The geology of Cuba: A brief overview and synthesis

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ABSTRACT

Cuba is the largest island in the Greater Antilles, and its geology records three important episodes: (1) the Jurassic breakup of North and South America (Pangea) and associated passive margin and oceanic sedimentary and magmatic evolution; (2) the sedimentary, magmatic, and metamorphic evolution of an intra-oceanic Cretaceous-Paleogene ophiolite-arc complex; and (3) the Paleogene "soft collision" and transfer of the NW Caribbean plate (and Cuba) to the North American plate. Thick sequences of Jurassic-Cretaceous strata (conglomerates, sandstones, limestones, dolostones, shales) and interlayered basaltic rocks characterize passive margin sequences preserved in the Guaniguanico terrane (western Cuba, related to the Mayan passive margin and the Gulf of Mexico) and the Bahamas Platform borderlands (north of Cuba). Passive margin deposition ceased in latest Cretaceous time, when increasing relief of accreted (overriding) oceanic arc and ophiolite complexes shed coarse sediments (olistostrome and flysch), followed by carbonate deposition. Fragments of the intervening oceanic lithosphere (Proto-Caribbean, connected to the Central Atlantic) and fore- and back-arc oceanic lithosphere (Caribbean, of Pacific origin) occur as tectonic fragments detached from the ophiolitic units, including serpentinized harzburgites and dunites, banded and isotropic gabbros, basalts (tholeiitic and fore-arc basalts, locally with boninites) and Late Jurassic (Tithonian) through Late Cretaceous (Coniacian and younger) oceanic sediments. Arc activity in the Cuban segment of the Greater Antilles produced sedimentary, volcanic, and plutonic rocks during Cretaceous times (ca. 135–70 Ma). A new arc developed in eastern Cuba during Paleocene–middle Eocene times. Cuban arc sequences include island-arc tholeiitic, calcalkaline, and alkaline bimodal suites of volcanic and plutonic rocks. Remnants of Proto-Caribbean oceanic lithosphere occur as exhumed mélange-bearing eclogite-, blueschist-, and garnet-amphibolite-facies tectonic blocks (oldest age ca. 120 Ma) within a serpentinite matrix intercalated with, or at the base of, the overthrusted ophiolitic bodies. Cuban Cretaceous arc magmatic activity ended due to the subduction of Proto-Caribbean passive margin sequences of the Caribeana terrane, an offshore protuberance of Yucatan. This event formed strongly deformed high-pressure metasedimentary and metaigneous rocks at ca. 70 Ma, when the Caribbean plate began to collide with North America. The collision, which included overriding of the ophiolitic and arc units over both subducted and unsubducted passive margin sequences, also produced synorogenic basins and filled them, a process that continued until ca. 40 Ma. This foldbelt was succeeded by local uplift and subsidence to form late Eocene–Recent unconformable post-orogenic continental basins.

INTRODUCTION AND GEOLOGIC SETTING

Cuba has had a very interesting geologic evolution. The island is geographically very near the United States, but for political reasons, U.S. geoscientists have not been able to study it much. In this overview[1], we highlight the geology of Cuba. Useful publications on Cuban geology produced during the past quarter century can be found in Ceballos Izquierdo and Iturralde-Vinent (2016). We hope that the improving political situation will increase mutually beneficial interactions in the future. A few relevant geographic and demographic facts about Cuba are listed in Table 1.

Cuba is the largest island in the Greater Antilles and has been part of the North American plate (NOAM) since late Eocene time. It is separated from other Greater Antilles islands by the North

Table 1. Facts about Cuba

Size	109,884 km^2 (about the size of U.S. state of Tennessee). The main island is 1250 km (780 mi) long. Cuba is the largest island in the Caribbean and the 17th largest island in the world.
Geography	Cuba consists of flat to rolling plains as well as low mountain chains with peaks between 600 and 1974 m (1968.5 and 6476 ft), surrounded by shallow platforms, keys, and islets, as well as deep depressions, such as the Bartlett trough (6810 m [~4.23 mi]).
Coastline	3740 km (2324 mi)
Highest point	Pico Turquino (1974 m [6476 ft])
Population (2014)	11,238,317
Political subdivisions	15 provinces and one special municipality: Isla de la Juventud.
Official language	Spanish
Geological resources	Cuba's most important mineral resource is nickel, with 21% of total exports in 2011. The output of Cuba's nickel mines that year was 71,000 tons, approaching 4% of world production. As of 2013, its reserves were estimated at 5.5 million tons, over 7% of the world total. Cuba is also a major producer of cobalt, a by-product of nickel mining operations. Oil exploration in 2005 by the USGS revealed that the North Cuba basin could produce ~4.6 billion barrels (730,000,000 m^3) to 9.3 billion barrels (1.48×10^9 m^3) of oil.

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Figure 1. (Top) Tectonic map of the northern Caribbean region. (Bottom) Generalized geologic-tectonic map of Cuba modified from Iturralde-Vinent (2011).

Caribbean Transform Fault System (including the Oriente Fault), which defines the present North American–Caribbean (NOAM-CARIB) plate boundary south of Cuba (Fig. 1A).

The Greater Antilles Arc began to form ~135 m.y. ago, after the breakup of Pangea, along the leading edge of CARIB, due to SW-dipping subduction of NOAM beneath NW CARIB. The Cuban arc finally collided with Florida and the Bahamian platform in middle to late Eocene time (ca. 48–40 Ma). About this time, the Cayman spreading ridge and the Oriente transform formed to the south (Fig. 1A), resulting in a new NOAM-CARIB plate boundary zone (PBZ) along the new fault system (Burke et al., 1978). This plate reorganization also resulted in the formation of the small Gonave plate SE of Cuba (Fig. 1A). These events transferred NW CARIB, including Cuba, to NOAM (Pindell and Kennan, 2009).

The geology of Cuba is dominated by three lithotectonic associations, which reflect its evolution as a Cretaceous-Paleogene convergent margin: (1) deformed (para)autochthonous NOAM Jurassic and Cretaceous continental margin and basin sections and Paleocene-Eocene synorogenic foredeep deposits; (2) oceanic lithosphere and associated sedimentary rocks that formed on CARIB, including ophiolite complexes and serpentinite mélanges. These oceanic crustal assemblages are associated with ca. 135–47 Ma magmatic activity and interbedded with or overlain by synorogenic basins; and (3) (neo)autochthonous late Eocene to Recent deposits that unconformably overlie the two older units (Figs. 1B and 2; Iturralde-Vinent, 2011). Many of these units were partially subducted, metamorphosed, and exhumed. These lithotectonic associations are briefly summarized in the following sections.

NORTH AMERICAN (NOAM) ACCRETED DEPOSITS

North American igneous rocks and sediments originally formed along the Yucatan and Bahamas passive margins and elsewhere in the Proto-Caribbean basin. These units now crop out as juxtaposed fold-and-thrust belts of the Guaniguanico terrane, the Northern Foldbelt, and the metamorphic Caribeana terranes (Fig. 1B).

Guaniguanico Terrane

This terrane includes Early(?) Jurassic to latest Cretaceous passive margin siliciclastics, marine basalts, limestone, shale, and chert that record the origin and evolution of the Proto-Caribbean seaway (Fig. 2; Pszczółkowski, 1999; Iturralde-Vinent, 2011). These rocks are overlain by Paleocene to Lower Eocene synorogenic foredeep sedimentary rocks, including limestones, flysch, and olistostrome deposits. This ensemble was overthrust by ophiolitic and volcanic arc units (Bralower and Iturralde-Vinent, 1997).

Northern Foldbelt

This belt preserves the southern edge of the Mesozoic Florida-Bahamas platform deposits (Figs. 1B and 2; Meyerhoff and Hatten, 1974). The Northern Foldbelt and the Guaniguanico Terrane share similar Late Jurassic and Cretaceous Proto-Caribbean marine deposits. Between Paleocene and early Upper Eocene time, a forebulge and synorogenic foredeep developed with olistostrome, flysch, and carbonate deposition ahead of the leading edge of CARIB; extensive overthrusting also occurred (Iturralde-Vinent, 2013; Iturralde-Vinent et al., 2008; van Hinsbergen et al., 2009).

Caribeana Metamorphic Terranes

These terranes comprise Proto-Caribbean Jurassic-Cretaceous passive margin and oceanic protoliths (Figs. 1B and 2) that were subducted and accreted to Cuba ~75–60 m.y. ago (García-Casco et al., 2008). Caribeana is represented in Cuba by (1) the Cangre glaucophane-bearing terrane; (2) the Pinos metamorphic terrane; (3) the Escambray greenschist to eclogite facies complex with inverted metamorphic structure; and (4) the Asunción lawsonite and glaucophane-bearing terrane (Figs. 1B and 2; Somin and Millán, 1981; García-Casco et al., 2008; Despaigne et al., 2016).

CARIBBEAN PLATE

CARIB allochthonous units are fragments of Pacific oceanic lithosphere that migrated into their present positions during Cretaceous time. An integrated geologic (Whattam and Stern, 2015) and geodynamic (Gerya et al., 2015) case has been made that Caribbean plate formation began when the Galapagos mantle plume head impinged on the Proto-Caribbean seaway in Early Cretaceous time. Alternatively, Pindell et al. (2012) proposed that onset of subduction at ca. 135 Ma occurred along an inter-American transform fault with no influence of plume head. The Greater Antilles subduction zone along the leading edge of the Caribbean plate was responsible for the subduction of at least 1500 km of Proto-Caribbean and NOAM lithosphere in a SW-dipping intra-oceanic subduction zone (Figs. 1B and 2). The following CARIB units can be distinguished in Cuba.

Ophiolites and Ophiolitic Mélange

These rocks outcrop discontinuously for more than 1000 km along the northern margin of Cuba. They were obducted onto the

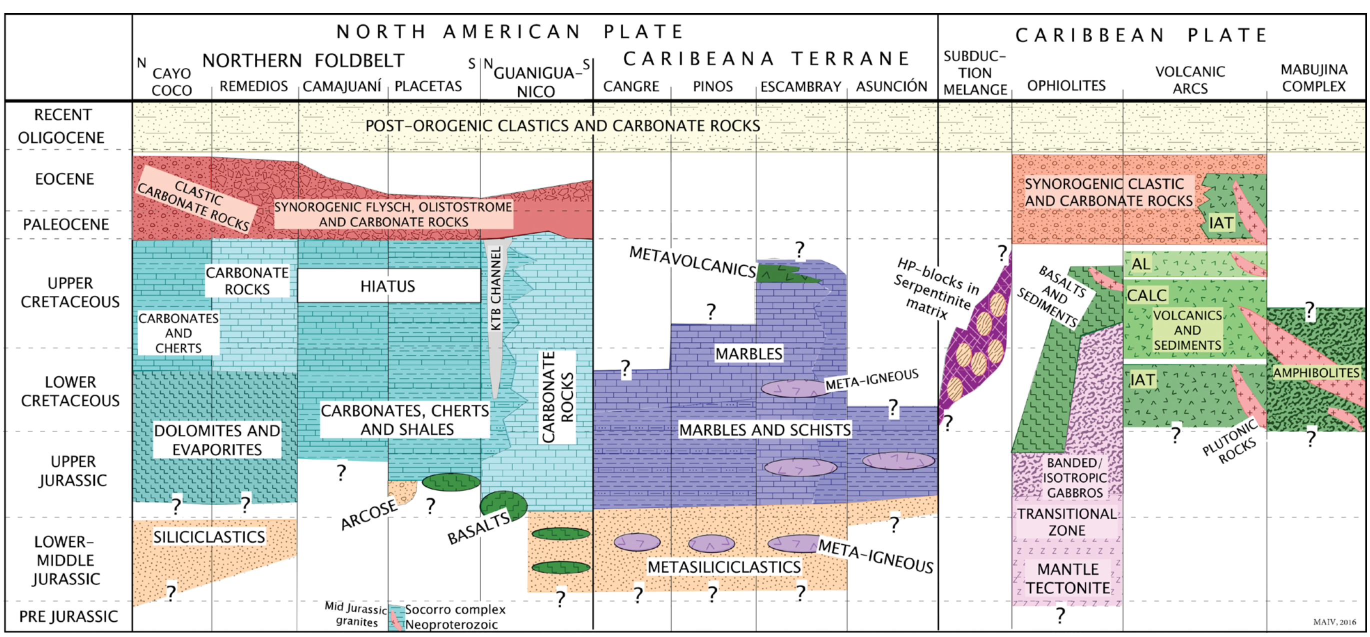

Figure 2. Generalized tectonic-stratigraphic chart of Cuba modified from Iturralde-Vinent (2011). Under "volcanic arcs," abbreviations refer to island arc tholeiite (IAT), alkaline suites (AL), and calc-alkaline suites (CALC). KTB channel refers to a deep erosional channel cut due to the Cretaceous-Tertiary boundary mass flows from the platform margins due to the impact.

NOAM paleo-margin in latest Cretaceous to late Eocene times. Ophiolites include serpentinized harzburgites and dunites, banded and isotropic gabbros, basalts, and hyaloclastites (tholeiitic and fore-arc basalts, locally with boninitic compositions) overlain by Late Jurassic (Tithonian) through Late Cretaceous (Coniacian and younger) oceanic sediments. Sheeted dikes and isotropic gabbro are rare (Figs. 2 and 3C; Iturralde-Vinent, 1996). The available petrological, geochemical, and geochronological data suggest that Cuban ophiolites include both mid-ocean-ridge and supra-subduction zone types (Kerr et al., 1999; Proenza et al., 2006; Marchesi et al., 2007; Lázaro et al., 2015). However, the widespread occurrence in the ophiolites of very refractory mantle peridotites as well as extrusive rocks with geochemical characteristics of island arcs indicate that the protoliths of most Cuban ophiolites formed above a subduction zone by both fore-arc and back-arc spreading. During subduction and obduction, the

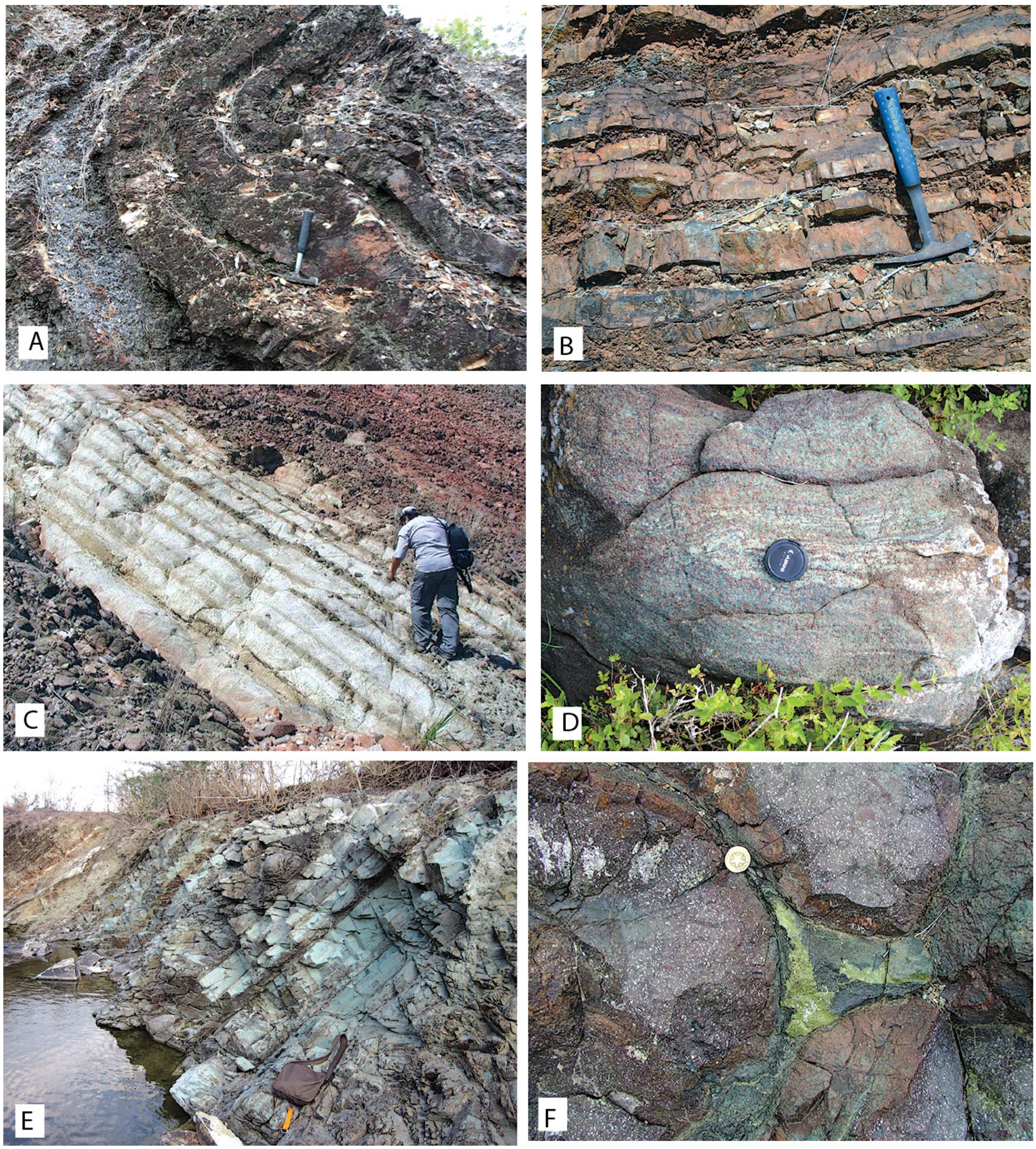

Figure 3. Outcrop photographs of some Cuban geologic units. (A) Recumbent fold in Jurassic continent-derived siliciclastics, Guaniguanico terrane, Alturas de Pizarra del Norte, Pinar del Río. (B) Aptian-Albian pelagic cherts of the Proto-Caribbean seafloor. Sierra de Rosario, Guaniguanico terrane, Pinar del Río. (C) Layered gabbros of the Moa-Baracoa Ophiolites, near Moa. (D) Block of mid-oceanic-ridge-basalt–derived epidote-Na-Ca amphibole eclogite in serpentinite mélange (north of Santa Clara city, central Cuba). (E) Intercalated well-bedded fine-grained green tuff with conglomerate and sandstones of the Brujas Formation (Cretaceous volcanic arc) at Palmarito Dam, south of Santa Clara. (F) Eocene pillow basalts and green ribbon cherts of the Paleogene arc at Sierra Maestra.

ophiolites were dismembered, and exotic fault blocks from NOAM and the Cretaceous arcs were incorporated within the deformed ophiolitic bodies. Associated strips of subduction-related mélanges contain high-pressure(high-*P)* blocks (eclogite-, amphibolite-, blueschist-, and high-*P* greenschist-facies rocks and jadeitite) in a serpentinite-matrix. These mélanges formed in a subduction zone from 120 Ma through latest Cretaceous (65 Ma; Fig. 3D); similar mélanges with high-*P* blocks occur as olistoliths within the foredeep basin and as tectonic slices within the Escambray complex (García-Casco et al., 2006; Blanco-Quintero et al., 2011; Cárdenas-Párraga et al., 2012).

Cretaceous Arc Complexes

Three stages of Cretaceous island arc volcano-sedimentary and plutonic rocks, separated by unconformities, are found in Cuba. Each arc sequence shows a distinct geochemical signature (Fig. 2). They are tectonically intercalated by thrust faulting with ophiolitic rocks and serpentinite mélanges and tectonically overlie the NOAM terranes (Figs. 1B and 2; Díaz de Villalvilla, 1997; Iturralde-Vinent and Lidiak, 2006; Marchesi, et al., 2007). In eastern Cuba (Purial complex) arc rocks metamorphosed in greenschist, and high-*P*, low-temperature blueschist-facies were partly subducted during the latest Cretaceous (García-Casco et al., 2008; Lázaro et al., 2015). Arc-related granitoid plutons range in age from ca. 89–83 Ma in the Santa Clara province (west-central Cuba) and 104–75 Ma in Camagüey province (east-central Cuba) (Hall et al., 2004; Rojas-Agramonte et al., 2011).

Mabujina Meta-Arc Complex

This complex structurally underlies the non-metamorphic arc rocks in Central Cuba (Figs. 1B and 2) and is composed of deformed gabbros, basalts, basaltic andesites, and pyroclastic rocks that were deformed and metamorphosed into the greenschist and amphibolite facies (Somin and Millán, 1981; Blein et al., 2003). Concordant and crosscutting granitic-gneissic rocks occur as pre-metamorphic (ca. 133 Ma), syn-metamorphic (ca. 93 Ma), and post-metamorphic intrusions/injections (ca. 89–83 Ma) (Grafe et al., 2001; Rojas-Agramonte et al., 2011). Several lines of evidence suggest that the Mabujina protoliths were detached from the Pacific margin of North America and accreted to the base of the Cuban Cretaceous arc complex at ca. 93–91 Ma (A. García-Casco and Y. Rojas-Agramonte, 2016, personal commun.).

Synorogenic Basins and Paleogene Arc

Late Campanian to late Eocene sedimentary strata unconformably overlie Cretaceous arc and ophiolite complexes (Fig. 2) with clastic deposits derived from the Cretaceous igneous substrate and interbedded carbonates (Iturralde-Vinent, 2015). In eastern Cuba, these deposits are interbedded laterally with Danian–middle Eocene arc lavas and volcaniclastics. Paleogene intraoceanic arc rocks are restricted to eastern Cuba (Fig. 2). Associated intermediate to felsic plutons are dated at 60.5 ± 2.2 to 46.9 ± 0.1 Ma (Cazañas et al., 1998; Iturralde-Vinent, 2011; Rojas-Agramonte et al., 2004, 2005). South of Sierra Maestra, the arc is truncated by the Oriente transform fault.

LATEST EOCENE TO RECENT DEPOSITS

Postorogenic latest Eocene to Recent basins and uplifted tectonic units formed above the strongly deformed foldbelt. Deposits include interbedded coarse clastics and limestone, which in Cuba are mildly deformed and characterized by open folds, steeply dipping normal faults, and NE-SW strike-slip faults. These strata are strongly deformed only along the present E-W transform boundary between NOAM and CARIB in southeastern Cuba, with recumbent folds and strike slip, reverse, and normal faults. Following establishment of modern sea level ~8000 years ago, Cuba attained roughly its present outline (Iturralde-Vinent, 2006).

RESEARCH OPPORTUNITIES

There is much that can we learn from future studies of Cuba, not only about the island itself but also about the tectonic evolution of the Caribbean region and other important tectonic processes of interest to the global geoscientific community. In the following sections, we briefly outline four promising research avenues: the Jurassic Caribbean, subduction initiation, intra-oceanic arc-trench systems, and collision tectonics.

Jurassic Caribbean

Better understanding of Cuban geology promises to provide important insights into the fit of Pangea and the origin of proto-Caribbean strata. Pre-Mesozoic clasts are found in Eocene, Cretaceous, and Jurassic conglomerates, but the sources of these and of the Jurassic siliciclastics are not well understood. For example, gneiss pebbles of ca. 400 Ma age (Millán and Somin, 1985) and 250–220 Ma (Somin et al., 2006) occur in the Eocene El Guayabo conglomerate of the Pinar del Río region of western Cuba. Focused studies should allow us to assign them to a source and provide a link between the Caribbean terrane and Central or South America. Furthermore, some poorly investigated metasedimentary blocks engulfed in the subduction mélange may sample early Atlantic–Proto-Caribbean oceanic sediments.

Subduction Initiation

It is important to understand how new subduction zones form. It has recently been suggested that emplacement of the Galapagos plume head formed most of the Caribbean plate, namely the (Caribbean Large Igneous Complex or "CLIP"), and that CLIP emplacement caused lithospheric collapse and formation of new subduction zones (Gerya et al., 2015), a process termed "plume-induced subduction initiation" (PISI). These subduction zones are argued to have formed around the plume head, perhaps first around the north at ca. 130 Ma, then around the southern, western, and northern margin at 85 ± 5 Ma. Alternatively, onset of subduction along the inter-American transform may have occurred with or without influence of the plume head. Studying the great Cuban ophiolite belt (Fig. 1B) provides a great opportunity to test and refine these hypotheses.

Intraoceanic Arc-Trench Systems

The Cuban arc is beautifully preserved and uplifted above sea level as a result of the soft-collision with NOAM. This gives us a 1000-km+ long arc section that may rival the classical arc crustal sections of California, Talkeetna, or Kohistan. The Mabujina Complex in particular promises important glimpses of arc crustal architecture and processes of arc crust formation. Examining potential correlations between CARIB early arc magmas and the evolution of the Mabujina arc and coeval magmatic rocks in the eastern Pacific would enhance the understanding of the early evolution of the Caribbean Plate. The subducted section of the Cretaceous arc in eastern Cuba (Purial complex) also offers the opportunity to inspect forearc crustal structure. On the other hand, the well-exposed Cuban Paleogene magmatic arc and its prolongation into Hispaniola require detailed studies in order to improve models for the Cenozoic tectonic evolution of northern CARIB margin. These arc rocks are associated with unusual and poorly understood subhorizontal emplacement of ophiolite thrust sheets and high-*P* metamorphism of Cretaceous arc suites in eastern Cuba.

Collision Tectonics

Evidence of NOAM-CARIB collision is well preserved in the rocks of Cuba, and the sequence of plate reorganization events that followed this is mostly understood. The rapidity of the plate reorganization by forming the transform margin south of Cuba arrested collisional deformation at an early stage; this may be the best example of a "soft collision" available for study anywhere in the world. The range of deformation styles and sedimentary responses that occurred during the early stages of collision are well preserved and available for study.

CONCLUSIONS

In addition to the topics discussed here, Cuban geodiversity embraces natural resources, such as oil and gas, mineral and groundwaters, ore and industrial minerals, marbles and construction materials, and beautiful landscapes, including karst, wetlands, and coral reefs. The fact that we do not have space here to review these important features does not diminish their importance. Further reconstructing of the details of the older geologic framework, exploiting the economic potential, understanding the geomorphic evolution, and preserving the geobiological features are challenges and opportunities for the collective geoscientific community. We hope in the future to see more U.S.-Cuban collaborative studies of Cuban geology and NW Caribbean tectonic evolution.

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