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Jurassic and Cretaceous Geological History of Cuba

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Abstract

The Mesozoic rocks of Cuba are a key element in reconstructing the geological history of the Mesoamerican (Gulf of Mexico and the Caribbean) area. Four different Jurassic–Cretaceous sections are recorded in Cuba, including three from tectonostratigraphic terranes. From north to south they include the following: (1) a portion of the Mesozoic passive margin of North America, with outstanding zonality, especially in the Middle Cretaceous of central Cuba; (2) the Northern Ophiolitic Belt, also with Upper Jurassic–Lower Cretaceous rocks, which is a huge mélange; all members of the ophiolitic suite are tectonically mingled along the northern part of Cuba; (3) the Volcanic Arc Terrane, mainly composed of Cretaceous volcanics, with older, primarily tholeiitic lavas (Aptian–Albian) and younger (Cenomanian–Campanian) calc-alkaline pyroclastics and lavas, with many sedimentary interbeds; Albian–Cenomanian deposits with a few volcanics separate both sequences, and an Upper Jurassic–Neocomian amphibolitic basement of the volcanic arc is present in some places; and (4) the Southern Metamorphic Terranes that contain rocks of a Mesozoic passive margin that experienced several metamorphic episodes during the Cretaceous.

The welding of these terranes occurred during the Cretaceous, and ended in the late Campanian and Maastrichtian. In the south, the volcanic terrane was emplaced upon the Southern Metamorphic Terranes, while in the north the volcanics and ophiolites were thrust over the Mesozoic margin of North America. In western Cuba, the beds are strongly deformed and thrust to the north or northwest. Nappes also are present in north-central Cuba, but an essentially Bahamian platform stratigraphy is present. Although the passive paleomargin of North America was deformed in the latest Cretaceous, this event is masked by the early Tertiary Cuban orogeny.

It is suggested that the Jurassic stratigraphy of the Southern Metamorphic Terranes shares features with the southern North American passive margin in western Cuba. The position of the Southern Metamorphic Terranes south of the ophiolite and arc terrane therefore does not support the idea of a Pacific origin for the Cretaceous island arcs of the Greater Antilles, but instead suggests that a proto-Caribbean genesis is more plausible.

Introduction

MESOZOIC ROCKS occur extensively in Cuba, in outcrop or below the Cenozoic cover. Despite the considerable progress made in understanding these rocks, the results are not well known outside Cuba, and little information is available in English. As a result, this new information has not always been consistently considered by those attempting to construct plate-tectonic models of the Caribbean and Gulf of Mexico (e.g., Pindell, 1985, 1994; Salvador, 1987; Pindell and Barrett, 1990; Stephan et al., 1990; Buffler and Thomas, 1994; Marton and Buffler, 1994). The study of Cuban Mesozoic formations also has economic implications, because many mineral and hydrocarbon deposits are located in the Jurassic and Cretaceous strata of Cuba. The purpose of this paper, therefore, is to review some of this more recent information and to present the author's interpretation of its plate-tectonic significance.

In general, two principal structural levels can be distinguished in the geological structure of Cuba (Fig. 1; Iturralde-Vinent, 1994, 1996a). The rocks belonging to the younger level (Middle Eocene to Quaternary) are little disturbed, and can be referred to as the cover. Below it occurs the great complex of the Cuban orogenic belt, which consists mainly of rocks of Jurassic to Middle Eocene age. In addition, small outcrops of Precambrian metamorphic rocks also occur in north-central Cuba (Somin and Millán, 1981; Renne et al., 1989).

The contacts between the major Mesozoic elements of the orogenic belt are nearly always tectonic (Figs. 1 and 2). With the exception of the rocks of the passive Mesozoic margin of North America in northern Cuba, most of the other Mesozoic units are generally considered to be allochthonous (Itur-

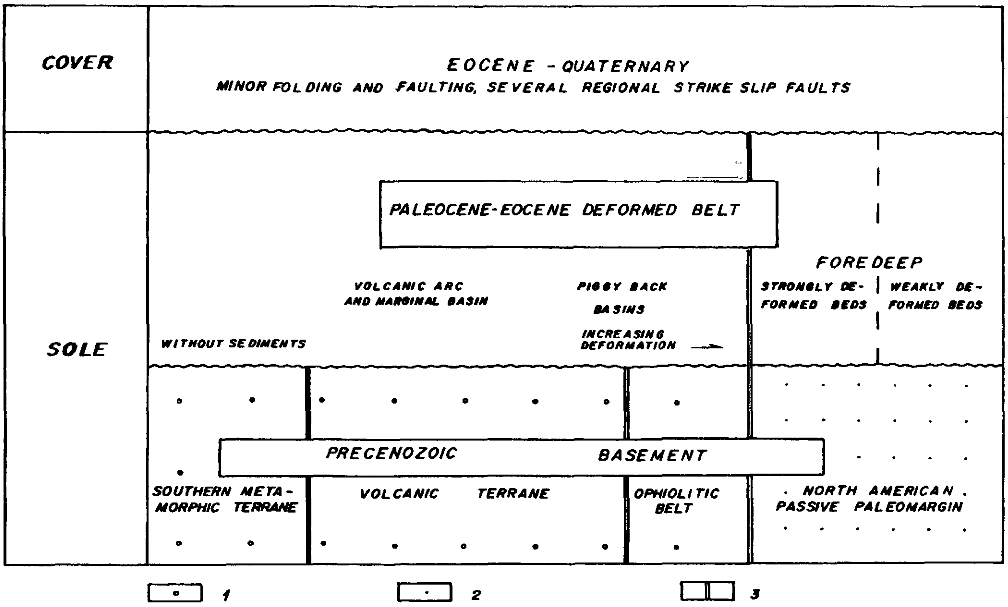

FIG. 1. Main structural levels of Cuba (from Cobiella-Reguera and Cruz-Gámez, 1999, with slight modifications). Legend: 1 = Mesozoic terranes; 2- Pre-Cenozoic margin of the North American plate; 3 = main faults in the socle.

ralde-Vinent, 1988a, 1996a; Bazhenov et al., 1996; Cobiella-Reguera, 1998b). The aforementioned authors contend that the pre-Cenozoic rocks of Cuba, south of the North American paleomargin, belong to different tectonostatigraphic terranes. The term "terrane" has been used in different ways by geologists, but this paper will employ Keppie's definition (in Meschede, 1994, p. 2):

> A terrane is… an area characterized by an internal continuity in geology (including stratigraphy, fauna, structure, metamorphism, igneous petrology, metallogeny, geophysical properties, and paleomagnetic record) that is bounded by faults, mélanges representing a trench complex, or a cryptic suture across which neighboring terranes may have a distinct geological record, not explicable by facies changes (i.e., exotic terranes) or may have a similar geological record (i.e., proximal terranes) that may only be distinguished by the presence of the terrane boundary representing telescoped oceanic lithosphere.

Structurally, the Mesozoic units extend parallel to the axis of the present main island of Cuba (Fig. 2). The northernmost unit is the Mesozoic passive continental margin of North America. It consists of a Jurassic–Cretaceous, mainly sedimentary sequence of neritic, slope, and basinal deposits that is now exposed as a fold-thrust belt along the northern edge of the Cuban mainland. One segment of this belt lies adjacent to the Bahamas platform and the other is adjacent to the southeastern Gulf of Mexico (Schlager and Buffler, 1984; Cobiella-Reguera, 1996a, 1996c, 1998c; Gordon et al., 1997; Hutson et al., 1998). In the south, three other structural units are present: the Northern Ophiolitic Belt, the Volcanic Arc Terrane, and the Southern Metamorphic Terranes.

In the following sections, some basic features of Cuban Mesozoic geology will be reviewed, and a brief description of the Mesozoic units given. The last section is devoted to a discussion of problems of the geologic and tectonic history of Cuba.

Passive Mesozoic Continental-Margin Rocks

Three major (and one minor) areas of Mesozoic passive continental-margin rocks, each with its own characteristics, exist in Cuba (Fig. 2).

Guaniguanico Cordillera

The first region is in the Guaniguanico Cordillera of western Cuba, where Mesozoic and lower Tertiary

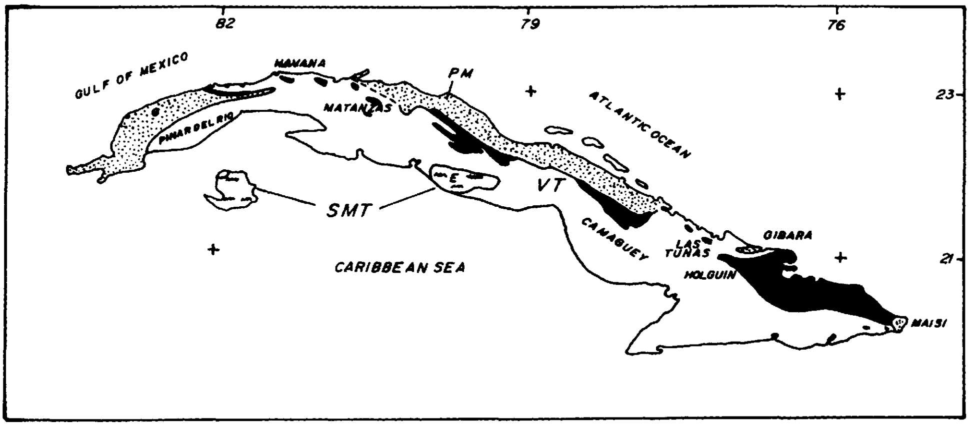

FIG. 2. Mesozoic domains of Cuba, after stripping of the Cenozoic cover. Abbreviations: PM = passive Mesozoic continental margin of North America; VT = Volcanic Arc Terrane (including the upper Campanian–Maastrichtian sedimentary cover); SMT = Southern Metamorphic Terranes; IY = Isle of Youth; G = Guaniguanico mountains; E = Escambray massif; areas in black = Northern Ophiolites.

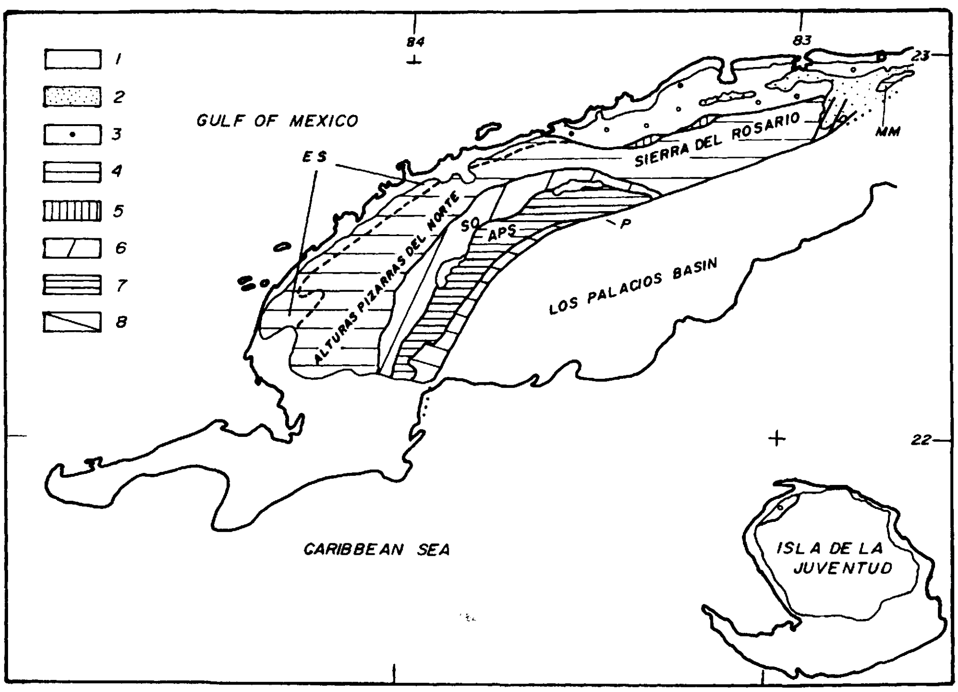

FIG. 3. Tectonic map of Guaniguanico mountains. Legend: 1 = Neogene and Quaternary; 2 = Lower Eocene turbidites (north of the Pinar fault); 3 = volcanic terranes and ophiolites ("Bahía Honda terrane," sensu Pszczolkowski, 1994, in northeast Pinar del Río and northwest Havana provinces; volcanic terranes in Isla de la Juventud); 4 = Sierra del Rosario; Alturas de Pizarras del Norte and Esperanza zone (ES) nappes; 5 = Guajaibón nappe; 6 = Sierra de los Organos nappes; 7 = Alturas de Pizarras del Sur nappes; 8 = Cangre belt. Abbreviations: SO = Sierra de los Organos; APS = Alturas de Pizarras del Sur; MM = Martín Mesa window; P = Pinar fault. Sierra de los Organos nappes are the lowest units, and are tectonically covered by the Alturas de Pizarras del Norte, Sierra del Rosario, and Alturas de Pizarras del Sur and Cangre belt nappes. All of these units of the passive paleomargin of North America lie below the ophiolites and the Volcanic Arc Terrane.

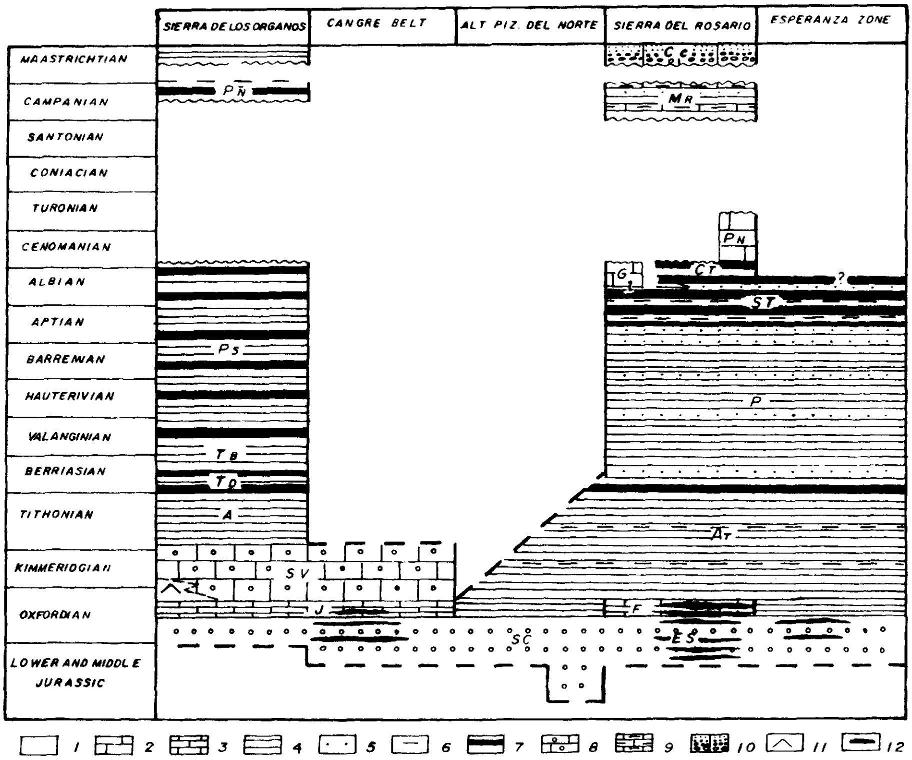

FIG. 4. Mesozoic correlation in the Guaniguanico Cordillera. Legend: 1 = deltaic sediments (including submarine fan deposits); 2 = neritic limestones; 3 = interbedding of shales and limestones; 4 = well-bedded outer neritic and/or deep-water limestones and calcareous turbidites; 5 = turbiditic sandstones; 6 = shales; 7 = cherts; 8 = mainly thick-bedded (bank) limestones; 9 = shaly limestones; 10 = Calcareous megaturbidite; 11 = evaporites; 12 = mafites. The thick discontinuous lines represent the main thrust planes. Abbreviations: SC = San Cayetano Formation; ES = El Sábalo Formation; J = Jagua Formation; SV = San Vicente Mb.; A = El Americano Mb.; Td = Tumbadero Mb.; Ta = Tumbitas Mb.; Ps = Pons Formation; At = Artemisa Formation; P = Polier Formation; ST = Santa Teresa Formation; Ct = Carmita Formation; G = Guajaibón Formation; Pn = Pinalilla Formation; Mr = Moreno Formation; CC = Cacarajícara Formation; Pñ = Peñas Formation. Data from: Pszczolkowski, 1978, 1982, 1986c, 1994; Cobiella-Reguera, 1992, 1996a, 1996b; Cobiella-Reguera et al., 1997.

beds belong to a great thrust nappe structure, several kilometers thick (Fig. 3; Piotrowska, 1978; Pszczolkowski, 1994; Gordon et al., 1997; Cobiella-Reguera et al., in press). In the southern fringe of the Guaniguanico Cordillera, the thrust planes are cut by the high-angle, Tertiary Pinar fault (Fig. 3). The nappes moved from south to north during the Late Paleocene–Early Eocene (Hatten, 1967; Khudoley and Meyerhoff, 1971; Piotrowska, 1978; Pszczolkowski, 1994; Gordon et al., 1997). The oldest deposits in Guaniguanico belong to the San Cayetano and Arroyo Cangre formations, thick terrigenous sequences that accumulated in a large, continentally derived delta (Khudoley and Meyerhoff, 1971; Haczewski, 1976; Somin and Millán, 1981; Pszczolkowski, 1986a; Cobiella-Reguera et al., 1997; Hutson et al., 1998; see also Fig. 4.). Their subsurface equivalents are also found in boreholes drilled in northwestern Pinar del Rio province (Cobiella-Reguera, 1996a, 1996b). The age of these strata are Lower and Middle Jurassic (fern spores; Areces-Mallea, 1991) to middle Oxfordian ammonites (Myczinski and Pszczolkowski, 1976; Pszczolkowski, 1978; Myczinski et al. 1998). Oxfordian tholeiitic diabase sills and some pillow lavas appear in several places between the terrigenous beds, frequently near their transitional contact with the Oxfordian carbonate beds in the lower part

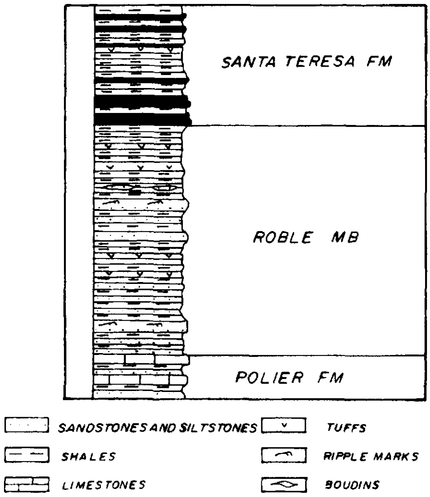

FIG. 5. Interbedding of tuffs with Aptian sediments in Sierra del Rosario. According to Pszczolkowski and Myczynski (1999), the beds at the contact between the Polier and Santa Teresa formations are lower Aptian in age. The locality is ~1 km west of Las Terrazas and the thickness of the section is ~25 meters. Cherts are shown in black.

of the overlying calcareous sequence (Pszczolkowski and Albear-Franquiz, 1983; Cobiella-Reguera, 1992, 1996a, 1996b; Pszczolkowski, 1994).

Above these terrigenous beds lies a mainly carbonate sequence of middle Oxfordian to Cenomanian age (Pszczolkowski, 1978; Cobiella-Reguera, 1996b) that locally may attain the Turonian. Two zones with different Upper Jurassic–Cretaceous sections can be distinguished: the Sierra de los Organos and Sierra del Rosario (Fig. 3). In Sierra de los Organos, a transitional sequence (the Jagua Fm., Fig. 4) occurs between the San Cayetano beds and a thick carbonate bank, 650 m thick, of upper Oxfordian–lower Tithonian age (Pszczolkowski, 1981). The overlying Tithonian–Cenomanian section is composed of deep-water limestones with some cherty levels (Fig. 4). The middle Oxfordian–Tithonian rocks in Sierra del Rosario are well-bedded limestones, with radiolaria and other pelagic fossils, and some shales, only 80 to 200 m thick (Pszczolkowski, 1978). Lower Cretaceous strata are mainly deep-water carbonates with frequent carbonate and terrigenous turbidites up to the Aptian. A trend toward deeper-water deposits with time is clear, with a peak between the Aptian and Cenomanian, when radiolarian cherts are frequent (Fig. 4; Pszczolkowski, 1982; Cobiella-Reguera, 1996b). Thin and very scarce beds of tuff appear in sediments of Aptian to Campanian ages in Sierra del Rosario (Fig. 5). The Albian–Cenomanian carbonate bank of the Guajaibón Formation (Ponce et al., 1985; Dìaz et al., 1992, 1997; Guajaibón nappe in Fig. 3) is particularly intriguing, because the coeval strata are all deep-water carbonates with some carbonate turbidites, and its contacts with other units are always tectonic.

The remaining Upper Cretaceous beds of the passive margin have a limited geographic distribution, and Coniacian and Santonian sediments seem to be absent. However, in some areas of Sierra del Rosario, Pszczolkowski (1994) reported the possibility of Coniacian and Santonian sediments (Fig. 4). The Moreno (Pszczolkowski, 1994) and Peñas (Hatten, 1957) formations, which are of limited outcrop, are the only units of demonstrated Campanian age in the passive paleomargin in western Cuba. In the Moreno formation, along with carbonate sediments, there are some tuffs and volcanoclastic beds, suggesting the proximity of a volcanic source (Pszczolkowski, 1994). Maastrichtian outcrops in the western Guaniguanico mountains (Sierra de los Organos) are very scarce and of limited thickness. Perhaps this was a time of condensed sedimentation or non-deposition in the area, but this is difficult to prove, because, with very few exceptions, the contacts between different lithostratigraphic units are tectonic. However, Pszczolkowski has maintained (1994, and pers. commun., 1998) that evidence of strong erosion exists at the base of the Cacarajícara Formation (upper Maastrichtian or K/T boundary). The uppermost Maastrichtian (or K/T boundary?) is present in the Sierra del Rosario (Fig. 4) and is represented by the Cacarajícara Formation, which is a huge (up to 450 m thick) calcareous megaturbidite unit that may be related to a catastrophic event at Cretaceous/Tertiary boundary near western Cuba (Pszczolkwski, 1986c; Cobiella-Reguera, 1998c). An unconformity is found at the base (middle Paleocene) of the Ancón Formation, according to Pszczolkowski (1994).

North-Central Cuba

The second area where the Mesozoic continental margin beds crop out is the northern part of the island from Matanzas to northwest of Holguin (Fig. 2). Different sequences, with distinct tectonic styles, occur as belts several hundred kilometers in length (Fig. 6; Furrazola-Bermudez et al., 1964 ; Meyerhoff and Hatten, 1968; Khudoley and Meyerhoff, 1971;

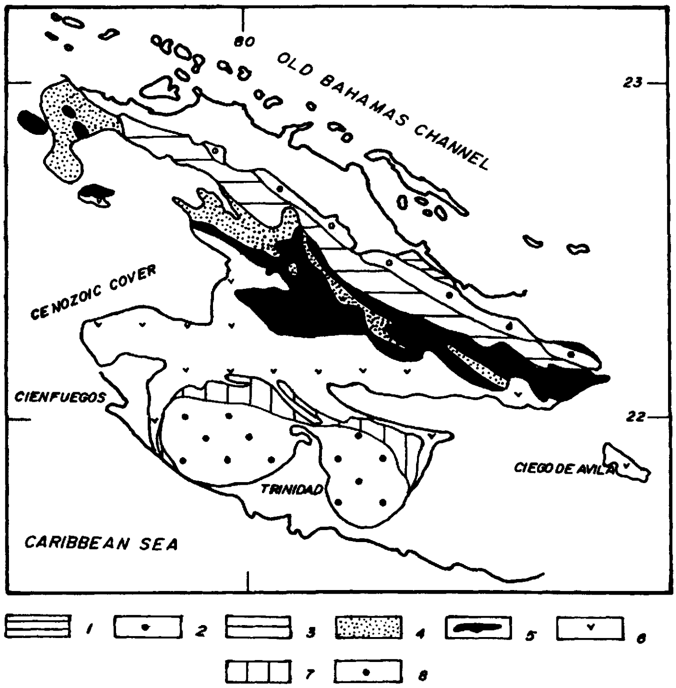

FIG. 6. Jurassic and Cretaceous tectonic and paleogeographic domains in central Cuba. (from Iturralde-Vinent, 1996, slightly modified). Paleomargin of North America: 1 = Cayo Coco zone; 2 = Remedios zone; 3 = Camajuaní zone; 4 = Placetas zone. Tectonostratigraphic terranes: 5 = ophiolites; 6 = Cretaceous arc volcanics; 7 = Mabujina complex; 8 = Southern Metamorphic Terranes.

Pardo, 1975; Draper and Barros, 1994; Iturralde-Vinent, 1997). Here, the author will adhere to the Cuban practice of calling these belts "zones." The three northern zones—Canal Viejo, Cayo Coco, and Remedios, have very similar pre-Aptian sections (Fig. 7). They all begin with (Middle?) Jurassic evaporites (halites and anhydrites) of the Punta Alegre Formation (Meyerhoff and Hatten, 1968; Pardo, 1975; Iturralde-Vinent, 1996a). Resting on the evaporites in the north is an Upper Jurassic– to Aptian-age sequence, ~1800 m thick, of carbonates and anhydrites (Cayo Coco Formation). Toward the south, evaporites disappear in the Cretaceous sections. Marked differences occur in the Aptian–Turonian sediments (Fig. 7). In the Cayo Coco zone, there are hemipelagic limestones, whereas thick platform carbonates occur in the Remedios (>2000 m) and Canal Viejo sections. In Camagüey province (Fig. 2; Iturralde-Vinent, 1996a), and perhaps in Gibara (northwest of Holguin), deep-water carbonates (turbidites) of Cenomanian and Turonian ages rest with conformity on the bank deposits (Jakus, 1983). There are no beds of demonstrated Coniacian and Santonian age in the Cayo Coco zone. The Campanian and Maastrichtian bank limestones are reported in the Remedios zone (Iturralde-Vinent, 1996a), but only upper Maastrichtian deep-water carbonates are present in Cayo Coco sections (Meyerhoff and Hatten, 1968; Pardo, 1975; Iturralde-Vinent, 1996a).

Tectonic contacts almost always separate the Remedios and Camajuaní zones, but a few sections with transitional features have been reported (Pardo, 1975; Meyerhoff and Hatten, 1968). Some Cuban petroleum geologists have proposed a new unit, the Colorado zone (Alvarez Castro et al., 1998; Sánchez Arango et al., 1998) for these transitional sections between the carbonate platform (Remedios) and the toe of the slope (Camajuaní). Although from the basin analysis point of view, it seems that a new and interesting zone has been introduced, the Colorado sections have been detected only in isolated boreholes. Therefore, at this time, this new zone should be viewed with some caution.

The Camajuaní zone contains mainly pelagic and turbiditic carbonates with some cherts of Kimmeridgian–Turonian age ~1200m thick (Fig. 8; Meyerhoff

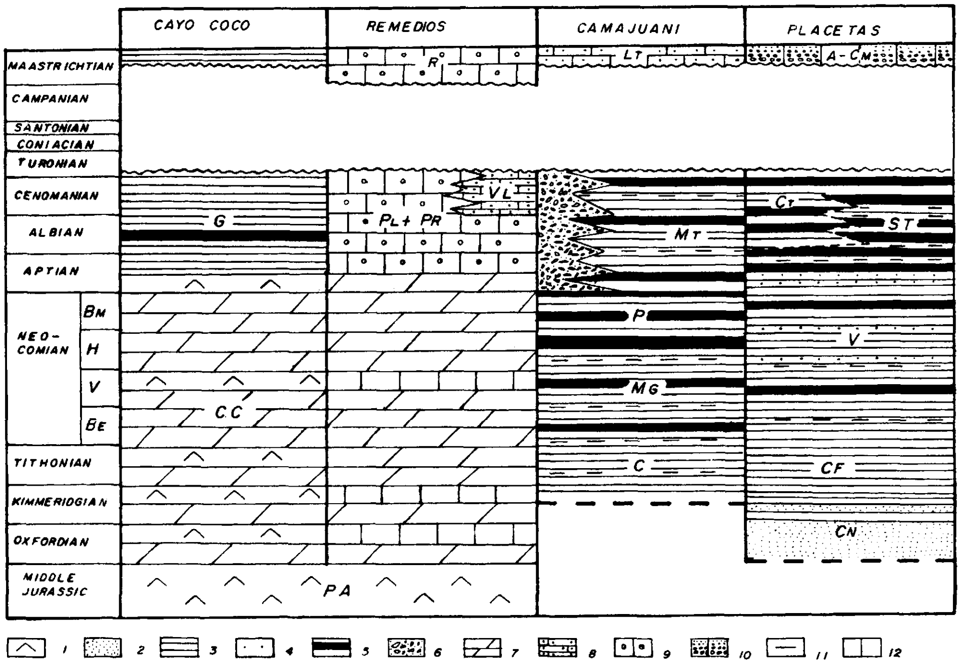

FIG. 7. Correlation chart of the Mesozoic rocks of the paleomargin of North America in central Cuba. Legend: 1 = evaporites (halites in Punta Alegre Formation, anhydrites in Cayo Coco Formation); 2 = continental and shallow-marine arkosic sediments; 3 = well-bedded outer neritic and/or deep-water limestones; 4 = turbiditic sandstone; 5 = cherts; 6 = carbonate talus deposits and carbonate turbidites; 7 = dolomites; 8 = carbonate turbidites; 9 = mainly massive, shallow-water limestones and dolomites (carbonate bank); 10 = megaturbidite; 11 = shales; 12 = shallow-water limestones. Abbreviations: PA = Punta Alegre Formation; Cn = Constancia Formation; Cf = Cifuentes Formation; CC = Cayo Coco Formation; G = Guaney Formation; Pl + Pr = Palenque and Purio formations; Vl = Vilató Formation; R = Remedios Formation; Mg = Margarita Formation; P = Paraiso Formation; Mt = Mata Formation; Lt = Lutgarda Formation; V = Veloz Formation; ST = Santa Teresa Formation; Ct = Carmita Formation; A = Amaro Formation (central Cuba); Cm = Camaján Formation (Camagüey). *Sources*: Meyerhoff and Hatten, 1968; Pardo, 1975; Pszczolkowski, 1982, 1986b, 1986c; Pushcharovsky, 1988; Iturralde-Vinent, 1996a.

and Hatten, 1968; Pardo, 1975; Alvarez Castro et al., 1998). An unconformity separates these strata from the overlying Maastrichtian clastic carbonates. The Camajuaní zone is severely deformed, and in the south it contacts tectonically with the Placetas zone (Pszczolkowski, 1986b).

The thin deposits of the Placetas zone form the southern fringe of the North American Mesozoic paleomargin in central Cuba (Figs. 6 and 7). Arkosic sediments rest at the base of preserved sections (Pardo, 1975; Pszczolkowski, 1986b). A Tithonian to Berriasian age has been assigned to these beds in the past, but new preliminary data suggest that, at least in a few places, these clastic deposits can attain an Oxfordian age, according to some planktonic foraminiferal (Díaz-Colell, 1996), and palynological data (Alvarez Castro et al., 1998; Blanco González, 1998). It is possible that the terrigenous sediments were deposited on a basement consisting of Proterozoic metamorphic rocks with Middle Jurassic granitic intrusions (Somin and Millán, 1981; Renne et al., 1989) that are now found as tectonic slices within the Placetas zone (Pszczolkowski, 1986b). In northern Camagüey, the basal unit of the Placetas zone consists of tholeiitic basalts and hyaloclastites, and no arkosic rocks have been reported. This could mean that in this region the Placetas basement is not continental, but oceanic (Iturralde-Vinent 1988b, 1996a, 1996c). Alternatively, the basalts may represent continental-margin magmatism (G. Draper, pers. commun., 1999).

The Tithonian–Cenomanian sections of the Placetas zone are quite similar to the coeval sediments in the Sierra del Rosario that occur ~300 km to the

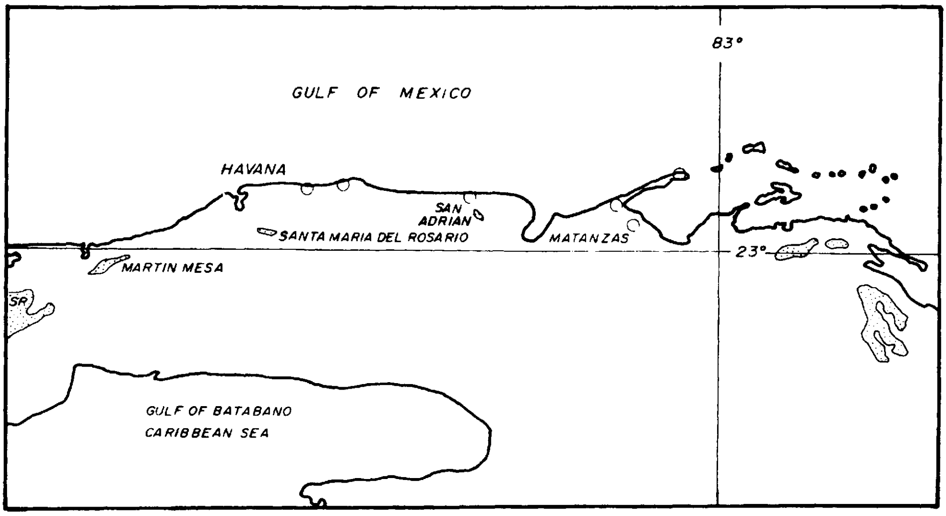

FIG. 8. Outcrops of the Mesozoic passive paleomargin sequences of North America (stippled areas) in Havana and Matanzas provinces. Except for the San Adrian quarry, where Jurassic(?) gypsum outcrops (Albear-Fránquiz and Piotrowski, 1984), the remaining localities are represented by deep-water carbonates and some cherts characteristic of the Placetas and Sierra del Rosario sections. The figure also shows the locations of several wells (circles) that penetrate the rocks of the paleomargin. Abbreviations: SR = Sierra del Rosario.

west. They consist of deep-water limestones interbedded with Berriasian to Aptian cherts, Aptian to Cenomanian shales, and Cenomian to Turonian deep-water limestones, cherts, and shales (Figs. 4 and 7; Pszczolkowski, 1982, 1986b). An uppermost Maastrichtian (or K/T boundary ?) calcareous megaturbidite ~150 m thick (Amaro Formation), coeval with the Cacarajícara Formation (Pszczolkowski, 1986c), rests with unconformity on the Turonian beds, ending the Cretaceous sections in the Placetas zone (Fig. 7; Meyerhoff and Hatten, 1968; Pardo, 1975; Rojas et al., 1995; Iturralde-Vinent, 1996a).

The Placetas and Camajuaní rocks are piled as stacks of nappes that moved from the SSW (Hatten, 1967; Meyerhoff and Hatten, 1968, Pardo, 1975, Iturralde-Vinent, 1997). Tectonic slices of deep-water Cretaceous carbonates (Martín Mesa oil field in western Havana province; Fig. 8) and deep-water Jurassic and Cretaceous limestones as well as arkosic rocks (Bacunayagua Formation) in eastern Havana province (Fig. 8) crop out among ophiolites and Cretaceous volcanic nappes. These Placetas-type lithologies also have been reported in wells in northern Havana and Matanzas provinces, below the ophiolites and Volcanic Arc Terrane (Fig. 8; Kuznetsov et al., 1985; Iturralde-Vinent, 1996a), suggesting that the Placetas and Sierra del Rosario beds were deposited in the same basin. This is a very important concept from an economic perspective, because the principal oil and gas fields of Cuba are in rocks of the North American Mesozoic margin (Echevarría-Rodríguez et al., 1991). Moreover, the Upper Jurassic–Turonian beds in Sierra del Rosario contain high amounts of organic matter and many oil seeps.

Eastern Cuba

The only other outcrops of rocks that may represent some form of Mesozoic continental margin are located in eastern Cuba, in Maisí (Fig. 2). There, dark-colored marbles and metaterrigenous rocks are exposed in an area of only a few square kilometers (Somin and Millán, 1981; Cobiella-Reguera, 1983; Millán et al., 1985). The structurally lowermost rocks are black phyllites and slates with some marbles and metamafites (Sierra Verde Formation). Upper Jurassic to Lower Cretaceous fossils are reported in this metaterrigenous unit by Millán et al. (1985), but they were found in an isolated outcrop (Millán-Trujillo, pers. commun.), lacking clear relationships with the other rocks of the unit. Resting tectonically above the Sierra Verde Formation are marbles and calcareous schists (La Asunción or Chafarina Formation; Cobiella-Reguera, 1983; Jakus, 1983). Upper Jurassic fossils were found in

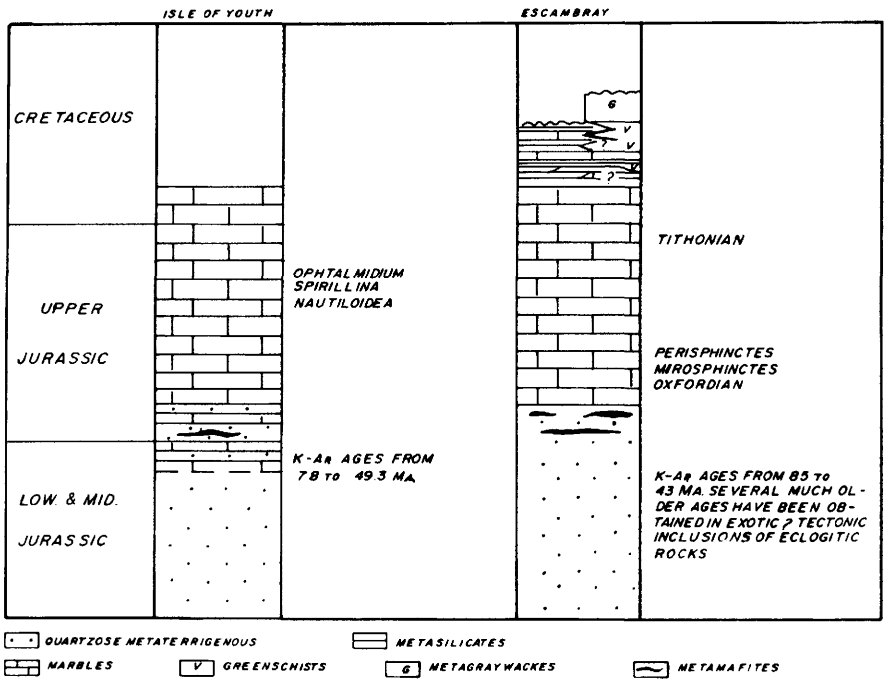

FIG. 9. Stratigraphy of the Southern Metamorphic Terranes.

only one marble sample (Millán et al., 1985). The geological scenario in Maisí differs from that in the rest of Cuba, because of the unclear tectonic relationships of the metasedimentary sequence (here considered as part of the passive paleomargin of North America) with the metamorphosed Volcanic Arc Terrane (Purial metamorphic complex) and the ophiolites (Cobiella-Reguera, 1983; Cobiella et al. 1984a; Millán et al., 1985; Iturralde-Vinent, 1996a, 1997).

Southern Metamorphic Terranes

The Southern Metamorphic Terranes (SMT) also have been considered part of a Mesozoic continental margin (Millán-Trujillo, 1990). They crop out in the mountains of south-central Cuba (Escambray massif), as well as in the Isle of Youth (Isla de la Juventud; prevoiusly known as the Isle of Pines; Figs. 2 and 9). The Jurassic sequences in both areas are quite similar. Graphitic meta-terrigenous rocks, with some concordant metamorphosed mafic intrusive rocks (especially in Escambray) occupy the lower part of the sequence. Higher up in the stratigraphic column, calcareous rocks (with Upper Jurassic ammonites in central Cuba) occur in both areas. In the Isle of Youth, the beds of the Agua Santa Formation are transitional between both sequences (Millán-Trujillo, 1992). The similarities between the Jurassic formations of the Guaniguanico Cordillera of western Cuba and the Southern Metamorphic Terranes sequences have been known for a long time (Furrazola et al., 1964; Khudoley and Meyerhoff, 1971; Somin and Millán, 1981). Cretaceous rocks have not been reported in the metamorphic terrane of the Isle of Youth, but may be present in the Escambray mountains (Fig. 9). Above the dark marbles with Tithonian fossils, there are light-colored marbles and metacherts, with some greenschists of volcanic origin and a metaflysch (psammite) unit of the El Tambor formation (Millán and Somin, 1985). In the Escambray mountains various bodies derived from an oceanic lithosphere are in tectonic contact with the metasediments. According to Millán-Trujillo (1996), they include high-pressure/low-temperature amphibolites (Yayabo Formation) and tectonic lenses of serpentinite mélange with eclogites and other oceanic-lithosphere-derived rocks, metamorphosed at the same time as the passive-margin country rocks (see also Puscharovsky, 1988).

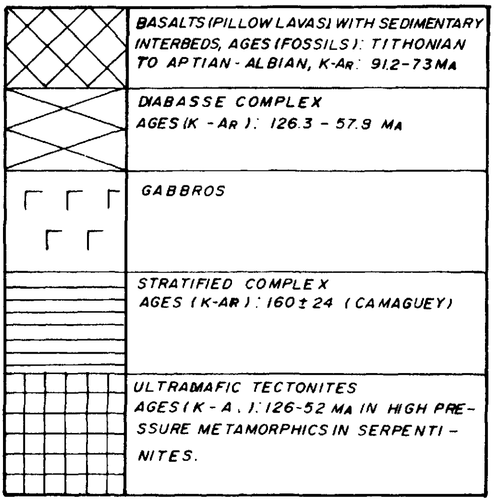

FIG. 10. Geological column of the Northern Ophiolitic Belt.

Radiometric age dating, almost all by the K-Ar method (40 samples from several sources, summarized in Iturralde-Vinent et al., 1996), in the metamorphic rocks gave mainly Late Cretaceous ages (103–43 Ma in Escambray; 78–49.3 Ma in the Isle of Youth). Ages from 106 to 102 Ma were obtained in high-pressure metamorphic zircons in eclogites from the Escambray mountains (U-Pb method, Millán-Trujillo, 1996). Much older ages (255 and 210 Ma) were obtained in glaucophane schists and eclogites, but their geological meaning is unclear (Hatten et al., 1988; Iturralde-Vinent et al., 1996).

The SMT tectonically underlies the Volcanic Arc Terrane. The latter is considered to have been thrust from the north (see Fig. 9 in Iturralde-Vinent, 1996a; Millán-Trujillo, 1990). The structural position of the metamorphic terrane sequences south of (and below) the volcanic terrane has great significance for regional geology and will be discussed later. This is an important question, ignored by many authors of hypotheses on the evolution of the northwestern Caribbean over the last 15 years that consider a Pacific origin for the Cuban volcanic arcs (Pindell, 1985, 1994; Stephan et al., 1990; Mann et al., 1991; Stanek, 1996; and others).

Northern Ophiolitic Belt

The northern ophiolitic belt (NOB) of Cuba extends, with some interruptions, along strike for ~1000 km (Fig. 2). A wealth of data from wells (Echevarría et al., 1991), geophysical research (Pardo-Echarte, 1996), and surface geology (Kozary, 1968; Meyerhoff and Hatten, 1968; Knipper and Cabrera, 1974; Cobiella-Reguera, 1984; and Iturralde-Vinent 1990, 1996b) shows that the ophiolites are a strongly deformed prism, transported from the south over the continental margin. They are tectonically overlain by the Volcanic Arc Terrane (see below). In eastern Cuba, the association differs; there coherent ophiolitic nappes are thrust over the volcanic-arc rocks (Knipper and Cabrera, 1974; Cobiella et al., 1984). Despite the tectonic complications, all the components of a standard ophiolite suite can be distinguished in the NOB. The best-preserved components of the ophiolites are the ultramafic rocks (Fig. 10; Fonseca et al., 1984; Iturralde-Vinent, 1996b), whereas the basaltic rocks are poorly exposed. As the belt is a mélange, few original contacts are maintained (Kozary, 1968; Knipper and Cabrera, 1974; Pardo, 1975; Cobiella-Reguera, 1984; Iturralde-Vinent, 1996b).

Over the last decade several paleontological findings have contributed to better constraints on the age of the ophiolites. Among the most interesting is the finding of Tithonian radiolaria in central Cuba (Llanes Castro et al., 1998), and of Hauterivian–Barremian radiolaria in siliceous rocks in the Holguin massif of eastern Cuba (Andó et al., 1996). Aptian–Albian foraminifera are present in the western Cuban ophiolites (Fonseca et al., 1984; Iturralde-Vinent, 1996b). Some younger (Cenomanian) ages ascribed to the ophiolites were obtained from samples from the mélanges (Andó et al., 1996), or from rocks not typical of the ophiolites (upper part of Margot Formation, sensu Iturralde-Vinent, 1996b).

A K-Ar age of 160 ± 24 Ma was reported in anorthite-rich rocks in east-central Cuba, near the city of Camagüey (Fig. 10, Somin and Millán, 1981). According to the data above, and to some regional evidence (the posible oceanic basement of the Placetas sequence in Camagüey), the age of the Cuban ophiolitic belt seems to embrace the Upper Jurassic to Lower Cretaceous interval (Pushcharovsky, 1988; Cobiella-Reguera, 1996a, 1998c; Iturralde-Vinent, 1996b).

Ophiolite nappe emplacement in easternmost Cuba concluded in Maastrichtian time (except for a small area near Maisí (Cobiella, 1978; Cobiella et al., 1984; Cobiella-Reguera, in press). In western Cuba, strong tectonic movements related to the arrival of the ophiolite at the earth's surface can be invoked to explain the serpentinite clasts in some

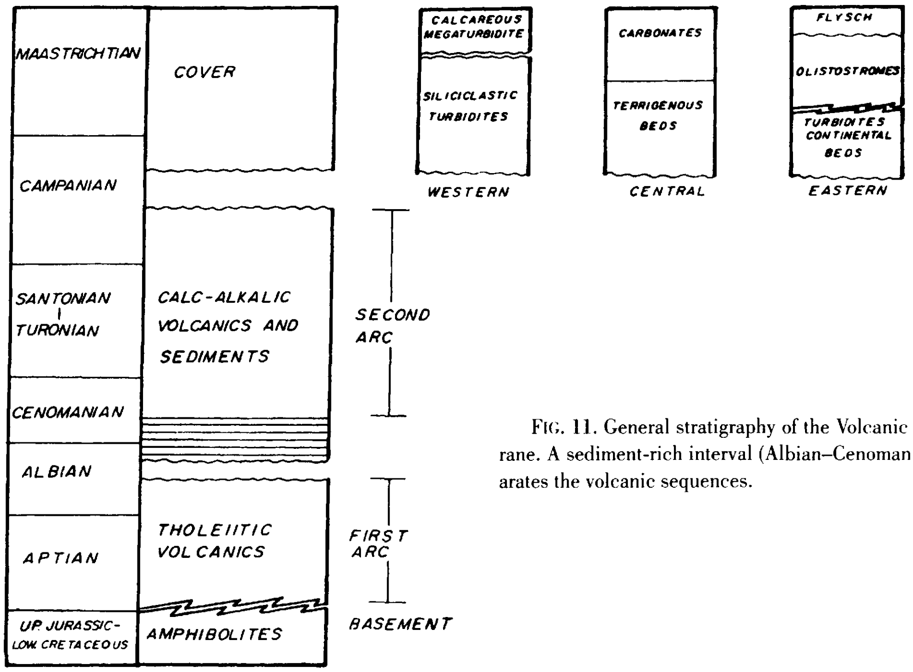

FIG. 11. General stratigraphy of the Volcanic Arc Terrane. A sediment-rich interval (Albian–Cenomanian) separates the volcanic sequences.

conglomerates of the Campanian–Maastrichtian cover of the Volcanic Arc Terrane (Albear-Fránquiz and Iturralde-Vinent, 1985). In central and western Cuba the emplacement finished in different moments during the Eocene (Cobiella et al., 1984; Cobiella-Reguera et al., 1984, 1998a).

Volcanic Arc Terrane

In the old geological literature on Cuba, following the geosyncline terminology, those sections with Cretaceous arc volcanics, serpentinites, and mafic rocks were referred to as the eugeosyncline, and were included with sections of the continental paleomargin of north-central Cuba in the classical zonal schemes of the 1950s and 1960s. The "eugeosyncline" was assigned different zonal names by different workers: Bahía Honda, San Diego, Santa Clara, and Auras (Furrazola-Bermúdez et al., 1964; Kozary, 1968; Khudoley and Meyerhoff, 1971; Pardo, 1975; Cobiella-Reguera, 1984). The most popular was the Zaza zone (Lewis and Draper, 1990). Today, if we intend to explain the geology of Cuba in plate-tectonic terms, the Zaza zone (or Zaza tectonostratigraphic unit) is an obsolete concept, because it mingles rocks of different origins—the ophiolites, on the one hand, and the rocks of at least two Cretaceous volcanic arcs and its Campanian–Maastrichtian sedimentary cover, in the other.

The Volcanic Arc Terrane is composed mainly of island-arc sequences that occupied a large part of Cuba below the Cenozoic deposits (Figs. 2 and 11). The northern boundary is tectonic, resting above the ophiolites (except in eastern Cuba). Sometimes the volcanic rocks are tectonically mingled with ophiolitic material (mélanges), whereas in the south the volcanic-arc sequences lie (also in a tectonic sense) on the Southern Metamorphic Terranes (Somin and Millán, 1981; Iturralde-Vinent, 1996a, 1996d). Three well-defined stratigraphic levels are present in the Volcanic Arc Terrane (Fig. 11). The first, the basement (Fig. 11), is mainly composed of amphibolites, derived from an oceanic protolith of gabbro cumulates, diabases, mafic volcanics, and serpentinites (Mabujina complex in central Cuba and the Guira de Jauco Formation in easternmost Cuba; Haydoutov et al., 1989; Iturralde-Vinent, 1996a; Millán-Trujillo, 1996). The rocks generally show a MORB geochemistry, but some calc-alkalic rocks also are recorded in the complex (Millán-Trujillo, 1996). These calc-alkalic rocks include meta-tuffs, meta-breccias, and meta-andesites. Greenschist-facies mafic and felsic rocks occupy the highest structural levels in part. Feebly metamorphosed dikes of lamprophyres cut the amphibolites (ibid.).

The contact of the basement rocks with the overlying Cretaceous volcanic-arc sequences is always tectonic (Pushcharovsky, 1988).

The second level in the volcanic-arc terrane is composed mainly of several thousand meters of arc volcanics with significant sedimentary intercalations in the upper part (Fig. 11). At least in central Cuba, three subsequences can be distinguished. The lower one is represented by tholeiitic bimodal volcanic rocks, perhaps of the Primitive Island Arc suite of Donelly and Rogers (1980), followed by submarine tholeitic mafics, with some andesites (Díaz de Villalvilla and Dilla, 1985; Díaz de Villalvilla, 1997). An unconformity separates these rocks from a second sequence that consists of Albian–Cenomanian rocks, mainly of sedimentary origin, which indicate a sharp reduction in volcanic activity. Examples of these mainly sedimentary units are the Guaos and Provincial formations in central Cuba (ibid.), the Barrederas Formation (Jakus 1983) in eastern Cuba, and part of the La Trampa Formation(?) in Havana province (Albear-Fránquiz and Iturralde-Vinent, 1985; see also Iturralde-Vinent, 1996d, 1997; Díaz de Villalvilla, 1997). Terrigenous beds with clasts of volcanic and intrusive rocks are reported in some areas (Iturralde-Vinent, 1996d). The latter may be important, as they may record some kind of orogenic episode. The third sequence consists of calc-alkaline rocks, which range in age from Cenomanian or Turonian up to lower Campanian (Fig. 11). Some authors have suggested a Maastrichtian age for the youngest volcanic beds (see Díaz de Villalvilla, 1997), but this does not seem very likely in context of the regional stratigraphy, because the Campanian–Maastrichtian sedimentary cover is deprived of volcanic intercalations, except for very rare tuff beds. Marine sedimentary beds are not uncommon, because the Late Cretaceous volcanic activity was mainly submarine. However, some volcanic islands rose from time to time and contributed debris to the basins located near the volcanic lands. A marked increase in alkalinity is particularly present in the volcanics in several localities (Iturralde-Vinent, 1996e). Intrusive magmatism developed coeval with volcanic activity, as is indicated by geologic and radiometric data (Iturralde-Vinent, 1996d; Stanek, 1996).

The third stratigraphic level of the arc terrane is separated from the second by a major unconformity (Fig. 11). This third level consists of an Upper Cretaceous sedimentary "cover" (Fig. 10; Cobiella-Reguera, 1996c, 1998c). The lower part of the cover is always a volcanomictic sequence at least several hundred meters in thickness (Rojas et al., 1995), sometimes with serpentinite and mafic clasts. In central and western Cuba, cover sediments are upper Campanian–Maastrichtian in age (Pszczolkowski and Flores, 1986). In western Cuba, the uppermost Maastrichtian (or K/T? boundary) is a calcareous megaturbidite, 30 to 180 m thick (Peñalver Formation), of the same age and composition as the continental-margin megaturbidite (Cacarajícara and Amaro formations; Pszczolkowski, 1986c). In central and east-central Cuba (including Camagüey and Las Tunas provinces), the lower part of the cover consists mainly of terrigenous beds (Monos, Durán, Yáquimo, and Sirvén formations) of Campanian–Maastrichtian age, some of them with flyschoidal aspect. The upper Maastrichtian is calcareous, sometimes with biogenic (rudist) constructions, but always with a wealth of detrital limestones (Carlota, Cantabria, Jimaguayú, and Arroyo Grande formations). No published sedimentological research on these calcareous clastic beds is known to the author, and their relationships with the megaturbidite bed are not known.

Campanian sediments (although their age has not been clearly demonstrated), have been reported in the cover of the Volcanic Arc Terrane in eastern Cuba (Fig. 11), and the Maastrichtian sediments are restricted to siliciclastics (Radocz and Nagy, 1983; Cobiella et al., 1984). Clasts of serpentinites or other representatives of oceanic lithosphere are absent in the older Maastrichtian layers of volcanomictic composition, but an upper Maastrichtian olistostrome, several hundred meters thick, is mainly composed of ultramafic and mafic materials. This olistostrome, related to the overthrusting of eastern Cuban ophiolites, is well developed in the mountains of northeastern Cuba (Iturralde-Vinent, 1976/1977, 1996b; Cobiella, 1978; Cobiella-Reguera et al., 1984).

Discussion and Conclusions

Passive continental-margin sequences

The above review presents the case that in northern and western Cuba, the southern margin of North America is represented by two passive Mesozoic margin sequences. In southern Cuba, the Southern Metamorphic Terranes form another passive-margin sequence that flanks the ophiolitic-arc axis of Cuba (Fig. 2; Iturralde-Vinent, 1981, 1996a; Cobiella-Reguera, 1996a, 1996c, 1998c, and others). Both

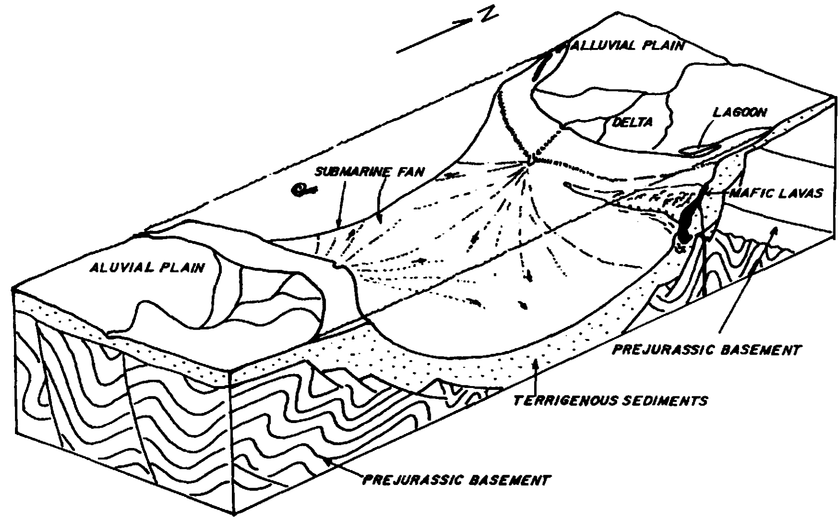

FIG. 12. A paleogeographic model for the beginning of the break-up of Pangea in the early to middle Oxfordian, during the accumulation of the thick terrigenous sections of Guaniguanico (San Cayetano and Cangre formations) and the coeval units in the Southern Metamorphic Terranes. In the deepest part of the forming basin, sediments from two sources were deposited (from Cobiella-Reguera and Cruz-Gámez, 1999).

northern and southern margins are overthrust by the axial terranes. Two types of Jurassic continental-margin sequences can be distinguished. The first encompasses the rocks of the Guaniguanico mountains, the Maisí area in easternmost Cuba, and the SMT (Isle of Youth and Escambray). The second, which is distiguished by the presence of evaporites, is located in north-central Cuba.

In the Guaniguanico mountains, the lower part of the section (Lower Jurassic–middle Oxfordian) contains deltaic sediments deposited during early stages of the breakup of Pangea (Fig. 12; Cobiella-Reguera, 1996a, 1996b; see also Fig. 16 in Iturralde-Vinent, 1996a). Tholeitic fissural magmatism was active during ?Callovian–Oxfordian time (Cobiella-Reguera, 1992, 1996a; Pszczolkowski, 1994). Perhaps the polymetallic deposits of the northwestern Pinar del Rio province (Zhidkov and Jalturin, 1976) are related to magmatism and reducing conditions in the narrow and poorly ventilated marine basin. Part of the siliciclastics of the Jurassic San Cayetano Formation could be derived from a northern source, possibly the Yucatán block (Pszczolkowski, 1986a; Hutson et al., 1998), but perhaps a significant fraction were eroded from a southern land area located in the other flank of a nascent continental margin (Fig. 12). A portion of the sediments derived from the south were deposited in the northern flank of the basin, in areas that later became part of the North American passive paleomargin. This might explain the N-directed paleocurrent indicators of Haczewski (1976), and also the different mineralogical composition of the San Cayetano sandstones in Sierra del Rosario and Sierra de los Organos (Cobiella-Reguera et al., 1997). The other sediments derived from the south could be represented by the metaterrigenous sequences in Escambray and the Isle of Youth. To resolve this intriguing and fundamental question, much more sedimentological (especially paleocurrent and mineral composition) research must be done.

The second type of paleomargin located in north-central Cuba (south of the Bahamas platform) was different and more difficult to understand, because a décollement is present at the Upper Jurassic level and outcrops of middle and lower Jurassic rocks are absent (the only older rocks are the tectonic slices of the Proterozoic marbles). In the Placetas zone, the arkosic sediments of local provenance (Constancia Formation and coeval clastic deposits (Pszczolkowski, 1986b) are the only indication of rifting in the proto-Caribbean Sea (Iturralde-Vinent, 1997). If the new data of the petroleum geologists are correct (Alvarez Castro et al., 1998), the change to carbonate sedimentation here occurred somewhat later than in the margins of the first type (Oxfordian ver-

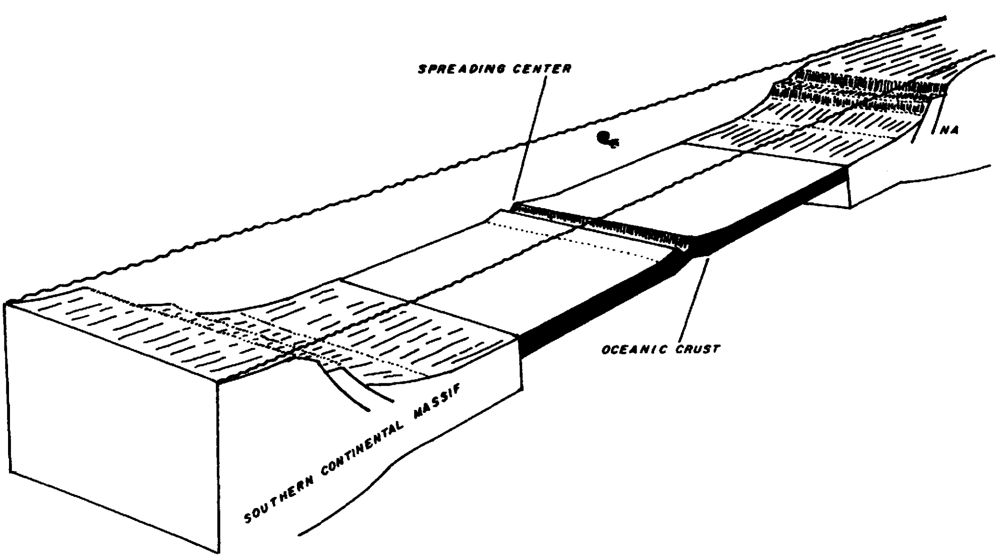

FIG. 13. Late Jurassic–Neocomian paleotectonic reconstruction. Abbreviations: NA = North American plate.

sus Kimmeridgian). The oldest salt deposits of Punta Alegre Formation could be the record of the first marine invasion of the southern Bahamas platform, which would have been in the Callovian or early in the Late Jurassic. Cyclical repetition of evaporitic conditions in the southern fringe of the Bahamas platform during the Late Jurassic and Early Cretaceous is documented in the Cayo Coco Formation (Fig. 7). The arkosic sediments in the Placetas zone are partly coeval with this last unit, and perhaps were deposited in a high that separated the evaporitic basin from the more open waters of the proto-Caribbean Sea.

In the Bahamas platform, the Triassic to Lower Jurassic rocks accumulated in tectonic basins (rifts). These siliciclastic rocks are separated by an unconformity from the Upper Jurassic non-terrigenous sediments (Ladd and Sheridan, 1987).

The general subsidence indicated by Upper Jurassic carbonate sections in the North American passive margin (Guaniguanico mountains, and northern Cuba) and in the SMT could be related to the generation of an oceanic depression between both margins and their thermal subsidence from the Late Jurassic (Fig. 13). A somewhat similar idea was proposed several years ago by Iturralde-Vinent (1988a, 1996a), but he did not consider the Guaniguanico beds to be part of the sequences of the late Mesozoic margin of North America, but as part of a continental mass (along with the Isle of Youth and Escambray rocks) that separated from the North American plate in the Late Jurassic. This problem will be discussed below (see Cobiella-Reguera, 1996a).

An essentially carbonate pre-Turonian or pre-Coniacian Cretaceous section is present in the North American continental margin in Cuba from the Guaniguanico mountains to eastern Cuba. Land areas were absent, except some small islands, as indicated by the quartzose turbidite interbeds in the Berriasian to Aptian beds in western and central Cuba (Pszczolkowski, 1982; Cobiella-Reguera et al., 1997). The splitting of the great Bahamas platform into several carbonate banks, separated by deep channels (Ball et al., 1985; Ladd and Sheridan, 1987), is represented in north-central Cuba by the Cayo Coco zone, where deep-water Aptian–Turonian carbonates are situated between the Remedios and Canal Viejo shallow carbonates. An extensional regime probably existed in the middle Cretaceous along the southern fringe of the platform.

As was stated above, the great similarities in the Cretaceous sections between Sierra del Rosario (western Cuba) and the Placetas zone in north-central Cuba (Figs. 4 and 7), plus the finding of Placetas–Sierra del Rosario type sediments in wells (Kuznetsov et al., 1985; see Figure 6 in Iturralde-Vinent, 1996a) and outcrops in northern Havana province (Fig. 8) provide evidence that the

Sierra del Rosario sequences, and all the related Mesozoic strata of the Guaniguanico mountains (Fig. 4), belong to the North American continental margin and are not a distinct tectonostratigraphic terrane (the Guaniguanico Terrane of the Southwestern Cuban Terranes of Iturralde-Vinent, 1996a). The emplacement of the ophiolites and Cretaceous arc volcanics over the Sierra del Rosario sections (Fig. 3; Cobiella-Reguera, 1996a; Gordon et al., 1997; Cobiella-Reguera et al.. 1997) also supports this view, because this situation is the same as in central Cuba, where the paleomargin of North America is overidden from the south by the Northern Ophiolite Belt and the Volcanic Arc Terrane (Meyerhoff and Hatten, 1968; Pardo, 1975; Cobiella-Reguera, 1996a; Iturralde-Vinent, 1996a).

In the Jurassic paleomargin sections of the Guaniguanico mountains and the SMT, the upper part of the stratigraphic section (middle Oxfordian–Tithonian) is dominated by carbonates (Pszczolkowski, 1978, 1994; Millán and Myczinski, 1978; Cobiella-Reguera, 1996a, 1996b). The striking similarities in the Jurassic stratigraphy and magmatism between both regions is a major feature of northern Caribbean geology and must be explained by any model on the geological evolution of Cuba and its surroundings. If the continental block (Pardo-Echarte, 1996) represented by the SMT were originally part of the North American Jurassic paleomargin, as their very close Jurassic correlation (including magmatic events) with Guaniguanico suggests (Cobiella-Reguera, 1996a), then the Escambray/Isle of Youth terranes are proximal (that is, proto-Caribbean) in their origins. It also appears that the SMT have always been located south of the volcanic arc (Iturralde-Vinent, 1988a, 1996a, 1996d; Cobiella-Reguera, 1996a, 1998c). The Southern Metamorphic Terranes are, therefore, a great obstacle to the popular models of a Pacific origin for the volcanic-arc sequences of Cuba and the Greater Antilles (Pindell, 1985, 1994; Pindell and Barrett, 1990; Stephan et al., 1990; Mann et al., 1991; Montgomery et al., 1992; and others).

Volcanic-arc sequences and the reversal of subduction polarity

The two volcanic-arc sequences in the Volcanic Arc Terrane may represent two different magmatic arcs (Cobiella-Reguera, 1998c). The oldest is of Aptian–Albian age (Rojas et al., 1995). The Neocomian age assumed for the older rocks of the volcanic-arc sections in central Cuba (Díaz de Villalvilla and Dilla, 1985) is not proven by paleontological or radiometric data. On the other hand, the oldest tuff interbeds in the Sierra del Rosario region of western Cuba (Fig. 5) and in the Placetas zone of central Cuba (Pardo, 1975) are Aptian. Therefore, recognizing that the data are not conclusive, an Aptian age for the beginning of the first magmatic arc seems the most plausible provisional conclusion. Metavolcanic interbeds in the Cretaceous(?) metasediments of the Escambray terrane (Millán and Somin, 1985) formerly may have been pyroclastic rocks, related to eruptions in the Aptian–Albian volcanic arc. Additional petrographic, geochemical, and stratigraphic research is basic for testing this idea.

The subduction zone related to the older arc probably dipped to the north, subducting the oceanic lithosphere between the arc and the Southern Metamorphic Terranes until the Albian, when the arrival of the low-density SMT stopped the process (Cobiella-Reguera, 1998c; Fig. 14). In this collision, the continental massif was metamorphosed and became the Southern Metamorphic Terranes. During Aptian–Albian time, oceanic lithosphere was created in a marginal basin north of the arc (see below). This scenario of arc zonation and development is based on: (1) the underthrusting of the Escambray and Isle of Youth Mesozoic sequences below the volcanic arc terrane (Iturralde-Vinent, 1981, 1988a, 1996a; Somin and Millan, 1981); (2) the existence of many tectonic lenses of serpentinites and other fragments of relict oceanic lithosphere in the Escambray massif (Geological Map of Cuba, 1:250,000; see Pushcharovsky, 1988), suggesting that an oceanic lithosphere was originally located between the arc and the southern terranes; (3) the radiometric ages (U-Pb) of 106–102 Ma (Albian) obtained in high-pressure metamorphic zircons in the Escambray mountains (Millán-Trujillo, 1996), which suggest a collisional event at that time; (4) the scarcity of volcanic rocks in upper Albian–Cenomanian sections;[1] (5) the fact that the orogenic(?) interval extended from the Albian to the Cenomanian, during which time, erosional agents carved deep in the volcanic pile, exposing the plutonic rocks (Iturralde-Vinent, 1996d), a tectonic event that may be related to the

[1] Non-volcanic sedimentary beds are very common in the same stratigraphic level in volcanic-arc sections elsewhere in the Greater Antilles (Robinson, 1994; Stanek, 1996; Iturralde-Vinent, 1996d; Jolly et al., 1998). This may be related to an attenuation or cessation of subduction.

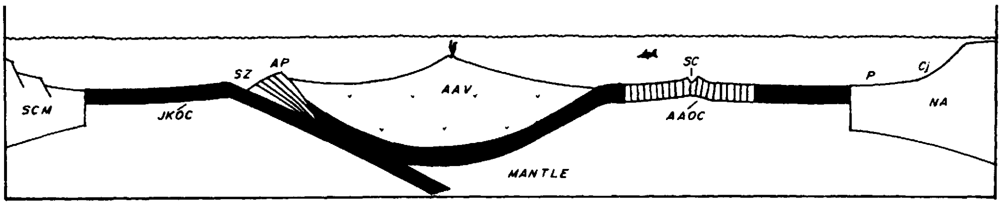

FIG. 14. Aptian–Albian paleotectonic-paleogeographic reconstruction. Abbreviations: SC = spreading center; AAV = Aptian–Albian volcanics; AP = accretionary prism; SZ = subduction zone; NA = North American plate; SCM = southern continental massif; AAOC = Aptian–Albian oceanic crust; JKOC = Upper Jurassic and Lower Cretaceous oceanic crust; P = Placetas zone; Cj = Camajuaní zone.

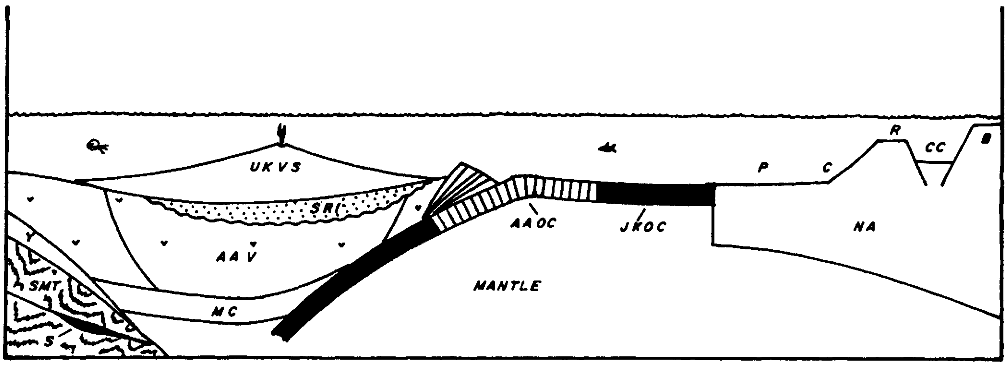

FIG. 15. Cenomanian–Campanian paleotectonic-paleogeographic reconstruction. Abbreviations: UKVS = Upper Cretaceous volcanics and sediments; SRI = Albian–Cenomanian sediment-rich interval; AAV = Aptian–Albian volcanic rocks; MC = Mabujina complex; SMT = Southern Metamorphic Terranes; AAOC = Aptian–Albian oceanic crust; JKOC = Upper Jurassic–Cretaceous oceanic crust; NA = North American plate; P = Placetas zone (deep waters); C = Camajuaní zone (talus); R = Remedios zone (carbonate bank; drowned from Coniacian to Campanian); CC = Cayo Coco zone (deep channel); B = Bahamas platform.

events of points 3 and 4; and (6) the fact that the youngest ophiolites are Albian—therefore the formation of oceanic lithosphere formation ended at the end of the Early Cretaceous.

A similar and more or less coeval change in subduction polarity has been proposed by Draper et al. (1996) in Hispaniola. Draper and Barros (1994) briefly suggested similar ideas as presented above for Cuba, but considered that the timing of the collision was Campanian. However, this was based on incomplete knowledge of the dates from the Escambray (G. Draper, pers. commun., 1999).

The second arc functioned from Cenomanian or Turonian until Campanian time, resulting from a subduction zone that probably dipped south, and consumed oceanic lithosphere that was located between the second arc and the continental margin of North America. In the Campanian, the second arc collided with the North American continental margin and arc-magmatic activity ceased (Cobiella-Reguera, 1998c; Fig. 15). In the author's view, the present relationships between the Volcanic Arc Terrane, the Northern Ophiolitic Belt, and the Mesozoic North American continental margin explained in the preceding paragraphs make this model the simplest and most logical, although other geologists may not agree with the concept of Late Cretaceous S-dipping subduction (e.g. Iturralde-Vinent, 1996a, 1996d; Millán-Trujillo, 1996).

Collision of the Late Cretaceous arc with the southern North American passive margin

Upper Campanian and Maastrichtian siliciclastic sediments in the arc cover, with a mixture of volcanic and ophiolitic clasts reported in some units of western (Albear-Fránquiz and Iturralde-Vinent, 1985) and eastern Cuba, and the Maastrichtian overthrusting of ophiolites upon the Volcanic Arc

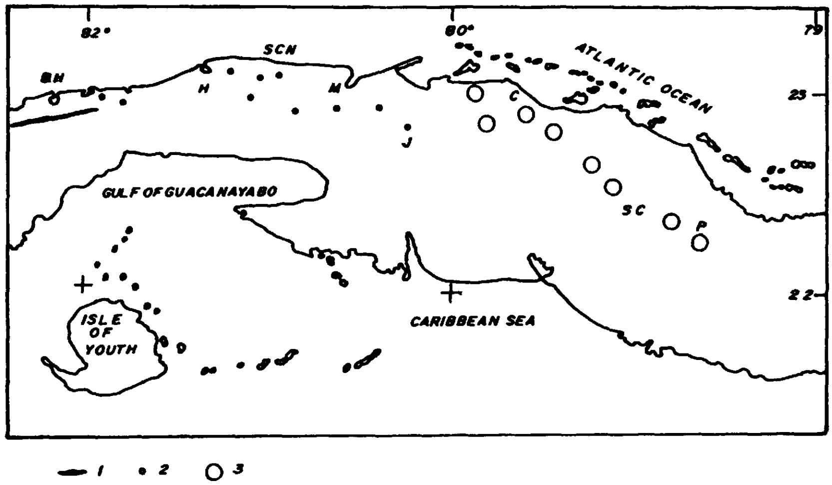

FIG. 16. Outcrop of the late Maastrichtian (or K/T boundary) megaturbidite in various locations: BH = Bahía Honda; H = Havana; J = Jovellanos; SCN = Santa Cruz del Norte; M = Matanzas; C = Corralillo; SC = Santa Clara; P = Placetas. Legend: 1 = Cacarajícara Formation in northern Sierra del Rosario; 2 = outcrops of Capdevila Formation; 3 = outcrops of Amaro Formation.

Terrane in eastern Cuba (Cobiella, 1978, 1984; Cobiella-Reguera et al., 1984) provide evidence that the ophiolites and Volcanic Arc Terrane were welded and partially merged before the end of the Cretaceous (Cobiella-Reguera, 1998c).

The calcareous megaturbidite of the continental margin (Cacarajícara and Amaro formations) and that of the western part of the volcanic terrane (Peñalver Formation) are of the same age (upper Maastrichtian or K/T boundary) and composition (Pszczolkowski, 1986c). They must be part of an extraordinary bed (Cobiella-Reguera, 1998c; Fig. 16), whose accumulation may be related to a catastrophic event at the K/T boundary near Cuba (Chicxulub crater in Yucatan; Alvarez et al., 1992). The existence of the megaturbidite is strong evidence that, at least in western Cuba and before the end of the Cretaceous, the Volcanic Arc Terrane and the Mesozoic North American continental margin were juxtaposed and part of the same basin (Pszczolkowski, 1986c). The oceanic depression between the extinct volcanic arc and the continental margin disappeared before the end of the Campanian (Fig. 15), leaving the ophiolitic belt of northern Cuba as a record. The abundant volcanic lithoclasts and plagioclase grains in sandstones of the upper part of the Moreno Formation (upper[?] Campanian) in the Sierra del Rosario (Pszczolkowski, 1994) is additional evidence that, at least in western Cuba, the closure of the small oceanic basin took place several million years before the end of the Mesozoic era. It is interesting that a similar age for an arc-continent collision is registered in northern Central America, south of the Yucatan platform (Burkart, 1994; Meschede, 1996). The Guatemalan ophiolites, long ago considered to be a part of the northern Caribbean ophiolitic belt, may represent another record of the proto-Caribbean lithosphere.

Emplacement of the ophiolites

Different ages, origins, and histories may be present in the relict oceanic lithosphere in Cuba (Cobiella-Reguera, 1998c). The oldest ocean-floor rocks were formed between the Late Jurassic and the Early Cretaceous (Neocomian) during the separation of North and South America, which formed a proto-Caribbean basin (Fig. 13; Marton and Buffler, 1994; Pindell, 1994; Meschede and Frisch, 1998). These rocks form the basement of the volcanic terrane (Mabujina complex) and dismembered meta-ophiolites in tectonic lenses in both the SMT and NOB. As the model in Figure 14 indicates, part of the Upper Jurassic–Neocomian oceanic lithosphere would have served as the basement for the Aptian–Albian volcanic arc. During development of the arc, this basement would have been intruded by plutons, which would have resulted in low-pressure/high-temperature amphibolite-facies

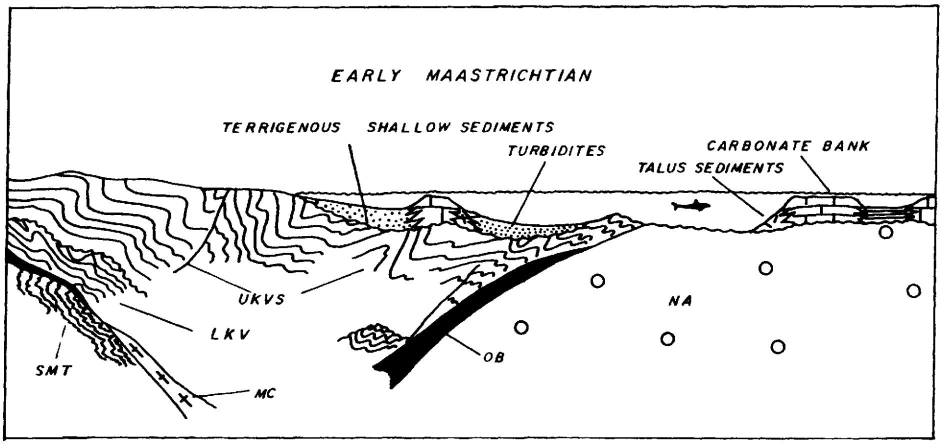

FIG. 17. Late Maastrichtian paleotectonic profile in central Cuba, before the sedimentation of the upper Maastrichtian (or K/T boundary) megaturbidite. Abbreviations: UKVS = Upper Cretaceous volcanics and sediments; LKV = Lower Cretaceous volcanics; MC = Mabujina complex; SMT = Southern Metamorphic Terranes (Escambray); OB = ophiolitic belt; NA = North American plate.

metamorphism. South of the arc, the recently created Upper Jurassic–Neocomian oceanic lithosphere was subducted to the north. In Albian time, the oceanic depression closed with the collision of a southern microcontinent with the arc. The eclogite-bearing serpentinite mélange and the high-pressure metamorphism in Escambray were likely associated with this event. North of the Aptian–Albian volcanic arc, a marginal basin developed, and accreted a new Aptian–Albian oceanic lithosphere to the Upper Jurassic–Neocomian lithosphere. Therefore, according to this hypothesis, the rocks of the NOB could have originated in two distinct tectonic settings (Cobiella-Reguera, 1998b, 1998c, in press): (1) in the Late Jurassic–Neocomian oceanic basin, formed by the separation and drifting of a southern continental mass from North America (Fig. 13); and (2) in an Aptian–Albian marginal basin, located between the Cuban volcanic arc and the North American plate (Fig. 14). More field and laboratory work is necessary to test this hypothesis.

Data from Iturralde-Vinent et al. (1996) show a well-defined peak of Campanian and Maastrichtian K-Ar radiometric ages (83 to 66.5 Ma), especially in the Southern Metamorphic and the Volcanic Arc terranes (~50% of the data for such domains), and less pronounced in the ophiolitic belt (~25% of the data for such rocks). Considering the characteristics of K-Ar data, the peak must be related to some regional tectonic event (or related events) that embraced all the tectonostratigraphic terranes (Cobiella-Reguera, 1998c). It is suggested that this event was the overthrusting of the ophiolite and metamorphic terranes of eastern Cuba (Cobiella-Reguera, 1983; Cobiella et al., 1984; Quintas, 1988). In central and western Cuba, the event is masked by strong lower Tertiary deformations (Meyerhoff and Hatten, 1968). However, examination of the regional structures in the Geological Map of Cuba (Pushcharovsky, 1988) show a significant difference in tectonic styles among the volcanic terrane (including its cover), the ophiolites, and the lower Tertiary beds that rest on them; this is particularly clear east of the city of Havana. An unconformity at the base of the Paleocene is almost universal in Cuba (Fernández et al., n.d.; Pardo, 1975; Pszczolkowski and Flores, 1986). Ball et al. (1985) reported a great anticlinal structure of Late Cretaceous age along the northern border of the Cuban fold belt.

In this way, data from varied sources and from all the major tectonic units strongly suggest an important tectonic event (or several linked events?) during the last few million years of the Cretaceous. This great event could have been the collision between the Mesozoic passive margin of North America in Cuba and the three tectonostratigraphic terranes (Fig. 17). A similar collision occurred in northern Central America more or less at the same time (Burkart, 1994; Meschede, 1994, 1996).

Conclusions

The record of four different tectonic and paleogeographic domains are present in Cuban Mesozoic sections. They are: (1) the Mesozoic passive margin of North America; (2) the Northern Ophiolitic Belt; (3) the Volcanic Arc Terrane; and (4) the Southern Metamorphic Terranes. The last three domains are considered to be distinct tectonostratigraphic terranes.

The volcanic terrane and the ophiolites form the central axial zone. These axial terranes were thrust over two passive margins in Cretaceous time. The Volcanic Arc Terrane, including its meta-ophiolitic basement, was emplaced southward over the SMT. The ophiolites and the Volcanic Arc Terrane were thrust from the south over the North American passive margin.

Very similar Jurassic sections exist in the Guaniguanico mountains (western Cuba) and the SMT, suggesting a common origin in the same basin, but the Cretaceous sections are quite different or absent in the SMT. The Jurassic features shared by the paleomargin of North America in western Cuba and the SMT, as well as the tectonic relationships of the latter, do not support the idea of a Pacific origin for the Cretaceous island arcs of Cuba (and of the Greater Antilles, in general), but instead suggest that a proto-Caribbean origin seems more plausible.

During the latest Jurassic, the SMT were separated from the margin of North America in Cuba and sea-floor spreading occurred in the proto-Caribbean basin. In the early Cretaceous (Aptian–Albian), a generally N-dipping subduction zone existed in the proto-Caribbean basin. The SMT collided with this subduction zone in late Albian or Cenomanian time, causing a reversal in subduction polarity. The new arc consumed the oceanic lithosphere of the Aptian–Albian marginal basin of the first arc until Campanian time, when the second arc collided with the North American paleomargin and subduction ceased. After the collision, in the late Campanian and Maastrichtian, a rough relief was developed on the old volcanic terrane, and thick terrigenous and carbonate deposits accumulated in some basins.

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