CHAPTER 1. GEOLOGY AND GEOPHYSICS

(Capítulo 1. Geología y Geofísica)
INTRODUCTION TO CUBAN GEOLOGY AND TECTONICS (*)

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Abstract

Cuba is considered here to consist of two separate geological units: a foldbelt and a neoaucthoton.

The foldbelt can be subdivided into (i) continental units, comprising the Mesozoic Bahamian platform and slope deposits, which are overlain by a Paleocene-Late Eocene foreland basin; and the Cuban SW Terranes (Guaniguanico, Pinos and Escambray), which were probably originally attached to the Yucatan Platform; (ii) oceanic units, namely: the northern ophiolite belt, the Cretaceous (?Aptian-Campanian) volcanic arc, which is overlain by Late Cretaceous -- Late Eocene piggyback basins; and the Paleocene-Middle Eocene volcanic arc, overlain by a late Middle-latest Eocene piggyback basin.

The neoaucthon is composed of slightly-deformed, latest Eocene to Recent sedimentary rocks, that unconformably overlie the folded belt.

A large number of plate tectonic models for the Caribbean area have been published in recent years, but they rarely include modern data on the geology of Cuba.

The Iturralde-Vinent (1994) plate tectonic model for the western Caribbean, is presented here, which is based on the following premises: (i) opening of the Caribbean took place along several parallel rifts zones, and a main transform fault located between the entrance of the Gulf of Mexico and the Demara Plateau; (ii) the Cretaceous Greater Antilles volcanic arc faced the Proto-Caribbean sea, and essentially northward-dipping subduction took place; and (iii) the western Caribbean Paleocene-Middle Eocene volcanic arc also faced the Caribbean sea, with subduction dipping towards the N-NW.

Resumen

Cuba se considera aquí que consiste de dos elementos estructurales principales: el cinturón plegado y el neoauctóctono.

El cinturón plegado se subdivide en (i) Unidades continentales y (ii) Unidades oceánicas. Las Unidades continentales comprenden a su vez, la plataforma mesozoica de las Bahamas y los depósitos de sus taludes que están cubiertos por sedimentos del Paleoceno-Eoceno tardío propios de cuencas de antepais. Además incluyen los terrenos...
cubanos sudoccidentales (Guaniguanico, Pinos y Escambray) que originalmente pudieron pertenecer a la plataforma (bloque) de Yucatán. Las Unidades oceánicas son las ophiolitas y los arcos volcánicos del Creteácico (Aptiano-Campaniano) y del Paleoceno-Éoceno Medio. Estos se cubren por depósitos sedimentarios que abarcan desde el Campaniano tardío-Maastrichtiano hasta el Éoceno Superior.

El neoautoCTono está constituido por los sedimentos poco plegados del Éoceno Superior tardío al Reciente, que cubren discordantes todos los componentes del cinturón plegado.

INTRODUCTION

Considerable geological research has been carried out in Cuba during the last 25 years. Thousands of papers and several books have been published on the subject. Geological cartography includes a 1:250 000 scale map of the island prepared by the Academies of Sciences of Cuba, Hungary, Poland, Bulgaria, and the former Soviet Union (Kantchev et al., 1976, Iturralde-Vinent, Tchounev, Cabrera et al., 1981, Somin and Millán, 1981, Nagy et al., 1983, Albear et al., 1985, Pszczolkowski et al., 1987, Puscharovsky, 1988). Also 1:50 000 and 1:100 000 scale maps of approximately 70 % of the land areas were prepared by geologists from Cuba, Germany, Czechoslovakia, Hungary, and the former USSR.

This studies included geochemical, gravity, magnetic and seismic surveys both on- and offshore (see Nuevo Atlas Nacional de Cuba, Cuban Academy of Sciences, 1988). Many publications deal with the interpretation of the origin and evolution of Cuba, and include tectonic maps at various scales (Shein et al., 1985, Puscharovsky et al., 1989); while reports have been published on the geology and tectonics of the Caribbean realm, and these provide a framework in which to place Cuban geology (Dengo & Case 1990).

This paper is not only an overview of the geology of Cuba, but also presents a classification of the Cuban's tectonic units that will be used in this book. Furthermore, provides a review of the current status of Cuban geology and tectonics, together with brief remarks on the interpretation of western Caribbean origin and evolution.

The geological framework and structure of the Cuban archipelago is by far the most complex within the NW Caribbean. In general terms, two main structural levels can be recognized: the foldbelt and the neoautochthon. (Fig. 1).

The neoautochthon is composed of latest Eocene to Recent slightly deformed sediments, which have not been displaced since deposition. Study of the neoautochthon provides clues to the understanding of the evolution of the islands since the last major deformational episode that took place during the Mid- to early Late Eocene. Thus, the geology of the neoautochthon is in a sense the “real” geology of Cuba, but this is not true for the foldbelt. This is composed of Latest Triassic (?) to early Late Eocene, deformed and metamorphosed continental and oceanic terranes, whose original position and evolution are related not to the actual area of Cuba itself. Geological units in the foldbelt represent larger paleogeographic entities. Therefore, the geological history of the different terranes which compose the foldbelt is that of the western Caribbean realm, as a minimum.

THE CUBAN FOLDBELT

Several geotectonic elements can be recognized in this belt (Fig. 1), namely:

- (i) Continental elements (the Bahamas Platform and the SW Terranes); and
- (ii) Oceanic elements (the northern ophiolite belt; a Cretaceous island arc; and a Paleogene island arc).

The general geological composition of these units is illustrated in figure 2.
Figure 1. Schematic geologic maps of Cuba. The outcrops of the foldbelt are distinguished with different patterns. The Latest Eocene to Recent neoautochthonous deposits are mapped in figure A.
Continental Units

The Bahamas platform

The Bahamas platform belongs to the Florida Strait Block (Pindell 1985) and crops out along the northern half of Cuba (Fig. 3). Within the platform, shallow-water carbonates and evaporites are dominant, but deep-water carbonates and cherts (channel facies) are also present. The platform is surrounded by deep-water carbonates, shales and cherts, representing the slope and deep-basinal environments. Representatives of all these lithologies can be found in Cuba (Fig. 4).

Basement rocks of the Florida Strait Block crop out in Cuba in several localities within the Placetas belt. It is represented by Grenville-age marbles and metasiliciclastics, intruded by small granitic bodies of Mid Jurassic U-Pb 172.4 Ma (Socorro Complex; Fig. 4 and 5; Somin and Millán, 1981, Millán and Somin 1985b). This basement is covered by arkosic paleosol and Late Tithonian-Early Cretaceous carbonates and siliciclastics.

Sialic basement is also found offshore NW Cuba (DSDP sites 537 and 538) and is composed of Cambrian-Ordovician phyllites, gneisses and amphibolites intruded by Lower-Middle Jurassic diabase dikes, covered by Lower Cretaceous sediments (Buffler, Schlager et al., 1984).

The southern part of the Bahamas platform, as it crops out in Cuba, have been subdivided in facies belts or structural-facies units with different names and involving different rock volumes. Khudoley and Meyerhoff (1971) and Lewis and Draper (1990) have summarized these different classification. Nevertheless, in the Cuban literature of the last twenty years five principal stratigraphic successions have been recognized in North Central Cuba based on lithostratigraphy and facies developments. These successions crop out as sub-parallel belts between Matanzas and Holguin and are named, from NE to SW: Canal Viejo de Bahama, Cayo Coco, Remedios, Camajuaní and Placetas (Fig. 4). They were originally studied in Central Cuba where most of the belts crop out (Fig. 5). The first three represent Bahamas platform carbonate facies; the Camajuaní Belt represents slope deposits; and the Placetas Belt the deep-water basinal environment (Ducloz and Vuagnat, 1962; Hatten, 1967, Hatten et al. 1988; Khudoley, 1967; Meyerhoff and Hatten, 1968; 1974; Khudoley and Meyerhoff, 1971; Pardo, 1975; Diaz and Iturralde-Vinent, 1981; Iturralde-Vinent and Roque Marrero, 1982a; b; Roque Marrero and Iturralde-Vinent, 1987; Pushcharovsky, 1988; Albear et al., 1985; Pushcharovsky et al., 1989).

The Canal Viejo de Bahama, Cayo Coco and Remedios belts have a common pre-Aptian siliciclastic-evaporite-carbonate section. Latest Triassic ?-Early Oxfordian ? siliciclastic rocks have been recognized on seismic lines (Schlager et al., 1984,; Ball et al., 1985) and outcrop as small fragments within the San Adrián, Punta Alegre and Turiguano evaporite breccias (Meyerhoff and Hatten, 1968; Pardo, 1975). These evaporites have been drilled in several deep, exploratory wells in Cuba and outcrop in the above mentioned localities. Their age is controversial, but an Oxfordian-Kimmeridgian age is suggested by their stratigraphic position. Overlying these saline deposits are Late Kimmeridgian ?-Early Aptian dolomites and evaporites, with the dolomites increasingly dominating the uppermost part of the section (Furrazola et al., 1964; Meyerhoff and Hatten, 1968; 1974; Iturralde-Vinent and Roque Marrero, 1982a; Roque Marrero and Iturralde-Vinent, 1987).

Aptian-Maastrichtian sections are different in each belt. In the Canal Viejo de Bahamas Belt, the section is represented by thick (4000 m) shallow-water dolomites and limestones which are slightly deformed, as interpreted by seismic surveys and deep, exploratory drilling (Khudoley and Meyerhoff, 1971; Walles, 1993). The Cayo Coco Belt characteristically presents a few hundred meters of Late Aptian-Turonian moderately deep-water limestones with cherts (lenses and rounded concretions). The Maastrichtian section is represented by deep-water limestones and calcirudites. Fossils of Coniacian-Campanian age have not been identified, so a hiatus is probably present.

Some reverse faulting and folding is evident. North of the Canal Viejo de Bahamas Belt, some Cayo Coco equivalent sections have been recognized on seismic sections (Fig. 3; Ball et al., 1985).
Figure 2. Tectonostratigraphic sequences of the Cuban foldbelt.
Figure 3. Facial map for the Mid Cretaceous marine environments of the Bahamian platform and slope deposits.
The Remedios Belt represents the southern edge of the Cretaceous Bahamian platform. The section is composed of about 2000 meters of Aptian through Maastrichtian shallow-water limestones and some dolomites, with a hiatus within the Turonian-Coniacian. The belt is strongly deformed with thrust and reverse faulting (Meyerhoff and Hatten, 1968; 1974; Pardo, 1975; Díaz and Iturralde-Vincent, 1981; Iturralde-Vincent, 1981; Iturralde-Vincent and Roque Marrero, 1987). To the NW, the belt was probably represented by isolated carbonate banks similar to the Pinar del Río knoll (Schlager et al., 1984), parallel with the Florida escarpment.

Figure 4. Generalized stratigraphic columns of the Mesozoic Bahamian platform and slope deposits. Formational names commonly used in Cuban geological reports. Outcrops shown in figure 2.
Figure 5. Generalized map and cross section of Central Cuba.
To the SW of the Bahamian Cretaceous Platform edge are the slope deposits of the Camajuani Belt (Figs. 3 and 4). In Central Cuba, Kimmeridgian shallow-water limestones have tentatively been identified (Pardo 1975), but westward (in Matanzas province), deep-water equivalents are well known in exploratory wells (S. Blanco, pers. com., 1991). Tithonian-Turonian and Maastrichtian deep-water limestones, shales and calcareous clastic beds, up to 1,500-meters thick, are the most common deposits of the Camajuani Belt. The whole belt is strongly deformed and thrusted, but also strike-slip faulting is recognized along its trend (Ducloz and Vuagnat, 1962; Khudoley, 1967; Meyerhoff and Hatten, 1968; Pardo, 1975). Indirect evidence suggests that the belt originally developed on thin, transitional crust.

The Placetas Belt sequence is located further south and SW and represents a deep-water, basinal sequence that changes laterally along the trend (Figs. 4 and 5). Sialic basement crops out within the belt suggesting that it was originally developed on thin (rifted) transitional crust. Early-Middle Tithonian extrusive tholeiites are present in east-central Cuba (Iturralde-Vinent and Marí, 1988) while pre-Tithonian arkosic paleosoils are found overlying basement rocks in west-central Cuba (Pardo, 1975; Pszczolkowski, 1986b). Tithonian-Turonian deep-water limestones, shales, siliciclastic sandstones and clays, with some calcarenaceous beds, 1,000-meters thick, are present in this section. Maastrichtian deposits include an unusually thick calcareous megaturbidite overlain by deep-water limestones. The whole belt is strongly deformed and thrusted. Sinistral wrench faulting is also evident (Rigassi-Studer, 1961; Ducloz and Vuagnat, 1962; Hatten, 1967; Meyerhoff and Hatten, 1968; Pardo, 1975; Iturralde-Vinent, 1981). The Placetas Belt is roughly a facies equivalent of the Rosario Belts in western Cuba (Pszczolkowski, 1987) and is also a Caribbean facies equivalent of the Gulf of Mexico deep-water section (Fig. 3).

After the Maastrichtian, a new tectonic regime affected the territory south of the Canal Viejo de Bahamas belt (Fig. 3). The carbonate platform was replaced by a foreland basin and Paleocene-early Upper Eocene deposits are mostly olistostromic and flyschoid rocks. Clastic materials have a bimodal composition. They are partially derived from local carbonates and shales but, upwards in the section, an increased proportion of exotic clastics, derived from ophiolites and the Cretaceous volcanic arc, are present. The exotic clastics are found within the Placetas Belt from the Maastrichtian-Paleocene onward and from the Middle to Late Eocene in the Remedios Belt. They are not found within the Cayo Coco or northern Belts. This pattern of distribution of the exotic clastics is in agreement with the northeast-ward movement of the allochthonous ophiolites and volcanic thrust sheets.

As the allochthon approached the southern edge of the foreland basin by latest Cretaceous it provided the source for exotic debris. While it moved NE during Paleocene-latest Eocene the source was displaced toward the platform edge. Thus, the whole basin is strongly deformed but the degree of deformation is reduced towards the platform (Meyerhoff and Hatten, 1968; Pardo, 1975; Iturralde-Vinent, 1981; 1988b; see also geologic and tectonic maps: Pushcharovsky, 1988; Pushcharovsky et al., 1989; Nuevo Atlas Nacional de Cuba, 1988).

A geological cross section north of Havana illustrate the position of the foreland deposits on top and in the front of each thrust sheet (Fig. 6). According to Rigassi (1961) and Iturralde-Vinent (1981) the structure of the hinge zone between the Bahamian margin and the northern ophiolites was additionally complicated by NW-SE trending sinistral strike-slip fault movements during the Eocene.

Asunción Massive

A Bahamian-equivalent outcrop is the Asunción Massive located in eastern Cuba (Figs. 1 and 4). It is composed of low degree high-P metamorphosed Late Jurassic-Early Cretaceous dolomites, limestones and shales associated with shales and arenites (Millán and Somin, 1985a; b). These rocks are quite similar to those present at the Samaná Peninsula in Hispaniola. The unusually large volume of fine clastic material in the Placetas Belt, Asunción Massive and Samana Peninsula may be sourced from uplifted terranes in South America (See Fig. 18; also Ross and Scotese, 1988; Pindell and Barrett, 1990).
Southwestern Cuban Terranes

Composite terranes crop out in three localities in southwestern Cuba: Guaniguanico, Pinos (Isle of Youth) and Escambray (Figs. 1, 2). The lithostratigraphy of these terranes is very complicated, with different types of sections mixed together, strongly deformed and metamorphosed. The most widespread rocks are Mesozoic continental margin deposits present in all three terranes with many similar characteristics. Ophiolite rocks (serpentinites, gabbroids, diabases and basalts) are present on thrust planes in Guaniguanico and Escambray, and in the later, showing high-P metamorphism. Volcanic sequences have been described in both Escambray and Guaniguanico, as will be discussed later.

The Guaniguanico Terrane present in western Cuba (Fig. 1), is a generally low to very low grade metamorphic massive with locally developed high-P metamorphic rocks (Cangre Belt) along the trend of the Pinar fault. Several sequences, differentiated according to lithostratigraphy and facies development, crop out in juxtaposed belts: Los Organos, Rosario South, Rosario North, Quinones and Felicidades (Fig 7).

In the Los Organos and both Rosario Belts the ?Lower Jurassic to early Oxfordian section is composed of siliciclastic deposits of deltaic, paralic and local shallow-marine environments. No evaporites have been recorded.

This is overlain by middle to late Oxfordian shallow-water conglomerates, sandstones, shales and limestones. Tholeiitic rocks are intercalated at different levels, but a thick, middle Oxfordian to early Kimmeridgian unit of tholeiitic extrusives, interbedded with shales and limestones, is present within the Rosario North belt (Pszczolkowski, 1987; 1989; personal communication 1992; Iturrade-Vinent, 1988c).

The Kimmeridgian and younger sections in the Los Organos and Rosario Belts are more differentiated. In Los Organos, a Late Oxfordian-Early Tithonian carbonate platform sequence is present whereas basinl carbonate and basalts of the same age are developed in both Rosario Belts.

Since Late Tithonian, deep-water limestones and cherts are found in all three belts. Shales and siliciclastic sandstones are common in both Rosario Cretaceous sections, but are not present in Los Organos. A thick unit of Albian-Cenomanian deep-water cherts is present only locally in Los Organos but is common in the Rosario and Felicidades Belts. It has a lithological and age-equivalent unit in the Placetas Belt of the Bahamian continental rise deposits.

The Quinones Belt is deformed and the section is difficult to restore. It is probable composed of Latest Jurassic to Early Cretaceous basinl deposits and a thick Albian-Cenomanian carbonate platform section (named Guajaibón).
Paleocene deposits are deep-water limestones with occasional breccia at the base. Paleocene limestones are thick and widespread in the Los Organos units, but pinch out toward the Rosario North and Quíones belts. On the other hand, synorogenic Lower to Middle Eocene deposits are fine clastics with a thick olistostromic unit at the top. The olistostromic beds dominate the section in Rosario North and Quíones belts. Allochthonous clastics in the olistostromes are mainly serpentinites, including some serpentinite slices. Small amount of coarse grained debris derived from the Cretaceous volcanic arc is present only in the Quíones and Felicidades Belts. In Los Organos Belt the volcanic-derived debris is sparse and of fine grain. This pattern of deposition is in agreement with the tectonic model presented herewith (Fig. 7 cross section and Fig. 8).

The thicker carbonate section with thinner synorogenic deposits is interpreted as a distal element in the foreland basin; while the thinner or null carbonate sedimentation with thicker synorogenic beds is interpreted here as a proximal element within the foreland basin (Fig. 8).

The presence of coarser clastic material derived from the volcanic arc mostly at the Quíones and Felicidades belts suggest that the source rocks (the allochthonous volcanic arc unit: Bahía Honda) approaches the basin from an original position closer to the Quíones Belt.

In consequence, one can conclude that as north-northwestward thrusting of the ophiolites and volcanics took place (Hatten, 1957; Pszczolkowski et al., 1987), the original sedimentary pattern of the foreland basin was tectonically reversed, due to detachment and thrusting of the underlying (Guaniguanico) sequences.

The structure of the Guaniguanico Terrane, as illustrated in figure 7, is also a consequence of the fact that thrusting took place toward the Gulf of Mexico basin, far from the Florida scarpment. In the given conditions, there was not any important structural barrier, and the tectonic sheets moving north and northwestward override the previous one. Therefore, each sheet reached a farthest position to the north than the previous.

A general hiatus (and uplift) spans the Coniacian, Santonian and Campanian in Los Organos and Rosario South Belts, but Campanian polymictic clastic rocks are found in Rosario North and Quíones (Pszczolkowski et al., 1987). The existence of this hiatus was confirmed by detailed sampling and paleontological studies in the type section of the Upper Cretaceous in Los Organos by S. Bianco, J. Fernández and the author. This hiatus was not recognized by Pszczolkowski et al. (1987). Maastrichtian rocks are deep-water carbonates and cherts in Los Organos, but elsewhere are represented by a thick calcarenaceous megaturbidite (Pszczolkowski 1986a).

The northernmost belt of Guaniguanico terrane is the Felicidades Belt (Figs. 2 and 7) which is composed of a thick sequence of Aptian-Albian to Turonian tholeiitic pillow basalts, hyaloclastites and tuffs, intercalated with limestones, cherts and sandstones. Campanian radiolarian cherts were recently found by the Author. There are also occasional isolated outcrops of serpentinites and gabbroids. The sedimentary rocks strongly resemble those of the Rosario Belts which implies that the Felicidades Belt can be interpreted as an oceanic basin that was juxtaposed to the Guaniguanico continental margin (Iturralde-Vinent, 1989).

The Guaniguanico is a north-northwestward-thrust terrane composed of a number of juxtaposed and partially superimposed belts (Hatten, 1957). During thrusting, the relative position of the belts was completely reversed so that those which are presently to the N were originally located farthest to the S and SW. This conclusion is based firstly on the actual position of the belts, as the structurally highest in the tectonic pile are those which yield the more allochthonous sections (Ophiolites and Cretaceous volcanics). Secondly, the interpretation is based on the inverted position of the folds on some northern units (Rosario belts), what means that these tectonic sheets are diving northeastward in the tectonic pyle. And third and very important, the concept is based on the composition of the Paleocene-Lower to Middle Eocene synorogenic deposits as will be explained below (field observations by R. Graham, J. Hurst, R. Buffer, P. Mann, G. Marton and M. Iturralde-Vinent, 1990).
Figure 7. Generalized geological map and cross section of western Cuba, showing present day position of the main stratigraphic sequences in the Guaniguanico Terrane.
Figure 8. Stratigraphic framework of the early Tertiary sediments of the Guaniquanico terrane and schematic evolutionary cross sections of the foreland (foredeep) basin. Note the tectonic inversion of the original framework of the basin. Explanation in text.
Probably deformation of the Guaniguanico terrane took place in several stages, as illustrated in Figure 8.

- First, a thin ophiolitic "exotic" thrust sheet reached the foreland basin and slid down mixed with the olistostromic unit.

- Second, the Guaniguanico foreland was compressed and strongly deformed and NW-ward thrusting reversed the original position of the belts. It means that the Felicidades, Quinones and Rosario units, originally in the south, were thrust on top of the Los Organos. Contemporaneously, the Bahia Honda allochthon was structurally emplaced on top of the tectonic pile.

- The final stage of deformation was probably the domal uplift of the whole terrane. This deformation folded the thrust planes so now Guaniguanico Terrane looks like a large brachicline (Fig. 7).

The Escambray Terrane is a high-P metamorphic massive with inverted zonal metamorphism (Somin and Millán, 1976; 1981; Millán and Myczyński, 1978; Millán and Somin, 1985a; Mossakovsky et al, 1986). It outcrops as two cupular uplifts in southcentral Cuba (Fig. 5). The terrane, despite the strong transformation of the rocks, includes stratigraphic sections remarkably similar to those of the Los Organos Belt, but without the Latest Cretaceous or younger rocks (Fig. 2). A metaflyschoid Cretaceous sequence together with some metasiliciclastic and metacarbonate sections may be identified as Rosario Belts partial equivalents. Some Cretaceous metavolcanics (Yaguanabo volcanics) locally developed may be a Felicidades Belt equivalent. High-P metaophiolites are found within fault planes as in Guaniguanico Terrane, and can be interpreted as fragments of the oceanic crust in a forearc area (Figs. 2 and 5).

In general, the Escambray is a structurally complex terrane that shows several stages of complex folding and thrusting previous to and during metamorphism (Fig. 9). The thrusting, according to Dublán, Álvarez Sanchez et al. (1986) is directed generally southward, as was predicted by Iturralde-Vinent (1981). The age of the last metamorphic event suggested by K-Ar dating and geological observations is pre-Maastrichtian latest Cretaceous (Somin and Millán, 1981; Hatten et al., 1988) and can be related to the underthrusting of the terrane into the subduction zone (i.e. under the volcanic arc).

The Pinos Terrane outcrops as the Isle of Youth (Fig. 1). The terrane includes Jurassic-Cretaceous metasiliciclastics with marbles and a few amphibolites (probably mafic magmatic rocks) intercalations mostly at the top of the section (Millán, 1975; Figs 1 and 2). It is, in general, similar to the Jurassic-Early Cretaceous section of the Los Organos Belt of the Guaniguanico and Escambray terranes, but with a larger proportion of clastics. The massive underwent Late Cretaceous mid-P/mid-T barrovian metamorphism and displays a cupular structure with a granitic? core (Pardo 1990). The Sabana Grande zone, located NW in the Isle of Youth (Fig. 1) is an allochthonous Cretaceous volcanic arc section partially metamorphosed in low degree High-T conditions (Somin and Millán, 1981, see also Chapter 3).

The orientation of the internal structure of the SW Cuban terranes is different. Guaniguanico has a NE-SW trend; Pinos a NW-SE trend and Escambray E-W (Pushcharovsky et al., 1989). These differences in the structural trends, generally diverse from the trend of the surroundings terranes as well, indicate that they have rotated during their emplacement. Therefore, the actual position of these terranes in a general NW to SE zone (Fig. 1, Pardo 1990) is most probably a consequence of the mechanism by which they were emplaced, and has little to do with the original position of these units.

The stratigraphical similarities of some Jurassic Pinos, Guaniguanico and Escambray sequences indicate that these terranes belong to the same paleogeographic realm as have been discussed by many authors (Millán, 1975; Somin and Millán, 1981; Iturralde-Vinent, 1988c, Pushcharovsky et al. 1989). The original position of these terranes has been a matter of debate. Some authors believe that they have always been attached to the Bahamian
Platform (Khudoley & Meyerhoff 1971, Shein et al. 1985, etc).

Others consider these terranes to be allochthonous (Iturralde-Vinent, 1981, 1988b, c, Pushcharovsky, 1988; Pushcharovsky et al., 1989).

- First because there are very few similarities between the stratigraphy of the Bahamas Platform and the Cuban SW Terranes (Fig. 2).

- Second, because the paleogeographic reconstruction of the Guaniguanico Terrane suggests that between Guaniguanico and the Florida escarpment there was a deep water basin, at least since Late Jurassic, so there was a gap (probably with oceanic and thin transitional crust) between the Guaniguanico and Bahamas-Florida scarpment (Fig. 3; Schlager et al. 1984).

- Third, because an important ancient fault suture trending between the Guaniguanico Terrane and the Bahamas is located at the southeastern Gulf of Mexico (Marton and Buffler 1992).

Pushcharovsky et al. (1989) suggested that Guaniguanico, Pinos and Escambray were originally part of northern South America. Theoretically this is possible, but in this case, is difficult to explain how these terranes reach the present position.

An alternate possibility for the original position of these terranes is the Caribbean borderland of the Yucatan block. This idea is not new, as it has been suggested that the Guaniguanico Terrane was originally located near the NE edge of the Yucatan Platform (Pszczolkowski, 1987; Ross and Scotese, 1988; Rosencrantz, 1990, in this chapter; Bartok 1993, Iturralde-Vinent 1994).

Figure 9. Generalized cross section of Southcentral Cuba showing a model of the tectonic position and internal structure of the Escambray Terrane. After H. Alvarez Sánchez (Personal communication 1993), simplified.
Therefore, since the Escambray, Pinos and Guaniguanico terranes have strong stratigraphical similarities, they are probable a single tectonic entity as suggested by the geophysical interpretation (Pardo 1990), and were originally part of the same paleogeographic unit (Somin and Millán, 1981; Pszczolkowski, 1987), it may be suggested that all of these terranes belongs to the eastern margin of the Yucatan Platform (Iturralde-Vinent, 1988c, 1994).

**Oceanic Elements**

**The Northern ophiolitic melange**

An allochthonous ophiolitic melange occurs in the northern half of the country and has been thrust north- and northeastward into the foreland basins (i.e. the Guaniguanico and Bahamas Platform; Figs. 1 and 2). The ophiolites are composed of two major elements. The melanocratic basement composed of ultramafic and mafic igneous rocks of latest Triassic (?) to Lower Cretaceous age, and the oceanic complexes composed of Hauterivian-Turonian tholeiites interbedded with radiolarites, limestones and shales (Iturralde-Vinent, 1989). This volcano-sedimentary section has been identified as backarc-marginal sea deposits because they are isochronous with the volcanic arc section and were laid down in a differen basin (Iturralde-Vinent, 1988a). Large metaflyschoid blocks are present within the ophiolitic melange (Somin and Millán, 1981) and may also be interpreted as backarc-marginal sea deposits.

The northern ophiolite melange has a complex tectonic position which varies in different parts of the country. In western Cuba, the Cajalbana ophiolites are a rootless, northward dipping subhorizontal sheet, one-to-two km thick, resting on the Guaniguanico Terrane (Fig. 7).

In Central Cuba, the S-SW dipping melange overlies the Bahamas margin and comprises a sub-horizontal to vertical dismembered tectonised sheet up to five or six km thick which dips steeply to the south (Knipper & Cabrera 1974). According to the interpretation of Bush and Sherbacova (1984) the ophiolitic melange is rooted into a deep fault that they named "Cuban Axial fault" as illustrated in Figure 10.

In eastern Cuba, the ophiolite thrust-sheet is up to one km thick and rests subhorizontally on Cretaceous backarc volcanoclastics (Fig. 11; Knipper and Cabrera, 1974; Fonseca et al., 1984; Bush and Sherbacova, 1986; Iturralde-Vinent, 1989, 1994; Pushcharovsky, 1988; Pushcharovsky et al., 1989; Andó et al., 1989).

![Figure 10. Deep geophysical structure of the Cuban foldbelt according to Bush and Sherbacova (1984). Bold values are density \( \text{[g/cm}^3\] }\) and \( \text{(y) velocity [m/ sec]}\) of the seismic waves. Location roughly as cross section 12 in figure 1.](image-url)
The Northern Ophiolites, in general, are interpreted here as a deformed Mesozoic marginal sea -- back arc basin. This will be discussed later in more detail.

The Cretaceous island-arc

Cretaceous island-arc rocks are widely present in Cuba (Fig. 1). The basement of the arc is a pre-Aptian oceanic crust that can be recognised in parts of Central and Eastern Cuba and is represented by amphibolitic ophiolites of the Mabujina and Guira de Jauco complexes (Somin and Milán, 1981; Iturralde-Vinent, 1989). These ophiolites may theoretically be as old as the early proto-Caribbean crust (i.e. Jurassic) as Oxfordian and older continental margin basalts have been reported in the circum-Caribbean area (Bartok et al., 1985; Iturralde-Vinent, 1988c). Part of the arc’s oceanic basement may also be metadiabases (spilitic rocks) found in deep, exploratory wells (Vegas and Mercedes, Fig. 1) south of La Habana and Matanzas Provinces (Somin and Milán 1981) unconformably underlying the volcanic arc section and the ophiolites in the Mabujina amphibolites.

The island-arc (Fig. 2) is composed of extrusive and volcanoclastics of Aptian (?) to late-Campanian age with typical tholeiitic to calc-alkaline and alkaline composition (Meyerhoff and Hatten, 1968; Khudoley and Meyerhoff, 1971; Iturralde-Vinent 1976-77; Pardo, 1975; Cobiella et al., 1977; Nagy et al., 1983; Albear et al., 1985; Díaz de Villavilta and Diia, 1985; Talavera et al., 1985; Tchounev et al., 1986; Pszczolkowski et al., 1987; Kozák et al., 1988; Iturralde-Vinent, Wolf and Thieke, 1989).

Some areas of the Ophiolite melange in north central Cuba (i.e. Iguaré-Perea; Figs. 1 and 5) have cummulative gabbroids and sheeted diabase dikes, metamorphosed in high-T amphibolitic facies (Somin and Milán 1981, Pushcharovsky 1988). Associated with the ophiolites are small intrusive bodies geochemically of the volcanic-arc type (Fig. 5; Eguipko et al., 1984; Milán and Somin, 1985b). The K-Ar ages of these rocks are latest Cretaceous-early Paleogene which probably dates later tectonic events (Millán and Somin, 1985b).

Figure 11. Generalized geological map and cross section of Eastern Cuba.
These outcrops can be understood in different ways. Somin and Millán (1981) proposed that these granitoids are the roots of a partially eroded Early Cretaceous remnant arc, because they are developed within the ophiolites north of the axial part of the Cretaceous arc (Fig. 5). Another point that favor this interpretation, is the fact that the ophiolites include Hauterivian-Turonian oceanic tholeiites and sediments, which are not intruded by granitoid bodies. These tholeiites are geochemically different from those of the volcanic arc (Fonseca et al., 1990, Iturralde-Vinent Chapter 2) and are age-equivalents of the active volcanic arc section.

Three main areas can be identified within the Cretaceous volcanic arc (Fig. 1):

- (i) to the north, a pyroclastic and sedimentary basin which here is interpreted as deposited in the backarc basin and outcrops in the Bahia Honda, La Habana, Matanzas, Central Cuba, Holguín and Mayari-Baracoa. The Albian-Cenomanian section are isolated basalts interbedded with tuffs, tuffites and sandstones. The Turonian to Campanian rocks are tuffs, tuffites, sandstones and limestones with few interbedded andesite-dacitic flows.

- (ii) further south is an area where extrusives and plutonic bodies are more common which probably represents the axial portion of the arc; this is present in the Isla de Youth (Sabana Grande zone), south-central and SE Cuba (Purial Complex). These are Aptian (?)-Albian basalts and andesite-basalts with agglomerates and tuffs. They are overlain by Late Albian to Turonian tuffs, tuffites, limestones and andesite-dacitic rocks. The Santonian-Campanian section are dacites and rhyolites with few basalts interbedded with tuffs, tuffites, sandstones and limestones. These rocks are intruded and metamorphosed by extensive plutonic bodies.

- (iii) the third region, known only in SE Cuba (Turquino: Fig. 1), is composed of Albian (?)-Turonian deep-water, fine-grained sediments mixed with chaotic volcanoclastics and tuffs which can be interpreted as trench-slope (fore-arc) deposits.

Two main unconformities (with hiatus) are present within the volcanic sequences: one within the Albian and another of Coniacian-Santonian age. The Albian unconformity is probably coincidental with the end of the evolution of the remnant arc, as late Albian basal conglomerates contain abundant reworked volcanics and plutonic arc-related rocks. The Coniacian-Santonian unconformity is related locally with a basal conglomerate, and represent also a change in the geochemistry of the magmas, from dominantly andesitic to dominantly dacitic and rhyolitic. These unconformities separate the volcanic sequence into three levels: the Aptian (?)-Albian section that yield primitive arc geochemical characteristics, the late Albian-Turonian section of calc-alkaline character, and the Santonian-latest Campanian section typically of the mature stage of arc evolution with alkaline and calcalkaline rocks (see Chapter 3).

The main intrusive bodies of the arc crop out along 400 km between N-Escambray and SW-Holguín and in the Purial area (Fig. 1). Tholeiitic to calc-alkaline and/or alkaline gabbroid-to-granitoids are of various Cretaceous ages, but the main bodies were emplaced during Campanian (Eguípolo et al., 1984; Perez et al., 1986; Tchounev et al., 1986; Pushcharovsky, 1988; Iturralde-Vinent, Wolf and Thieke, 1989). Contact metamorphism and metasomatic transformations are related with these bodies.

After the demise of the Cretaceous volcanic arc in the latest Campanian, a general uplift took place, and shortly after several new sedimentary basins evolved in the same area. These late Campanian (or Maastrichtian)-Eocene basins filled with slightly-deformed sedimentary sections (graywakes and limestones). Debris in these sediments are mostly fragments of Cretaceous volcanics and plutonic island-arc rocks, some are ophiolite-derived fragments, and minor amounts of
problematic limestones and chert fragments that probably belongs to the Bahamian and Guaniguanico sequences. These post-arc basins evolved during the orogenic movements that took place in the oceanic domain.

Two general stages of post-arc basinal evolution can be recognized which involve changes from transgressive-clastic to regressive-carbonate deposition. The first occurs during Campanian-Maastrichtian and generally ends with a Danian hiatus and unconformity. It was related with vertical movements within the extinct arc. The second (Paleocene-early Late Eocene) stage was piggyback in character, as it was age-equivalent to large scale overthrusting of the arc and ophiolites, and ends with a major disconformity.

Figure 12 is a general cross section in Camaguey province of east central Cuba that illustrates the general structure of the foldbelt. From NE to SW are evident several major tectonic units. First are found the carbonate sections of the Bahamas platform and slope deposits, deformed along with the Lower to Late Eocene foreland sediments. Overlying the carbonate deposits are the allochthonous ophiolites, partially covered by klippens of the Cretaceous volcanic arc. SW-ward the ophiolites are in steep tectonic contact with the Cretaceous volcanic arc rocks. The last covered by the slightly deformed Maastrichtian-Late Eocene post-arc basins.

The Paleogene Island Arc

Paleocene to early Middle Eocene island-arc suites are well-known in eastern Cuba, but never found elsewhere in the island (Lewis and Straczek, 1955; Iturralde-Vinent, 1976-77; 1981; 1990; Cobiella, 1988; Cobiella et al., 1977; Breszynianszky e Iturralde-Vinent, 1978; Nagy et al., 1983).

The axial portion of the arc, composed of calc-alkaline extrusive and pyroclastics rocks intruded by granodiorites and granite plutons, is present along the Sierra Maestra (Fig. 1). Northwards, only backarc pyroclastics and sediments are present while to the west, in Central and Western Cuba, Paleogene volcanism
is represented by thin, tuffaceous intercalations within the sedimentary sections of the piggyback basins. Volcanic activity diminished and became extinct about early Middle Eocene. Major intrusions took place by late Middle Eocene.

Middle to Late Eocene carbonates and clastics were deposited conformably in post-arc basins onto the island-arc rocks. Conglomerates and sandstone become coarser southward in Eastern Cuba which suggests the presence of a provenance area south of the Sierra Maestra. This source was most probably Hispaniola, as has been pointed out by many authors (Bresnyanszky et Iturralde-Vinent, 1978; Cobiella, 1988; Iturralde-Vinent, 1988b; etc).

The Cretaceous to Oligocene rocks in Eastern Cuba and Northwestern Hispaniola are so remarkably similar that there is no doubt that they were part of the same foldbelt. This conclusion was reached after two field conferences organized by J. Lewis (George Washington University), Grenville Draper (Florida International University) along with Cuban and Hispaniolan geologists. These facts also suggest that Hispaniolan terranes, as they are evident today (Mann et al. 1992) were detached from Eastern Cuba after the Oligocene. Lower Miocene deposits, with large clinoforms, south of Eastern Cuba, also corroborate the timing of the disruption event that was coeval with the opening of the Cayman trench.

No magmatic activity is recorded. New basins evolved above the deformed belt with clastic and carbonate deposition.

Three main stages in the evolution of these basins can be recognized, each one representing a complete cycle of transgression and regression: latest Eocene to Oligocene, Lower Miocene to late Miocene and Pliocene to Recent. However, throughout this time, uplift dominated the overall tectonic evolution.

Neoautochthon evolution began after the activation of the Oriente-Swan Fault Zone, when compressive stresses in the Caribbean
Plate shifted to the East, and trusting collisional tectonic environments ceased in Cuba. According to Iturralde-Vinent (1991), the Oriente fault evolved in two stages: first by Late Eocene-Oligocene sinistral strike-slip displacement with deformation along the trend of the fractures; and secondly, during the Miocene-Recent, with sinistral strike-slip and extensional displacements (pull-apart basin formation).

As a consequence, the pre-Miocene rocks on the southern flank of the Sierra Maestra are strongly deformed while the Miocene and younger deposits are horizontal or only slightly tilted, and have been uplifted more than 200 meters above sea-level.

North and NE of the Sierra Maestra the latest Eocene-Recent deposits in Cuba are slightly deformed with synsedimentary deformations related to normal faulting and minor strike-slip faults. Roughly parallel with the Oriente fault are the Nipe-Guacanayabo, Camagüey, La Trocha, and Pinar faults, with less than 50 km of sinistral wrench displacement and minor deformations along very narrow strips (Fig. 13; Iturralde-Vinent, 1978; 1988b).
PLATE TECTONIC MODEL

Many plate tectonic models have been proposed to explain the origin and evolution of the Caribbean Realm, but most of them contradict major aspects of Cuban geology. There are three main points of conflict: (1) the early reconstruction of Pangea; (2) the orientation of the Cretaceous island arc; and (3) the orientation of the Paleogene island arc.

The author's current ideas on the plate tectonic evolution of Cuba are presented here as paleogeographic maps and two sets of paleotectonic profiles; one oriented NE-SW on the southern edge of Bahamas and the other NW-SE at the edge of the Yucatan Block. These profiles integrate the sedimentary, magmatic and tectonic events that have been described previously, in order to answer the above three questions. As well, the evolution of the magmatic activity in Cuba and its surroundings areas has to be taken into consideration (Fig. 14). The evolution on the Western Caribbean area (including Cuba) can be traced in several stages, starting by those proposed by Sawyer et al. (1991).

Late Triassic-Early Jurassic

According to Sawyer et al. (1991), this is "the early phase of rifting" in the Gulf of Mexico, but the same is true for the whole pre-Caribbean area. Continental margin magmas related to epicontinental siliciclastics are recognized around the Gulf of Mexico, Florida, SW Cuban Terranes, Bahamas and northern South America (Iturralde-Vinent, 1988c; Figs. 2 and 14).

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Figure 14. Major magmatic events related with the evolution of the Caribbean area.
During this stage continental extension and rifting along linear zones took place. This was the initial phase in the break-up of Pangea (Pindell, 1985; Ross and Scotese, 1988).

The Grenville age of the basement rocks in north Central Cuba (Socorro Complex) may looks problematic because mostly Pan African datings have been obtained from Florida, while a Grenville province is located only in northern South America (Bartok 1993). According to the early reconstruction of the Caribbean introduced here (Fig. 15), the southernmost Bahamian margin (Central Cuba) and northern South America (Guyana Shield) were very close. One can conclude from this interpretation that the contact between Grenville and Pan African basements was located near the suture between Laurasia and Gondwana along the northwestern Caribbean. Therefore, a fragment of the Grenville basement (the Socorro Complex) remain attached to the Strait of Florida block after the break-up of Pangea.

Middle Jurassic

In the Gulf of Mexico "the main phase of crust attenuation" took place and "thick salt was deposited throughout the broad central area" (Sawyer et al., 1991). In the SW Cuban Terranes and the Strait of Florida block clastic deposition and some continental magmatism took place (Fig. 2).

Along the northern edge of South America (Siquisique area of Venezuela) Middle Jurassic ocean-floor basalts are found (Fig. 14), the oldest indication of oceanic crust in the Caribbean area. These rocks are associated with ammonites that suggest a Tethyan - Pacific Ocean communication (Bartok et al., 1985). These implies that within the mesoamerican area the earliest break-up took place between the Yucatan Block and South America.

Late Jurassic-Earliest Cretaceous

According to Sawyer et al. (1991), the "Late Jurassic is characterized by the emplacement of oceanic crust after sea-floor spreading began along a generally east-west-striking weakness in the thinning continental crust" that "was accompanied by a general transgression into the Gulf of Mexico basin area as the basin began to cool and subside". This event had a significant equivalent in the Caribbean where since Oxfordian, drifting probably became more active.

An important Oxfordian continental margin basalt event is recorded in the Guaniguanico Terrane (Figs. 2 and 14). In the early Caribbean sea (Guaniguanico and Escambray) a major Oxfordian marine transgression took place and spread into the Gulf of Mexico. Deposits associated with this transgression in Guaniguanico contain a very rich Caribbean Jurassic biota (Ammonites, fish, pterosauria, plesiosauria, crocodiles, pelecypods, etc), which has some relationships with the Eastern
Pacific and European faunas. This suggests that there was faunal exchange between the Pacific and the Tethys. This exchange was initiated relatively early by ammonites (Bartok et al., 1985).

Many Caribbean plate tectonic models interpret this stage with various success but fail to take into account the Pinos and Escambray terranes, just ignoring its existence, or consider them as unrelated units (Pindell, 1985; Ross and Scotese, 1988; Pindell and Barrett, 1990; etc.).

Fig. 15 shows a model assumption that the Guaniguanico, Pinos and Escambray Terranes originated at the edge of the Yucatan Block, as was discussed previously. The evolutionary profiles in Fig. 16 were constructed by reorganizing the belts of the Guaniguanico Terrane approximately parallel with the Yucatan margin. This area evolved from pre-Oxfordian intra-continental rifting to a Kimmeridgian-Early Cretaceous passive-margin. Later, during the opening of the western Yucatan oceanic basin (Rosencrantz, 1990), these terranes became detached from the Yucatan Platform and were incorporated into the Cuban Foldbelt.

The original plate boundary from the break-up of Pangea in the Caribbean and surrounding areas were of two types. One set occurred as two parallel oceanic ridges located one between North America-Yucatan Block and another between Yucatan Block-South America. The other set were transform faults perpendicular to them. The most significant fault extended between the Gulf of Mexico and the Demarara Plateau (Fig. 8; Pindell, 1985; Ross and Scotese, 1988; Sawyer et al., 1991; Marton and Buffer, 1992). As a consequence, the southern margin of the Bahamas Platform (Strait of Florida Block) was strongly affected by sinistral transform movements, while the eastern margin of the Yucatan Block and the Gulf of Mexico basin evolved parallel to the ocean ridges (Fig. 18).

These contrasting tectonic environments explain the magmatic and sedimentary differences between the southern Bahamian slope sequences and the eastern Yucatan margin sequences (SW Cuban Terranes). The development of the late Oxfordian-early Tithonian carbonate platform and its basinal equivalents in Guaniguanico and Escambray (Yucatan Block borderland) indicate that rifting continued during the whole Late Jurassic. In the Gulf of Mexico and the Caribbean margin areas, subsidence has taken place since Tithonian, a byproduct of cooling of the oceanic crust.

Cretaceous

Since Early Cretaceous time the Gulf of Mexico was mostly a stable area with general subsidence and local uplift (Sawyer et al., 1991). In the proto-Caribbean realm, however, the geodynamic environment was drastically modified, probably associated with the opening of the South Atlantic Ocean. As a consequence, extensional stress changed to compressional (plate convergence), continental margin magmatism vanished, and island-arc evolution was initiated (Figs. 14 and 18).

The early oceanic crust of the Caribbean began to be subducted, while backarc spreading occurred in the NW Caribbean. Basalt volcanism took place under a backarc (suprasubduction) environment from the Hauterivian through Turonian and is found within the ophiolites in northern Cuba (Figs. 2 and 14).

Concerning this stage in the evolution of the western Caribbean the problem of the original orientation of the Cretaceous arc and its subduction zone needs to be considered. There are various points of view regarding the polarity of the Cretaceous subduction zone and arc (Nagy, 1972; Malfait and Dinkelma, 1972; Pindell, 1985; Pushcharovsky et al., 1989; Pindell and Barrett, 1990; etc.). However, several lines of evidence point toward a northward-dipping subduction zone located south of the present-day volcano-plutonic outcrops (Iturralde-Vinent, 1981; 1988a; b; c).

Rosencrantz (1990, also in this Chapter) has interpreted a northward-dipping reflection as a fault plane on a seismic line located between southcentral Cuba and the Yucatan basin (Fig. 1, SE of Camaguey). The fault now is inactive and buried by Tertiary sediments. This fault can be interpreted as the suture of the Cretaceous subduction zone. Westward, in south central Cuba, the same fault plane
Figure 16. Evolutionary cross section of the western Caribbean between the Yucatan platform and the Guaniguanico terrane. Legend as in figure 17A. Location on Figure 15.
Figure 17A. Evolutionary cross sections through Bahamas and Central Cuba, characterizing the western Caribbean history. Location on Figure 15.
Figure 11B. Evolutionary cross sections through Bahamas-Central Cuba. Location as in Figure 15.
probably crops out around the Escambray Terrane (Fig. 5), separating high-P metamorphic rocks of the Escambray below from Mabujina high-T amphibolites above (Somin and Millán, 1976). This is an example of superimposed paired metamorphic belts. A similar situation is found N on the Pinos Terrane (Somin, 1977). Therefore, the outcrop of the suspected subduction plane can be traced south of Cuba, an interpretation that is in agreement with the distribution of the arc-related volcanics and plutonics rocks in Cuba (Fig. 1).

Within the Bahamian continental rise deposits (Placetas belt), intercalations of volcanic ash and pyroclastic debris within the Albian-Cenomanian-Turonian section have been reported. This suggests that the arc and Bahamas were in relatively close proximity at that time. Also, Maastrichtian and Paleocene to Eocene deposits in the Placetas and Camagüey Belts contain large blocks of Cretaceous volcanic and intrusive rocks, suggesting that the volcanic arc was never far away from its present position. Renne et al. (1991), based on paleomagnetic research, suggested that the Cretaceous volcanic arc was located between 200 and 1,600 km south of its present location during the Albian-Cenomanian.

Therefore, it may be concluded that the cretaceous volcanic arc has probably been within the western Caribbean since Albian time. This position cannot be explained by a south-dipping subduction zone north of the arc during the Cretaceous.

In several plate tectonic models the northern Cuban ophiolite melange is considered to be part of the Proto-Caribbean crust while the arc is related to Pacific crust (Pindell, 1985; Ross and Scotese, 1988; Pindell and Barrett, 1990; etc.). This framework does not explain the fact that ophiolite gabbroids in Camagüey Province (Fig. 1) have the highest alkali concentration of any such rocks on the island and that the same primary anomaly is present in Cretaceous volcanic and intrusive rocks in this area (Fonseca et al., 1984). These geochmical anomalies in crustal and supracrustal rocks cannot be coincidental. They probably reflect a long lasting, deep-mantle anomaly sourcing both complexes. Consequently, it is suggested that the northern ophiolites and the volcano-plutonic suites belong to the same crustal province, a framework consistent with the model proposed here (Fig. 18).

The existence of eclogites and blueschists has been the supporting evidence for interpreting the northern ophiolite melange as a subduction complex (Somin and Millán, 1981; Andró et al., 1989). High-P metamorphic rocks are not abundant in the northern ophiolite melange (<< 3% of the volume) and are generally found along linear belts of cataclastic serpentinites (which are a few kilometers wide and tens of kms long) associated with high-T and non-metamorphic rocks (Somin and Millán, 1981; Kozák et al., 1988).

The high-P metamorphic inclusions within the ophiolite melange may also be associated with strike-slip combined with dip-slip movements. This framework can be described as non-magmatic underthrusting at the Bahamas-ProtoCaribbean crust contact, along the same trend of the Mesozoic transform boundary (Fig. 15). Rigassi-Studer (1961) and Iturralde-Vinent (1981) have described strike-slip features along this suture in central Cuba, while thrusting is well known in the same area (Meyerhoff and Hatten, 1968). This kind of tectonic framework have been described for many plate boundaries, including the Puerto Rico trench (Dengo and Case, 1990).

One example of High-P metamorphism in shallow deeps is the eclogites and blueschists of the Escambray (Fig. 5). This terrane has inverted metamorphism with lower degree (less than greenschist facies) in the core, and higher in the periphery (up to amphibolitic facies).

According to Somin and Millán (1981) this metamorphic pattern is due to the underthrusting of the Escambray below the ophiolites and volcanic arc suites. In this example, the high-P metamorphic rocks of high degree were formed at shallow deeps as the rocks were never melted, because this is a huge sialic massive that can not plunge very deep into the mantle. In this example the Escambray is probably present in a subduction suture, but such a tectonic environment can easily be present in a dip-slip fault.
K-Ar ages derived from high-P rocks of the northern ophiolite melange [58-128 Ma (n=31)] and magmatic rocks of the Cretaceous volcanic arc [49.5-100.1 Ma (n=79)], indicate that older thermal (tectonic) events are recorded within the ophiolites (Iturralde-Vincent et al., 1992). K-Ar ages in the ophiolites suggest a minimum age of Lower Cretaceous for the first High-P metamorphic event in the ophiolites (Somin and Millán, 1981; Millán and Somin, 1985b). This event may reflects the activity of the fault located south of the Bahamian Platform.

The just mentioned Early Cretaceous or older high-P metamorphic event recorded in the ophiolites, if it is interpreted as a subduction-related event, is problematic for the Plate tectonic models that require a pre-Albian north dipping subduction zone (Ross and Scotese, 1988; Pindell and Barrett, 1990). This subduction suture is placed south of the arc in these models, and the ophiolites are present in the northern flank of the arc.

In the framework of the post-Albian Cretaceous south dipping subduction models, K-Ar ages obtained in high-P metamorphic rocks and minerals from Escambray [43-85 Ma (n=15)] and Guira de Jauco [58-72 Ma (n=4)] are also problematic (Fig. 1). According to these models Escambray (and probably Guira de Jauco) were involve in the subduction zone contemporaneously with the northern ophiolites. Therefore, the differences in the ranges of the K-Ar ages in the high-P assemblages remain without explanation.

This K-Ar age pattern is in agreement with the tectonic model proposed here. According to this model (Figs. 16 and 17), Pinos and Escambray terranes were underthrust below the arc since the end of the Cretaceous, while the northern ophiolites had a long-lasting deformation history related with the Caribbean-Bahamas (plate) boundary.

If a north-dipping subduction zone for the Cretaceous volcanic arc proves to be true, and the arc originated within the Caribbean (Fig. 18), many Caribbean plate tectonic models must be reformulated (Pindell, 1985; Shein et al., 1985; Ross and Scotese, 1988; Pszczolkowski, 1987; Pindell and Barrett, 1990; and many others).

The evolution of the Cretaceous volcanic arc in the Cuban area reflects two important events; one during Albian and the other during Coniacian-Santonian, as discussed above (Fig. 2). Such events are not only related to tectonic processes within the Caribbean, but they have global counterparts (Schwan, 1980). This fact suggests that these two events can not be explained just as local phenomena related to the geological history of the arc. More probably they are local reactions to global tectonic transformations.

The Cretaceous arc split into two about Albian time and one part became inacive as a remnant arc (Figs. 16 and 18). Thereafter, the active arc migrated southward and extensional stresses were developed between the arc and the Bahamas Platform. As a consequence, the backarc basin became enlarged and the Bahamas Platform was fractured. A number of deep water-channels divided the platform into separate shallow-water areas (Fig. 2).

It is well known that the long-lasting Cretaceous positive magnetic event ended about Santonian as a consequence of global tectonic events (Schwan, 1980). Coincidently, the Caribbean tectonic regime suffered a major change. After Campanian the Cretaceous volcanic arc became extinct (Fig. 7), and deformational processes started along the NW Caribbean margin (the North Caribbean Orogeny: Pszczolkowski and Flores, 1986).

As a consequence, foreland basins evolved along the southern Bahamian and NE Yucatan margins and “piggyback” basins developed above the aborted Cretaceous volcanic arc (Figs. 16 and 17). Southward underthrusting of the Bahamian slope deposits and part of the ophiolites took place later during the evolution of the foreland basins (latest Cretaceous-Late Eocene). Simultaneously, formation of oceanic crust probably began within the western Yucatan basin, a process that is generally recognized for Paleocene—Mid-to-Late Eocene time (Rosencrantz, 1990).

In some areas of the foldbelt outcrops low degree high-P complexes (Cangre, in Guaniquanico: Fig. 7; metavulcanics of Purial, metaophiolites of Guira de Jauco and metasedimentary rocks of Asunción, in Eastern Cuba: Fig. 11). These rocks were
Figure 18. Tithonian and Albian paleogeography of the western Caribbean area.
metamorphosed within the Maastrichtian-Paleocene interval (Somin and Millán, 1981; Millán and Somin, 1985a, b) but can not be explained by a magmatic-producer subduction because they can not be related with contemporaneous arc rocks. In Eastern Cuba the Paleocene-Eocene volcanics stratigraphically overlie these metamorphic rocks.

At the present time these metamorphic rocks are located along strike-slip and thrust faults (Cangre: Fig. 7), or are piled as superimposed thrust sheets (Fig. 11: Eastern Cuba). The author believe, on the base of geological observations, that this metamorphism is related with overpressure due to thrusting of heavy tectonic sheets as the ophiolites.

**Latest Cretaceous-Late Eocene**

Starting in the latest Cretaceous in some places, and since Paleocene in eastern Cuba, a new volcanic arc (or set of arcs) evolved facing the Caribbean sea (Fig. 14). In most Caribbean plate tectonic models, Paleocene-early Middle Eocene volcanic activity is related to a subduction zone dipping S, located N of the Greater Antilles including the Cuban area (Pindell, 1985; Ross and Scotese, 1988; Pindell and Barrett, 1991; etc.). But again this contradicts the known geometry of the volcanic-plutonic suite, and is not supported by the geology of Cuba. A Paleogene subduction zone has not been recognized on- or offshore in Cuba (see geologic and tectonic maps: Pushcharovsky, 1988; Pushcharovsky et al., 1989).

On Cuba, all observations point to a Paleocene to early Middle Eocene subduction zone located S of the arc and dipping N or NW (Cobiella, 1988; Iturralde-Vinent, 1988c; 1990). This subduction zone was developed some distance away from Cuba but is probably represented in Hispaniola because these terranes were originally located south of Eastern Cuba during early Tertiary (Bresznyánsky and Iturralde-Vinent, 1978; Cobiella, 1988; Ross and Scotese, 1988; Pindell and Barrett, 1990).

The extinct subduction suture for the Paleocene-Eocene arc is probably located in the Peralta-Ocoa Belt of SW Hispaniola, which strongly resembles an accretionary prism (Unruh et al. 1991), as the following features suggest (Fig. 19; Huebeck et al. 1991):

- (i) it is a deformed and partially-metamorphosed prism that plunges northeastward below Cretaceous and Tertiary volcanic terranes;
- (ii) the belt exhibit a progressive deformational history from NW (older) to SE (younger), a pattern that reflects the accretionary history of blocks along the trend of the belt;
- (iii) the Maastrichtian to Early Miocene sediments are described as turbidites, debris flows, olistostromes, and slump deposits, yielding both deep-water fossils and reworked contemporaneous shallow-water fossils;
- (iv) sediments include clastic material derived from the Cretaceous volcanic arc (Tireo Formation and intrusive bodies) outcropping NE of the Peralta-Ocoa belt.

Furthermore, deformation and metamorphism of latest Cretaceous to Late Eocene rocks in the belt is time-equivalent with magmatic activity in SE Cuba. Post-Eocene sedimentation and deformation in the Peralta-Ocoa Belt -- Muertos Trough was probably related to sinistral strike-slip movements associated with the Oriente fault system (Mann et al., 1992) and deformation along the Sierra Maestra of Cuba (Iturralde-Vinent 1991).

In Cuba, the Paleocene to early Middle Eocene volcanic arc rocks overlaps only partially the Cretaceous arc suites as the younger arc is located S and SE of the former (see Figs. 1 and 19). Therefore, the Paleogene subduction zone was probably located SE of the previous (Cretaceous) zone. Eastward, in the Hispaniola-Virgin Islands area, the early Tertiary subduction zone probably followed the same trend and position of the Cretaceous one because Cretaceous and Paleogene arcs complexes are generally superimposed in these territories (Khudoley and Meyerhoff, 1971; Dengo and Case, 1990).

There may be a number of local explanations for the "jump to the SE" of the
subduction zone in the Western Caribbean at the end of the Cretaceous, but it may be a byproduct of global tectonic events that started in the Santonian (Schwan, 1980).

**Latest Eocene to Recent**

A final important geodynamic change in the western Caribbean, as elsewhere (Schwan, 1980), took place in about the middle-late Eocene, and was probably related to activity of the Swan-Oriente strike-slip fault which has evolved since the Miocene into a rift-transform system (Iturralde-Vinent, 1991). As a consequence, plate convergence shifted towards the Eastern Caribbean along the Lesser Antilles arc.

Within the western Caribbean, in the so-called Cuban microplate, transpressional-transensional tectonic environments became active and oceanic crust was produced at the Cayman Ridge (Figs. 13 and 14). Some strike-slip faulting and minor deformations were associated with vertical oscillatory movements along the Cuban neoautochthon.
CONCLUSIONS

The geology of Cuba is the most complex in the Caribbean realm owing to the island’s location in the NW Caribbean. To the north, the Cuban orogen is sutured to the southern part of the Bahamas Platform, while to the west, it is intimately related with the Yucatan Platform and includes terranes detached from the platform’s NE margin. In the south, the alpine-type compressional belt is related to structures in the Yucatan basin, the Cayman Rise and the Cayman trench, while to the east, there are many similarities with Hispaniola.

As a consequence, the Jurassic-Late Eocene foldbelt includes oceanic and continental complexes representative of the western Caribbean. These complexes can be classified according to their composition and origin, as either continental units (parts of Bahamas and Yucatan Platforms); or oceanic units (the Cretaceous and early Paleogene volcanic arcs and ophiolites). Above all these, a post-orogenic neoautochthon (latest Eocene-Recent) is present composed of slightly-deformed sedimentary rocks.

Many plate tectonic models of the Caribbean geological development have been published in recent years but frequently they do not take into account the geology of Cuba. Here is presented a plate tectonic model for the western Caribbean, which is based on the following premises:

- (i) opening of the Caribbean took place along several parallel rifts zones and a main transform fault located between the entrance of the Gulf of Mexico and the Demarara Plateau;
- (ii) the Cretaceous Greater Antilles volcanic arc faced the Proto-Caribbean sea related with northward- dipping subduction; and
- (iii) the western Caribbean Paleocene-Middle Eocene volcanic arc also faced the Caribbean sea, with subduction zone dipping towards the N-NW.