THE TECTONIC EVOLUTION OF THE NORTH CENTRAL CARIBBEAN PLATE MARGIN

by

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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.

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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).

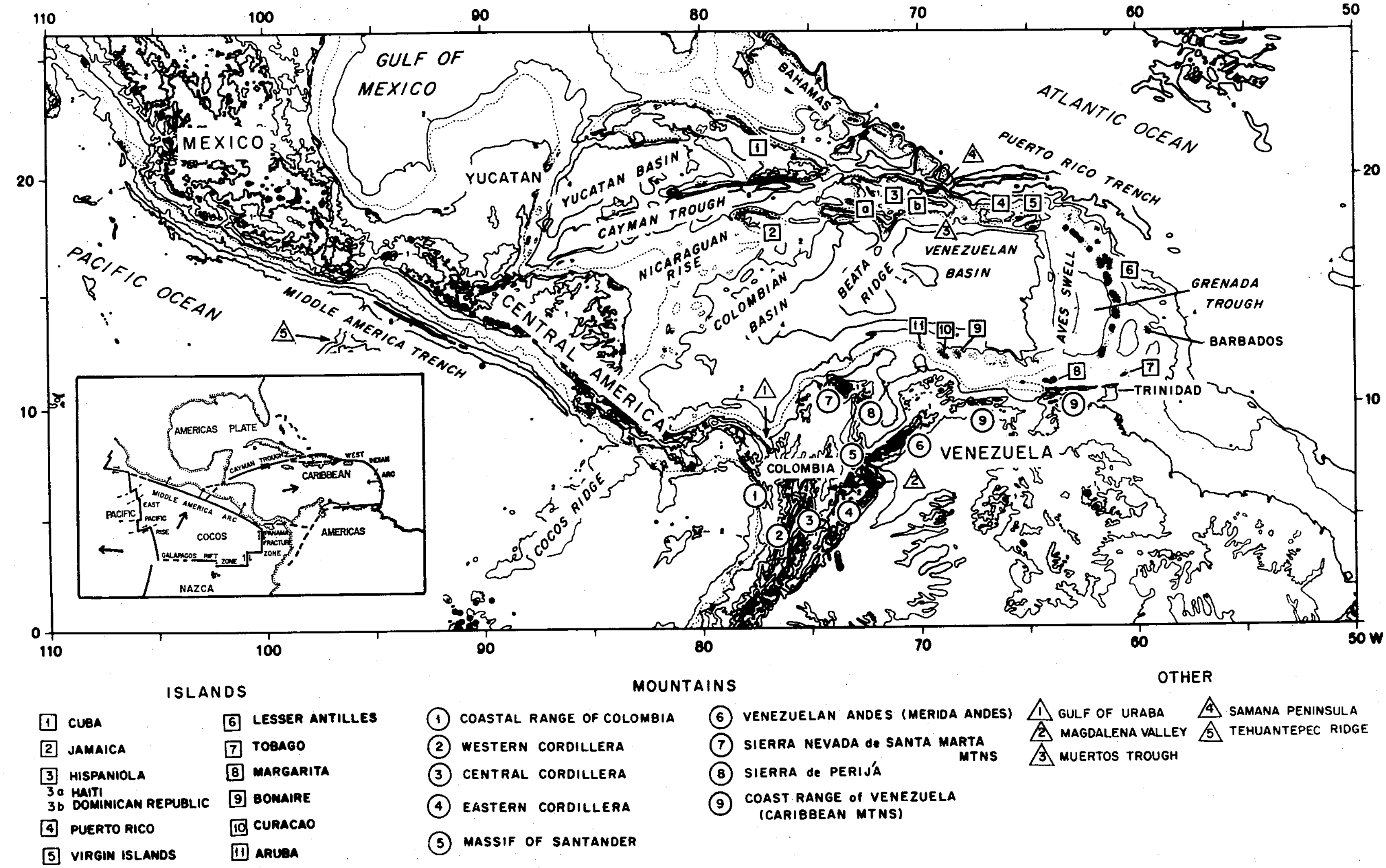

GULF OF MEXICO
MEXICO
YUCATAN
YUCATAN BASIN
CAYMAN TROUGH
NICARAGUAN RISE
COLOMBIAN BASIN
BEATA RIDGE
VENEZUELAN BASIN
AVES SWELL
GRENADA TROUGH
BARBADOS
TRINIDAD
BAHAMAS
ATLANTIC OCEAN
PUERTO RICO TRENCH
PACIFIC OCEAN
MIDDLE AMERICA TRENCH
CENTRAL AMERICA
COCOS RIDGE
COLOMBIA
VENEZUELA
AMERICAS PLATE
CAYMAN TROUGH
CARIBBEAN
WEST INDIAN ARC
MIDDLE AMERICA ARC
EAST PACIFIC RISE
PACIFIC
COCOS
AMERICAS
PANAMA FRACTURE ZONE
GALAPAGOS RIFT ZONE
NAZCA
110
100
90
80
70
60
50 W
20
10
0
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)

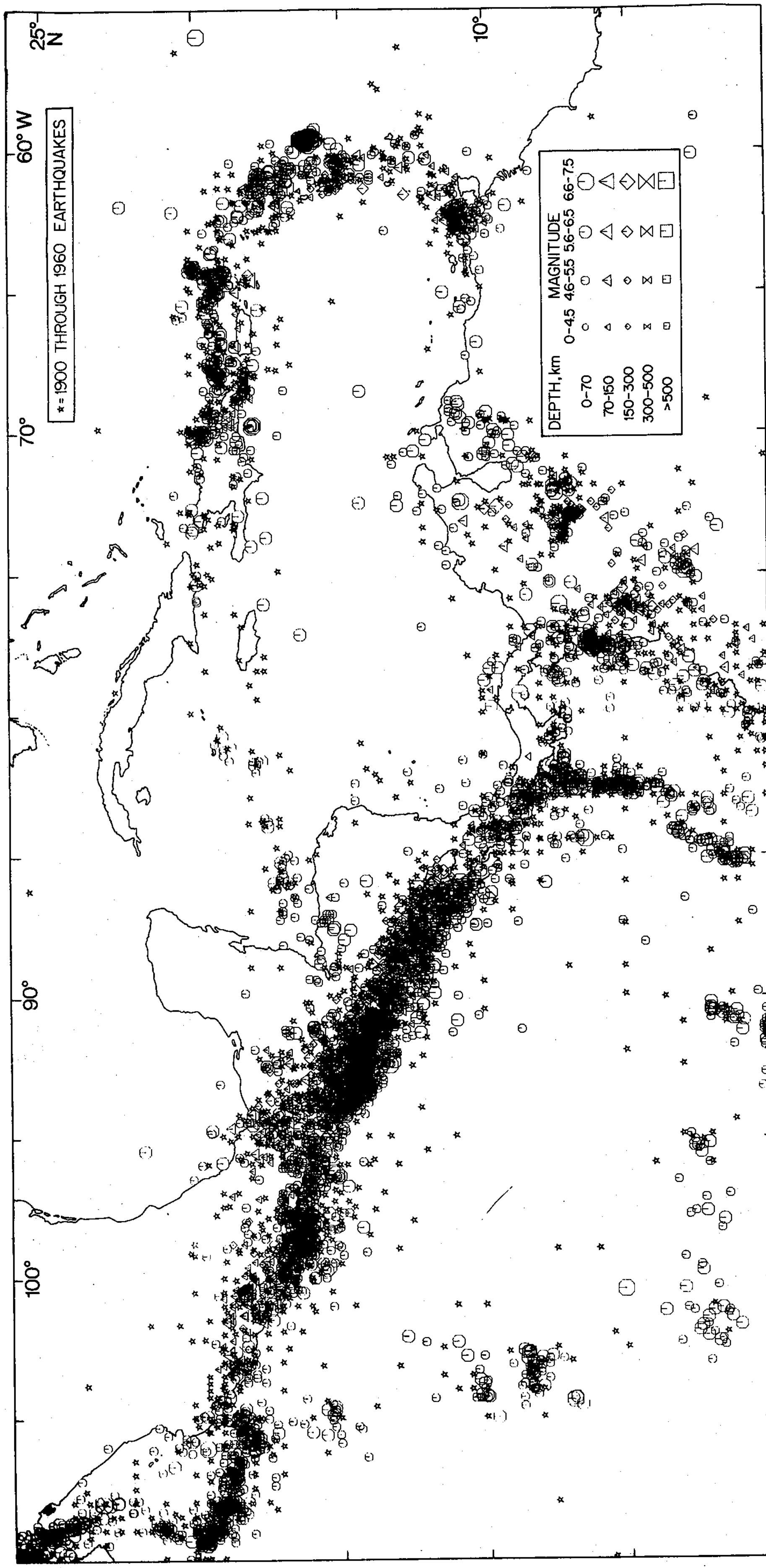
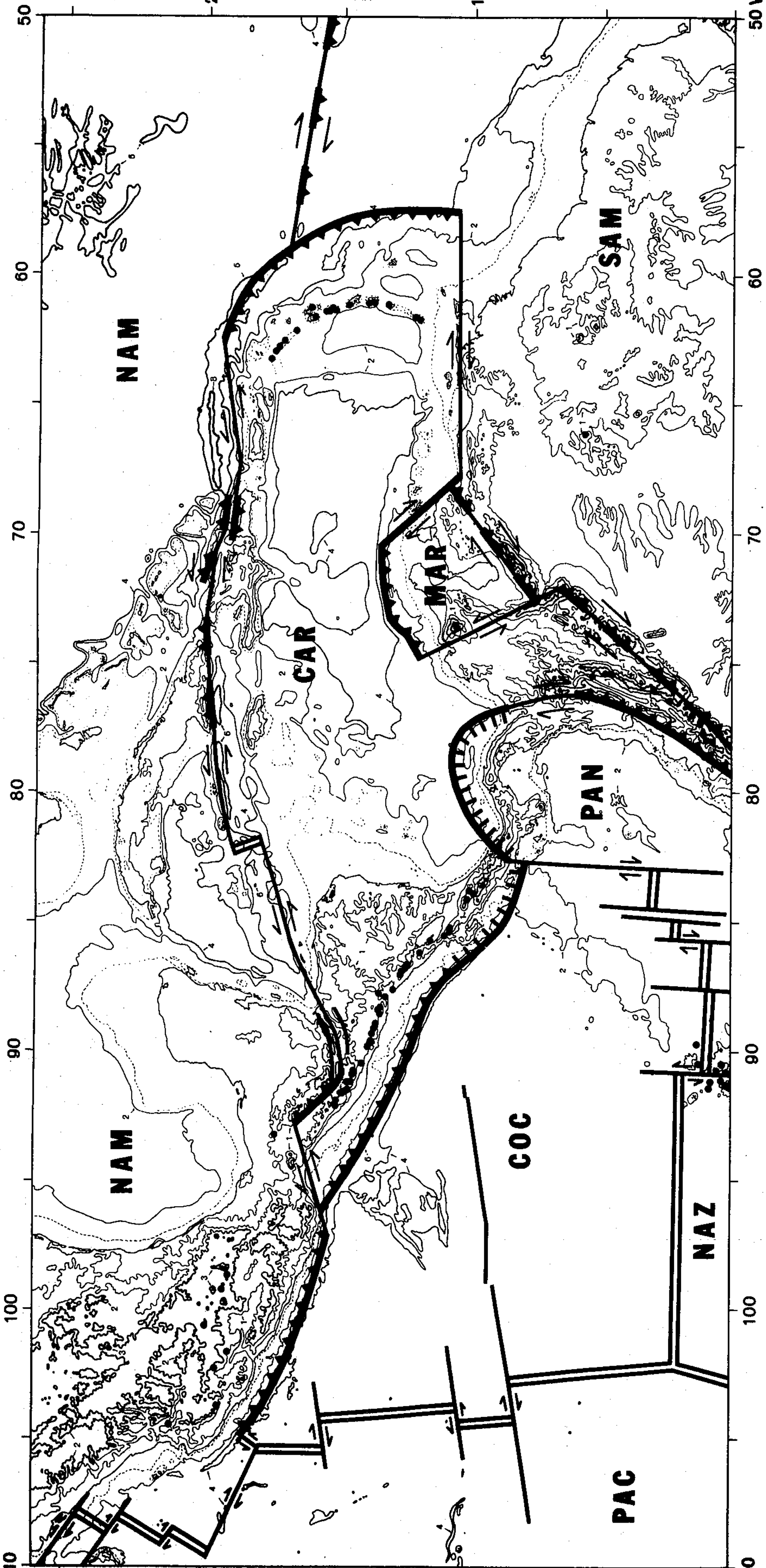

25° N
60° W
70°
90°
100°
10°
* = 1900 THROUGH 1960 EARTHQUAKES
DEPTH, km
MAGNITUDE
0-4.5 4.6-5.5 5.6-6.5 6.6-7.5
0-70
70-150
150-300
300-500
>500

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

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).

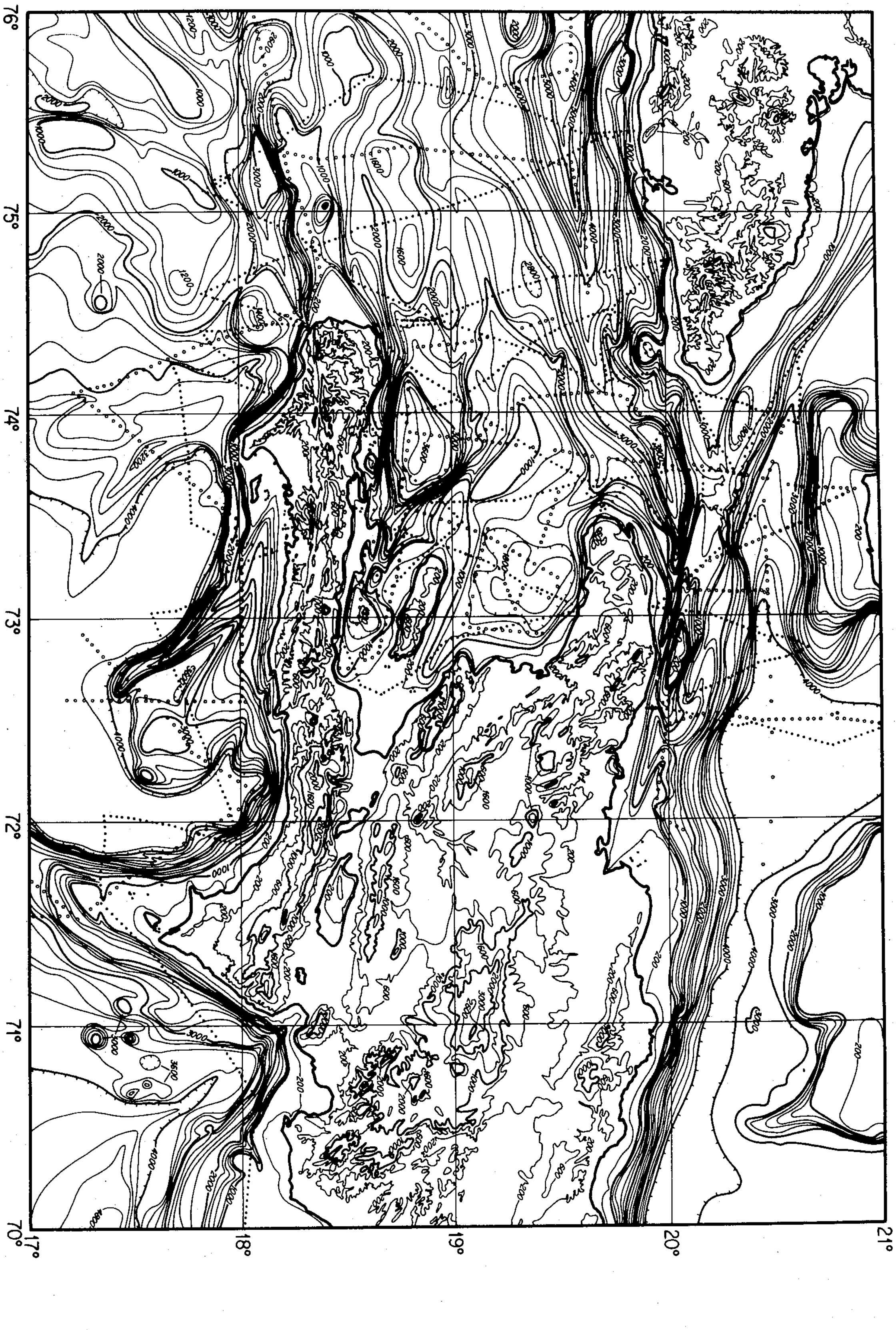
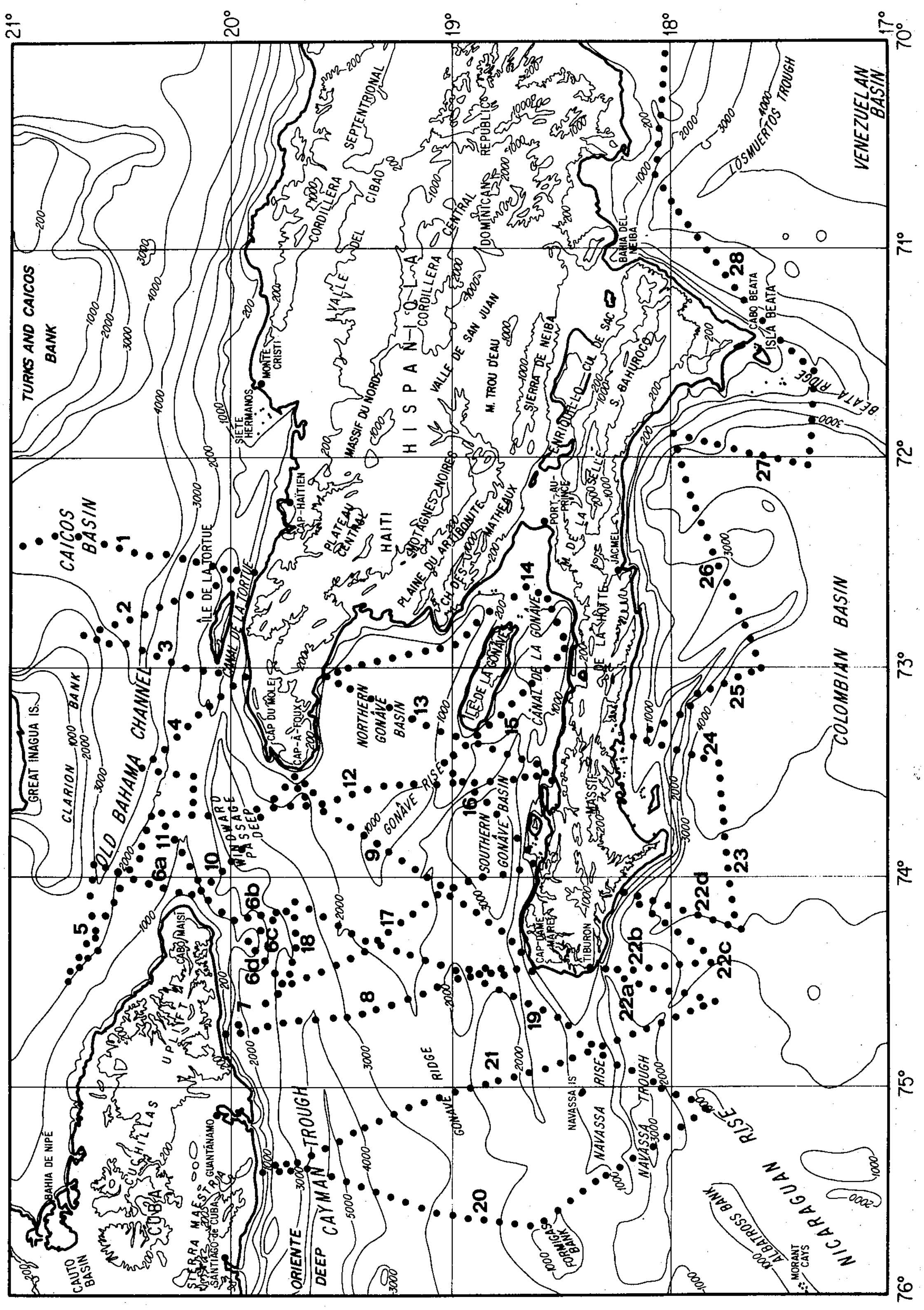

76°
75°
74°
73°
72°
71°
70°
17°
18°
19°
20°
21°

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°
70°
71°
72°
73°
74°
75°
76°
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
SIETE HERMANOS
MONTE CRISTI
CORDILLERA SEPTENTRIONAL
VALLE DEL CIBAO
CORDILLERA CENTRAL
DOMINICAN REPUBLIC
HISPANIOLA
VALLE DE SAN JUAN
M. TROU D'EAU
SIERRA DE NEIBA
ENRIQUILLO
CUL DE SAC
S. BAHUROCO
BAHIA DEL NEIBA
CABO BEATA
ISLA BEATA
BEATA RIDGE
LOSMUERTOS TROUGH
VENEZUELAN BASIN
COLOMBIAN BASIN
MASSIF DU NORD
CAP-HAÏTIEN
PLATEAU CENTRAL
HAITI
MONTAGNES NOIRES
PLAINE DU ARTIBONITE
CHAÎNE DES MATHEUX
PORT-AU-PRINCE
M. DE LA SELLE
JACMEL
M. DE LA HOTTE
MASSIF
ILE DE LA GONÂVE
CANAL DE LA GONÂVE
NORTHERN GONÂVE BASIN
GONÂVE RISE
SOUTHERN GONÂVE BASIN
CAP DU MÔLE
CAP-À-FOUX
CAP DAME MARIE
TIBURON
CABO MAISI
UPLIFT
CUCHILLAS
CUBA
BAHIA DE NIPE
CAUTO BASIN
SIERRA MAESTRA
GUANTÁNAMO
SANTIAGO de CUBA
ORIENTE DEEP
CAYMAN TROUGH
GONÂVE RIDGE
NAVASSA IS
NAVASSA RISE
NAVASSA TROUGH
FORMIGAS BANK
ALBATROSS BANK
MORANT CAYS
NICARAGUAN RISE
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

CHAPTER II

GEOLOGIC SETTING

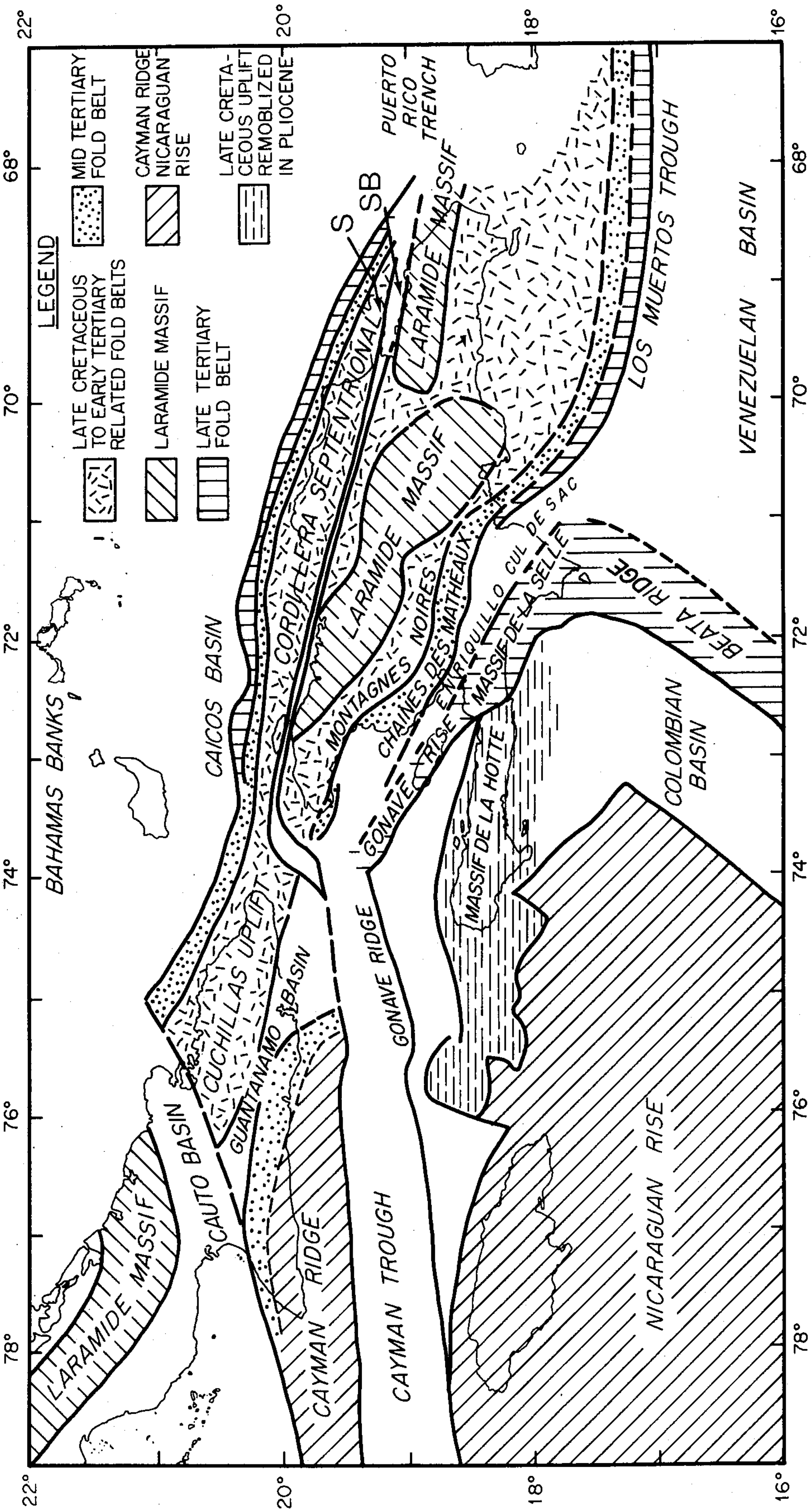
It is apparent from the bathymetric map that the study area is marked by considerable physiographic complexity (Figure 4). For simplicity I subdivide the area into a series of morphologically and genetically related basin and rise systems (Figures 5-7). These divisions are based on physiography, stratigraphy 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
CORDILLERA SEPTENTRIONAL
LARAMIDE MASSIF
MONTAGNES NOIRES
CHAINES DES MATHEAUX
ENRIQUILLO CUL DE SAC
MASSIF DE LA SELLE
GONAVE RISE
MASSIF DE LA HOTTE
BEATA RIDGE
PUERTO RICO TRENCH
LOS MUERTOS TROUGH
VENEZUELAN BASIN
COLOMBIAN BASIN
NICARAGUAN RISE
CAYMAN TROUGH
CAYMAN RIDGE
GONAVE RIDGE
GUANTANAMO BASIN
CUCHILLAS UPLIFT
CAUTO BASIN
S
SB
22°
20°
18°
16°
68°
70°
72°
74°
76°
78°