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# MESOZOIC STRATIGRAPHY OF CUBA: DEPOSITIONAL ARCHITECTURE OF A SOUTHEAST FACING CONTINENTAL MARGIN

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## ABSTRACT

Cuba is the product of northward convergence between an island arc and a southeast facing continental margin extending south of the Bahamas during Late Cretaceous-Early Tertiary. We establish the depositional architecture of the margin by (1) palinspastically restoring the constricted margin thrust slices and melange back to more southerly positions so that the southern edge of the margin extended 450 km to the south of the frontal thrust, (2) reconciling new Cuban academic and government stratigraphic data with prerevolution industry data from several companies, and (3) revising interpretations of fossil ages and environments.

The Mesozoic depositional architecture of Cuba is best depicted in a north-to-south series of tectonostratigraphic belts representing precollision environments including carbonate platform, slope/rise, abyssal plain, and island arc. An integration of stratigraphic data from all the belts suggests the following evolution: (1) Jurassic-rifting, red-bed and evaporite deposition, and bimodal volcanism in a broad transform zone linking the opening Central Atlantic and Gulf of Mexico basins, (2) Neocomian-subsidence and pelagic sedimentation on the margin of the opening proto-Caribbean Sea, (3) Barremian/Albian-deposition of fragmental carbonates and turbidites because of regional block faulting, (4) Cenomanian/Santonian-pelagic sedimentation with intercalated tuffs derived from the northward moving Cuban island arc, and (5) Campanian/Maastrichtian-widespread erosion of Turonian-Campanian section and deposition of unconformably overlying flysch related to beginning of arc-margin collision.

## INTRODUCTION

Previous attempts to interpret the stratigraphy of Cuba have suffered from incomplete, outdated, and politically

influenced data sets. Most non-Cuban geologists have relied chiefly on data collected by American oil company personnel during exploratory field campaigns of the 1950s (Meyerhoff and Hatten 1968; Pardo 1975). Many geologists have more recently used this data to constrain tectonic and stratigraphic reconstructions of the northern Caribbean relative to the southern edge of North America (*e.g.*, Gealy 1980; Salvador and Green 1980; Pindell and Dewey 1982; Burke *et al.* 1984; Pindell 1985). The problem with using this old industry data is that it has not been reanalyzed since the 1950s. Since that time, knowledge about faunal ranges has increased and biostratigraphic zonation has been revised (Hardenbol and Berggren, 1978). Consequently, many of the age picks made by industry paleontologists in the 1950s are no longer valid. Cuban, Soviet, Polish, Bulgarian, and Hungarian geologists have continued to study Cuban stratigraphy since Castro's rise to power in 1959. The European geologists have generated much new data. Unfortunately, most of these studies are reported in obscure (and sometimes inaccessible) papers and maps.

In an attempt to shed light on the Mesozoic stratigraphy of Cuba, this study has (1) re-examined thin sections from critical units to re-evaluate faunal content and stratigraphic range, (2) reanalyzed old industry stratigraphic picks based on modern biostratigraphic zonation and paleoenvironmental concepts, and (3) integrated re-evaluated industry data with new data from communist-bloc studies.

This paper summarizes the most pertinent descriptive data and interpretations that help constrain paleogeographic and paleotectonic interpretations. The Mesozoic stratigraphy of Cuba is significant for many reasons. Because of the development of a thrust belt in Cuba, it is possible to sample large Mesozoic exposures in Cuba that are correlative with those under the Bahamas, Florida, the southeast Gulf, and Yucatan. Hence, a detailed knowledge of the Cuban Meso-

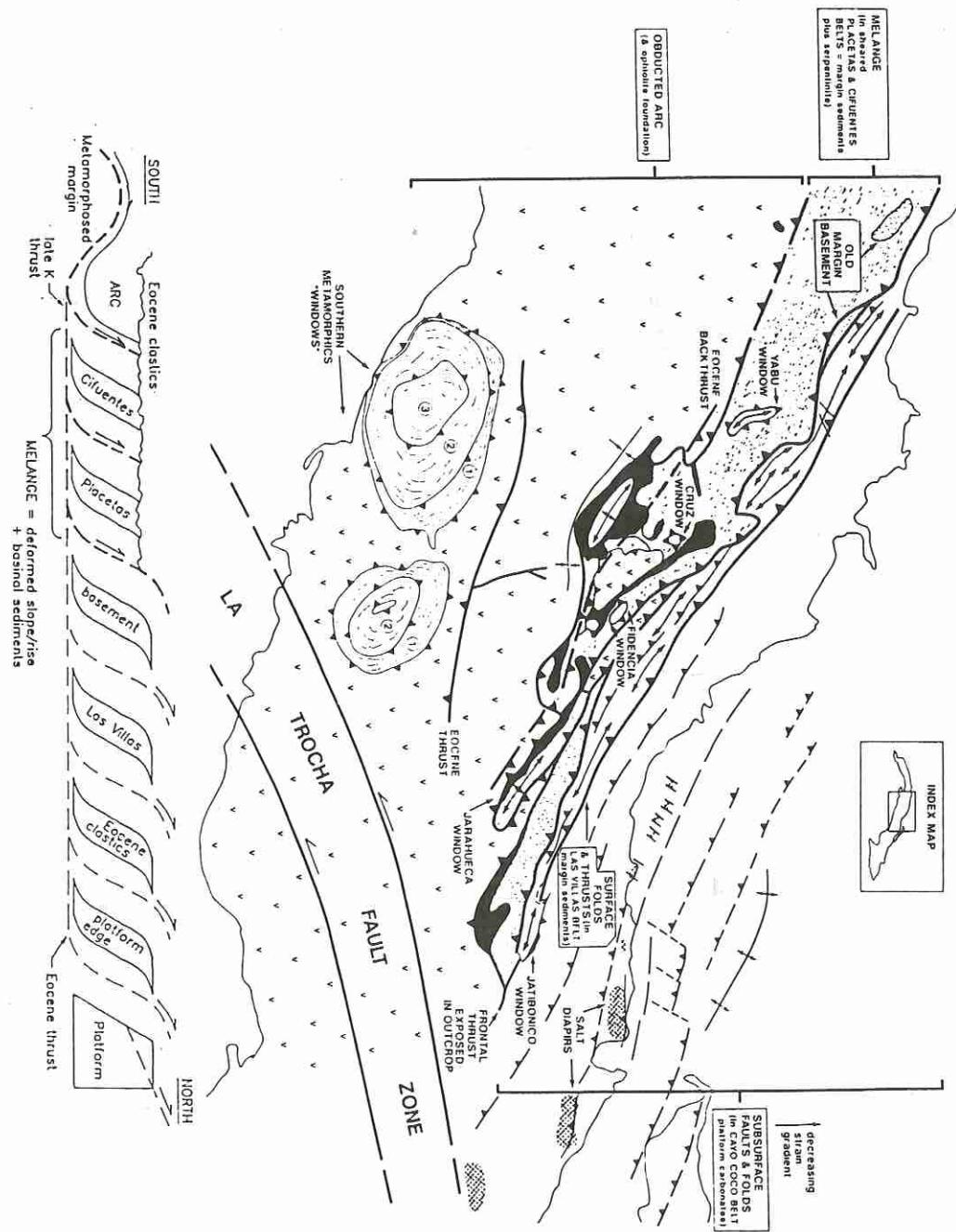


Figure 1. Simplified structure map and schematic cross-section of central Cuba illustrating spatial relationships of tectonostratigraphic belts.

Zoic units can shed light on similar rocks thought to underlie surrounding areas. The Cuban Mesozoic stratigraphic units can be used to interpret the nature of the rifted margin of southeastern North America in the Mesozoic prior to Latest Cretaceous collision with the Cuban island arc. Tectonic interpretations suggest that the proto-Cuba, Florida, and Bahamas area was part of an extensional terrane in the Triassic to Early Jurassic related to the breakup of Pangea and opening of the Central Atlantic and Gulf of Mexico ocean basins. Throughout the Mesozoic, the area subsided and formed a "continental margin." Yet, we know very little about the nature of that margin.

Because the Mesozoic stratigraphic units are exposed in thrust-bounded packets or "slices," the best method to analyze these units is in terms of tectonostratigraphic belts. This approach was used by some of the first geologists in Cuba (e.g., Ruttent 1936). The tectonostratigraphic belt scheme developed by this study built upon the classification of

Pardo (1954, 1975), but simplified and modernized it in terms of current concepts of tectonic and depositional environments. Thus, in a progressive north-to-south traverse across Cuba, the suture zone between the southeastern continental margin of North America and the Cuban island arc is analyzed by examining east-west-oriented belts of distinctive thrust slices representative of particular tectonic and depositional environments just prior to arc/margin collision (Fig. 1). It is important to emphasize that the continental margin of North America involved in the collision consisted of the Bahamas carbonate platform in the north and a broad slope/rise and abyssal plain section in the south. All these tectonostratigraphic belts were underlain by stretched continental crust.

The tectonostratigraphic belt approach to the Mesozoic stratigraphy of Cuba presents an analysis of the components of each belt from base to top. In order to demonstrate the spatial relationships of these belts through time and the

stratigraphic evolution of the Cuba/Bahamas/Florida margin it is necessary to palinsastically restore the Cuban thrust belt. A detailed analysis of strain throughout the Cuban thrust belt showed that at least 450 km of northward thrusting had been accommodated (Hempton 1991). In other words, the Cuba/Bahamas/Florida margin extended at least 450 km to the south of the frontal thrust in the carbonate platform belt. This analysis has allowed us to restore each belt within the margin to a more appropriate width just prior to collision with the Cuban arc.

In the descriptive scheme employed here, we traverse through (north-to-south) platform carbonates along the north coast (Cayo Coco belt), slope/rise sediments (Las Villas belt), proximal abyssal plain (Placetas belt), distal abyssal plain (Cifuentes belt), island arc, and Southern Metamorphics belt (metamorphosed margin sediments). The stratigraphic character of each belt is dissected from the basement (when possible) up through the youngest part of the section. After describing the depositional architecture of each belt we propose a Mesozoic tectonostratigraphic history of the Cuba/Florida/Bahamas margin and its response to the northward-moving Cuban island arc.

#### CAYO COCO BELT (PLATFORM)

The Cayo Coco belt is the northernmost tectonostratigraphic belt in Cuba (Fig. 2). It is known mostly

from wells, especially the Cayo Coco No. 2 in north central Cuba. Outcrops are rare. Evaporite diapirs in north central Cuba contain inclusions thought to be entrained from the subsurface Cayo Coco belt section. Most of the data on the Cayo Coco belt was generated by oil companies in the 1940s and 1950s. Estrella (Royal Dutch/Shell) drilled the Cayo Coco No. 2 well and cored extensively. Gulf and Chevron both had access to the cores in the 1950s and conducted their own analyses as summarized in proprietary reports such as those by Pardo (1954) and Bronnemann (1954) for Gulf and Hatten *et al.* (1958) for Chevron (these reports are now in the public domain). Open literature reports by these geologists (Meyerhoff and Hatten 1968; Pardo, 1975) contain detailed summaries of the Cayo Coco stratigraphy. Since the 1950s, the Soviets have drilled new wells into the Cayo Coco belt in north central Cuba (*e.g.*, Cayo Fragoso-1 and Cayo Frances-1) and in the Veradero area but have reported few of the details. In general, the Cayo Coco belt consists of a thick (14,000 feet) sequence of Late Jurassic to Tertiary carbonates that are thought to overlie an unknown thickness of Jurassic redbeds and evaporites. In the following sections, pertinent aspects of each part of the section are discussed.

Information concerning basement is derived from geophysical techniques such as gravity, magnetics, and seismic reflection data. Royal Dutch/Shell conducted a wide-meshed gravity survey of this area and noted a residual

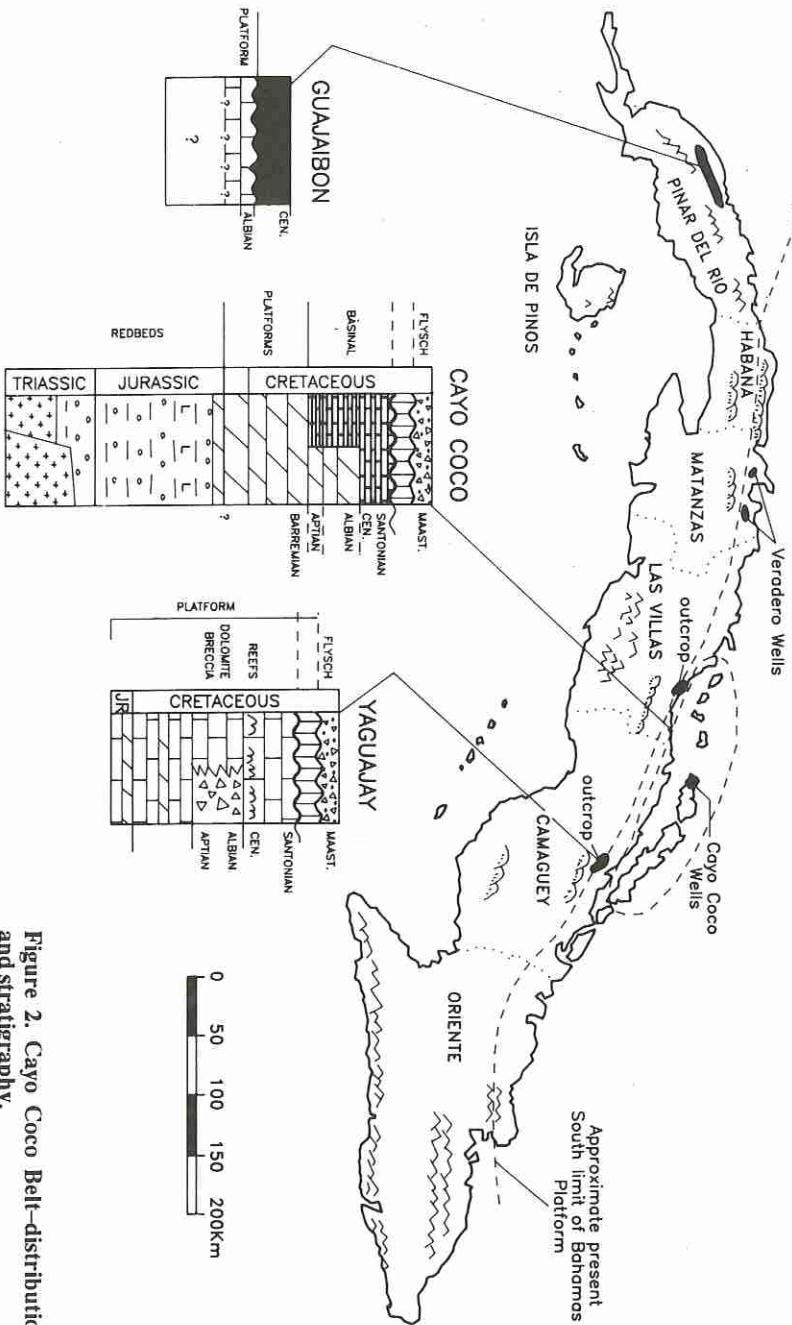


Figure 2. Cayo Coco Belt—distribution and stratigraphy.

gravity maximum under Cayo Coco. They drilled Cayo Coco No. 2 over this maximum and postulated that the gravity maximum was caused by "tectonical deformation of the top of the Lower Cretaceous dolomites." Shell explorationists suggested that basement lies at a depth of 30,000 feet, an interpretation supported by magnetic and seismic reflection data (Hatten *et al.* 1958). The age of basement is thought to be early Paleozoic to Precambrian based on an extrapolation from isotopic dates of basement from the Cifuentes belt (Hatten *et al.* 1986) and the Straits of Florida area (Schlager and Buffler 1984).

Within the Cayo Coco belt along the north coast of Cuba, several evaporite diapirs crop out. The age of the salt is problematic. An age of Middle Jurassic has been proposed by Cousminer (in Hatten *et al.* 1958) based on spores. This would correspond to the approximate age of the Louann salt in the Gulf of Mexico, as many authors have noted (*e.g.*, Pardo 1975). A Middle Jurassic age is supported by the presence of Middle Jurassic and younger inclusions entrained within the salt. Roy Waite of Shell has found Late Jurassic and Early Cretaceous spores in salt samples from the Collazo-1 well (personal communication, 1987). It is clear that salt probably did not occupy all of the sedimentary section between the bottom of the Cayo Coco No. 2 well (10,563 feet deep) and the proposed top of basement (30,000 feet). A seismic survey suggests the presence of carbonates overlying a sand/shale sequence at depth (Argudo *et al.* 1958).

The best clues about the sequence under the drilled section of the Cayo Coco (Tithonian to Tertiary carbonates) come from the lithology of rocks entrained in the salt on its ascent to the surface. These include a variety of sedimentary rocks such as red and maroon shale, silty shale, anhydrite, sucrosic dolomite, limestone, and a trace of chert. These rocks are very similar to the San Cayetano rocks of western Cuba. The San Cayetano rocks may represent Triassic-Upper Jurassic redbeds generated within a rift setting. The present areal distribution of salt diapirs may delimit the original area of the rift basin in the Cayo Coco area during the Jurassic.

Above the rift-related redbeds and evaporites lies an unknown thickness of probable platform carbonates (Hatten *et al.* 1958) which, in turn, are overlain by a thick section of platform carbonates drilled in the Cayo Coco-2 and Collazo-1 wells and cropping out in central and western Cuba. It is best described by data from the Cayo Coco-2 well (Schaub and Fillman 1948; Bandt 1958) where 6,565 feet were penetrated. Because dipmeter readings average about 30 degrees, the true drilled thickness was estimated by Hatten *et al.* (1958) as 5,695 feet. This sequence was labeled the Cayo Coco Formation by both Estrella/Shell and Gulf explorationists. The Cayo Coco Formation consists of varying proportions of secondary dolomite, anhydrite, anhydritic

dolomites, limestone, and minor oolitic zones. Porosity is both intergranular and vugular and ranges up to 15 percent. Traces of asphalt were found between 8,765 and 9,000 feet in the Cayo Coco-2 well, and oil stains are common throughout the section. Although fauna are scarce, both Lower Cretaceous (*Coskinoloides*) and Upper Jurassic (*Lombardia angulata*, *Cuneolina*, and *Favreina joukowskyi*) fossils have been reported (Hatten *et al.* 1958). Based on lithologic character, the carbonates of the Cayo Coco Formation have formed in shallow, warm water behind a reef where evaporating conditions prevailed. Rocks similar to the Cayo Coco Formation in lithologic character and thickness are found in the wells of north central Cuba, the northwestern Bahamas, wells between Cuba and Florida, and deep wells onshore Florida. All of these Upper Jurassic to Lower Cretaceous sections are interpreted to have been deposited on a single carbonate platform (or megabank).

The Lower Cretaceous platform records a very rapid change from platform sedimentation to basinal sedimentation. This change occurred at different times in different places (but typically during the Aptian-early Cenomanian). From the Aptian time on, there is a segmentation of the platform. Some areas go down very rapidly (*e.g.*, the Cayo Coco-2 area in the Aptian) and receive basinal sediments until the Latest Cretaceous. Other areas remain high and characterized by platform sedimentation. This behavior was probably caused by the reactivation of underlying basement faults and segmentation of the continuous platform due to a reorganization of spreading direction and movement of plates around the Central Atlantic (Emery and Uchupi 1984). Above the Cenomanian, massive chalky limestones dominate through the Santonian, where an unconformity marks the top of the section (Bronnemann and Rigassi 1963; Barros 1987).

All Upper Cretaceous sections in the Cayo Coco belt (both basinal and platform) are topped by an unconformity which is overlain by fragmental limestone and dolomite labeled the Mayajigua Formation by Truitt (1956). These rocks range up to 220 m thick and exhibit a fining-upward trend. In the Yaguajay area, these rocks are about 100 m thick and were labeled the Frio Formation by Truitt (1956) and the Palone Formation by Barros (1987). Bronnemann (1954) assigned a Maastrichtian age to both the Mayajigua and Palone formations. This age has been corroborated by the Campanian-Maastrichtian age range of the reworked limestone clasts and the overlying marls of the Remedios Formation which have been dated conclusively as Paleocene based on the presence of *Borealis floridanus* (Ted Robinson, personal communication, 1987).

The unconformity below these formations was generated between the Maastrichtian and the Santonian (age of the youngest rocks below it). It was most likely generated during a Campanian-Maastrichtian initiation of collision

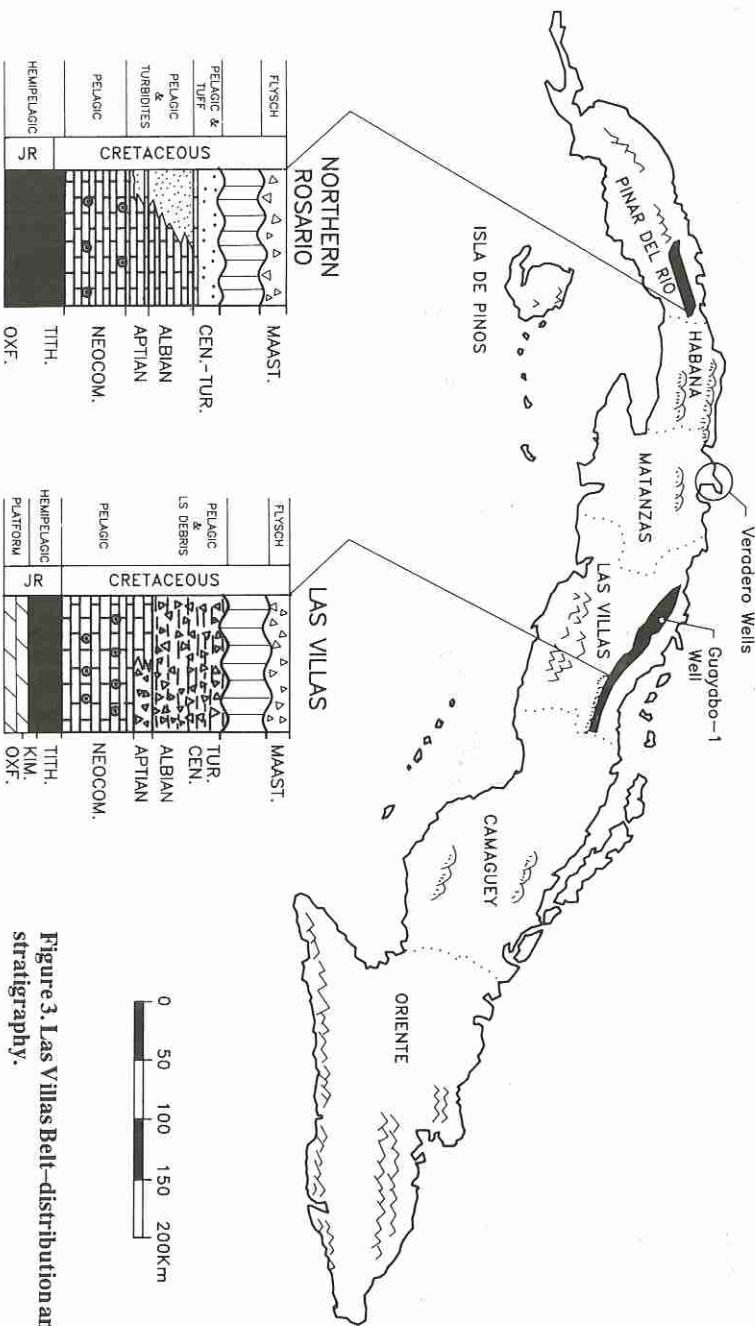


Figure 3. Las Villas Belt—distribution and stratigraphy.

between the Cuban island arc and the edge of the platform. The Mayajigua and Palone formations can be interpreted as orogenic deposits (carbonate turbidites) generated by structural disruption and erosion of platform fault blocks caused by the onset of the collision.

#### LAS VILLAS BELT (SLOPE/RISE)

The Las Villas belt (Fig. 3) is one of the better exposed tectonostratigraphic belts in Cuba. Knowledge of the Las Villas belt is derived from old oil company reports (*e.g.*, Pardo 1954; Truitt 1956; Hatten *et al.* 1958; and Ducklo 1958) and recent Soviet and Polish collaborations with the Cubans (*e.g.*, Furrazola *et al.* 1981; Pszczolkowski 1982; and Kuznetsov *et al.* 1985). Much new information about the Las Villas belt has been generated by the ambitious deep drilling program of the Soviets along the north coast in the Veradero area Kuznetsov *et al.* 1985 (Echevarria *et al.* 1991, and Sanchez *et al.* 1991). An old Gulf well, the Guayabo-1, provides the best available subsurface control.

The base of the Las Villas section in central Cuba consists of 700 m of dolomitized platform limestone with minor chert layers (the Hoya Colorado Formation of Kuznetsov *et al.* (1985)). Originally, Brönnimann and Rigassi (1963) had dated this unit as Tithonian, but recent data from Veradero wells suggest that the Late Jurassic to Early Cretaceous formations of central Cuba are similar to the Artemisa Formation of western Cuba (Kuznetsov *et al.* 1985). Therefore, according to this correlation, this basal

platform unit is most likely Kimmeridgian or uppermost Oxfordian in age (Barros 1987).

Hemipelagic sediments of the Jaguita and Caguaguan formations overlie the platform and form the top of the Jurassic section. They are exposed in both central and western Cuba (where they form the base of the section). These sediments are 520 m thick and consist of oolitic grainstones interbedded with laminated carbonaceous limestones and shales. Organic content is reported as high (Pszczolkowski 1982). Because of the newly released well data, the age of these hemipelagic sediments has been revised to fall in the Kimmeridgian/Tithonian range (Furrazola *et al.* 1981).

Starting in the Berriasian, pelagic sediments dominate the stratigraphic section up to the Aptian. The pelagic sediments (labeled Capitolio Formation in central Cuba and the Sumidero Member of the Artemisa Formation in western Cuba) are characterized by dense limestone with carbon-rich laminae, interbedded chert, and intraformational conglomrates containing fragments of carbonate. *Aptychus* (the operculi of ammonites) are common, and this section is often referred to as the "Aptychus limestone" after Rutten (1936) and Palmer (1945). Total thickness is constrained by the 420-m section of Capitolio Formation drilled in the Guayabo-1 well (Calveche, 1958). Pardo (1954) reports an age of Neocomian to Aptian for the Capitolio Formation. For the Sumidero Member of western Cuba, Pszczolkowski (1982) reports an age of Berriasian-early Hauterivian.

The Capitolio Formation is rich in carbon. It is similar to Neocomian-Albian organic-rich, but immature, lime-

stone drilled in DSDP Site 535 to the west in the western Straits of Florida/southeast Gulf of Mexico region. (Schlaeger and Buffler 1984). According to Maksimov *et al.* (1986), the Upper Jurassic to Neocomian slope/rise limestones of Cuba comprise the principal source rock.

In the Aptian, the slope/rise sediments of the Las Villas belt were contaminated with interbedded sands in the west and fragments of Upper Jurassic and Lower Cretaceous hemipelagic and platform limestone in central Cuba. These deposits are most likely related to Aptian through Cenomanian reactivation of basement faults throughout the margin. In central Cuba, the southernmost exposures of the Las Villas belt contain 600 m of pelagic limestone with beds composed of fragmental hemipelagic and platform limestone no more than one-inch thick. These fragmental beds probably originated as turbidity flows. These rocks range from Aptian through the early Turonian (Hatten *et al.* 1958). In western Cuba, clastics first appear in the Polier Formation as interbedded sandstones and shales (Pszczolkowski 1978). The sandstones contain angular quartz grains, plagioclase, and muscovite, suggesting erosion from basement highs such as those known to exist in the western Straits of Florida/southeast Gulf region, e.g., Catoco Knoll, Jordan Knoll, and Pinar del Rio Knoll. Thickness of the sandstone beds decreases to the south, supporting the notion of a northern source. Dating of these beds is difficult, but Myczynski (1976) suggests a Hauterivian to Barremian age. The Polier sandstones do not occur everywhere in the western Las Villas belt; they interfinger with micritic limestone and chert of the Sabanilla Formation, suggesting that the sands may be deposited in fan lobes. The top of the Polier Formation consists of 20 m of thick-bedded sandstones and shale intercalations of Aptian/Albian age (Pszczolkowski 1978). Above the Albian, the section consists of Sabanilla Formation micritic limestones and cherts.

In the Cenomanian/Turonian, volcanoclastics of the Moreno Member are deposited. They consist of sandstones and conglomerates of volcanic material plus "dactic tuffites" totaling 15 m thick (Pszczolkowski 1978). These volcanoclastics could be the first sign of the Cuban island arc approaching from the southwest.

Turonian carbonates of both central and western Cuba are truncated by a major angular unconformity which, in turn, is overlain by Maastrichtian orogenic turbidites generated during the arc/margin collision. In central Cuba, the turbidites of the Lutgardo Formation consist of 50 percent limestone clasts, 40 percent clay, and 10 percent chert fragments. However, in western Cuba, the turbidites of the Cascaraíca Formation also contain sandstones and fragments of volcanic and metamorphic rocks. An Upper Maastrichtian age for these turbidites is established by the presence of the following planktonic fauna within inter-

bedded shales: *Rugotrumcana mayaroensis* (Bolli) and *Rugoglobigerina rugosa* (Plummer).

#### PLACETAS BELT (PROXIMAL ABYSSAL PLAIN)

The Placetas belt crops out to the south of the Las Villas belt in scattered discontinuous exposures in central Cuba and as a continuous, coherent exposure in the southern Rosario area of western Cuba (Fig. 4). Most of our knowledge of this belt in central Cuba is derived from oil company reports generated in the 1950s (e.g., Pardo, 1954; Truitt, 1956; Hatten *et al.*, 1958). In western Cuba, the Polish/Cuban field studies generated significant new data (e.g., Piotrowski, 1977; Pszczolkowski, 1978, 1982; Pszczolkowski and Flores, 1985). Although numerous shallow wells have penetrated Placetas belt lithologies in the subsurface, no deep wells have been drilled entirely through it. However, because the Placetas belt crops out in numerous imbricated thrust slivers exposing sections of different stratigraphic position, it is thought that nearly the whole section is exposed at the surface.

In central Cuba, the Placetas belt consists entirely of pelagic sediments, most of which are limestones. No pre-Cretaceous is exposed. The Neocomian section is very similar to the Capitolio Formation of the Las Villas belt except that it contains more interbedded shale. The proportion of shale increases to the south. Approximately 1,000 feet of this limestone is known as the Ronda Formation, which also occurs in the Cifuentes belt farther to the south. These sediments are interpreted as proximal abyssal plain accumulations. The top of the Neocomian section contains turbidite beds composed of fine-grained quartz and muscovite sandstone, suggesting that a granitic source area was being eroded in the Barremian. Interbeds of clastics are more numerous in the Aptian section. Above the Aptian lies an Albian-Turonian section (the Carmita Formation = 50 m thick) composed of fragmental argillaceous limestone with numerous secondary and primary chert layers and intervals of carbonaceous shales with less common sandstone beds. The fragmental and clastic materials probably were deposited by turbidity flows into the abyssal environment and signify greater erosion than during the Neocomian interval (possibly from relict topography and bathymetry created during the Aptian/Albian tectonism?). The top of this unit is marked by a major angular unconformity, followed by flysch of the Corona Formation (Maastrichtian). It contains interbedded fragmental limestone (with igneous grains), sandstone (with quartz and volcanic grains), shales, and cherts (possibly silicified shale beds). This flysch is related to initial obduction of the Cuban island arc in the Campanian/Maastrichtian.

In western Cuba in the southern Rosario area, the Placetas belt is built upon Triassic-Jurassic redbeds of the San Cayetano Formation. The San Cayetano Formation is

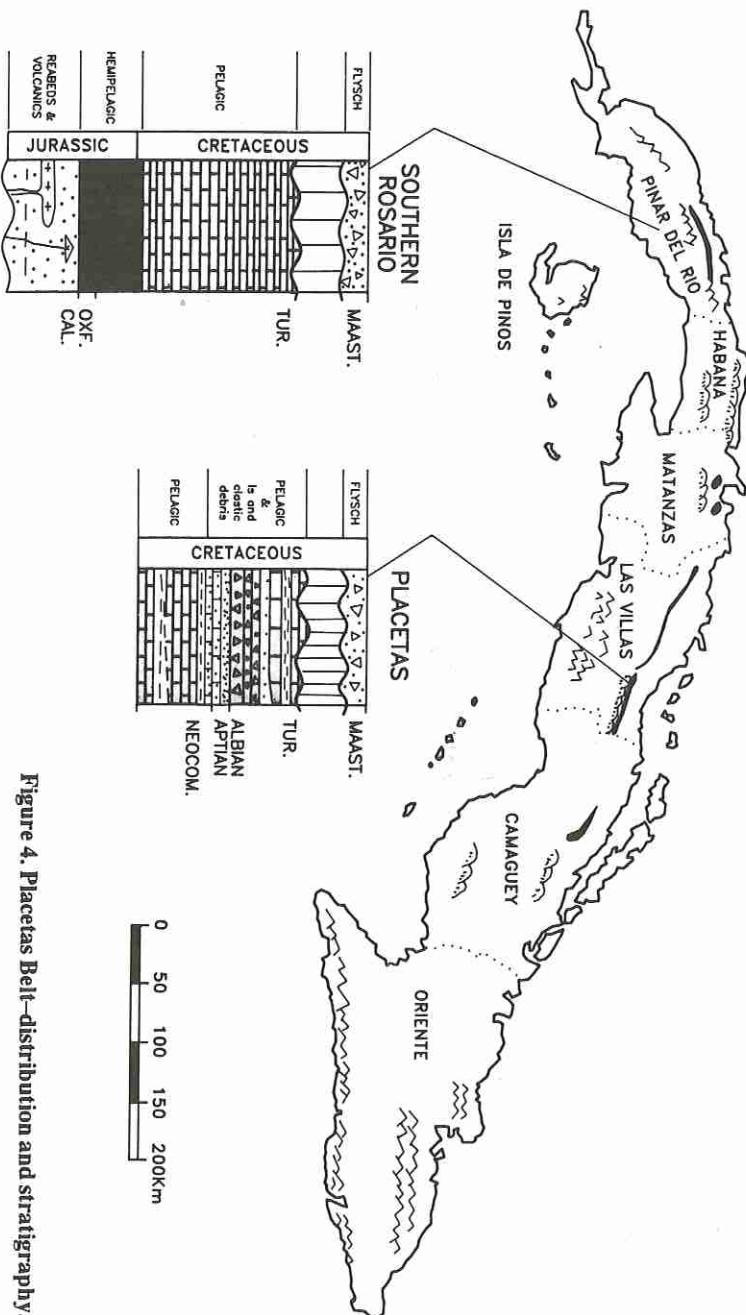


Figure 4. Placetas Belt-distribution and stratigraphy.

exposed in numerous thrust slices in both the Placetas and Cifuentes belts. The outcrops in western Cuba are unique in that they are the only surface exposures of Jurassic rebeds in the southeastern Gulf of Mexico and northern Caribbean area. Similar rocks are entrained in the salt diapirs of the Cayo Coco belt, and have been penetrated in the South Florida Basin area. Numerous authors have written about the San Cayetano Formation including De Golyer (1918), Imray (1942), Bermudez (1961), Haczewski (1976), Pszczolkowski (1978, 1982) and Barros (1987).

In general, the San Cayetano Formation consists of sandstones, siltstones, shales, and minor limestones with rare intrusions of gabbro and extrusions of "trachyites." Total thickness ranges up to 3,000-5,000 m (Barros 1987). Haczewski (1976) has divided the San Cayetano rocks into nine facies that were deposited in fluvial-deltaic, lagoonal, or deepwater basinal environments. For many years a debate has raged about the exact nature of San Cayetano depositional environment and its paleogeographic significance. The depositional environment has been interpreted as continental (Korin *et al.* 1973), lacustrine (Bermudez, 1961), paralic-lagoonal (Rigassi-Studer 1963; Khudoley and Meyerhoff (1971), deltaic (Pszczolkowski 1971a,b), or deepwater environment of flysch deposition (Santucci 1972). The interpretation offered here is that the San Cayetano rocks are typical rebed facies found in rift (Frostick *et al.* 1986) or pull-apart basin (Hempton and Dunne 1984) environments.

The upper sands are interbedded with limestones containing ammonites of Oxfordian age. Constraints on the lower boundary are less well known. According to Barros (1987), the basal San Cayetano is at least as old as Bajocian, based on the presence of dinosaur bones and pelecypods. However, it could extend down into the Triassic-Early Jurassic if reports of fern fragments are credible (Meyerhoff and Hatten, 1974). Hemipelagic carbonates of the Francisco and Zarza formations overlie the San Cayetano rebeds. These rocks are similar to the Zarza Formation in the Las Villas belt and range in age from the Oxfordian to the end of the Jurassic. Pelagic rocks of the Buenavista Formation overlie the hemipelagic sediments and range in age from Berriasian to Turonian. A major angular unconformity overlies the pelagic section, and above it lies Maastrichtian flysch containing *Rugotruncana mayarensis* and *Rugoglobigerina rugosa* in interbedded shales. These planktonic fauna date the flysch as Upper Maastrichtian.

#### CIFUENTES BELT (DISTAL ABYSSAL PLAIN)

The Cifuentes belt (Fig. 5) is exposed at the surface interleaved with and to the south of the Placetas belt. In central Cuba, old oil company reports are the source of most of the data, while in western Cuba, Pszczolkowski (1978, 1982) generated most of the data on the Cifuentes belt exposures. No deep wells penetrate the Cifuentes belt, but

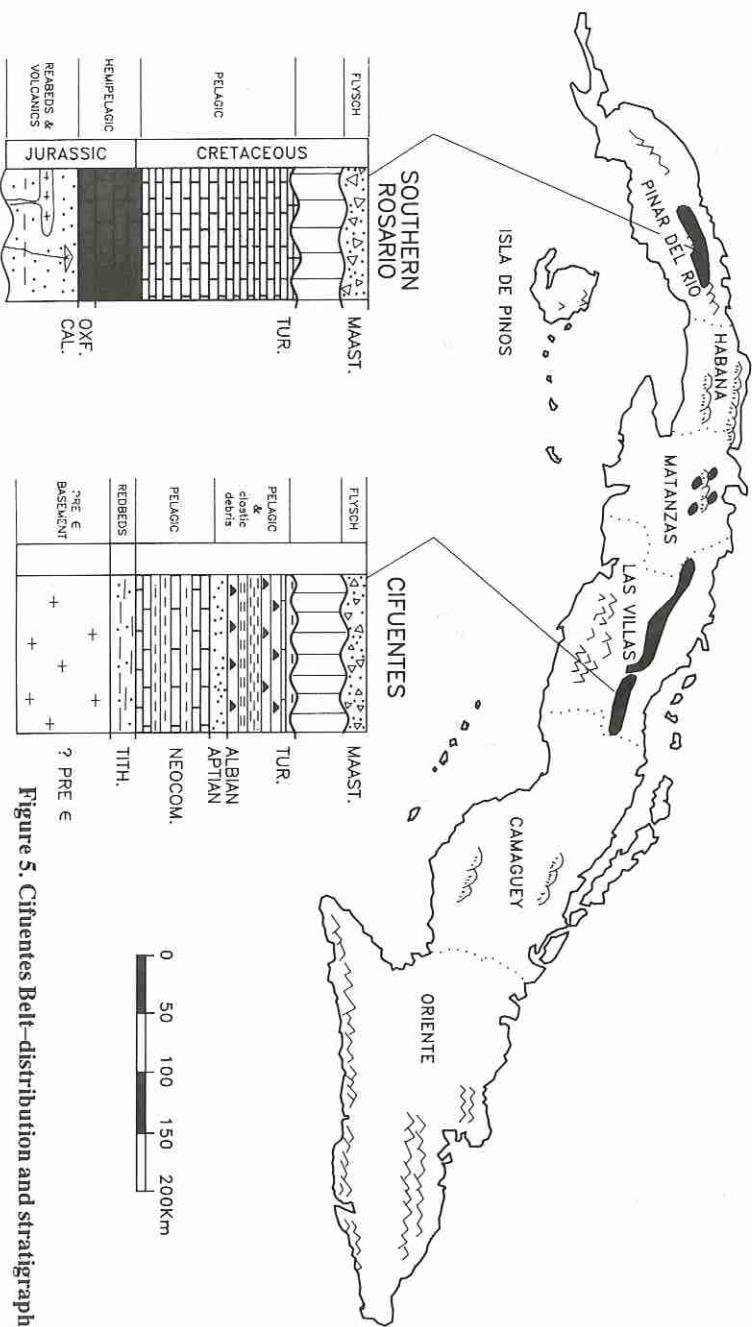


Figure 5. Cifuentes Belt—distribution and stratigraphy.

because of its imbricated nature, sections from all portions are thought to be exposed at the surface.

In central Cuba, the section is similar to that of the Placetas belt except that there is more arc-derived shale (volcaniclastics?) and chert with less limestone in the Albian-Turonian, more shale in a thinner Neocomian section, and Tithonian redbeds at the base of the section. The first two features suggest a more distal abyssal plain environment in the Cretaceous prior to arc collision. Otherwise, the sedimentary rocks are identical to those of Placetas with the Aptian to Albian muscovite-bearing sandstones, missing Turonian-Campanian section, and Maastrichtian orogenic flysch deposited over a major angular unconformity.

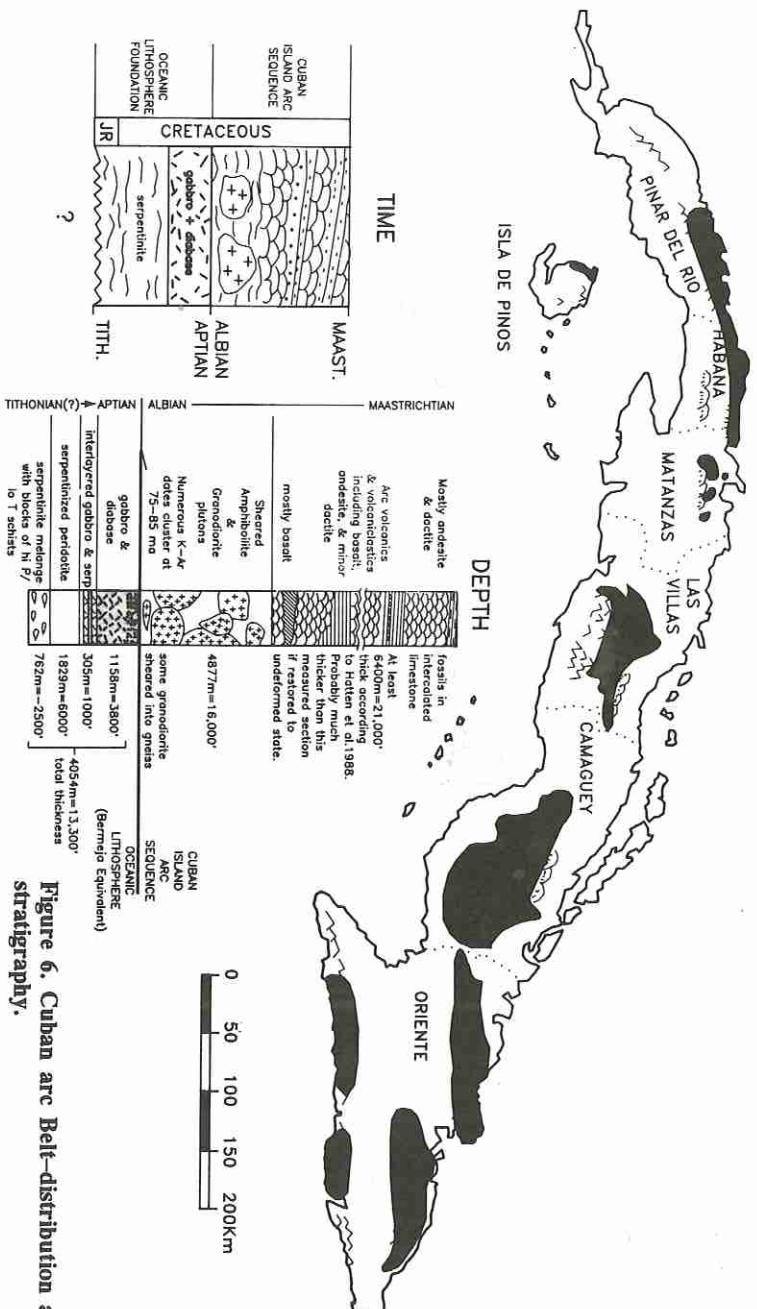
The major difference with the Placetas belt (and the single most unique feature of the Cifuentes belt) is that its sedimentary rocks overlie exposed crystalline basement. The Soviets have dated this basement as being 945+25 Ma and 910+25 Ma or “Grenville” age (Somin and Milian 1977). They dated (K-Ar) a phlogopite crystal from a piece of marble float intruded by granite or granodiorite. Although many Caribbean workers lack confidence in the Soviet age data, it has supposedly been duplicated by Polish workers (Mark Somin, personal communication via Charlie Hatten, 1986). Pardo (1954) reported observing inclusions of marble and other metamorphics in other granitoids in similar structural positions in central Cuba. Other K-Ar dates reported from the granitoids include 150 Ma, 139 Ma, and 140 Ma (Somin and Milian 1977), and 613 Ma (Khudooley and Meyerhoff 1971). However, it is possible that these ages

represent younger thermal events and not the true age of the granitoids. Controversy still broils about the true age of the granitoids (Hatten *et al.*, 1986). We do know that they are older than the Tithonian, based on the age of the overlying redbeds.

When compared to possible analogues, it is plausible that the granitoids are currently thrust-bounded slivers of basement that were originally basement highs bounded by normal faults in a rifting continental setting. Slivers of older basement rocks are common in other orogenic zones involving arc/margin collision (*e.g.*, the Puture Massif in southeastern Turkey (Hempton 1985); the Precambrian Jebel culminations in Oman (Searle 1985)). This hypothesis is supported by the presence of Tithonian redbeds overlying the basement complex. The redbeds argue for active rifting during the Latest Jurassic in the proto-Cifuentes area unlike pelagic and hemipelagic sedimentation in belts to the north. Thus, in the Tithonian, the proto-Cifuentes area was higher than areas to the north but subsided quickly in the Earliest Cretaceous based on the overlying Neocomian section.

#### CUBAN ARC BELT

The Cuban arc sequence (and its oceanic crust foundation) is exposed in large outcrops in every province of Cuba (Fig. 6). In central Cuba, these rocks are found south of the Cifuentes belt and overlie structural windows of metamorphosed margin sediments comprising the Southern Meta-



morphics belt. Arc sequence rocks have been studied extensively by Rutten (1936), Thiadens (1937), Pardo (1954), Wassall (1956), Hatten *et al.* (1958), Somin and Millan (1977), and Millan and Somin (1981).

In total, the arc sequence consists of at least 37,000 feet (10.3 km) of (from bottom to top) amphibolites, granodiorites, and volcanics and volcanoclastics of basalt, basaltic andesite, andesite, dacite, and possible rhyolite. According to Hatten *et al.* (1958, 1986), the basal 16,000 feet (4,877 m) consists of sheared amphibolite and granitoid plutons that they labeled the "Manicaragua Unit". The thickness of the unit is difficult to ascertain because of extreme shearing and probable structural repetition and elimination (this is true for all units within the arc sequence). Above the amphibolites and granitoids lies the thick (6,400 m = 21,000 feet) volcanic and volcanoclastic section. In general, it is composed of basaltic pillow lavas at the base. Toward the top, the volcanics are more silicic and grade through basaltic andesite to dacite and possibly rhyolite. Limestone intercations within tuffs yield Albian and Cenomanian fauna. Patch reefs found at the top of the section yield Campanian and Maastrichtian fauna (Hatten *et al.* 1958).

Based on the reported proportions of igneous rock types in this sequence and the apparent progression from basal basalt to andesite and dacite at the top, the assemblage is interpreted as the product of an island arc. According to the criteria of Miyashiro (1973, 1975), the arc was probably an ensimatic intraoceanic island arc similar to the Marianas arc in the Pacific Ocean. The basal amphibolite and granitoids

represent the sheared roots of the arc sequence. The protoliths of the amphibolites were basalts.

Isotopic age dating of the basal amphibolites and granitoids reported by Khudoley and Meyerhoff (1971), Millan and Somin (1981), Hatten *et al.* (1986), and P. Renne (Univ. of California Berkeley, personal communication, 1986) shows a modal range of 75-85 Ma. This is a cooling or alteration age range and is more representative of the last deformation episode than of the original formation. Preliminary  $87\text{Sr}/86\text{Sr}$  ratios from granitoids generated by Renne (personal communication, 1986) are 0.703, which support the notion that the arc sequence is intraoceanic and that its basal volcanics and granitoids represent the first products of the arc. If the fossil picks from the sequence can be trusted, then the arc began at least by the Albian and continued up to the Maastrichtian.

According to Hatten *et al.* (1958), a sequence of ultramafic and mafic rocks underlies the arc sequence and is at least 13,300 feet (4,054 m) thick. These "ophiolitic" sequences have been studied extensively by Fonsec *et al.* (1985). The ultramafics are mostly serpentinitized, and the lowermost exposures comprise a melange with blocks of high pressure/low temperature blueschists. The upper part of the sequence is composed of interlayered gabbro and serpentinite and, above that, gabbro and sheeted diabase. This sequence is interpreted as a segment of deformed oceanic lithosphere. If this hypothesis is correct, then this oceanic lithosphere (ophiolite) found in Cuba formed the

oceanic foundation upon which the arc sequence was generated.

A similar model has been proposed for analogous exposures in Puerto Rico. According to Hayes and Luttrell (1986) and Joyce *et al.* (1985), the Bermeja Complex of southwest Puerto Rico consists of serpentinitized peridotite, metatholeiite, and radiolarian cherts and forms the oceanic foundation for the overlying Cenomanian-Maastrichtian island arc sequence. The age of the oceanic complex is constrained by radiolarian picks as being between early Tithonian and late Aptian (Mattsson and Pessagno 1979; Montgomery *et al.* 1992). The arc exposures in Puerto Rico are similar to those of Cuba, and they were probably all part of the same intraoceanic arc system. Thus, the age of the basal oceanic sequence in Cuba may also range from Tithonian to Aptian, supporting the hypothesis that arc activity did not begin until the Albian. A Soviet/Cuban team, Fonsec *et al.* (1985), also "tentatively" date the ophiolite sequence as pre-Albian, although they do not base this conclusion on any "hard" data.

#### SOUTHERN METAMORPHICS BELT

The Southern Metamorphics belt is exposed in large discontinuous outcrops along the southern coast of Cuba and on the Isla de Pinos (Fig. 7). Although poorly studied by oil company geologists (Hatten *et al.* 1958; Pardo 1975),

they have received a fair amount of study from western academics (Thiadsen 1937; Hill 1959; and Renne, personal communication, 1986), and Soviet/Cuban teams, *e.g.*, Millan and Myczynski (1978) and Millan and Somin (1981). Many diverse ideas concerning the age and origin of these rocks have been proposed in the literature. Because of their metamorphic character, many authors have argued that these rocks are Paleozoic or older and equivalent to Paleozoic basement exposed in Central America (Tijomirov 1967; Dengo 1975). Thiadsen (1937) studied the Escambray exposure in central Cuba and suggested that lithologically the mica schists and marbles of the Escambray were similar to less deformed rocks in western Cuba that contained Late Jurassic and Early Cretaceous fossils. Thus, according to him the metamorphics were generated in post Early Cretaceous orogenic activity - a position supported by Furrazola *et al.* (1964).

In recent years, new light has been shed on the metamorphic character, age, and origin of the Southern Metamorphics belt by Millan, Somin, Hatten, Renne, and Cobella. The Escambray complex of central Cuba has received the most study. According to Millan and Somin (1981), it consists of at least three thrust slices composed predominantly of mica schist and marble exhibiting an inverted metamorphic grade from lower greenschist facies at the base to upper greenschist at the top. Millan and Somin (1981) suggest that

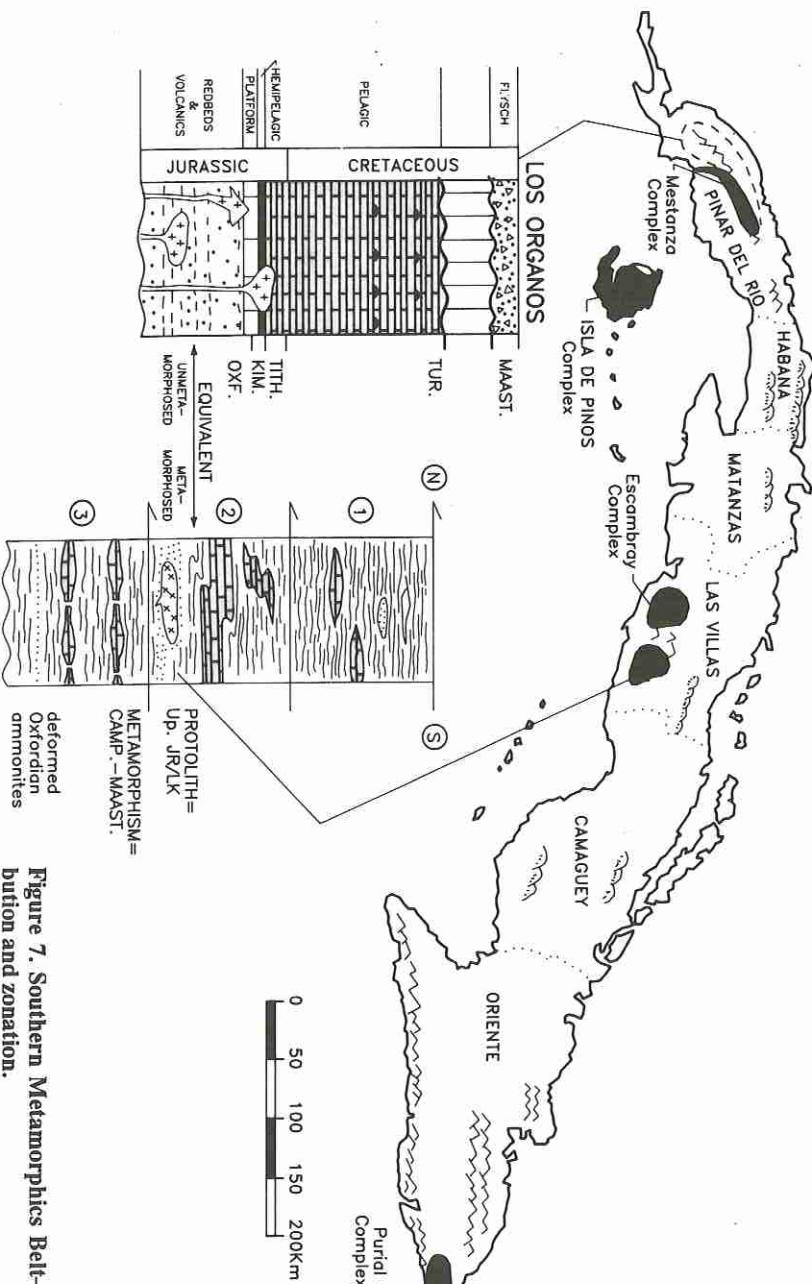


Figure 7. Southern Metamorphics Belt-district, deformed Oxfordian ammonites button and zonation.

these metamorphic facies indicate a metamorphic temperature and pressure of 550-600° C and 5.5-7.5 kbars, respectively. Such conditions are typically found at depths of 16-20 km, which shows how much uplift and erosion must have occurred to expose them at the present surface. Included within the micaschists and marbles are common sheared pods of metabasite (probably from basalts or gabbro) and greenschists of probable volcaniclastic origin. The lower greenschist section is very similar in character to the Mesianza metamorphics in western Cuba and the metamorphics on the Isla de Pinos (although more metapsamite is found there). Millan and Somin (1981) report the presence of middle Oxfordian and Tithonian ammonites in the metamorphics that are similar to those seen in western Cuba.

At the very top of the metamorphic section in the Escambray complex lie blueschist facies schists, eclogites, and tectonic slivers of serpentinite and amphibolite entrained during overthrusting of the overlying arc sequence. These rocks are particularly indicative of high pressure metamorphism as should be expected directly under an arc sequence in a subduction zone/french setting (Miyashiro, 1975). Hatten *et al.* (1986) used K-Ar techniques to date amphibole from a pre-eclogite facies metabasite and generated dates of 255+7 Ma and 247+20 Ma (late Permian). These rocks were probably originally part of Permian oceanic crust incorporated into North American crust during late Paleozoic orogeny and later subducted under the Cuban arc and caught up in its subduction/accretion complex.

The best explanation for the origin of the greenschist facies rocks involves much shearing and metamorphism of a margin sequence under the obducting arc complex. This metamorphism occurred at depths of 15-20 km. The obduction of the hot arc and its associated shearing explains the inverted metamorphic gradient. Analog metamorphic terranes are found along the northern margin of Arabia in the Bitlis/Zagros mountains. Hempton (1985) has shown that they were generated during the Campanian-Maastrichtian obduction of the circum-Arabian arc system. The high-pressure/low-temperature blueschist facies rocks such as eclogite, glaucophane, and lawsonite could probably develop either (1) before obduction within an accretionary/subduction complex in front of the arc, or, alternately, (2) during an early phase of obduction directly under the arc where high pressures and relatively low temperatures prevail (Dewey *et al.*, 1986).

Isotopic dating of metamorphic rocks reported by Khudoley and Meyerhoff (1971), Hatten *et al.* (1986), and Renne (personal communication, 1986) show a modal range of 65-70 Ma. Most of these dates were derived by the K-Ar technique in Soviet labs, so their reliability is suspect. However, similar ages are being obtained by Renne using the UC-Berkeley lab. The 65-70 Ma is interpreted as a cooling age (the age at which potassium-bearing minerals

cooled below the temperature of argon retentivity). The cooling age should reflect a slightly younger age than the age of metamorphism. The cooling age probably represents the age of uplift.

The proposed protolith of the greenschist facies rocks in western Cuba in the Los Organos zone consists of (from base to top) (1) redbeds and volcanics of the San Cayetano Formation ranging up to Oxfordian, (2) platform carbonates deposited during the late Oxfordian and early Kimmeridgian, (3) pelagic carbonates of Tithonian to Turonian age (with no Aptian-Cenomanian breccia or flysch as is common in other belts), (4) a major unconformity in place of the missing Coniacian-Campanian, and (5) Maastrichtian flysch. This section is different from that of the Cifuentes belt to the north in that it appears to have been shallow throughout its history. The redbed sequence is covered by platform carbonates as opposed to hemipelagic carbonates in the Cifuentes belt. The Cretaceous section is pelagic but lacks the fragmental limestones or turbidite accumulations of other belts as if it was too high (shallow) to receive those sediments. Mafic igneous rocks intrude the redbeds of the San Cayetano Formation as in other belts but also intrude the overlying Late Jurassic carbonates (Piotrowska 1976). Given these features, it is likely that the Los Organos area stood higher than surrounding areas somewhat like the proposed development for the Brianconais zone in the Alps (Lemoine and Trumpy 1987; Funk *et al.* 1987).

## SUMMARY OF MESOZOIC STRATIGRAPHY: EVOLUTION

The following sections present a tectonostratigraphic evolution of the margin. This summary focusses on the evolution in cross-section. A simplified map view of the scenario is presented in Figure 8.

### EARLY-MEDIAL JURASSIC Figure 9

Redbeds and associated bimodal volcanics indicate rift basins and stretched continental crust. These rocks are present in the northernmost belt (the Cayo Coco belt), and metamorphosed equivalents appear in the southernmost belt (the Southern Metamorphics belt). Hence, all Mesozoic stratigraphic units in Cuba are interpreted to have been deposited over stretched continental crust (with the exception of the Cuban arc terrain). The redbed basins are separated by high standing, fault-bounded basement blocks with no cover. Exactly how much lateral slip is accommodated by bounding faults is uncertain.

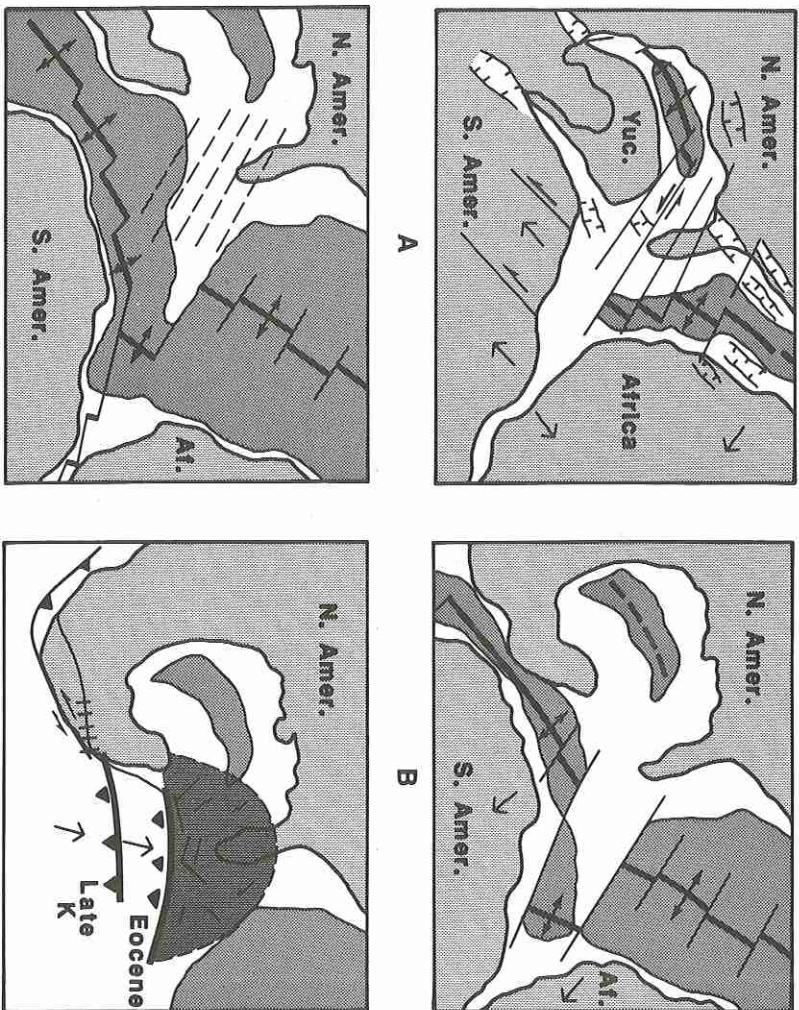


Figure 8. Simplified paleogeographic evolution of the Caribbean region. A, Triassic-Jurassic rifting and sea floor spreading. B, Early Cretaceous margin, subsidence equals source rock and reservoirs. C, Barremian-Aptian, reaction equals traps. D, Late Cretaceous-Eocene, Arc Margin collision equals traps and charge.

#### LATE JURASSIC

Figure 10

In the north, from the Las Villas belt to the Cayo Coco

belt, shallow-water carbonates overlie the redbeds to form a large platform. In the Latest Jurassic, the platform carbonates retreat to the Cayo Coco belt. In the Placetas belt, hemipelagic carbonates are deposited, while in the Cifuentes belt, redbeds are still accumulating. Farther to the south in the Los Organos (protoliths of the Southern Metamorphics belt), an initial platform carbonate sequence is followed abruptly by hemipelagic and pelagic carbonates. Basement highs in the Cifuentes and Placetas belts capped with platform carbonates are separated from the large platform to the north.

#### NEOCOMIAN

Figure 11

This phase is marked everywhere by pelagic carbonates except in the Cayo Coco belt where platform carbonates persist. Associated subsidence must have been very rapid because pelagic carbonates overlie (with sharp lower boundaries) Jurassic platform carbonates, hemipelagic carbonates, and even redbeds. This quick transition and rapid subsidence could be related to the onset of seafloor spread-

ing in the proto-Caribbean ocean (after seafloor spreading in the Gulf of Mexico died). If this hypothesis is correct, it suggests that seafloor spreading in the Gulf of Mexico had died by the end of the Jurassic.

#### BARREMIAN-ALBIAN

Figure 12

Everywhere in the Mesozoic of Cuba, the latest Barremian through Albian section contains rocks suggesting region-wide faulting. Carbonate fragments are derived from the Upper Jurassic to Lower Cretaceous carbonate sequences, while clastics emanate from exposed basement highs. Paleocurrents are from all directions and seem to reflect erosion and fault reactivation of all parts of the margin. Parts of the carbonate platform in the Cayo Coco belt subsided rapidly and are overlain abruptly by pelagic facies, whereas other parts emerged rapidly and are karstified. Meanwhile, to the south of the margin, southward subduction had begun under the Cuban island arc.

#### CENOMANIAN-SANTONIAN

Figure 13

The margin subsides, although not below the CCD (based on the presence of pelagic limestone in all parts of

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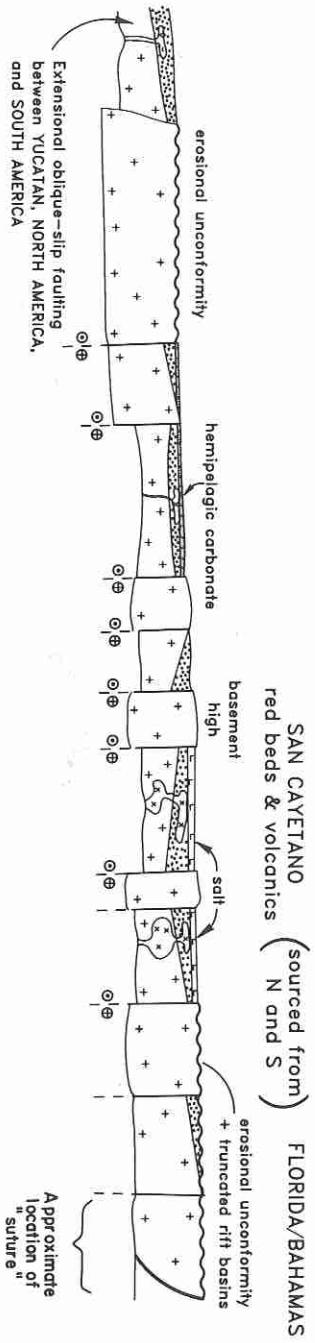


Figure 9. Tectonostratigraphy of the Early and Middle Jurassic. Wrenching-rifting between opening central Atlantic and Gulf of Mexico Basins.

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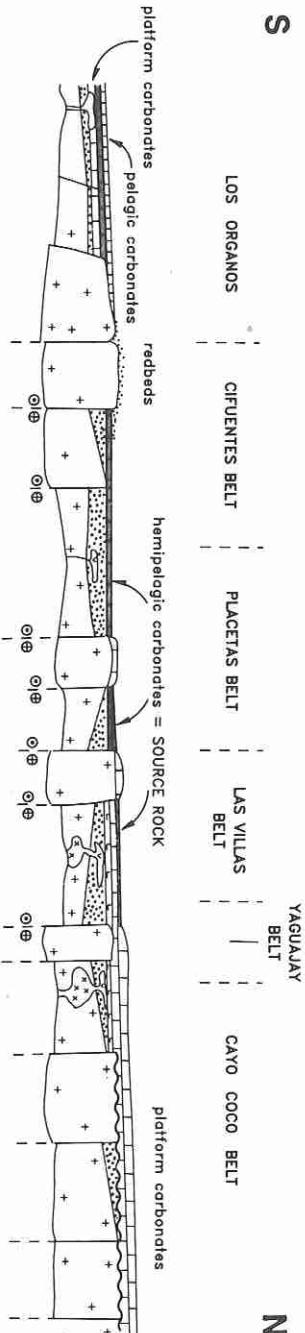


Figure 10. Tectonostratigraphy of the Late Jurassic. Transform zones dies, extension between North America, Yucatan and South America accelerates.

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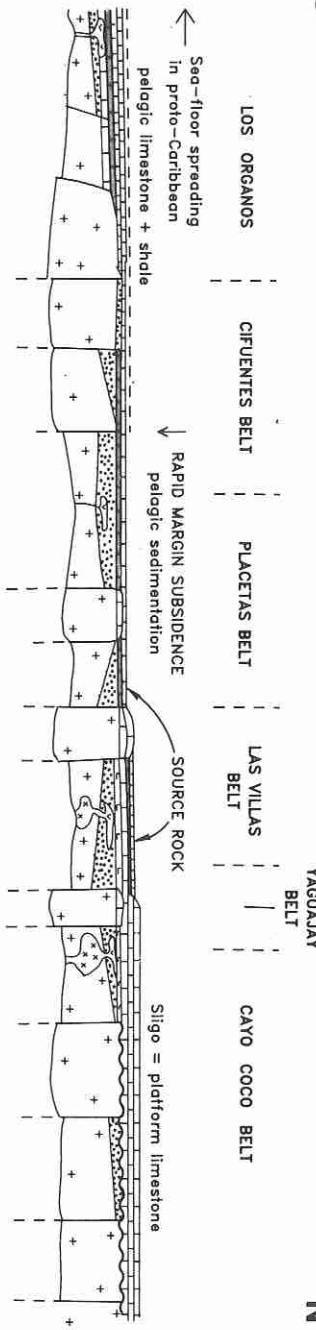


Figure 11. Tectonostratigraphy of the Neocononian. Margin subsides rapidly, pelagic sedimentation dominates, southern margin stretched by sea floor spreading in Proto-Caribbean Ocean.

the margin). Chalks are deposited on the platform to the north. In the south, arc-generated tufts probably from the northward-moving Cuban island arc accumulate along the deeper parts of the margin to form shales and cherts that intercalate with pelagic limestone.

#### CAMPANIAN-MAASTRICHTIAN

Figure 14 and 15

All belts contain an unconformity, above which lies Maastrichtian carbonate breccias and flysch. Below the

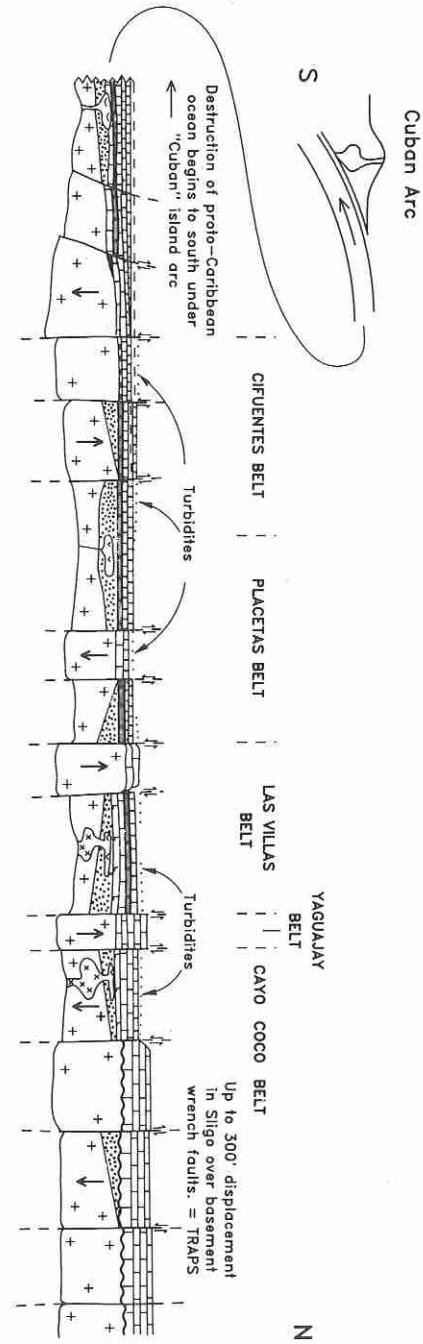


Figure 12. Tectonostratigraphy of the Barremian-Albian. Reactivation of basement wrench faults, new faults propagate into overlying section creating highs and lows at surface.

CUBAN ARC: moving to NE, consuming proto-Caribbean oceanic crust

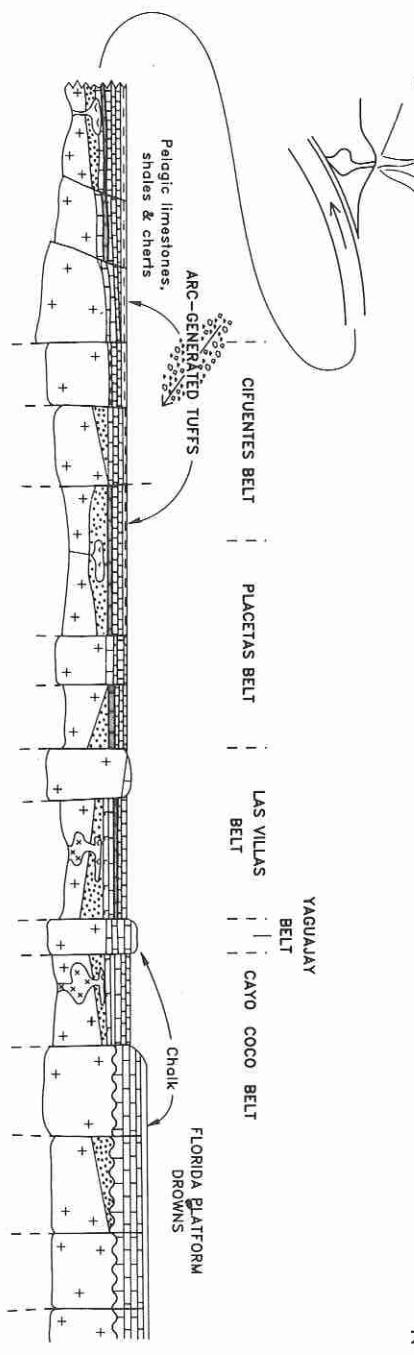


Figure 13. Tectonostratigraphy of the Cenomanian-Santonian. Margin subsides, chalk deposition over Florida platform, southern margin receives much tuff from Cuban arc, pelagic limestone deposited elsewhere.

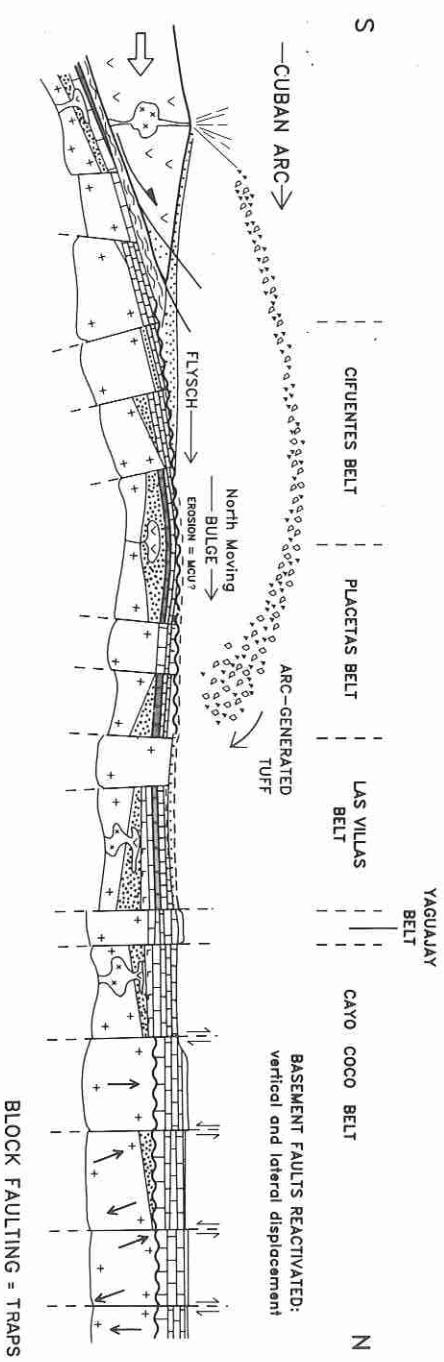
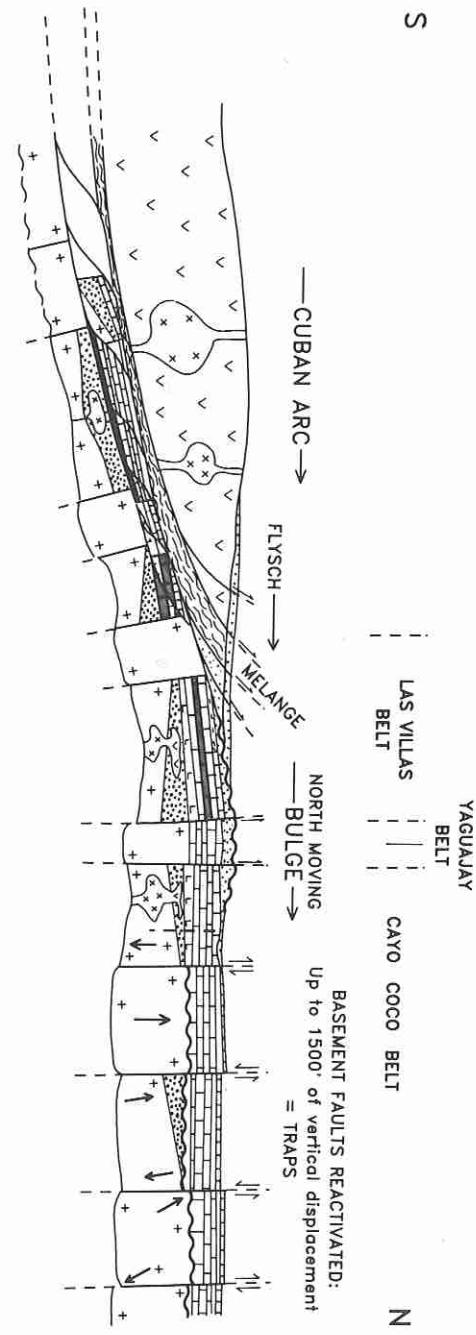


Figure 14. Tectonostratigraphy of the Campanian. Cuban arc collides with Florida-Bahamas margin resulting in reactivation of basement faults and much block faulting.



**Figure 15.** Tectonostratigraphy of the Maastrichtian. Cuban arc continues colliding with Florida-Bahamas margin, much deformation in foreland producing bulges, block faulting and wrench faults.

unconformity lie Turonian rocks in the south and Santonian rocks in the north. The Campanian is missing everywhere except in the Cuban arc rocks and limited exposures of Upper Campanian flysch in the Las Villas belt. Hence, the unconformity and associated erosion happened everywhere across the margin, supporting the notion of initial convergence of the arc with the margin in the Campanian-

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