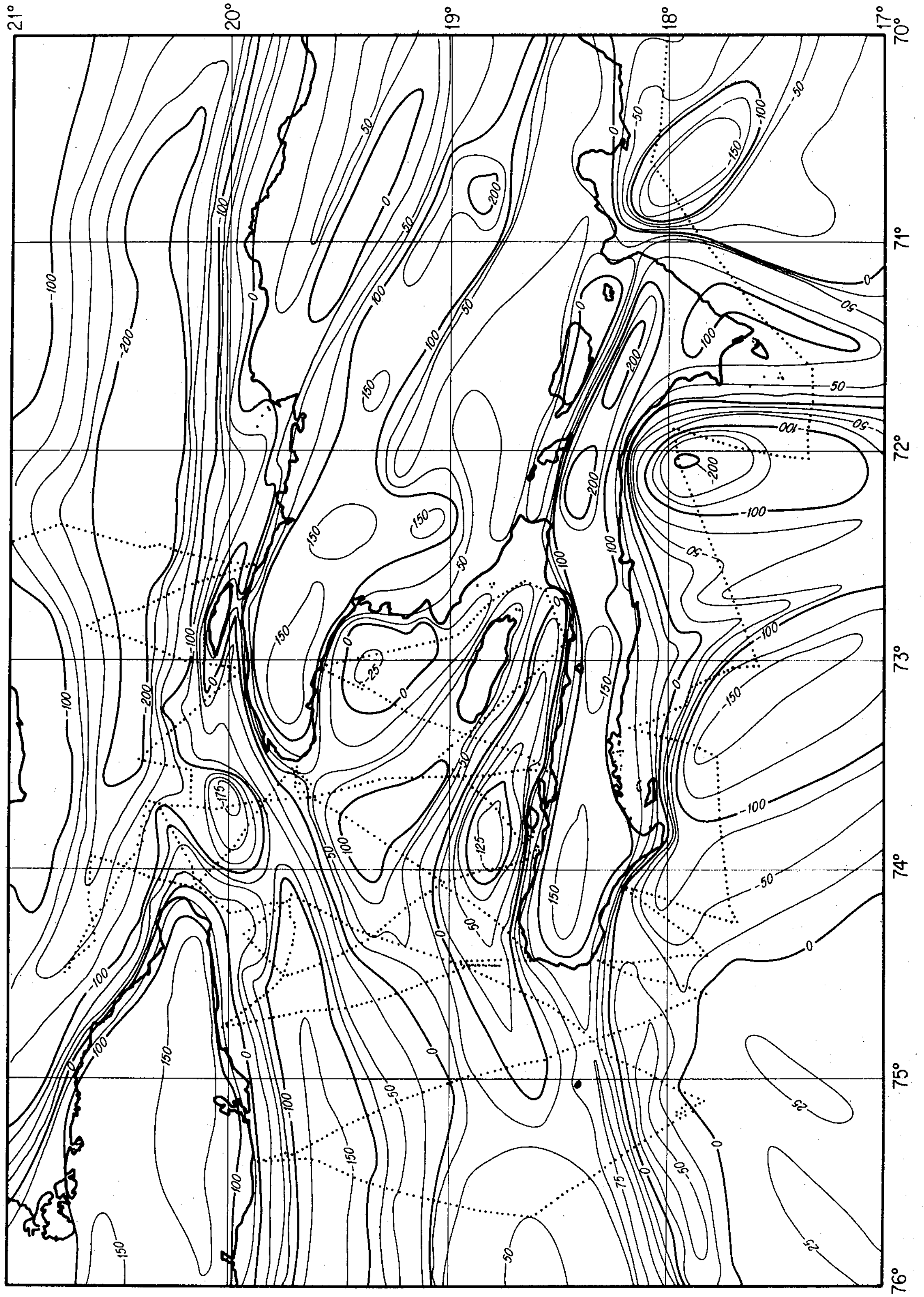
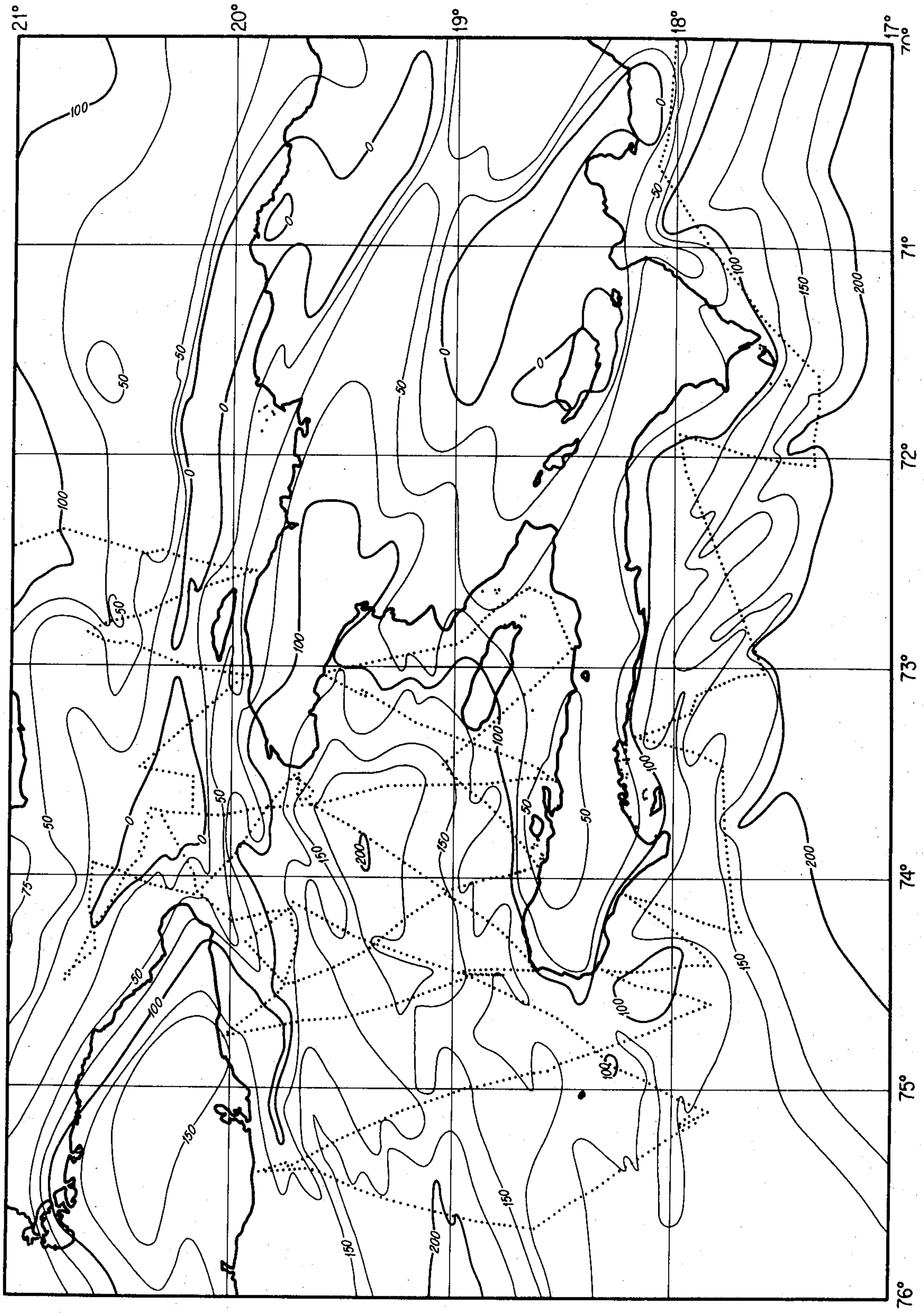

21°
20°
19°
18°
17°
70°
71°
72°
73°
74°
75°
76°
-100
-200
-100
200
-100
-200
-100
100
0
150
-100
-50
0
50
0
50
100
150
150
150
100
50
200
0
25
0
150
50
175
125
50
100
50
0
50
0
-50
150
150
200
100
100
150
200
0
-50
0
-100
-150
-50
-100
-50
-50
-100
-200
-100
-50
0
-100
-150
-100
-50
0
25
0
-50
0
75
-25
50

Figure 13. The Bouguer gravity anomaly contour map for the study area. Anomalies are in milligals, and the contour interval is 25 mgals. This map was compiled from data obtained during ATLANTIS II Cruise 97/leg 1 (black dots) and data from Bowin (1976).


21°
20°
19°
18°
17°
70°
71°
72°
73°
74°
75°
76°
0
50
75
100
150
200

The Windward Passage Sill/Isle de la Tortue shelf System.

As shown by lines 1, 2, 3, (Figures 5, 9, 10, 11). This Windward Passage System is structurally complex with the character of a massive deformed sedimentary wedge underthrust from the north. The acoustic horizons tend to be discontinuous. However, there are discrete acoustic horizons that dip southward for up to 25 kms beneath the system (Figures 9-11). The geometry of these horizons is suggestive of the imbricate structures characteristic of convergent margins. From the present data set it is impossible to determine uniquely whether these surfaces are primary sedimentary strata or imbricate decollement surfaces along which thrusting has occurred. They are interpreted in this study to be decollement surfaces which may or may not coincide with sedimentary strata. Low angle reverse faults are inferred to occur on lines 1, 2, 3 (Figures 9-11). Most faults within the convergence zone north of Hispaniola tend to be vertical, and often control the distribution of small perched basins with flat laying to folded strata, superimposed upon the deformed mass (Figures 9-11).

Free air gravity anomalies range from +25 to -100 mgals reflecting the topography of the deformed wedge (Figure 12). The Bouguer anomalies are fairly constant at the +50 mgal level, but do reflect a high frequency component due to the rugged surficial topography of the accretionary prism (Figure 13). Magnetic anomalies are on the order of 150 gammas with a wavelength of roughly 10 kms (Figure 8). They define a continuous ridge of high amplitude short wavelength anomalies extending from the Cuchillas Uplift to the Cordillera Septentrional. This indicates a continuity in the geological character between eastern Cuba and northern Hispaniola (Appendix 1).

The Windward Passage Deep/Canal de la Tortue System.

The Windward Passage Deep is a sigmoidal graben, bound to the northwest and southeast by normal faults (Figures 4, 5, 6, 14, 15, 35). Basement is not visible within the graben, and must lie at depths of greater than 2.0 sec (Figures 14, 16, 17). Sediment distribution within the graben indicates that deposition is fault controlled (Figures 14-16). Limited deformation effects the most recent sediments in the deep, a fact implying present day tetonic activity.

The Windward Passage Deep is located on the Windward Passage Sill, a feature that is physiographically continuous with the Cuchillas Uplift to the west, the Ile de la Tortue shelf and the Cordillera Septentrional (Figures 5, 14, 16). The Windward passage Sill is heavily faulted with less sediment accumulation than the Windward Passage Deep (Figures 14-16).

Folded sediments are common on the sill in contrast to the relatively undisturbed sediments within the Deep (Figures 11-13).

The acoustic stratigraphy of the Windward Passage Sill (Figures 15, 17) differs markedly from that of the Windward Passage Deep (Figures 14, 16). The deeper sedimentary strata on the sill are divided into numerous small cuspate basins. Their form implies a periodic migration of the topographic lows within which they were deposited, indicative of sedimentation on a tectonically active uplift with a continually changing surface morphology. This unit is below a uniform sediment cover reminiscent of stable platform sedimentation (Figure 12). This stratigraphic sequence is interpreted to be due to the cessation of instability followed by a period of relative quiescence with continuous sedimentation. The Windward Passage Deep cuts both of these sequences and contains a thicker more uniform strata (Figures 11, 12).

The Canal de la Tortue is a heavily faulted topographic low (Figures 10, 11). It is assumed that these faults are related to a laterally continuous major fault system that sub-parallels the topographic grain in the region (Figures 1-3). An absence of any discernable sedimentary reflectors within the canal is further evidence for the existence of a fracture system. The physiographic continuity between the canal, the Windward

Figure 14. Interpretation of seismic profile Line 10, with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

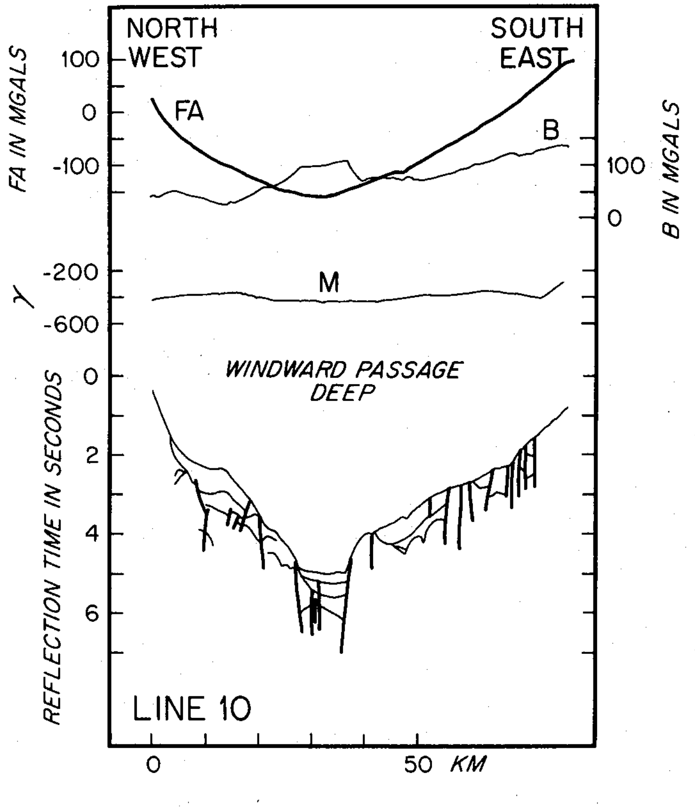

NORTH
WEST
SOUTH
EAST
FA
B
M
100
0
-100
-200
-600
FA IN MGALS
100
0
B IN MGALS
γ
WINDWARD PASSAGE DEEP
0
2
4
6
REFLECTION TIME IN SECONDS
LINE 10
0
50 KM

Figure 15. Interpretation of seismic profile Line 11, with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

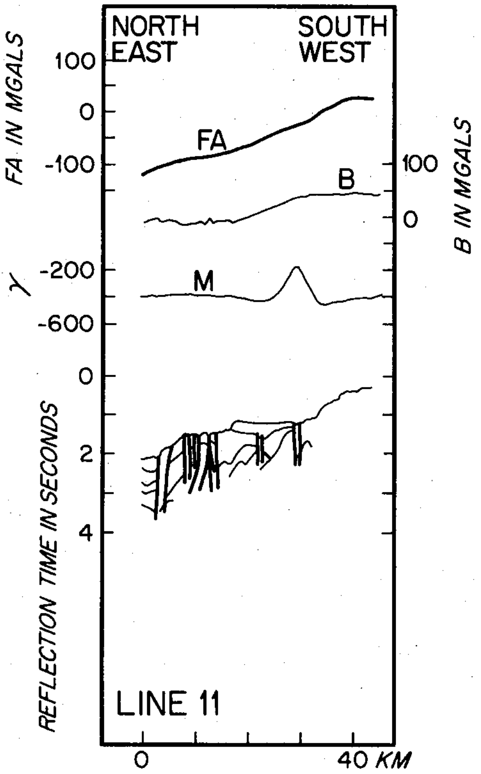

NORTH EAST
SOUTH WEST
FA IN MGALS
100
0
-100
FA
B
100
0
B IN MGALS
γ
-200
-600
M
0
2
4
REFLECTION TIME IN SECONDS
LINE 11
0
40 KM

Figure 16. Interpretation of seismic profile line 12 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

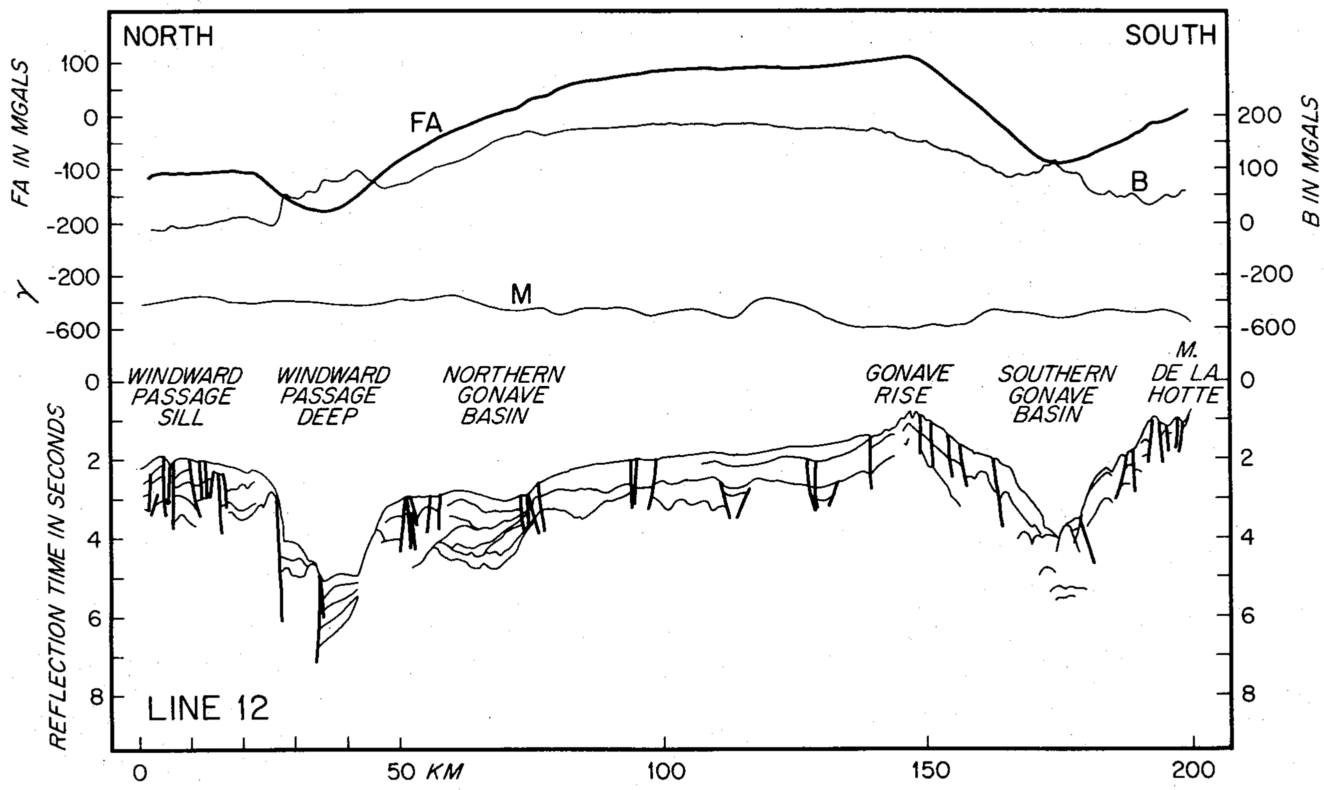
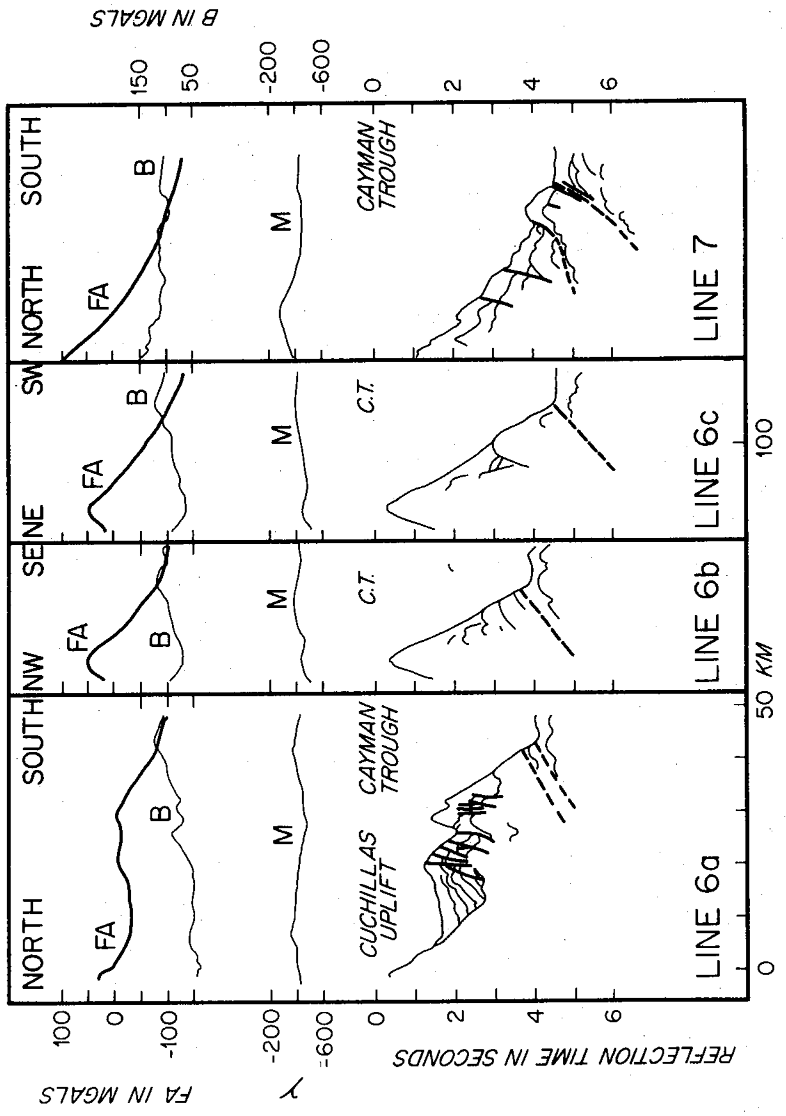

NORTH
SOUTH
FA IN MGALS
B IN MGALS
FA
B
M
γ
100
0
-100
-200
-200
-600
200
100
0
-200
-600
WINDWARD PASSAGE SILL
WINDWARD PASSAGE DEEP
NORTHERN GONAVE BASIN
GONAVE RISE
SOUTHERN GONAVE BASIN
M. DE LA HOTTE
REFLECTION TIME IN SECONDS
0
2
4
6
8
LINE 12
0
50 KM
100
150
200

Figure 17. Interpretation of seismic profiles 6 and 7 with merged geophysical data. For symbols see Figure 9. For location see Figure 5. C.T.: Cayman Trough.


FA IN MGALS
100
0
-100
-200
-600
γ
0
2
4
6
REFLECTION TIME IN SECONDS
B IN MGALS
150
50
-200
-600
NORTH
SOUTH
FA
B
M
CUCHILLAS UPLIFT
CAYMAN TROUGH
LINE 6a
NW
SE
C.T.
LINE 6b
NE
SW
LINE 6c
NORTH
SOUTH
LINE 7
0
50 KM
100

Passage Deep and the Valle del Cibao suggest a similar tectonic genesis. Structurally and physiographically the Canal de la Tortue and the Deep are young features (Figures 1, 6, 7, 11, 12). Bowin (1975) suggested a Pliocene to Holocene development for the Valle del Cibao. The physiographic variation along this system, in particular the Windward Passage Deep, is due to the deflection of the failure plane with respect to the principal shearing stress between the North American and Caribbean plate (Figure 35). The geometry of this system therefore allows the Canal de la Tortue/Valle del Cibao System to be principally a transform boundary, while the Windward Passage Deep remains predominantly divergent. If these assumptions are correct the maximum translation along the Canal de la Tortue/Valle del Cibao cannot exceed the divergence across the Windward Passage Deep. This value is approximately 50kms (Figure 5).

Free air gravity anomaly in the Windward Passage Deep is -175 mgals, consistent with the interpretation of active divergence (Figure 12). Within the Canal de la Tortue, the free air anomaly rises to approximately 0 mgals, reflecting the topographic trend (Figure 12). Bouguer anomalies are in the +50 mgal range (Figure 13). Magnetic variations are small ranging around 50 gammas with a 10 km wavelength (Figure 8). A large magnetic anomaly of 350 gammas occurs just east of the Cuchillas Uplift, indicating high susceptiblity material at shallow crustal levels (Figure 15). This implies a seaward continuation of the ultramafic suites of the Cuchillas Uplift.

The Cayman Ridge/ Sierra Maestra System.

Within the study area, the Cayman Ridge is restricted to those portions of the Sierra Maestra north of the Oriente Deep and southwest of the Guantanamo Basin (Figures 1, 4, 5, 6; Section 10, Figure 7).

The marine portions of the Cayman Ridge are structurally complex and dominantly compressive (Figures 15, 17-21). On all lines the lower part of the slope is marked by thrust faults, folds, or both, involving the most recent sedimentary strata.

The acoustic character of the region is similar to that of the Ile de la Tortue shelf with a large tectonized sedimentary unit containing small perched basins (Figures 15, 17-21). Acoustic reflectors dip towards the north beneath Cuba, suggesting the existence of major thrust surfaces (Figures 15, 17-21). The thrust faulted, folded, and rotated sedimentary strata are reminiscent of the juvenile stages of an convergent margin. Most of the structural and stratigraphic features are analogous to those classified by Dickinson and Seely (1979)

Figure 18. Interpretation of seismic profile Line 8 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

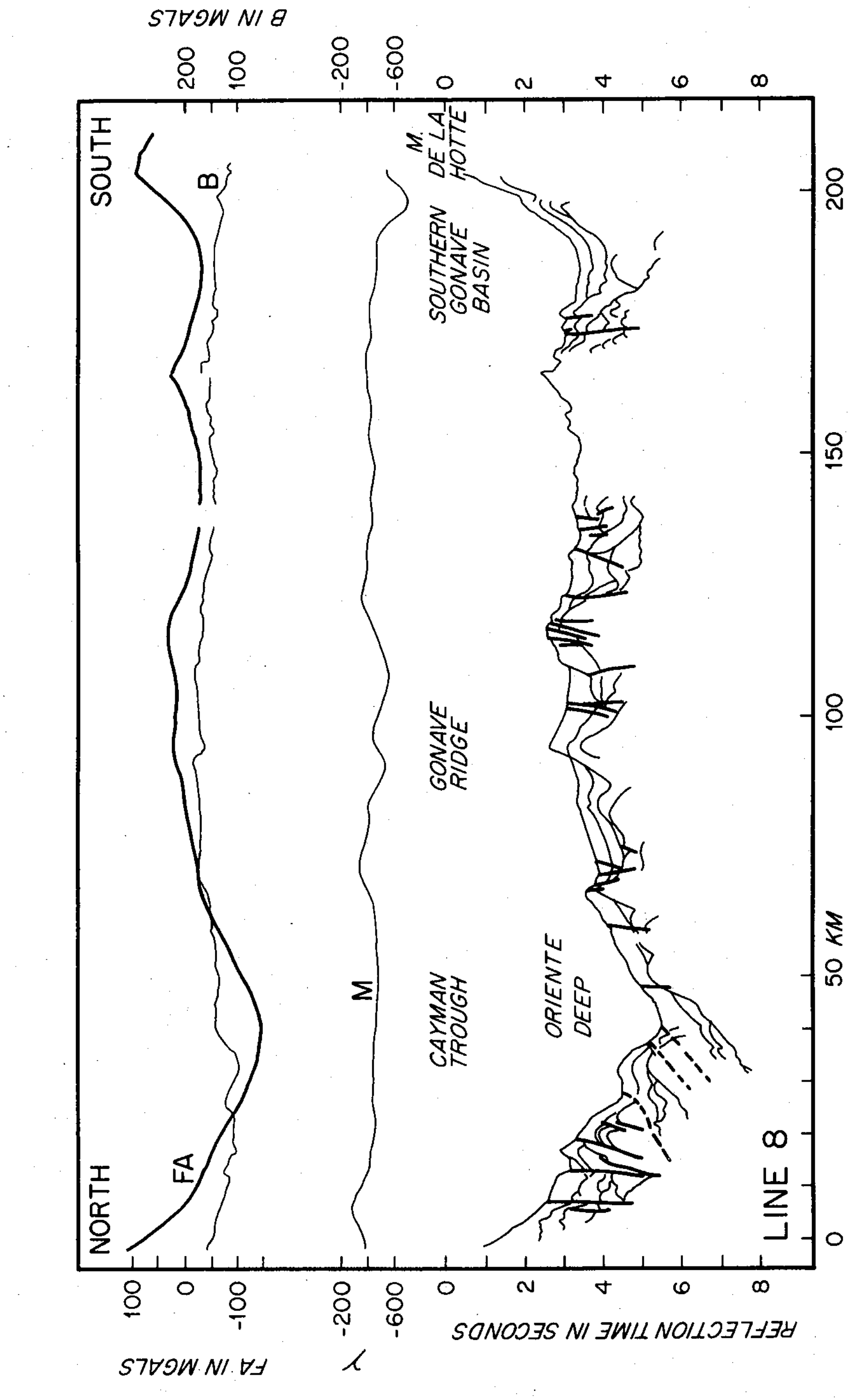

NORTH
SOUTH
FA
B
M
CAYMAN TROUGH
ORIENTE DEEP
GONAVE RIDGE
SOUTHERN GONAVE BASIN
M. DE LA HOTTE
LINE 8
0
50 KM
100
150
200
100
0
-100
FA IN MGALS
-200
-600
γ
0
2
4
6
8
REFLECTION TIME IN SECONDS
200
100
B IN MGALS

Figure 19. Interpretation of seismic profile Line 17 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

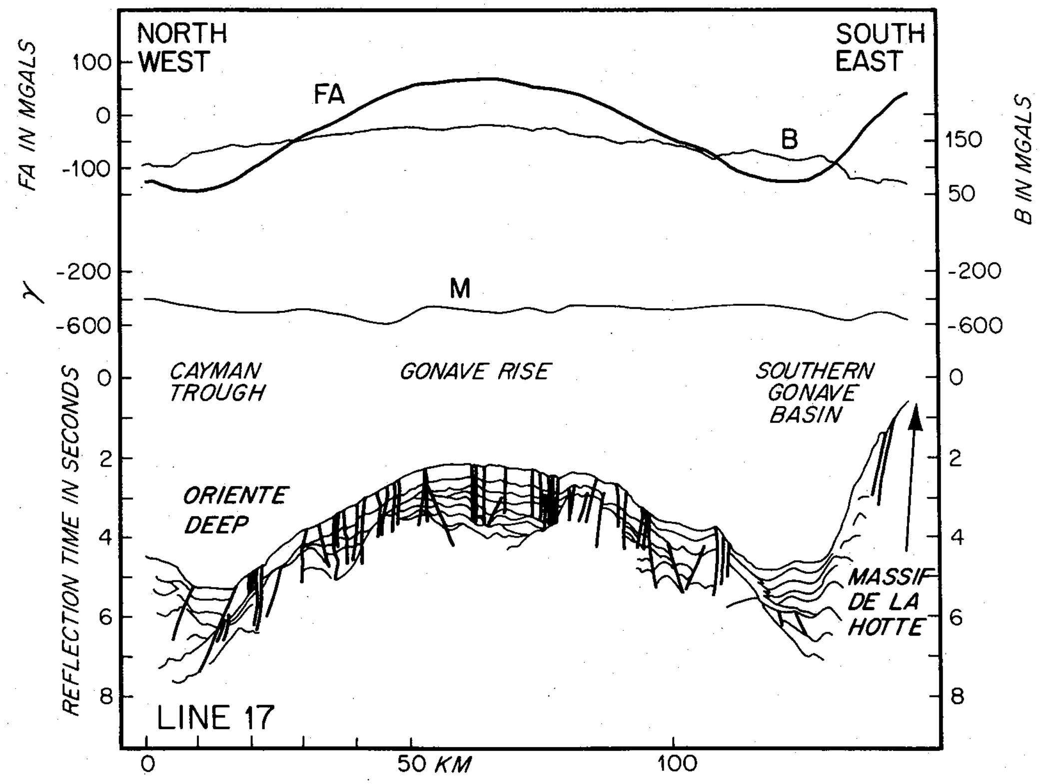

NORTH WEST
SOUTH EAST
FA
B
M
FA IN MGALS
100
0
-100
B IN MGALS
150
50
γ
-200
-600
REFLECTION TIME IN SECONDS
0
2
4
6
8
CAYMAN TROUGH
GONAVE RISE
SOUTHERN GONAVE BASIN
ORIENTE DEEP
MASSIF DE LA HOTTE
LINE 17
0
50 KM
100

Figure 20. Interpretation of seismic profile line 20 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

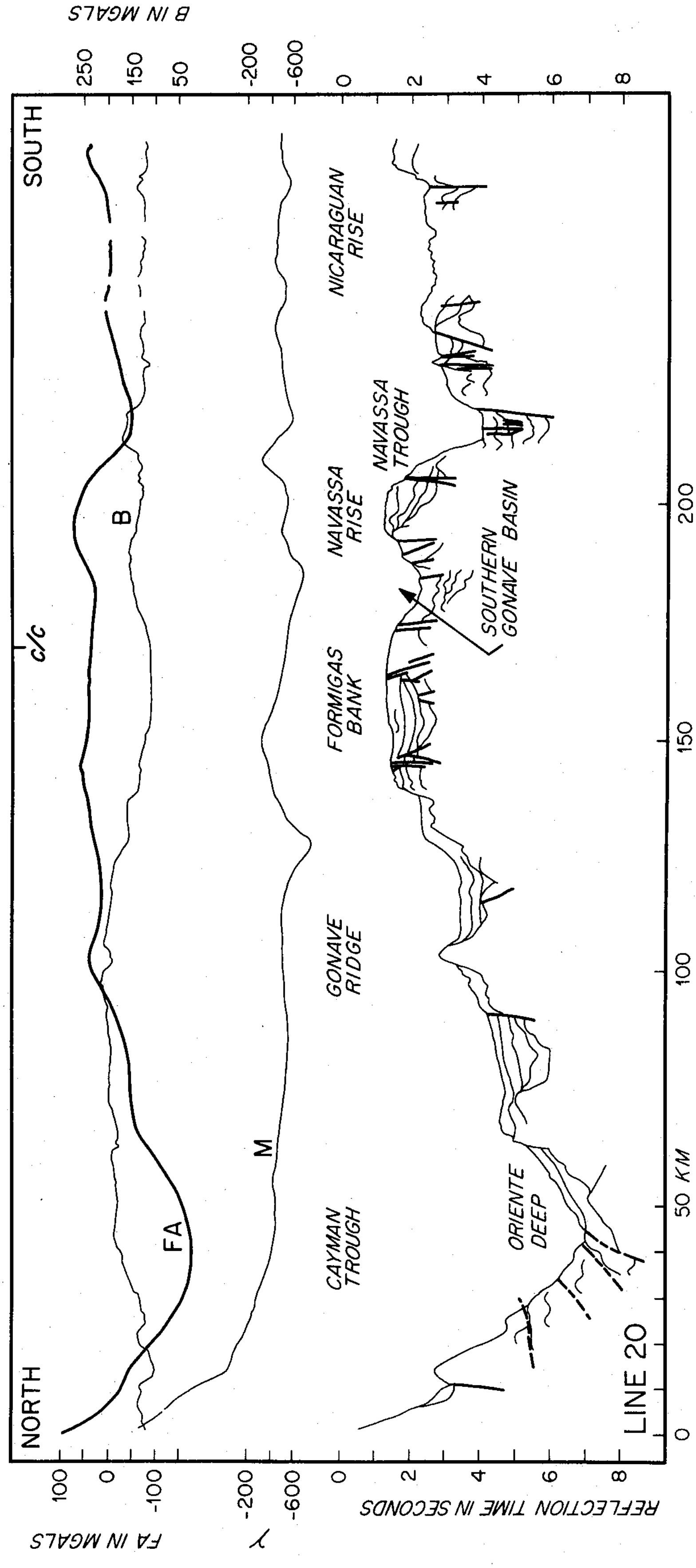
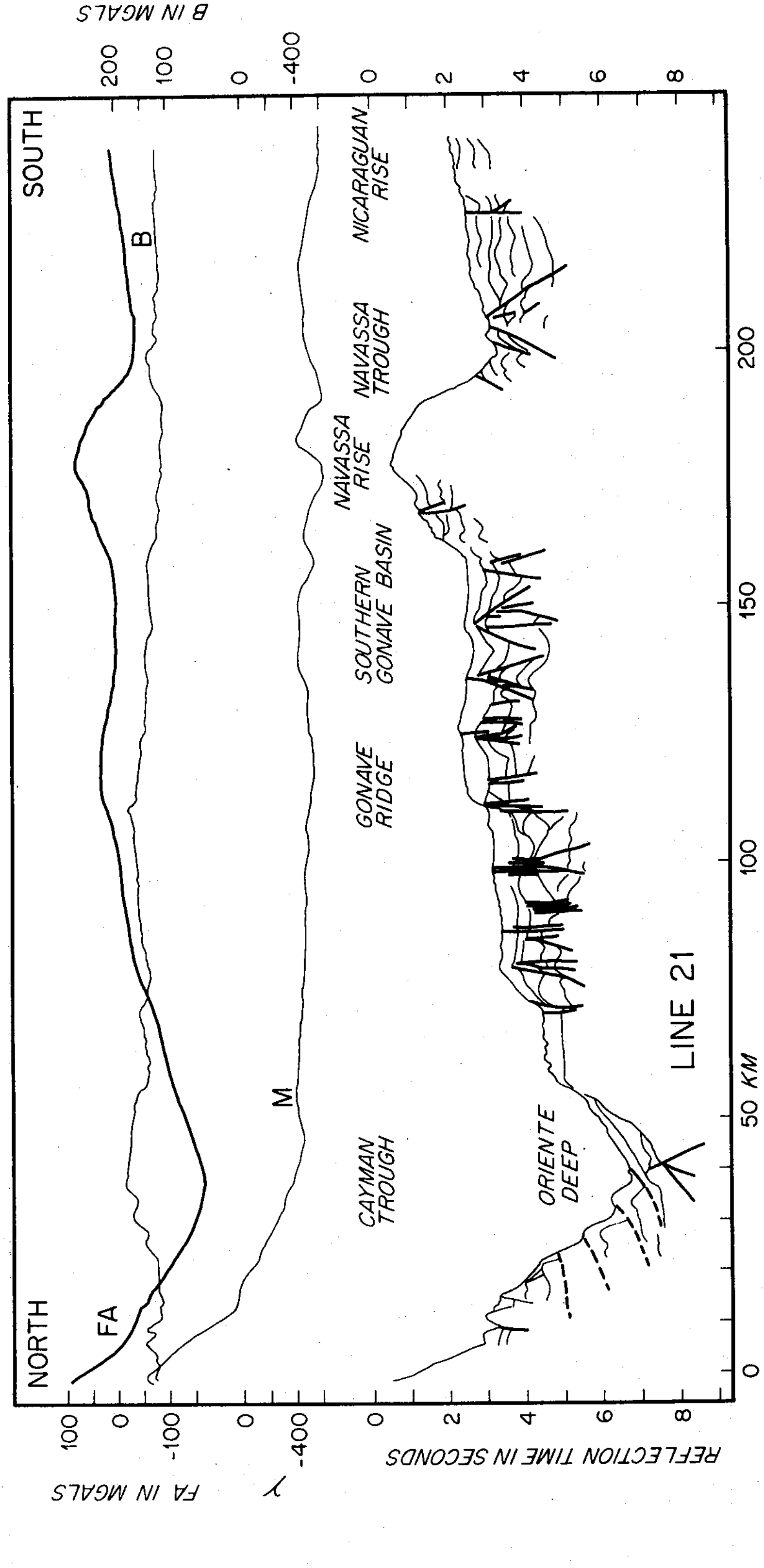

NORTH
SOUTH
LINE 20
c/c
FA
M
B
CAYMAN TROUGH
ORIENTE DEEP
GONAVE RIDGE
FORMIGAS BANK
NAVASSA RISE
NAVASSA TROUGH
SOUTHERN GONAVE BASIN
NICARAGUAN RISE
0
50 KM
100
150
200
FA IN MGALS
100
0
-100
γ
-200
-600
REFLECTION TIME IN SECONDS
0
2
4
6
8
B IN MGALS
250
150
50

Figure 21. Interpretation of seismic profile Line 21 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.


NORTH
SOUTH
FA
B
M
CAYMAN TROUGH
ORIENTE DEEP
GONAVE RIDGE
SOUTHERN GONAVE BASIN
NAVASSA RISE
NAVASSA TROUGH
NICARAGUAN RISE
LINE 21
0
50 KM
100
150
200
100
0
-100
0
-400
0
2
4
6
8
200
100
0
-400
0
2
4
6
8
FA IN MGALS
γ
REFLECTION TIME IN SECONDS
B IN MGALS

The free air gravity anomaly varies from less than -150 mgals over the lower portion of the Cayman Ridge adjacent to the axis of the Oriente Deep to +50 mgals inshore (Figure 12).The pronounced free air gravity anomaly low in this region is consistent with an interpretation of present day convergence along the margin. The anomaly minimum does not coincide with the axis of the Oriente Deep but is displaced to the north beneath the folded sedimentary units (Figures 4, 12, 17-21). This is a feature commonly associated with active subduction systems with the magnitude of the anomaly attesting to the dynamic state of the region and the sustained tectonic mass deficiency due to underthrusting (Bowin, 1976). The Bouguer Gravity anomaly is generally on the order of +100 mgals, with no major gradients (Figure 13).

The magnetic anomalies in the area are interesting (Figure 8). On lines 7 and 8 (Figures 17, 18) a 200 gamma anomaly occurs over the antiformal structure at a depth of 2000 m, indicating high magnetic susceptibility material incorporated into the folded material. On lines 20 and 21 an enormous anomaly of greater than 1200 gammas occurs inshore (Figures 20, 21). Few materials have that sort of anomaly associated with them. Among the possibilities are, an ore body, or a fragment of oceanic crust.

The Cayman Trough/Northern Gonave Basin System.

The Cayman Trough/Northern Gonave Basin System is shown in figures 4, 5, 6 (Profiles 6-8, 12-14, 17, 19-21; Figures 16-24). The deepest acoustic reflector in the Cayman Trough varies from 0.0 to 2.0 seconds beneath the sea floor. It has a pronounced regional dip to the north beneath the Cayman Ridge (Figures 16-24). In lines 6, 7, 8, 17-21 (Figures 17-19, 20, 21, 24) the acoustic basement can be traced for 10-15 kms beneath the Cayman Ridge (Oriente Province) to the north with compressive structures increasing to the north.

The central part of the Cayman Trough south of the Oriente Deep has a marked monoclinal arch subparalleling the axis of the trough (Figures 17-21, 24). It forms a nearly flat terrace-like structure seperating the gently northward dipping strata to the north from the thicker ponded sediments to the south (e.g. Figure 21). Line 8 provides an illustration of the structure in this region (Figure 14). The monoclinal arch appears to have been an important factor in sediment distribution in this region.

The contact between "basement" and the overlaying sedimentary strata is discordant (onlapping) with the sediments effectively smoothing the rough underlaying topography (Figures 17-21, 24). Sedimentary units are thin and of limited lateral

Figure 22. Interpretation of seismic profile line 13 with merged geophysical data. For symbols see figure 9. For location see Figure 5.

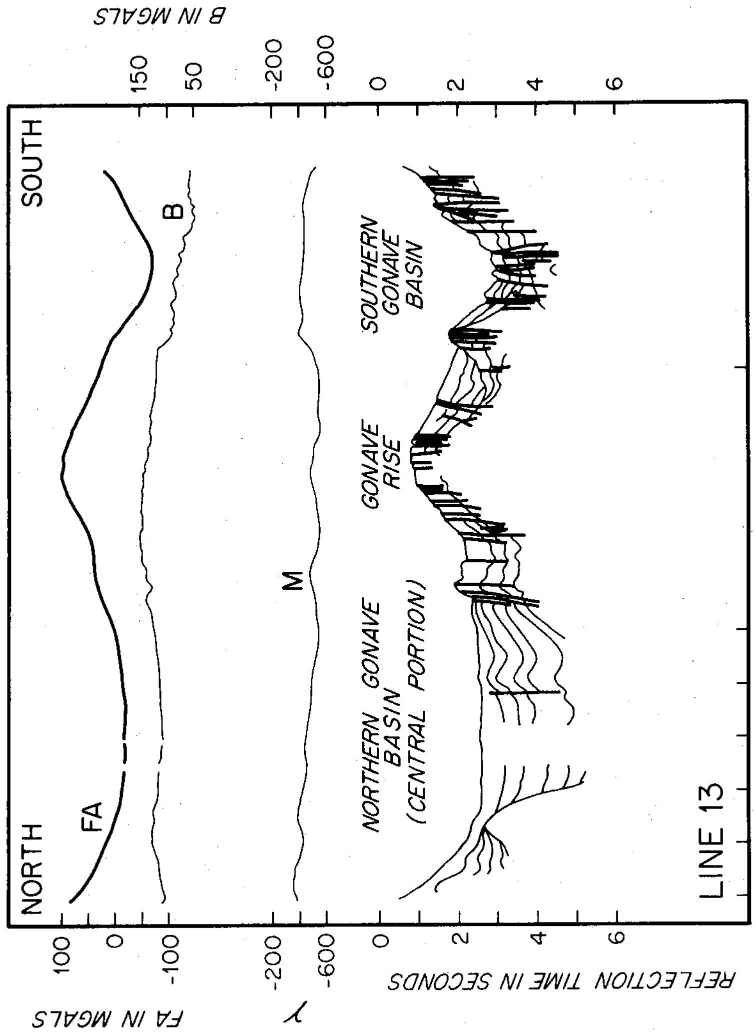

NORTH
SOUTH
FA
B
M
NORTHERN GONAVE BASIN (CENTRAL PORTION)
GONAVE RISE
SOUTHERN GONAVE BASIN
LINE 13
0
50 KM
100
FA IN MGALS
100
0
-100
-200
-600
λ
0
2
4
6
REFLECTION TIME IN SECONDS
B IN MGALS
150
50
-200
-600
0
2
4
6

Figure 23. Interpretation of seismic profile Line 14 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

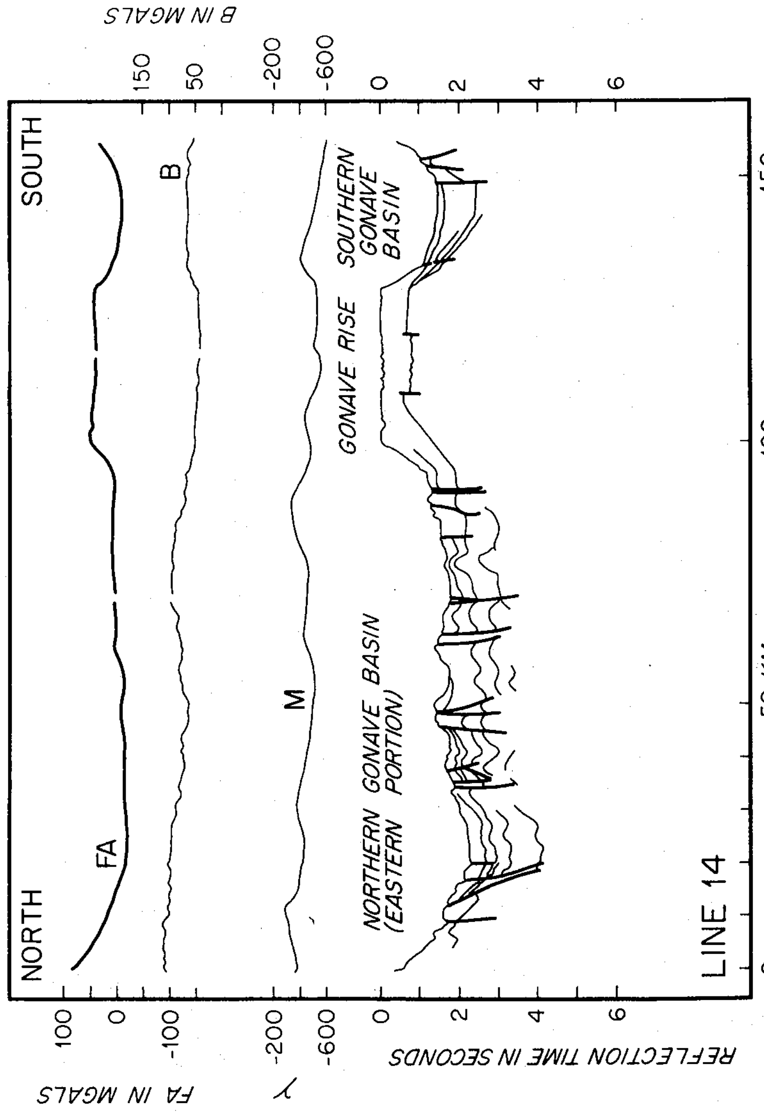
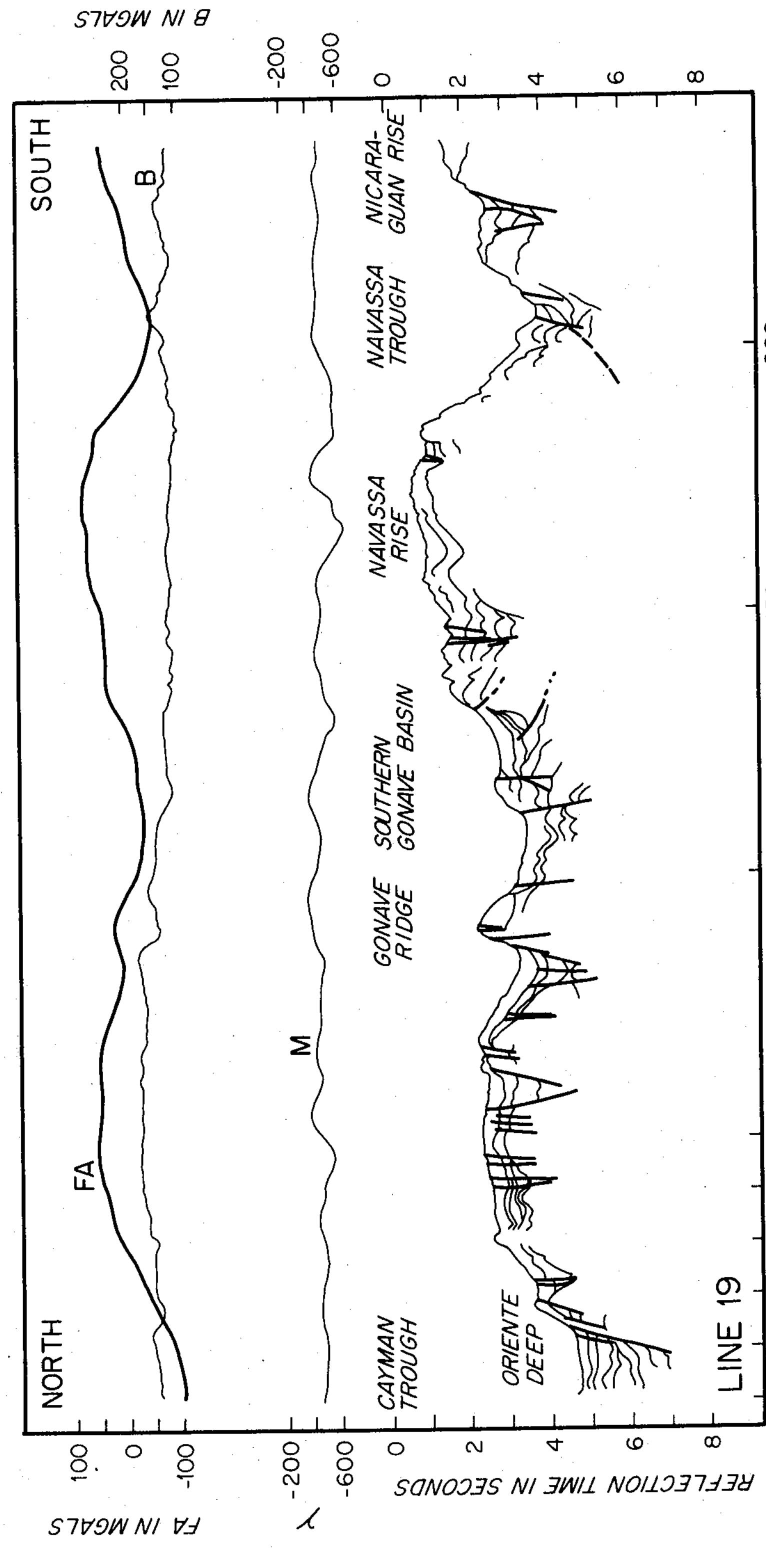

NORTH
SOUTH
FA
B
M
NORTHERN GONAVE BASIN
(EASTERN PORTION)
GONAVE RISE
SOUTHERN GONAVE BASIN
LINE 14
0
50 KM
100
150
100
0
-100
FA IN MGALS
-200
-600
γ
0
2
4
6
REFLECTION TIME IN SECONDS
150
50
-200
-600
0
2
4
6
B IN MGALS

Figure 24 Interpretation of seismic profile Line 19 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

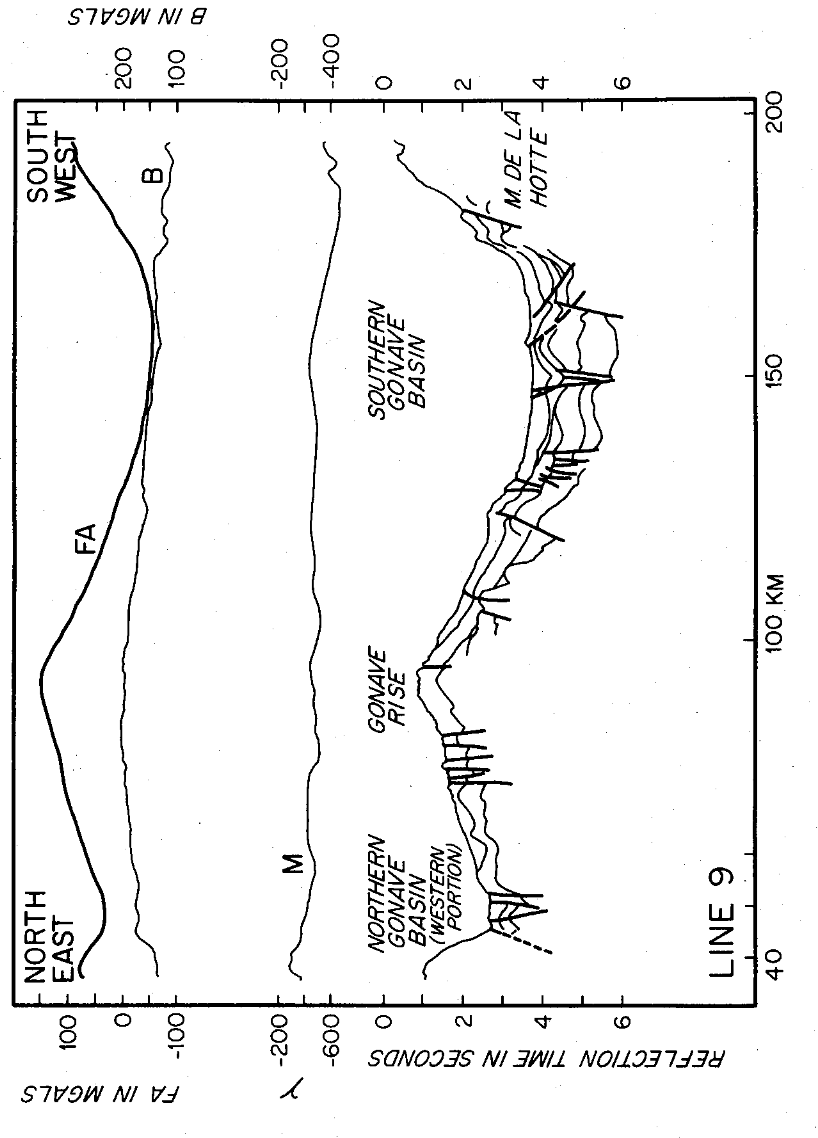

NORTH
SOUTH
FA
B
M
CAYMAN TROUGH
ORIENTE DEEP
GONAVE RIDGE
SOUTHERN GONAVE BASIN
NAVASSA RISE
NAVASSA TROUGH
NICARA-GUAN RISE
LINE 19
0
50 KM
100
150
200
FA IN MGALS
100
0
-100
B IN MGALS
200
100
γ
-200
-600
REFLECTION TIME IN SECONDS
0
2
4
6
8

continuity. Pinch-outs are common (Figures 17-21, 24). As previously discussed, this pattern of sedimentation is taken to infer a degree of tectonic instability at the time of sedimentation resulting in migration of depocenters. Modern sedimentary fill in the Cayman Trough is volumetrically insignificant and shows signs of present day compressive deformation (profiles 6-8; Figures 17, 18).

In the Northern Gonave Basin (Profiles 9, 12-14; Figures 25, 16, 22, 23, 25) the deepest returns have a sedimentary character, and share the structure of the overlaying strata. Sediments thicken to the north, exceeding 2.5 sec along the basins northern margin (Figures 22, 23). To the south the basal sediments of the Northern Gonave Basin are uplifted to form the Gonave Rise with the superficial strata onlaping the rise (Figures 16, 22, 25). These relationships indicate that the Gonave Rise post dates the formation of the northern Gonave Basin. The Gonave Rise has exerted control on subsequent sedimentation in the basin.

The Northern Gonave Basin fill is deformed with long wavelength low amplitude folds that appear to sub parallel the Gonave Rise (Figures 19, 20). A comparison of the eastern and central portions of the low (Lines 13 and 14; Figures 22 and 23) shows the progressive development of the structures. In the eastern portion of the basin, the structures are shallow and achieve their maximum relief. The deformation affects the most superficial sediments (Figure 23). To the west, these structures are deeply buried with minimal involvment of the younger sediments (Figure 22). In both cases the Free air gravity anomaly ranges from 0 mgals to -25 mgals indicating the absence of pronounced compression across the basin at the present day (Figure 12). Bouguer values range from 175 mgals to 100 mgals suggesting a thinning of the crust from continental to oceanic from east to west within the basin and the corresponding shallowing of the mantle (Figure 13). The folding may be due to either compressive tectonism or differential compaction over a deeper foundered basement. Of these possibilities the former is not corroborated by the geophysical evidence. The amplitude of the structures increase eastward, achieving maximum relief just west of the Chaines des Matheaux (Figures 22 and 13). This suggests that they are either deformed by the same compressive deformation that gave rise to the Chaines des Matheaux, or are drapped over the foundered western extension of that fold belt. The onlaping relation of the superficial deformed strata with the Gonave Rise suggests that they postdate the formation of the rise (Figures 22, 23, 25). However, since the Gonave Rise/Massif de la Selle System post dates the formation of the Chaines des Matheaux, the deformation occuring within the Northern Gonave Basin must post date the formation of the Chaines des Matheaux. I propose that the structural fabric is

Figure 25. Interpretation of seismic profile Line 9 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.


NORTH EAST
SOUTH WEST
FA
B
M
NORTHERN GONAVE BASIN (WESTERN PORTION)
GONAVE RISE
SOUTHERN GONAVE BASIN
M. DE LA HOTTE
LINE 9
40
100 KM
150
200
FA IN MGALS
100
0
-100
γ
-200
-600
REFLECTION TIME IN SECONDS
0
2
4
6
B IN MGALS
200
100
-200
-400

caused by differential compaction of the sediments deposited upon the foundered western extremity of the Chaines des Matheaux. By corollary, the Chaines des Matheaux structures continue beneath the Northern Gonave Basin, deepening to the west and predating the observed sedimentary sequences. The event giving rise to the foundering of the western Chaines des Matheaux is almost certainly associated with the formation of the Cayman Trough during the Miocene and will be discussed in a later section.

Unambiguous compressive features occur only along the northern margin of the Northern Gonave Basin (Figures 22, 23, 25). These affect the most recent sedimentary units, are limited in amplitude and importance, and indicate the existance of a present day diffuse compressive regime across the Greater Antilles Ridge.

Free air gravity anomalies in the main Cayman Trough range from 0 mgals along the Gonave Ridge to less than -150 mgals in the axis of the Oriente Deep (Figure 9). The topographic effect of the increasing depth to the north only partially explains the large negative anomaly. Bowin (1976) has indicated that the area may be under compression with a resulting large mass deficiency. The Northern Gonave Basin has free air gravity anomaly values of -25 mgals, indicating isostatic equilibrium (Figure 12). The absence of appreciable Free air gravity anomalies tends to support the contention that the major structures within the basin are the result of differential compaction over a pre-existing structures rather than compression.

The Bouguer gravity anomaly has an interesting pattern (Figure 13). A +150 mgals high extends from the southern Cayman Trough just north of the Gonave Ridge to the western portion of the Northern Gonave Basin (Figure 13). This region of high values continues into northern Haiti with one arm aligned with the Plaine de l'Artibonite, with another arm crossing north of the Montagnes Noires to the Plateau Central (Figure 13). As previously discussed this gravity trend indicates the existence of high density mantle at higher levels than one would ordinarily expect, and gives an embayed structure to the geometry of the Moho in the region. This is interpreted as the relict structure due to a rifting event in the Northern Gonave Basin. This event post-dates the formation of the Chaines des Matheaux and led to the foundering of the western portion of that fold belt.

The magnetic anomalies in the Cayman Trough are low in amplitude with the exception of an anomaly of approximately 120 gamma over the monoclinal arch discussed previously (Figure 8, 18). This suggests the arch contains material of high magnetic susceptibility, and may be a primary structure within the oceanic basement of the Trough. Anomalies of 100-200 gammas with wavelengths varying from 10-25 kms, are common in the Northern Gonave Basin (Figure 8).

The Gonave Ridge/Gonave Rise/Massif de la Selle/ Beata Ridge System

The Gonave Ridge/Gonave Rise/Massif de la Selle/Beata Ridge System is illustrated in figures 1-3. Seismic reflection coverage over this System is contained in portions of lines 8, 9, 12-17, 19-21, 26-28 (Figures 16, 18-24, 26-30).

The Gonave Ridge/Gonave Rise separates the Cayman Trough/Northern Gonave Basin from the Southern Gonave Basin (Figures 4, 19-21). The ridge itself is an antiformal basement high with slight sediment deformation on either flank (Figures 19-21, 24). Sediments in the Cayman Trough to the north onlap the Gonave Ridge and dip northwards into the Oriente Deep. Sediments to the south are ponded behind the ridge (Figures 20, 21, 24). The ridge has influenced the distribution of sediment within the Cayman Trough during its entire history. (assuming the deepest reflectors in the region are representative of the upper oceanic crust). The Gonave Ridge is interpreted to be a relict translational tectonic boundary associated with the formation of the Gonave Rise/Massif de la Selle/Beata Rise System. This conclusion is based on the geometric relationship between the Gonave Ridge and Gonave Rise, and the parallelism between the ridge and the major trend of the Cayman Trough and related transform structures (Figures 4, 35). The Gonave Ridge is physiographically and structurally continuous with the

Gonave Rise (Figure 4). It shallows and broadens to the east changing strike from the nearly west-east Gonave Ridge to W35°N along the Gonave Rise (Figures 4, 5, 6, 35).

Isle de la Gonave (Figure 5) situated on the crest of the Gonave Rise, is a broadly antiformal structure with the fold axis striking roughly W35°N (Butterlin, 1954; Bowin, 1976). Recent exploratory multi-channel seismic profiling in a limited region of the Port au Prince Bay, southeast of the Isle de la Gonave, by Crux International Inc. indicated the existence of a deep basement arch extending from the Isle de la Gonave to the Massif de la Selle/Sierra de Bahoruco (Crux International Inc., personal communication). Drilling just north of the arch bottomed in Miocene reefal carbonates at 3000 m subsurface (Crux International Inc., personal communication). This implies the existence of a major Tertiary basin between the Gonave Rise/Massif de la Selle and the Chaines des Matheaux. The basin may extend to the Los Muertos Trough by way of the Enriquillo Cul de Sac (Figure 5). Line 14 crossed the carbonate platform between Isle de la Gonave and the Enriquillo Cul de Sac (Figure 23). Unfortunately our single channel record failed to penetrate the massive carbonates to any depth.

Lines 9, 12, 13, 15, 16 cross portions of the central Gonave Rise (Figures 16, 22, 25-27). The rise structure is broadly antiformal. Faulting is common, both on the crest and flanks, and seems to be related to compressive structures.

Figure 26. Interpretation of seismic profile line 15 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

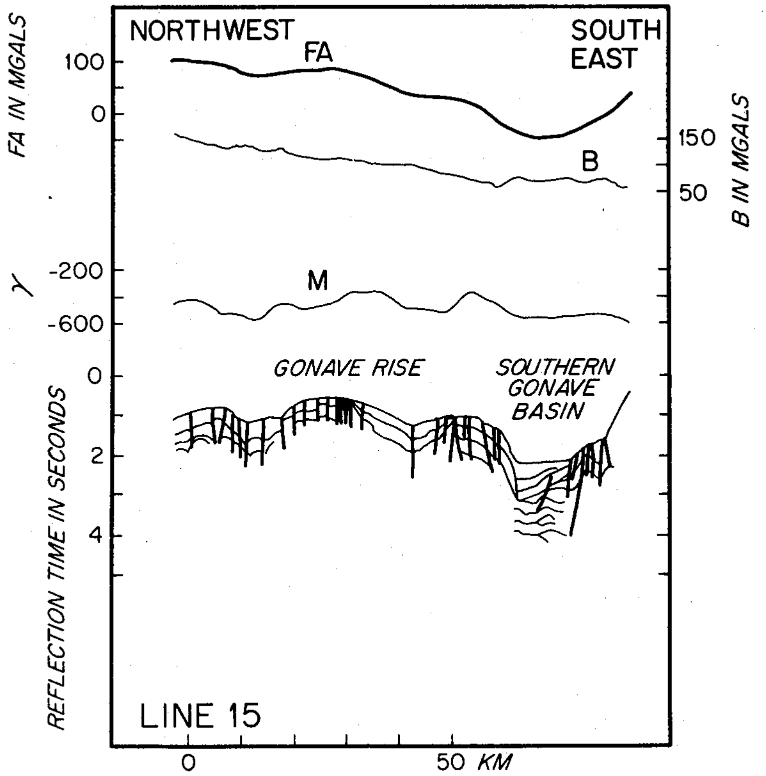

NORTHWEST
SOUTH EAST
FA
B
M
FA IN MGALS
100
0
150
50
B IN MGALS
γ
-200
-600
0
2
4
REFLECTION TIME IN SECONDS
GONAVE RISE
SOUTHERN GONAVE BASIN
LINE 15
0
50 KM

Figure 27. Interpretation of seismic profile Line 16 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

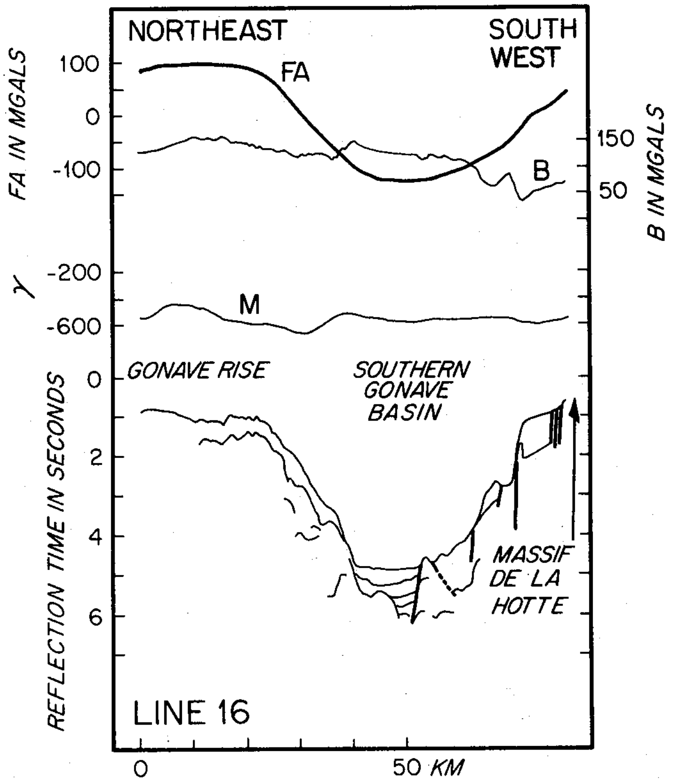

NORTHEAST
SOUTH WEST
FA
B
M
FA IN MGALS
100
0
-100
150
50
B IN MGALS
γ
-200
-600
0
GONAVE RISE
SOUTHERN GONAVE BASIN
REFLECTION TIME IN SECONDS
2
4
6
MASSIF DE LA HOTTE
LINE 16
0
50 KM

Figure 28. Interpretation of seismic profile Line 26 with merged geophysical data. For symbols see figure 9. For location see Figure 5. A" and B" are prominent acoustic horizons in the Colombian Basin.

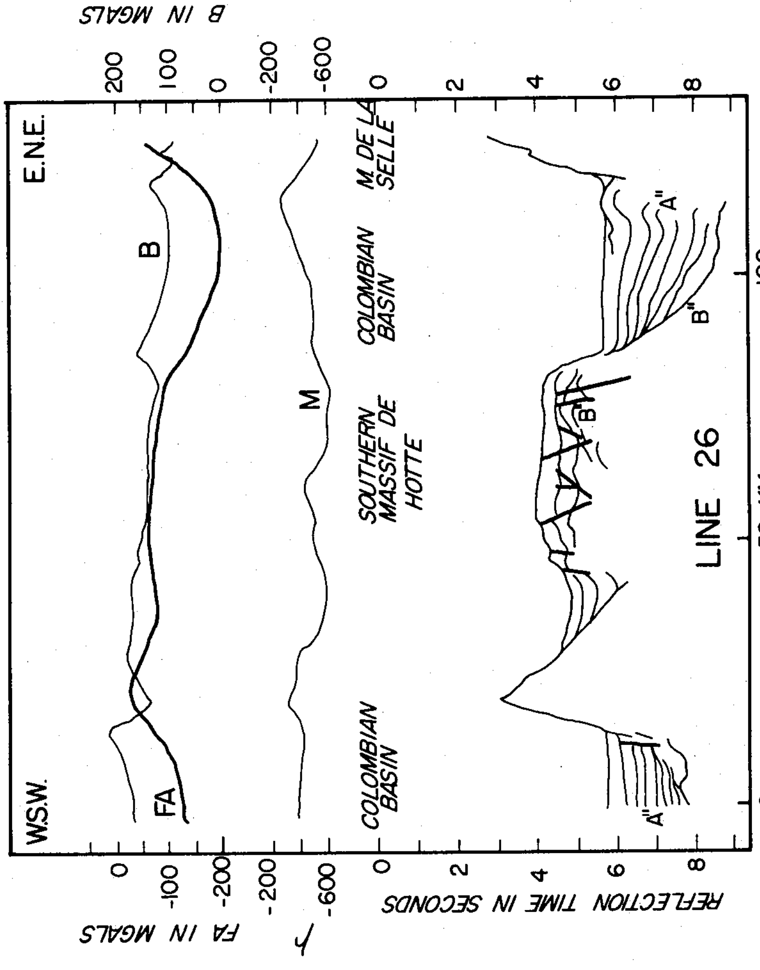

W.S.W.
E.N.E.
FA
B
M
COLOMBIAN BASIN
SOUTHERN MASSIF DE HOTTE
COLOMBIAN BASIN
M. DE LA SELLE
A''
B'
B''
A''
LINE 26
0
50 KM
100
FA IN MGALS
0
-100
-200
-200
-600
γ
REFLECTION TIME IN SECONDS
0
2
4
6
8
B IN MGALS
200
100
0
-200
-600
0
2
4
6
8

Figure 29. Interpretation of seismic profile Line 27 with merged geophysical data. For symbols see Figure 9. For location see Figure 5. A" and B" are prominent acoustic horizons in the Colombian Basin.

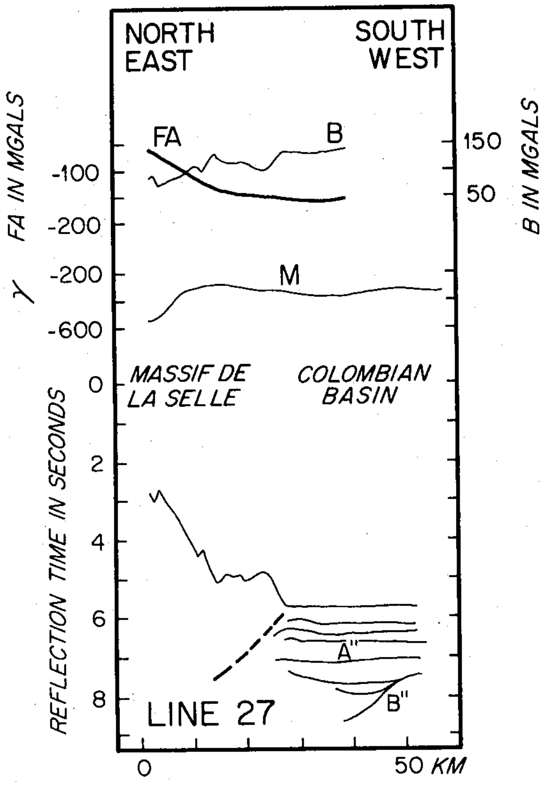
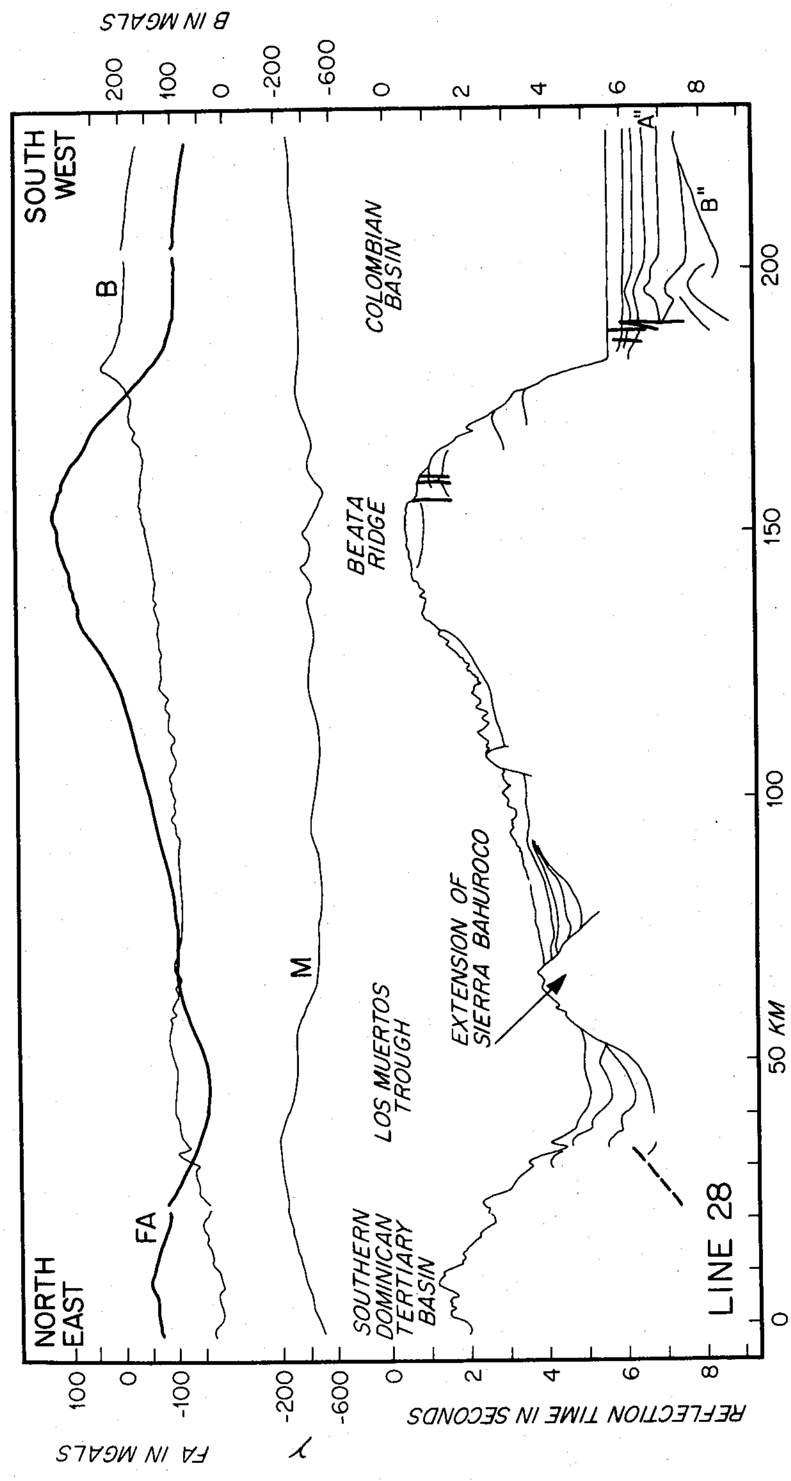

NORTH
EAST
SOUTH
WEST
FA IN MGALS
γ
-100
-200
-200
-600
FA
B
150
50
B IN MGALS
M
MASSIF DE
LA SELLE
COLOMBIAN
BASIN
REFLECTION TIME IN SECONDS
0
2
4
6
8
A''
B''
LINE 27
0
50 KM

Figure 30. Interpretation of seismic profile Line 28 with merged geophysical data. For symbols see Figure 9. For location see Figure 5. A" and B" are prominent acoustic horizons in the Colombian Basin.


NORTH EAST
SOUTH WEST
FA
B
M
LINE 28
SOUTHERN DOMINICAN TERTIARY BASIN
LOS MUERTOS TROUGH
EXTENSION OF SIERRA BAHUROCO
BEATA RIDGE
COLOMBIAN BASIN
A"
B"
0
50 KM
100
150
200
100
0
-100
-200
-600
0
2
4
6
8
FA IN MGALS
γ
REFLECTION TIME IN SECONDS
200
100
0
-200
-600
0
2
4
6
8
B IN MGALS

True affinity (i.e., reverse, or normal) is indeterminable from the offsets.

The deepest observed reflectors on the Gonave Rise appear to be deformed sediments (Figures 12, 19, 22-24). Penetration varies greatly from line to line, with the deepest reflectors appearing to be heavily tectonized, and a major factor controling the distributition of the strata above. These strata above the tectonic reflector vary in thickness from 0.0 to 0.5 sec thick and are limited to small basins. The morphology of these basins is controlled by the rugged topography of this reflector and local faulting (Figures 16, 22, 25-27). Folding, especially along the flanks, is common in the superficial strata. The strata thicken away from the Gonave Rise indicating that it may have been a sedimentary source in the past. Sediment ponding is common on the flanks of the rise, often controlled by large compressive or possibly diapiric structures (Figures 16, 22, 25).

Lines 17 and 19 (Figures 19, 24) are similar in most respects with up to 2.0 seconds of subsurface penetration. Line 17 contains good examples of small discontinuous sedimentary units onlapping each other and structural highs (Figure 19). This type of sedimentation is suggestive of tectonic instability, causing local lateral migrations of these small sedimentary basins.

The hummocky surface topography along the crest of the

Gonave Rise is suggestive of karst morphology (Figures 16, 22, 25-27). As such the rise may have undergone extended subaerial exposure during the late Tertiary.

Free air gravity anomalies range from over +100 mgals over the Gonave Rise to 0 mgals over the Gonave Ridge (Figure 12). A high of +200 mgals in the Bouguer anomaly coincides with the Gonave Ridge and the north-eastern tip of the Gonave Rise (Figure 13). The existence of this high indicates a degree of crustal thinning beneath the Gonave Ridge. This factor corroborates the proposal that it has been a transform boundary in the past. Crustal thinning has been observed along oceanic fracture zones in the North Atlantic basin by White and Stevens (1979). This thinning effect is retained even after transform tectonics cease along the fracture zone. Magnetic anomalies ranging in amplitude from 75 to 150 gammas with approximate wavelengths of 10 to 15 kms are associated with the Gonave Rise and ridge (Figure 8).

No coherent returns were received from the southwestern margin of the Massif de la Selle forming the north east rim of the Colombian Basin (lines 26, 27; Figures 5, 28, 29). Consequently this study contributes no direct information on the structure of this margin. On line 28 (Figure 30) across the Beata Ridge, the quality of the records are poor. Acoustic basement was not identified. Information was derived for only the most superficial strata on the Beata Ridge (Figures 28, 29). These units are flat-lying, 0.3-0.4 secs in thickness. Fox and Heezen (1975) describe the A" and B" acoustic horizons from the Beata Ridge. Thus the uplift ridge must postdate the mid-Tertiary, the age of horizon A".

The ship track crossed the Beata Ridge at an oblique angle in passage to the western end of the Los Muertos Trough (Figure 5). The structural character of this portion of line 28 (Figure 30) suggests gravity tectonics and slope modification. The Beata Ridge plunges directly into the Los Muertos Trough just east of the Enriquillo Cul de Sac (Figures 4, 5). The deepest reflectors in the region are ill defined but appear to be sediments (Figure 30).

Two structuraly prominent zones occur to the north and south of the Los Muertos Trough. The southerly of these is single antiformal structure, directly seaward of the Sierra Bahuroco, which dams the sediments on the eastern limb of the northern Beata Ridge (Figure 30). Several profiles across the Beata Ridge to the south show similar features (Rezak et al., 1972; Case, 1975; Heezen and Fox, 1975) suggesting that the antiformal structure parallels to the Beata Ridge.

Sediments along the northern margin of the Los Muertos Trough are strongly folded (Figure 30; Ladd and Watkins, 1978). The sedimentary units within the trough dip to the north and are involved in folds at the base of the southern Dominican Republic shelf (Figure 27). Underthrusting has been demonstrated in this region (Case, 1975; Ladd and Watkins, 1978; Holcombe and Mathews, 1976). The acoustic properties of the seismic system used in this study were not sufficient to determine the extent of the underthrusting in this region. On morphological grounds, however, the basin may be inferred to be underthrusting the deformed sediment prims to the north, as has been shown to the east along the same structure (Ladd and Watkins, 1978).

Measured free air gravity anomalies range from +50 to +100 mgals over the crest of the Beata Ridge (Figure 12). However values between the two compressive features in the axis of the Los Muertos Trough decrease to less than -150 mgals indicating a substantial departure from isostacy. This supports the interpretation of present day underthrusting in the trough region with a resulting tectonic mass deficiency (Bowin, 1976). Bouguer gravity anomalies range from between +100 mgals and +150 mgals over the Beata Ridge, and between +100 mgals and +50 mgals for Los Muertos Trough (Figure 13).

Magnetic anomalies over the ridge vary in amplitude from 100 to 200 gammas and wavelengths from 7 kms to 15 kms (Figure 8). They are more subdued in the Los Muertos Trough (Figure 30). A broad regional anomaly of approximately 300 gammas occurs over Los Muertos Trough and the deformed sediment prism.

The Southern Gonave Basin

The southern Gonave Basin (Figures 4-6) is covered by portions of lines 8, 9, 12-17, 19-21 (Figures 16, 18, 19, 20-27). The deepest sedimentary reflectors (2.0-2.5 seconds) are involved in structures that affect the entire stratigraphic column above them (Figures 16, 18, 19, 20-27).

The contact between the Southern Gonave Basin and the Gonave Rise is dominated by compressive features, sediment ponding in perched basins and perhaps some diapiric(?) influences. All strata in the eastern half of the basin are folded, both in the basin and along the southern flank with the Massif de la Hotte (Lines 13-17; Figures 19, 23, 26, 27). The entire northern margin of the Massif de la Hotte is involved in compressive tectonics with well developed fold axes running parallel to the contours from sea level to the floor of the Southern Gonave Basin. The sedimentary units in the Southern Gonave Basin can be traced into these compressive features. The distribution of deformed sediments suggests that the northern margin of the Massif de la Hotte is constructed of deformed sediment derived from the Southern Gonave Basin (Figures 12, 14, 15, 17-24).

In line 17 (Figure 19), well stratified slightly folded units interfinger with a transparent sedimentary sequence coming off the Gonave Rise (Figure 19). This indicates that the southern Gonave Basin has had at least two major sediment sources which varied in dominance over the late Tertiary to Holocene. Initially acoustically transparent sediments derived from the Gonave Rise to the north dominated the basin (Figure 19). Later a shift of sediment source from the Gonave Rise to the Massif de la Hotte resulted in the deposition of a well bedded sedimentary unit which dominates the upper strata. The interfingering and shift in sedimentary dominance implies that the Gonave Rise was a major sediment source in the late Tertiary (Figure 19). Uplift and erosion from the Massif de la Hotte, possibly combined with subsidence of the Gonave Rise (removing it as a major sediment source) may have caused the switch in the sedimentation pattern in the late Tertiary to Holocene.

Dominance of compression along the northern margin of the Massif de la Hotte argues for continuing present day convergence over the region. This requires a switch of active underthrusting from the southern flank of the Gonave Rise to the northern margin of the Massif de la Hotte at some stage during the late Tertiary. Clearly, the sedimentation history of the Southern Gonave Basin reflects this change in tectonic boundary conditions.

Free air gravity anomaly values range from 0 mgals over the southern Gonave Basin margin to -125 mgals in the central portions (Figure 12). The large negative anomaly is taken as an indicator of a tectonic mass deficiency due to compression across the basin (e.g. Bowin, 1976). Bouguer gravity anomalies range from +75 mgals to +150 mgals (Figure 13).

Magnetic variations within the basin are low amplitude with long wavelength (Figure 8). The only significant anomalies in the region occurs over the margin of the Gonave Basin and the Isle de la Gonave (Figure 8). These may reflect the existence of the Cretaceous(?) dolerites determined by Butterlin (1954) to form the basement of the Massif de la Hotte, and by Weyl (1966) to form the core of the Isle de la Gonave anticline (Gonave Rise).

Formigas Bank/Navassa Rise/Massif de la Hotte System

Portions of lines 19-21, 24-26 cover the Formigas Bank--Massif de la Hotte system (Figures 20, 21, 24, 28, 30). Acoustic basement on the Navassa Rise is a massive, topographically variable surface (Figures 20, 21, 24). This well defined basement is restricted to the northern portion of the Navassa Rise, and could be either a highly tectonized sedimentary unit, or a massive basement unit similar to that observed in the adjacent Massif de la Hotte (Bowin, 1975; Weyl, 1966; Butterlin, 1954). Magnetic and free-air gravity variations are substantial over this portion (Figures 5, 9). Contacts between the overlaying strata and acoustic basement are unconformable and onlapping. Sedimentation is primarily controlled by basement topography (Figures 20, 21, 24). At lower stratigraphic levels sedimentation is isolated in small basement controlled basins. The basement topographic variation appears controlled by the compressive tectonics that dominate both margins of the Navassa Rise (Figures 20, 21, 24). Sediments within the basement basins are themselves folded by a roughly north-south compressive component. Faults (both normal and reverse) are common, and affect both basement and sediments, indicating present day compressive tectonics.

Basement was not detected on any profile along the southern margin of the Navassa Rise. All reflectors there are sedimentary in nature, strongly folded and underthrust along the Navassa Trough (Figures 20, 21, 24). Hence, the geology of the southern margin of the Navassa Rise is dominated by accreted sediments derived from the basin to the south.

Compressive tectonics occur along the northern and southern margins of the Navassa Rise. However, the structural character is assymetric. The northern margin is clearly compressive with the sediments of the Southern Gonave Basin dipping towards the rise. Acoustic basement is clearly distinguishable above it. The quantity of deformed sediment is not large (Figures 20, 21, 24). The southern margin of the Navassa Rise has no discernible acoustic basement and has the character of a deformed sediment mass. Thrusting and possibly translation are involved in its formation (Figures 20, 21, 24). The character of the supra-basement strata implies two episodes of sedimentation (Figures 17, 18, 21). Initially sedimentation occured in small basement controlled basins, with possible contemporaneous erosion from exposed basement highs. Although no stratigraphic data exists for the Formigas Bank and the Navassa Rise from this time, inference from the geology of the Massif de la Hotte suggests that this episode occured during the Late Cretaceous. Portions of the rise may have been subaerially exposed during this stage. The carbonates of this age on the Massif de la Hotte are of shallow water derivation. The second sedimentation episode resulted in the deposition of a thick uniform sediment blanket which masks all basement topographic irregularities along the Navassa Rise (Figures 20, 21, 24). These Tertiary accumulations are involved in subsequent folding.

Acoustic basement of the Formigas Bank is similar to that of the northern limb of the Navassa Rise (Figures 20, 21, 24). Faults occuring on the platform can be traced well into the region of incoherent reflections below the acoustic basement. This implies the existence of a massive faulted basement section; a basement of igneous origin if inference from the Massif de la Hotte is correct. This interpretation is corroborated by the magnetic, and free-air gravity anomalies over the bank (Figures 8, 12, 20, 21, 24). The amplitudes and wavelength of these anomalies are similar to those on the Navassa Rise (Figures 20). Thus, the Formigas Bank is interpreted as a partially decoupled portion of the Navassa Rise/Massif de la Hotte System.

The broad platform morphology of the Formigas Bank/Navassa Rise suggests that this region was once in the proximity of sea level. Carbonate platform conditions are common in the area today, and may have existed along the bank in the past allowing the deposition of 0.5-1.5 seconds of sediments prior to subsidence.

Compressive tectonics are not obvious on the Formigas Bank, although the platform is extensively faulted. Faulting involves the entire stratigraphic column and controls the distribution and thickness of the sediments over a small horst and graben system (Figures 20). Where the contact is unambiguous (a minority of cases) the overlaying sediments onlap the basement.

The southern Massif de la Hotte margin is characterized by extremely steep topography along its western margin (Figures 4, 5, 6). No acoustic information was derived from these areas. On the Massif crest, however, slopes are gentle and penetration is considerably improved.

Sediment cover over the southern extension of the Massif de la Hotte is thin (Lines 24-26; Figures 31, 32, 28). Basement is broken up into a series of horsts and grabens which control the deeper strata in a similar fashion to the Formigas Bank and Navassa Rise (Figures 28, 32). Basement which may be exposed on some of the horst structures is massive. High amplitude short wavelength magnetic anomalies suggests that it is made of high magnetic susceptiblity material occuring at high levels in the crust (Figures 8, 28, 32). Basement in this region is assumed to be similar to the Late Cretaceous dolerites recognized by Butterlin (1954) in the subaerial portions of the Massif de la Hotte.

Sedimentary units above basement are discontinuous, of variable thickness in the shallower portions, ranging from 0.0-1.2 seconds (Figures 28, 32). Faults affect sediment and basement alike. There is no evidence for horizon A" or the beds in the B"-A" interval in any portion of the system (Figure 28, 32).

In the southern and deeper portions of the Massif de la Hotte, sedimentary layers are more continuous (Figures 28, 32). The sediment/basement contact is unconformable where visible.

Free air gravity anomalies over the Navassa Rise and the Formigas Bank range around +50 mgals and those over the southern Massif de la Hotte margin average -50 mgals (Figure 9). Bouguer anomalies range around +125 mgal +150 mgals for both regions (Figure 10). Magnetic anomalies along the northern Navassa Rise and the Formigas Bank range in amplitude from 100-200 gammas (Figure 5). A large 300 gamma anomaly occurs over the southern flank of the Navassa Rise in the region of the deformed sediments. This suggests that high magnetic susceptibility material is incorporated into the thrust faulted region (Figure 5). Anomaly wavelengths range from 10-20 kms (Figure 5). Magnetic anomalies range from 400-900 gammas in the shallower regions and 200-300 gammas for the deeper portions of the southern Massif de la Hotte (Figure 5). Anomaly wavelengths average 5-10 kms for both depths. The largest anomalies occur over the topographic lobe extending into the Colombian basin on a N45^{o}W axis (Figure 5). The largest anomalies are associated with small topographic features on the crest of the lobe. They probably indicate the presence of dolerites at high levels in the crust.

The Nicaraguan Rise.

The basement of the Nicaraguan Rise is geologically and structurally complex (Arden, 1975; Kudoley and Meyerhoff, 1971; Wright et al., 1974; Draper, 1978, 1979). The sediment blanket of the rise (Lines 19-23; Figures 20, 21, 24, 33, 34) varies in thickness from 0.5-2.5 seconds. Faulting and folding affect all the strata with deformation increasing in intensity towards the north and east. Underthrusting occurs along the contact between the Navassa Rise/Massif de la Hotte and the Nicaraguan

Figure 31 Interpretation of seismic profile line 24 with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

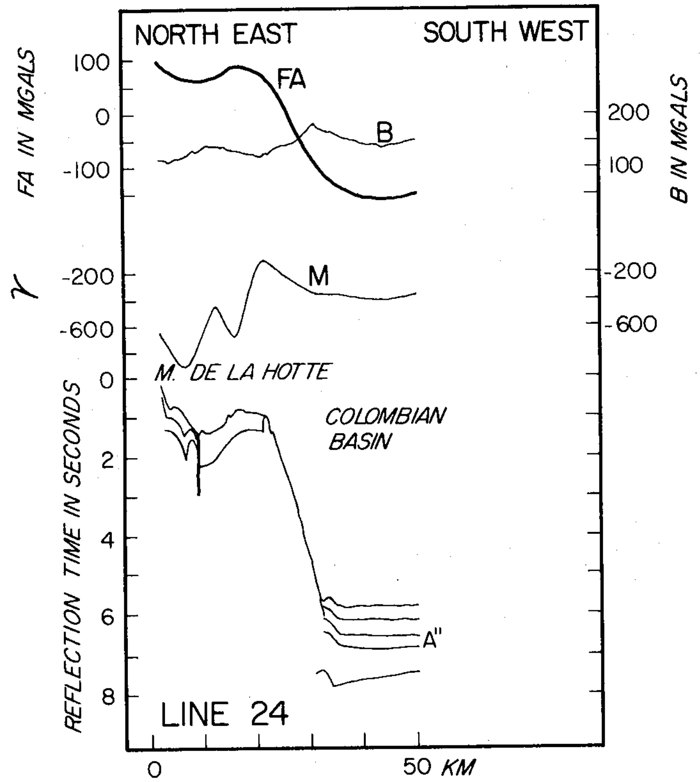
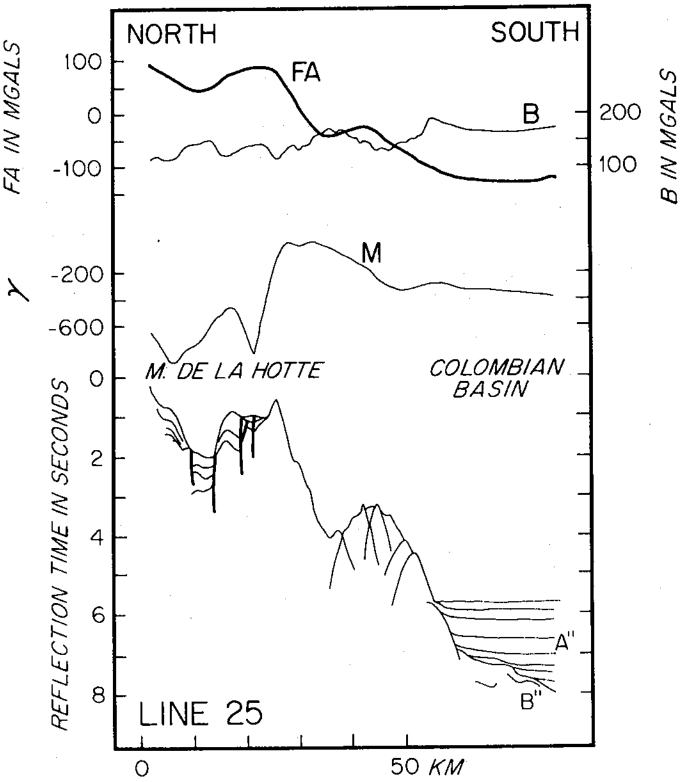

NORTH EAST
SOUTH WEST
FA IN MGALS
100
0
-100
FA
B
200
100
B IN MGALS
γ
-200
-600
M
-200
-600
M. DE LA HOTTE
COLOMBIAN BASIN
REFLECTION TIME IN SECONDS
0
2
4
6
8
A''
LINE 24
0
50 KM

Figure 32. Interpretation of seismic profile line 25 with merged geophysical data. For symbols see figure 9. For location see Figure 5. A" and B" are prominent acoustic horizons in the Colombian Basin.


NORTH
SOUTH
FA
B
M
FA IN MGALS
B IN MGALS
100
0
-100
200
100
γ
-200
-600
M. DE LA HOTTE
COLOMBIAN BASIN
REFLECTION TIME IN SECONDS
0
2
4
6
8
A''
B''
LINE 25
0
50 KM

Rise (Figures 20, 21, 24, 33, 34). The classical underthrust morphology is best developed in lines 22a and 22b (Figure 33) where the underlaying basement is visible beneath an imbricated subduction complex, structural high and residual (forearc) basin (Seely and Dickinson, 1979).

High angle faults of indeterminate throw occur along the contact between the 'fore arc basin' and the Massif de la Hotte on lines 22a and 22b (Figure 29). These faults are continuous with the previously mentioned transform fault system that extends the length of the Massif de la Hotte (Figure 35). This system is interpreted as a feature of the translative tectonic regime that dominates the region (Molnar and Sykes, 1969).

The 'subduction complex', developed in lines 22a and 22b are not evident in lines 22c and 22d which are 20 and 35 kms to the east of line 22b, respectively (Figures 5, 33). The Massif de la Hotte margin is composed of highly deformed sediments in this region. I propose that the structural and tectonic units are continuous from the marine to the subaerial environment and that sediments derived from the northeastern Nicaraguan Rise are preserved along the south western margin of the Massif de la Hotte.

Line 23 crosses the topographically discontinuous boundary between the Nicaraguan Rise and the Colombian Basin (Figure 34). The boundary is geometrically and bathymetrically continuous with the underthrust region covered by lines 22c and

22d, although the thrusting polarity is reversed (Figures 33, 34, 35). The Nicaraguan Rise overthrusts the Colombian Basin to a limited degree in this region. The overthrust zone is marked by a double anticline which provides for a small rimmed basin. This basin displays some of the structural and stratigraphic characteristic of forearc basins (Figure 34).

The entire region between the Nicaraguan Rise/Navassa Trough and the Navassa Rise/Massif de la Hotte/Colombian Basin is characterized by structural and stratigraphic morphologies normally associated with subduction (Figures 20, 21, 24, 33, 34, 35). There are several important differences however. These are:

i) Scale. The 'trench' to 'massif' distance is only 40 kms from "trench" to "massif". This contrasts strongly with true subductive systems where distances average 250-300 km (Figure 33).

ii) No volcanism. Considering the scale and the depths necessary for magma generation, this is hardly surprising.

iii) No well defined seismicity.

Clearly compression is the common ingredient, and while the magnitude of convergence for this region is nothing like that normally associated with true subductive plate margins, the geometry is identical. These facts also may be explained by recalling that the present data set artificially selects for those processes that are dominant in the plane of the seismic

Figure 33. Interpretation of seismic profiles, Lines 22a, 22b, 22c, 22d, with merged geophysical data. For symbols see Figure 9. For location see Figure 5.

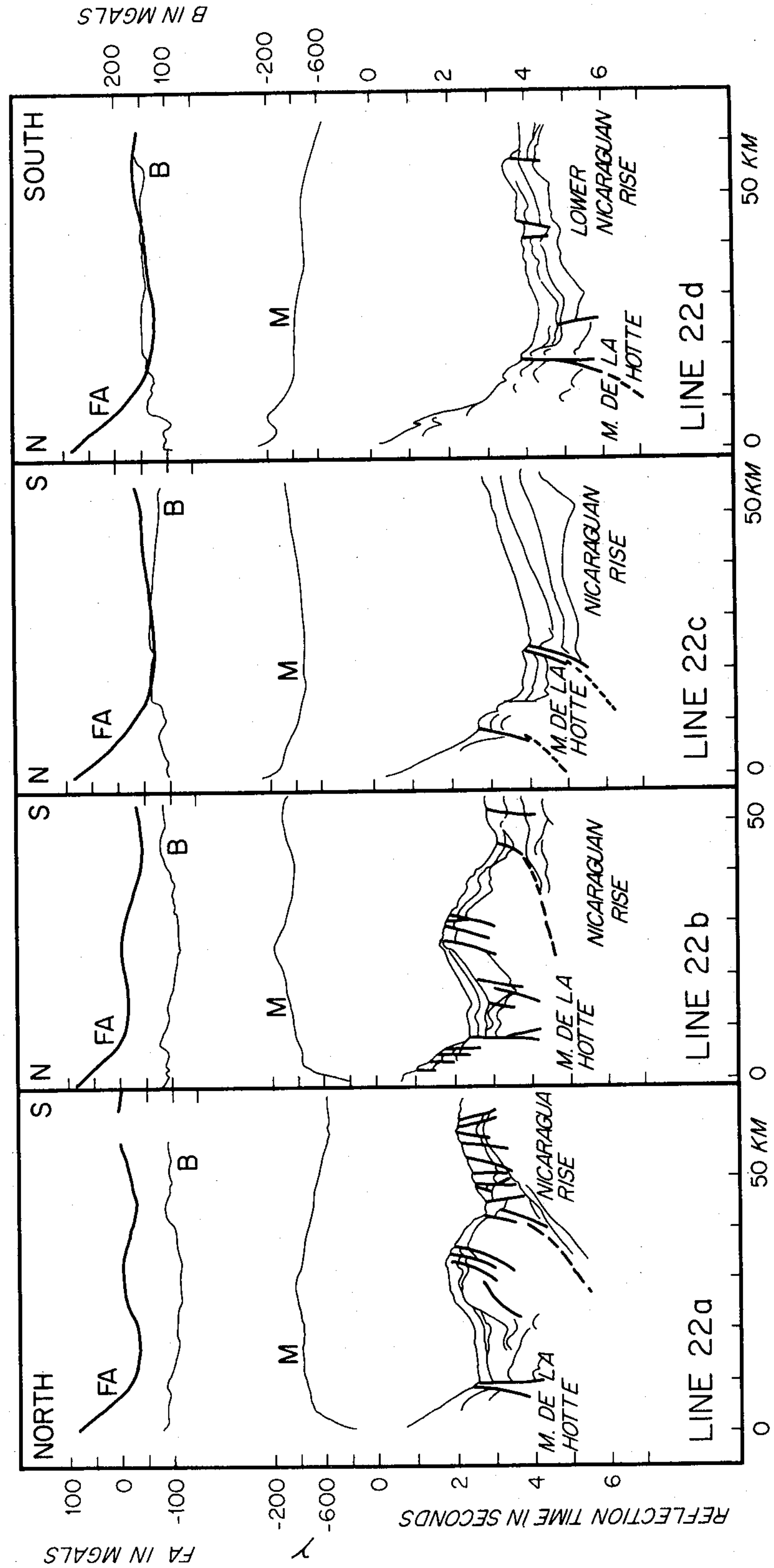
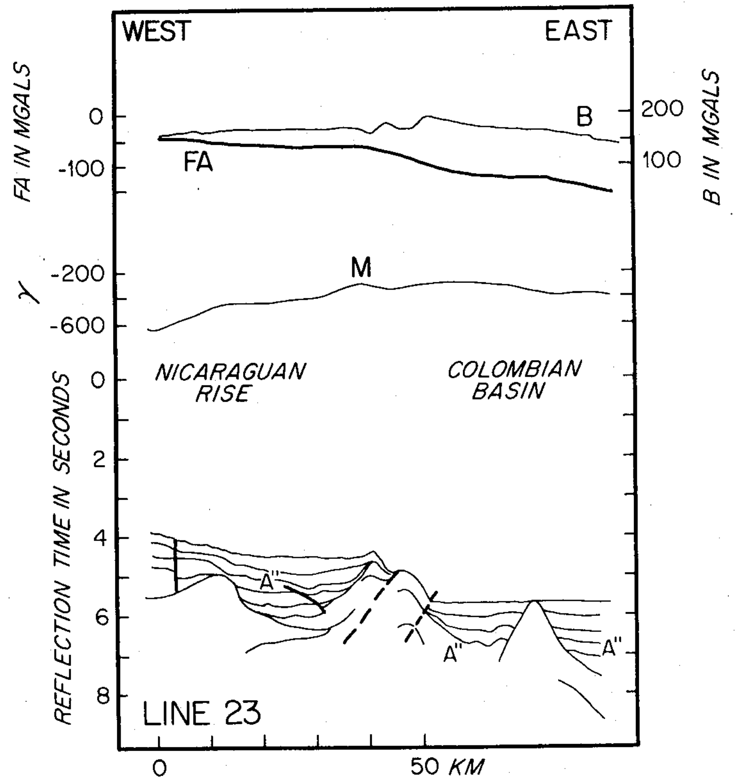

NORTH
SOUTH
N
S
FA
B
M
LINE 22a
LINE 22b
LINE 22c
LINE 22d
M. DE LA HOTTE
NICARAGUA RISE
NICARAGUAN RISE
LOWER NICARAGUAN RISE
FA IN MGALS
100
0
-100
γ
-200
-600
0
REFLECTION TIME IN SECONDS
0
2
4
6
B IN MGALS
200
100
0
50
50 KM

Figure 34. Interpretation of seismic profile Line 23 with merged geophysical data. For symbols see Figure 9. For location see Figure 5. A" is an acoustically prominent stratigraphic horizon in the Colombian Basin.


WEST
EAST
FA IN MGALS
0
-100
B
200
100
B IN MGALS
FA
M
γ
-200
-600
NICARAGUAN RISE
COLOMBIAN BASIN
REFLECTION TIME IN SECONDS
0
2
4
6
8
A''
A''
A''
LINE 23
0
50 KM

section (i.e. convergence) but which may be completely secondary in the true tectonic scheme of things (i.e. translative tectonic dominance). Also, if the strain rate associated with translation is much greater than that for convergence, the geophysical properties of instantaneous nature are far more prone to reflect the former (e.g. Molnar and Sykes, 1969). This leads to an artificial tectonic dichotomy caused by the different selective responses of the different data sets.

Free air gravity anomalies over the Nicaraguan Rise range around 0 mgals with a -50 mgal negative anomaly coinciding with the Navassa Trough (Figure 12). Bouguer anomaly values range around +150 to +125 mgals (Figure 13). Magnetic variations over this portion of the Nicaraguan Rise and Navassa Trough are generally subdued, on the order of 50 gammas (Figure 8). Significant anomalies of 350 gammas occur along the margin of the western Massif de la Hotte. A smaller anomaly of 150 gammas occurs over the accretionary wedge crossed by lines 22a and 22b (Figure 33). The presence of this anomaly may indicate involvement of basement in the tectonized regions (Figure 8).

The Colombian Basin.

As discussed previously, the general stratigraphic character is assumed to be similar between the Venezuelan and

Colombian basins. Thus, the general stratigraphy of the Venezuelan Basin is known down to horizon B" (Saunders et al, 1973; Case, 1975). The deepest observed reflector in the Colombian basin is an irregular surface ranging in depth between 0.2 seconds and more commonly 2.0-3.0 seconds sub-sea floor (Lines 23, 24, 25, 26, 27, 28; Figures 28-32, 34). In contrast to the Venzuelan Basin, the surface morphology of the basal reflector in the Colombian Basin is far more variable. Within the study area, the B" horizon shallows towards the Massif de la Hotte, rising from depths exceeding 9.0 seconds below sea level, to 5.0 seconds along the southeastern margin of the extension of the Massif de la Hotte. I interpret it to be continuous with the basal units of the Massif de la Hotte (Figure 28).

Conversely horizon B" dips beneath the entire margin with the Massif de la Selle/Beata Ridge and is involved in folding at the base of the margin. The B" complex is lost at depths of greater than 3.0 second sub-sediment surface in this region (Figures 28-30).

The relationship of the B" complex with the southern portion of Massif de la Hotte (Figure 28) indicates that the basement observed on the Massif may be uplifted B". In this case the Massif de la Hotte must have been formed after the Late Cretaceous event which gave rise to the B" sills. As previously discussed the massif has remained topographically elevated since then. This interpretation is further corroborated by the sediment/basement relationships in this region (Figures 28-30).

There have been at least two episodes of tectonism affecting the Massif de la Hotte and the northern Colombian Basin:

i) Late Cretaceous uplift after the B" igneous event and prior to the deposition of the Carib beds and the A" horizon. The Carib beds and the A" horizon onlap the B" surface in the southeastern extesion of the Massif de la Hotte (Figure 28).

ii) Recent tectonism associated with the convergence between the Colombian Basin/Massif de la Hotte and the Nicaraguan Rise/Navassa Trough (Figure 34), the Southern Gonave Basin and the Gonave Rise/Massif de la Selle/Beata Ridge Systems (Figure 35).

The structural/stratigraphic relations in the region allow the implicit conclusions that:

a) the Massif de la Hotte is rigidly coupled to the Colombian Basin (e.g. Figure 28).

b) The Colombia Basin/Massif de la Hotte is decoupled from the Nicaraguan Rise (compression; Figures 34, 35), the Venezuelan Basin (compression along the Beata Ridge; Figure 30), the Massif de la Selle (compression; Figures 28, 29) and the southern Gonave Basin (compression; e.g. Figure 27).

The Colombian Basin/Massif de la Hotte has a compressive tectonic history along its margins. This suggests that major geometrical restrictions occured during the development of this region leading to severe competition between the major plates for the available space (to the demise of the Colombian Basin).

The superficial sedimentary units of the northern Colombian Basin average 2.5 seconds in thickness, and are characterized by continuous highly stratified sediments. They appear to represent a continuous sedimentation sequence since the Late Cretaceous. The Carib beds (Ewing, 1969; the sedimentary unit between the B" and A" horizons) and horizon A" show on all the records within the Colombian Basin (Figures 28-32, 34). The Carib beds form a highly reflective thinly-layered sediment sequence 0.3 to 0.4 seconds thick. Sedimentary units within the basin have an onlapping relationship with the acoustic basement along the extension of the Massif de la Hotte (Figures 28-32, 34).

The sediments of the Colombian Basin are folded against the base of the Beata Ridge (Figures 28-30). The folds are broad antiformal structures affecting all layers of the sedimentary sequence in lines 26 and 27 (Figures 28, 29), and all but the uppermost on line 28 (Figure 30). This implies that compression along the northeast margin is still continuing, while on the eastern margin it has recently ceased. This may be a simple geometrical effect. Faulting (normal or transform?) is presently extant at the base of the Beata Ridge and effects the uppermost sediment layers (Figure 30). Clearly underthrusting is dominant along the Massif de la Selle/Beata Rise margin and is probably responsible for the formation of the Beata Ridge/Massif de la Selle. This underthrusting implies that the stratigraphy of the uplifted Massif de la Selle/Beata Rise (and by continuity, the Gonave Rise) is derived from the Colombian Basin. This has been postulated for the Massif de la Selle (Maurasse et al, 1978).

Free air gravity anomalies with the Colombian Basin indicate isostatic equilibrium over the basin as a whole (Bowin, 1976). However, measured free air gravity anomalies in the northern section of the basin range from less than -150 mgals in the northwest to less than -200 mgals in the northeast (Figure 9). Both regions depart substantially from isostatic equilibrium, with the tectonic mass deficiency associated with recent compressive tectonics over the region. Bouguer gravity anomalies in the region range from +150 to +200 mgals (Figure 10). The higher frequency components of the Bouguer gravity anomaly indicate some morphological complexity (Figure 10). The paucity of data in the region does not allow their resolution. Magnetic anomalies over the Colombian Basin are low amplitude long wavelength features (Figure 5). A 350 gammas anomaly occurs at the vertex of lines 26 and 27 (Figure 25, 26). It may represents high magnetic susceptibility material incorporated into the upper crustal levels, and be analogous with the B" igneous unit incorporated into the Massif de la Selle to the north.

CHAPTER 4

GEOLOGICAL EVOLUTION

Introduction

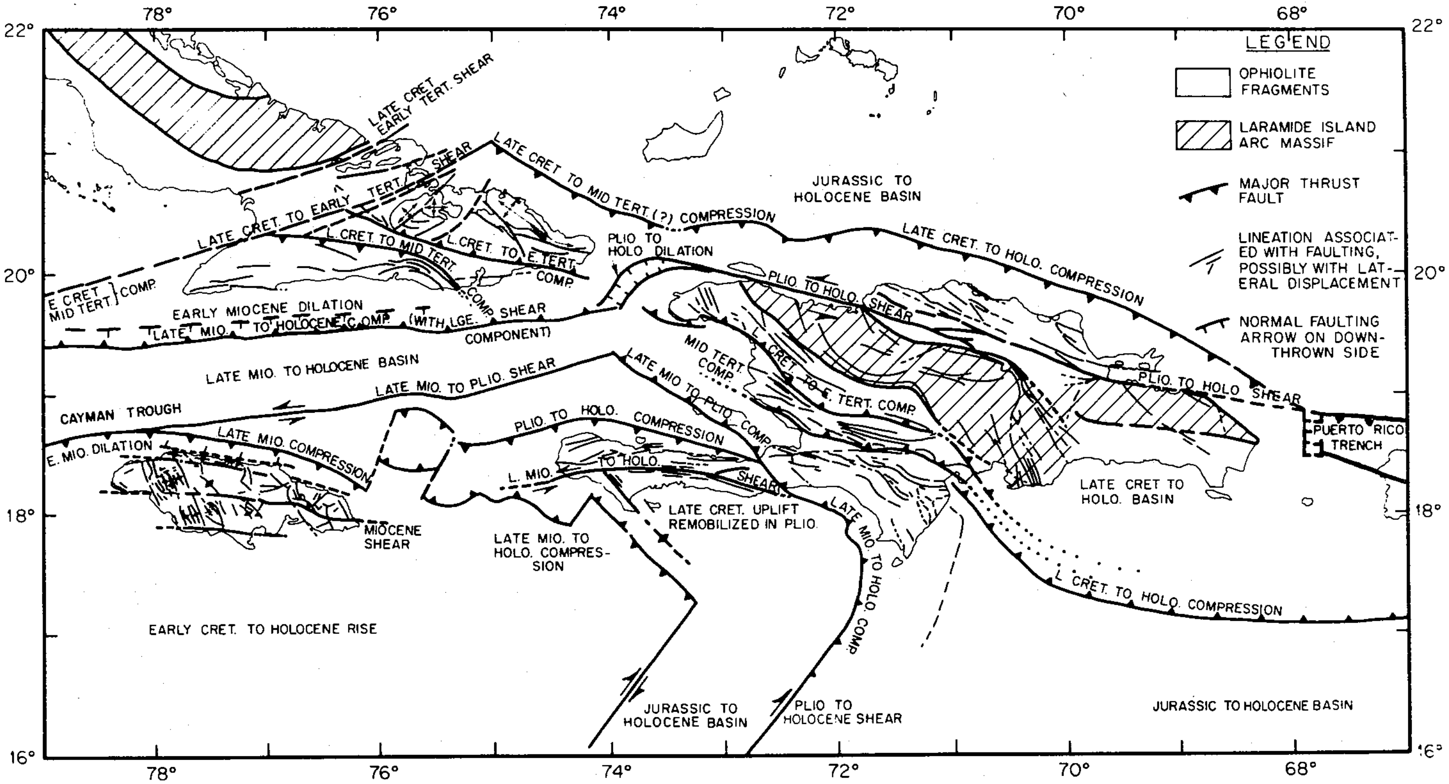
Geological interpretations of the tectonic development of the Caribbean tend to be based on areally insignificant exposure of existing tectonic elements. The result is the enormous range of opposing hypotheses which include land and sea reversals (Woodring, 1954), permanently stable geosynclines (Khudoley and Meyerhoff, 1971), fracture contraction hypothesis (Meyerhoff and Meyerhoff, 1972, Iturralde-Vinent, 1975) and a broad variety of plate tectonic models (Freeland and Deitz, 1971; Malfait and Dinkleman, 1972; Mattson, 1973; Burke et al., 1978; Mattson, 1979; Goreau, 1979). This study is based on the new data base described previously. These data, however, have several natural limitations. These include:

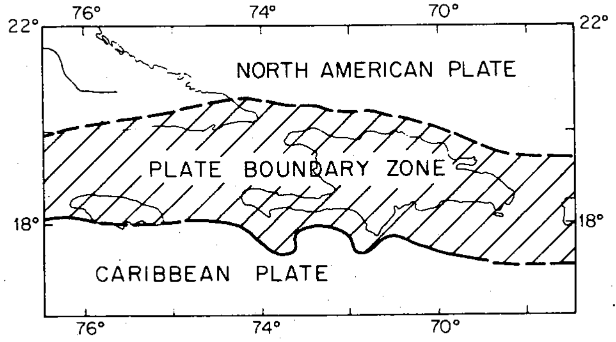
1. The seismic reflection profiles provide information in the plane of the profile and tend to exaggerate the importance of compressional and vertical tectonics to the detriment of tectonic phenomenon normal to the plane of the profile, e.g. translation.

2. The line spacing limits the resolution of features with a wave length smaller than that spacing. In such cases the geometry of the feature can be inferred from other factors, such as physiographic continuity and structural grain.
3. Little stratigraphic data exists from the marine realm. This information must be inferred from adjacent subaerial portions, and from structural relationships between acoustic reflectors and uplifted regions where basins are concerned.

The uncertainty caused by these limitations is made up to some extent by the use of the data base to divide the region into a series of geologically related physiographic provinces (Figure 6). The marine portions are identified with specific geological provinces on land, thus providing the only stratigraphic information available for the basins (Figure 6). Further, structural information derived from the marine realm is extended to those subaerial portions which are poorly mapped. It remains the fundamental nature of this work to be interpretative and speculative, as is any three-dimensional time series with a paucity of data. However, by treating data in just such a way, a simple solution for the present geometry is derived. Bear in mind that by nature, interpretation of complex geological information tends to be non-unique. The present-day structural entities are delineated in Figure 35.

Figure 35. Tectonic map of the northern Caribbean compiled from seismic profiles; Geological Map of Jamaica (Jamaican Geological Survey, 1977); Earth Resource Telemetry Satellite photographs of Jamaica, Hispaniola and Cuba; Boiteau et al (1972a, 1972b); Bowin (1975); Draper (1979); Lewis and Straczek (1955), Rigassi-Studer (1961); Weyl (1966). This map includes all major tectonic features dating from the late Mesozoic to the Holocene.


LEGEND
OPHIOLITE FRAGMENTS
LARAMIDE ISLAND ARC MASSIF
MAJOR THRUST FAULT
LINEATION ASSOCIATED WITH FAULTING, POSSIBLY WITH LATERAL DISPLACEMENT
NORMAL FAULTING ARROW ON DOWNTHROWN SIDE
78°
76°
74°
72°
70°
68°
22°
20°
18°
16°
LATE CRET EARLY TERT. SHEAR
LATE CRET. TO EARLY TERT. SHEAR
LATE CRET TO MID TERT.(?) COMPRESSION
L. CRET TO MID TERT. COMP. SHEAR
L. CRET. TO E. TERT. COMP.
E CRET MID TERT COMP.
EARLY MIOCENE DILATION
LATE MIO. TO HOLOCENE C. OMP. (WITH LGE. COMPONENT)
PLIO TO HOLO DILATION
JURASSIC TO HOLOCENE BASIN
LATE CRET. TO HOLO. COMPRESSION
PLIO. TO HOLO. SHEAR
LATE MIO. TO HOLOCENE BASIN
LATE MIO. TO PLIO. SHEAR
CAYMAN TROUGH
MID TERT. COMP.
L. CRET. TO E. TERT. COMP.
LATE MIO TO PLIO. COMP.
PLIO. TO HOLO SHEAR
PUERTO RICO TRENCH
E. MIO. DILATION
LATE MIO. COMPRESSION
PLIO. TO HOLO. COMPRESSION
L. MIO. TO HOLO. SHEAR
LATE CRET. UPLIFT REMOBILIZED IN PLIO.
LATE MIO. TO HOLO. COMP.
LATE CRET TO HOLO. BASIN
L. CRET. TO HOLO. COMPRESSION
MIOCENE SHEAR
LATE MIO. TO HOLO. COMPRESSION
EARLY CRET. TO HOLOCENE RISE
JURASSIC TO HOLOCENE BASIN
PLIO TO HOLOCENE SHEAR
JURASSIC TO HOLOCENE BASIN


76°
74°
70°
22°
18°
NORTH AMERICAN PLATE
PLATE BOUNDARY ZONE
CARIBBEAN PLATE

Tectonic Fabric.

The tectonic map (Figure 35) has been simplified to include only the major structural entities within the study area. It also has been extended to cover those physiographically continuous adjacent terrains where only bathymetric data exists.

A zone of translation and associated compression separates the Greater Antilles Ridge from the Old Bahama Channel/Caicos Basin System (Figures 9, 10, 11, 35). This zone extends from the Puerto Rico Trench to the Cuban margin adjacent to the Cauto Basin (Figures 1-6, 35). Underthrusting along this belt lasted from the Late Cretaceous to the mid-Tertiary west of the Windward Passage, and from the Late Cretaceous to Holocene from the Windward Passage to the Puerto Rico Trench (Figure 35). The temporal heterogeneity along this zone is due to the transfer of the North American/Caribbean plate boundary from the Cauto Basin to the Cayman Trough during the mid-Tertiary. This event marked the capture of the Cayman Ridge by the North American Plate and the formation of the Cayman Trough.

Geometrical considerations imply that the Cauto Basin marked the eastern extent of a major transcurrent boundary between the North American and Caribbean plates. This boundary, herein named the Cauto Basin Shear, existing from the Late Cretaceous to the mid-Tertiary. This has been proposed by several authors including Malfait and Dinkleman (1972), Perfit and Heezen (1979), and Goreau (1979).

The northern margin of the Cayman Ridge adjacent to the Cauto Basin marks the locus of a major subductive boundary that existed along the northern Nicaraguan Rise during the Late Cretaceous to mid-Tertiary. This subductive system was the direct result of the 80° sinistral rotation of the Nicaraguan Rise during the Cretaceous to mid-Tertiary as postulated by Gose and Swartz (1978) (Figure 38). When closure was achieved between the Nicaraguan Rise, the Cuchillas Uplift and the Greater Antilles Ridge during the mid-Tertiary, subduction terminated and the Cauto Basin Shear was overridden (Appendix 1). Thus, from the Late Cretaceous until the mid-Tertiary, the boundary between the northern margin of the Cayman Ridge and the Cauto Basin was a transform plate margin between North America and the Caribbean and a subductive one between the Nicaraguan Rise and the Caribbean (Figure 35). It has been defunct since the mid-Tertiary when major tectonic activity between the North American and Caribbean Plates switched to the Cayman Trough.

A thrust fault system is inferred to extend from the Cauto Basin along the southern flank of the Cuchillas Uplift in the Guantanamo Basin via the north east peninsula of Hispaniola and the southern flank of the Montagnes Noires/Massif Trou d'Eau to the Los Muertos Trough (Figures 6, 35; Appendix 1). Portions of the northern Caribbean Basin underthrust the Greater

Antilles Ridge along this system during the Late Cretaceous and early Tertiary.

A similar, but younger mid-Tertiary thrust system extends from the southern Cauto Basin via the Guantanamo Basin, to the Chaines des Matheaux/Sierra Neiba and Los Muertos Trough (Figure 6, 35). Structurally heterogeneous, the polarity of underthrusting is inferred to be to the south where the Nicaraguan Rise abutted the Guantanamo Basin, and to the north where the Caribbean Basin underthrust the Greater Antilles Ridge (Figure 35).

Extreme topographic scarps mark the northern and southern margins of the Cayman Trough (Figure 4). This is a structurally heterogeneous zone, with early Miocene divergence and associated normal faulting, masked by late Miocene to Holocene convergence, which has caused limited underthrusting (secondary to shear) along the flanks of the Cayman Trough (Figures 20, 24, 35). Foundered structures of the Chaines des Matheaux extend into the northern Gonave Basin exerting structural control on the superficial sediments (e.g. Figure 23). Thus the divergence that gave rise to the Cayman Trough had effects on western Hispaniola.

The southern Oriente margin has a large component of shear associated with the Pliocene to Holocene transcurrent boundary extending from Central America via the Oriente Deep, the Windward Passage Deep, the Valle del Cibao, the Bahia de Samana and the Puerto Rico Trench (Figure 2, 4, 35). Thus since the early Miocene the southern Oriente margin has had a geological history which includes all the end members of plate tectonic processes.

A major late Miocene to Pliocene transcurrent boundary occurs along the Gonave Ridge (Figures 6, 20, 24, 35). It terminates along the northwest Gonave Rise/Massif de la Selle/Beata Ridge fold belt beneath which the Colombian Basin was thrust to the northeast (Figure 6, 35). While this failure boundary is complex, each portion of this boundary owes its structural character to the geometrical relation between the strike of the portion and the local stress ellipsoid at the time (Figures 6, 35). The northern margin of the Massif de la Hotte overthrusts the southern Gonave basin (Figure 3, 24, 31). The age of this feature appears to be Pliocene to Holocene.

The northern margin of the Nicaraguan Rise underthrusts the Navassa Rise/Massif de la Hotte System along the Navassa Trough (Figures 33, 35). The polarity of the underthrusting changes where the rise abuts the Colombian Basin, although the extent of convergence appears to be limited (Figures 34, 35).

Miocene sinistral faults occur along the northern Nicaraguan Rise (Jamaica) and on the Massif de la Hotte (Figures 4, 35). These are clearly related to the relative motions between the North American and Caribbean plates and follow the structural trend of the Cayman Trough (Figure 35). The fact that they are detected primarily on land attests to the selectivity of the marine geophysical data in detecting vertical tectonics. These lateral faults certainly exist within the marine realm too.

The Los Muertos Trough is an important underthrust margin (Ladd and Watkins, 1978). Ladd (personal communication) indicates a prolonged Tertiary to Holocene development of the Southern Dominican Tertiary basin (Figures 30, 35). In this study, underthrusting along the trough is assumed to have lasted from the Late Cretaceous to Holocene on geometrical grounds (Figures 6, 35).

Large free air gravity anomalies occur along all the forementioned regions of underthrusting (Figures 12, 35). The major discrete locus of strain accommodation (i.e. "Plate Boundary") has migrated all over the "Plate Boundary Zone" (P.B.Z.; Figure 3, 31). However, the entire zone is under generalized diffuse compression today as evidenced by the ubiquitous deformation of all the most recent sediments (e.g. Figures 9-11, 20, 21, 27, 29, 33). This presumably aids in the maintainance of the large tectonic mass deficiencies necessary to cause the free air gravity anomalies (Figure 12). There are two scales of strain accomodation. A primary one is associated with whichever failure surface is geometrically and tectonically optimal, and along which major strain accomodation occurs. The secondary one is associated with a broad deformational front dispersed across the entire P.B.Z. (Burke et al, in press). The location of sites of major strain adjustment are the result of a complex interaction between local, regional, and global influences (Figure 51, Schwann, 1980).

A simplified tectonic map including only important Pliocene and Holocene tectonics is presented in Figure 36. This is as accurate a map of the present day plate boundaries as is feasible. Seismicity in the region falls well within these boundaries and the broad shear zones associated with them (Figures 36, 37). The deeper seismicity in the region is isolated to the eastern portion of the study area and defines a vertical boundary beneath the Plate Boundary Zone (Figure 37). This zone may represent the actual North American/Caribbean Plate boundary for the deeper portions of the study area. The distribution of these earthquakes may reflect a region where the North American/Caribbean Plate Boundary is under compression. This may account for the absence of deep earthquakes in the western portion of the study area where the North American and Caribbean Plates are presently seperated by the oceanic Cayman Trough and so presumably where the deeper portions of the plates are not in contact. Above this zone the Plate Boundary Zone is entrained as partially decoupled bouyant geological debris displaying the 'flower structure' common of

Figure 36. Present day tectonic map of the northern Caribbean compiled using only features interpreted as Pliocene to Holocene.

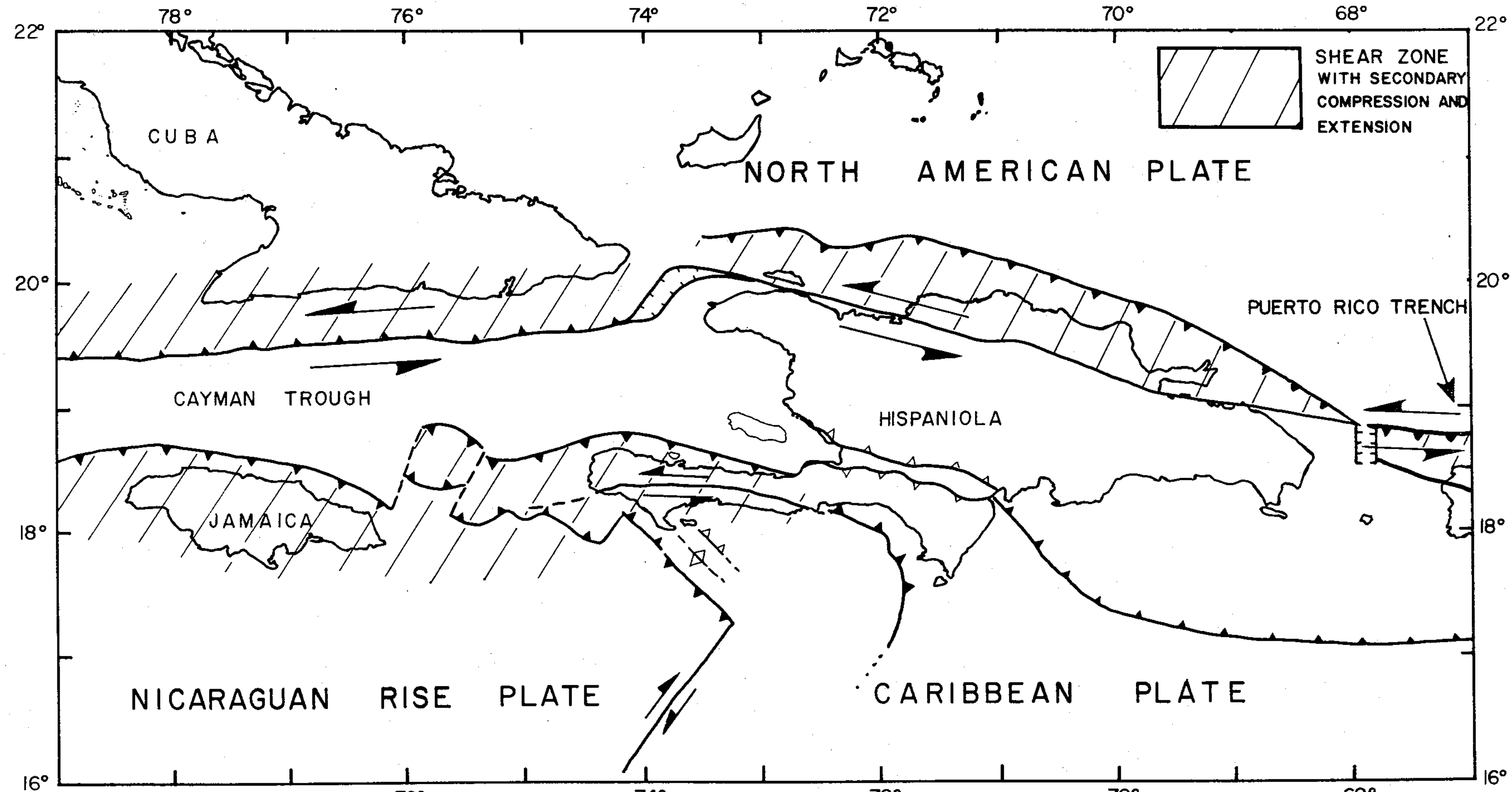
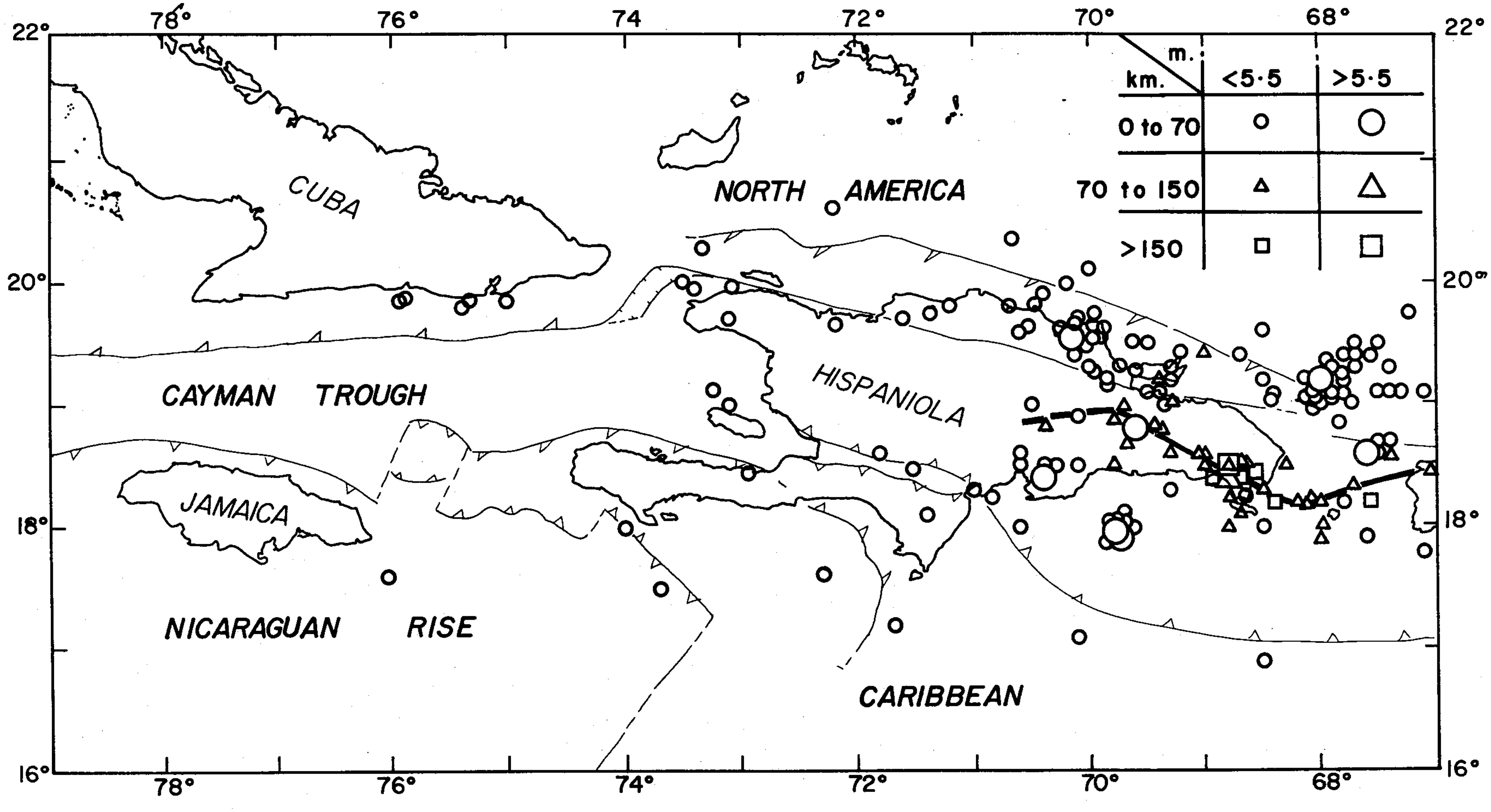

78°
76°
74°
72°
70°
68°
22°
20°
18°
16°
SHEAR ZONE WITH SECONDARY COMPRESSION AND EXTENSION
CUBA
NORTH AMERICAN PLATE
PUERTO RICO TRENCH
CAYMAN TROUGH
HISPANIOLA
JAMAICA
NICARAGUAN RISE PLATE
CARIBBEAN PLATE

Figure 37. Seismicity in study area from 1963 to 1976. Earthquake data compiled by the M.I.T. Earthquake Data Center. The present day tectonic map is superimposed for reference. The heavy line coincides with the majority of intermediate and deep earthquakes in the region. It defines a vertical plane that might represent the location of the North American/Caribbean Plate Boundary beneath the Greater Antillean Ridge.


m.
km.
<5·5
>5·5
0 to 70
70 to 150
>150
NORTH AMERICA
CUBA
CAYMAN TROUGH
HISPANIOLA
JAMAICA
NICARAGUAN RISE
CARIBBEAN
78°
76°
74
72°
70°
68°
74°
22°
20°
18°
16°

translational tectonic environments with a secondary compressive component acting across it (Harding, 1979).

In summary, the map (Figure 35) displays a complex plate boundary zone within which strike slip motion dominates. Oblique translation has resulted in a complex fabric of compressive and dilative structures. Major features within the zone are:

1. A translation zone borders the northern margin of the Cuchillas Uplift, the Windward Passage Sill, the Tortue Rise, and the Cordillera Septentrional. Evidence suggests tectonism lasting from the Late Cretaceous to the mid-Tertiary west of the Windward Passage Sill, and from the Late Cretaceous to the Holocene east of the sill.
2. The Cauto basin strike-slip zone, active from the Late Cretaceous to the mid-Tertiary.
3. The Oriente Deep/Windward Passage Deep/Canal de la Tortue/Valle del Cibao/Samana Bay strike-slip system active from the Pliocene to Holocene.
4. The ancestral Los Muertos Trough/Montagnes Noires/Cuchillas Uplift thrust belt and flanking basin development during the Late Cretaceous and early Tertiary.
5. The northern Cayman Ridge/Nicaraguan Rise subductive system active until the mid-Tertiary.
6. The ancestral Los Muertos Trough/Sierra Neiba/Chaines des Matheaux/Sierra Maestra System and related basins of mid-Tertiary age.

7. The Sierra Maestra/Cayman Ridge and the Nicaraguan Rise rift system of early Miocene age, with associated oceanic spreading in the Cayman Trough.
8. The Gonave Ridge/Gonave Rise/Massif de la Selle/Sierra Bahuroco/Beata Ridge System of late Miocene to Pliocene age.
9. The Formigas Bank/Navassa Rise/Massif de la Hotte/Colombian Basin System of Late Cretaceous to Pliocene age.
10. The Los Muertos Trough System and flanking Southern Dominican Tertiary basin and 'subduction complex' of Late Cretaceous to Holocene age.
11. The Cordillera Central ancestral island arc active from the Early to Late Cretaceous.

The Tectonic Model

General Statement

The analysis of all available data in the study area has allowed the delineation of the structural and temporal relationships between the major physiographic entities in the northern Caribbean. The developmental tectonic scheme to be presented is based on the tectonic framework established by Silver and Anderson (1975), Anderson and Schmidt (1978), Schmidt and Anderson (1978) and Anderson (personal communication) for Central America; and Gose and Swartz (1977) and Gose (personal communication) for the Nicaraguan Rise.

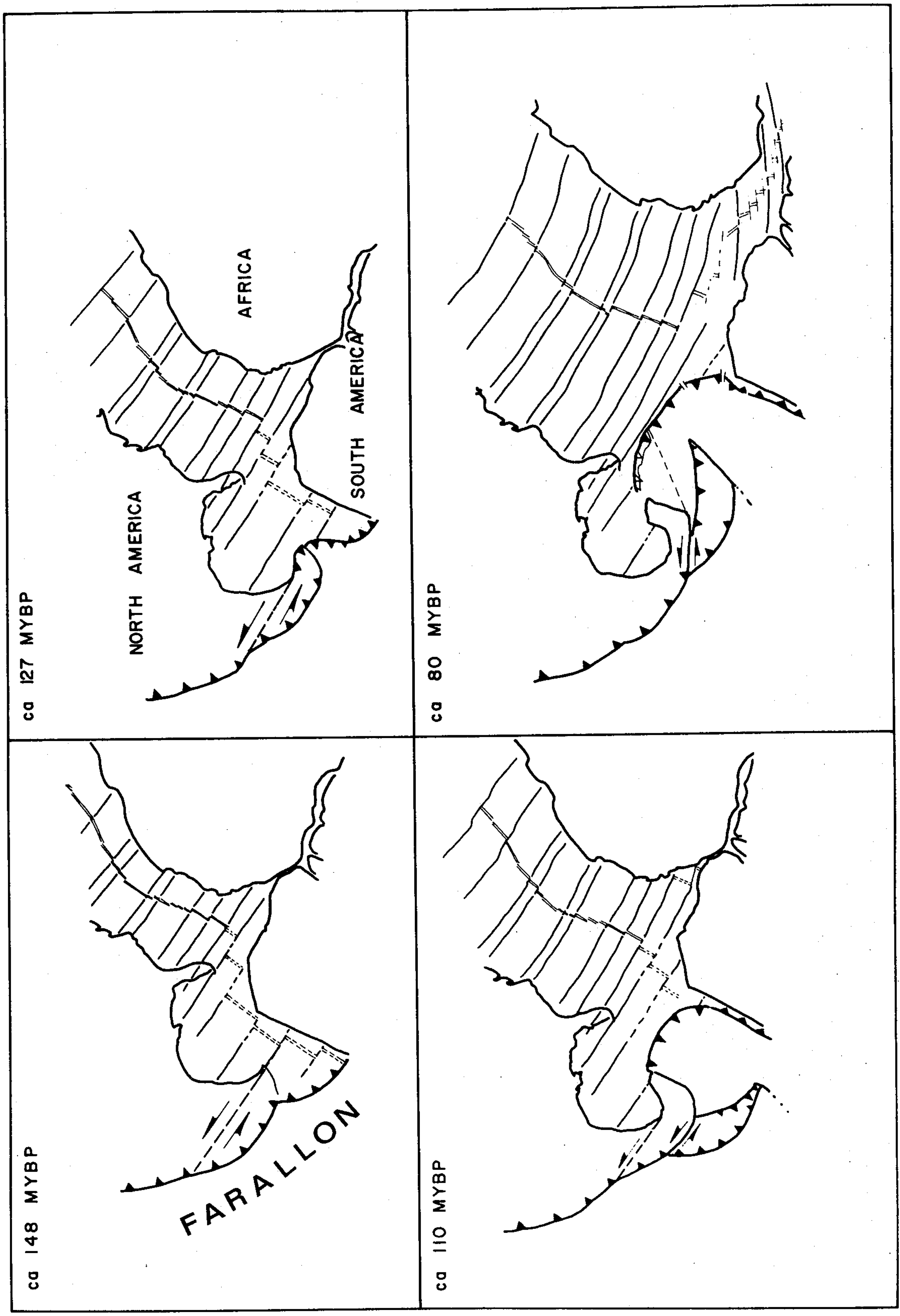
The evolution of the Caribbean is intimately connected with the spreading history of the Atlantic basins and the relative motions between the North American, South American and the Farallon Plates since the Late Jurassic (e.g. Schwan 1980). Klitgord and Schouten (1980) have calculated the relative paleopositions for the Americas and Africa from detailed magnetic anomaly data. Their paleo-positions have been used to provide the geometric boundary conditions within which Caribbean tectonic developments were constrained (Figure 38). No such information is available for the Farallon plate. Those portions of the plate that remain in the Colombian and Venezuelan basins are too heavily tectonized and altered by events of the Late Cretaceous and Tertiary to provide a spreading history (Schouten and Klitgord, personal communication). The relative motions between the Americas and the Farallon plates have to be derived purely by inference from the structural development of the surrounding mobile belt (the ancestral Greater Antilles Ridge). The scheme of Gose and Swartz (1977) for Nicaragua and the Nicaraguan Rise is assumed. This effectively removes the rise from involvement in the Caribbean arena until the mid-Tertiary.

Assumptions about the initial boundary conditions come also from the developmental model proposed by Anderson and Schmidt (1978) and Schmidt and Anderson (1978). Thus, the Maya Block (Anderson and Schmidt, 1978) is assumed to have been decoupled from the Mexican mainland by a sinistral transform system positioned along the small circle defined by the Mexican Volcanic Belt. Unfortunately this belt is overprinted with Quaternary volcanism which masks evidence on its antiquity. Thus, this assumption is a geometrical rather than geological one. Further assumptions are made about the geometry of northwestern South America. These include major dextral shear along the Dolores Fault (Gansser, 1975) and related shears during the Late Mesozoic and Tertiary which have radically altered the geometry of that region (Goreau, 1979). These assumptions are necessary in order to remove as much of the Central American and northern Andean Orogens from the Caribbean arena as possible thus allowing for the unhindered development of the ancestral Greater Antillean island arc along the lines presented by Goreau (1979). A speculative tectonic scenario for the region surrounding the study area is developed below.

Pre Mid-Tertiary ca. 160-53 MYBP

The earliest phase of tectonism (Jurassic to Late Cretaceous, ca. 160-80 MYBP) in the proto-Caribbean region involved divergence between the Americas (presumably forming an oceanic basin), and convergence between the Farallon and the North American Plate (Figure 38).

Figure 38. Late Mesozoic development of the Caribbean. Positions of the North and South American plates are taken from Klitgord and Schouten (1980, in press).


ca 148 MYBP
FARALLON
ca 127 MYBP
NORTH AMERICA
SOUTH AMERICA
AFRICA
ca 110 MYBP
ca 80 MYBP

It is likely that the initial subduction was of the Farallon beneath the Atlantic, the latter being younger and topographically elevated (e.g. Mattson, 1979). However the bulk of geological evidence indicates the subduction of the Atlantic plate by the Caribbean (nee Farallon) plate during the "Laramide" (e.g. Pardo, 1975; Bowin, 1975, Mattson, 1979). This necessitates a polarity change in the early history of the ancestral Greater Antillean Arc. The mechanism or reasons for the switch is not known. Mattson (1979) believes continental material "plugged" the subduction zone. I propose that the switch may have occurred for geometrical reasons associated with the opening of the South Atlantic, which gave new kinematic boundary conditions for the Caribbean/Americas interaction.

Geological relicts of this early subduction are scarce. Possible Jurassic rocks which were involved in this tectonic episode are thought by Mattson (1979) to occur in eastern and central Cuba, the Cuchillas Uplift, the Cordillera Central of Hispaniola and the Sierra Bermeja of Puerto Rico (Mattson and Pessagno, 1979; Appendix 1). However, fragments of the continental material which Mattson (1979) suggests were responsible for the blocking of the ancestral subduction system are not in evidence throughout the Greater Antilles Ridge.

Mattson (1979) suggests that the Cuchillas Uplift is the product of Late Jurassic to Early Cretaceous tectonism. Their evidence for this timing is circumstantial (e.g. Boiteau et al 1972b; Appendix 1). Pillow lavas and keratophyric breccias in the ultramafic complex of the Cuchillas Uplift are interbedded with Senonian (Mid-Late Cretaceous) limestones (Lewis and Straczek, 1955). The greenschist facies metamorphism with local ecologites and amphibolites described by Boiteau et al. (1972a,b) occur within these Senonian formations. I propose that the Cuchillas Uplift is of the same Late Cretaceous origin as the Montagnes Noires/San Juan Basin System to the southeast (Appendix 1).

The physiography of the Caribbean during the Jurassic is speculative (Figure 38). However, certain generalities apply. The ancestral arc was probably continuous with the convergent margins of North and Central America during the upper Mesozoic, and as such extended from Central America to South America.

During the Early to Late Cretaceous (ca. 127-80 MYBP) the North Atlantic was subducted beneath the Caribbean (nee Farallon) along the Ancestral Greater Antillean Ridge (Figures 38, 39). Fragments of this system form the central inliers of Cuba west of the Cauto Basin, Hispaniola, Puerto Rico, and also may include portions of the Aves Ridge, and northern Venezuela (Figures 1, 38). The polarity of the subduction system is well established from Cuba (e.g. Iturralde-Vinent, 1975), Hispaniola (Bowin, 1975), and Puerto Rico (Mattson and Pessagno, 1979). The geology of the central inliers of these islands show a well developed northeast facing volcanic arc/subduction complex at this time.

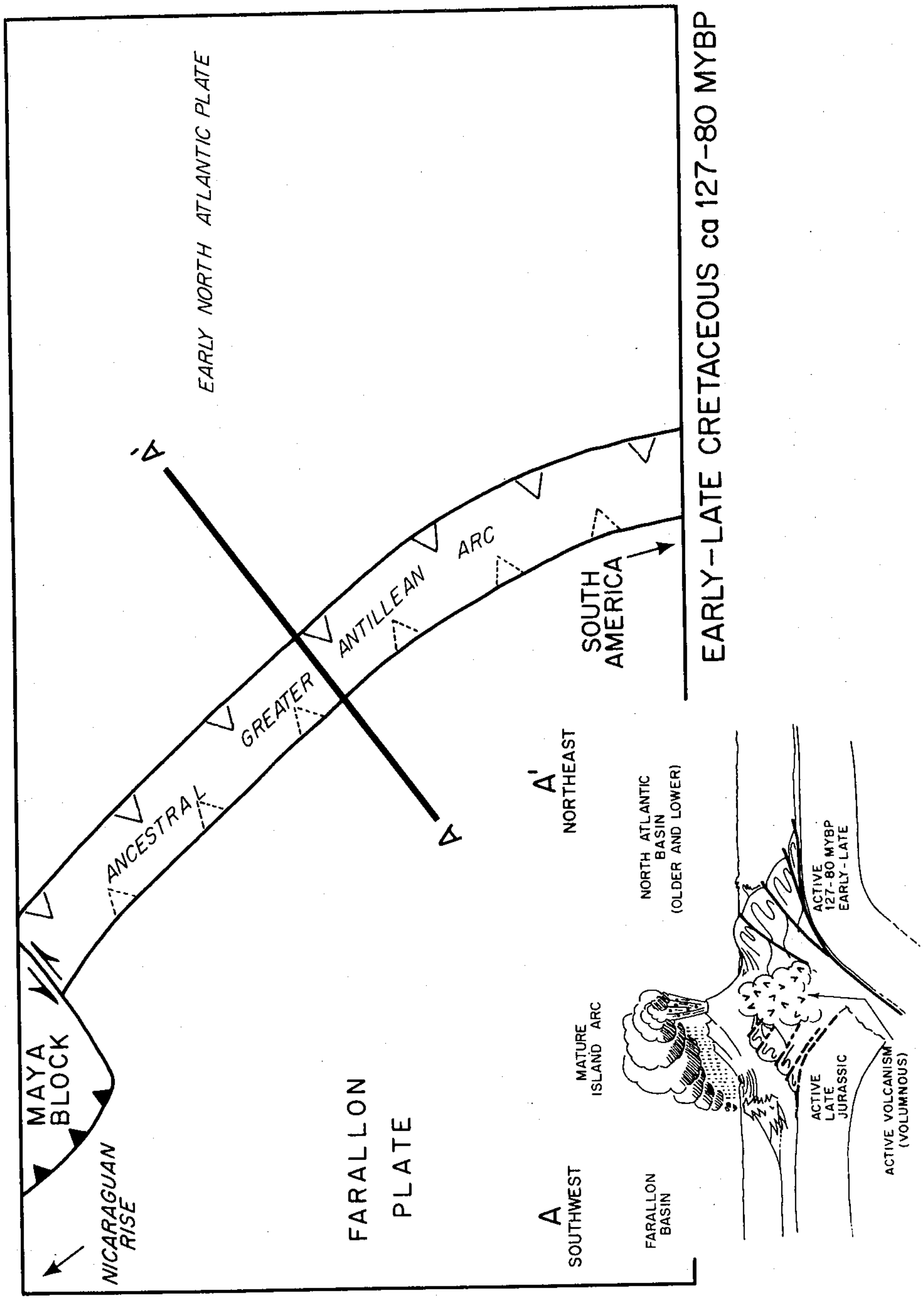
No direct evidence exists for the gross geometry of the arc system. However, it is assumed the fragments observed today are portions of a laterally continuous ancestral arc, convex to the Atlantic (Figures 38, 39). The terminations of the arc are assumed to have been geometrically continuous with the leading edges of the North and South American Plates of the late Mesozic. The Caribbean/North American plate margin at this time was a northeastward facing, predominantly subductive boundary merging with the westward facing convergent leading margins of the North and South Americas (Figure 38).

Fragments of the Jurassic to Early Cretaceous arc are volumetrically insignificant in the face of the massive volcanism and island arc development that occurred Ca 127-80 MYBP (Figures 38, 39). This stage of island arc development in the Caribbean is commonly called the "Laramide Orogeny". In strict terms the "Laramide" was a Paleocene orogeny, and although the term is a misnomer, it is established in the literature (e.g., Khudoley and Meyerhoff, 1972). This terminology is retained herewith.

The Late Cretaceous Ca. 80-75 MYBP is a period of great importance in the Caribbean. Several major tectonic events heralded the cessation of simple island arc tectonism for the ancestral Greater Antillean Arc (Figures 39, 40). These events include:

1. Collision between the Cuban segment of the ancestral Greater Antillean Arc west of the Cauto Basin and the Bahama Platform (Figure 40). The effect of this collision is multifold. It marks the initiation of major sinestral fracturing within the Cuban massif (e.g. Malfait and Dinkleman, 1972), and the capture of Cuba and the Yucatan Basin by the North American Plate. This entails a switch of the Caribbean/North American plate boundary from a subductive system along northern Cuban to a transcurrent system along the Cauto Basin Shear. This boundary extended to Central America along an oceanic fracture zone analagous in scale to the modern Cayman Trough (Figures 35, 40). The geometric necessity for such a boundary has been recognized by Rigassi-Studer (1961), Malfait and Dinkleman (1972), Perfit and Heezen (1979) and Goreau (1979).
2. Fragmentation of the ancestral Greater Antillean Arc into the central inliers of Cuba, Hispaniola, Puerto Rico, the Virgin Islands (and possibly Aves Ridge, the Caribbean Mountains of northern Venezuela (Maresch, 1975), and the Bonaire Block (Silver, 1975)). This event resulted in the rotation the Hispaniola-Virgin Island segment of the

Figure 39. Speculative plan view and cross section for the ancestral Greater Antilles Ridge during the Cretaceous ca. 127-80 MYBP.



EARLY-LATE CRETACEOUS ca 127-80 MYBP

ancestral Arc in an anticlockwise sense, causing "boudinage" on a major scale (Figure 40). This left the fragments physically separated by extension discontinuities and gave rise to a small oceanic basin in the region between the Cuban and Hispaniolan portions of the ancestral Arc (Figure 40).

3. Cessation of simple subduction and island arc volcanism throughout the fragmented ancestral Greater Antilles Ridge. No significant volcanism or heat production has occured along the Greater Antilles Ridge since then.
4. Convergence continued between the North American and Caribbean plates east of the Cauto Basin Shear. Incipient thrust zones developed along the proto Cuchillas Uplift/Cordillera Septentrional and the Cuchillas Uplift/Montagnes Noires/Los Muertos Trough (Figure 35). The geometry of the system predicates underthrusting along both the northern and southern margins of the plate boundary zone. The sinistral rotation of the plate boundary zone between the North American and Caribbean plates leads to some interesting effects. The convergence vector between the Plate Boundary Zone and the North American Plate becomes increasingly oblique with time, leading to the development of a highly sheared "subduction complex" along its northern margin, without necessitating appreciable subduction of the North American Plate (ergo no

volcanism). The convergence vector between the Plate Boundary Zone and the Caribbean Plate conversely becomes less oblique with time. However, the sinistral rotation of the Plate Boundary Zone necessitates the subduction of a wedge shaped segment of the northern Caribbean Plate (area increasing to the west; Figure 47) with the Virgin Islands positioned at the eastern vertex (Figures 39, 47). This clearly implies an increasing convergence rate to the west along the southern limb of the Plate Boundary Zone. Both these factors combine to form the geometric boundary conditions which in this authors view provide the essential framework for the tectonic development of the northern Caribbean during the Tertiary.

5. The Nicaraguan Rise subducted the Caribbean Plate south of the Cauto Basin Shear (Figures 38, 40). The rotation of the rise necessitates the formation of a volcanic arc/ subduction complex along its leading edge. The constraints on the motion of the Nicaraguan Rise are provided by Gose and Schwarz (1978).
6. The intrusion of the B" basaltic event throughout at least the northern Caribbean Basin (Donnelly, 1975; Saunders et al., 1973). This B" igneous event is as enigmatic as it is important. Its more important features are as follows:
   a. The B" unit occurs on a basinwide scale extending from the eastern flank of the Nicaraguan Rise to the

eastern Venezuelan Basins (Case 1975).

b. Where sampled, it consists of oceanic dolerite sills (e.g. Saunders et al 1973) intruded into Coniacian sediments, thus, giving a lower age limit of ca. 80 MYBP (Saunders et al 1973).

c. Geophysical profiles taken during site surveys for the DSDP drill sites in the basin indicate that the stratigraphic unit below the sill may be up to 750-1000 m thick (Primoli Silva, personal communication). Below horizon B" there appear to be major thicknesses of slightly deformed strata in the northern Caribbean Basin (Saunders et al, 1973; Ladd and Watkins, 1978). These reflectors suggest that there was an appreciable sedimentary history within that basin prior to the Late Cretaceous.

d. The structure contour map of the B" horizon indicates an orthogonal fracture pattern occurring on a basinwide scale (Edgar et al., 1973; Case, 1975; Burke et al, 1978). If the orthogonal fracture pattern extends to the Caribbean crust and exists on a basin wide scale, they could provide potential conduits for the delivery of basaltic magmas to a uniform gravitationally determined level over a large area.

The areal extent of the B" horizon suggests an excess of

$10^6 km^3$ of basalt are involved (Donnely, 1975). The anomalously thickened character of the Colombian and Venezuelan basins presumably dates from this time. In my opinion the intrusion of such a uniform and widespread event could only have occurred as a result of a basinwide tectonic event. The formation of a Prandtl Cell fracture pattern (Burke et al, 1978) in response to the relative motions between the North and South American Plate (Figure 38). This event was probably the major contributing factor to the anomalous thickness and bouyancy of the Caribbean Basin. These factors in combination with the geometric boundary conditions discussed earlier represent the essential factors in determining the Tertiary development of the southern Plate Boundary Zone in the northern Caribbean.

This profound basin modification heralded the demise of the Farallon Plate as a recognizable entity. I suggest that the Caribbean Plate did not exist as a viable unit prior to the B" basaltic event.

Since this period is of such import to the regional evolution of the Caribbean Plate it may be wise to summarize the important developments in the plate margins at the time (Figures 38-40). These are:

1. The capture of Cuba by the North American Plate, and the switch in the position and tectonic character (from convergence to translation), of the northwestern Caribbean/North American plate boundary.

2. The fragmentation and shear extension of the ancestral Greater Antillean Ridge east of the Cauto Basin and the first recognizable development of the northern Caribbean Plate Boundary Zone.
3. The counterclockwise rotation of the Plate Boundary Zone with oblique convergence between the North American Plate and the Plate Boundary Zone, and normal convergence between Plate Boundary Zone and the Caribbean Plate, albeit with increasing strain rate to the west.
4. Subduction of the western Caribbean along the leading edge of the Nicarguan Rise, and translation between the southestern flank of the rise and central Caribbean.

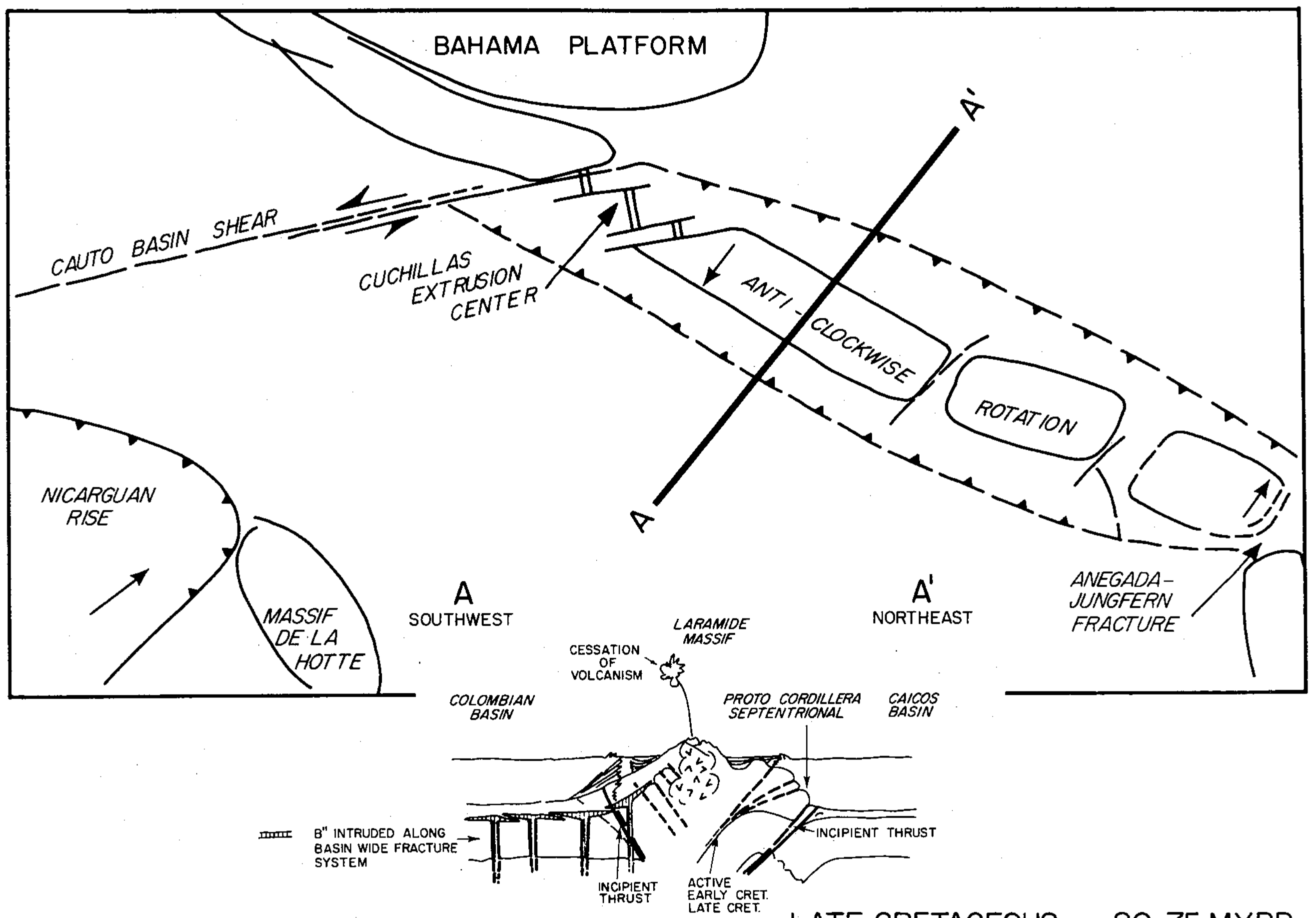
Clearly, the northern edge of the Caribbean Basin was subject to a complex stress pattern due to the relative motions between it and the North American and Nicaraguan Plates, and the Plate Boundary Zone.

As stated previously the Massif de la Hotte was uplifted shortly after the development of the B" basaltic event. It is impossible to determine its locality other than to indicate that it appears to have remained coupled to the northern Colombian Basin and that it has remained a high since uplift. There is no evidence of volcanism on the Massif de La Hotte postdating the B" event. Therefore, the massif has been held as a topographic high by tectonic rather than thermal forces. This implies that the Massif has been subject to compression over its entire geological history and may represent a leading edge of the Colombian Basin in its long association with the Nicaraguan Rise Plate.

During the latest Cretaceous and Paleocene ca. 75-53 MYBP (Figure 41), the Caribbean/North America plate margin re-established itself as a broad deformational front nucleating around the fragments of the Laramide Arc. Evidence suggests that the entire Plate Boundary Zone was partially decoupled from both the Caribbean and the North American Plates and entrained as a topographic welt between them. The character of this zone changes markedly along strike depending on whether the Plate Boundary Zone nucleated around a fragment of the older "Laramide" system or not.

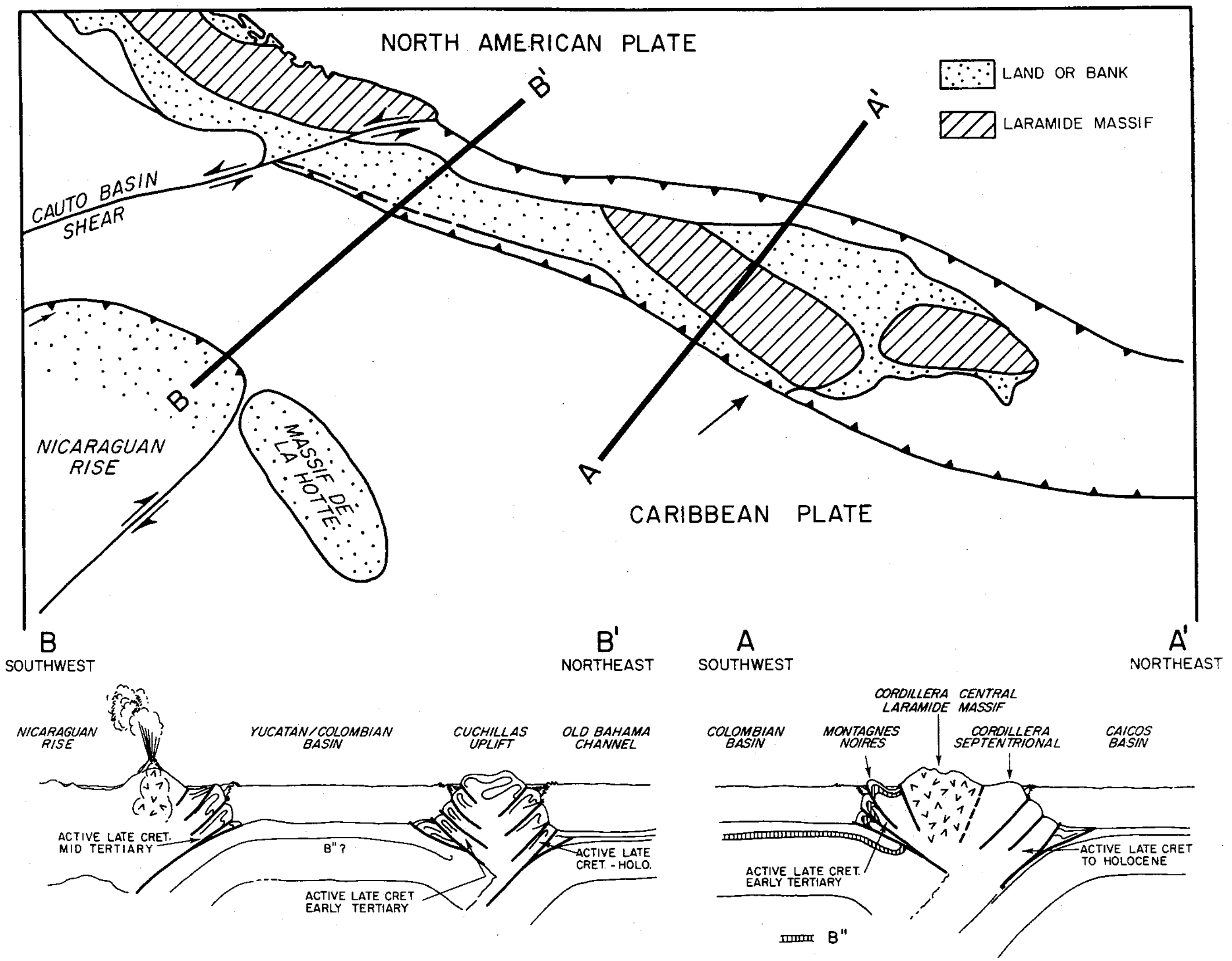
Increasingly oblique underthrusting of the North American Plate continued along the northern margin of the Plate Boundary Zone from the Cauto Basin to the Puerto Rico Trench. This initiated the 'subduction complex' of the Cuchillas Uplift/Cordillera Septentrional System. In response to the anticlockwise rotation of the Plate Boundary Zone, a secondary underthrust belt developed on its southern flank. This resulted in the formation of the thrust belt and flanking basin of the Cuchillas Uplift/Montagnes Noires/Los Muertos Trough and the Plateau Central/Valle de San Juan/Southern Dominican Tertiary Basin System. The secondary system was formed by the underthrusting of the Colombian Basin beneath the southern

Figure 40. Plan view and cross section of a portion of the Greater Antilles Ridge in the Late Cretaceous ca 80-75 MYBP.



LATE CRETACEOUS ca 80-75 MYBP

Figure 41. Plan view and cross sections of the Greater Antilles Ridge and the Nicaraguan Rise during the Late Cretaceous and early Tertiary. ca. 75-53 MYBP.



L. CRETACEOUS—E. TERTIARY ca 75-53 MYBP

flank of the Plate Boundary Zone (Figure 41).

The Cuchillas Uplift formed by convergence across the basin created by the fragmentation of the ancestral Greater Antillean Arc (BB', Figure 41). In a sense it represents a pristene system without any relict island arc material. Its stratigraphy is oceanic, and it is entrained within the Plate Boundary Zone. Its western terminus coincides with the Cauto Basin Shear.

This model requires the Cuchillas Uplift to be of Late Cretaceous age (Figure 41, Appendix 1). It also offers a mechanism for the formation and occurrence of the blueschist/eclogite assemblage described by Boiteau et al. (1972a,b) along the southern flank of the Cuchillas Uplift (Figure 41, Appendix 1).

The section across central Hispaniola have several markedly different features (Figure 41). Underthrust regions flank an older core consisting of the fragmented ancestral Greater Antillean arc (AA', Figure 41). To the north of this core, the stratigraphic succession in the accretionary prism is derived from the Caicos Basin. There is also an appreciable clastic component derived from the central inlier, occurring in the 'forearc basin'. The stratigraphic succession preserved in the Montagnes Noires/Valle de San Juan System to the southwest is derived from the Colombian Basin (BB', Figure 41).

The Nicaraguan Rise Plate continued subducting the western

Caribbean Plate along its northern margin (BB', Figure 41). Active volcanism occured along its leading edge. The boundary between the Nicaraguan Rise and the ancestral Colombian Basin is assumed to be translative. The Massif de la Hotte was a topographic high with shallow water carbonate accumulations along the boundary between the Colombian Basin and the Nicaraguan Rise Plate.

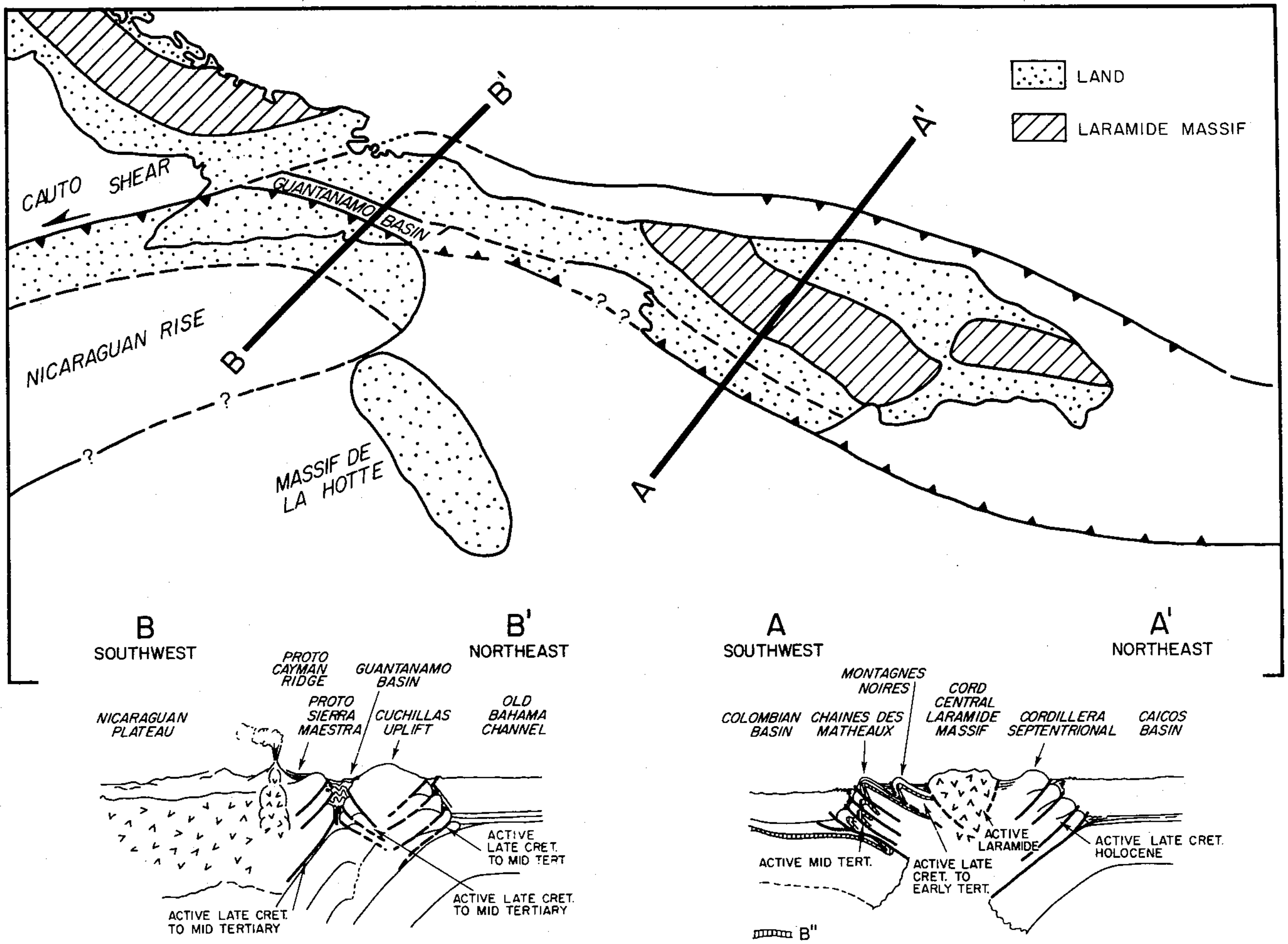
Mid-Tertiary ca. 40 MYBP

With several notable variations the bipolar nature of the Plate Boundery Zone continued during the mid-Tertiary (ca. 40 MYBP; Figure 42). The Plate Boundery Zone represented a broad deformational front with limited decoupling between it, the North American and Caribbean plates. The zone was effectively a sheared welt of bouyant island arc complex entrained along the North American/Caribbean Plate boundary.

Along the northern margin of the Plate Boundary Zone oblique convergence continued (Figure 42), extending from the Cauto Basin Shear to the Puerto Rico Trench (Kozary, 1968; Case, 1975; Uchupi, 1975; Mattson and Pessagno, 1979).

The southern margin of the Plate Boundary Zone is more complex. During the mid-Tertiary the locus of thrusting shifted south. It extended from the Sierra Maestra to the Los Muertos Trough by way of the Chaines des Matheaux and the Sierra Neiba,

Figure 42 Plan view and cross sections across the Greater Antilles Ridge and the Nicaraguan Rise during the mid-Tertiary. ca. 40 MYBP.



MID TERTIARY ca 40 MYBP

flanking the Guantanamo Basin and the Valle de l'Artibonite (Sections 4, 10, Figure 7; Figure 42; Appendix 1). This event represents the final suturing of the Sierra Maestra and the Cuchillas Uplift after which they have identical stratigraphic sections (Appendix 1). In this model the Sierra Maestra is genetically associated with the Cretaceous to mid-Tertiary volcanic/subduction complex of the northern Nicaraguan Rise (e.g. Perfit and Heezen, 1979; Goreau, 1979). The subduction complex along the leading edge of the Nicaraguan Rise overrode the Cauto Basin Shear west of the Cuchillas Uplift to a limited extent (Figures 42, 35). Thus the Caribbean Plate underwent a second major reduction in surface area (the first being the capture of the Cuba/Yucatan Basin by the North American Plate). Thus, during the second reduction, the western Nicaraguan Rise/Caribbean Plate margin became the Nicaraguan Rise/North American Plate margin. The Guantanamo Basin formed along the suture between the Nicaraguan Rise and the Cuchillas Uplift (Figure 42). This model predicts a high degree of compressive deformation in the lower stratigraphic levels of the basin (BB', Figure 42).

The sub-division of southeast Cuba into the genetically distinct Cauto Basin, Cuchillas Uplift, Guantanamo Basin, and Sierra Maestra is an important feature of this model (Appendix 1). It is at odds with the genetic uniformity proposed for this region by previous workers (Khudoley and Meyerhoff, 1971; Boiteau et al, 1972a, 1972b).

The section across central Hispaniola is considerably different (AA', Figure 42). Active underthrusting shifted south from the Montagnes Noires System to the Chaines des Matheaux System. Reasons for the shift are not clear. They may be due either to the effect of underthrusting the anomalous buoyant Caribbean Basin, or a response to a global plate motion reorganization (Schwan, 1980).

As previously discussed the Chaines des Matheaux are a mid-Tertiary fold belt (Bowin, 1975; Section 4, Figure 7). Its stratigraphy is inferred to be comparible the Late Cretaceous through mid-Tertiary succession of the Colombian Basin. This model also predicts a similar succession beneath the Plaine de l'Artibonite. Clastics derived from the Chaines des Matheaux, the Montagnes Noires and bioclastics from periodic marine incursions have dominanted its succession since then. Cross-sections of the Artibonite basin indicate broad open folding of even the late Tertiary clastic sequence, indicating that the entire region has undergone compression since the mid-Tertiary (Section 4, Figure 7). This supports the idea of a broad deformational front existing in the Plate Boundary Zone throughout the Tertiary, with only the locus on major tectonism shifting with time.

The geometry and position of the Massif de la Hotte is uncertain (Figure 42). It is assumed that it was maintained within the interactive boundary between the eastern Nicaraguan Rise and the Colombian Basin. It certainly existed as a topographic high at that time with thin shallow water and continental deposition along its crest.

Early Miocene Ca 20 MYBP

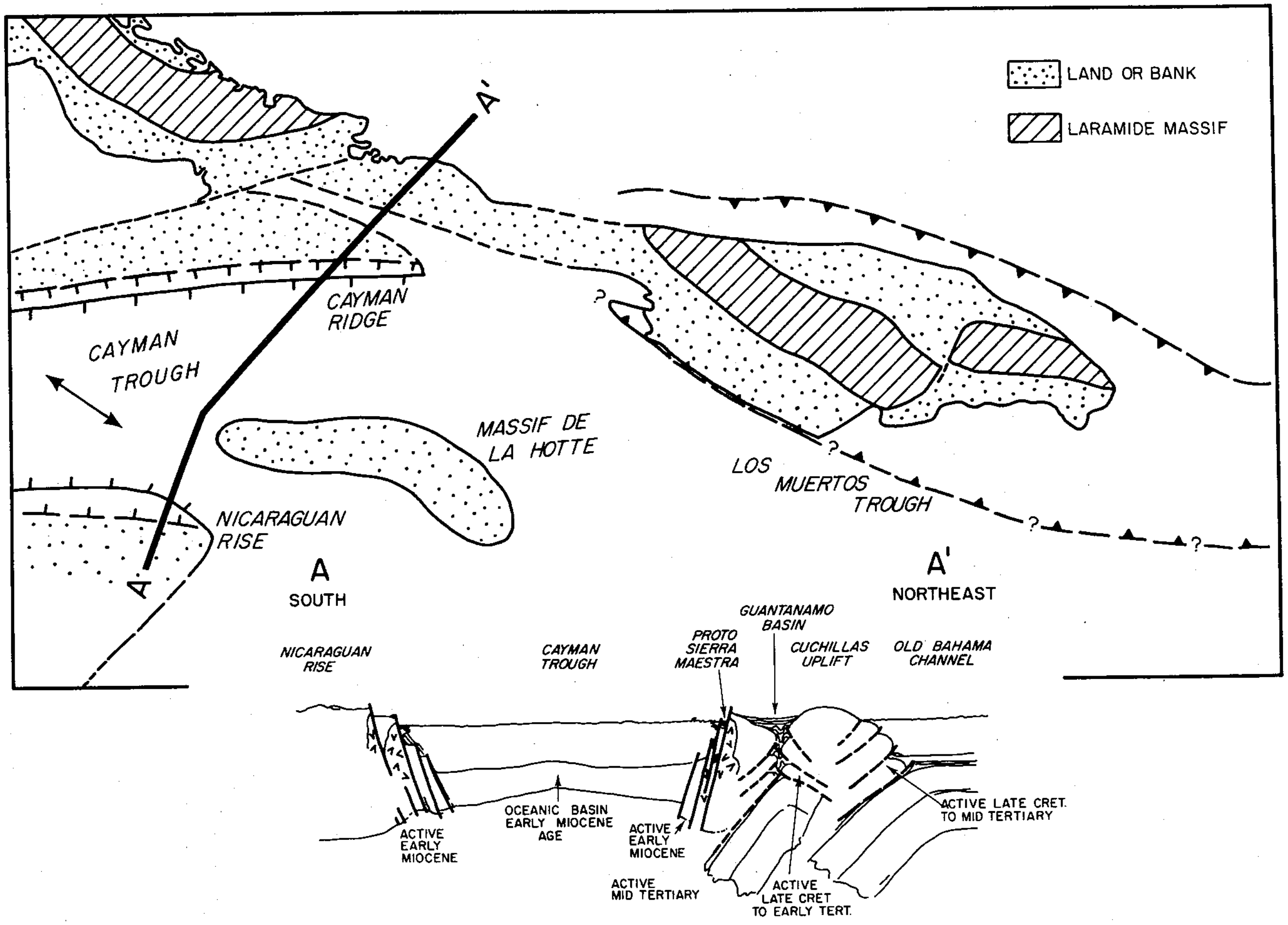
After the suture between the Sierra Maestra and the Cuchillas Uplift (Figure 42), but prior to the development of the Gonave Ridge/Gonave Rise/Massif de la Selle/Sierra de Bahuroco/Beata Ridge System (Figure 43), the Cayman Trough was formed by rifting along the leading edge of the Nicaraguan Rise (Figures 42, 43). No evidence exists for the Cayman Trough prior to the early Miocene. However, in the late Miocene the Gonave Ridge was active within the trough. Therefore, the Cayman Trough had to be in existence by then.

Accompanying this extension, subsidence occured along the bordering Nicaraguan Rise and Cayman Ridge (Figures 5; AA', Figure 43). Emery and Milliman (in press) have described Miocene shallow marine and lacustrine carbonates collected in situ using the R.V. ALVIN at depths in excess of 3000 m along the southern flank of the Cayman Ridge.

The exact cause and timing for the formation of the Cayman Trough is unknown. Khudoley and Meyerhoff (1971) have inferred a purely divergent process resulting in the formation of a classical graben. Geophysical and petrologic evidence precludes the formation of a simple graben because of the oceanic character of the basin (Bowin, 1972, 1976; Edgar et al., 1962; Perfit and Heezen, 1979). Malfait and Dinkleman (1972), and Case (1975) believe that the Cayman Trough was formed because of a slight departure between the principal stress vector and the small circle defined by the Nicaraguan Rise/North American Plate pole of rotation. Previously mentioned constraints on the timing of the opening of the Cayman Trough imply that divergence may have been a primary component for a brief period in the early Miocene.

The formation of the Cayman Trough is related to the kinematics of the North American Plate/Nicaraguan Rise interaction. Geological evidence implies a brief excursion from a normally translational character of the plate margin, allowing divergence to predominate during the early Miocene. During this period the leading edge of the Nicaraguan Rise was transected along the volcanic axis and scavenged by North American Plate (Figure 43; Malfait and Dinkleman, 1972; Perfit and Heezen, 1979; Goreau, 1979). The affect of this interaction extended to the Northern Gonave Basin and the western Chaines des Matheaux (Figure 23).

Figure 43. Plan view and cross section over the Greater Antilles during the opening of the Cayman Trough in the early Miocene. ca. 20 MYBP.



EARLY MIOCENE ca 20 MYBP

These events during the early Miocene do not reflect any drastic alteration in the kinematics of the North American/Plate Boundary Zone/Caribbean boundary. Consequently, tectonic coditions appear to have remained uniform to the east during the opening of the Cayman Trough.

Late Miocene to Early Pliocene Ca 15-10 MYBP

From the late Miocene to early Pliocene tectonism was distributed in the following areas:

1. Oblique subduction continued along the northern edge of the Plate Boundary Zone from Windward Passage to the Cordillera Septentrional (Figures 6, 44).
2. Convergence also occured along:
   a. The Gonave Rise, the Massif de la Selle and Sierra Bahuroco (Figure 44).
   b. The Beata Ridge (physiographically continuous with the Massif de la Selle) (Figures 6, 44).
   c. The Los Muertos Trough (Figures 6, 44).

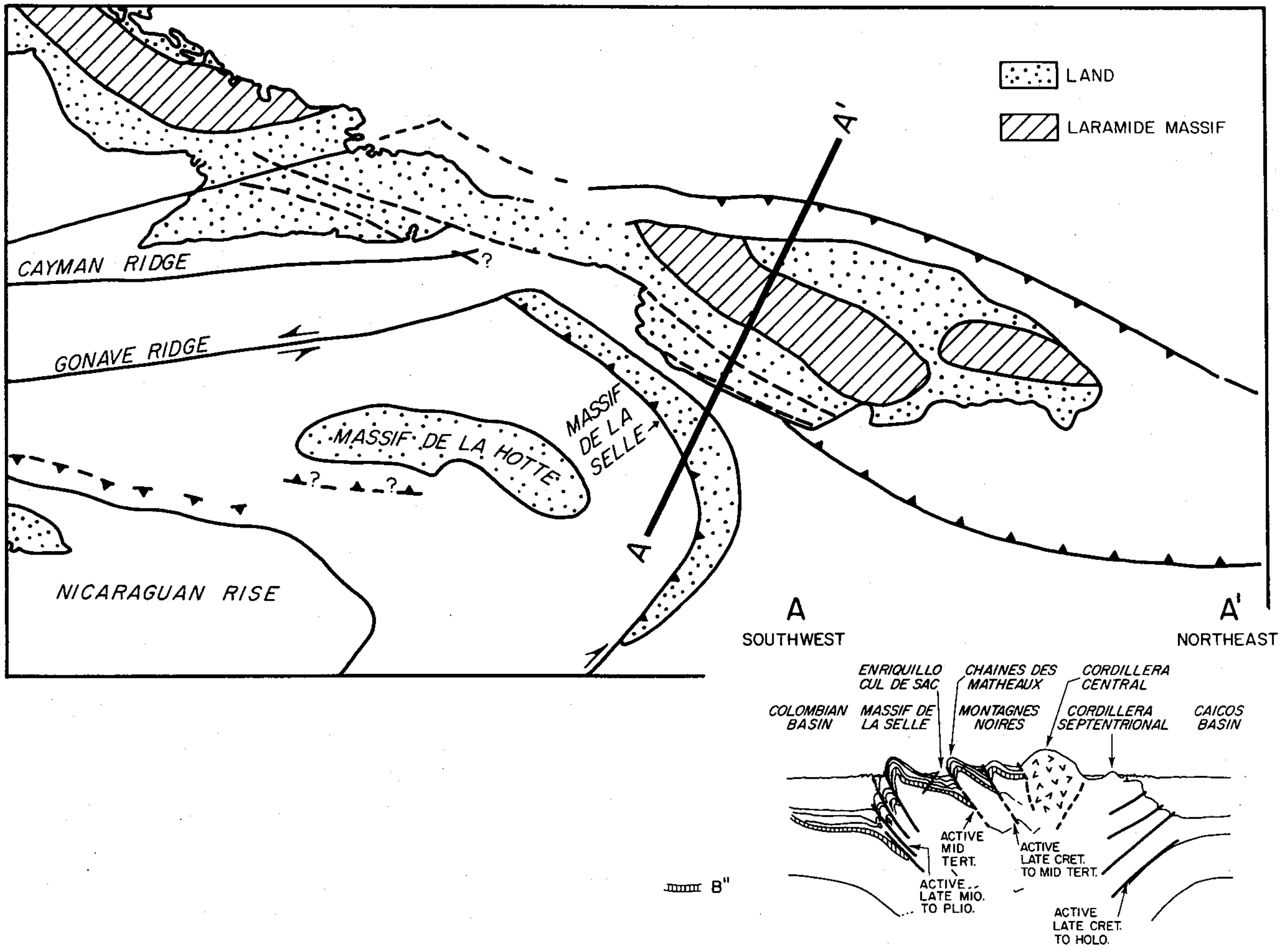
A secondary thrust system developed between the Massif de la Selle/Sierra Bahuroco and the Chaines des Matheaux/Sierra Neiba Systems across the Enriquillo Cul de Sac (Figure 44; Bowin, 1975). The shallow marine late Miocene sediments along the northern limb of the Enriquillo Cul de Sac were intensly folded. Similar deformation also took place along the southern limb of the basin, but involving deep water late Miocene sediments (H.A.Meyerhoff, personal communication). These data suggest that marine conditions prevailed within the Enriquillo Cul de Sac during the late Miocene with a regional shallowing from southwest to northeast. They also give a maximum age of late Miocene for origin of the Enriquillo Cul de Sac and the Gonave Rise/Massif de la Selle/Sierra Bahuroco/Beata Ridge Systems.

Concurrent translational tectonics occurred along:

1. The Gonave Ridge within the Cayman Trough (Figure 6). Translation is a geometrical necessity resulting from the abrupt change in strike and the termination of the upthrust Gonave Rise. The position of the Gonave Ridge suggests that translation within the Cayman Trough was restricted to its southern margin at this time (Figure 44). Corroberation for the translational nature of the Gonave Ridge comes from the coincident Bouguer gravity anomaly high. This suggests crustal thinning in the region (Figure 13). Translation along this boundary has obvious implications for the development of the mid-Cayman Trough spreading center (Mid-Cayman Rise).
2. The southern Beata Ridge in a limited sense.

Several important events occured along the southern Plate Boundary Zone which indicate a limited geometrical adjustment within the Caribbean Basin. The tectonic history of the

Figure 44. Plan view and cross section over central Hispaniola during the upper Miocene and Pliocene ca. 15-10 MYBP.



UPPER MIOCENE-PLIOCENE ca 15-10 MYBP

Greater Antilles Ridge is a sequence of physical responses of the Plate Boundary Zone to changing kinematic boundary conditions between the North American and Caribbean plates which imposed severe space restriction. As such, the Beata Ridge is most simply explained as the result of limited spatial readjustment within the Caribbean Plate. This readjustment involved the Colombian Basin underthrusting the Venezuelan Basin along the Beata Ridge. The geometry and physiography of the Beata Ridge suggests that underthrusting increased to the north from a hinge zone at the southern terminus of the ridge (Figures 44, 47). The origin of the Beata Ridge introduces some complexities in the tectonic evolution of the northern Caribbean and the Plate Boundary Zone. It appears that this high was formed by the interaction of four partially decoupled blocks, the Nicaraguan Rise, the Colombian and Venezuelan Basins, and the Plate Boundary Zone. Why adjustment occured along the Beata Ridge is uncertain. It may have been the site of an older fracture zone within the Farallon basement that was remobilized. However, there is no direct evidence for the antiquity of the "Beata Lineament". For the purposes of this study the ridge is interpreted as an late Tertiary feature. Prior to this time the Colombian and Venezuelan basins did not exist as viable entities. It is only after the segmentation of the Caribbean by the Beata Ridge that these physiographic terms have any meaning.

The stratigraphic succession preserved along the Gonave Rise/Massif de la Selle/Sierra Bahuroco/Beata Ridge is here interpreted to be equivalent to that of the Colombian Basin during the late Tertiary (AA' Figure 44). It is impossible to say whether compression occurred between the Cayman Ridge and the Nicaraguan Rise across the Cayman Trough at this time.

Late Pliocene Ca 5 MYBP

During the late Pliocene, tectonic activity ceased along the Gonave Rise/Massif de la Selle/Beata Ridge System (Figures 36, 45). Tectonic activity was transferred to:

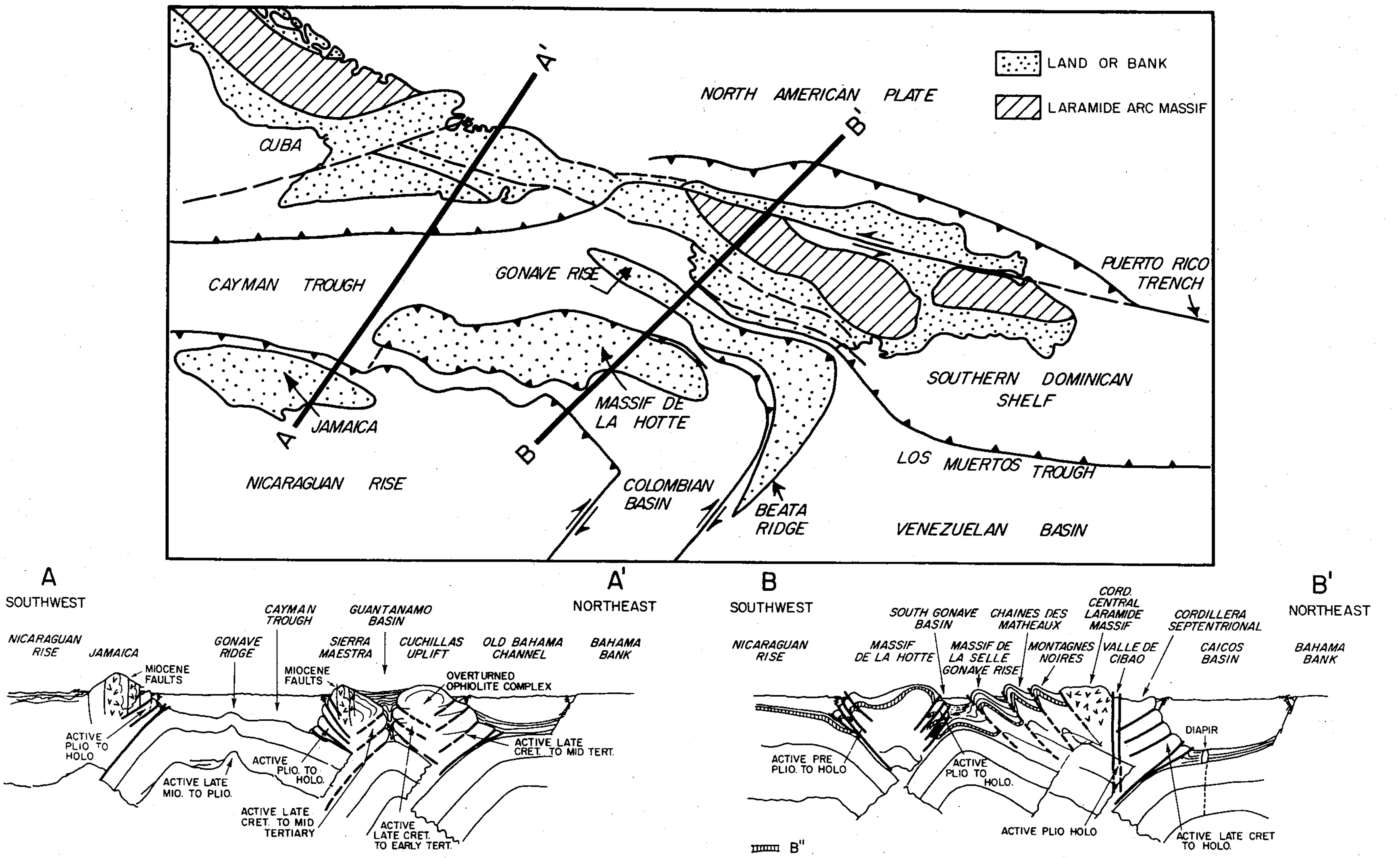
1. Between the Navassa Rise/Massif de la Hotte/ Colombian Basin System and the Southern Gonave Basin along the northern margin of the Massif de la Hotte/Navassa Rise. This represents continued (oblique?) convergence between the Colombian Basin and the Plate Boundary Zone, with the polarity of underthrusting reversed from that prior to the late Pliocene of the Tertiary. The Southern Gonave Basin is presently underthrusting the Massif de la Hotte/Navassa Rise.
2. Convergence between the Nicaraguan Rise/Navassa Trough and

Figure 45. Plan view and cross sections over the eastern Cayman Trough and central Hispaniola during the late Pliocene. ca. 5 MYBP.

the Navassa Rise/Massif de la Hotte/Colombian Basin Systems, along the Navassa Trough (Figures 35, 36, 45). This convergence implies dextral shear between the eastern Nicaraguan Rise and the Colombian Basin (Figures 6, 35, 36, 45).

3. The strike-slip boundary associated with the Gonave Ridge switched north to the Oriente Deep and via the Windward Passage Deep/Canal de la Tortue/Valle del Cibao/Bahia de Samana to the Puerto Rico Trench. The geometric relation of the Windward Passage Deep and the principal stress vector between the North American and Caribbean Plates require a tensional tectonic environment across it. The sigmoidal geometry of the Windward Passage Deep is reminiscent of sigmoidal shear structures found on many length scales in the geological environment. Displacement along this system is estimated at 20-50 kms since the Pliocene (Figures 36).
4. The Cayman Ridge margin north of the Oriente Deep has a significant compressional component associated with the translative plate boundary. This is indictive of a convergent relationship between the Nicaraguan Rise and the Cayman Ridge (Figures 36, 45 section AA').

Oblique convergent tectonics continued along the northern Plate Boundary Zone, with the North American Plate underthrusting the Cordillera Septentrional along the southern Caicos Basin. The parallelism between the between the Ile de



PLIOCENE—HOLOCENE ca 5 MYBP

la Tortue Rise and the stress trajectory makes it likely that deformation is presently due to almost pure shear (Figures 4, 6). Normal convergence also continued along the southern edge of the Plate Boundary Zone with the Venezuelan Basin underthrusting the southern Dominican shelf along the Los Muertos Trough.

Discussion Of The Tectonic Evolution

The geological evolution of the Caribbean appears to have neen as follows:

1. Ca. 148 MYBP, Subduction was initiated along the ancestral Greater Antilles Ridge.
2. Ca. 115-110 MYBP, The polarity of subduction changed with the North Atlantic Plate subducted beneath the Caribbean Plate.
3. Ca. 80-75 MYBP, The ancestral Greater Antillean Arc underwent tectonic fragmentation heralding the cessation of true island arc volcanism. The Caribbean basin underwent basin wide fracturing leading to the implacement of the B" dolerites (Figures 38, 40).

4. Ca. 75-53 MYBP, A transpressive tectonic regime re-established itself across that region between and around the fragmented portions of the ancestral Greater Antillean Arc, creating the Plate Boundary Zone. The northern Colombian Basin underthrust the southern edge of the Plate Boundary Zone, forming the Cuchillas Uplift/Montagnes Noires thrust belt and related basins. To the north, the North American Plate underthrust the northern edge of the Plate Boundary Zone along the southern Caicos Basin forming the Cuchillas Uplift/Cordillera Septentrional System (Figure 41).
5. Ca. 40 MYBP, The Nicaraguan Rise collided with the Cauto Basin Shear and the Cuchillas Uplift along the Guantanamo Basin. In the east the Colombian Basin underthrust the Plate Boundary Zone along the Chaines des Matheaux/Sierra Neiba System (Figure 42).
6. Ca. 17 MYBP, A brief period of divergence occured along the northern Nicaraguan Rise volcanic axis forming the Cayman Ridge, Sierra Maestra and the Cayman Trough. This divergence also caused the foundering of the western portions of the Chaines des Matheaux within the northern Gonave Basin (Figure 44).

7. Ca. 10 MYBP, The Gonave Ridge transcurrent fault was formed along the southern Cayman Trough. This boundary terminated at the northwestern Gonave Rise. The northern Colombian Basin underthrust the southern edge of the Plate Boundary Zone along the Gonave Rise/Massif de la Selle/Beata Ridge System. To the west the compressive regime between the Nicaraguan Rise and the Cayman Ridge was re-established with the development of limited underthrusting of the Cayman Trough along its northern and southern margin (Figure 44).
8. Ca. 5 MYBP. The Massif de la Hotte abutted the Massif de la Selle and overthrust the Southern Gonave Basin (Figure 45). A major transcurrent boundary developed along the Oriente Deep, the Windward Passage Deep, the Valle de Cibao and the Bahia de Samana. Compressive structures due to oblique translative motion continued to develop within the Plate Boundary Zone.

The geologic evolution of the Caribbean appears to be related to:

1. The age and topographic elevations of the appropriate ocean basins and their development over the last 150 my. This certainly affected the initial polarity of the ancestral Greater Antilles Ridge with the large topographic difference between the Farallon Plate(?) and the proto-North Atlantic becoming less of a dynamic factor during the Late Cretaceous.

2. The crustal structure and thickness of the Caribbean Plate and its variation over time. The thickening of the Colombian and Venezuelan basins crusts by the intrusion of the B" dolerites undoubtedly played an important role in the character of the pre- and post B" tectonics
3. The spatial constraints placed on the Caribbean by the geometric evolution of the leading margins of the surrounding lithospheric plates i.e, the Americas and the Cocos Plates and the jumble of smaller blocks. In a way the geological evolution of the Caribbean is predicated by competition for a limited surface area.
4. The geometric evolution of the entire late Mesozoic mobile belt in the Caribbean including the ancestral Greater Antillean Ridge, the Aves Ridge, the Bonaire Block, and the western Cordillera of northwestern South America (Goreau, 1979).
5. The corresponding geometric evolution of the late Mesozoic and Tertiary mobile belts of western Central America and the Nicaraguan Rise (Gose and Schwartz, 1978; Anderson and Schmidt, 1978).

The anomalously thick and bouyant crust within the Caribbean basin may have affected the tectonics of the study area in several ways:

1. By preventing true subduction and associated volcanism along the convergent margin bordering the northern Colombian and Venezuelan basins. This is due to the failure of the underthrust crust to penetrate the mantle to sufficient depths for partial melting to occur.
2. By causing the observed anomalous topographic elevations within the overthrust members. This also leads to an increased overburden and therefore increased frictional resistance across thrust plane. Once the resisting stress exceeds the compressive strength of the basin crust, the locus of underthrusting is transfered to a new dynamically suitable position (Figure 46). In the case of western Hispaniola, this is expressed as the southerly migration of the thrust belt and subordinate basins in the series of discrete steps outlined previously. This sequence of events accounts for the increasing emergence of southwestern Hispaniola during the Tertiary.

Two possible models for the development of the imbricate thrust belts and basins are presented in Figure 48. Model A assumes the existance of a decollment surface along oceanic basement. In such a case the successive fold belts develop only within the superficial stratigraphic sequence found within the basin. Model B (Figure 47) assumes the involvement of the basement as well as the superficial strata. The available geological data do not allow the resolution between these two models. However, on geometrical grounds model B is more pleasing, because it obviates the necessity of explaining the necessary interaction between the lower levels of the Caribbean basement with the Atlantic basement underthrusting the Cordillera Septentrional from the north.

The complex virgation of the southern convergent margin occurs at the western terminus of the Los Muertos Trough. The reasons for the coincidence of this change in tectonic style at the northern Beata Ridge is not clear. If the ridge represents the trace of a primary feature within the Caribbean Basin as suggested by Malfait and Dinkleman (1972) and Duque-Caro (1978), then the virgation most probably has a secondary relation it. However, the converse also may be true. That is, the Beata Ridge may have developed where it did precisely because the virgation existed. In the absence of evidence for the antiquity of the Beata Ridge beyond the late Tertiary, I propose that the virgation existed prior to the development of the Ridge. As such, the virgation existed for geometrical reasons associated with the development of the entire northern Caribbean. The Beata Ridge appears to be primarily related to the development of the Gonave Rise/ Massif de la Selle system. It clearly records an episode of basement fracturing and geometrical adjustment (underthrusting) within the Caribbean Basin due to small differential motion between the Colombian and Venezuelan basins. These may reflect the relative motions between the Nicaraguan Rise and the South American Plate.

I present two end member models for the Tertiary development of the southern convergent system in Figure 46.

1. Model A assumes pure shear between the Caribbean and North America. In this case any convergent or dilitative tectonics owe their origin to the geometrical relation between the failure surfaces and the applicable stress ellipsoid. While this model is adequate in explaining the tectonics of western Hispaniola, it is inadequate for the Los Muertos Trough, where Ladd et al (in press) demonstrate a long history of convergence in the development of the Southern Dominican Tertiary Basin. Model A also is inadequate for the Cuchillas Uplift/Tortue Rise/Cordillera Septentrional, which while tangential to the shear stress in this model clearly owes its origin to some significant component of convergence (e.g. Bowin, 1975).
2. Model B is somewhat more complex and assumes the anti-clockwise rotation of the plate boundary zone by approximately 40 degrees during the Tertiary. This was initiated during the Late Cretaceous fragmentation of the

Figure 46. Two alternative models for the development of the triple virgation of the southern P.B.Z. underthrust margin during the Tertiary. For discussion see text.

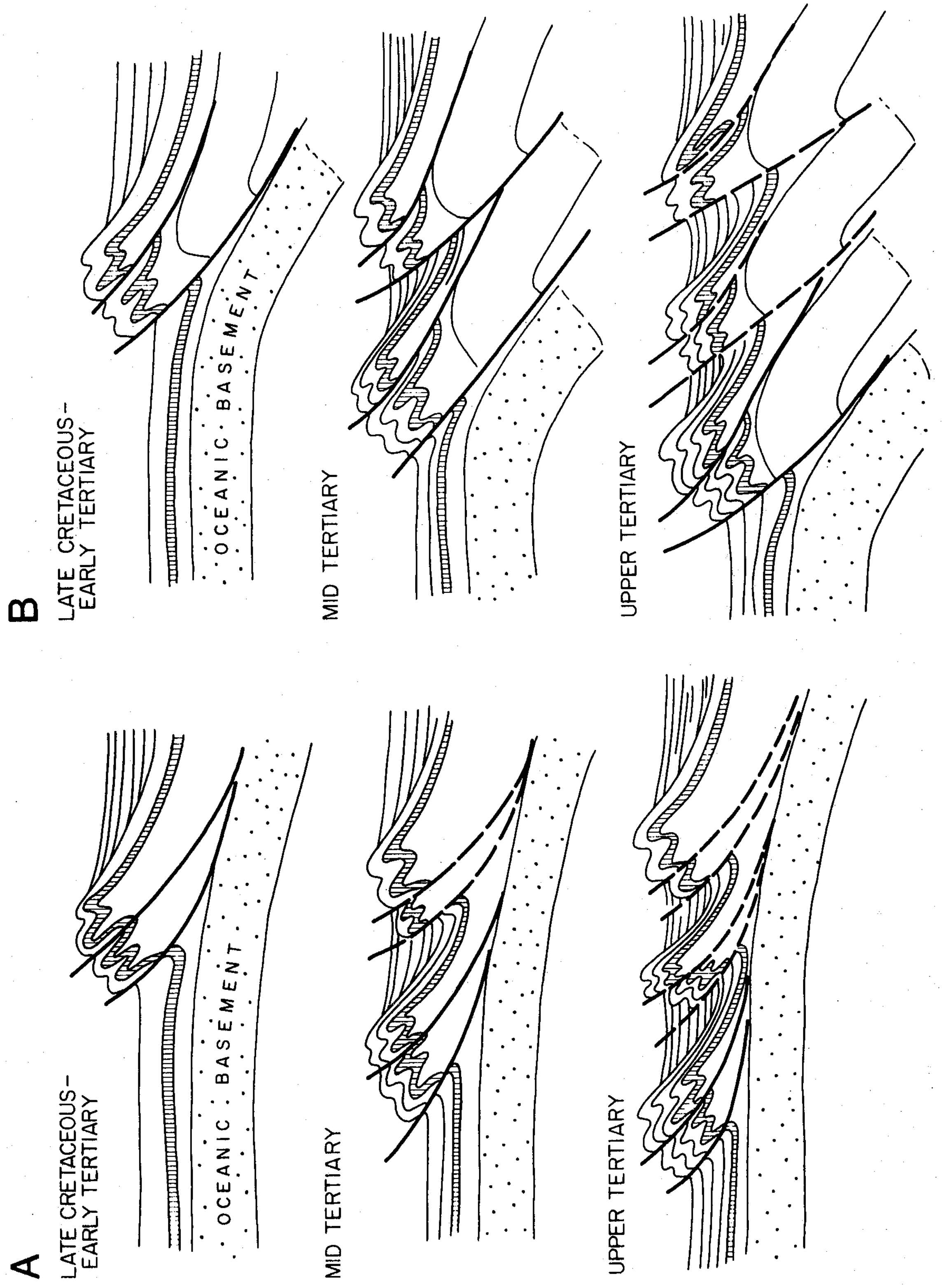
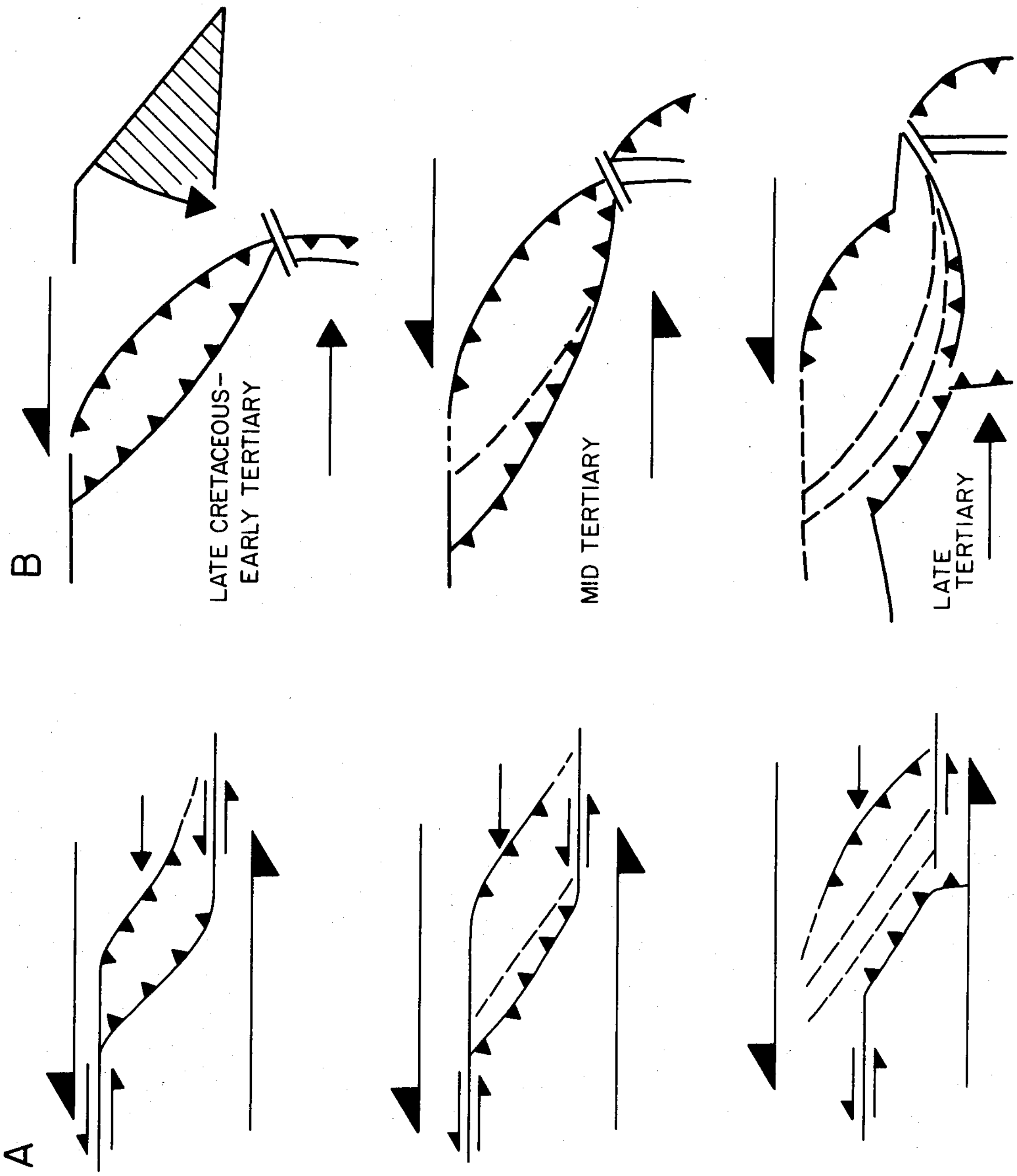

A
LATE CRETACEOUS-
EARLY TERTIARY
OCEANIC BASEMENT
MID TERTIARY
UPPER TERTIARY
B
LATE CRETACEOUS-
EARLY TERTIARY
OCEANIC BASEMENT
MID TERTIARY
UPPER TERTIARY

Figure 47. Two alternative models for the tectonic development of the northern Caribbean plate boundary zone. Model A is pure shear. Model B includes a sinistral rotation of 40° for the P.B.Z. during the Tertiary. See text for discussion.


A
B
LATE CRETACEOUS-
EARLY TERTIARY
MID TERTIARY
LATE
TERTIARY

ancestral Greater Antillean Arc. It is compatible with the model proposed by Goreau (1979), and includes the ancestral Greater Antillean Arc, the Aves Ridge, the Bonaire Block, and the Caribbean Coastal Cordillera as portions of a previously continuous upper Mesozoic subductive system. It was subsequently fragmented by the action of the major lithospheric plates and subjected to considerable geometric readjustment during the Tertiary. Implicit in this model is the removal of a wedge shaped segment of the northern Caribbean by underthrusting along the southern margin of the Plate Boundary Zone (Figure 46, model B). Clearly then, the geometry of this wedge necessitates increasing convergence rate and underthrust area to the west. These facts alone can explain the along strike variation in the structural styles observed, bearing in mind the increased frictional resistance across the thrust plane due to the bouyant properties of the Caribbean Basin. The regional sinistral rotation of the Plate Boundary Zone allows for continuous (or periodic as the case may be) underthrusting along the entire northern margin of the Plate Boundary Zone, with an increasing obliquity of the convergence vector over the Tertiary.

APPENDIX 1.

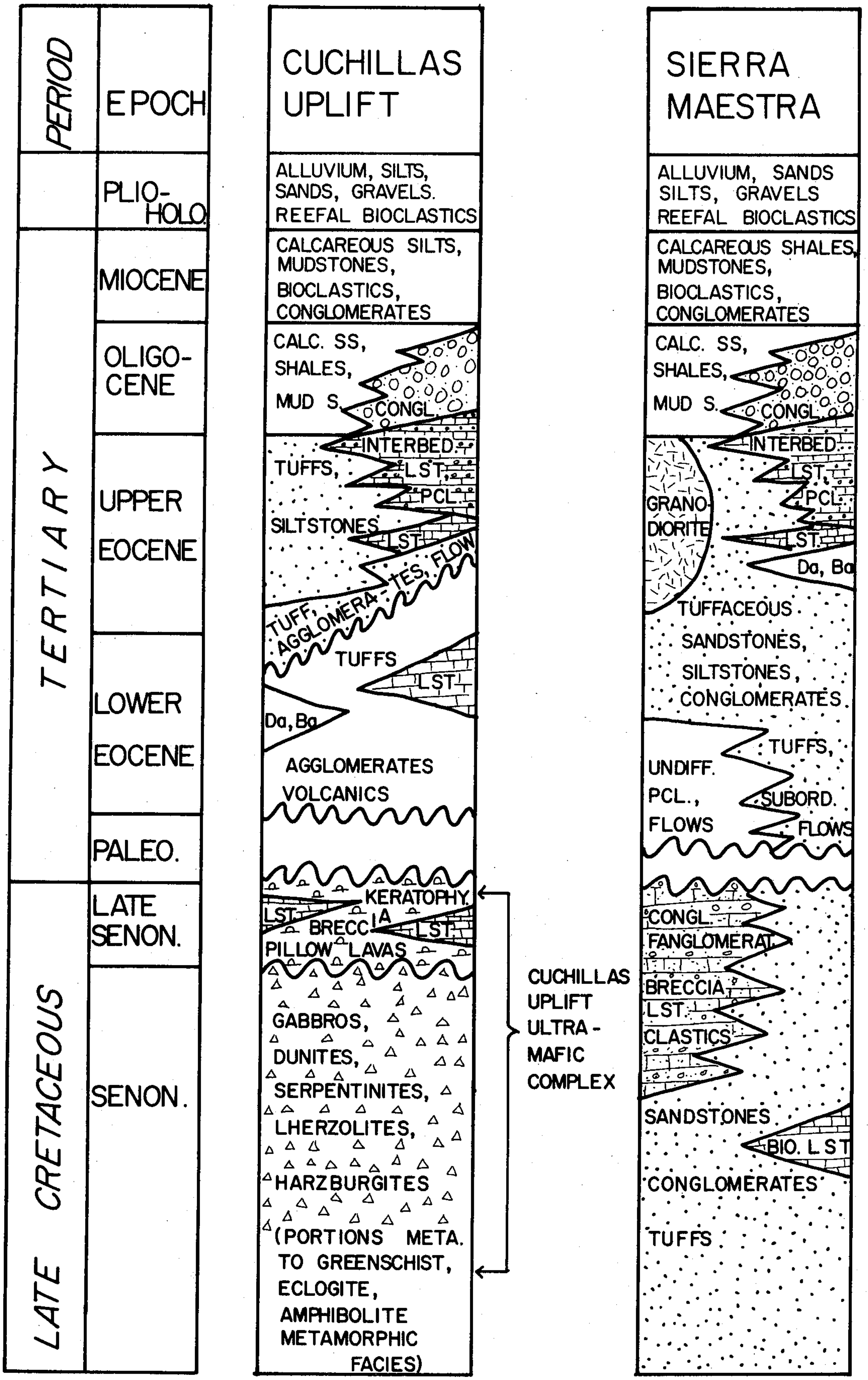
The geology of Oriente Province in Cuba has never been adequately mapped. Lewis and Straczeck (1955) mapped a small region in south central Cuba around the Sierra Maestra and the Guantanamo Basin. The formation names from the Sierra Maestra have since been arbitrairily extended over the entire Oriente Province (e.g. Khudoley and Meyerhoff, 1971). In fact the geological history of the rgion has been treated as a single genesis (Khudoley and Meyerhoff, 1971). This has hindered the differentiation of genetically distinct geological terrain in the province. Profound differences occur in the stratigraphy and structure in the region which I believe signify different geological histories prior to the mid-Tertiary for the Cuchillas Uplift and the Sierra Maestra.

The generalized stratigraphic columns for the two main topographic highs are shown in Figure 49. It will be apparent to the reader that since the early Eocene the lithofacies are similar. This allows the conclusion that the Cuchillas Uplift and the Sierra Maestra have remained fixed with respect to one another and have been subject to broadly similar depositional environments since that time. The early Tertiary stratigraphic sequence consists mainly of pyroclastic deposits interbedded with siltstones, sandstones and limestones with minor dacitic and basaltic flows. Coarse conglomerates interbedded with finer grain calcareous mudstones, shales, sandstones and bioclastic carbonates dominate the late Eocene to Holocene sedimentation. Mid to late Eocene batholithic intrusives occur only within the Sierra Maestra. Perfit and Heezen (1979) recovered similar plutonic material from the submarine scarps south of the Sierra Maestra. Apparently the formation of the Cayman Trough transected the intrusives along the Sierra, and as such must post date the 46 ± 6 my and 58 ± 7 my age for the rocks (Khudoley and Meyerhoff, 1971).

Before the early Tertiary however, the stratigraphic columns are very different. An incomplete overturned Late Cretaceous (Senonian, Lewis and Straczeck, 1955) ophiolitic sequence (Kumpera, 1968) dominates the Cuchillas Uplift, including the highlands of the Sierriana del Nipe, Cristal, and Purial. Unconformably overlaying the Harzburgites is a pillow lava member containing keratophyric breccias, explosion breccias and interbedded Late Senonian limestones (Lewis and Straczeck, 1955). This unit is metamorphosed to greenschist facies with local occurances of eclogite and amphibolite facies (Boiteau et al, 1972). Unconformably above lay early Tertiary pyroclastics, and agglomerates of a volcaniclastic member.

The Sierra Maestra is quite different, with the Late Cretaceous section consisting of clastic sediments derived from a mature island arc (presumably the leading edge of the

Figure 48. Comparison of the stratigraphic columns of the Sierra Maestra and the Cuchillas Uplift in Oriente Province, Cuba. Data derived from Boiteau et al (1972a, 1972b), Lewis and Straczeck (1955), Khudoley and Meyerhoff (1971), Rigassi-Studer et al (1961, 1963), and Thayer and Guild (1964).


PERIOD
EPOCH
CUCHILLAS UPLIFT
SIERRA MAESTRA
PLIO-HOLO.
ALLUVIUM, SILTS, SANDS, GRAVELS. REEFAL BIOCLASTICS
ALLUVIUM, SANDS SILTS, GRAVELS REEFAL BIOCLASTICS
TERTIARY
MIOCENE
CALCAREOUS SILTS, MUDSTONES, BIOCLASTICS, CONGLOMERATES
CALCAREOUS SHALES, MUDSTONES, BIOCLASTICS, CONGLOMERATES
OLIGO-CENE
CALC. SS, SHALES, MUD S.
CONGL.
UPPER EOCENE
INTERBED.
LST.
PCL.
TUFFS,
SILTSTONES
TUFF, AGGLOMERATES, FLOW
GRANODIORITE
Da, Ba
TUFFACEOUS SANDSTONES, SILTSTONES, CONGLOMERATES.
LOWER EOCENE
TUFFS
Da, Ba
AGGLOMERATES VOLCANICS
UNDIFF. PCL., FLOWS
TUFFS,
SUBORD. FLOWS
PALEO.
LATE CRETACEOUS
LATE SENON.
KERATOPHY.
LST.
BRECCIA
PILLOW LAVAS
CONGL.
FANGLOMERAT.
BRECCIA
LST.
CLASTICS
SENON.
GABBROS, DUNITES, SERPENTINITES, LHERZOLITES, HARZBURGITES (PORTIONS META. TO GREENSCHIST, ECLOGITE, AMPHIBOLITE METAMORPHIC FACIES)
CUCHILLAS UPLIFT ULTRA-MAFIC COMPLEX
SANDSTONES
BIO. LST
CONGLOMERATES
TUFFS

Nicaraguan Rise). The sediments consist of sandstones, conglomerates, some tuffs and biohermal limestones interfingering with a fanglomerate member (Lewis and Straczeck, 1955). The early Tertiary has a larger volcaniclastic component, with some undifferentiated pyroclastics and lava flows, of calc-alkali affinity. It unconformably overlays the Cretaceous section.

The Cuchillas Uplift is entirely of oceanic derivation, while the Sierra Maestra stratigraphy is typical of an island arc province. Several authors including Kozary (1968), Perfit and Heezen (1979), and Goreau (1979), have suggested that the Sierra Maestra and the Cayman Ridge are genetically related to the Nicaraguan Rise.

The overturned nature of the Cuchillas Uplift ophiolitic sequence imply a major deformational event occurred prior to the extrusion of the pillow lava sequence that overlays it. A possible model for this event is discussed in Chapter 4. The occurence of a high pressure mineral assemblage along the southern limb of the Cuchillas Uplift has puzzled workers in this region (Boiteau et al, 1972a, 1972b) especially in view of the predominance of underthrusting along the northern margin of the region and the Old Bahama Channel.

The main structural trends of Oriente Province vary widely between the Sierra Maestra and the Cuchillas Uplift. They are as follows:

1. The N75°E trend of the synformal Cauto-Nipe Basin (Kozary, 1968).
2. The N60°W trend of the domal antiform of the Cuchillas Uplift (Rigassi, 1961, 1963). A trend similar to the Montagnes Noires/Massif Trou d'Eau of western Hispaniola.
3. The N60°W to E-W trend of the Guantanamo Basin which intersects the coast at Guantanamo Bay and appears to be continuous with the southern margin of the northwestern Haitian peninsula.
4. The E-W trend of the Sierra Maestra and Turquino Ranges which are clearly continuous with the main trend of the Cayman Ridge.

The interconnection between the Cauto and Guantanamo Basins is striking. No structural or stratigraphic information exists for these basins. The problem is further confounded by major late Tertiary fill (both marine and terrestrial). It will take a great deal of effort to unravel their sedimentary and structural histories (see Chapter 4. for proposed model).

The striking coincidence of structural style and the remarkable physiographic continuity between the Cuchillas Uplift and both the Ile de la Tortue/Cordillera Septentrional and the Montagnes Noires/Massif Trou d'Eau is especially obvious when the Pliocene to Holocene Windward Passage Deep is closed. The similarity becomes even more obvious when the timing of uplift for the Montagnes Noires (Late Cretaceous - early Tertiary) is compared to that of the Cuchillas Uplift (clearly post Senonian). Several authors have proposed dates for the implacement of the Cuchillas Uplift which vary from Late Jurassic (Mattson, 1979) to Early Cretaceous (Boiteau et al, 1972b) on circumstantial evidence and model compatibility. It seems obvious that the Cuchillas Uplift remained in the marine realm at least until the uppermost Cretaceous when the pillow lava member was deposited.

Lewis and Straczeck (1955) indicate that most structural features in Oriente Province are related to a compressional regime with two major episodes of deformation:

1. A Late Cretaceous to early Tertiary localization of the Cuchillas Uplift.
2. The Late Eocene to mid Miocene uplift of the Sierra Maestra.

These facts imply that the Cuchillas Uplift, the Montagnes Noires and the Cordillera Septentrional are genetically related to a Late Cretaceous to lower Tertiary mobile belt, bound to the west by a transcurrent boundary coincident with Cauto-Nipe Basin. They also imply a temporal relation between uplift of the Sierra Maestra and the uplift of the Chaines des Matheaux/Sierra Neiba of western Hispaniola. Both schemes are discussed in Chapter 4. This interpretation explains the (hitherto anomalous) location of the high pressure metamorphic assemblage described by Boiteau et al (1972a), which is coincident with a major underthrust belt extending from the Los Muertos Trough to the Cauto Basin.

APPENDIX 2.

Copies of the original seismic reflection profiles can be obtained from:

1. Woods Hole Oceanographic Institution
   Woods Hole, MA 02543
2. U.S. National Geophysical and Solar Terrestrial Data Center
   Boulder Colorado 80303

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