

Chapter 2

Overview of the Geology of Cuba

Abstract The Cuban Orogen can be divided into two major structural and stratigraphic units: basement and cover. The basement is the mega complex of igneous, metamorphic, and sedimentary rocks that lies below the little deformed section of the cover. It is divided into several tectonic large units, according to its structural style and age of the rocks. We can distinguish three large complexes: (a) Proterozoic basement, (b) Mesozoic basement, and (c) Paleogene folded belt. The Proterozoic basement outcrops in very limited areas and its structure is unclear. The Mesozoic basement consists of four complexes of very different nature: the Mesozoic paleomargin of the SE North American plate, containing Jurassic-Cretaceous sequences with varying degrees of deformation; the remaining three units, the ophiolite association, successions of volcanic arcs, and southern metamorphic terrains, have traits of tectono stratigraphic terrains. The links between the four major structures of the Paleogene deformed belt are much clearer. However the outstanding deformations and horizontal transport suffered by some units, the primary spatial relationships (paleogeographic) between them are essentially preserved. At the Paleogene folded and faulted belt are distinguished: • Foreland basin successions. • Piggyback basins successions. • Sierra Maestra-Cresta Caimán volcanic arc. • Synorogenic basin of Middle and Upper Eocene S Eastern Cuba. The cover composed of deposits from Lower or Middle Eocene to Quaternary, comprises the younger deposits of the section, little deformed in relation to the underlying layers, usually separated from these by remarkable structural discordance. Throughout Cuba, the cover is completely devoid of evidences of magmatic, metamorphic, and hydrothermal activity.

Keywords Cuban orogen • Base • Cover • Mesozoic continental paleomargin • Mesozoic ophiolite association • Cretaceous volcanic arcs terrain • Paleogene piggyback basins • Cuban foreland basin

2.1 Introduction

Cuba and its surroundings are a geological mosaic belonging to the southeastern portion of the North American plate. In the mosaic are rocks whose age ranges from Proterozoic to Quaternary, formed in various geological contexts. Much of Precenozoic registration is from rocks originated at a considerable distance from their current location. Cuban territory is part of the Antillean-Central America orogen (ACAO), which extends from northern Central America to the Virgin Islands, located east of Puerto Rico. From the Middle Eocene, the deformed belt, located immediately at the border of North American-Caribbean plates, has been dissected by numerous faults that have generated large marine depressions as the Cayman trough and the Yucatan basin, which significantly impede the decipherment of their structure and history. Today the northern part of ACAO, where Cuba lies, belongs to the North American plate, while the south (where lie the other Greater Antilles) is part of the Caribbean plate.

This chapter aims to provide an overview of the geology of Cuba, particularly of the central western, central, and center eastern regions of the territory, with which the research papers presented in Chaps. 3 and 4 relate to. Its content aims to satisfy the geological interpretation of the various issues raised in the geophysical interpretation of potential and airborne gamma spectrometry fields in the mentioned chapters.

2.2 The Cuban Orogenic Belt

The ACAO in Cuba can be divided into two major structural and stratigraphic units described here as basement and cover (fold belt and Neotecton, *sensu* Iturralde-Vinent 1996a, 1997). The basement (Cobiella-Reguera 2000) is defined as the mega complex of igneous, metamorphic, and sedimentary rocks that lies below the little deformed section of the cover. The cover consists of deposits of Lower or Middle Eocene to Quaternary (west of Yabre lineament-Y); Middle Eocene to Quaternary (between this lineament and the Guacanayabo-Nipe lineament-GN) and Upper Eocene high to Quaternary in Eastern Cuba, the south and east of GN lineament. Throughout Cuba, the cover is completely devoid of evidence of magmatic, metamorphic, and hydrothermal activity.

Cuban base is divided into several tectonic larger units, according to its structural style and age of the rocks. We can distinguish three large complexes: (a) Proterozoic basement, (b) Mesozoic basement (c) Paleogene folded belt.

The Proterozoic basement outcrops are very limited and its tectonic style is unclear.

The Mesozoic basement consists of four complexes of very different nature: the Mesozoic paleomargin of the SE North American plate presents Jurassic-Cretaceous sequences with varying degrees of deformation; the remaining three,

the ophiolite association, Cretaceous volcanic arcs, and the southern metamorphic terrains, have traits of tectonostratigraphic terrains. Southern metamorphic massifs may be considered proximal terrains, as their cuts show a clear stratigraphic link with the Mesozoic paleomargin of southeastern North America.

The links between the four regional structures of the Paleogene deformed belt are much clearer and, notwithstanding the considerable deformations and horizontal transport suffered by some, the primary spatial relationships (paleogeographic) between them are essentially preserved. At the Paleogene folded and faulted belt are distinguished:

- Foreland basin successions.
- Piggyback basins successions.
- Sierra Maestra-Cresta Caimán volcanic arc.
- Synorogenic basin of Middle and Upper Eocene S Eastern Cuba.

The Eocene-Quaternary cover comprises younger deposits of the stratigraphic section, little disjointed in relation to the underlying layers, usually separated from these by remarkable unconformities.

Basement

The basement meets an extremely varied set of rocks of different composition and ages, located below the Eocene-Quaternary sedimentary cover.

2.2.1 Proterozoic Basement and Jurassic Granites

The Precambrian basement is of great interest to the Antillean regional geology. In Cuba, it is known from small outcrops of Precambrian phlogopitic marbles with Proterozoic radiometric ages (903 and 952 million years ago) to the east and north of Motembo, Villa Clara province. These radiometric ages fall within the geochronological interval corresponding to the greenvillian orogeny, recorded in the southeast North American plate. At Socorro (Matanzas), these marbles are possibly cut by Jurassic granites with an age (U-Pb) of 172 million years (Renne et al. 1989; 139 and 150 Ma, according to previous dating of Somin and Millán 1981) and covered by an arkosic paleosoil (Pszczółkowski 1986). The paleosoil lies beneath the Upper Jurassic Constancia Formation, the marbles are the only known Precambrian rocks in the Greater Antilles. The discovery of marble and granite clasts in the nearby Jurassic arkose (Pszczółkowski and Myczyński 2003) is a strong indicator of a basement with Precambrian rocks for the southern edge of the North American plate.

Moreover, in areas near the North American Plate (SE Gulf of Mexico, Belize-Yucatan and Florida-Bahamas platform) Paleozoic rocks are known. The presence of Paleozoic fossils redeposited in Jurassic rocks of the Guaniguanico mountain range also suggests the presence of layers of that age in the Premesozoic basement.

2.2.2 *Mesozoic Basement*

The Mesozoic basement is the most complicated basement element formed by four large complexes of varied composition, age, and origin, separated by tectonic boundaries. These complexes are:

- North American paleomargin.
- Mesozoic ophiolite association.
- Cretaceous volcanic arcs terrain (KVAT), including its metamorphic basement and Campanian-Maastrichtian sedimentary cover).
- Southern metamorphic terrains.

2.2.2.1 *North American Mesozoic Paleomargin*

They form a diverse group of Jurassic and Cretaceous sedimentary sequences accumulated in an extensional continental margin, with some mafic tholeiitic magmatic bodies.

We can consider four different sections, related to different structures of the Mesozoic margin of the North American plate. From west to east they are:

- a. Cordillera de Guaniguanico, linked to the Yucatan platform and the southeast Gulf of Mexico.
- b. Sections between Havana and Camagüey, linked to the Florida–Bahamas platform.
- c. Sections from northwest Holguín (Gibara), linked to the southeast of the Florida–Bahamas platform.
- d. Sections from easternmost Maisí, possibly related to the Florida–Bahamas platform (Southeastern border), affected by an episode of regional metamorphism.

In each of them, the North American Mesozoic paleomargin is divided into smaller units, characterized by their own structural position, stratigraphy, and tectonic style (Meyerhoff and Hatten 1968; Pardo 1975; Pszczółkowski 1978; Iturralde-Vinent 1996a; Cobiella-Reguera 2000; Pszczółkowski and Myczyński 2003; Linares Cala et al. 2011, among others).

For the purposes of this study, the most interesting cuts of North American Mesozoic paleomargin are concentrated between Havana and Holguín. Therefore, only they will be treated in this text.

Havana-Holguín sections, linked to the Florida–Bahamas platform

From Havana, the paleomargin stratigraphy presents significant changes compared to Western Cuba. This is the region (Bahamas paleomargin, sensu Iturralde-Vinent 1996a) where the concept of zones or structure-facial units, widely used in Cuban

geology (Khudoley and Meyerhoff 1971; Pszczółkowski 1982; Echevarría-Rodríguez et al. 1991; Linares Cala et al. 2011), present the broadest and robust development. In outcrops and wells, from north to south, one can distinguish the following tectonostratigraphic units of North American paleomargin:

- Cayo Coco.
- Remedios (R).
- Camajuaní (C).
- Placetas (P).

The essential features of each (sometimes with different names) are discussed in various publications (Meyerhoff and Hatten 1968; Khudoley and Meyerhoff 1971; Pardo 1975; Iturralde-Vinent 1996a; Cobiella-Reguera 2009; Linares Cala et al. 2011, among others).

In the territory between the meridian $83^{\circ} 30' W$ and Yabre lineament (in the provinces of Havana, Mayabeque, and Matanzas), outcrops of the paleomargin rocks are limited. However, data from wells near the north coast and some brachianticlines in northern Matanzas indicate that, under the nappes of the Cretaceous volcanic successions and the rocks of the ophiolite association that form the core of the so-called “Havana-Matanzas anticline”, must lie the Jurassic- Cretaceous paleomargin rocks. These mainly belong to Placetas unit, to a lesser extent, the Camajuaní units (latter only found in depth in this area) and Cayo Coco units (evaporites, Fig. 2.1). Further east from Yabre lineament, paleomargin outcrops are arranged rather continuous throughout North Cuba to circa $76^{\circ} W$ (Holguín).

Remedios unit usually appears in the northernmost cuts. It is integrated by sections of carbonate rocks with thick to massive layering, accumulated mostly in shallow water, representing the thick banks of the southern edge of the Florida–Bahamas platform. The Remedios unit outcrops in Central Cuba, east to Yabre lineament, but is known for deep wells in the Hicacos peninsula (Matanzas), south of

Fig. 2.1 Layers of gypsum of San Adrian Formation, of possible Jurassic age, in the homonymous quarry in NW Matanzas. At this point, tectonic inclusions of ophiolitic association rocks, Cretaceous volcanic terrains and North American paleomargin are presented



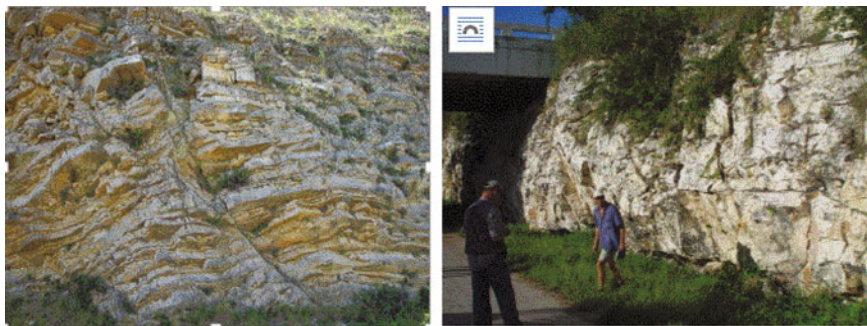


Fig. 2.2 Northern paleomargin successions. The photo on the *left* corresponds to deposits with turbidite traits of the Upper Jurassic Camajuaní unit, near Zulueta, Villa Clara. On the *right*, massive rocks of Cretaceous banks Remedios unit, south of that city

the Straits of Florida. East of Chambas (Ciego de Ávila), Remedios cut contains an intermediate stratified package of carbonated turbidites (Vilatá Fm., Albian–Cenomanian), which divides it into three parts.

Further south of Remedios platform and, tectonically superimposed, outcrop tectonic scales of well-stratified successions of the Camajuaní unit (Fig. 2.2) which, in essence, represent the slope layers of the Remedios platform edge. The Camajuaní unit is not known (at least on the surface) to east of La Trocha lineament. The southern portion of the North American paleomargin in Central Cuba is represented by well-stratified deep basinal sections of Placetas unit (Profile 7–8, Fig. 2.3), dated between Upper Jurassic and the K/Pg boundary. They tectonically rest on the Camajuaní unit and their stratigraphy is essentially similar to the Sierra del Rosario-Alturas de Pizarras del Norte-Esperanza unit (SR-APN-E) nappes of the Guaniguanico mountain range (Western Cuba). However, in Placetas unit, siliciclastic deposits, underlying the clay carbonated-carbonated succession of Upper Jurassic in northern Villa Clara, are under thin arkosic cuts (Pszczółkowski and Myczyński 2003), while those in Western Cuba are much more siliceous, formed in deltaic conditions (San Cayetano Formation and equivalent). This implies a pre-Tithonian tectonic differentiation between the two regions. The Placetas unit (something metamorphosed) outcrops in the “Esmeralda Complex” and inside of Veloz, Santa Teresa and Carmita formations (Upper Jurassic to Cenomanian) northeast of the city of Camagüey. In this unit there are scarce Upper Jurassic mafic magmatism. In the Sierra de Camaján (Camagüey), the base of the tectonostratigraphic unit Placetas is represented by pillow basalts, interspersed with thin layers of hyaloclastites (radiometric age 146 ± 6 Ma, Tithonian) and, to a lesser extent, of tuffites and fossiliferous tuffitic limestone.

East of La Trocha lineament, outcrops of North American northern paleomargin are mostly limited to the thick layers, usually massive, of Remedios unit. Sporadically, further north, are presented isolated outcrops of Cayo Coco unit, including possible evaporites Jurassic age of the Punta Alegre Formation (Meyerhoff and Hatten 1968;

Cuba, where the ophiolite slab emplaced at the Maastrichtian end remains much more integrated. Such inversion of KAVT/ophiolite belt spatial relationships with respect to Western and Central Cuba distinguishes both areas (Cobiella-Reguera et al. 1984; Iturralde-Vinent 1996b; Cobiella-Reguera 2005) from the ophiolitic rocks emplaced more to the west.

There is not much quantitative information on the magnitude of displacement of the northern ophiolite belt. The 50–70 km to the north northeast displacement of the Placetas unit in Central Cuba by Pszczółkowski (1983) serves as a minimum estimate for the translation of the NOB. For the Camagüey massif was calculated 20 km (minimum) (profiles 9–10, 11–12, Fig. 2.4). For ophiolites west of Havana, a minimal displacement of 26–32 km (Cobiella-Reguera 2009) was calculated. In eastern Cuba, with a less complex geological situation, it can be estimated about 60 km of northward displacement (minimum) for the rocks of Sagua-Baracoa massif. Cobiella-Reguera (2009) considered a minimum translation to the N of 22.5 km for the ophiolites of Maniabón (profile 13–14 Fig. 2.5). In that region, it was described an elongated block of an ortogneiss of granodiorite origin, embedded in serpentinite with a K-Ar age of 196 million years (Jurassic-Sinemurian), which may reflect the minimum age of the protolith. It is considered that this block could be a basement scale of North American paleomargin, ripped off by the ophiolitic massif. All this indicates that the northern ophiolitic belt is considerably shifted to the N of its “roots” and it is not an “ophiolite suture” that marks an ancient subduction zone, as some authors have supposed.

2.2.2.3 Cretaceous Volcanic Arc Terrain (KVAT)

In much of Cuba, structurally located on ophiolitic rocks and occupying in surface a more southerly position, is arranged the terrain of Cretaceous volcanic arcs (KVAT), formed by Cretaceous volcanic and volcanic-sedimentary rocks, its metamorphic substrate and an Upper high Cretaceous sedimentary cover. The tectonic nature of their basal contact and the absence, until Campanian, of stratigraphic relationships with pre-Maastrichtian rocks of the remaining Mesozoic tectonic units, allow considering this set of volcanic-sedimentary rocks of Cuba as a tectonostratigraphic terrain (Blein et al. 2003). It forms part of the great Cretaceous magmatic complex that extends throughout the Greater Antilles to the Virgin Islands and possibly covers southern Guatemala. The most complete and better-outcropped area of the Cretaceous volcanic arcs is presented in the central provinces (Villa Clara, Cienfuegos, and Sancti Spiritus). In this region, the lower structural position is occupied by the Mabujina Complex amphibolite rocks. It is a diverse group of metamafics and some ultramafics are cut by granitoid intrusives, which tectonically contact with the metamorphic Guamuhaya (Escambray) massif. There is some consensus to consider this contact as a collisional suture continental margin (Escambray metamorphic massif, high-pressure/low-temperature metamorphism)—volcanic island arc (Mabujina Complex, low/medium-pressure high-temperature metamorphism). On the other hand, some experts suggest that this might be a

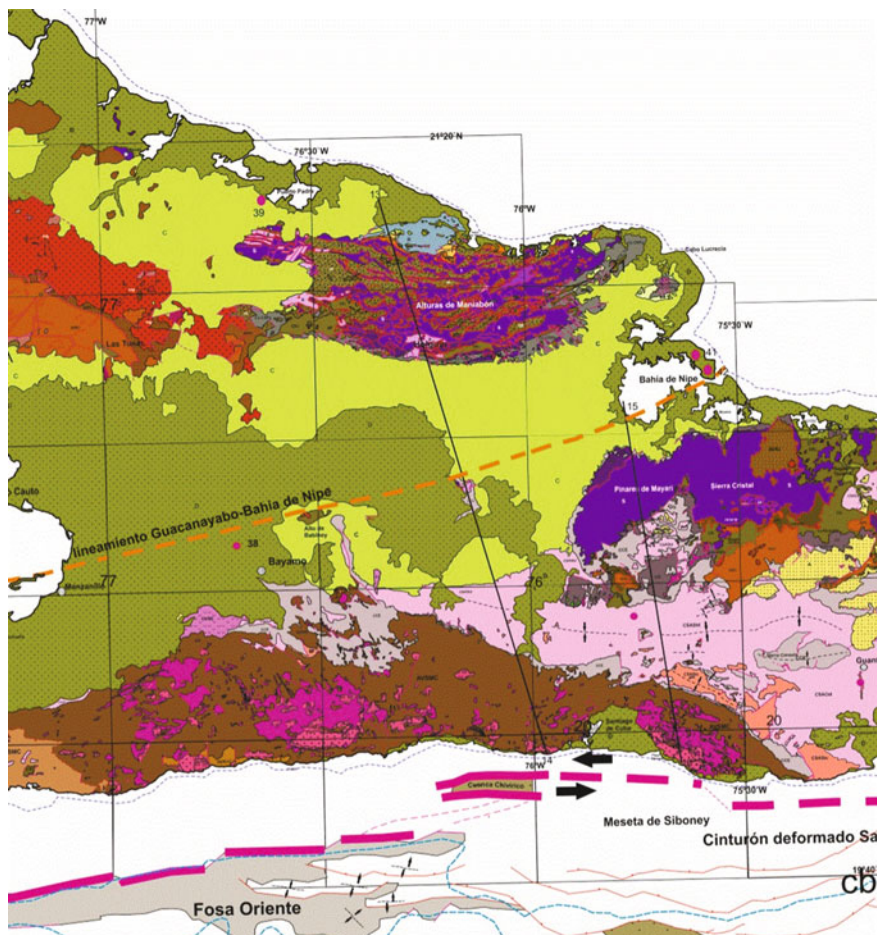


Fig. 2.5 Profile 13–14 in the Tectonic Map of Cuba (Cobiella-Reguera 2016)

distensional fault, due to the rise of Guamuhaya massif and gravitational “delamination” of overlying rocks (meaning, Mabujina Complex) that slid on its flanks (Pindell et al. 2006) during the Paleocene.

The Mabujina Complex is cut by numerous intrusions of various sizes. The oldest, with radiometric ages (U-Pb zircon) between 133 (Valanginian) and 110 Ma (Albian), are plagiogranites with gneissic structure and have been metamorphosed together with the amphibolites in a collisional event occurred between 90 and 88 Ma (Turonian–Coniacian). A younger generation, dated between 87 and 80 Ma (Coniacian–Campanian), corresponds to the so-called Manicaragua batholith (Stanek et al. 2009), which also injected successions of KVAT. According Stanek et al. (2006), in both Mabujina amphibolites and the Yayabo amphibolites, small pegmatite intrusive bodies are observed as well as with quartz and mica veins and

milky quartz. These bodies have no ductile deformation and are post-metamorphic. For the pegmatites is recorded ages between 88 and 80 Ma (Coniacian to Middle Campanian). Therefore, the metamorphic event is prior to such record.

Above Mabujina Complex lie the bimodal volcanics Los Pasos and Porvenir formations, the last with metamorphism of greenschist facies and possible prealbian Cretaceous age. Its boundaries are tectonic with amphibolites and are cut by intrusives also injected into the Mabujina Complex. On this complex, there are the volcanic-sedimentary cuts of two volcanic island arcs (Aptian?-Albian, the lower, and Cenomanian-Campanian high, the youngest), separated by a package rich in sedimentary rocks (Provincial Fm, Albian-Cenomanian, and other more local units, Kantchev et al. 1978; Fig. 2.3). In the Tectonic map of Central Cuba (Cobiella-Reguera 2016) this situation is very clear, but it is not so clearly observed on the west and east of the region. Some differences in the chemical and petrographic composition of both arcs have been found (Draper and Barros 1994; Stanek et al. 2009), a fact that has been tried to explain in different ways (Cobiella-Reguera 2000; Proenza et al. 2006). Increasing of siliciclastic component in the Upper Cretaceous arc and the presence of some calc-alkaline rocks enriched in potassium are also remarkable. However, in general, no significant structural discordance between the two arcs is recorded.

Eastward, in the Ciego de Avila-Camagüey-Las Tunas territory, the KVAT has abundant potassic volcanics of alkaline trend in Camujiro (considered Albian-Cenomanian or Turonian) and, to a lesser degree, Piragua formations (considered Coniacian-Campanian). The overlap in their distribution areas and the evidence of a coeval volcanism with the accumulation of Piragua allow considering the possibility that this is about (at least partially) different facies of the of Late Cretaceous volcanic arc deposits (Fig. 2.4). Thus, Camujiro corresponds to the volcanic apparatus facies and its vicinity, while Piragua belongs to volcanic-sedimentary facies peripheral to volcanic foci, with terrigenous contributions from volcanic arc erosion. Further south, away from volcanoes, well-stratified beds of Aguilar Fm., considered Santonian, were deposited. North of the central belt of granitoids volcanics are calc-alkaline (Caobilla Fm., Coniacian?-Santonian?) and largely consist of pyroclastic. A fifth type, also with some presence of rocks with alkaline trend occurs in the Eastern part of Camagüey and Las Tunas, consisting of the Guaimaro Fm. (Aptian? -Cenomanian?) of basaltic rocks, and Martí Fm. (Campanian) formed by lavas and pyroclastic rocks, with some interbedded sedimentary, partially originated in subaerial conditions.

In Camagüey four groups of granitoids are distinguished:

- Granodiorite complex
- Granosienite complex
- Plagiogranite complex
- Leucocratic alkaline granites complex (Maraguán granites).

Additionally, stand out subvolcanic intrusive bodies, many possible volcanic necks. They are particularly abundant within Camujiro and Piragua formations, but also intrude the granitoids (Fig. 2.4).

There is little definition of the age of the volcanic-sedimentary successions between Ciego de Ávila and Las Tunas. Unlike Central Cuba, the absence of beds with Lower Cretaceous proven age is remarkable. Only in a oil well near the city of Camagüey was cut, below the Camujiro Fm. (pre-Camujiro layers), a cut-rich in sediments and fossil association from Aptian-Albian, possibly coeval with Provincial Fm. Central Cuba.

Radiometric data show 95 ± 5 to 64 ± 5 million years ages (Cenomanian-Danian) for the various granitoids E of Camagüey (Marí-Morales 1997), while the age of granitoids in the whole east-central Cuba comprises a somewhat different range, Aptian to Campanian. In both cases, this means that the intrusives, together with the volcanics, form a large volcanic-plutonic complex, active for about 40–60 million years.

Some reports, in the 1980s, assigned thicknesses above 10 km to volcanic-sedimentary successions in the territory between Ciego de Ávila and Camagüey (Belmustakov et al. 1981), but this seems exaggerated. The absence of a clear linearity and orientation in most outcrops point to a lying nearly horizontal for these layers in this broad region.

Further east, in the mountains of Maniabón, northwest of Holguín, some features of Volcanic Arcs Terrain change. For its composition, two mélanges (Iberia and Loma Blanca) are distinguished. The so-called “Iberia Fm.” contains lavas and pyroclastic of composition between andesites and basalts and occupies much of the area. The “Loma Blanca Fm.” has a generally more acidic and more varied composition and tuffs often find zeolitised. It emerges toward the western portion of Alturas de Maniabón. In both units, there are many bodies of serpentinites, tectonically located (profile 13–14, Fig. 2.6; Kozary 1968; Knipper and Cabrera 1974) that mix with the volcanic-sedimentary rocks, forming a mélange. At las Alturas de Maniabón granitoids are absent, in contrast to its abundance in the territory of Ciego de Ávila–Camagüey–Las Tunas. This may relate to the fact that Maniabón is located north of the extension to the East of the granitoid belt.

The top of the KVAT contains sedimentary beds of Campanian to Maastrichtian age. At the west of the Yabre lineament, the cover contains accumulated deposits in

Fig. 2.6 Outcropping of serpentinitic-volcanic mélange near Guardalavaca, Holguín



basins that received hundreds of meters of thickness of volcanic turbidites between the late Campanian and the Maastrichtian (Vía Blanca Fm., Brönnimann and Rigassi 1963; Piotrowski 1987; Gil-González et al. 2007), coming from nearby elevated areas. On these rest detrital-carbonated deposits (Peñalver Fm.), linked to the of the Cretaceous/Paleogene boundary event (Takayama et al. 2000; Tada et al. 2002; Goto et al. 2008). In the central and Camagüey provinces KVAT cover contains terrigenous and carbonate clastic sediments in its lower portion (Monos, Duran, and others formations), with some interbedded pyroclastic in Central Cuba (Kantchev et al. 1978), from local focus, possibly located south of Santa Clara and the deposits of the K/Pg boundary. The younger layers are shallow water carbonate deposits (Yáquimo, Cantabria, and other formations).

The contact Upper Cretaceous cover with KVAT underlying successions has a variable nature. In the northwest of Artemisa (Bahía Honda-Mariel), the cover rests with structural unconformity (Campanian unconformity) on KVAT and ophiolitic belt. In the provinces of Havana and Mayabeque, contact appears to mark a takeoff tectonic plane (decollement) on the KVAT substrate very deformed and ophiolitic mélange. The decollement possibly developed taking advantage of the Campanian unconformity. Between Varadero lineament and Yabre lineament, contact is stratigraphic with KVAT rocks, but tectonic with ophiolitic rocks. Accepting this interpretation, it can be assumed that part of the cover remained in situ, during the orogenic event and part participated in local decollement.

Toward Central Cuba, from the Yabre lineament to Camagüey lineament, the contact is always stratigraphic, with an outstanding unconformity of terminal Campanian age. In the extended area from La Trocha fault to the west of Las Tunas, basal units are terrigenous and of Upper Campanian age (Duran Fm.). The rocks of the arc cover rest on both the granitoids and on the different lithostratigraphic units of the KVAT, evidencing a structural discordance that must be correlated with that of the late Campanian more to the west. In the Alturas de Maniabón, relationships KVAT—Campanian—Maastrichtian cover are complex. On the one hand, shallow carbonated deposits (Tinajita Fm., Figure 2.7) always have tectonic contacts and are part of a large regional mélange, but terrigenous units (La Jíquima and Sirvén

Fig. 2.7 Silla de Gibara. The top of this remarkable elevation (and many other hummocks in the Alturas de Maniabón) is formed by carbonated bank limestones (Tinajita Formation), resting tectonically on serpentinite



formations) possibly lie stratigraphically on the *mélange*. This points to a violent tectonic event during the Maastrichtian.

In tectonic schemes of the 1950s to 1980s of last century, the ophiolites, along with rocks of the Volcanic Arcs Terrain and piggyback basins as well as other units, were often grouped in a large tectonic unit called “Zaza zone”, or Cuban eugeosinclinal (Kozary 1968; Knipper and Cabrera 1974; also see Linares Cala et al. 2011). With the decline of the geosynclinal theory and use of the ideas of plate tectonics in the past 40 years, the term eugeosinclinal has been abandoned, although it occasionally appears. The same applies to the sections of the northern Mesozoic passive paleomargin, then known as miogeosinclinal.

2.2.2.4 Southern Metamorphic Terrains

Outcrop in Isla de la Juventud and the Guamuhaya (Escambray) massifs. In several aspects are one of the most enigmatic and, at the same time, complex elements of Cuban geology.

The lithostratigraphy of Guamuhaya (Escambray) has points of contact and divergence with the present in the Isla de la Juventud. Like this, the lower sections have a siliciclastic protolith, while the top is made of carbonate protolith (Fig. 2.8), in whose lower part there are Upper Jurassic fossils. The degree of metamorphism of these rocks varies from greenschist to high-pressure metamorphites (Millán Trujillo 1997a, profile 7–8, Fig. 2.3). In the older layers, there are some lenses of metavolcanic green schists. Above, the rocks differ. Although still dominating the marbles, there are units where the metavolcanics content varies from significant (Los Cedros Fm.) to dominant (Yaguanabo Fm.). A few bad preserved fossil remains indicate an age between the Tithonian and Albian to the basal portion of this upper part of the cut. Younger rocks are considered Cretaceous (Millán Trujillo 1997a).

The Guamuhaya massif forms two large dome-shaped structures (Trinidad and Sancti Spiritus), well marked in relief, separated by the Trinidad basin, to S, and to N, by Eocene clastic deposits of Meyer Fm. The domes are clearly reflected in the



Fig. 2.8 On the *left*, deposits of possible Jurassic age (Cobrito Formation) at Guamuhaya terrain (Escambray). On the *right*, marbles with the folded foliation, also possible Jurassic

package of Cretaceous volcanic-sedimentary rocks that are arranged in tectonic contact on the metamorphic complex. This deviation of the structures is perceptible in the tectonic map at distances greater than 20 km from the edge of metamorphic Guamuhaia Massif, indicating that the domes are deep structures (profile 7–8, Fig. 2.3). The age of the KVAT emplacement on the Guamuhaia massif is Late Cretaceous since a basal slip plane (decoulement) affects arc rocks of the Upper Cretaceous, but apparently not to its Campanian–Maastrichtian sedimentary cover. Millán Trujillo (1997b) says that this event is simultaneous with the metamorphism of greenschist facies recorded throughout Guamuhaia, which was estimated as about 85 million years old (Santonian). In the author's opinion, a slightly younger age (Campanian) is most likely.

Millán Trujillo (1997a) distinguishes four major tectonic packages (thrusts) called major tectonic units (MTU, Fig. 2.3). The lowest in the structure is the first MTU and the fourth MTU is the highest. Internally, each MTU (except the fourth) is divided into smaller nappes. The first and second MTU in the tectonic map are distinguished as lower MTU (MTL) and the third and fourth are higher MTU (MTH). The massif has a high-pressure metamorphism, with an inverted zonality between the first and third MTU. The metamorphic peak is reached in the third unit, with records of pressure/temperature 15–23 kbar/470–630 °C (Gavilanes nappe by Stanek et al. 2006). The fourth MTU contains metamorphosed rocks under high pressures, but lower temperatures than the third. A subsequent episode of metamorphism of greenschist facies (quoted above) affects the whole massif. The first metamorphic event may correspond to approximately 106–100 Ma (Albian), according to Millán Trujillo (1997b).

Numerous serpentine and metamaphyte bodies are included tectonically, often forming serpentinite mélanges. The most notable of them constitute high-pressure amphibolites (12–14 kbar/550–580 °C, Stanek et al. 2006) of Yayabo Fm. (Millán Trujillo 1997a). These may originally be part of the base of the volcanic arc, tectonically mixed with Guamuhaia metamorphites (Stanek et al. 2006). Some of the metamaphytes of igneous protolith (especially those not linked to serpentinites) may be manifestations of continental margin magmatism (e.g., Esquistos Felicidad or metavolcanics in the top of the La Chispa Fm.), similar to that observed in the SR-APN-E unit and the Arroyo Cangre Fm.

Stanek et al. (2006) estimate that the exhumation of the Guamuhaia massif began about 70 million years ago (Maastrichtian), although the first clasts of metamorphites in sedimentary basins of its periphery appear in rocks of Middle Eocene (45 million years). The uplift process of both domes remains active today.

In our opinion, sections of metamorphosed extensional (passive) continental margin type present in the lower portion of all MTU could form a terrain (nearby), related to the terrain Pinos. In MTU 3 and 4, that terrain is geographically isolated, but in MTU 1 and 2 is in tectonic contact, interdigitated with metamorphosed volcanic-sedimentary successions (Los Cedros and Yaguanabo formations) of possible Cretaceous age, which may be originally linked to the sequences of Cretaceous volcanic arcs.

2.2.3 Paleogene Folded and Faulted Belt

The KVAT—Upper Cretaceous Cover unconformity, together with the burial of the southern metamorphic terrains under TKVA and other events are evidence of the KVAT collision with the southern paleomargin of North America. This collision caused the end of the Cretaceous volcanic arc and the restructuring of plate boundaries (Cobiella-Reguera 2000, 2008) to early Paleocene. The theme of the early and middle Paleogene tectonic zonality has been treated in Cuban geological literature (Dilla and Garcia Méndez 1984; Cobiella-Reguera 1988, 2009; Iturralde-Vinent 1996c), but not with the depth required by the subject. In the tectonic map of Cuba (Cobiella-Reguera 2016), the following main structures of the early and middle Paleogene, where sediment accumulation occurs, are recognized (Fig. 2.9):

- Foreland basin.
- Paleogene piggyback basins.
- Sierra Maestra-Cayman Ridge volcanic arc.
- Upper and middle Eocene synorogenic basin of Southeastern Cuba.

The last two structures are not described in this chapter as being beyond the scope of this publication.

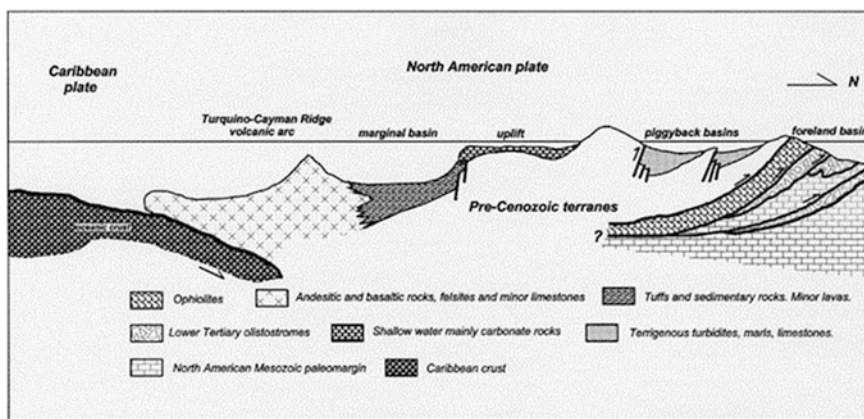


Fig. 2.9 North–South schematic tectonic profile showing the different structures present toward the center of Cuba in the range Paleocene–Middle Eocene. *Note* that in this interpretation (Cobiella-Reguera 2009), the Caribbean plate is subducted under the Paleogene volcanic arc and structures of thrust in northern Cuba, located several hundred kilometers to the north. This situation is not attributed to a collision of Bahamas platform with the Caribbean plate, but a more superficial process, linked to a thrust sheets tectonics, proper from the inner edge of foreland basins, according to Miall, in Busby and Ingersoll (1995)

2.2.3.1 Foreland Basin

Throughout North of Cuba, from Pinar del Río northwest until Gibara (Holguín), North American paleomargin rocks are covered by the foreland basin deposits (Fig. 2.9). These are successions accumulated in front of the over thrust generated during the Cuban orogeny, as a result of the erosion of its frontal region and the rapid subsidence of the basin (due to the weight of the nappes) creating the space for accommodation of large amounts of sediment. Sedimentation in these depressions is coeval with the orogenic deformation and the dating of deposits mark the event age (Busby and Ingersoll 1995). There is a strong imbrication between the tectonic scales from the southern portion of the foreland basin, formed mainly by olistostromes, and the scales of ophiolitic rocks, KVAT and the North American paleomargin. This strip of narrow interweaving of Mesozoic rocks of North American paleomargin, the ophiolitic rocks and KVAT with deposits of Paleogene foreland basin (Hatten 1957; Pardo 1975; Piotrowski 1987; Pszczółkowski 1994a; Iturralde-Vinent 1997; Cobiella-Reguera 2008) is caused by a combination of compressional and gravitational tectonics (Fig. 2.9). It has been called “Paleocene–Eocene deformed belt” (Cobiella-Reguera 2000) or “Northern Cuba folded and faulted belt”. Some geologists (Rojas-Agramonte et al. 2006; Pindell et al. 2006) have interpreted this scaled belt as an accretionary prism, linked to a subduction zone located to the north of Cuba but, taking into account the simultaneity of the folded belt deformations with the activity of Paleogene volcanic arc (Fig. 2.9), there are arguments for another possible model.

The foreland basin modifies some of its features along the strike. From the composition, age and degree of deformation of their deposits and architecture of depression, we can distinguish the following sectors:

1. West Sector. It comprises from northwest Pinar del Río to the Yabre lineament. The deposits of the foreland basin in this sector are known as Manacas Fm., up to around Havana (Martin Mesa structure) and, from this city to the east, are designated as Vega Alta Formation (Fig. 2.10). Manacas-Vega Alta rocks lie as huge

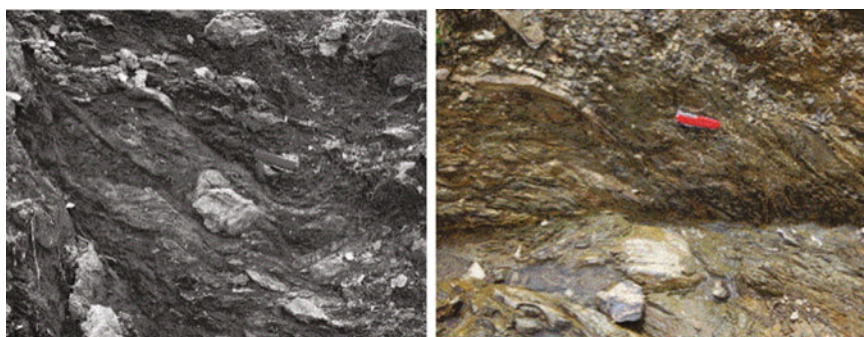


Fig. 2.10 Vega Alta Formation, strongly tectonized chaotic succession (observe the foliation bordering clasts) that characterizes the inner portion of the foreland basin in North Central Cuba

tectonic lenses sandwiched between tectonic scales of Mesozoic rocks of North American paleomargin. Its thickness is in the order of tens to hundreds of meters. They are mostly chaotic deposits, composed of clasts of different Mesozoic units (except the southern metamorphic terrains) greatly affected by intense deformation immediately after its accumulation (Pszczółkowski 1994a, b; Bralower and Iturralde-Vinent 1997; Cobiella-Reguera 1998). Genetically, are gravitational deposits (olistostromes) formed in front of thrust sheets.

2. Central Cuba Sector. It covers a band extending from the Yabre lineament to Tamarindo (Ciego de Avila), in the La Trocha fault zone. In its southern portion (inner basin) there are crushed, chaotic, olistostromic deposits, rich in ophiolite clasts and rocks of Placetas unit with minor amounts of volcanics from Cretaceous arcs (Formation Vega Alta, Fig. 2.10). Although, obviously the Vega Alta Formation rocks were originally deposited unconformably on the Mesozoic paleomargin, their current contact with paleomargin deposits is probably tectonic in the vast majority of cases. In essence, the layers of the foreland basin are divided into several tectonic scales that, in depth, possibly join in a main basal decollement plane.

Deposits located in the northern half (external foreland basin), which lie on Camajuaní and Remedios units, mostly contain clasts derived from these units (Iturralde-Vinent et al. 2008, Fig. 2.11). Its lower contact is considered tectonic for the Vega Fm. (Paleocene–Middle low Eocene), which rests essentially on the Camajuaní unit, and stratigraphic, when it comes of formations Grande (Paleocene–Lower Eocene) and Caibarién (Lower Eocene–Middle low Eocene), which lie on the Remedios tectonostratigraphic unit (Profile 7–8, Fig. 2.3).

3. Ciego de Ávila-Camagüey Sector. It is located between La Trocha and Camagüey lineaments, north of these provinces, with discontinuous outcrops between near Bolivia (Ciego de Avila) to the north of Minas (Camagüey). As in

Fig. 2.11 Carbonated brechya of Vega Formation near Camajuaní. These deposits are the main litho stratigraphic unit distinguished in external foreland basin of the North Central Cuba



Central Cuba, a zonality occurs in the composition of the sedimentary infill, which allows distinguishing two depressions. The inner basin contains thick clastic deposits, largely olistostromes, of the Senado Formation, very similar to the Vega Alta Formation, with abundant clasts of ophiolitic origin. Some of the olistolites present can reach 1 km in diameter. There are also clasts derived from Placetas North American paleomargin unit. In the matrix some sub-rounded clasts, possibly derived from KVAT, appear. According to Iturralde-Vinent et al. (2008), the formation is upper Middle Eocene to lower Upper Eocene. The external basin is composed of clastic carbonate sediments, largely derived from erosion of Cretaceous carbonate North American paleomargin deposits (Paso Abierto, Embarcadero, Lesca, Calciruditas Félix and Venero formations, Lower and Middle Eocene). Partially overlies the Remedios unit, but northward the substrate is formed by rocks of Cayo Coco unit. It is significant the presence of fine interbedded thin tuffs in layers of Middle Eocene (Lesca Formation) showing the distant presence of a coeval volcanic source (Sierra Maestra-Cresta Caimán volcanic arc).

In the southern edge, deposits of the Senado Formation tectonically rest on external foreland basin formations, but to the north, formation lies with stratigraphic contact on the layers of the outer basin. This may be related to progress toward the north of nappes located to the south of the foreland basin, accompanied by displacement in the same direction, of the depositional front.

4. Holguín Sector. In this territory, the foreland basin has similarities to Ciego de Ávila-Camagüey, with a sedimentary infill, which also lies on the Remedios unit (Fig. 2.5). Southward, a tectonic contact separates it from the ophiolitic rocks and Iberia mélange. The equivalent of the Senado Formation is the Rancho Bravo Formation. Like the first, the Rancho Bravo Formation is largely olistostromic, with abundant ophiolitic clasts and KVAT rocks. The Embarcadero and El Recreo formations form the filling, mostly carbonate-detrital, of external basin. As partially occur in Camagüey, deposits of the inner basin (with clasts of volcanics and ophiolites) lie stratigraphically above the beds of the outer basin (clastic carbonates), suggesting a shift to north of the thrust mantles front contacting with Rancho Bravo Formation.

In fact, despite its limited dimensions, the situation of the foreland basin in Holguín is fundamental to understand the relationships between the folded and faulted belt north of Cuba and the Paleogene volcanic arc, located further south. Relations outlined in Fig. 2.12 summarize a regional interpretation that responds to the model of a back-arc collisional foreland basin.

In the four studied foreland basin regions, on their rocks generally lie ophiolite association cuts, more rarely of the KVAT, tectonically emplaced, or from the cover.

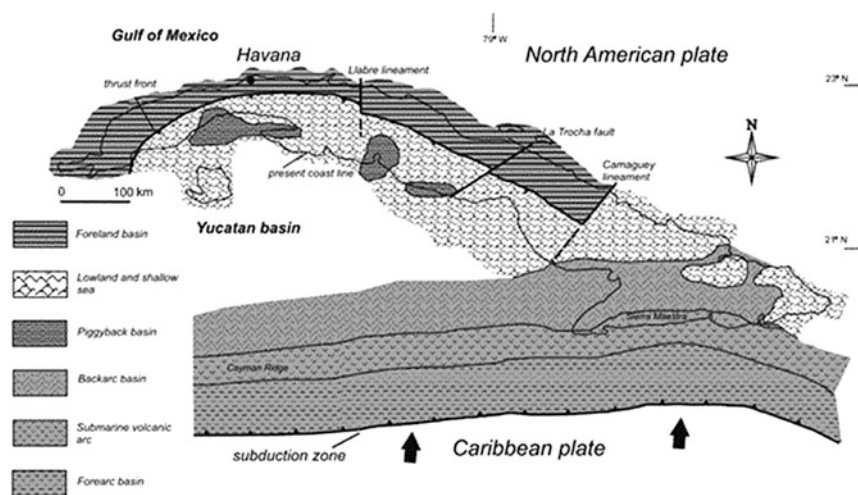


Fig. 2.12 Paleogeographic map of Later Paleocene–Early to Middle Eocene interval in Cuba and southwestern part of the Caribbean (Cobiella-Reguera 2009)

2.2.3.2 Piggyback Basins

Piggyback basins (PB) are small depressions, developed on the back of thrust sheets during the advancement of these (Busby and Ingersoll 1995). In the Cuban territory, there is evidence of the development of several of these basins, especially during the early Paleogene (Cobiella-Reguera 2009; Linares Cala et al. 2011). As is the case with other structures, Cuban piggyback basins modify some of its features from one region to another.

Piggyback basins in Central Cuba reach a development much higher than their counterparts in the West (west Yabre lineament). Three types are distinguished: Cienfuegos and Santa Clara (Fig. 2.3) in the west of the territory and, Cabaiguán, the east. In all is visible the participation of cover rocks of volcanic arcs terrain, only slightly older (and concordant) in the substrate, so that its development is evident in inherited depocentres from basins that subsidize since the late Cretaceous. Therefore, in the tectonic map they differ as inherited piggyback basins. In these are recorded some interbeds of reworked tephra and tuffs of late Maastrichtian and Paleocene age, evidence of a weak explosive volcanic activity in nearby areas. A generation of younger pyroclastic (Lower and Middle Eocene) is presented geographically limited to the southeastern Cabaiguán basin (Bijabo Formation of Kantchev et al. 1978). The Eocene intercalations should be linked to the volcanic foci of submarine Sierra Maestra-Cresta de Caimán volcanic arc (Cobiella-Reguera 2009, Fig. 2.12).

In Camagüey, the clastic composition and age of the filling of piggyback basins have particular features. Piggyback basins of Ciego de Avila and Camagüey have two varieties. To the north and mostly resting on ophiolitic rocks, lie thick clastic

sediments, assigned to the Taguasco Formation (Upper Paleocene–Lower Eocene). By its composition, the clastic material obviously comes from KVAT erosion. At south, the filling of the basins is younger (Lower and Middle Eocene) and more varied, with sandstones, siltstones, carbonate intercalations and some layers of tuff and tuffites (Vertientes Formation) and shallow carbonate facies (Florida Formation; Profile 9–10, Fig. 2.4). The coeval volcanic material must come from Sierra Maestra-Cresta de Caimán arc (SMCVA, Turquino arc, sensu Cobiella Reguera 1988; see also Bresznysky and Iturralde-Vinent 1978), which should be located relatively close to the south. From the methodological point of view, the dilemma of how to classify the deposits of Vertientes Formation arises, as also they admit to being considered part of the northern edge of the SMCVA back-arc basin. In the tectonic map, it was considered Vertientes Formation southern outcrops, in the south of Camagüey, as the filling of an intermediate depression between a piggyback basin and a back-arc basin (BA-PBPg).

In Holguín, southern the Alturas de Maniabón, the Paleogene siliciclastic-carbonate deposits from the Upper Paleocene and Middle Eocene contain some abundant interbedded pyroclastic and, even some isolated intrusive bodies (Paleogene?) are presented, that apparently cut structures originated during Maastrichtian deformations. Upper Paleocene deposits are thick terrigenous (Haticos Fm., Jakus 1983), with some resemblance to the Taguasco Fm. of Camagüey, but derived here from erosion of nearby ophiolitic massifs. The younger layers contain finer siliciclastic rocks and alodiapics limestone beds, in both cases with frequent turbidite features (Vigia Fm., Jakus 1983). The Haticos and Vigia formations contain interbedded pyroclastic. For this reason, and their spatial relationship with the foreland basin in the region of Gibara, in the tectonic map appear as a particular part of the north flank of back-arc basin (BA-PBPg) of SMCVA.

2.2.3.3 Synorogenic Basins and Oil–Gas Potential in Cuba

According to Cruz Orosa (2012), the formation of major Cuban tectonic corridors was coeval with the orogeny, which led to the segmentation of the orogen in a series of structural blocks that evolved independently. Linked to one of these tectonic corridors is the Central Cuba synorogenic basin (Central Basin), related to the La Trocha fault zone. The kinematics of the plates and the structural evolution of La Trocha fault zone indicate that the Central Basin is a polygenic tear basin and that the formation of this system (i.e., fault zone—tear basin) was a consequence of the oblique collision that occurred during the Paleogene between the Caribbean Volcanic Arc and the margin of the Bahamas (North American plate). In the opinion of this author, from tectonostratigraphic analysis of synorogenic basins, and its structural and tectonic implications, can be established a set of criteria for hydrocarbon exploration in Cuba. In this sense, the author states that the characteristics of Cuban petroleum systems are tightly controlled by the structure of the orogen. Therefore, there have been identified three main plays systems, which are associated to the Cuban folded belt, major tear structures and foreland system,

respectively. The author suggests that the deposits discovered in the plays systems associated with the folded belt and tear structures may contain crudes of any quality depending on the primary characteristics and maturity of the source rock, the type and magnitude of migration, the overlapping or not of different oil systems and/or the occurrence of secondary processes. It also believes that these deposits are mostly small in volume of its reserves and will be linked to structural traps type: duplex, triangular areas and back thrusts, in the plays system of the folded belt and; faulted anticlines, flower structures and seals against faults, in the plays system associated with tear structures. Instead, he suggests that undiscovered oil fields in the foreland plays system may have high-quality crudes and large volumes of reserves. However, it states that one must consider that, although the play system associated with the foreland is currently the greatest interest attracts by their assessment of risk/reward; by geochemical and structural characteristics of Cuban Orogen, other areas should not be dismissed.

2.2.4 Eocene-Quaternary Cover

The cover (Neoaethocon sensu Iturralde-Vinent 1997) comprises the large upper structural stage of the Cuban orogen. From Western Cuba to northwestern Holguín, it includes little deformed strata, accumulated after the Cuban orogeny. In eastern Cuba, south and east of the Guacanayabo–Bahía de Nipe lineament, the cover embraces the layers accumulated after the Eocene magmatic activity in the late Eocene. Since the events of the Cuban orogeny not concluded simultaneously throughout the territory are affected, the chronostratigraphic fingerboard of the cover is different in different regions. There is strong evidence of the decisive role played by several narrow strips arranged transversely to the general direction of the structures generated by the Cuban orogeny. These structures (transverse tectonic lineaments) have a linear character, better defined in certain sectors, less clear in other. In the tectonic map of Cuba (Cobiella-Reguera 2016), the following tectonic lineaments related to the chronology of the deformations occurred during the Cuban orogeny are identified: 1—Yabre lineament, 2—La Trocha lineament, 3—Camagüey lineament, 4—Guacanayabo-Bahía de Nipe lineament.

As previously noted, the orogenic events are genetically linked to the arrival in the foreland basin of chaotic deposits (synorogenic), whose age is dated acceptably well. West of Yabre lineament are Manacas and Vega Alta formations (Lower Paleocene–Lower Eocene). Between Yabre and La Trocha lineaments correspond to the Vega Alta Formation (Lower Paleocene–Middle low Eocene). East of La Trocha lineament, the Senado Formation (Middle Eocene) spans throughout the foreland basin to the north of Camagüey and, further east, the Rancho Bravo Formation (Middle Eocene) contact tectonically with ophiolitic rocks west of Gibara.

The above data, combined with other evidence, allow concluding that west to the Yabre lineament, orogenic processes elapsed between the Early Paleocene and

Early Eocene. Between Yabre and La Trocha lineaments, orogenic deformation conclude up to early Middle Eocene and, from La Trocha lineament to the northwest of Holguin, the orogeny takes place during the late Middle Eocene and possibly reaches the Late Eocene. Therefore, the base of the cover is markedly diachronic.

The cover outcrops in more than 50% of the Cuban territory. As previously noted, it is not homogeneous either horizontally or vertically. From the study of the cover's sediment thickness in 40 wells, its average thickness is approximately 760 m, with a significantly greater thickness reported in wells Candelaria-1 (about 3740 m) located near Pinar fault, Las Mangas-1 (2145 m) and Vegas-1 (2500 m) in southern Mayabeque.

According to the data available and considering the limitations of the scale, it is proposed to distinguish four substages arranged in the following sequence (from bottom to top): A, B, C, D. Together, these substages range from the Lower Eocene up to Quaternary for the territory west of the Guacanayabo- Bahía de Nipe lineament. To the southeast of Cuba, east of the above lineament, in the substrate over thrust deformations are not recorded and there are some differences in the chronostratigraphic fingerboard of the cover respect to the cut in the west and center. Here, the following substages are proposed: A', C', and D', covering the Upper Eocene to Quaternary.

Substage A. Transitional successions

In several regions, it is included in the basal portion of the cover successions with some degree of structural complication and evidence of accumulation in even unstable conditions. Transitional successions (A) are located in areas at the base of the cover. They are siliciclastic nature, largely, sandstones and immature conglomerates. They were deposited in basins of limited extent in conditions of tectonic instability, reflected by numerous synsedimentary deformations (especially submarine landslide folds). Among the formations belonging to this group are Capdevila (Lower low Eocene), extended from Pinar del Rio to Mayabeque (Brönnimann and Rigassi 1963), Marroquí and Arroyo Blanco (Kantchev et al. 1978), in the northwest of Ciego de Avila. These units contribute to dating the end of the thrusts in the Western and Central Cuba, showing they become younger from west to east.

In Matanzas, substage seems to be represented by the Perla Formation (Lower and Middle Eocene) of siliciclastic nature at its lower portion, transitioning vertically to carbonate deposits. This unit lies both on the North American paleomargin as on KVAT rocks. Therefore, the orogeny was concluded by mid-Early Eocene in the current central Matanzas. To the east, in the Trinidad basin, Meyer Fm. (Middle Eocene) is considered as the base of the cover. This unit is composed by massive brechya of metamorphic clasts, with a maximum thickness of 300 m. The Condado Formation (Subfloor B) unconformably covers the Meyer Formation.

Another structure where the substage is recorded in the Central Basin (located between the cities of Sancti Spiritus and Morón). In it, substage A is represented by the Arroyo Blanco (100–600 m thick) and Marroquí formations, both from Middle

Eocene high–Upper Eocene, which lie unconformably on structural units of the Middle Eocene (Kantchev et al. 1978).

Substage B. Western Cuba—Camagüey (up to about 77° 30' W)

The substage B is fully formed by marine deposits. At them, siliciclastics play a subordinate role with marl and limestones as main lithologies. It is mainly located in west of La Trocha lineament, with minor inliers in Camagüey. The stratigraphic record includes deposits between the Lower or Middle Eocene and Upper Oligocene. In Western Cuba, its layers lie with moderate unconformity on rocks of the transitional sequence. To the east of Varadero lineament, virtually disappear outcrops of substage A until Central Cuba, and then, B rests on the basement, with marked structural unconformity, as consequence of the late Cretaceous events and the Cuban orogeny.

Between the Varadero and Yabre lineaments, substage B outcrops are located mostly toward the center of the territory, being part of the core of large antiforms. Sedimentary thicknesses appear to be discrete. From the available data, a thickness not exceeding 700–800 m can be considered (Brönnimann and Rigassi 1963).

Stratigraphic successions of substage B (Eocene–Upper Oligocene) between Mayabeque, Cienfuegos and Villa Clara largely are also formed by marl and limestone, with fine terrigenous deposits, all of marine origin (Nazareno, Hatillo, Peñón, Jicotea, La Jía, Caunao, Tinguaro and Saladito formations). All have a total thickness of the order 400–500 m in the structures between Bejucal and Cidra and, about 1000 m, in Cienfuegos basin. In these regions, the subfloor involved in the core of various structures of anticline type, includes Bejucal, Madruga, Cidra, Coliseo, Cantel-Camarioca, Perico-Colón and the broad Santo Domingo syncline. This, coupled with the frequent presence of subfloor deposits in deep drilling, shows its extensive underground distribution.

South of the Guamuhaya massif (Trinidad basin), the substage B shows a different lithological character. On the substage A and/or the basement rest, unconformably, about 1000 m of siliciclastic deposits with southern homoclinal lying (Condado Formation Upper Eocene–Oligocene). The cut ends with carbonated layers (Las Cuevas Formation, Oligocene). The equivalent of the Condado Formation in Cienfuegos basin, located to the west, is the Damuji Formation. In both sequences, the siliciclastic grains come from the erosion of Guamuhaya Mesozoic metamorphites. The maximum thickness of the substage B in Trinidad basin should exceed 1200 m.

The Central Basin is a poorly defined geological structure in Cuban literature, including therein, successions from both the basement and the cover. In the tectonic map, it is considered that the depression is a structure of the Eocene–Quaternary cover that should include only spatially and genetically (?) deposits associated to La Trocha lineament. In the Central Basin, the substage B is represented by Chambas, Tamarindo, and Jatibonico formations, covering the Oligocene. The first two are carbonates, but the third contains abundant terrigenous material. Substage B in the

Central Basin includes deposits of Lagunitas Fm., reaching the Lower Miocene. Its terrigenous nature, with abundant clastic material derived from metamorphic rocks, approaches it to substage B characteristic units near the Guamuhaia massif. The fact of reach the Lower Miocene must be connected with the activity associated with La Trocha lineament. Tectonic map (Cobiella-Reguera 2016) clearly shows the spatial continuity of the outcrops of the Central Basin and the Trinidad basin, pointing to a genetic connection.

Further east of the Central Basin, substage B outcrops occupy limited areas. Eastward, they correspond to Nuevitas Formation, which lies with a marked structural unconformity on various units of the base. The unit, of about 50 m thick, is composed of marl and limestone interbedded with gypsum, resting as little deformed strata. East of the city of Camagüey, belong to this substage the strata of Saramaguacán Formation (upper Eocene) and Guaicanamar Formation (north of Santa Cruz del Sur).

Substage C. Western Cuba—Holguin northwest

Substage C strata (Upper Oligocene–Middle Miocene) lie separated by a discrete structural unconformity from underlain subfloor B and contain the most extensive cover outcrops. Unlike A and B, outcropping mainly in inliers, C rocks occupy two large areas, a Western, from 80° 15' W to the outskirts of the city of Pinar del Rio. In the eastern half of Cuba, the substage C comprises much of the territory between the La Trocha lineament and the Nipe bay.

In Mayabeque, the thickness substage C reaches about 600 m. In Matanzas the substage C registers between 600 and 780 m thick. In the central provinces, C is almost absent. East of La Trocha lineament, B floor strata are scarce and C layers generally lie with marked unconformity on the basement (especially KVAT and ophiolite association). In the territory between Ciego de Ávila and northwest of Holguin, the substage C again contains abundant shallow carbonate deposits (Güines and Camazán formations), although siliciclastic deposits (Pedernales and Los Arabos formations) and carbonate-siliciclastic (Vazquez and Paso Real formations), accumulated in shallow marine and coastal conditions, become relatively more frequent.

South of the city of Holguin substage C reaches between 400 and 800 m of thickness, in north Las Tunas more than 200 m (Jakus 1983).

Substage D

Unlike underlying substages, the D (Upper Miocene-Quaternary) contains abundant inland, coastal and shallow marine sediments. Generally, they are arranged away from the axial region of Cuba, but there are some inland areas where they reach a certain extension (for example, in the province of Ciego de Ávila and the Cauto river basin).

In Vegas and Broa basins (South Mayabeque), the occupied strip by D is greatly reduced. In this section, the substage contains only marshy quaternary sediments.

In the Cienaga de Zapata and the Cienfuegos basin, on the surface are mainly peat that lie on coastal formations (Vedado and Jaimanitas) or fluvial (?—Villaroja) which, in turn, rest discordant on the substage C, except in the eastern edge of the Cienfuegos basin, where the substage is located on the basement or substage B.

Deep Cochinos bay is the geomorphological reflection of the homonym graben, very young structure in the NNW direction.

In the Trinidad basin, substage D basal deposits are formed by shallow carbonate of Vedado Fm. that, apparently, lie in a small angular unconformity on substages B and C. Further south are the deltas of the Agabama and Zaza rivers, which join the East with the South Jatibonico. This low coast extends to Júcaro, forming a relatively extensive coastal plain in the south of the province of Sancti Spiritus, testimony of subsidence and Quaternary progradation in South Central Basin. In the coastal plain of Southern Camagüey, the substage forms a thin layer of Quaternary deposits, currently suffering erosion.

Along the northern coast of Western Cuba, width of D outcrops is very small, predominantly of marshy deposits until Bahía Honda. From this town to Matanzas bay, the substage D forms a narrow strip mostly represented by coastal Quaternary carbonates, modeled on marine terraces, whose maximum height is presented on its eastern edge, at the entrance to the Matanzas bay. Geomorphology of Matanzas bay and the distribution of D deposits show the existence of an active syncline along the valley of the Yumuri river. Moreover, the marine terraces on the western side of the bay and the west coast are a classic periclinal close sinking to the east.

In Villa Clara northeast and Sancti Spiritus small enclaves of subfloor C rocks (Güines Formation) are recorded in areas occupied by D. Currently, some tiny rocky islets, formed by rocks of this formation are presented, which sharply contrast to the “normal” keys, formed by quaternary deposits. Two evolutionary models seem feasible to explain the rocky keys: 1—these rocky keys (Salinas, Guainabo and others) east of Caibarién are the tops of small elevations, possibly buried because of Holocene rise of sea level. The substage C enclaves can be explained by a more advanced stage of this transgression and; 2—the keys might be related to upward movements of the Jurassic diapirs thus, immediately to the east, the three major salt diapirs Central Cuba are located: Punta Alegre, Turiguano and Cunagua. These structures are alive and are reflected in the current peculiar relief, determined by geographical features such as Laguna de Leche, the Cunagua hill and the river network south of this elevation. Therefore, there should not rule out the possibility that the above “rocky keys” may be linked to the current upward movement of the Jurassic salts, which, in turn, could be related to tectonic activity according to La Trocha lineament.

East of Cunagua hill, the D is mostly occupied by thin marshy deposits, lying on C, except in the region of Nuevitas, where they rest on the subfloor B. Nuevitas bay is a small depocentre, and supplied by the Saramaguacán and other rivers. Eastward, the strip of deposits D is mostly coastal biogenic carbonates (Jaimanitas Fm.). From Gibara, the basement of D is formed by calcareous and loamy marine deposits of the Upper Miocene-Pliocene.

2.3 Conclusions

The Cuban orogen can be divided into two major structural and stratigraphic units: basement and cover. The basement is the mega complex of igneous, metamorphic, and sedimentary rocks that lies below the little deformed cut of the cover. It is divided into several tectonic larger units, according to its structural style and age of the rocks. We can distinguish three large basement complexes: (a) Proterozoic basement, (b) Mesozoic basement, and (c) Paleogene folded belt.

The Proterozoic basement emerges are very limited.

The Mesozoic basement consists of four complexes of very different nature: the Mesozoic paleomargin of the SE North American plate, which presents Jurassic-Cretaceous sequences with varying degrees of deformation; the remaining three, the ophiolite association, the Cretaceous volcanogenic successions and southern metamorphic terrains, have traits of tectonostratigraphic terrains.

The links between the four regional structures of the Paleogene folded belt are much clearer and, notwithstanding the considerable deformations and horizontal transport suffered by some, the primary spatial relationships (paleogeography) between them is essentially preserved. At the Paleogene folded and faulted belt are distinguished:

- Foreland basin successions.
- Piggyback successions.
- Cuts of Sierra Maestra-Cresta Caimán volcanic arc.
- Synorogenic basin of Middle and Upper Eocene of South Eastern Cuba.

The cover, composed of deposits of Lower or Middle Eocene to Quaternary age, comprises the younger deposits of the stratigraphic cut, little dislocated in relation to the underlying layers, usually separated of these by remarkable structural discordances. Across Cuba, the cover is totally devoid of evidence of magmatic, metamorphic, and hydrothermal activity.

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2017, XIV, 76 p. 48 illus., 45 illus. in color., Softcover

ISBN: 978-3-319-56743-3