Caribbean Geology: An Introduction
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CHAPTER 4

Cuba

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INTRODUCTION

THE CUBAN archipelago consists of some 4,194 islands and cays, including the main island of Cuba and the Isla de la Juventud (previously the Isla de los Pinos—the Isle of Pines), covering a total of 110,922 square km (the main island making up some 105,007 square km). The archipelago is the only part of the Greater Antilles situated on the North American Plate.

Modern geological investigations in Cuba were initiated in the 1950s by oil company geologists[11,25]. Much of this work remains unpublished, but several review papers were published in the 1960s and 1970s[16,18,33], including summaries of the accomplishments of petroleum geologists[9,19,26]. Since 1959, much new knowledge has been added by Cuban geologists aided by eastern European colleagues. There is now a large literature concerning the geology of the island, including geologic, tectonic and metallogenic maps at a scale of 1:500,000, and a new geologic map at a scale of 1:250,000[24] With the exception of the papers by Pardo[26] and Lewis[17], few of the general descriptions of the island's geology are available in English. The purpose of this chapter, therefore, is to give a broad overview of modern interpretations of Cuba's geology for an English speaking audience. The main text is supplemented by two appendices, explaining the map symbols used in the Cuban geological literature (Appendix 1) and the sub-Upper Eocene stratigraphy of the structural facies zones of the four principal structural blocks (Appendix 2).

GEOGRAPHY

The major geographic features of Cuba are shown in Figures 4.1 and 4.2. The Cuban literature often refers to the political provinces in which geological features occur, and these are shown in Figure 4.1. Figure 4.1a shows the provinces prior to 1959 (as referred to in the older literature), and Figure 4.1b shows how they were re-arranged following the revolution.

The physiographic relief of most of Cuba (Fig. 4.2) is relatively subdued compared to other islands in the Greater Antilles, and mountainous areas are found only in the western province of Pinar del Rio, the Escambray region in the centre of the island and in the eastern province of Oriente. The last contains Pico Turquino in the Sierra Maestra which, at 1,972 m, is the archipelago's highest peak.

BASIC COMPONENTS OF CUBAN GEOLOGY

The geology of Cuba differs significantly from that of other areas of the Greater Antilles in several respects. Cuba contains Precambrian rocks (900 Ma metamorphic rocks in Santa Clara province; Fig. 4.1b) and extensive outcrops of continental margin, sedimentary rocks of Jurassic to Cretaceous age. It is structurally characterized by large thrust and nappe structures, which are not present in the other islands of the northern Caribbean.

Cuba can be divided into two broad geological provinces (Fig. 4.3):

1. Western and central Cuba constitute a complexly deformed orogen resulting from the collision of amid to late Cretaceous island arc with the late Jurassic to late Cretaceous sedimentary rocks of the Florida-Bahamas platform[10,34]. This event occurred in the late Cretaceous, producing both the obduction of the Cuban ophiolite belt and a large, northward-verging, fold and thrust belt. Some of these structures were reactivated by a second orogenic

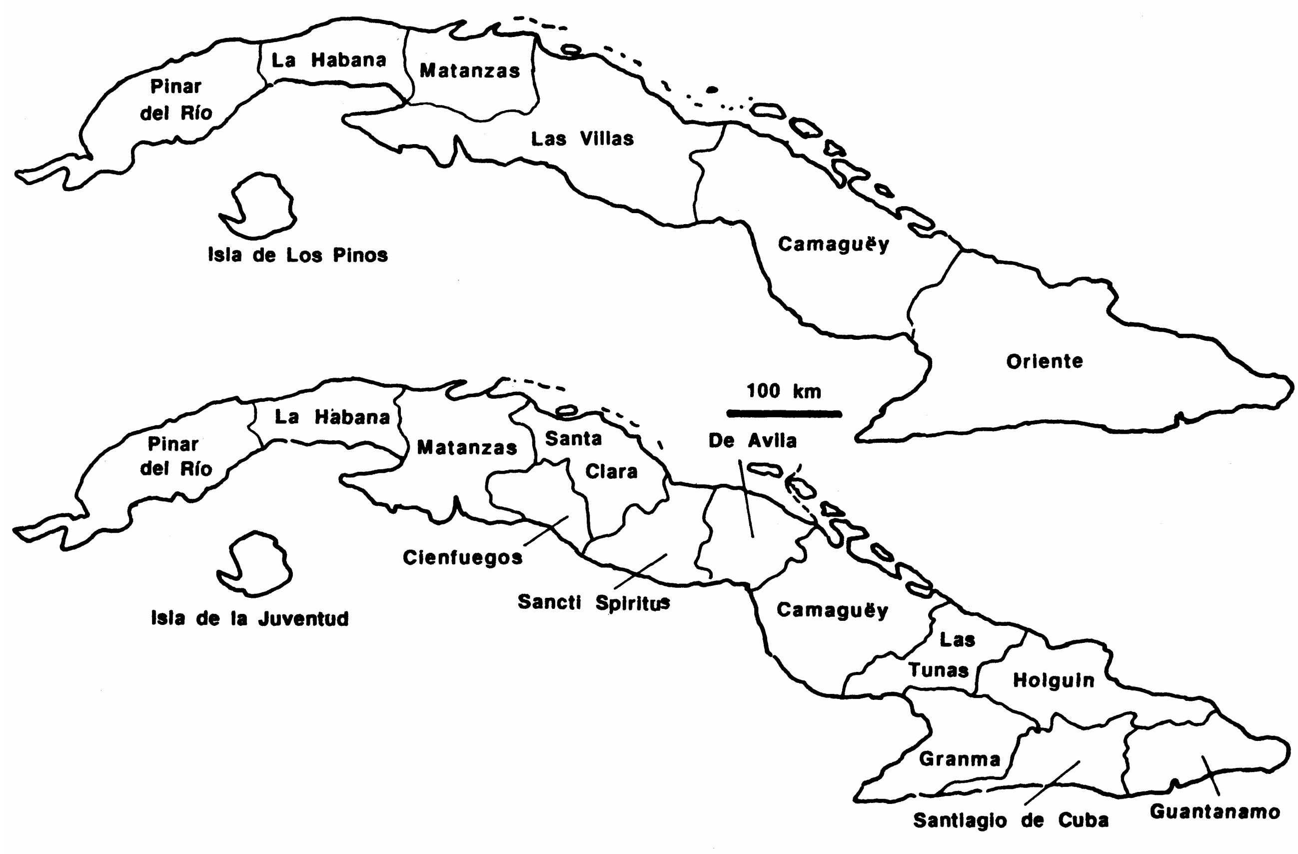

Figure 4.1. Major geographic features and provinces of Cuba (a) prior to the 1959 revolution and (b) at the present day.

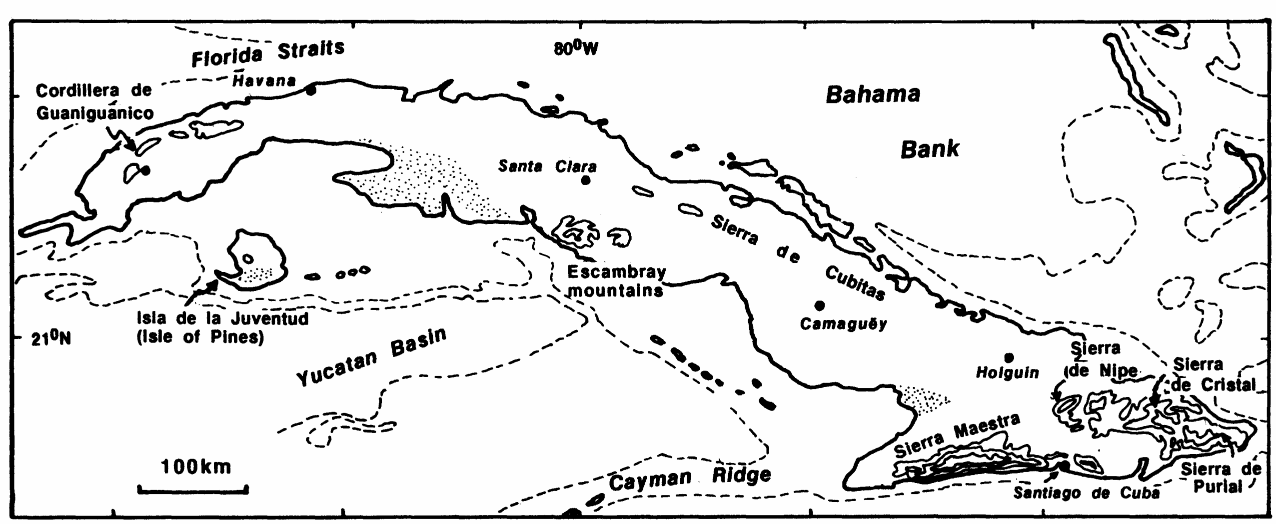

Figure 4.2. Physiography of Cuba. Contours above sea level are shown as *solid lines* at 1,000 m intervals. *Stippled areas* indicate low lying, wetland regions. Bathymetric contours are shown as *broken lines*, also at 1,000 m intervals. Adapted from Weyl[35].

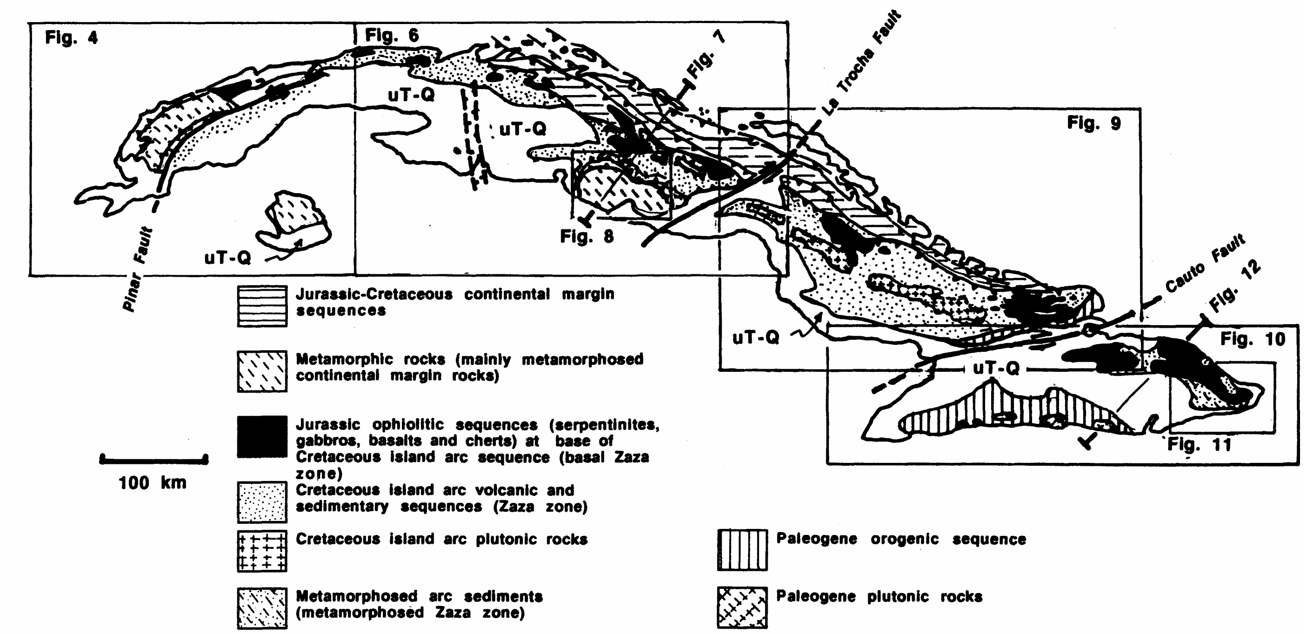

Figure 4.3. Main structural blocks and structural-facies zones of Cuba; Pinar del Rio Block (Fig. 4.4), Isla de la Juventud Block (Fig. 4.5), Central Cuba Block (Fig. 4.6), Camaguey Block (Fig. 4.9), and Oriente Block (Fig. 4.10). Note especially the Jurassic ophiolites, which lie at the base of the Cretaceous island arc rocks, both of which are thrust over the Jurassic to Cretaceous, passive margin, sedimentary rocks that form the northernmost structural facies zones of Cuba.

phase in the Paleocene to early Eocene[28]. This later deformation seems to have been diachronous and becomes progressively younger to the east . The precise plate tectonic configurations that gave rise to this orogen are still hotly debated. These orogenically deformed rocks are overlain by relatively undeformed, post-orogenic sedimentary rocks.

2. Eastern Cuba (southeast of the Cauto basin) is characterized by a Cenozoic (Paleocene-Middle Eocene) volcanic-plutonic arc complex of the Sierra Maestra. North and east of the Sierra Maestra, ophiolitic and arc rocks of the Mesozoic orogen occur, overlain by Paleogene sedimentary rocks and tuffs. Although the older rocks have similarities to those in central Cuba, they are different in the sense that continental margin rocks are rarer. In contrast to western and central Cuba, Tertiary sedimentation related to tectonism persisted until the Oligocene.

STRUCTURAL GEOLOGY OF OROGENICALLY DEFORMED ROCKS OF CUBA

The orogenically deformed rocks of Cuba (that is, pre-Middle Eocene in the west and central part of the island; pre-Oligocene in the east) can be conveniently divided into five major geologic-structural segments or blocks[17,19]. These are, from east to west (Fig. 4.3):

1. Pinar del Rio block (located west of Havana).
2. Isla de la Juventud block.
3. Central Cuba block (located between Havana and the La Trocha fault zones).
4. Camaguey block (between the La Trocha and Cauto fault zones).
5. Oriente block (south and east of the Cauto fault zone).

It is important to note that this division is slightly different from that used by previous authors, especially in our distinction between the central Cuban and Camaguey blocks. However, it is considered that there are sufficient structural, if not stratigraphic, differences between these two regions to justify this distinction.

Within these structural blocks, the geology is further sub-divided into what Cuban investigators have called structural-facies zones. The structural-facies zones can be identified, partially or completely, in each of the blocks and are fault bounded belts or nappes, which have distinctive stratigraphic, metamorphic and/or palaeogeographic characteristics. The original concept was introduced by Pardo[25], after which it was adopted and refined by numerous authors[8,11,26]. Hatten *et al.* have gone so far as to label these zones in central Cuba as tectonostratigraphic terranes, a concept that is still controversial. The structural-facies

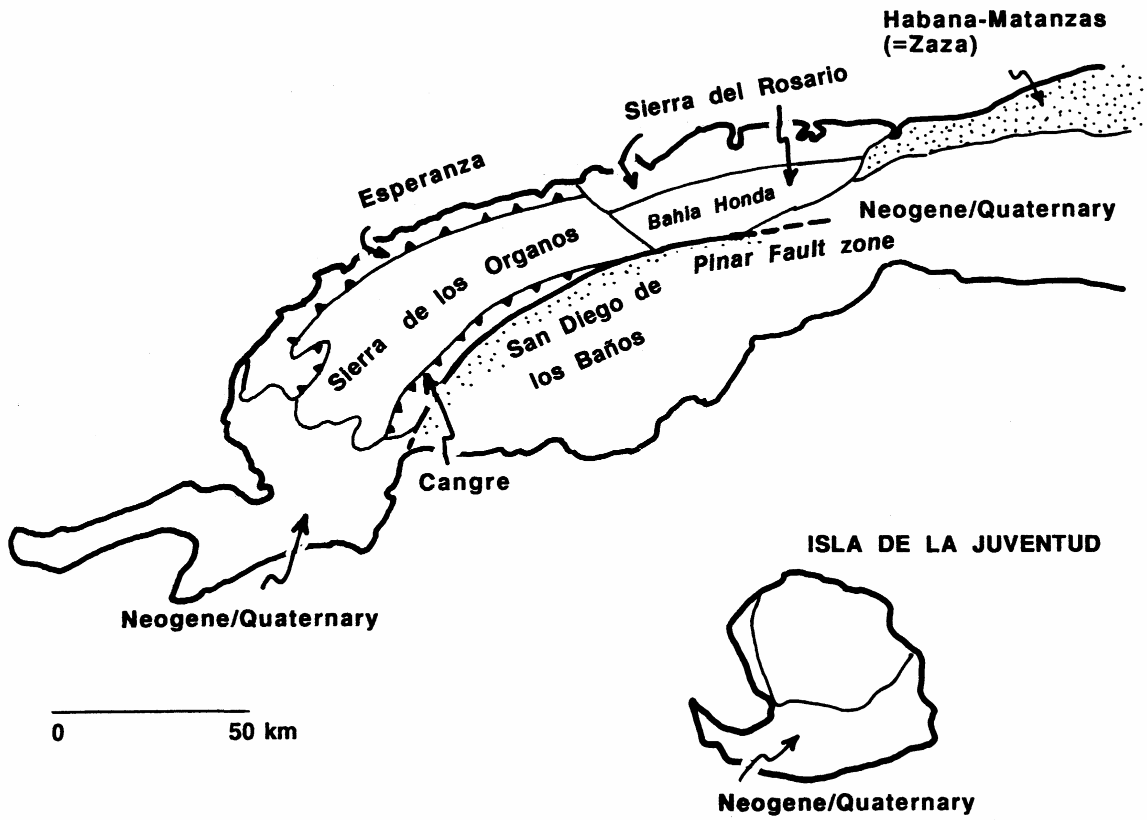

Figure 4.4. Structural facies zones of the Pinar del Rio Block of western Cuba *Stippled area* represents the Zaza zone (island arc rocks and basal ophiolites) which extend west of Havana

zone concept is nonetheless usefiil in describing the major features of the geology of Cuba and is adopted in the following account. A thorough terrane analysis of Cuba awaits further investigation.

PINAR DEL RIO BLOCK

Western Cuba consists of five structural facies zones (Fig. 4.4). The northernmost, which is poorly exposed, is the Esperanza zone. To the south, three of the zones (the Sierra de Rosario in the north, the Sierra de los Organos in the south and the Cangre zone, also in the south) form the Cordillera de Guaniguanico (Fig. 4.2). The Cangre zone forms a thin sliver on the southernmost flanks of the Cordillera de Guaniguanico and is separated from the San Diego de los Banos zone by the Pinar del Rio fault.

Esperanza zone

The Esperanza zone outcrops as a thin belt in the northernmost part of western Cuba The rocks of the region are poorly exposed and most of the useful information on the zone comes from subsurface studies. The rocks of this belt consist of Upper Jurassic to Lower Cretaceous evaporites, dolomites and limestones similar to those found in the Cayo Coco and Los Remedios zones of central Cuba (see below). These rocks are deformed by thrust faulting into at least three nappes. Subsurface information suggests that they structurally overlie Upper Cretaceous to Paleocene flysch-like sandstones and shales.

Sierra del Rosario zone

The rocks of the Sierra del Rosario form an antiformal arrangement of three nappes, each of which is composed of Jurassic to Upper Cretaceous ophiolitic rocks and (mainly) carbonate sedimentary rocks. The Bahia Honda sub-zone is the northernmost, and structurally highest, unit of the Sierra del Rosario zone and consists of ophiolitic rocks. The structurally lowermost units of the sub-zone consist of mafic and intermediate lavas, siliceous slates and well-laminated limestones, whereas the uppermost units consist of basalts, gabbros and ultramafic rocks. These relations have led some investigators[23] to conclude that the sequence is overturned. Instead, we suggest that these outcrop patterns are more likely to be due to duplication by imbricate thrusting.

The Quinones tectonic sub-zone structurally underlies the Bahia Honda sub-zone and is separated from it by a north dipping thrust fault. The Quinones sub-zone consists of Lower Cretaceous to Maastrictian limestones organized into three thrust sheets, each of which is associated with an

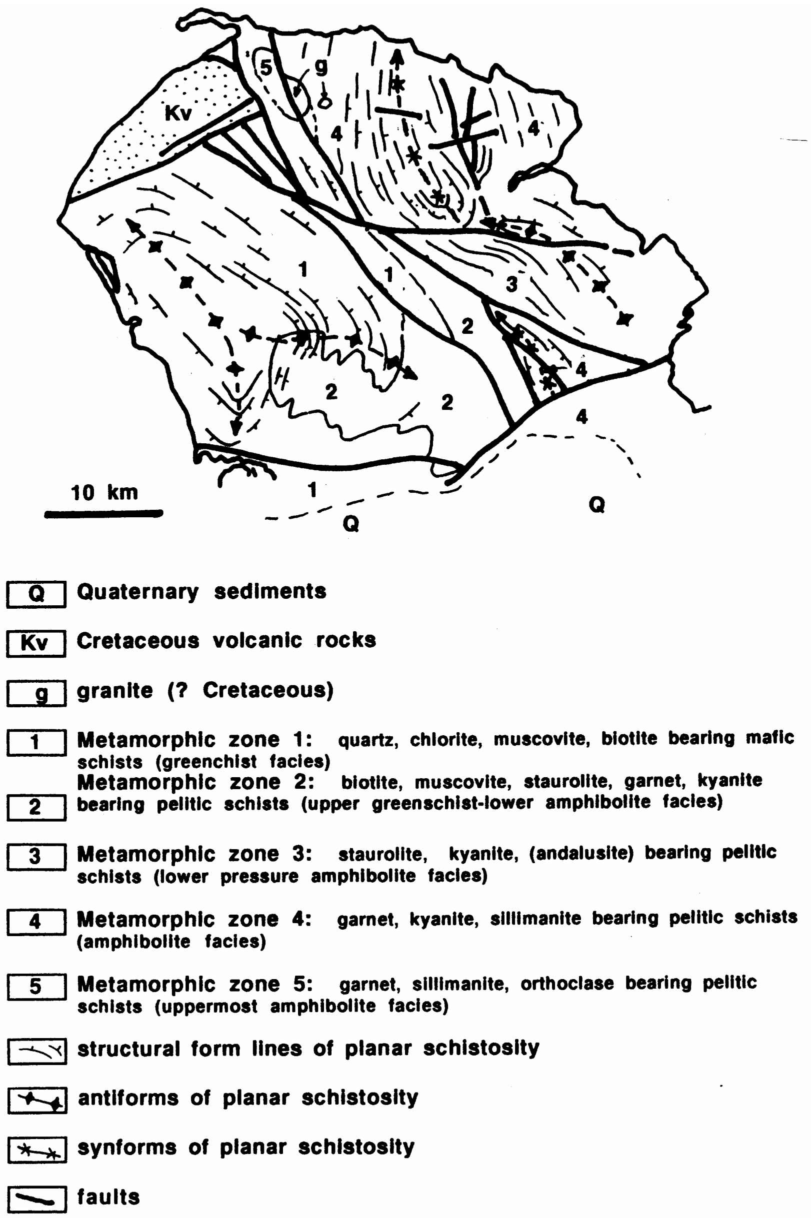

Figure 4.5. Structural and metamorphic facies map of the Isla de la Juventud terrane.

olistostrome unit.

The Cinco Pesos tectonic sub-zone forms the southward dipping, southern limb of the Rosario antiform. It consists of thrust sheets of Jurassic to Lower Cretaceous carbonates with Upper Cretaceous flysch-like clastic sedimentary rocks, and Jurassic deltaic sandstones (San Cayetano Formation). The southern limit is bounded by the eastern extremity of the Pinar fault.

Sierra de los Organos zone

The Sierra de los Organos contains the largest exposure of Jurassic rocks in Cuba. These are the deltaic sandstones, siltstones, and micaceous and carbonaceous shales of the Middle Jurassic (Bajocian) San Cayetano Formation. This formation has been metamorphosed and finer grained lithologies have been converted to well-developed phyllites.

The San Cayetano Formation is overlain by a thick sequence of Oxfordian to Tithonian shallow water limestones of the Jagua, and the lowermost member of the Guasasa (previously Vinales) Formations. However, the post-Tithonian members of the Guasasa Formation are composed of pelagic limestones and cherts, and thus record a

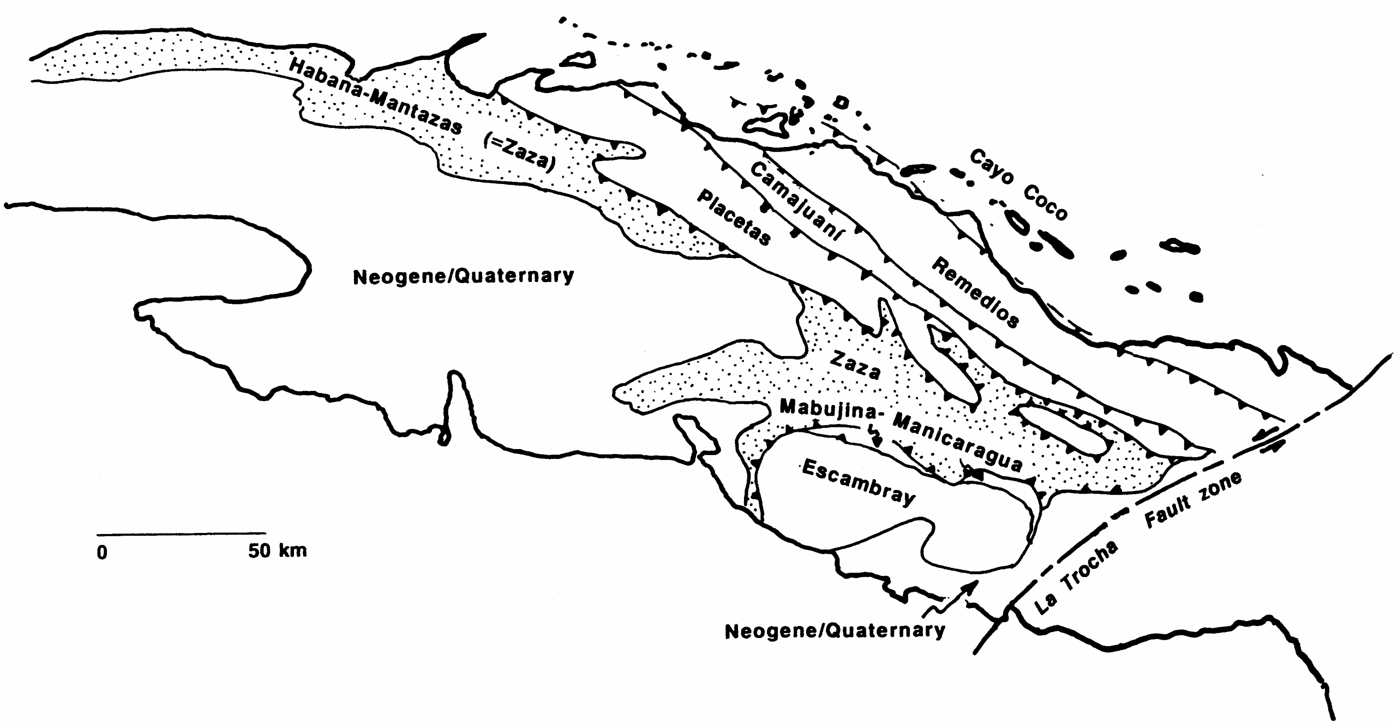

Figure 4.6. Structural facies zones of the Central Cuba Block. *Stippled area* represents the Zaza zone (basal Jurassic ophiolites and Cretaceous island arc rocks). Teeth on thrust fault are on the upper plate (hanging wall) of the fault.

sudden deepening of the basin[27]. These in turn are (?conformably) overlain by Upper Cretaceous to Paleocene conglomerates and sandstones.

Structurally, the Sierra de los Organos sequence is sliced into a series of nappes. In the northwestern Sierra Guaniguanico the San Cayetano Formation is thrust (north verging and north dipping) over the younger Cretaceous carbonates. In the southeastern part of the Sierra, the San Cayetano Formation structurally overlies the limestones and is separated from them by a southward-dipping thrust. The carbonates are thus exposed as a tectonic window in the central part of the Sierra.

Cangre zone

The Cangre belt forms a narrow, wedge-shaped belt on the southern boundary of the Guaniguanico massif. It is composed of quartzose meta-arenites, mica phyllites and occasional graphitic phyllites. According to Millan and Somin , these rocks are metamorphosed equivalents of the San Cayetano Formation. The metamorphic grade is difficult to estimate, but sills of metadolerite and gabbro found in the formation have glaucophane-pumpellyite assemblages that indicate a high pressure/low temperature metamorphic environment[20].

San Diego de los Banos (Zaza) zone

The San Diego de los Banos (SDB) zone occurs south of the Cangre belt and is separated from the latter by the Pinar fault. As the SDB zone consists of a thick Tertiary basin, and lies topographically lower than the Cordillera Guaniguanico, this suggests a considerable dip-slip component of displacement on the Pinar fault, although aleft lateral strike slip component has also been suggested.

Limited outcrop of pre-Tertiary rocks adjacent to the Pinar fault expose Cretaceous strata with tuffaceous and epiclastic layers. The presence of these rocks suggests that the basement of the San Diego de los Banos basin is correlatable with the Cretaceous island arc rocks (Zaza zone) of central Cuba[13].

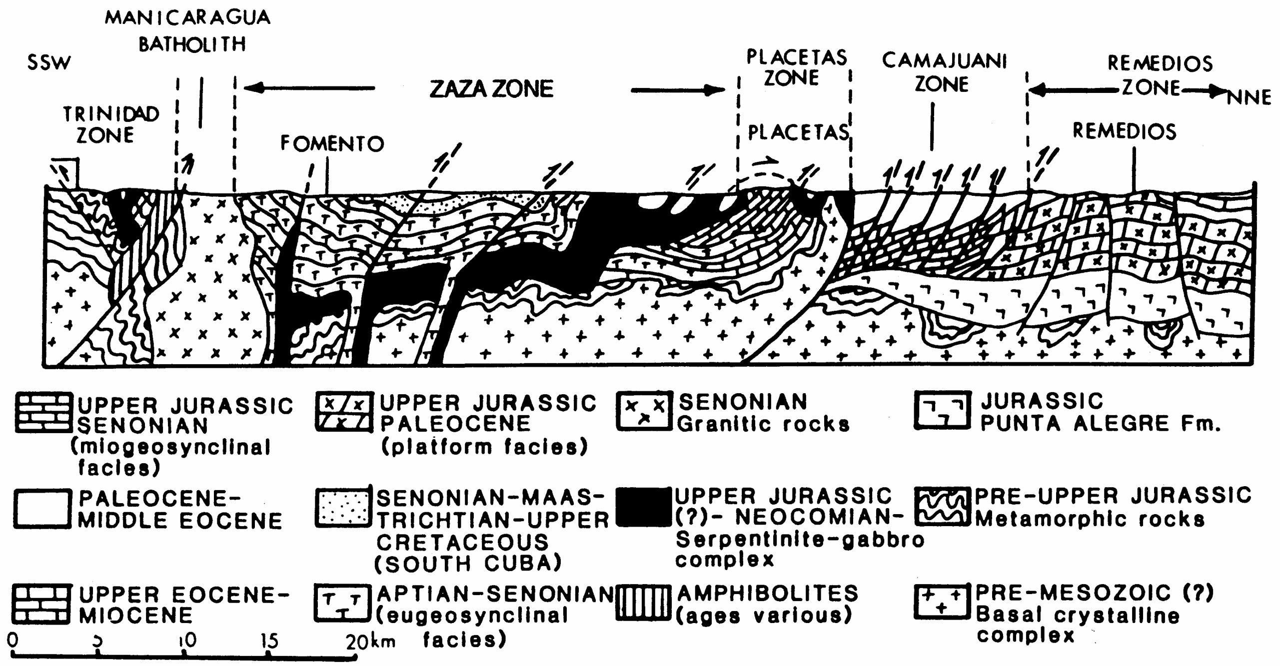

Figure 4.7. Schematic cross section across central Cuba (after Lewis[17]). See Figure 4.3 for approximate location.

ISLA DE LA JUVENTUD (ISLA DE PINOS) BLOCK

Most of the Isla de la Juventud consists of metamorphosed Mesozoic sedimentary rocks (Fig. 4.5). The lower part of the protolith sequence (Canada Formation) incorporates intercalations of micaceous and graphitic pelites with quartzose psammites. The middle part of the sequence (Agua Santa Formation) contains similar lithologies, but is characterized by increasing quantities of marble and calc - silicate beds. The upper part (Gerona Group) consists almost entirely of black to dark grey dolomitic marbles. A scarce and poorly preserved fauna indicates a Jurassic age and, therefore, the rocks may be correctable with the Jurassic San Cayetano and Cangre zone of the Cordillera de Guaniguanico (G. Millan, personal communication, 1990).

Overall, the metamorphism of the Jurassic rocks of Isla de la Juventud is of high temperature/medium pressure type, which contrasts with that of the Escambray and Purial regions (see below). Millan[20] divided the rocks of the terrane into 5 metamorphic zones, which are, in order of increasing metamorphic grade: greenschist (biotite zone) facies; staurolite-, kyanite- and garnet-bearing schists; staurolite and kyanite schists with occasional andalusite; garnet, kyanite and biotite schists with occasional sillimanite, and scapolite-bearing marbles; and sillimanite, garnet, pottassium-feldspar gneisses andmigmatites. Potassium-argon ages from muscovite indicate that the time of metamorphism of the Isla de la Juventud massif was about 55-66 Ma (late Cretaceous to early Tertiary[32]).

Some small plutons of unknown age intrude the metamorphic rocks in the northern part of the island. A small area of poorly exposed (and poorly dated) Cretaceous volcanic rocks outcrops in the northwest. Pliocene to Quaternary deposits compose the low-lying southern third of the island.

CENTRAL CUBA BLOCK

Central Cuba is divided into several structural facies zones (Fig. 4.6). Although most authors agree on the geology that occurs in these zones, several nomenclatural schemes have been proposed which has led to some confusion in the literature. Here we use the scheme of Meyerhoff and Hatten[19] and Hatten *et al.*[12]. Figure 4.7 shows schematic cross sections across central Cuba and illustrates the broad structural relations between the zones. The first four of the zones described below are composed mainly of continental margin, continental slope and pelagic sedimentary deposits.

Cayo Coco zone

The Cayo Coco zone has very limited exposure and most of the information concerning this zone comes from subsurface data derived from petroleum exploration wells. The oldest unit penetrated consists of Lower to Upper Jurassic evaporites of the Punta Allegre Formation (these evaporites have developed diapiric structures at several localities in north central Cuba). The evaporite sequence is overlain by Upper Jurassic to Cretaceous (Albian) shallow

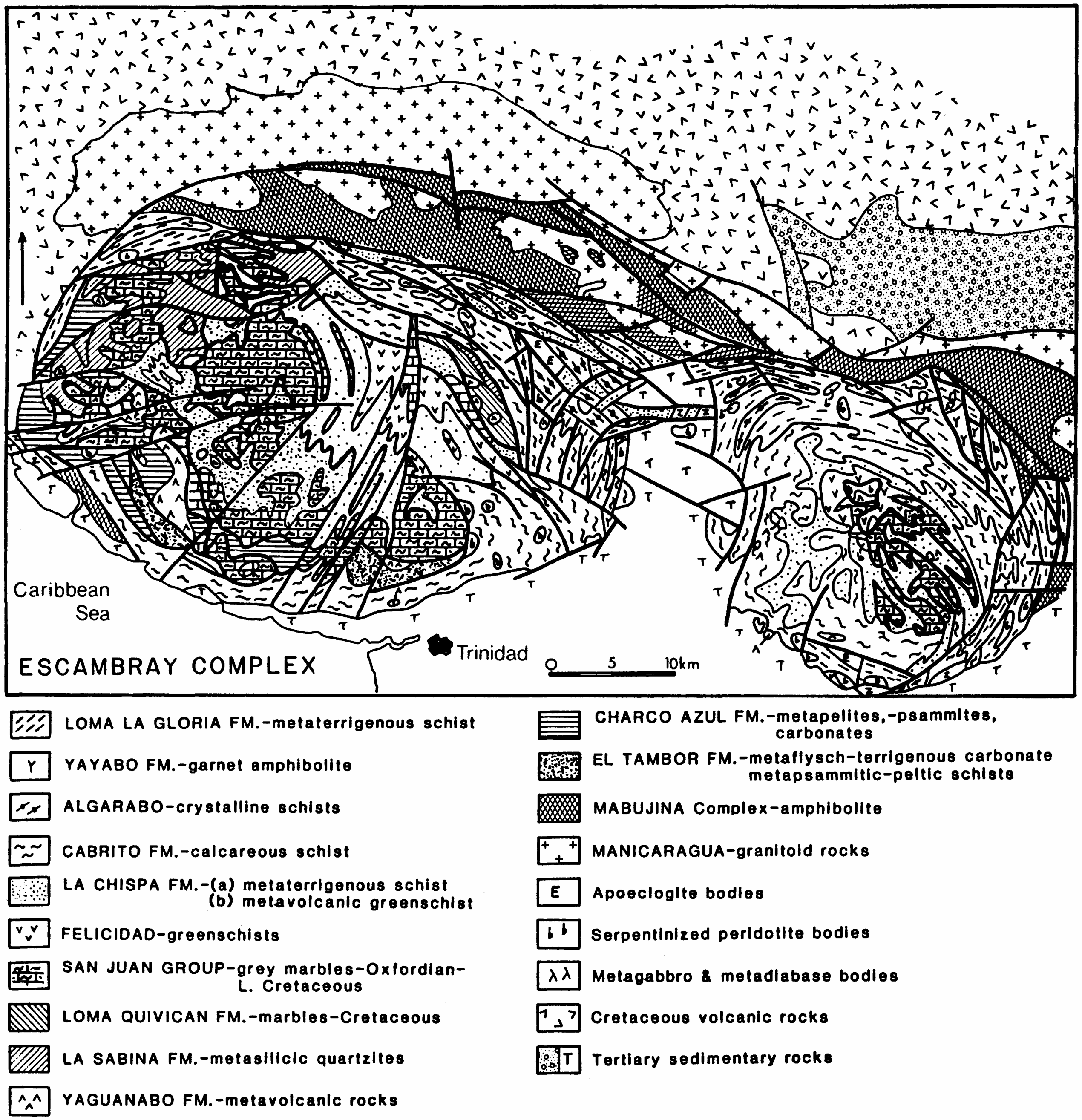

Figure 4.8. Geological map of the Escambray, Mabujina-Manicaragua and southernmost Zaza zones (from Lewis[17]).

water dolomites, anhydrites and oolitic limestones. These are overlain in turn by deeper water, intercalated shales, limestones and cherts of Aptian to Coniacian age. A major unconformity separates these units from Upper Maastnchtian to Middle Eocene marls, limestone breccias and shallow water platform limestones. Structurally, the Cayo Coco zone is characterized by diapiric structures developed in the evaporites, with considerable evidence of thrust faulting.

Remedios zone

This zone consists of a carbonate bank sequence of Upper Jurassic to Santonian age. This in turn is overlain by a thick sequence (about 2,000 m) of Maastrichtian to Paleo-

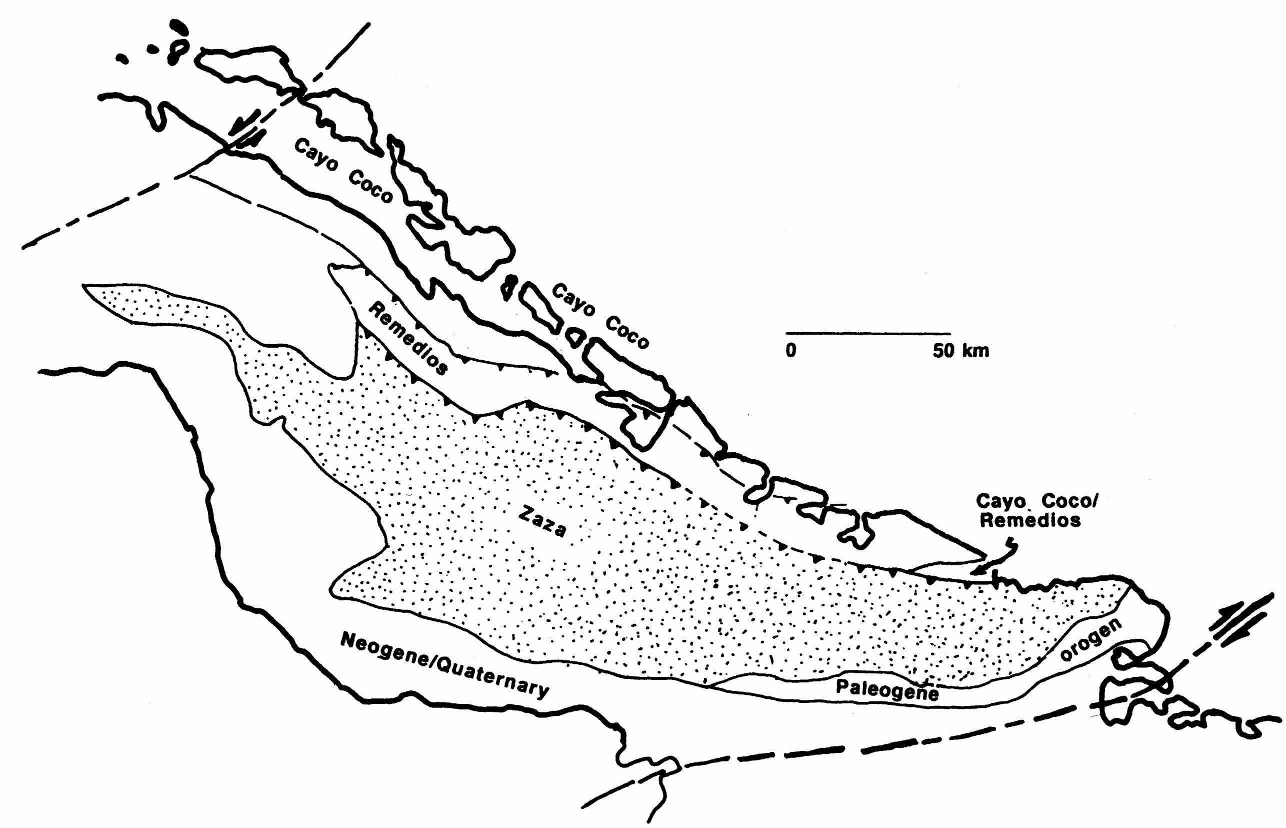

Figure 4.9. Structural facies zones of the Camaguey block. *Stippled area* indicates Jurassic ophiolite and Cretaceous andesitic rocks of the Zaza zone.

cene limestone breccias and shallow water limestones similar to those of the Cayo Coco zone. A clastic unit consisting of Lower Eocene greywackes also occurs. High angle thrust faults, often with a right lateral strike slip component, cut through the limestones of the Remedios zone.

Camajuani (Zulueta) zone

The lower part of the sedimentary sequence of the Camajuani zone (Zulueta zone of Hatten *et al*) consists of a continuous sequence of Upper Jurassic to low Upper Cretaceous, deep-water limestones with intercalations of clastic limestones. These clastic limestones contain a shallow-water fauna and were presumably washed in from a nearby shallow carbonate bank (probably the Remedios zone).

An angular unconformity separates the lower sequence from an overlying Maastrichtian to Middle Eocene sequence of polymictic olistostromic conglomerates. Clasts are derived from the pelagic limestones of the Las Villas zone as well as shallow-water clasts from the Remedios zone (the latter make up about 70% of the clasts). The conglomerate is overlain in turn by a thinner sequence of Middle Eocene calcarenite and coquina beds. The final unit represented is a thick sequence of olistostromic conglomerates ('wild-flysch') considered to be upper Middle Eocene. Most Cuban geologists consider this deposit to mark the final movements of the Cuban orogeny. The deformation in the Camajuani zone is intense, consisting of tight, often steeply plunging folds. Both thrust and belt orthogonal tear faults are present.

Placetus (Las Villas) zone

The Placetus zone (Las Villas zone of Hatten *et al*[12]) occurs as sporadic outcrops from near Havana (the Martin Mesa tectonic window) to central Camaguey and often occupies tectonic windows beneath the allochthonous ophiolites of the Zaza zone. There are many lateral variations in the deposits of this belt. In some places, the base of the sedimentary sequence consists of quartzose and arkosic sandstones and conglomerates which are possibly Upper Jurassic; in others the base consists of Tithonian (Upper Jurassic) radiolarian, pelagic limestones. Overlying this is a series of Lower Cretaceous pelagic cherts, limestones and shales. Maastrichtian breccias were disconformably(?) deposited on the Lower Cretaceous pelagics.

Ophiolitic rocks occur in parts of the zone, and some controversy exists concerning the age and nature of these

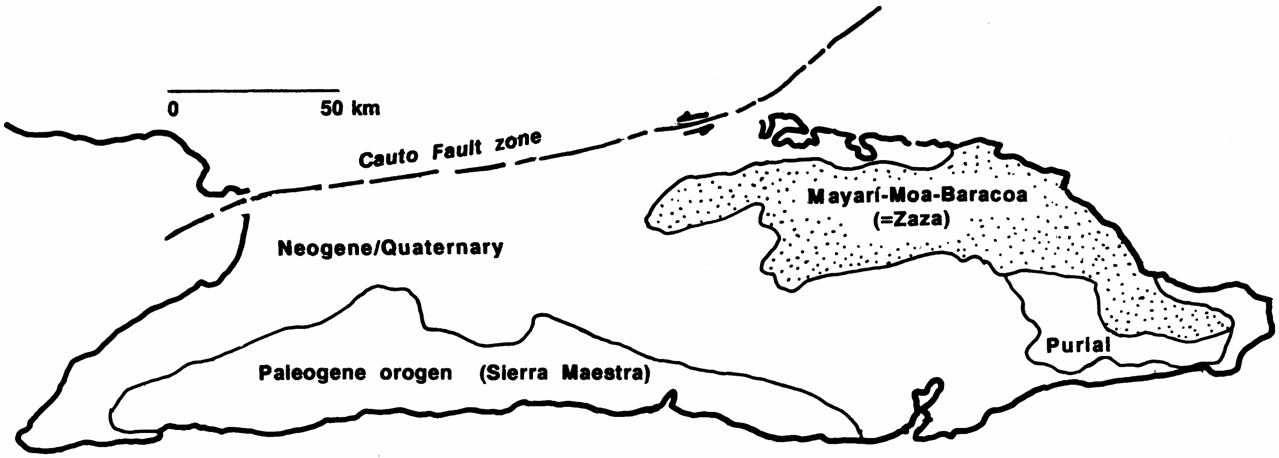

Figure 4.10. Structural facies zones of eastern Cuba. *Stippled area* indicates Jurassic ophiolitic and Cretaceous andesitic rocks of the Zaza zone. Metamorphic and magmatic zones of the Cretaceous Purial and Sierras Maestra zones (respectively) are also shown.

units. Some ophiolitic rocks are clearly part of the Zaza zone (see below), and are cut by dykes and granitoid stocks that have an island arc geochemical signature[12]. However, some authors have suggested that a second basaltic sequence that is not cut by granitoids may occur beneath the Jurassic sedimentary sequence. This has been interpreted as the basaltic portion of ocean crust. J.A.B. is doubtful of the existence of this second proposed basaltic occurrence.

A remarkable metamorphic, pre-Mesozoic basement is exposed in at least three areas of the Placetas zone, and consists of marbles, mylonitic schists and granitoids. Somin and Millan[33] reported controversial K-Ar mica ages of 910 and 945 Ma from schists near to the village of Sierra Morena. However, these Precambrian ages were confirmed by Renne *et al.*[29], who obtained $^{40}Ar/^{39}Ar$ ages of 903 Ma from phlogopite in marbles of the Socorro Complex situated in the northwestern part of the Placetas zone. These very old rocks are intruded by granitoid plutons of early Cretaceous age[29,33]. Deformation within the Placetas zone is complex and is characterized by tight isoclinal folds and repetition of sequences by steeply dipping thrust faults.

Zaza zone

In contrast to the continental margin or 'miogeosyncli-nal' deposits of the structural-facies zones of north-central Cuba (see above), the Zaza zone contains Jurassic to mid-Cretaceous igneous rocks of oceanic and island arc ('eugeo-synclinaT) origin. Although originally defined for central Cuba, many Cuban geologist use the term Zaza zone to refer to all pre-middle Cretaceous igneous rocks throughout Cuba.

The lowest structural unit recognized in the Zaza zone outcrops its the northern margin, adjacent to the Las Villas thrust (which separates the Zaza zone from the Placetas zone). This unit is a highly sheared serpentinite melange containing high pressure/low temperature schists and eclo-gites. Lying above it is an interlayered serpentinite, gabbro and dolerite complex. Somin and Millan[33] reported a K-Ar age of 160 Ma (middle Jurassic) from an anorthosite in this complex. These two units are part of the Cuban ophiolite belt which characterizes northern Cuba. We interpret this unit as the oceanic basement of the overlying island arc volcanic sequence.

Overlying the mafic and ultramafic rocks is a pile of porphyritic, basaltic and andesitic lavas (occasionally pil-lowed), overlain in turn by a sequence of tuffs and epiclastic sedimentary rocks with interbedded pelagic and shallow-water rudist limestones. The age of this volcanic-sedimen-tary sequence is Aptian-Albian to Campanian[4,26]. This interval represents the period of island arc magmatism in the Zaza zone thoughout Cuba. Uppermost Cretaceous to Pa-leogene sedimentary rocks overlie the volcanic sequence in the Zaza zone, and are composed mainly of flyschoid grey-wackes and calcarenites with localized conglomerate and breccia deposits.

Mabujina-Manicaragua zone

The Mabujina complex, a large mass of amphibolite which is intruded by numerous granitoid bodies, lies to the north of the Escambray complex (Fig. 4.8). In addition, Mabujina amphibolites also occur at the southwestern rim of the Trinidad dome and the eastern part of the Sancti

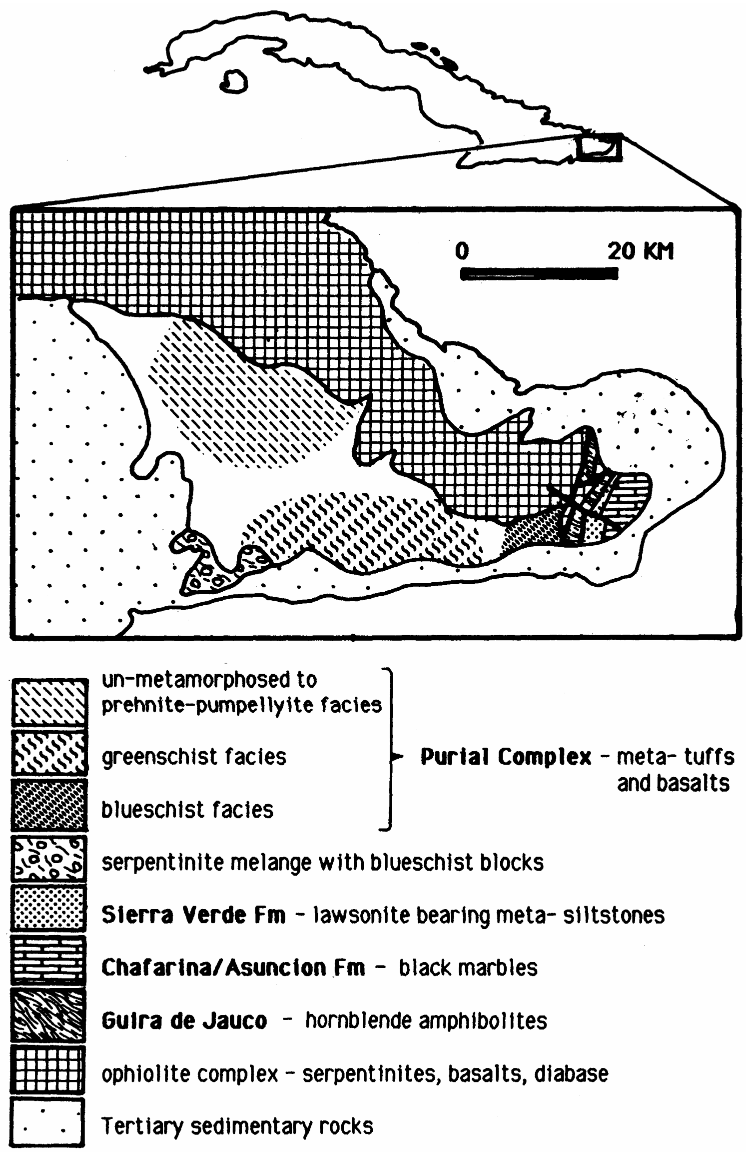

Figure 4.11. Geological map showing details of the Purial zone.

Spintus structure. This suggests that the Mabujma complex may have structurally overlain the entire Escambray complex prior to the doming. Whole rock K-Ar ages of 76-89 Ma have been obtained, although the younger end of this range may represent cooling ages after the intrusion of the Manicaragua granitoids (see below). The age of the protolith of the Mabujina complex is unknown. The Mabujina amphibolites have been interpreted as the oceanic basement of the Zaza arc (Millan and Iturralde-Vinent, personal communications), an opinion with which we concur. If this is correct, the Mabujina complex is perhaps correlatable with the Jurassic mafic and ultramafics rocks that outcrop in the northernmost parts of the Zaza zone.

The Manicaragua unit proper is a granitoid batholith that both intruded, and outcrops to the north of, the Mabujina amphibolite. Mapping indicates that it is also intrusive into Middle Cretaceous sedimentary rocks of the Zaza zone, indicating a late Cretaceous intrusive age. This is also indicated by isotopic data. A U-Pb zircon date of 89 Ma (Turonian) was reported by Hatten *et al.*[12], who considered this to represent the intrusion age of the body. K-Ar ages on biotite and hornblende are 69-73 and 69-95 Ma, respectively. These may represent cooling ages. Strontium isotope studies show that initial Sr isotope ratios are all below 0.7040, indicating no continental contamination for the Manicaragua granitoids (that is, an intra-oceanic island arc origin).

Escambray Complex

The Escambray complex occurs as two structural

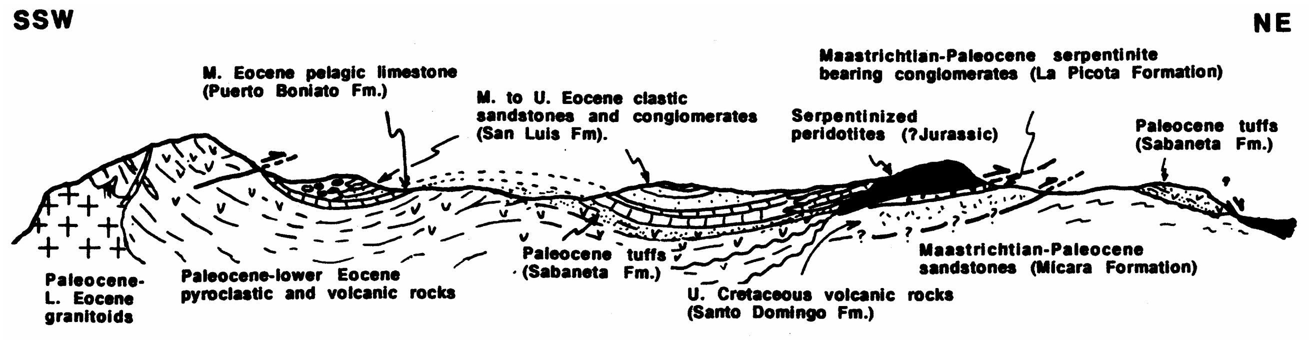

Figure 4.12. Sketch section from the eastern Sierra Maestra to the Mayari-Moa-Baracoa zone (after Cobiella, personal communication). See Figure 4.3 for approximate location. Not to scale.

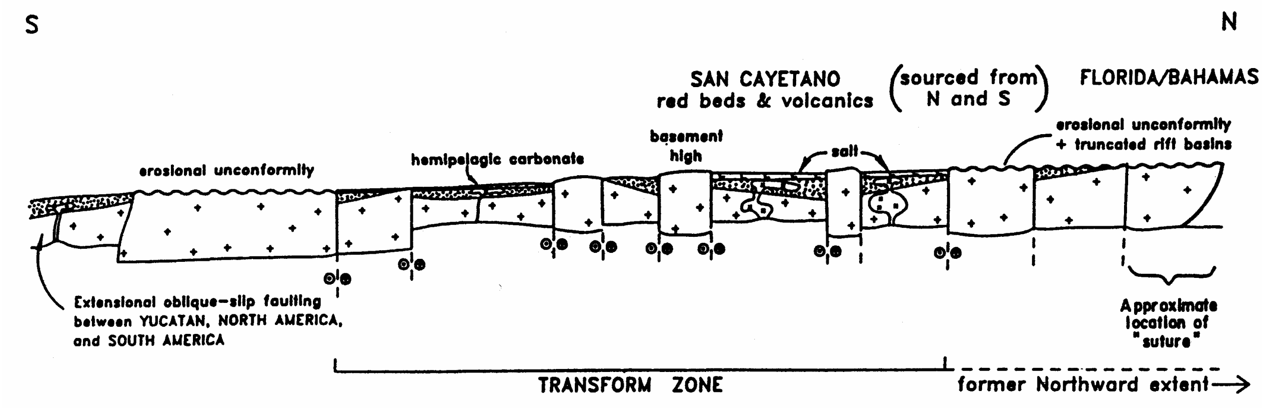

Figure 4.13. Oblique, sinsistral rifting of North and South America occurred in the middle Jurassic to form the Cuban passive margin on the southern boundary of North America.

domes or 'cupulas' (Fig. 4.8), that is, the western Trinidad dome and the eastern Sancti Spiritus. Lithologically, the complex consists of pelitic and psammitic schists and marbles, which represent a metamorphosed terrigenous carbonate terrane. Exotic lenses and pods of serpentinized peridotite, eclogite and garnet blueschist occur within the sedimentary rocks around the margins of both domes. Ammonite and radiolarian faunas discovered in less deformed parts of the Escambray complex indicate a late Jurassic (Oxfordian) age for the sedimentary protolith of the complex, that is, about the same age as the San Cayetano Formation of western Cuba (Millan, personal communication). Granitoid intrusions do not occur in the central parts of Hie Escambray complex.

The metamorphism of the Escambray complex is inverted and pre-dated the doming of the complex[22], and therefore a concentric pattern was produced by the zoning. Thus, the lowest grade rocks are also structurally the lowest and are found at the centre of the domes, with the highest grades being encountered at the margin.

A mica K-Ar age of 80 Ma[22] from a pegmatite cutting the complex gives a minimum age for metamorphism, and Halten *et al.*[12] reported an 85 Ma age from an eclogite (but give no details of the determination). Metamorphism seems to have taken place sometime during the Turonian to Campanian interval.

CAMAGUEY BLOCK—EAST CENTRAL CUBA

The Camaguey block is bounded on the west by the La Trocha fault and the east by the Cauto Fault (Figs 4.3, 4.9). Although there are similarities with the geology of central Cuba, there are also some significant differences. For example, the Escambray, Manicaragua-Mabujina, Camajuani and Placetas zones do not have significant outcrops in Camaguey (although the Camajuani and Placetas zones are encountered in windows in the ophiolite and in the subsurface), and the width of outcrop of the Zaza zone is much greater than in central Cuba.

Cayo Coco and Remedios zones

The Cayo Coco and Remedios zones outcrop in the Sierra de las Cubitas in northern Camaguey and the strati-

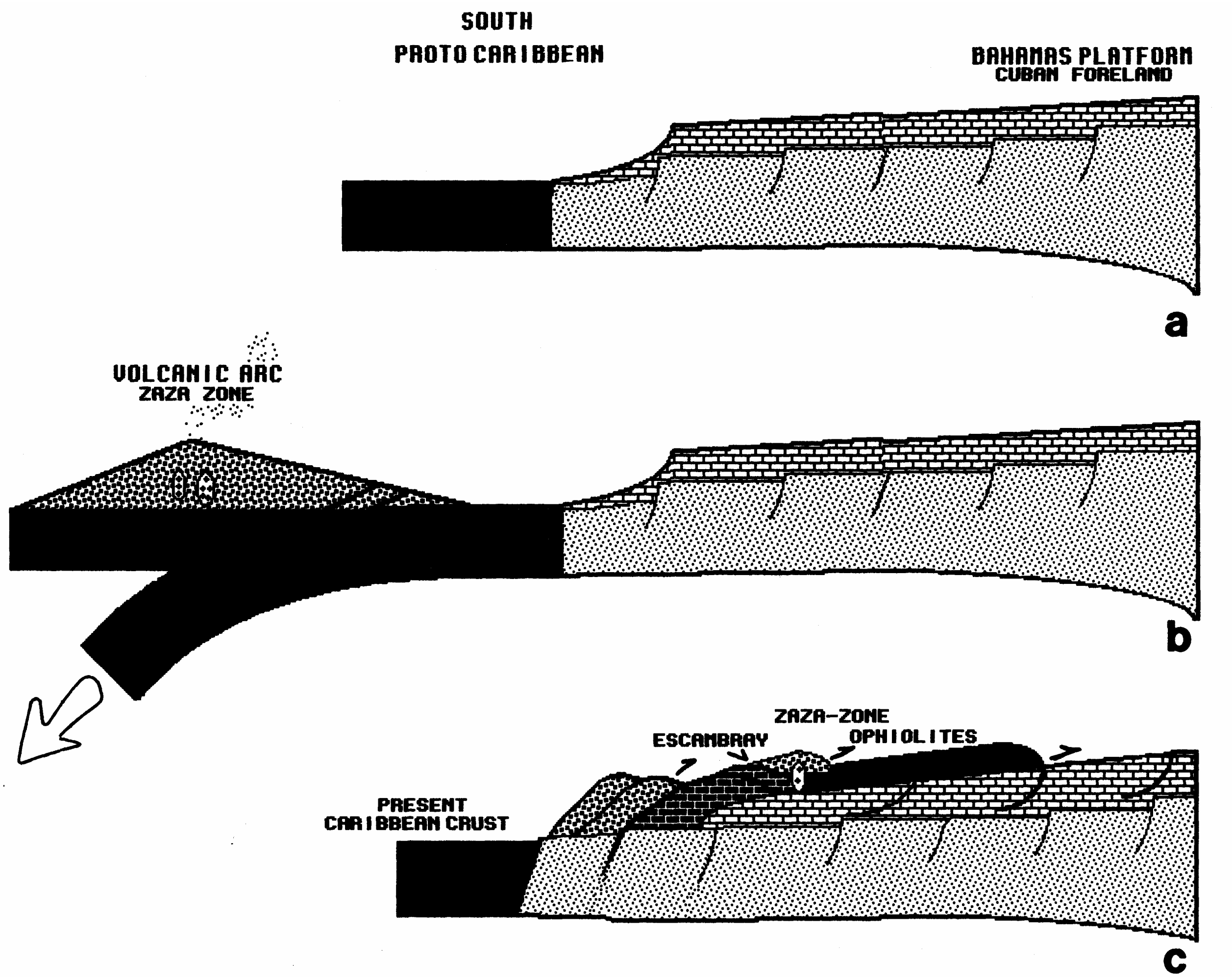

Figure 4.14. Tectonic model of the collision of a north-facing island arc (Zaza zone) with the Cuban passive margin, (a) The Cuban passive continental margin in the late Jurassic-early Cretaceous, (b) The approach of the island arc in the middle Cretaceous, (c) Approximate configuration after the late Cretaceous-early Tertiary collision.

In this model, the Zaza zone is considered totally allochthonous and overrides the passive margin; the Cuban ophiolite belt is interpreted as the forearc and/or oceanic basement of the arc.

graphy of the zones is essentially the same as in central Cuba. The main difference between the two areas is the age of the Cenozoic deformation. In central Cuba, this deformation began in the early Eocene, but in Camaguey it was initiated in the middle Eocene.

Zaza zone

The Zaza zone is separated from the continental margin sedimentary rocks to the north by a serpentinite melange, as in central Cuba. The stratigraphic range of the volcanic units is essentially the same as for central Cuba. However, the outcrop of both the ophiolitic and arc parts of the Zaza zone in Camaguey are broader than in central Cuba. Another major difference of Camaguey is the presence of several large plutons which intrude the volcanic rocks in northern and southern belts. The northern belt contains bimodal plutons of early Cretaceous age, but the southern belt ranges in age from Coniacian to late Campanian (Stanek, personal communication).

Paleogene Orogen

The El Cobre Group is a sequence of Paleocene to Middle Eocene andesitic volcanic and sedimentary rocks that outcrop extensively in the Sierra Maestra of southeastern Cuba Extensive outcrops of the El Cobre Formation also occur in the southern part of the Camaguey block. According to Mossakovsky *et al* [24], the largest area is occupied by the limestones and clastic sedimentary rocks, which are distal to the main volcanic locus and are probably also equivalent to the upper part of the group of the Sierra

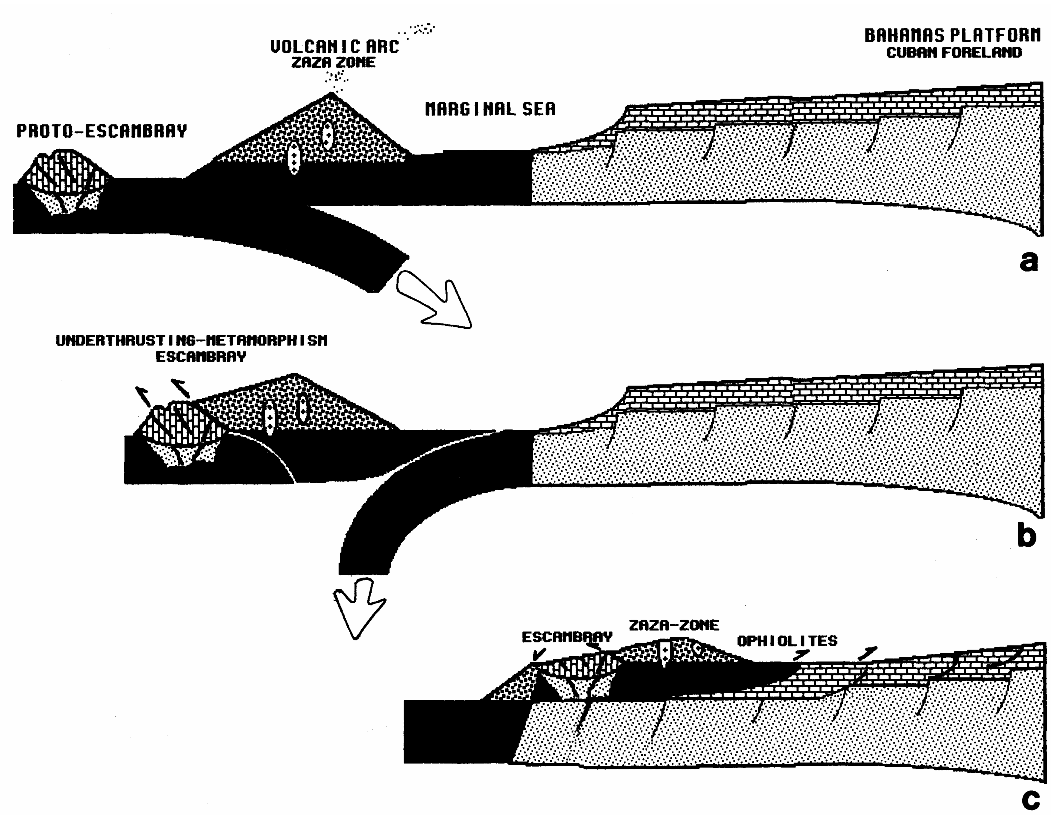

Figure 4.15. Tectonic model of the collision of the Escambray terrane with an initially south-facing island arc, followed by emplacement of the back arc and arc onto the Cuban passive margin, (a) The approach of the Escambray terrane in the mid Cretaceous, (b) Collision and attempted subduction of the Escambray terrane with the Zaza arc in Campanian time, causing high pressue metamorphism of the former. The collision may have blocked the subduction zone and initiated a short period of underthrusting of the back arc basin beneath the arc which finally resulted in (c) the emplacement of the arc and ophiolite on the passive margin.

In this model, the Cuban ophiolite belt is interpreted as part of the back arc basin and/or the oceanic basement of the rear of the arc.

Maestra. The lower, volcanic part of the sequence is found only in the easternmost part of Camaguey.

ORIENTE BLOCK

The geology of Oriente differs from central Cuba in three major respects: except for a small outcrop of metamorphic rocks, no rocks of continental provenance are known; in addition to rocks of the Mesozoic orogen, eastern Cuba also contains rocks formed in a Paleogene island arc setting, which is here called the Paleogene orogen (Iturralde-Vinent, personal communication); and diastrophism and diastrophically controlled sedimentation may have continued to the Oligocene or younger.

For the purposes of this discussion we have divided the geology of the area into three structural-facies zones (Fig. 4.10), the first two of which form part of the Mesozoic orogen, and because of their dominantly igneous nature might be regarded as part of the Zaza zone[2].

Purial zone

The Purial zone consists of three units of regionally metamorphosed rocks that outcrop in the eastern part of Cuba and is made up of several units (Fig. 4.11). In the extreme east, a complex of black marbles and sericite schists occurs. On the basis of their lithology, these rocks have been correlated with those of the Escambray region; consequently, a protolith age of Jurassic-early Cretaceous has been suggested for them, but no direct evidence has yet been discovered for this date. A major fault separates the marble-schist complex from the Purial Complex to the west. A small

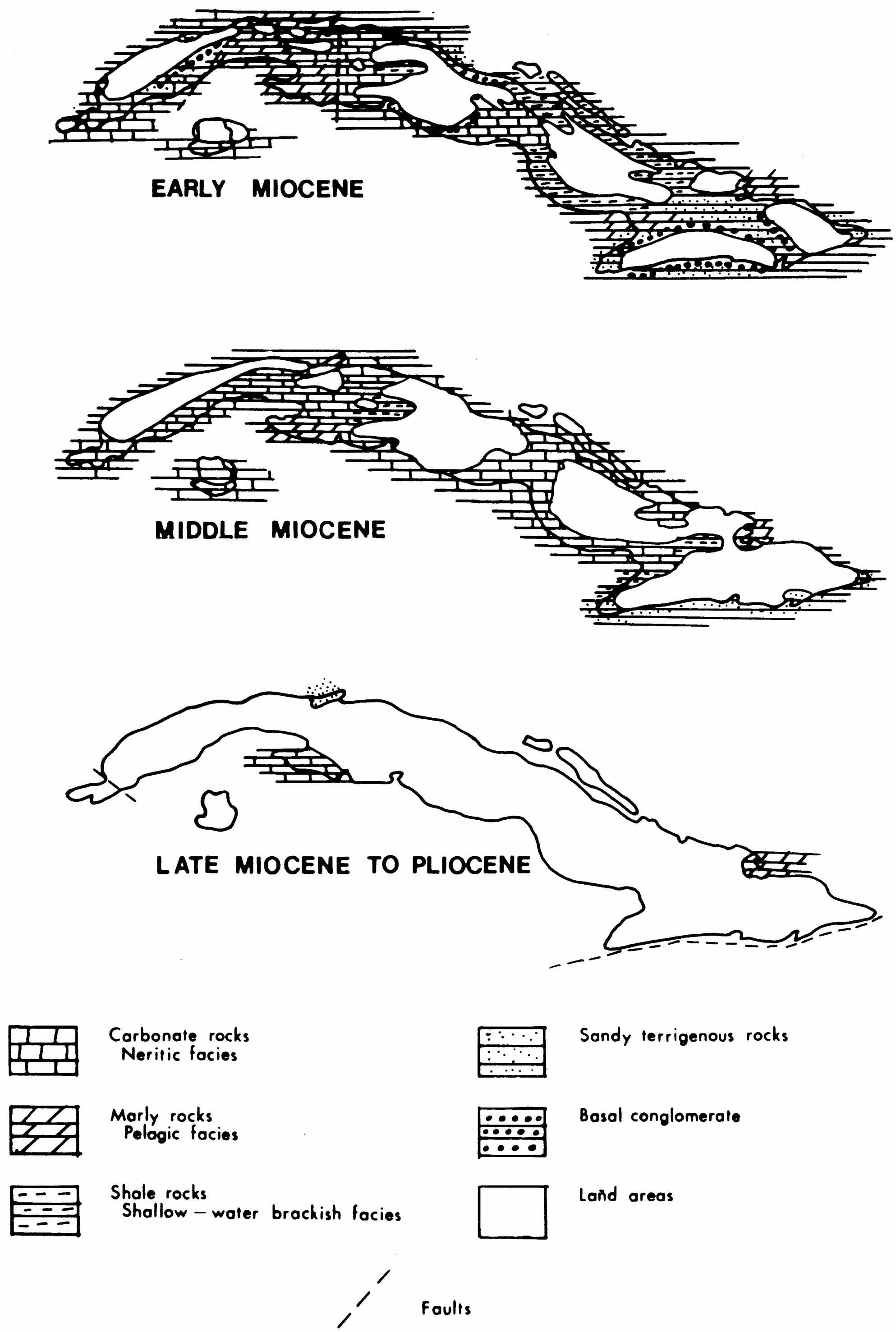

Figure 4.16. Palaeogeography of Cuba in the Miocene to Pliocene.

complex of garnet-amphibolites, ultramafics, gabbros and dolerites occurs to the west of the fault, and may compose part of the Purial Metamorphic Complex proper.

The Purial Metamorphic Complex consists of a large area of high-pressure, low-temperature blueschist and greenschist facies rocks. Most of the protolith consists of lavas, tuffs and volcanogenic sedimentary rocks with occasional limestones. Microfossils in the sedimentary rocks indicate a Campanian age. Rocks in the eastern and northeastern part of the complex are barely metamorphosed, and metamorphic grade generally increases toward the southwest. Unmetamorphosed Maastnctian age rocks of the Rio

Cana Formation unconformably overlie the Purial rocks, suggesting that burial, metamorphism and subsequent unroofing of the complex must all have occurred in the Campanian to Maastrictian, an interval of less than 20 million years.

The Sierra del Convento melange, at the southwest corner of the Purial complex, is a serpentinite matrix melange and contains blocks of blueschist and amphibolite. The blocks have not been dated and their age is unknown.

Mayari-Moa-Baracoa zone

This zone outcrops in the northern part of Oriente province and is dominated by the two large ophiolite bodies of Nipe-Cristal and Moa-Baracoa (Figs 4.10, 4.12). Neither of these bodies exhibits a complete ophiolite sequence as they consist mainly of serpentized harzburgite (with minor Iherzolites and wherlites) with gabbros and dolerite. The age of these bodies is not known, but they are thought to be Upper Jurassic to Lower Cretaceous. The Nipe-Cristal body is associated with a high pressure/low temperature serpentinite melange which outcrops to the south of the ophiolite (Cobiella, personal communication).

The oldest Cretaceous rocks in this zone are poorly dated Albian?-Turonian mafic volcanic rocks of the Santo Domingo Formation. These are considered by many Cuban geologists to be equivalents of the weakly metamorphosed part of the Purial Complex.

Upper Campanian to Maastrichtian serpentinite conglomerates (La Picota Formation) overlie the volcanic sequence, and these are thought to have been deposited as olistostromes in front of the northward advancing Nipe-Cristal ophiolite thrust sheets; they therefore time the age of emplacement of the ophiolite. The conglomerates interdigitate with, and are ultimately overlain by, Upper Campanian to Maastrichtian (possibly lowermost Paleocene), rhythmically-bedded sandstones and siltstones (Micara Formation). The rocks overlying the Micara Formation are pyroclastic and sedimentary rocks are associated with the Paleogene orogen.

Paleogene Orogen—Sierra Maestra zone

The Sierra Maestra was the locus of Paleocene to middle Eocene island arc magmatism. Island arc magmatism ceased at the end of the Campanian elsewhere in Cuba, and in this sense the geology of southern Oriente is more like that of northern Hispaniola, where island arc magmatism also persisted until the middle Eocene.

The single most important unit in this zone is the El Cobre Group (previously Cobre Formation) which consists of a thick sequence of waterlain tuff and agglomerate deposits with subordinate lavas and sedimentary rocks. The upper part of the El Cobre Group consists of greywackes (San Luis Formation) and pelagic to neritic limestones (Puerto Boniato Formation). On the south coast of Oriente, the lower part of the El Cobre Group is intruded by low potassium granitoids (Fig. 4.11). K-Ar ages of 46 and 58 Ma indicate an early to middle Eocene intrusive age.

TECTONIC EVOLUTION OF CUBA

An understanding of the tectonic evolution of Cuba in terms of the plate dynamics of the northern Caribbean is obviously crucial to any explanation of the tectonic evolution of the Caribbean region as a whole. Despite progress in understanding the timing of events, many aspects of the tectonic evolution of Cuba, especially the geometry and kinetics of the various crustal movements, remain elusive.

It is clear from the above discussion that Cuba comprises five major components:

(1) A Jurassic to Lower Cretaceous continental margin and slope sequence deposited on both continental and oce anic crust (western Cuba, Cayo Coco/Remedios/Zulueta/Placetas zones of central Cuba and Camaguey).
(2) A Lower to low Upper Cretaceous island arc complex built upon a Jurassic oceanic basement (Zaza zone throughout the island).
(3) Jurassic continental slope deposits that outcrop south of the island arc complex (Escambray and Isla de la Juventud).
(4) A Paleogene island arc complex (Sierra Maestra).
(5) Middle Eocene to Recent, post-orogenic sedimentary deposits.

Any explanation of the tectonic evolution of Cuba must explain the origin and present structural states of these units.

The Mesozoic Orogen—-western and central Cuba

Continental margin deposits began to accumulate in Cuba during the subsidence resulting from the rifting of South from North America during the Jurassic (the earliest deposits were probably the deltaic sediments of the San Cayetano Formation). The age of the basement of this passive margin is uncertain. The Socorro complex[29] is Grenville in age (approximately 1,000 Ma, the same as that of a large area of the North American continent east of the present Appalachian mountain chain) and this may suggest that at least part of the Cuban basement is Grenvillian. Alternatively, the contintental basement may have a Pan-African age (400-500 Ma) as suggested by the age of basement encountered at the base of an ODP hole drilled in the Gulf of Mexico northeast of Cuba.

Further lithospheric extension between North and

South America resulted in the formation of oceanic crust between the two continents (the 'Proto-Caribbean' of Pindell, *Chapter* 2, this volume). On the northern boundary, a passive continental margin sequence developed. Carbonate banks accumulated on the subsiding, stretched continental crust and deeper water, continental slope deposits probably prograded southward onto oceanic crust.

In the early Cretaceous, an island arc system (Zaza zone) began to develop somewhere south or west of the continental margin, possibly in the Pacific realm (Pindell, Chapter 2, this volume). In about the Campanian this arc system collided with the continental margin and began to create the Cuban orogen. The evidence for this comes from the Campanian metamorphic ages of the Escambray (and possibly the Purial) metamorphics, and the presence of clasts of volcanic rock in Cenomanian passive margin sedimentary rocks. However, the exact geometry of this collision is obscure and two possible scenarios have been proposed:

1. The arc faced north (that is, the suduction zone dipped south), and ocean floor was subducted between the passive margin and the arc (Fig. 4.13,4.14). When all of the ocean had been subducted, the arc collided with the passive margin, and completely overode it. In this scenario, the Zaza zone is completely allochthonous, and the Escambray region represents the structurally imbricated edge of the passive margin whose inverted metamorphism resulted when the arc overode the complex. The Isla de la Juventud would presumably have been overridden in the same event. The ophiolites of central and western Cuba would represent fragments of the oceanic basement beneath the arc and/or the Proto-Caribbean ocean crust.

There are several problems with this model. It fails to explain the location, metamoiphism (high temperature/low pressure) and plutonism in the Isla de la Juventud. Moreover, an entire island arc would have to be detached and thrust over 200 km (a hypothesis that G.D. feels is mechanically unreasonable). The tectonic provenance and metamorphism of the Purial Complex also remains unresolved in this model.

2. In the second scenario (Fig. 4.15), the arc was south-facing and a small ocean basin separated it from the passive margin[30] (Iturralde-Vinent, personal communication). The collision event would have resulted when buoyant (unsubductable) ocean crust, represented by the Escambray and Isla de la Juventud blocks, entered the subduction zone. As a result the Escambray (and Purial?) rocks were metamorphosed to blueschist facies under the fore-arc, the ocean basin behind the arc was thrust onto the passive margin, and subduction ceased. In this scenario the Cuban ophiolites represent fragments of the basement beneath the arc and/or the small, marginal basin, but not the major Proto-Caribbean ocean floor.

As with the first model, there are problems. The model implies that the Isla de Juventud and Escambray are separate continental fragments, and while this may be the case, their tectonic provenance and evolution is unclear. There is little evidence of volcanic material in the sedimentary rocks of the northern passive margin sequences before the Cenomanian[27], which is at least 20 Ma after the beginning of arc activity. It is also difficult to explain the presence of high pressure/low temperature metamorphism in the Cangre zone.

Paleogene Orogen—eastern Cuba

Subduction-related magmatic activity apparently ceased with this Campanian collisional event, as no evidence of Maastrichtian magmatism is known in Cuba. Magmatic activity resumed in the Paleocene, but only in eastern Cuba, where the locus of activity was the Sierra Maestra, although some pyroclastic deposits are found in the south-eastern Camaguey and northern Oriente. The Paleogene magmatic terrane terminates abruptly at the Cayman fault (the northernmost fault of the northern Caribbean plate boundary zone—NCPBZ) on the southeastern coast of Cuba. This has led to the speculation by several authors[1,3,5-7] that the Paleogene arc of Cuba was related to, and contiguous with, similar rocks in Hispaniola, and that latest Paleogene to Neogene left-lateral strike-slip on the NCPBZ has subsequently separated the two regions (that is, dispersed the Paleogene terrane).

An explanation of the Paleogene arc (orogen) remains an outstanding problem of plate geometry and kinematics. The Paleogene arc was deposited upon the Mesozoic orogenic rocks of Oriente which seem to have been already attached to the southern margin of the North American plate. To produce arc activity means the subduction of significant quantities of ocean crust. Since there is only continental crust to the north, then a south-dipping subduction zone seems an unlikely explanation. Equally there appears to be no evidence of a Paleogene, north-dipping subduction zone (major accetionary complex or blueschist complex) south of Cuba or in Hispaniola. The only possible candidate might be the Trois Rivieres-Peralta belt of Hispaniola (see Draper *et al*., Chapter 7, this volume).

The plate kinematic cause of the early Eocene (second phase) deformation in central Cuba also remains obscure, but may have been associated with the movement of the Caribbean plate into the meso-American region and the opening of the Yucatan basin (although this was an extensional, not a compressional, event).

Mid-Eocene to Recent

From the middle Eocene to the present, much of Cuba has been (relatively) tectonically quiescent. By examining later Paleogene and Neogene sedimentary deposits, Itturalde-Vinent[14,15] determined that post-orogenic Cuba consists of a series of differentially subsiding horsts and grabens (Fig. 4.16). Subsidence was most rapid and widespread during the late Eocene and Oligocene, but continued through the Miocene and Pliocene in several areas. Pleistocene to Recent sedimentation was of moderate extent.

The major, post-orogenic tectonic activity was, and is, south of Oriente on the Oriente transform fault system that separates Cuba from the present Caribbean plate. As mentioned above, several authors consider that southeastern Cuba and northern Hispaniola were once continuous, although the precise palaeogeography is still uncertain. It is also unclear as to when this separation began. Extensive clastic sedimentation, probably related to rapid uplift and erosion, began in the middle to late Eocene in both southeastern Cuba and northern Hispaniola. We suggest here that this was the time of initiation of the separation of the two areas. Extrapolation of the spreading rates in the Cayman Trough[31] also suggests that major motion on the Cayman transform fault also began at this time[5-7]. Motion continues on this fault and the region is seismically active.

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APPENDIX 1

Map symbols used in Cuban literature

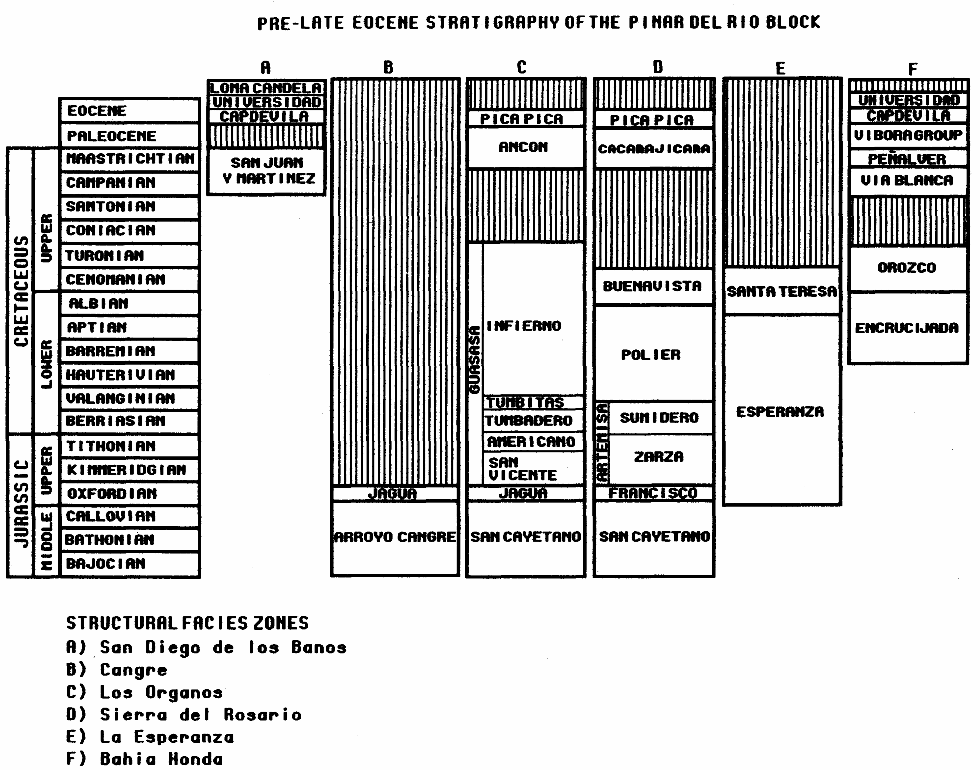
Many maps, sections, columns and diagrams of Cuban geology use a different notation for the ages of rocks than is otherwise used in the literature of the Caribbean and North and South America. The notation principally derives from a system developed in eastern Europe. It is presented here for those readers who may wish to delve deeper into the Cuban literature.

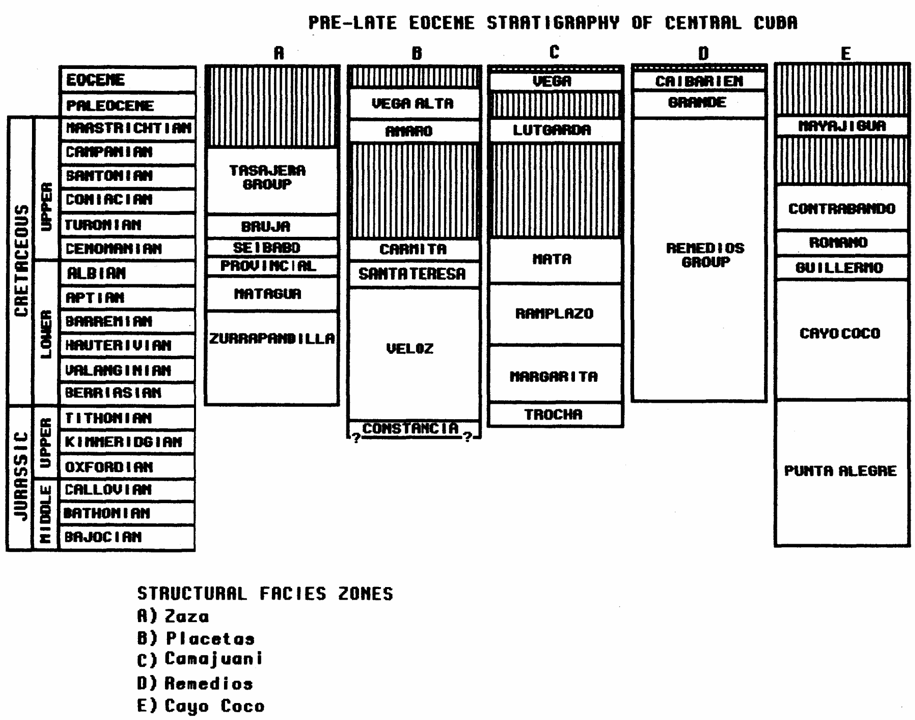
System	Series	Stage
Quaternary (**Q**)	Holocene ($\mathbf{Q_2}$)	
	Pleistocene ($\mathbf{Q_1}$)	
Neogene (**N**)	Pliocene ($\mathbf{N_2}$)	
	Miocene ($\mathbf{N_1}$)	
Paleogene (**P**)	Oligocene ($\mathbf{P_3}$)	
	Eocene ($\mathbf{P_2}$)	
	Paleocene ($\mathbf{P_2}$)	
Cretaceous (Upper) ($\mathbf{K_2}$)		Maastrichtian ($\mathbf{K_2m}$)
		Campanian ($\mathbf{K_2cp}$)
		Santonian ($\mathbf{K_2st}$)
		Coniacian ($\mathbf{K_2cn}$)
		Turonian ($\mathbf{K_2t}$)
		Cenomanian ($\mathbf{K_2c}$)
		Albian($\mathbf{K_1al}$)
Cretaceous (Lower) ($\mathbf{K_1}$)		Aptian ($\mathbf{K_1ap}$)
		Barremian ($\mathbf{K_1bm}$)
		Hauterivian ($\mathbf{K_1h}$)
		Valanginian ($\mathbf{K_2v}$)
		Berrasian ($\mathbf{K_1b}$)
Jurassic (Upper) ($\mathbf{J_3}$)		Tithonian ($\mathbf{J_3t}$)
		Kimmeridgian ($\mathbf{J_3k}$)
		Oxfordian ($\mathbf{J_{30}x}$)
Jurassic (Middle) ($\mathbf{J_2}$)		Callovian ($\mathbf{J_2ca}$)
		Bathonian ($\mathbf{J_2bt}$)
		Bajocian ($\mathbf{J_2bj}$)

Series and stages can be further subdivided by adding superscripts to the symbols. For example, Lower, Middle and Upper Eocene rocks would be denoted as $\mathbf{P_2^1}$, $\mathbf{P_2^2}$ and $\mathbf{P_2^3}$, respectively.

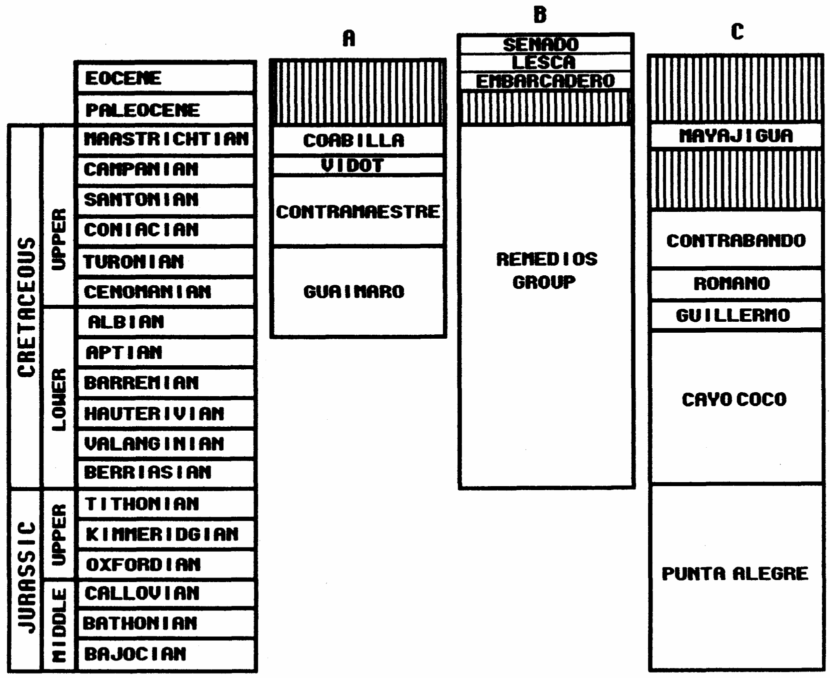
APPENDIX 2

Sub-Upper Eocene formations in the structural facies zones of the four



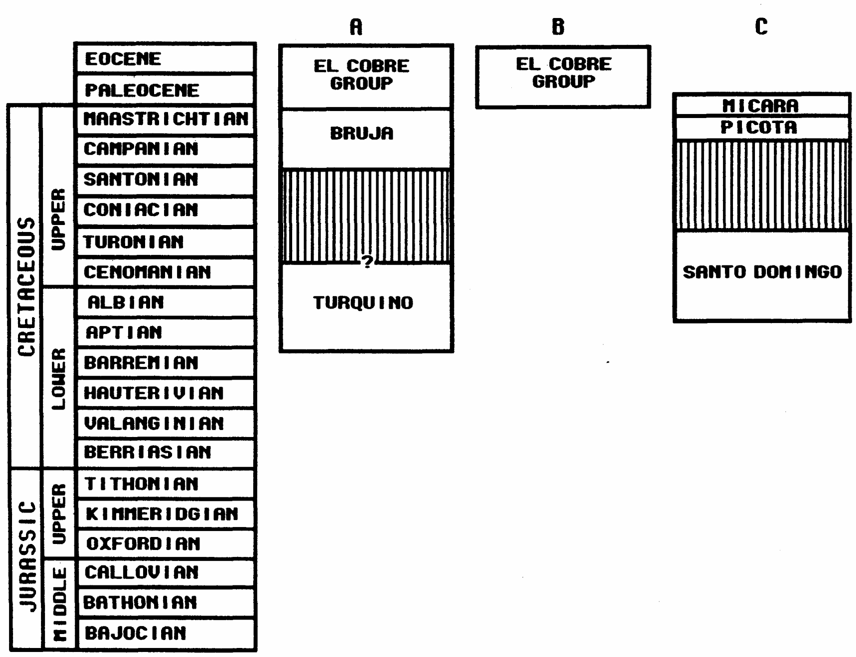


PRE-LATE EOCENE STRATIGRAPHY OF THE CAMAGUEY BLOCK



STRUCTURAL FACIES ZONES
A) Zaza
B) Remedios
C) Cayo Coco

PRE-LATE EOCENE STRATIGRAPHY OF ORIENTE



STRUCTURAL FACIES ZONES
A) SIERRA MAESTRA (PALEOGEN OROGEN)
B) BAYAMO-SAN LUIS BASIN
C) NIPE CRISTAL BARACOA (ZAZA ZONE)