

Mineral Resources Program

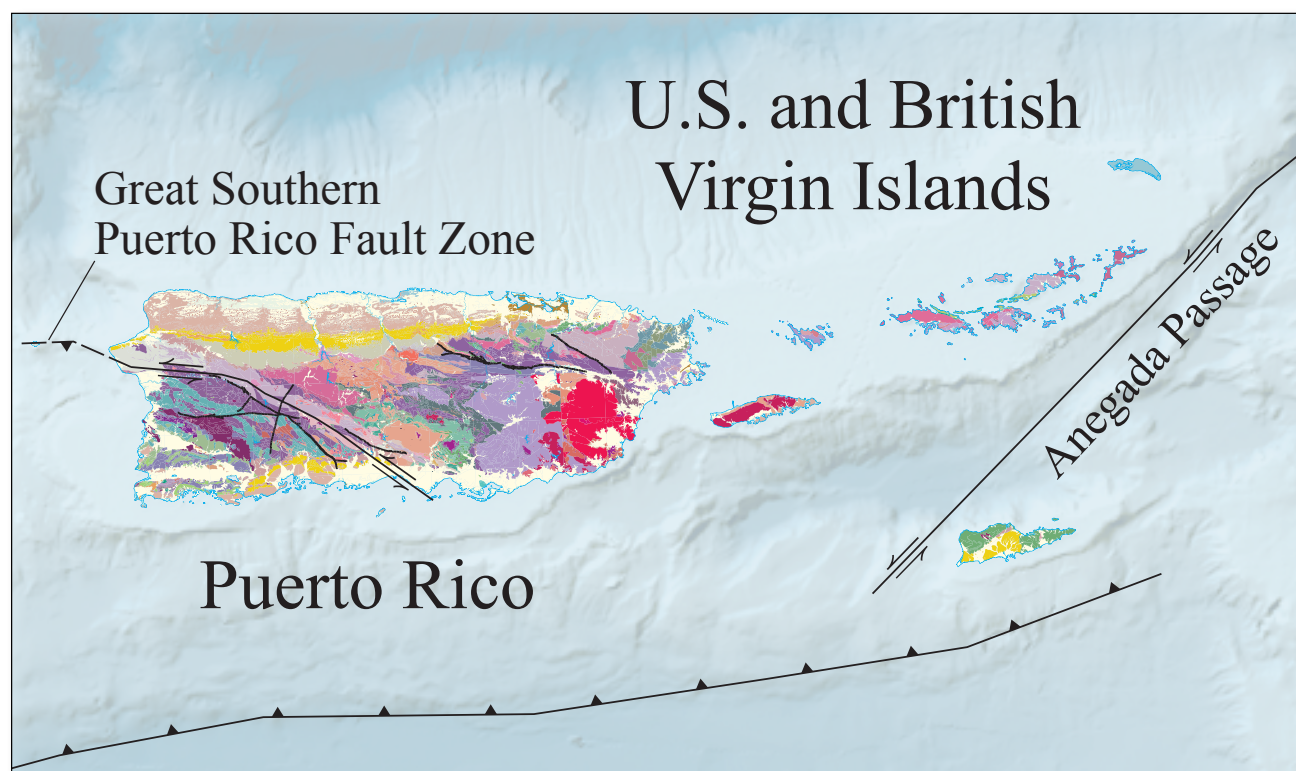
Geologic Map of the Greater Antilles and Virgin Islands

By Frederic H. Wilson and Keith A. Labay

Pamphlet to accompany

Scientific Investigations Map 3534

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Cover. Image from the southeast part of sheet 1, from the Geologic Map of the Greater Antilles and Virgin Islands, this report.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
mile (mi)	1.609	kilometer (km)

Datum

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84).

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Abbreviations

$^{40}\text{Ar}/^{39}\text{Ar}$	argon-40/argon-39
cm	centimeter
Ga	giga-annum (billion years before present)
GNPRFZ	Great Northern Puerto Rico Fault Zone
GSPRFZ	Great Southern Puerto Rico Fault Zone
IGP	Cuban Institute of Geology and Paleontology
K/Ar	potassium/argon
km	kilometer
m	meter
Ma	mega-annum (million years before present)
MMER	Haitian Ministry of Mines and Energy Resources
mm/yr	millimeters per year
$\text{Pb}^{206}/\text{U}^{238}$	lead-206/uranium-238
PBZ	northern Caribbean plate boundary zone
Rb/Sr	rubidium/strontium
SHRIMP	sensitive high resolution ion microprobe
TIMS	thermal ionization mass spectrometry
U/Pb	uranium/lead
USGS	U.S. Geological Survey
VMS	volcanogenic massive sulfide

Geologic Map of the Greater Antilles and Virgin Islands

Compiled by Frederic H. Wilson and Keith A. Labay

Introduction

The geologic map of the Greater Antilles and Virgin Islands is a compilation of information from the literature, integrated to provide a seamless geologic map of the region. This map was prepared to serve as a base map for a mineral resource assessment of the region. Several small-scale regional geologic maps of the region have been prepared in the past (Case and others, 1984; French and Schenk, 2004). This report supersedes an earlier version of the geologic map of the Greater Antilles and the Virgin Islands that was released as U.S. Geological Survey (USGS) Open-File Report 2019–1036 by Wilson and others (2019); the two maps from (Wilson and others, 2019) were the first detailed, digital compilations of the geology of the region.

For this report, the regional geologic overview shown on sheet 1 covers Cuba; the island of Hispaniola, which includes Haiti and Dominican Republic; Jamaica; the Cayman Islands; Puerto Rico; and the U.S. and British Virgin Islands. Sheet 2 shows the geology of Cuba and Cayman Islands, sheet 3 the geology of Jamaica, sheet 4 the geology of Hispaniola, and sheet 5 the geology of Puerto Rico and Virgin Islands. Accompanying the maps are three tables: table 1 lists the map units (in alphabetical order by map-unit label), their ages, and the countries or territories in which they can be found. These are listed in alphabetical order for ease in locating unit names from the symbols on the maps. Table 2 is a list of sources for the geologic map compilation of Puerto Rico. Table 3 shows formations in the Devil's Race Course Group of Jamaica. A note on abbreviations in citations; the Cuban Institute of Geology and Paleontology will be referred to hereinafter as "IGP" and the Haitian Ministry of Mines and Energy Resources will be referred to hereinafter as "MMER" for brevity and simplicity when using citations.

Geologic Summary

The Greater Antilles and Virgin Islands, although they appear to reflect the character of a magmatic arc, actually represent multiple distinct geologic features. Only in Cuba are there unquestioned Jurassic-age, and perhaps older, rocks present (IGP, 2011). Metamorphic assemblages contain rocks that may have Jurassic protolith age are present on the islands of Hispaniola (Haiti and Dominican Republic) (MMER, 1989; Toloczyki and others, 1991), Jamaica (McFarlane and others, 1984), and Puerto Rico

(Mattson, 1960; Volckmann, 1984b, c; Llerandi Roman, 2004). Ultramafic rocks that may in part be ophiolite assemblages and that may include rocks of Jurassic age are present in Cuba (IGP, 2011), Dominican Republic (Toloczyki and others, 1991), Haiti (Vila and others, 1985; MMER, 1989), and Puerto Rico (Mattson, 1960; Llerandi Roman, 2004). Metamorphic rocks of Cretaceous age are more widespread, present in Cuba (Puscharovsky and others, 1988; IGP, 2011), Hispaniola (Vila and others, 1985; MMER, 1989; Toloczyki and others, 1991), and the U.S. and British Virgin Islands (Helsley, 1960; Rankin, 2002). Cretaceous plutonic rocks are present in Cuba (IGP, 2011) and Puerto Rico (many sources, see unit descriptions), as well as in Dominican Republic (in the Cordillera Central and in the eastern part of the country; Toloczyki and others, 1991). Gabbro and trondhjemite of inferred Early Cretaceous age are present in the U.S. Virgin Islands (Rankin, 2002). Cretaceous volcanic rocks are widespread in Cuba, Hispaniola, Puerto Rico, and the Virgin Islands; they are of several ages, and based on this, do not appear to reflect a single magmatic arc system. Lidiak and Anderson (2015) concluded that the region contains the remnants of three, extinct, and subduction related magmatic belts or arcs. Cretaceous volcanic rocks are also found in Jamaica, in mapped inliers on the eastern part of the island (McFarlane and others, 1984). Eocene volcanic rocks are prominent along the southern coast of Cuba (IGP, 2011), and in Haiti (MMER, 1989), eastern Jamaica (McFarlane and others, 1984), Puerto Rico (several sources, see unit descriptions), and the Virgin Islands (Helsley, 1960; Donnelly, 1966; Rankin, 2002). Volcanic rocks possibly as young as early Miocene are present in southern Dominican Republic (Toloczyki and others, 1991); the youngest volcanic rocks in the region are the Low Layton Lavas of Jamaica of late Miocene age (McFarlane and others, 1984) and alkali basalt of Pliocene to Quaternary age on Hispaniola (Vila and others, 1985; MMER, 1989; Toloczyki and others, 1991).

Carbonate rocks are an important component of the sedimentary section in the Greater Antilles; the carbonates are as old as Jurassic in Cuba and as young as Holocene in many areas. In Cuba, Lower Cretaceous sedimentary rocks tend to be dominantly carbonates; volcanic clasts and debris begin to occur in the carbonates in the Late Cretaceous in Cuba and in Jamaica (McFarlane and others, 1984; IGP, 2011). In contrast, Early Cretaceous volcanic and volcanoclastic sedimentary rocks are common in the Virgin Islands and Puerto Rico (Helsley, 1960; Broedall, 1961; Banks, 1962; Donnelly, 1966; Briggs, 1971; Seiders, 1971a; M'Gonigle, 1978, 1979; Briggs and Aguilar-Cortes, 1980; Rankin, 2002; and several other Puerto Rican sources); those in the Virgin Islands

and on Culebra are keratophyre and spilite (Helsley, 1960; Banks, 1962; Donnelly, 1966; Rankin, 2002). Olistostrome deposits are commonly described in latest Cretaceous (Vila and others, 1985; Via Blanca Formation of Cuba [IGP, 2011]) through Eocene rocks; in the Paleocene and the lower Eocene, these deposits, the informally defined Haticos and Senado Olistostromes in Cuba, are commonly associated with *mélange* units (IGP, 2011). Volcanic debris and tuff are common in sedimentary rocks of Paleocene and Eocene age, typically associated with carbonate rocks. Sedimentary rocks that postdate the Eocene either are dominantly carbonates or are mixed clastic and carbonate rocks in which the clastic component reflects erosion of earlier units, including older carbonate rocks. Rocks that contain lignite, which are present in Cuba, on Hispaniola, and to a very limited extent, Puerto Rico, generally are of Miocene age; apparently none of the lignite is in volumetrically large amounts. The map units shown on sheets 1 to 5 are integrated across the islands of the Greater Antilles and the Virgin Islands; table 1 provides a list of map units, alphabetical by unit label, that indicates the countries or territories within which a unit is present.

Major Structures and Tectonics

A fundamental distinction in the geology of the Greater Antilles and the Virgin Islands concerns the basement upon which the islands lie. Only Cuba and the Cayman Islands lie on the North American plate. The rest of the islands lie on the Caribbean plate. Separated by the Cayman Trough from the rest, Cuba was obducted onto the North America plate (Pardo, 2009; Iturralde-Vinent and others, 2016). The Oriente Fault forms part of the northern boundary of the Cayman Trough and may extend into the Septentrional Fault that crosses north of Haiti and is the southern boundary of the Samaná Peninsula in Dominican Republic (Leroy and others, 2015). The other islands of the Greater Antilles and the Virgin Islands continue to move with the Caribbean plate. Pindell and Barrett (1990) constructed a tectonic model that postulates Cuba, the Cayman Ridge, Hispaniola, Puerto Rico, and Virgin Islands all formed a single magmatic arc system. This was predicated on subduction related volcanism beginning in Cuba and Hispaniola in the Early Cretaceous (~145 to 136 million years before present [Ma], Cuba) and the latest Early Cretaceous or early Late Cretaceous in Puerto Rico and Virgin Islands. The Cuban source map (IGP, 2011) provides little evidence for volcanism in Cuba older than Aptian or Albian except for the Los Pasos Formation felsic volcanic rocks associated with the Escambray Massif. In Jamaica and Dominican Republic, Albian and older(?) basalt and andesite are locally present. Earliest Cretaceous tuff and andesite flows of the Rio Abajo Formation in eastern Puerto Rico indicate an early episode of volcanism. In the Virgin Islands, spilitic basalt and keratophyre are considered Early Cretaceous, partly based on the presence of radiolaria that are similar to Lower Cretaceous forms from Mexico (Donnelly, 1966).

Seiders and others (1972) described several major structures in the Greater Antilles. The Cayman Trough trends roughly east-west, extending from the east coast of Guatemala, cutting offshore of the southern coast of Cuba, and ending off the north coast of Haiti. The Puerto Rico trench has an arcuate

shape starting north of the Samaná Peninsula of Dominican Republic and curving around the Lesser Antilles. To the north-west of Puerto Rico, the North Hispaniola Fault is an extension of the Puerto Rico trench, where the rocks of the Caribbean plate collide with the Bahamas platform (Grindlay and others, 2005). South of Puerto Rico, the Muertos Trough runs east-west from Dominican Republic to south of Saint Croix (Mann and others, 2005). Cutting across Jamaica is the Plantain Garden Fault, which transitions to the Enriquillo-Plantain Garden Fault Zone of the offshore to the east and ultimately crosses southern Hispaniola in Haiti (Leroy and others, 2015).

Cuba

The Las Villas Fault was shown by Seiders and others (1972) as running somewhat parallel to the north coast of Cuba; the Domingo Fault of Pardo (2009) follows a similar trace. This fault is interpreted as a low-angle thrust fault whose upper plate consists of obducted ultramafic bodies and of Cretaceous volcanic rocks and sedimentary rocks that were derived from erosion of carbonate rocks in the lower plate. Pardo (2009) extended the Domingo Fault into western Cuba and showed a short segment of it on Isla de la Juventud, separating the Jurassic metamorphic rocks of the Cañada Formation from the Upper Cretaceous volcanic and volcanoclastic rocks of Sabana Grande Formation. The segment on Isla de la Juventud has a clearly different character than the fault of the same name on the Cuban mainland and likely is a distinct fault. In general, Cuba consists of several structurally uplifted Jurassic to Cretaceous metamorphic, ultramafic, and (or) Cretaceous volcanic and sedimentary rock sequences largely surrounded by and floating in a sea of post-Eocene limestone. To the north, the limestones are part of what Pardo (2009) called the Florida-Bahamas carbonate-bank province. Pardo (2009) then defined three terranes of intensely folded and faulted Middle Jurassic to middle Eocene sections. The terranes are somewhat confusingly named. The northcentral sedimentary terranes are in central Cuba, and they lie largely farther south than does the southwest sedimentary terrane, which is actually in northwest Cuba. The terranes are:

- the northcentral sedimentary terranes, characterized by Upper Jurassic very thick platform carbonate and evaporite rocks overlain by a relatively thin sequence of Lower Cretaceous deepwater carbonate rocks and thin to missing Upper Cretaceous mostly pelagic and distal carbonate bank turbidites and radiolarian chert; comparable to the Northern Foldbelt of Iturralde-Vinent and others (2016);
- the ophiolitic mafic igneous and volcanic rock terrane, consisting of ultramafic intrusive rocks, and abundant mafic, basaltic to andesitic volcanic rocks, volcanic-derived sedimentary rocks, and granodioritic plutons. This terrane is a thrust sheet lying above the Domingo Fault where sheared serpentinite forms the base immediately above the thrust. It is present in northern, central, and southern Cuba. Overlying the ultramafic complexes are Cretaceous oceanic volcanic and sedimentary rocks succeeded by arc volcanic and sedimentary rocks; somewhat comparable to the ophiolites and serpentinite matrix *mélange* terrane of Iturralde-Vinent and others (2016);

- the southwestern sedimentary terranes, characterized by a thick sequence of Middle Jurassic variably metamorphosed older, continentally derived clastic rocks overlain by an Upper Jurassic and Lower Cretaceous sequence like that of the northcentral sedimentary terrane. This southwestern sedimentary terrane includes the metamorphic rocks of the Escambray Massif as well as those of the Isla de la Juventud, which are dominantly Middle Jurassic clastic rocks. Upper Cretaceous sedimentary rocks are generally not present in these terranes; this is in part comparable to the Caribeana Metamorphic terranes of Iturralde-Vinent and others (2016).

The three terranes are lithologically distinct; the ultramafic terrane is generally accepted as autochthonous (Pardo, 2009; Iturralde-Vinent and others, 2016), the two sedimentary terranes represent different aspects of Caribbean history. The exposed southwestern sedimentary rock terranes contain the oldest rocks in Cuba and the Greater Antilles and show enough facies relationships that Pardo (2009) interpreted this to permit meaningful, paleogeographic reconstructions of the early stages of the opening of the Caribbean. The northcentral sedimentary rock terranes in central and eastern Cuba were thought to better represent the later volcanic Caribbean plate (Pardo, 2009). Pardo (2009) characterized Cuba as an example of a Cretaceous to Paleogene Alpine orogenic feature in which thrust sheets moved northward over the craton of North America.

Hispaniola

Hispaniola is offset from Cuba by left-lateral motion of the Oriente Fault Zone along the north side of the Cayman Trough with the Walton and Swan Fault Zones, along the south side of the Cayman Trough; together these faults have an estimated 1,000 kilometers (km) of left-lateral offset and create a pull-apart basin in the Cayman Trough (Mann and Burke, 1984; Rosencrantz, 1990). The Camu and Septentrional Fault Zones of northern Hispaniola are landward extensions of the Oriente Fault Zone and the oblique-slip faults of the Puerto Rico trench (Mann and others, 1984). The two faults of northern Hispaniola bound the Cordillera Septentrional where elevations reach 1,249 meters (m) along a ridge parallel to and 2–3 km north of the Septentrional Fault Zone (Mann and others, 1984). The Septentrional Fault Zone has a steep fault scarp as high as 400 m for over 2 km in the central section and is marked by a single prominent fault scarp along its central and eastern trace. The Septentrional Fault Zone forms a remarkably straight contact between Tertiary sedimentary rocks and Quaternary alluvium and forms a straight contact along the southern edge of the Cordillera Septentrional and bounds the Cibao Valley. The fault trace exhibits geomorphic features characteristic of active strike-slip faults; the Camu Fault Zone is much less topographically distinct (Mann and others, 1984).

Mann and others (1984) map the Enriquillo-Plantain Garden Fault Zone through southern Hispaniola, primarily Haiti, and extending through the Jamaica Passage to western Jamaica. It ultimately apparently ends east of the Cayman Trough, although Rosencrantz and Sclater (1986) and ten Brink and others (2002) appear to extend this fault zone to join with the Walton Fault that bounds the southern side of the Cayman Trough. Active seismicity

has been noted along this left-lateral strike-slip fault system (which includes the unexposed subparallel Léogâne Fault, the source of the 2010 magnitude 7.0 Haitian earthquake [Calais and others, 2010¹]); offset on the Enriquillo-Plantain Garden Fault Zone is estimated to be between 10 and 30 km (Mann and others, 1990). To the east, the Enriquillo-Plantain Garden Fault Zone cannot be traced across Dominican Republic, obscured by alluvial deposits in the Enriquillo valley and possibly truncated by faulting along the Beata Ridge, which projects northeast into southern Hispaniola. Hispaniola's setting is that it effectively lies within the northern Caribbean plate boundary zone (PBZ), which Burke and others (1980) describe as being as much as 200 km wide lying south of Oriente, Walton, and Swan Fault Zones. Rosencrantz and Mann (1991) defined the Gonâve microplate, which encompasses part of Hispaniola and areas within the eastern Cayman Trough. They suggest that measures of the opening of the Cayman Trough, because of the presence of this microplate, does not indicate the rate of offset between the North American and Caribbean plates. The opening of the Cayman Trough only reflects the rate of offset between the microplate and North America. Edgar and others (1992) in a "Comment and Reply" exchange with Rosencrantz and Mann (1991), suggest the Gonâve microplate does not exist and hence disagree with Rosencrantz and Mann's conclusions.

Jamaica

The Enriquillo-Plantain Garden Fault Zone crosses Jamaica, passing just north of Kingston and continuing across the island. Several names are used for the fault zone, from west to east, the Rio Minho, Crawle River, Cavaliers, and Plantain Garden Faults (Burke and others, 1980). Burke and others (1980) estimated an offset rate of about 4 millimeters per year (mm/yr) for the last 10 million years, though they thought this estimate was likely low. Running parallel to this are the Duanvale Fault along the north coast of Jamaica and the South Coast Fault, on the south coast. The Duanvale Fault is presumed to be another left-lateral strike-slip fault, whereas offset on the South Coast Fault has not been recognized (Burke and others, 1980). Jamaica also lies within the PBZ, and the 4 mm/yr offset rate is only a fraction of the magnitude of motion between the North America and Caribbean plates, which is estimated to be at least 15 ± 5 mm/yr, but could be as much as 37 ± 5 mm/yr (Mann and others, 1990). However, Rosencrantz and Mann (1991) suggest the rate is more like 20 mm/yr. Burke and others (1980) describe numerous northwest-trending thrust faults in Jamaica whose net shortening may account for some of the discrepancy.

Puerto Rico

Puerto Rico appears to lie south of the PBZ and as such, strike-slip faulting is not an important feature in Puerto Rico. The Great Southern Puerto Rico Fault Zone (GSPRFZ) (Glover, 1971; Seiders and others, 1972; Piety and others, 2018), which cuts diagonally across western Puerto Rico appears to be a major suture zone. Puerto Rico can be divided into four tectonostratigraphic terranes (appendix 1, fig. 1.1 and table 1.1) of which the fault zone itself is one, the San Sebastian terrane. The fault zone, which is

¹See also Mann and others (2008).

quite wide, at least 2 km, has bounding faults that can be distinguished along its southwestern margin. Its northeastern margin is best defined by the limit of Eocene age volcanic and volcanoclastic rocks. Northeast of the GSPRFZ, as Seiders and others (1972) pointed out, the volcanic and sedimentary rock sequence is Lower Cretaceous and mainly the lower part of the Upper Cretaceous. No “basement” to these rocks is apparent and they are intruded by several larger plutons that vary in age between ~110 and 60 Ma and by undated mafic dikes of Late Cretaceous or Tertiary age. Southwest of the GSPRFZ, Upper Cretaceous volcanic and sedimentary rocks and Tertiary, as young as Eocene, volcanic and sedimentary rocks are associated with ultramafic complexes. The Lower Cretaceous is not present and the younger volcanic and sedimentary rock complexes are spatially associated with the GSPRFZ. Uppermost Cretaceous volcanic and volcanoclastic rocks of the Concepción, Lago Garzas, Sabana Grande and Maricao Formations bound either side of the fault zone, which is largely defined by block and ash deposits of Eocene age (unit Tv_c). These Eocene deposits in Puerto Rico are restricted to within the GSPRFZ. Ultramafic rocks in Puerto Rico are only exposed southwest of the GSPRFZ and appear to be allochthonous and in two distinct belts.

Uranium-lead (U/Pb) dating of several Puerto Rican rocks yielded several ages that confirmed the earlier potassium-argon (K/Ar) results (see Wilson and Labay [2025] for associated digital databases). However, one sample stood out, yielding quite unexpected results. A sample of meta-andesite (18PWs008) was collected north of the large Monte del Estado (or Rio Guanajibo) ultramafic body in southwestern Puerto Rico. The sample after processing yielded only 5 zircons, which ranged in age from 2.4 to 1.89 billion years before present (Ga), more than an order of magnitude older than any other ages determined in Puerto Rico and significantly older than any other emplacement or crystallization ages determined in the map area. Rojas-Agramonte and others (2016) and Proenza and others (2018) have recovered inherited and xenocrystic zircons in ophiolitic rocks of Cuba and in lavas, volcanoclastic rocks, and alluvial sand of the Lesser Antilles that range as old as 3.47 Ga (Rojas-Agramonte and others, 2017). Rojas-Agramonte and others (2016) compared the ages of xenocrystic zircons from Cuba with the age distribution of the old zircons with magmatic episodes and tectonic events in nearby exposed crustal terranes from Central America and northern South America. Their xenocrystic zircons have yielded ages of about 275 and 240 Ma; which correspond to known events in Mexico, Columbia, and Ecuador; they related Silurian zircons (about 430 Ma) to terranes in Mexico and Columbia. They suggested only that their Proterozoic zircons most likely originated from nearby continental sources. Rojas-Agramonte and others (2017) collected samples from the Lesser Antilles, including rocks and sand, which yielded several zircons that they suggested were derived from an old (heterogeneous) continental source such as the Guyana Shield and Amazon Craton. Proenza and others (2018) sampled chromite deposits in eastern Cuba, which yielded similar results to Cuban samples of Rojas-Agramonte and others (2016). Our Puerto Rican sample lies spatially between the Cuban and Lesser Antilles sample sites; the presence of solely Proterozoic and older zircons in our sample suggests incorporation only of what Rojas-Agramonte and others (2016) and Proenza and others (2018) describe as “proto-Oaxaquita” terranes of southern Mexico and the paleo-Pacific margin of the Gondwana supercontinent.

A Great Northern Puerto Rico Fault Zone (GNPRFZ) (Piety and others, 2018) has also been described; however, it is not as well defined and does not appear to be as geologically significant a feature as the GSPRFZ although it forms the boundary between the Virgin Islands and Utuado terranes (appendix 1, fig. 1.1). Jolly and others (1998) describe the Cerro Mula Fault as the major strand of the GNPRFZ. It trends roughly east-west in northeastern Puerto Rico and lies just north of the San Lorenzo batholith. The Cerro Mula Fault is about 50 km in length, and as no common units are found on both sides, Jolly and others (1998) citing Pease (1968a, b, c) suggest that 50 km is the minimum offset in an inferred left-lateral direction. An extension to the east would project between the islands of Vieques and Culebra. We infer that Culebra is more geologically similar to the Virgin Islands than to the remainder of Puerto Rico because of the presence of keratophyre in common with the Virgin Islands. Only north of the GNPRFZ, in northeast Puerto Rico, is the presence of keratophyre documented on the main island.

Virgin Islands

The Anegada Passage separates Saint Croix from the rest of the Virgin Islands. It is structurally complex and is defined geologically by several faults. It contains several distinct basins. From west to east, the Whiting Basin, Vieques and adjacent Virgin Islands Basins, Saint Croix Basin, and the easternmost Sombrero Basin, which opens into the Atlantic (Laurencin and others, 2017). Laurencin and others (2017) describe 4 tectonic models from the literature for the Anegada Passage which to an extent, conflict with each other. These tectonic models are:

- A. Northwest-southeast pure extension across the Lesser Antilles forearc, a result of partitioning in the Lesser Antilles forearc (for example, Feuillet and others, 2002);
- B. Left-lateral strike-slip faulting, a result of plate boundary accommodation (for example, Mann and Burke, 1984; van Benthem and others, 2014);
- C. Right-lateral transtension resulting from escape of the Puerto Rico-Virgin Islands microplate (for example, Jany and others, 1990); and
- D. Northwest-southeast extension associated with right-lateral strike-slip faulting due to the rotation of a Puerto Rico-Virgin Islands microplate (for example, Masson and Scanlon, 1991; Mann and others, 2005).

The models above are largely based on data from the western part of the Anegada Passage. Laurencin and others (2017) on the basis of new seismic data in the eastern region (Sombrero Basin) of the Anegada Passage suggest that during the Miocene, models C or D were most appropriate for the tectonic setting of the passage. The evolving tectonics of the region presently suggest that the passage is an active left-lateral system containing pull-apart basins and restraining bends (Laurencin and others, 2017). Liu and Wang (2015) indicate that Saint Croix is moving away from the other Virgin Islands at a rate of 1.7 mm/yr in a S 55° E direction. Their conclusion is that faulting associated with the passage results in 1.2 mm/yr of left-lateral motion in a nearly east-west direction, and extension of 1.2 mm/yr in a nearly north-south direction.

Table 1. Map units in the Greater Antilles and the Virgin Islands (listed alphabetically by map-unit label), showing unit age or position (in parentheses) and general geographic distribution (country or territory).

Map-unit label	Map unit (age or position)	Country or territory
bu	Bedrock of unknown type or age	Dominican Republic, Haiti, Puerto Rico
Jdb	Diabase and basalt flows and marine sedimentary rocks, undifferentiated (Jurassic, late Oxfordian)	Cuba
Jff	Francisco Formation (Upper Jurassic, upper to middle Oxfordian)	Cuba
Jgr	Rio Cana Granite (Middle Jurassic)	Cuba
Jjg	Jagua Formation of Cuba (Upper Jurassic)	Cuba
Jm	Metasedimentary rocks including marble (Jurassic)	Cuba, Dominican Republic
Jpa	Punta Alegre Formation of Cuba (Upper Jurassic)	Cuba
Jqp	Quartzite and phyllite, undifferentiated (Jurassic?)	Cuba
Jsch	Metamorphic complexes characterized by glaucophane schist (Jurassic?)	Cuba, Dominican Republic
Jvs	Schistose metasedimentary rocks (Jurassic, Oxfordian to Early Jurassic)	Cuba
Kas	Augite syenite (Cretaceous, Coniacian to Albian)	Puerto Rico
Kbb	Tuff of the Fajardo Formation (Early Cretaceous, Albian)	Puerto Rico
Kbt	Cotorra and Jayuya Tuffs, undivided (Late Cretaceous, Santonian to Turonian)	Puerto Rico
Kcgl	Volcaniclastic conglomerate (Upper Cretaceous, Maastrichtian to Santonian)	Cuba, Jamaica, Puerto Rico
Kch	Chert (Cretaceous, Cenomanian to Aptian or lower)	Cuba, Jamaica, Puerto Rico, U.S. Virgin Islands
Kcls	Mixed clastic and carbonate rocks, undifferentiated (Upper Cretaceous, Maastrichtian to Campanian)	Cuba, Dominican Republic, Puerto Rico
Kcr	Limestone and chert, undifferentiated (Cretaceous)	Cuba, Dominican Republic
Kd	Dikes, granite to diorite (Cretaceous)	Cuba, Puerto Rico
Kdi	Diorite (Cretaceous)	Cuba
Kec	Carbonate rocks, including biomicritic limestone (Lower Cretaceous)	Cuba, Haiti, Jamaica, Puerto Rico
Kegb	Doña Ruth gabbro and gabbro of the Careen Hill Intrusive Suite of Rankin (2002) (Early Cretaceous)	Cuba, Dominican Republic, U.S. Virgin Islands
Kelc	Limestone and minor calcarenite, undifferentiated (Cretaceous, Santonian to Albian)	Cuba, Puerto Rico
Kevc	Volcaniclastic rocks, undifferentiated (Lower Cretaceous, Albian)	Puerto Rico
Kevf	Felsic volcanic rocks (Early Cretaceous, Barremian to Berriasian)	Cuba
Kevi	Intermediate-composition volcanic rocks (Early Cretaceous, Albian to Barremian?)	Dominican Republic, Jamaica, Puerto Rico
Kevm	Basalt and basaltic andesite, undifferentiated (Early Cretaceous)	Cuba, Dominican Republic, Puerto Rico, U.S. Virgin Islands
Kfp	Felsic pyroclastic rocks (Late Cretaceous, Maastrichtian to Campanian)	Puerto Rico
Kfv	Intermediate and felsic volcanic rocks (Late Cretaceous, Campanian to Coniacian)	Cuba, Dominican Republic, Haiti, Puerto Rico
Kgb	Gabbro (Cretaceous?)	Cuba, Puerto Rico
Kgd	Granodiorite (Late Cretaceous, Maastrichtian and Campanian)	Cuba, Puerto Rico
Kgr	Older granite (Cretaceous, Coniacian to Albian)	Cuba, Dominican Republic
Kgs	Marble and greenschist, undifferentiated (Cretaceous, Turonian or older)	British Virgin Islands, U.S. Virgin Islands
Kgu	Granitic rocks, undifferentiated (Cretaceous)	Cuba, Puerto Rico
Khg	Hornblende gabbro and diorite, undifferentiated (Late Cretaceous, Coniacian to Cenomanian)	Dominican Republic
Khk	Hypabyssal rocks, keratophyre porphyry (Early Cretaceous)	U.S. Virgin Islands

Table 1. Map units in the Greater Antilles and the Virgin Islands (listed alphabetically by map-unit label), showing unit age or position (in parentheses) and general geographic distribution (country or territory).—Continued

Map-unit label	Map unit (age or position)	Country or territory
Kib	Intrusive breccia of the Dagua Formation (Early Cretaceous, Albian to Barremian?)	Puerto Rico
Kip	Intermediate and silicic pyroclastic rocks (Late Cretaceous, Santonian to Cenomanian)	British Virgin Islands, Cuba, Puerto Rico, U.S. Virgin Islands
KJam	Mabujina complex amphibolite without biotite (Early Cretaceous or Late Jurassic)	Cuba
KJb	Zurrapandilla Formation and Cajul Basalt (Early Cretaceous to Late Jurassic)	Cuba, Puerto Rico
KJba	Mabujina complex biotite-bearing amphibolite (Early Cretaceous or Late Jurassic)	Cuba
KJca	Mabujina complex and Puerca Gorda schist derived from mafic sources (Early Cretaceous or Late Jurassic)	Cuba, Dominican Republic
KJcl	Chert-rich limestone (Lower Cretaceous to Upper Jurassic)	Cuba
KJcm	Mariquita Chert and Mate Prieto Unit (Upper Cretaceous, middle Turonian? to Upper Jurassic, lower Tithonian to upper Kimmeridgian)	Cuba, Puerto Rico
KJdg	Gabbro and diorite, undifferentiated (Cretaceous or Jurassic)	Cuba
KJgm	Garnetiferous amphibolite (Early Cretaceous, Barremian to Jurassic, Tithonian)	Cuba
KJgn	Mabujina complex metagranitic rocks (Early Cretaceous or Late Jurassic)	Cuba
KJm	Marble (Early Cretaceous to Late Jurassic)	Cuba, Dominican Republic, Puerto Rico
KJmc	Mabujina complex and equivalent units (Early Cretaceous or Late Jurassic)	Cuba, Dominican Republic, Puerto Rico
KJmm	Metamorphosed mafic and ultramafic rocks, undifferentiated (Early Cretaceous to Late Jurassic)	Cuba, Dominican Republic
KJmq	Marble and quartzite, undifferentiated (Early Cretaceous to Late Jurassic)	Cuba
KJms	Mabujina complex amphibolite and Gaspar Hernández and Helechal peridotite associated with serpentinite (Early Cretaceous or Late Jurassic)	Cuba, Dominican Republic
KJmu	Dike complex (Cretaceous or Jurassic)	Cuba
KJsi	Metasedimentary and metaigneous rocks, undifferentiated (Early Cretaceous to Late Jurassic, Tithonian)	Cuba, Jamaica
KJuc	Mafic cumulate rocks (Cretaceous to Jurassic)	Cuba, Dominican Republic
KJv	Mixed sedimentary and volcanic component of ophiolite (Cretaceous to Jurassic)	Cuba
Kkp	Keratophyre (Early Cretaceous)	British Virgin Islands, Dominican Republic, Puerto Rico, U.S. Virgin Islands
Klc	Limestone and limestone conglomerate, undifferentiated (Upper Cretaceous, Maastrichtian and Campanian)	Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, U.S. Virgin Islands
Klcv	Mixed clastic, carbonate, and volcanic rocks, undifferentiated (Upper Cretaceous, Campanian to Coniacian)	Cuba, Jamaica, Puerto Rico
Klg	Granite (Late Cretaceous, Maastrichtian or Campanian)	Cuba
Klmv	Basalt, pillowed and nonpillowed flows, breccia, and tuff, undifferentiated (Late Cretaceous, Maastrichtian to Santonian)	Jamaica, Puerto Rico
Klqm	Quartz monzonite (Late Cretaceous, Maastrichtian and Campanian)	Cuba, Puerto Rico
Klsv	Sedimentary and volcanic rocks, undifferentiated (Upper Cretaceous, Maastrichtian and Santonian)	Cuba, Dominican Republic, Jamaica, Puerto Rico
Kmgb	Gabbroic amphibolite and amphibolite, undifferentiated (Cretaceous?)	Dominican Republic
Kmgd	Granodiorite and tonalite, undifferentiated (Cretaceous, Santonian to Albian)	Cuba, Dominican Republic, Puerto Rico
Kmk	Mélange (Cretaceous?)	Dominican Republic

Table 1. Map units in the Greater Antilles and the Virgin Islands (listed alphabetically by map-unit label), showing unit age or position (in parentheses) and general geographic distribution (country or territory).—Continued

Map-unit label	Map unit (age or position)	Country or territory
Kmm	Martin Mesa Formation and similar formations, undivided (Cretaceous, Turonian to Aptian)	Cuba
Kmv	Metavolcanic and meta-volcaniclastic rocks, undifferentiated (Early Cretaceous)	Cuba, Dominican Republic, Haiti
Kmvm	Mafic volcanic rocks (Cretaceous, Cenomanian to Barremian)	Cuba, U.S. Virgin Islands
Kmvs	Metavolcanic rocks, metasandstone, and blueschist, undifferentiated (Cretaceous, Turonian to Aptian)	Cuba
Koba	Older basalt and andesite flows, breccia, and tuff, undifferentiated (Cretaceous, Santonian to Albion)	Cuba, Haiti, Puerto Rico
Kpd	Porphyritic diorite (Late Cretaceous, Maastrichtian and Campanian)	Cuba, Puerto Rico
Kpf	Polier Formation (Lower Cretaceous, Albion to Valanginian)	Cuba
Kps	Pelitic schist, minor greenstone, and marble, undifferentiated (Cretaceous)	Cuba
Kqd	Quartz diorite and tonalite, undifferentiated (Late Cretaceous, Maastrichtian and Santonian)	Cuba, Dominican Republic, Haiti, Puerto Rico
Kqt	Quartz diorite, tonalite, and trondhjemite, undifferentiated (Cretaceous, Santonian to Albion)	Cuba: Puerto Rico, U.S. Virgin Islands
Kso	Siltstone and local olistostrome deposits, undifferentiated (Upper Cretaceous, Maastrichtian to Campanian)	Cuba, Dominican Republic, Haiti
Kspf	Spilitic basalt (Early Cretaceous)	Puerto Rico, U.S. Virgin Islands
Ksv	Older mixed clastic, carbonate, and volcanic rocks, undifferentiated (Cretaceous, Turonian to Albion)	Cuba, Puerto Rico
Ktu	Tutu Formation (Cretaceous, Santonian to Albion)	British Virgin Islands, U.S. Virgin Islands
Ku	Undifferentiated clastic rocks (Upper Cretaceous, Maastrichtian to Turonian)	Cuba, Dominican Republic, Jamaica, Puerto Rico
Kue	Older undifferentiated clastic rocks (Upper Cretaceous, Santonian to Cenomanian)	Jamaica, Puerto Rico
Kva	Andesitic volcanic rocks and volcanoclastic sedimentary rocks, undifferentiated (Late Cretaceous, Maastrichtian to Santonian)	Cuba, Jamaica, Puerto Rico
Kvib	Iberia Formation of Cuba, Hato Puerco Formation of Puerto Rico, and similar rocks (Cretaceous, Turonian to Albion)	Cuba, Puerto Rico
Kvr	Volcanic rocks, undifferentiated (Cretaceous)	Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico
Kvss	Volcanoclastic sandstone and mudstone, undifferentiated (Upper Cretaceous, Maastrichtian to Turonian)	Cuba, Puerto Rico, U.S. Virgin Islands
Kwi	Water Island Formation, volcanic-clast wacke (Lower Cretaceous)	U.S. Virgin Islands
Kwt	Intermediate and mafic pyroclastic rocks (Cretaceous, Turonian to Aptian)	Cuba, Puerto Rico
Mzs	Serpentine (Cretaceous or Jurassic?)	Cuba, Dominican Republic, Jamaica, Puerto Rico
Mzsm	Serpentine mélange (Cretaceous or Jurassic)	Cuba, Dominican Republic
Mzum	Ultramafic and associated rocks, undifferentiated (Mesozoic or older)	Cuba, Dominican Republic, Haiti
Pm	Oldest marble (Proterozoic)	Cuba
Qpm	Artificial-fill deposits (Quaternary, Holocene)	Puerto Rico
Qs	Surficial deposits, undifferentiated (Quaternary)	British Virgin Islands, Cayman Islands, Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, U.S. Virgin Islands
QTcr	Deposits associated with carbonate reefs and reef complexes (Quaternary and upper Tertiary, Pliocene)	British Virgin Islands, Cayman Islands, Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico
QTcs	Continental sand and conglomerate (Quaternary and upper Tertiary, Pliocene)	Dominican Republic

Table 1. Map units in the Greater Antilles and the Virgin Islands (listed alphabetically by map-unit label), showing unit age or position (in parentheses) and general geographic distribution (country or territory).—Continued

Map-unit label	Map unit (age or position)	Country or territory
QTmc	Marine conglomerate and sand, undifferentiated (Quaternary and upper Tertiary, Pliocene)	Cuba, Puerto Rico
QTV	Volcanic rocks of Dos Hermanos and Valle Nuevo (Quaternary, Pleistocene and Tertiary, Pliocene)	Dominican Republic
Qv	Alkali basalt (Quaternary)	Dominican Republic, Haiti
Tab	Andesite and basalt, undifferentiated (Tertiary, Eocene)	British Virgin Islands, Haiti, Jamaica
Tbt	Intermediate to felsic biotite tuff (Tertiary, early Eocene to early Paleocene)	Puerto Rico
Tca	Calcarene, biocalcarene, limestone, and marl, undifferentiated (Tertiary, Pliocene to Miocene)	Cuba, Dominican Republic, Haiti, Puerto Rico
Tcc	Continental clastic rocks (Tertiary, Pliocene to Miocene)	Dominican Republic, Haiti
Tec	Limestone containing igneous-rock debris (Tertiary, Eocene)	British Virgin Islands, Cuba, Dominican Republic, Haiti, Puerto Rico
Tecd	Limestone and igneous-rock debris, deepwater facies (Tertiary, Eocene)	Cuba, Haiti, Puerto Rico
Tech	Guacio Member of the Rio Culebrinas Formation (Tertiary, Eocene)	Puerto Rico
Tecr	Mixed clastic and volcanic rocks, undifferentiated (Tertiary, Eocene)	Cuba, Dominican Republic, Jamaica, Puerto Rico
Tecs	Limestone and igneous-rock debris, shallow water facies, undifferentiated (Tertiary, Eocene)	Cuba, Dominican Republic, Jamaica
Ted	Diorite and tonalite, undifferentiated (Tertiary, Eocene and Paleocene)	British Virgin Islands, Cuba, Dominican Republic, Puerto Rico, U.S. Virgin Islands
Tegr	Granite and granodiorite, undifferentiated (Tertiary, Eocene?)	British Virgin Islands, Cuba, Puerto Rico
Tepc	Clastic rocks, limestone, and breccia, undifferentiated (Tertiary, lower Eocene to Paleocene)	Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico
Tes	Mixed clastic and carbonate rocks, undifferentiated (Tertiary, Eocene)	Cuba, Dominican Republic, Jamaica, Puerto Rico
Tesv	Volcaniclastic and clastic rocks, undifferentiated (Tertiary, Eocene)	Cuba, Puerto Rico
Tfg	Fault- or mega-breccia (Tertiary, Eocene)	Puerto Rico
Tfv	Felsic volcanic rocks (Tertiary, Eocene)	Puerto Rico
Tgb	Gabbro and diorite, undifferentiated (Tertiary, Miocene to Eocene)	Cuba
Tgn	Gabbro, norite, and diorite, undifferentiated (Tertiary, Eocene)	British Virgin Islands, Puerto Rico, U.S. Virgin Islands
Thb	Hypabyssal dikes and intrusions, undifferentiated (Tertiary)	British Virgin Islands, Cuba, Puerto Rico, U.S. Virgin Islands
TKfd	Felsic dikes and sills, undifferentiated (Tertiary, Eocene to Late Cretaceous)	Puerto Rico, U.S. Virgin Islands
TKfs	Flysch (lower Tertiary to Upper Cretaceous)	Cuba
TKga	Granite and aplite, undifferentiated (Tertiary, Paleocene to Late Cretaceous, Maastrichtian)	Puerto Rico
TKgb	Gabbroic rocks, including Fountain Gabbro (Tertiary, Paleocene or Late Cretaceous, Campanian)	Puerto Rico, U.S. Virgin Islands
TKgm	Granodiorite and quartz monzonite, undifferentiated (Tertiary, Paleocene to Late Cretaceous, Maastrichtian)	Jamaica, Puerto Rico
TKgs	Alkali syenite (Tertiary, Paleocene to Late Cretaceous, Maastrichtian)	Puerto Rico
TKht	Hydrothermally altered rocks (Tertiary, Eocene or Cretaceous)	Puerto Rico
TKI	Limestone, marl, and tuff, undifferentiated (Tertiary, Paleocene and Cretaceous, Maastrichtian)	Cuba, Haiti
TKmd	Mafic dikes and sills, undifferentiated (Tertiary, Eocene to Late Cretaceous)	Puerto Rico
TKmp	Porphyritic andesite-diorite (Tertiary, Eocene to Late Cretaceous)	Puerto Rico

Table 1. Map units in the Greater Antilles and the Virgin Islands (listed alphabetically by map-unit label), showing unit age or position (in parentheses) and general geographic distribution (country or territory).—Continued

Map-unit label	Map unit (age or position)	Country or territory
TKmv	Andesite and basalt flows and tuff, undifferentiated (Tertiary, Eocene to Cretaceous, Campanian)	Puerto Rico
TKq	Quartz keratophyre (early Tertiary? or Late Cretaceous)	Puerto Rico
TKqt	Quartz diorite and diorite, undifferentiated (Tertiary, Paleocene to Late Cretaceous, Maastrichtian)	Puerto Rico, U.S. Virgin Islands
TKrd	Dacite and keratophyre, undifferentiated (Tertiary, Eocene? to Late Cretaceous)	Cuba, Puerto Rico
TKrr	Rhyodacite and rhyolite, undifferentiated (Tertiary, Paleocene to Late Cretaceous)	Dominican Republic
TKsl	Sedimentary rocks of Central Aguirre (Tertiary, Paleocene? or Upper Cretaceous)	Puerto Rico
TKtm	More mafic granitic rocks, tonalite, monzonite, quartz diorite, and granodiorite (Tertiary, Eocene to Late Cretaceous, Maastrichtian)	Dominican Republic, Haiti, Puerto Rico
TKvc	Mixed volcanic and clastic rocks, undifferentiated (lower Tertiary? to Cretaceous, Campanian or older?)	Cuba, Puerto Rico
Tlme	Limestone, marl, and evaporite deposits, undifferentiated (Tertiary, Pliocene to Miocene)	Cuba, Dominican Republic, Jamaica
Tmc	Carbonate rocks (Tertiary, Miocene)	Cuba, Dominican Republic, Puerto Rico
Tmcc	Mixed clastic and carbonate rocks, undifferentiated (Tertiary, Miocene)	Cuba, Haiti
Tml	Limestone (Tertiary, middle Miocene to middle Eocene)	Cayman Islands, Dominican Republic, Jamaica
Tmmc	Mixed clastic rocks (Tertiary, Miocene)	Cuba, Dominican Republic, Haiti
Tmo	Mélange and olistostromes, undifferentiated (Tertiary, Eocene to Paleocene)	Cuba, Dominican Republic, Puerto Rico
Tmoc	Limestone and marl, undifferentiated (Tertiary, lower Miocene to upper Oligocene)	Cuba, Dominican Republic, Jamaica, Puerto Rico, U.S. Virgin Islands
Tmocc	Clastic rocks associated with carbonate-rock formations (Tertiary, lower Miocene to upper Oligocene)	Dominican Republic, Puerto Rico
Tmos	Clastic rocks (Tertiary, Miocene to Oligocene)	Cuba, Puerto Rico
Tn	Necker Formation (Tertiary, Eocene?)	British Virgin Islands
Toc	Carbonate rocks including clay-rich limestone (Tertiary, Oligocene)	Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico
Tocc	Mixed carbonate and clastic rocks, undifferentiated (Tertiary, Oligocene)	Cuba, Dominican Republic, Haiti, Puerto Rico
Toct	Older clastic rocks (Tertiary, Oligocene to Eocene)	Cuba, Dominican Republic
Tols	Reef limestone and chert, undifferentiated (Tertiary, Oligocene to Eocene)	Cuba, Dominican Republic, Haiti
Tosc	Clastic rocks, including conglomerate (Tertiary, Oligocene)	Cuba, Dominican Republic, Puerto Rico, U.S. Virgin Islands
Tpcv	Clastic and volcanic clast-bearing rocks, undifferentiated (Tertiary, lower Eocene to Paleocene)	Cuba, Jamaica, Puerto Rico
Tpm	Young mélange (late Tertiary, Pliocene?)	Dominican Republic
Tpv	Extrusive rocks, flows, tuff, and breccia (Tertiary, Paleocene)	Puerto Rico
Tv	Volcanic rocks including Low Layton Lavas of Jamaica (Tertiary, early Pliocene to Oligocene)	Cuba, Dominican Republic, Haiti, Jamaica
Tvc	Pyroclastic rocks (Tertiary, Eocene)	British Virgin Islands, Cuba, Puerto Rico
Tvcv	Mixed carbonate and clastic rocks and tuff, undifferentiated (Tertiary, Eocene)	Cuba
Tve	Basalt to andesite, undifferentiated (Tertiary, Eocene?)	Cuba
Tvep	Tuff and breccia, undifferentiated (Tertiary, early Eocene and late Paleocene)	Cuba, Haiti, Puerto Rico
Tvs	Volcanic and sedimentary rocks, undifferentiated (Tertiary, Eocene)	Dominican Republic

Sources of Mapping

The primary source of mapping for Cuba was the compilation (in Spanish) by the Cuban Institute of Geology and Paleontology (IGP, 2011). Puscharovsky and others (1988) was used to a limited extent. The stratigraphic nomenclature used by Puscharovsky and others (1988) and Pardo (2009) differ in many areas, whereas the terminology of the Institute of Geology and Paleontology (IGP, 2011), generally used in this report, is more in accordance with Pardo (2009). For unit descriptions that needed more detail than was provided by IGP (2011), Pardo (2009) was used to supplement the descriptions. Iturralde-Vinent and others (2016) provided an overview of the geology of Cuba. It appears that on maps from IGP (2011) the application of “teeth” on thrust faults is not consistent everywhere; the teeth at places, switch sides along a mapped fault. Also, in some areas, where the teeth (on thrust faults) might be consistently present along a particular fault, it appears that the symbol is used opposite of standard practice. For example, in standard practice, the teeth are on the upper plate (older over younger), but in some areas on the IGP (2011) map sheets the teeth are on the younger unit, again opposite of standard practice. An example of the problem is visible on the southeast part of the Cienfuegos sheet (IGP, 2011; sheet no. 4182) in the Trinidad Dome region.

The Haitian Ministry of Mines and Energy Resources (MMER, 1989) was the primary source of mapping for Haiti (in French), and Toloczyki and others (1991) provided data for the Dominican Republic (in Spanish) supplemented by Escuder-Viruete and others (2013a) and Draper and Lewis (1991a). However, neither of these sources used stratigraphic nomenclature in any systematic way. In Haiti, MMER (1989), as well as Vila and others (1985) tended to combine similar units throughout the country. In Dominican Republic, Toloczyki and others (1991) generally described units using lithologic terminology, not stratigraphic names. We have integrated the map units across the island of Hispaniola where the available information allowed correlation. A secondary source of mapping in Dominican Republic was Mann and others (1991). Mann and others (1991) is contemporary with Toloczyki and others (1991) and provided better detail in some areas. Unfortunately, capturing the digital data from several of the sheets was not possible because we could not consistently separate contacts from contours and culture (roads, buildings). All the map units from this source have been entered into our accompanying unit text database table (see Wilson and Labay, 2025).

McFarlane and others (1984) was the primary source of mapping for Jamaica, supplemented by multiple sources that provided more detailed stratigraphic descriptions. Particularly helpful was mapping by Hastie (2007) and by Mitchell (2000, 2013a, b), Mitchell and Blissett (2001), and Mitchell and others (2011).

A detailed geologic map of the Cayman Islands does not exist; the only available source of mapping was Matley (1926).

The geology of the island of Puerto Rico is based on a new compilation from the 1:20,000-scale quadrangle maps of the Island of Puerto Rico (fig. 1 and table 2), supplemented by mapping for Isla de Mona by Kaye (1959); the geology of

Isla de Culebra was from mapping by Banks (1962); and the geology of Isla de Vieques was from mapping by Learned and others (1973). One issue that had to be resolved relative to an earlier Puerto Rico compilation (Krushensky and Schellekens, 1999) involved the spatial registration of the quadrangles. As published, the individual quadrangle maps used the Puerto Rican datum of 1940; however, when digitized in the 1990s the North American Datum of 1927 and the North American Datum of 1983 were inconsistently used to capture the data resulting in mismatches between quadrangles. For this map, the data were captured using the Puerto Rican Datum of 1940 and then converted to the World Geodetic System of 1984 (WGS 84) datum. Additionally, our redigitized maps were captured at higher precision and incorporate more of the original source data. Stratigraphic correlations incorporated in this report and on the map sheets vary somewhat from Krushensky and Schellekens (1999), as do the age or stratigraphic positions we accepted for some map units.

In the U.S. Virgin Islands, Donnelly (1966) was the source of mapping for Saint John and Saint Croix, and Rankin (2002) for Saint Thomas. Helsley (1960) was the primary source of mapping for the British Virgin Islands, except for Anegada Island, whose geology was inferred from information in Kaye (1959).

Most of these sources focus on sedimentary and, to a lesser extent, volcanic rock units. A few sources, however, reported and integrated radiometric ages on igneous rock units, particularly for plutonic rock units. We compiled radiometric age determinations available from the region, and evaluated their quality and applicability to determining the age of rock units (see Wilson and others [2024] for associated digital databases). In part, this has involved recalculating all potassium-argon (K/Ar) ages to the decay constants of Steiger and Jager (1977). Many sources of radiometric age data did not provide information on the decay constants used, and were inferred in different ways, depending on the source. For example, we inferred that the Russian sources used the Russian decay constants that were in use at the time of analysis. We inferred that the sources that used American and European laboratories dating from 1977 and earlier used the decay constants commonly in use prior to the revision of Steiger and Jager (1977). In addition, we found that some of the later (post-1977) sources continued to use older age determinations (that is, ages determined using decay constants that predate Steiger and Jager [1977]), sometimes mixing the older ages with newer ones that used the newer decay constants. The few uranium/lead (U/Pb) dates included in this report are relatively modern, and we assumed that they were determined using modern and consistent constants. For ages determined by other methods, we were not able to determine the decay constants used. We also provide newly determined radiometric ages completed as part of this project.

An additional (and more serious) problem with many of the radiometric ages was that their sources frequently did not provide detailed sample descriptions or even rudimentary location information. Typically, the only location information was from a small graphic image that could not be accurately georeferenced. We have tried to indicate the map unit to which

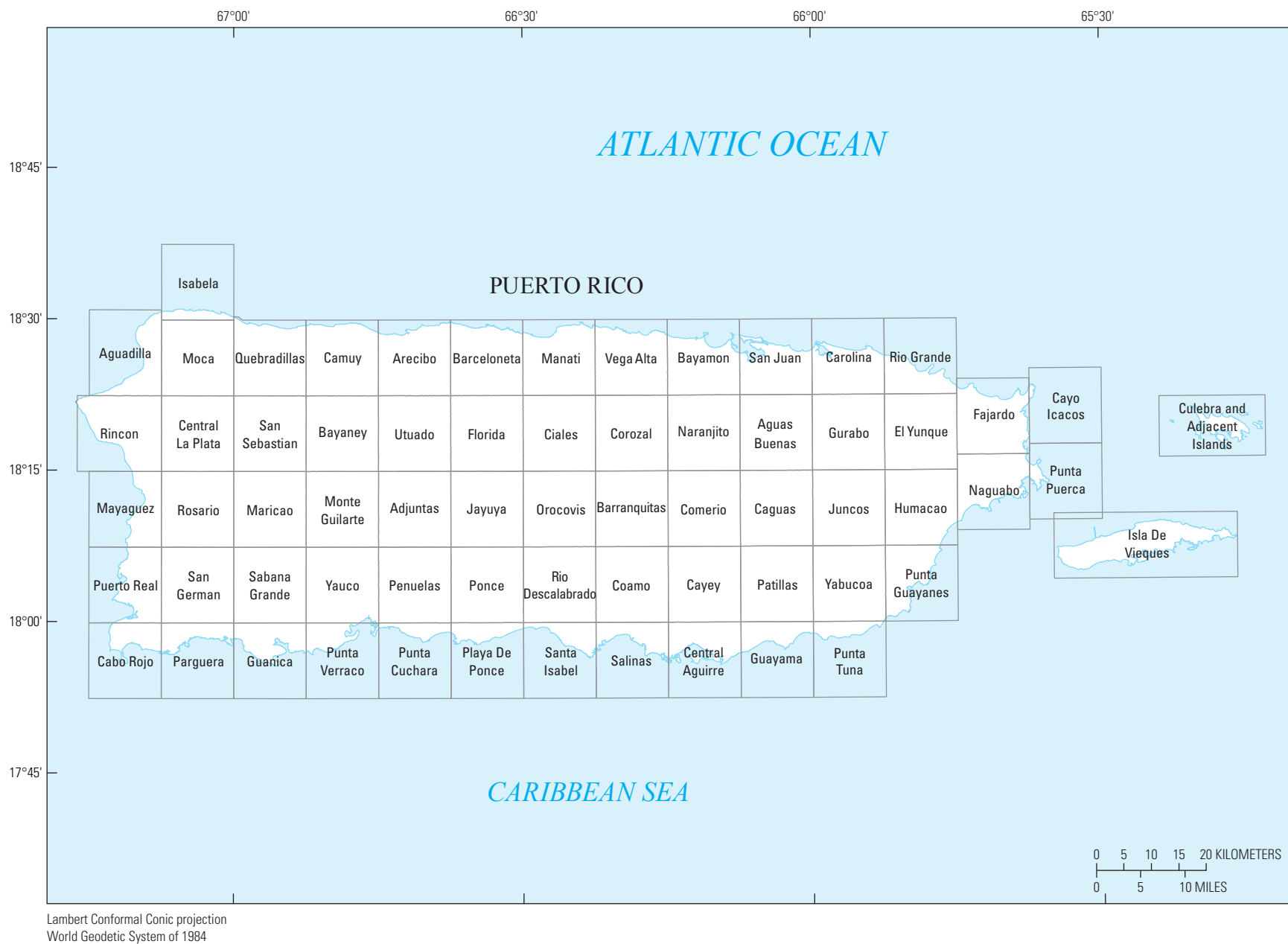


Figure 1. Map showing index to 1:20,000-scale quadrangles of Puerto Rico.

Table 2. Sources of mapping for quadrangles in Puerto Rico and the associated database code.

[The database code is a unique identifier for each source in the geodatabase (see Wilson and Labay, 2025)]

Quadrangle	Source	Database code
Adjuntas	Mattson (1968a)	GAP030
Aguadilla	Monroe (1969a)	GAP041
Aguas Buenas	Pease (1968b)	GAP049
Arecibo	Briggs (1968)	GAP012
Barceloneta	Briggs (1965)	GAP011
Barranquitas	Briggs and Gelabert (1962)	GAP015
Bayamon	Monroe (1973)	GAP043
Bayaney	Nelson and Tobisch (1968)	GAP048
Cabo Rojo and Parguera	Volckmann (1984a)	GAP060
Caguas	Rogers (1979)	GAP053
Camuy	Monroe (1963b)	GAP037
Carolina	Monroe (1977)	GAP044
Cayey	Berryhill and Glover (1960)	GAP010
Central Aguirre	Berryhill (1960)	GAP008
Central La Plata	McIntyre (1971)	GAP032
Ciales	Berryhill (1965)	GAP009
Coamo	Glover (1961a)	GAP020
Coamo area	Glover (1971)	GAP072
Comerio	Pease and Briggs (1960)	GAP051
Corozal	Nelson (1967a)	GAP045
El Yunque	Seiders (1971a)	GAP054
Fajardo and Cayo Icacos	Briggs and Aguilar-Cortes (1980)	GAP014
Florida	Nelson and Monroe (1966)	GAP047
Guánica	Addarich-Martínez (2009)	GAP064
Gurabo	Seiders (1971b)	GAP055
Humacao	M’Gonigle (1978)	GAP028
Isla de Culebra	Banks (1962)	GAP006
Isla de Mona	Kaye (1959)	GAP005
Isla de Mona	Briggs and Seiders (1972)	GAP016
Isla de Vieques	Learned and others (1973)	GAP007
Isla Desecheo	Seiders and others (1972)	GAP070
Jayuya	Mattson (1968b)	GAP031
Juncos	Broedall (1961)	GAP017
Manati	Monroe (1962)	GAP035
Manati	Monroe (1971)	GAP034
Maricao	McIntyre (1975)	GAP033
Mayagüez and Rosario	Curet (1986)	GAP018

Table 2. Sources of mapping for quadrangles in Puerto Rico and the associated database code.—Continued

Quadrangle	Source	Database code
Moca and Isabela	Monroe (1969b)	GAP042
Monte Guilarte	Krushensky and Curet (1984)	GAP027
Naguabo and Punta Puerca	M’Gonigle (1979)	GAP029
Naranjito	Pease (1968c)	GAP050
Northwestern Puerto Rico	McIntyre and others (1970)	GAP058
Orocovis	Briggs (1971)	GAP013
Patillas and Guayama	Glover (1982)	GAP021
Penuelas and Punta Cuchara	Krushensky and Monroe (1978)	GAP025
Playa de Ponce and Santa Isabel	Glover and others (1977)	GAP023
Ponce	Krushensky and Monroe (1975)	GAP024
Puerto Real	Volckmann (1984b)	GAP061
Puerto Rico	Krushensky and Schellekens (1999)	GAP002
Puerto Rico	Cox and Briggs (1973)	GAP003
Puerto Rico	Briggs and Akers (1965)	GAP062
Punta Guayanes	Rogers (1977)	GAP039
Quebradillas	Monroe (1967)	GAP040
Rincon	Aaron (1968)	GAP065
Rio Descalabrado	Glover and Mattson (1973)	GAP022
Rio Grande	Pease and Briggs (1972)	GAP056
Sabana Grande	Colon (2003)	GAP063
Sabana Grande	Colon and Llerandi Roman (2004)	GAP068
Sabana Grande	Llerandi Roman (2004)	GAP069
Salinas	Glover (1961b)	GAP019
San German	Volckmann (1984c)	GAP059
San Juan	Pease and Monroe (1977)	GAP052
San Sebastián	Tobisch and Turner (1971)	GAP057
Southern Puerto Rico	Monroe (1980)	GAP071
Utado	Nelson (1967b)	GAP046
Vega Alta	Monroe (1963a)	GAP036
Yabucoa and Punta Tuna	Rogers and others (1979)	GAP038
Yauco and Punta Verraco	Krushensky and Monroe (1979)	GAP026

an age might apply; however, many ages were determined on hydrothermal minerals or dikes that were not separately mapped. We identified sampling locations as best as we could, but in some cases the locations may only be within a few kilometers of the actual sample collection site. A further concern is that some of the age determinations are analytically suspect, owing to exceedingly large analytical errors. For other samples,

the age results may be suspect due to using inappropriate materials (for example, using whole-rock samples to date coarse-grained plutonic rocks). Multiple, widely varying age determinations are reported for some plutonic-rock units; these are difficult to evaluate. We do not know if they reflect dates that are suspect or if they reflect mapping that grouped plutonic phases of varying age into a single plutonic-rock unit or both.

Table 3. Formations of the Devil's Race Course Group in Jamaica.

[Originally mapped by McFarlane and others (1984) as the Devil's Race Course Formation of the Benbow inlier; elevated to the Devil's Race Course Group by Brown and Mitchell (2010), who then divided it into nine distinct formations; herein, mapped together as the intermediate-composition volcanic rocks subunit (Kevi). Stratigraphic sequence is from top to bottom. m, meters]

Unit	Description	Thickness (m)	Age (stage)
Airy Mount Formation	Volcaniclastic pebble conglomerate and minor sandstone	350	late Aptian or early Albian
Golden Grove Formation	Mafic pillow flows and thin associated volcaniclastic sedimentary rocks	430	late Aptian or early Albian
Burtens Formation	Hard, dark-gray, micritic limestone	8	late Barremian to early Aptian
Ragville Formation	Mafic pillow flows and thin associated volcaniclastic sedimentary rocks	280	late Barremian or early Aptian
Benbow Formation	Very hard, compact, dark-blueish-gray biomicrite, rich in rudists, gastropods, and corals, and having smaller numbers of chondrodonts and columnar stromatolites	400	Barremian
Boozy Ridge Formation	Volcaniclastic shale, sandstone, and conglomerate	510	late Hauterivian or early Barremian
Jubilee Formation	Compact, very hard, dark- to medium-gray limestone interbedded with mudstone and volcanically derived sandstone and conglomerate	100 to 375	Hauterivian
Redwood Formation	Volcaniclastic pebble conglomerate and sandstone	510	Valanginian or early Hauterivian(?)
Cistern Formation	Basaltic andesite and dacite to rhyolite flows and a few thin tuff beds	1,600	Valanginian or early Hauterivian(?)

DESCRIPTION OF MAP UNITS

The map units are generally based on age and lithology; defined formal stratigraphic units may include a variety of lithologies as distinct members or subunits. Where these members or subunits were mapped separately by previous authors, they may be assigned to different map units in this report. For example, limestone members of otherwise volcaniclastic formations are assigned to a carbonate map unit where possible.

UNCONSOLIDATED DEPOSITS

- Qs** **Surficial deposits, undifferentiated (Quaternary)**—Unconsolidated deposits, including material that ranges in size from clay to coarse cobbles and boulders, mixed with organic debris. Unit represents variety of environments and deposit types, which include alluvium; alluvial fans and talus deposits; lacustrine, swamp, and salt-marsh deposits; landslide and slump deposits; beach and estuarine deposits; and eolian deposits. Compositions include clay, silt, sand, and gravel. In Cuba, several formally defined map units are included in this unit, including the eolian Playa Santa Fé and Guanabo Formations, the beach deposits of the Cayo Romano Formation, and the Pleistocene surficial deposits of the Guevara Formation (IGP, 2011)
- Qpm** **Artificial fill deposits (Quaternary, Holocene)**—Variety of rock types reworked for artificial fill. Mapped only in Puerto Rico (Briggs, 1965, 1968; Monroe, 1973, 1977; Krushensky and Monroe, 1975, 1979; Glover and others, 1977; Pease and Monroe, 1977; M'Gonigle, 1978, 1979; Briggs and Aguilar-Cortes, 1980; Curet, 1986), but most likely also present elsewhere
- QTcr** **Deposits associated with carbonate reefs and reef complexes (Quaternary and upper Tertiary, Pliocene)**—Semiconsolidated and partly consolidated deposits that represent carbonate reef complexes, located primarily in Cuba but also in Dominican Republic, Haiti, Cayman Islands, British Virgin Islands, Puerto Rico, and Jamaica. Locally, deposits are assigned to formal geologic units. In Cuba, many defined units either include or entirely consist of reef deposits and are mapped in this unit. These include the Jaimanitas Formation of Pleistocene age, exposed along much of the coast of Cuba; limestone of the Vedado and Rio Maya Formations, of which the Vedado Formation, of late to early Pleistocene to late Pliocene age, commonly may be dolomitized and is primarily exposed along the south coast of central Cuba; and the Versailles Formation of middle Pleistocene age and Canimar Formation of Pliocene age, exposed along the north shore of Cuba (IGP, 2011). The El Salado Formation on the Isla de la Juventud of Cuba consists of reddish clay that re-cements angular fragments of the Jaimanitas Formation. On offshore islands, north of Cuba, the Cayo Guillermo Formation is an oolitic calcarenite

and limestone of late Pleistocene age (IGP, 2011). In Haiti and Jamaica, reef deposits are terraced; they extend to elevations as high as 640 m in Haiti, indicating rapid uplift. In the British Virgin Islands, the Rogue's Bay Calcarene is limestone that contains well-sorted fragments of pelecypods, gastropods, and large foraminifera; these fragments have been reworked and are moderately well rounded, and they are cemented with calcite to form limestone that has about 10 percent porosity. Very few silicate grains are present, only plagioclase and epidote were observed, and they make up considerably less than one percent of the rock (Helsley, 1960). The Ironshore Formation of the Cayman Islands consists of white and cream-colored, consolidated coral sand and marl, which contains abundant coral heads, and coralliferous limestone; the many reef-building corals in this formation are in excellent condition (Matley, 1926). Earle (1924) described similar reef deposits on Anegada Island in the British Virgin Islands. On the southern part of Isla de Mona, which essentially is elevated coral reef, Kaye (1959) also defined the "Reef Limestone," and they correlated it with the Ironshore Formation of the Cayman Islands. Along the north coast of Puerto Rico, Pleistocene age beach deposits are uplifted as much as 4 m and dip to the north (Monroe, 1963a, 1971) and are included in this unit

QTmc Marine conglomerate and sand, undifferentiated (Quaternary and upper Tertiary, Pliocene)—Also associated with unit QTcr in Cuba are clastic deposits of marine sand and conglomerate. Deposits of semiconsolidated conglomerate, sand, and marl constitute the Holocene and Pleistocene Los Pinos, Villaroja, La Cabaña, Jamaica, Sigüanea, Cocodrilo, Cauto, and Camacho Formations, which are widely exposed in eastern and central Cuba near its coast; the lower Pleistocene to upper Pliocene Guane Formation of westernmost Cuba; the Dátil and Bayamo Formations of southeastern Cuba; and the locally undivided Guane and Guevara Formations of western Cuba and Isla de la Juventud (IGP, 2011). The Dátil Formation consists of chert-rich blocks and pebbles derived from hydrothermal alteration of volcanic rocks having variegated coloring. It also contains interbeds and lenses of polymictic clay-rich sand (IGP, 2011). Pleistocene, raised beach deposits in Puerto Rico consisting of crossbedded quartz- and shell-sand and gravel at altitudes as much as 50 to 70 m occur in northwest Puerto Rico indicating significant Quaternary uplift (Monroe, 1967, 1969a, b)

QTcs Continental conglomerate and sand (Quaternary and upper Tertiary, Pliocene)—Restricted to Dominican Republic are rocks of the Arroyo Seco, Sanchez, and Via Formations (De Zoeten and others, 1991; Mann and others, 1991; Toloczyki and others, 1991). Toloczyki and others (1991) described the Arroyo Seco Formation as poorly sorted coarse to fine-grained conglomerate and subordinate sand and silt that is largely nonmarine containing some soil horizons, though some marine influences are present, in part reflected in reworked marine microfossils. It unconformably overlies older units and may be as much 1,000-m-thick. Unit is distinguished from modern terraces because of significant river dissection and the absence of terrace surfaces. De Zoeten and others (1991) show the Sanchez Formation in northern Dominican Republic that consists of mudstone and lignite. Mann and others (1991) describe the Via Formation as a proximal facies of the Arroyo Seco Formation, containing poorly consolidated conglomerate and sandstone

SEDIMENTARY ROCKS

Tlme Limestone, marl, and evaporite deposits, undifferentiated (Tertiary, Pliocene to Miocene)—Older deposits of reef limestone and marl that represent intertidal facies in Jamaica, Dominican Republic, and Cuba. Rocks of this unit exposed on the north coast of Jamaica are part of the Coastal Group (which includes the Bowden and Buff Bay Formations) and are made up of limestone, marl, and clay beds (McFarlane and others, 1984). In Dominican Republic, these deposits are found in two general areas: near Bahía de Samaná (Samaná Bay) and Parque Nacional Los Haitises (Los Haitises National Park) and in the vicinity of Lago de Enriquillo (Enriquillo Lake) and Parque Nacional Sierra de Bahoruco (Sierra de Bahoruco National Park) (Toloczyki and others, 1991). Associated with unit in the vicinity of Lago de Enriquillo and, in particular, Laguna del Rincon (Rincon Lagoon) are Pliocene-age evaporite-facies rocks that consist of red clay and silt with gypsum and salt beds; individual gypsum beds are up to 2 m thick and salt beds are up to 80 centimeters (cm) thick; also associated are modern salt-marsh deposits near Bahía de Samaná (Toloczyki and others, 1991). In Cuba, the evaporite facies rocks consist of the Manzanillo Formation, exposed in the western part of southernmost Cuba, and the Júcaro and La Cruz Formations, found farther east (IGP, 2011)

Tca Calcarene, biocalcarene, limestone, and marl, undifferentiated (Tertiary, Pliocene to Miocene)—A largely clastic unit of similar age to the limestone, marl, and evaporite deposits of unit (Tlme) that was mapped in this study but is more widely distributed, being present in Cuba, Haiti, Dominican Republic, and Puerto Rico. In Cuba and Puerto Rico, the unit is exposed in coastal regions. In Cuba, it includes the calcarene of the Loma Triana Formation and clay-rich micritic and micritic-bioclastic limestone

containing occasional interbeds of calcarenite and coquina of the Caobas Formation; both formations have limited exposure in northern Cuba (IGP, 2011). Also included is the calcareous shale of the Santiago Member of the La Cruz Formation, exposed in southernmost Cuba (IGP, 2011). In Haiti, the unit typically is exposed inland, somewhat distant from the coast, possibly reflecting rapid uplift as indicated by the reef deposits of unit QTcr. In northern exposures on Haiti's Plateau Centrale (Central Plateau), the unit consists of alluvium of the Hinche Formation, which has been deposited on an erosion platform (Maurrasse, 1982). The alluvium has a high proportion of calcareous pebbles and a maximum thickness of 100 m. On the eastern part of the southern peninsula, in the valley of the Bras Gauche (Gauche River), this unit includes marine conglomerate containing calcareous and volcanic-rock blocks and pebbles, as well as sand and marl. The conglomerate there is folded and has a maximum thickness of 500 m. Elsewhere, near Port-au-Prince, 1,000 m of coarse conglomerate rests on marl of latest Miocene (Messinian) age (Vila and others, 1985; MMER, 1989). Toloczyki and others (1991) reported in the Dominican Republic a deltaic unit that consists of conglomerate, sandstone, marl, and calcarenite in the northwestern part of the Valle del Cibao (Cibao Valley), and a similar marine sandstone, sandy marl, and conglomerate unit likely equivalent to the Hinche Formation of Haiti in the Cordillera Central and which is adjacent to the continental clastic rock unit Tcc. In Puerto Rico, the Camuy Formation along the north coast is biomicrite, rich in foraminifera, and contains clay lenses; ferruginous calcarenite interbedded with chalky breccia; and, in its upper part, chalky sandstone, sandy limestone, and limestone; estimated maximum thickness is 170 m (Monroe, 1963a, 1967, 1969b, 1971; Briggs, 1965, 1968)

Tcc Continental clastic rocks (Tertiary, Pliocene to Miocene)—Limited to Hispaniola, this unit is mainly exposed in the central part of the island (in Haiti and Dominican Republic) and is also exposed between Bahia de Samaná and Monte Cristi in Valle del Cibao in Dominican Republic. A limited area of exposure is on Ile de La Gonâve (Gonâve Island) of Haiti and on the southern peninsula of Haiti. Continental lignite facies rocks are found on the west end of the southern peninsula and as the Lascachobas Formation (Vila and others, 1985) of central Haiti (or the Las Cahobas Formation of Maurrasse, 1982), which consists of conglomerate, sandstone, sandy shale, local coarse unconsolidated sand, and lignite (Maurrasse, 1982). The Lascachobas Formation is roughly age equivalent with the finer grained Thomonde Formation and largely younger than the Maissade Formation, a partly equivalent unit that consists of shale, marl, and sandstone. All three units contain lignite (though not in great quantities) that is found in lenses throughout (Maurrasse, 1982). The rocks are highly folded. A similar coarse clastic unit probably is present in Dominican Republic, though Toloczyki and others (1991) did not describe the presence of lignite there

Tmcc Mixed clastic and carbonate rocks, undifferentiated (Tertiary, Miocene)—These clastic and carbonate rocks largely reflect undivided carbonate rocks (subunit Tmc) and mixed clastic rocks (subunit Tmmc). In Cuba, the Yayai Formation of claystone, limestone, and marl is exposed north of Santiago de Cuba, in southeastern Cuba; at both its eastern and western limits, the unit grades to the carbonate rocks subunit Tmc; to its north, the unit is adjacent to outcrops of limestone and marl of Miocene to Oligocene age (unit Tmoc). Farther north, the Arabos and Manga Larga Formations, exposed in limited areas north and east, respectively, of Colón (22°44' N., 80°51' W.), consist of claystone, marl, sandstone, limestone, and siltstone and are associated with Mesozoic rocks, yet near the carbonate rocks of subunit Tmc. In Haiti, available mapping (Vila and others, 1985) did not distinguish rock units that are equivalent to the carbonate rocks (subunit Tmc) or the mixed clastic rocks (subunit Tmmc). Where unit Tmoc is adjacent to the border with central Dominican Republic, unit Tmoc appears to merge with either continental clastic rocks (unit Tcc) or limestone (unit Tml) as mapped in Dominican Republic (Toloczyki and others, 1991). In Haiti, the unit is quite variable and includes several distinct sedimentary sequences. Exposures in northern Haiti (near Gros Morne) have upper Oligocene conglomerate at the base, overlain by hard, detrital, locally echinoderm-fossil-bearing, yellow limestone, alternating with clayey limestone, gray or brown marl, and calcareous and volcanoclastic sandstone; locally, coarse, clastic lower Miocene rocks contain blocks bearing Eocene fossils. Similar facies are observable in Montagnes Noires (Black Mountains) and the Chaîne des Matheux, along the north side of Golfe de la Gonâve (Gulf of Gonâve). In northwestern Haiti near Trois-Rivières (Three Rivers) and in Nord-Ouest region (Northwest region), Aquitanian to Burdigalian detrital rocks are present. In Chaîne des Matheux and also along Haiti's southern peninsula, upper Oligocene chalky red flint, commonly slumped, and lower Miocene (Aquitanian to Burdigalian) clastic rocks are present (Vila and others, 1985). Locally, divided into subunits Tmc and Tmmc

Tmc Carbonate rocks—Limestone, marl, and calcarenite of Miocene age are very widespread throughout the Greater Antilles. Forming a large part of Cuba, it consists of the Cabo Cruz, Güines, Cojímar, Caobas, San Antonio, and Vázquez Formations, some of which may be partially dolomitized. Widely exposed

in northern Cuba, the middle to lower Miocene Güines Formation is white, yellowish, beige, or gray recrystallized, massive, rarely stratified, bioclastic, biohermic, dolomitized limestone and dolostone. It is as much as 1,200 m thick (Pardo, 2009). Locally, it contains lenses of calcareous marl and calcarenite (IGP, 2011). In much of the same area, the middle Miocene Cojimar Formation, a partial lateral equivalent of the Güines, is cream, yellowish, whitish, and greyish calcareous, argillaceous, arenaceous, and sometimes, nodular marl, chalk, bioclastic clay-rich limestone, and calcarenite that has a marly matrix and claystone (IGP, 2011). It is as much as 390 m thick (Pardo, 2009). In the same area, but west of the Cojimar near the community of Matanzas, the lower Miocene Caobas Formation is exposed in a small area and consists of yellowish-gray clay-rich micritic and micritic-bioclastic limestone that contains local interbeds of calcarenite and coquina (IGP, 2011). The Vázquez Formation, exposed between the Camagüey and Holguín regions, consists of alternating beds of marl, calcareous or clayey siltstone, and smectitic and arenaceous claystone. Also present is subordinate bioclastic argillaceous limestone, micritic limestone, calcilutite, calcarenite, sandstone, and calcareous and polymictic conglomerate (IGP, 2011). Exposed in a very small area on the southeast coast of Cuba, the lower Miocene San Antonio Formation consists of creamy, yellowish, whitish, and greyish calcareous, argillaceous, arenaceous and sometimes nodular marl, chalk, clay-rich bioclastic limestone, and calcarenite having a marly and clay-rich matrix (IGP, 2011). Exposed at the extreme west and east ends of the southern coast of Cuba, the upper Miocene Cabo Cruz Formation is variegated reddish sandy bioclastic and fossiliferous limestone that is slightly phosphatized (IGP, 2011). Rocks of this age and type are also widely distributed in Dominican Republic, being exposed on the southernmost coast, along the north coast, and in the central part of country north of Valle del Cibao. Unit is largely described as marl that has interbedded calcarenite, except at the eastern tip of Peninsula de Samaná (Samaná Peninsula) where a small area of cream-colored limestone is described (Toloczyki and others, 1991). In Puerto Rico, the Aguada Limestone and the Aymamon Limestone constitute much of the northern part of the island; the Aguada Limestone contains calcarenite at its base overlain by chalky marl and rubbly limestone, whereas the similar-age Aymamon Limestone consists of dense limestone and chalk, which may be locally dolomitized. It is 190–200 m thick and commonly solution riddled and indurated on the surface into hard limestone having abundant sharp spires as much as 30 cm high (Monroe, 1963a, b, 1967, 1969a, 1971, 1973, 1977; Nelson and Monroe, 1966; Nelson, 1967a; Pease and Briggs, 1972; Pease and Monroe, 1977). The Ponce Limestone, which locally has beds of brown clay, reaches its estimated maximum thickness of 850 m on the southwest coast of Puerto Rico (Monroe, 1980). Also, along the southwest coast of Puerto Rico, calcarenite and calcirudite of the Guanajibo Formation has a maximum thickness of only 30 m and contains a fauna largely equivalent to the Ponce Limestone (Monroe, 1980, Volckmann, 1984b). On Isla de Vieques (Vieques Island), soft yellow limestone and dolostone described by Learned and others (1973) may correspond to the Ponce Limestone. In western Puerto Rico, the Isla Mona Limestone (renamed the Isla de Mona Dolomite by Briggs and Seiders, 1972), a thick-bedded, dense, and finely crystalline limestone and dolostone described by Kaye (1959), makes up most of Isla de Mona and Isla Monito (Mona and Monito Islands). It is capped by the Lirio Limestone, originally defined to be Quaternary, but redefined by Briggs and Seiders (1972) to be Miocene. On Isla de Mona and Isla Monito in western Puerto Rico, the Lirio Limestone is a thick-bedded, dense, and finely crystalline limestone and dolostone that commonly is indistinguishable from the underlying Isla de Mona Dolomite though the Lirio weathers darker (Kaye, 1959). The Lirio Limestone is not separately mapped in this report because it was distinguished only in cliff faces

Tmmc

Mixed clastic rocks—Exposed in central to southeastern Cuba are conglomerate, sandstone, siltstone, and claystone of the Lagunitas Formation (IGP, 2011), which is likely derived from erosion of Mesozoic igneous and metamorphic rocks and is in close contact with the marl and limestone of the Arroyo Palmas Formation (part of the carbonate rocks subunit, Tmc). In northern Cuba, the whitish and cream-colored Santa María del Rosario Formation is included in this unit; it consists of calcareous claystone, containing *Ostrea* fossils, and conglomerate having a marly matrix, both containing clasts of limestone, volcanic rocks, and to a lesser extent, quartz. In Dominican Republic, small areas of Miocene clastic rocks are present; conglomerate is exposed on Peninsula de Samaná just north of Bahía de Samaná and west of Santo Domingo near Padre Las Casas; shallow marine sandstone, sandy marl, and conglomerate are exposed in the highlands west of Santo Domingo (Toloczyki and others, 1991). This marine sandstone also locally includes a clastic limestone derived from landslides off reef complexes. Widely exposed in Haiti is sandy-pelitic flysch of the Central Plateau of the Madame Joie Formation and calcareous sandstone of Gros Morne Basin of the La Crête Formation (MMER, 1989)

Tmos	Clastic rocks (Tertiary, Miocene to Oligocene)—In southeastern Cuba, the Maquey Formation, which is exposed north and east of Guantánamo, consists of sandstone, siltstone, calcareous clay, and marl that has interbeds of silty bioclastic limestone, and contains large <i>Lepidocyclina</i> sp., as well as gypsum, lignite, and plant remains (IGP, 2011). Included in this unit is the Cilindro Member [in some literature, this unit is considered a formation] of the Maquey Formation, a weakly cemented polymictic conglomerate that contains lenses of sandstone and lignite. It is found in two distinct areas, the western exposures associated with Miocene to Oligocene limestone of unit Tmoc. The eastern exposures are associated with Eocene clastic rocks of unit Tecr and Cretaceous to Jurassic metamorphosed ultramafic rocks of unit KJmm (IGP, 2011). The Pedernales Member of the Camazán Formation is also a weakly cemented polymictic conglomerate, distinctive for containing clasts of diabase, gabbro, and ultramafic rocks (IGP, 2011). Polymictic sandstone and siltstone of the Cabacú Formation, which has sparsely distributed clayey marl lenses at its base, is exposed in a small area near Baracoa on the easternmost part of the north coast (IGP, 2011). In Puerto Rico, the Mucarabones Sand of northern Puerto Rico is grayish-orange to yellowish-brown crossbedded medium- to coarse-grained quartz sand interbedded with glauconitic calcareous sandstone and clay. The unit overlies the San Sebastian Formation (unit TOcc) and interfingers with the Cibao Formation (unit Tmoc); the Mucarabones Sand has a maximum thickness of 120 m (Nelson, 1966, 1967b; Monroe, 1973, 1980; Pease, 1968c; Pease and Monroe, 1977)
Tml	Limestone (Tertiary, middle Miocene to middle Eocene)—Generally white limestone found in Cayman Islands, Jamaica, and Dominican Republic, all in the southern part of the Greater Antilles. Best exposed in Jamaica, the Montpelier Formation of the White Limestone Group is well-bedded limestone and chalk that has flint nodules in its lower sections. Rare marl beds are present interbedded with the chalk (McFarlane and others, 1984). The White Limestone Group of Jamaica, which varies widely in age, has both shallow- and deepwater facies of which the Montpelier Formation is a deepwater (700–1,000 m) facies; in this report exposures mapped by McFarlane and others (1984) do not include the Montpelier belt of Mitchell (2013a) but do include the deepwater facies that Mitchell (2013a) assigned to the North Coast and John Crow Mountain belts. As defined, the Montpelier Formation ranges in age from early Miocene to middle Eocene. The Bluff Limestone of the Cayman Islands was correlated with the White Limestone Group by Matley (1926) and based on Matley's (1926) description, may correspond to the Montpelier Formation. The Bluff Limestone consists of hard, compact, locally dolomitic limestone containing what Matley (1926) described as colloidal silica and is devoid of terrigenous material. In southern Dominican Republic on the north shore of Lago Assuey (Lake Azuei) and Lago Enriquillo (Enriquillo Lake), an undifferentiated limestone (unit teo-tmis'c of Toloczyki and others, 1991) containing marl and calcarenite, as well as chert beds and nodules, is likely to include rocks equivalent to the Montpelier Formation
Tmoc	Limestone and marl, undifferentiated (Tertiary, lower Miocene to upper Oligocene)—Dominantly limestone; also includes lesser amounts of marl, clay-rich limestone, calcarenite, and minor sandstone and conglomerate. Widely exposed throughout the region, rocks of this unit are found in Cuba, Dominican Republic, Jamaica, Puerto Rico, and the U.S. Virgin Islands. Multiple geologic units in Cuba are represented here (IGP, 2011). The Paso Real Formation is the most widespread of these Cuban units; it consists of clay and bioclastic, dolomitized, recrystallized limestone and also contains minor dolostone, calcarenite, marl, calcareous clay, and incidental interbeds of sandstone and calcareous siltstone. The Paso Real Formation is consistently found on the south slope/face of older complexes the length of Cuba. In westernmost Cuba, the Sevilla Arriba Formation is a cream, whitish and greenish, hard bioclastic limestone containing large <i>Lepidocyclina</i>, interstratified with calcareous shale and silty marl. It also contains a variable proportion of volcanic debris. In the Havana region of Cuba, the Colón Formation contains biocalcarenite and biocalculutite that has a marly matrix, bioclastic breccia, and biomicritic limestone containing <i>Lepidocyclina</i>. Minor calcareous-clay-rich polymictic sandstone, marl, and calculutite are present. Also found in the Havana region of Cuba is the Jaruco Formation consisting of interstratified clay-rich bioclastic limestone and marl. It contains subordinate reef limestone, calcirudite and calcarenite. East of these units, on either side of the basin between Holguín and Contramaestre, the Camazán Formation is yellow, beige, brown, and gray limestone that is locally clay-rich, as well as having calcarenite, calcirudite, calcareous siltstone, interbeds of marl and clay, and uncommonly, gypsum. In the same area, the Bitiri Formation is found in a linear belt from Mayarí to Bayamo. It is a yellowish-gray to brownish karst-forming algal limestone that has a fine-grained, hard, compact matrix, infrequently containing fragments of corals and large <i>Lepidocyclina</i>. The easternmost exposure of this map unit, in the Guantánamo region, is represented by the Yateras Formation, which is a detrital, bioclastic, and biogenic limestone that may resemble porcelain. Similar to the other Cuban units, it commonly contains large <i>Lepidocyclina</i>, and is white, beige, pink, or sometimes caramel colored. In southern Dominican Republic,

rocks there, which include the Rio Arriba Formation, may contain more marl than do similar rocks in Cuba. These are primarily marly limestone and rarely contain chert (Toloczyki and others, 1991). The exposures continue to the border with Haiti; however, the available Haitian mapping does not distinguish a similar unit although it is quite likely that rocks of this lithology and age are present in Haiti. In Jamaica, the lower Miocene to upper Oligocene Newport Formation, which is one of the youngest shallow-water members of the White Limestone Group, is characterized by thick-bedded or massive, white or pale-colored wackestone and carbonate-rich mudstone; it is generally exposed in southernmost Jamaica (McFarlane and others, 1984, Mitchell, 2013a). The Browns Town Formation, a partial lateral equivalent of the Newport Formation, is characterized by white and locally pale-pink packstone, wackestone, and carbonate mudstone that contains common to abundant, large, lenticular foraminifers or abundant coral (Mitchell, 2013a). According to Mitchell (2013a), previous mappers suggested that the Newport Formation was stratigraphically higher than the Brown's Town Formation and that the Brown's Town Formation was laterally equivalent to the Walderston Formation, whereas Mitchell (2013a) said that the Browns Town Formation of the White Limestone Group is age equivalent to the Newport Formation. McFarlane and others (1984), however, mapped the Brown's Town Formation and the underlying, lower Oligocene Walderston Formation as a composite unit, which is included here within carbonate rocks unit **Toc**, though they recognized that the Brown's Town Formation was early Miocene in age based on fossils and suggested that it stratigraphically was lower Miocene to upper Oligocene. In Puerto Rico, the Cibao Formation and its various members form a continuous linear belt across northern Puerto Rico. It is dominantly chalky limestone and contains lesser amounts of marl a few hundred meters thick (Monroe, 1963b, 1969a, 1977, 1980; Berryhill, 1965; Briggs, 1965, 1968; J.M. Aaron, U.S. Geological Survey, unpublished data, 1968; Pease, 1968c; Pease and Monroe, 1977). Fossils, especially *Lepidocyclus* sp., are present at many places in the lower two-thirds of the formation. The large echinoid *Echinolampus semiorbis* Guppy is abundant at many places in the marl below the Quebrada Arenas Limestone Member (Nelson and Monroe, 1966). The lowest defined member of the Cibao Formation is the Montebello Limestone Member, originally defined by Nelson and Monroe (1966); it consists of more than 200 m of fine- to very-fine grained pure limestone that is locally highly fossiliferous (Briggs, 1968). Monroe (1980, p. 30–31) provides a stratigraphic diagram of the Cibao and its members; the Montebello Limestone Member lies at the base of the formation in its central area, whereas the stratigraphically equivalent Rio Indio Limestone Member forms the base of the Cibao towards its eastern extent. Overlying the Rio Indio Limestone Member is the Quebrada Arenas Limestone Member of hard limestone interbedded with soft, chalk-rich limestone. It is only sparsely fossiliferous and exposure areas are characterized by the development of karst topography. Also included in the Cibao, the Guajataca, the Almirante Sur Sand Lentil, and the Miranda Sand Members (unit **Tmocc**) are distinct clastic rock units up to a few hundred meters thick. The Juana Diaz Formation of southern Puerto Rico contains an informally defined upper crystalline and coralline limestone member as much as 400 m thick (Krushensky and Monroe, 1978). It contains *Lepidocyclus undosa* and *Clypeaster oxybaphon*, as well as reef-building coral fossils. On Saint Croix in U.S. Virgin Islands, the Kingshill Marl is buff-to-white, moderately thick bedded, hard and rather brittle limestone that alternates with soft white or cream-colored marl (Whetten, 1966). The Kingshill Marl was subsequently renamed as the Kingshill Limestone (Gerhard and others, 1978); in addition, its age was extended to late Miocene to late Oligocene, dominantly Miocene (Lidz, 1988).

Tmocc

Clastic rocks associated with carbonate-rock formations, undifferentiated (Tertiary, lower Miocene to upper Oligocene)—Exposed in the Dominican Republic and Puerto Rico are clastic rock units commonly associated with the limestone and marl of unit **Tmoc**. In Dominican Republic, as much as 1,000 m of conglomerate, sandstone, subordinate marl and limestone, and rare gypsum is found near Luperón on the north coast. The basal conglomerate appears to contain debris from erosion of Cretaceous arc rocks (Toloczyki and others, 1991). Similarly, the Almirante Sur Sand Lentil of the Cibao Formation, which is interbedded within the Rio Indio Limestone Member, and the Miranda Sand Member, which overlies the Quebrada Arenas Limestone Member are also included here. Exposed in small exposures in northcentral Puerto Rico, the Almirante Sur Sand Lentil Member and the Miranda Sand Member, are largely clastic rocks. The Almirante Sur Sand Lentil Member (Berryhill, 1965; Monroe, 1971) is quartz-sandstone and pebbly quartz-sandstone that grades into glauconitic calcarenite, whereas the Miranda Sand Member (Monroe, 1963a, 1971) reflects a channel deposit into the Quebrada Arenas Limestone Member as much as 260 m thick that consists of sandstone and pebble- to cobble-conglomerate. West of these exposures, the Guajataca Member of the Cibao Formation can be calcareous clay like the rest of Cibao but contains lenses as thick as 15 m of sand and gravel derived from volcanic rocks including cobbles of silicified rock as much as 10 cm in diameter. Thickness is up to 160 m (Monroe, 1967, 1969b, 1980; Tobisch and Turner, 1971).

Tocc

Mixed carbonate and clastic rocks, undifferentiated (Tertiary, Oligocene)—Present in Cuba, Haiti, and Dominican Republic and to a lesser extent in Puerto Rico, the unit includes limestone, marl, siltstone, and sandstone. In Cuba, four map units are included and are restricted to the northwest half of island (IGP, 2011). The Las Cuevas Formation, which is spatially associated with the Mabujina complex (unit KJmc) of central Cuba is biogenic, detrital, sandy limestone, calcareous sandstone, siltstone, silty marl, containing interbeds of polymictic conglomerate. The Guanajay Formation of marl, sandy marl, sandstone, biogenic limestone, claystone, and siltstone is in the extreme northwestern part of Cuba; according to Pardo (2009) the Guanajay has been subdivided on the basis of paleontology an upper Eocene interval characterized by the *Globigerina ciperoensis*–*Globorotalia opima* biozone and a lower Oligocene interval, of similar lithology, characterized by the *Globigerina sellii*–*Globigerina ampliapertura* biozone; unfortunately, available mapping does not allow us to show this distinction. The Jatibonico Formation, found east of the Mabujina complex, consists of marl, interbedded with sandstone and polymictic conglomerate, sandy-clastic limestone, clay-rich and coral limestone. The similar, though more carbonate rich, Chambas Formation consists of microgranular limestone, biogenic and detrital limestone, and clayey limestone grading to marl (IGP, 2011). It also contains conglomerate and sandstone that contain abundant rounded fragments of volcanic rocks. According to Pardo (2009), Eocene fossils at the base of the unit probably reflect reworking. In Dominican Republic, the unit is exposed in two general areas, surrounding Santo Domingo and north of the Cordillera Central. Just southeast of Sabaneta, north of the Cordillera Central, a small area of marl with interbedded calcarenite is present (unit tolm'm+car, Toloczyki and others, 1991). Southeast of there, near Yaque Abajo, a much larger area of conglomerate, sandstone, subordinate limestone reef deposits is as much as 2,400 m thick (unit tolm-s'ar, Toloczyki and others, 1991). Surrounding Santo Domingo is marl and interbedded conglomerate (unit tol'm+cg, Toloczyki and others, 1991); approximately 35 km west of there is a small outcrop area of sandy marl and interbedded calcarenite (unit tol'm+car, Toloczyki and others, 1991). In Haiti, available mapping places two formations, the La Crête (base) and Jeremie Formations within the same unit (MMER, 1989). We have separated the units and place the Jeremie Formation in our Oligocene carbonate unit, **Toc**. The base of the La Crête Formation consists of clay and sandstone in the Gros Morne Basin of central Haiti. It is possible that rocks equivalent to the La Crête Formation may also occur along strike in southern Dominican Republic. Additionally, coarse limestone and conglomerate is exposed along the south side of Canal de la Tortue in northern Haiti. In northcentral Puerto Rico, an informal sandy limestone member of the San Sebastian Formation is locally found at the transition between the clastic San Sebastian Formation (unit **Tosc**) and the overlying Lares Limestone (unit **Toc**). Locally, subdivided into subunits **Toc** and **Tosc**

Toc

Carbonate rocks including clay-rich limestone—Limestone and marl of this unit are widespread in the region and are present in Cuba, Hispaniola, Jamaica, and Puerto Rico. In Cuba, these rocks have been mapped largely on the east half of the island, including the Tinguaro, Tamarindo, and Jia Formations (IGP, 2011). The Tinguaro Formation is primarily marl, clay-rich limestone, and siltstone. It is the most widespread of the units and is exposed in northern Cuba in the vicinity of Havana and also southeast of Colón. The Tamarindo Formation of recrystallized and dolomitized limestone, calcarenite, marl, and claystone are exposed in central Cuba, between the communities of Jatibonico and Moron. The Jia Formation, exposed wrapping around the eastern exposure of the Tinguaro Formation is brecciated and clastic limestone, that rarely contains flint or chert fragments (IGP, 2011). Exposed along the southern peninsula of Haiti, the Jeremie Formation is chalk and limestone. Equivalent rocks may extend into Dominican Republic and if present, may be included in unit **Tols**, reef limestone and chert of Eocene to Oligocene age. A late Oligocene exposure of reef limestone is present in a small area near Santo Domingo, where it is interbedded with the mixed carbonate rocks and clastic rocks of unit **Tocc** (Toloczyki and others, 1991). This unit is most extensively exposed in Jamaica where it consists of the Walderston Formation of the White Limestone Group. According to Mitchell (2013a), the Walderston Formation usually is pink, locally gray or cream-colored grainstone and subsidiary packstone and generally has medium to thick bedding, though in many outcrops bedding is not apparent. It also contains rare thin white grainstone beds. Fossils are common in the Walderston Formation; however, Sr-isotope analysis suggests an early Oligocene age (Robinson, 1994, as cited in Mitchell, 2013a). In Puerto Rico, the Lares Limestone is widely exposed on the northern part of island. Its upper part is very hard, light-buff, or very pale orange to white, semicrystalline algal limestone containing corals, mollusks, and larger foraminifera. This overlies very calcareous clay interbedded with unconsolidated clayey flakey limestone containing abundant fossils; lower part of this clay unit is interbedded with hard crystalline limestone containing abundant coral heads. Below this

crystalline limestone is yellowish to white, thin-bedded to massive, crumbly limestone in which brown limonitic specks are common, and the lowermost 20 m is locally sandy and silty. Some lenses near the base contain significant proportions of silt and clay, and the unit has a maximum thickness of 310 m. The contact with underlying San Sebastian Formation is gradational (Berryhill, 1965; Nelson and Monroe, 1966; Nelson, 1967a, b; Nelson and Tobisch, 1968; Monroe, 1969b, 1971, 1980; McIntyre, 1971; Tobisch and Turner, 1971)

Tosc

Clastic rocks, including conglomerate—Ranges from claystone to conglomerate; most commonly associated with limestone units. In Dominican Republic, polymictic conglomerate and interbedded sandstone are found locally on either side of the Cordillera Central; those exposed on the north side of the Cordillera also contain limestone reef deposits and are as much as 2,400 m thick, whereas the deposits on the south side likely do not exceed 500 m thick (Toloczyki and others, 1991). The northern exposures are considered Oligocene in age; no age control exists for the southern unit though it overlies middle Eocene marl and sandstone (unit Tes) (Toloczyki and others, 1991). In Puerto Rico, the upper clastic beds of the Juana Diaz Formation, a channel-fill deposit, are likely Miocene, and are exposed in the Penuelas 1:20,000-scale quadrangle in southern Puerto Rico (Krushensky and Monroe, 1978). It consists of gray to light-brown, fine- to coarse-grained sandstone, conglomerate containing angular fragments of limestone, calcite, and sandstone in a matrix of medium-grained sand, and carbonaceous sandy clay exposed in a very limited area. The lower part of the Juana Diaz Formation is conglomeratic sandstone and very coarse gravel composed of well-rounded boulders, cobbles, and pebbles of volcanic and intrusive rocks, as well as serpentinite, locally, all in a poorly sorted, generally coarse-grained, very poorly cemented sand matrix. Fossils may be locally abundant in all but the uppermost part of the formation; generally, they include the sea urchin *Clypeaster oxybaphon*, and foraminifera *Lepidocyclina undosa*, and smaller less conspicuous foraminifera. Thickness ranges from about 130 m at the western edge of the quadrangle to about 400 m near Ponce (Colon, 2003; Colon and Llerandi Roman, 2004; Glover and Mattson, 1973; Krushensky and Monroe, 1975, 1978). It is overlain by interbedded, thin- to medium-bedded, light-bluish-gray calcareous mudstone and sandstone, which is, in turn, overlain by lenticular, thin- to thick-bedded and locally very thick bedded, white to pale-orange, argillaceous chalk and chalky limestone (unit Tmoc), which locally is massive biosparite limestone. Locally, upper limestone beds of the Juana Diaz are overlain by fine- to coarse-grained, crossbedded, carbonaceous, light-brown sand and gravel composed of angular clasts of limestone in a sand matrix, as well as a few beds of light-gray and pebbly limestone, all in channels cut into limestone. The San Sebastian Formation is exposed throughout the length of northern Puerto Rico. It is commonly pale-red sandy clay, but also includes mainly sand and gravel-rich beds. It is deeply weathered in most exposures. Thickness varies, but it can be as much as 300 m. The lower approximately 20 m is chiefly volcanic boulder- and cobble-gravel having a clay matrix; pebble gravel interstratified with sand and clay is more common toward the east. Tobisch and Turner (1971) describe the basal conglomerate as having clasts as large as 1 m and including cobbles of jasper and petrified wood. The San Sebastian Formation grades upwards and interbeds with the Lares Limestone, and lies unconformably on an irregular, eroded surface of early Tertiary volcanoclastic and igneous rock. Generally, the unit grades from coarse, highly weathered and oxidized material near the base to finer-grained, unoxidized material toward the top. Locally, silicified wood is present as is lignite (Monroe, 1963a, 1969a, b, 1973, 1980; Berryhill, 1965; Nelson and Monroe, 1966; Nelson, 1967b; Nelson and Tobisch, 1968; Pease, 1968c; McIntyre and others, 1970; McIntyre, 1971; Tobisch and Turner, 1971; Pease and Monroe, 1977). In northwestern Puerto Rico, Monroe (1969b) mapped a middle member of the Lares Limestone that is lithologically identical to the San Sebastian Formation and is included here. On Saint Croix in U.S. Virgin Islands, the Jealousy Formation is montmorillonite-bearing mudstone and a few thin conglomerate and limestone beds. In the subsurface, it is more than 400 m thick; the lowest approximately 90 m is gray clay in which a few streaks of limestone, not more than about 10 cm thick, are present; overlying this is less than 2 m of calcareous conglomerate that contains volcanic-rock clasts, 25 m more of gray clay, then 5 m more of calcareous conglomerate, finally overlain by about 300 m of greenish-gray clay (Cederstrom, 1950, as cited in Whetten, 1966). The Jealousy Formation is poorly stratified, consisting of pebbles, cobbles, and boulders of the Judith Fancy Formation (mapped as the volcanoclastic sandstone and mudstone subunit Kvss in this report), as well as minor diorite, thin oyster beds, corals, and other shallow-water fossil fragments, lenses of red and green clay as long as 6 m and about 2 m thick, all in a calcareous sandy matrix. Wherever the contact between the Jealousy Formation and the Judith Fancy Formation is well exposed in the unnamed mountains along the north side of the island, it is an unnamed fault that dips 60° to 75° southwest (Whetten, 1966)

Toct	Older clastic rocks (Tertiary, Oligocene to Eocene) —Dominantly coarse clastic conglomerate and polymictic sandstone; this unit also includes minor siltstone and, locally, marl and limestone. In Cuba, it consists of the Caunao and the Condado Formations of early Oligocene to late Eocene age (IGP, 2011) and apparently has more limestone than similar rocks in Dominican Republic. In Dominican Republic, this unit is found in two areas. In northern Dominican Republic (Cordillera Septentrional) it consists of middle Oligocene to early Eocene (with an early Oligocene gap) turbiditic sandstone, marl, loamy claystone, and subordinate sandy limestone and locally, thick interbeds of whitish to violet limestone and thinner conglomerate interbeds as well as zones of olistostrome deposits. In southern Dominican Republic, north of Bahia de Ocoa, the rocks are similar, though some limestone is characterized as thin bedded and pelagic (Toloczyki and others, 1991)
Tols	Reef limestone and chert, undifferentiated (Tertiary, Oligocene to Eocene) —Present in Cuba and Dominican Republic, this unit is also likely present in Haiti. In a small area of northern Cuba, the Manuelita Formation consists of bioclastic limestone and interbeds of biogenic clay-rich limestone, and calcareous clay-rich sandstone; breccia and dolomitized limestone are present at the base of the formation. East of these exposures, between Havana and Güines, the much more extensive exposures of the La Charca Member of the Nazareno Formation (see also units Tec and Tecr) are primarily marl and interbedded siltstone, as well as rare shale and clay-rich limestone. In central Cuba, near Cienfuegos, the Saladito Formation detrital and sandy limestone is associated with the Caunao Formation (Toct) clastic rocks. In Dominican Republic south of Lago Enriquillo, shallow-water, white, compact to porous limestone containing bauxite lenses and beds is as much as 700 m thick (Toloczyki and others, 1991). These beds are of late Oligocene to middle Eocene to age; however, early Oligocene rocks have not been confirmed (Toloczyki and others, 1991); these rocks may be partly equivalent to the White Limestone Group in Jamaica (unit Toc in part). Across the border in Haiti, this limestone adjoins an upper to middle Eocene unit that has thick, monotonous limestone sequences (Ennery Formation and Plaisance Limestone, unit Tec, MMER, 1989). Vila and others (1985) reported that the stratigraphy of this Haitian sedimentary unit is difficult to establish because of abundant carbonate rock facies that are similar with those of the Miocene to Oligocene carbonate rocks of the region. Rocks of Eocene sedimentary sequences form the major rock component of the mountains in Haiti; Eocene rocks consist of massive limestone or thin-bedded, white or yellow limestone, which has conchoidal fracturing and reef beds (MMER, 1989)
Tvs	Volcanic and sedimentary rocks, undifferentiated (Tertiary, Eocene) —Limited exposures of these rocks in eastern Dominican Republic were described as volcano-sedimentary rocks by Toloczyki and others (1991, unit teo'v-s). Two general areas of outcrop are found, one west of Cotuí and another northwest of Higüey in eastern Dominican Republic. These consist of tuff and graywacke, and they contain thin limestone lenses and are likely derived from the underlying Cretaceous andesite (mapped as the intermediate-composition volcanic rocks subunit Kevi in this report)
Tec	Limestone containing igneous-rock debris (Tertiary, Eocene) —Limestone found throughout Greater Antilles and Virgin Islands, having exposures in Cuba, Jamaica, Haiti, Dominican Republic, Puerto Rico, and British Virgin Islands. Widely distributed in Cuba; included formations are the Damuji, Loma Candela, Nuevitas, Perla, Puerto Boniato, Rodas, Venero, and Yeras Formations (IGP, 2011). Westernmost of these is the upper to middle Eocene Loma Candela Formation, exposed in a thin linear belt on the south side of the Sierra de Los Organos and consisting of calcareous claystone, clay-rich limestone, marl, and calcareous sandstone and conglomerate. East of Havana, the lower Eocene Perla Formation is similar, consisting of marl, claystone, calcarenite, clay-rich clastic and biogenic limestone, and conglomerate. Rocks of this unit surround highlands of older rock units suggesting the presence of former islands. North of Cienfuegos, limestone of the upper Eocene Damuji Formation consists of white or yellowish fossil-rich limestone, and the lower Eocene Rodas and Yeras Formations are limestone, marl, and chert or siliceous limestone, respectively. The upper Eocene Nuevitas Formation, exposed on the north coast of Cuba northwest of Nuevitas, is gray marl, clay-rich marl with fine-grained limey interbeds, and clayey biogenic limestone. Immediately northwest of the Nuevitas Formation, rocks of the Venero Formation crop out adjacent to the coast and are calcareous breccia, clastic limestone, and flint lenses. The Puerto Boniato Formation, of porcelaneous limestone, algal fragments, marl, and interbedded chert is exposed on the north side of the Sierra Maestra and to the north and south across the basin from Holguín. The areas of exposure appear to have different basements, the northern outcrops lying on older igneous and mafic rocks found to the north, and the southern area of exposure is associated with Eocene or Paleocene volcanic and plutonic rocks. Near southern exposures of the Puerto Boniato Formation, and on the south side of the Sierra Maestra is a small area of quartz-rich limestone for which no age was reported; this may be an equivalent unit.

Available mapping in Haiti does not subdivide the Ennery and Plaisance Formation, both carbonate rocks of Eocene age. At the border with Dominican Republic, both Haitian units adjoin carbonate rocks of Oligocene and Eocene age. As mentioned above, Vila and others (1985) reported that the stratigraphy of this Haitian sedimentary unit is difficult to establish because of abundant carbonate rock facies that are similar with Miocene to Oligocene rocks, as well as the monotony of these facies. However, as described, the Ennery Formation, pelagic biomicrite, is exposed on the southern peninsula and the southern slope of the Massif du Nord, and the platform limestone of the Plaisance Formation is exposed in the Massif du Nord. In Dominican Republic, middle to lower Eocene multicolored arenaceous limestone is exposed west of San Cristobal, in the vicinity of the lake at Presa Valdesia (Valdesia dam) (Toloczyki and others, 1991) and discordantly overlies magmatic rocks and Cretaceous arc-derived sedimentary rocks. A linear structure, the Great Southern Puerto Rico Fault Zone (GSPRFZ) extends across Puerto Rico from the northwest to southcentral coast and the middle Eocene Cuevas Limestone (Glover, 1961a, b; Glover and Mattson, 1973; Krushensky and Monroe, 1975), Rio Prieto Formation (Mattson, 1968a), and limestone of the Rio Descalabrado Formation (Glover and Mattson, 1973) are located along this structure; this structure marks a transition from largely Mesozoic units to the northeast to Tertiary units to the southwest. Each of these Puerto Rican limestone units is characterized by algal fragments and scattered coral in calcarenite and calcirudite. Each also contains clasts or sandy lenses derived from erosion of the igneous rocks to the northeast. In British Virgin Islands, the middle Eocene Mount Healthy Limestone of the Tortola Formation is a shallow-water-limestone lentil interbedded in breccia and tuff of the upper part of the Shark Bay Member (mapped as the pyroclastic rocks unit Tvc in this report) of the Tortola Formation. It is light-tan to brown limestone about 15 m thick and consists of algal material, pelecypod fragments, and foraminifera in fine-grained calcite matrix. “It has been mildly sheared and locally recrystallized and altered with the introduction of iron hydroxide staining. * * * In addition to the outcrops in the vicinity of Mount Healthy, the limestone crops out on Rogue’s Point; and is probably also present farther to the east near the contact with the batholith where a garnet, diopside, epidote, hematite skarn has developed” (Helsley, 1960). Locally, divided into subunits **Tecs** and **Tecd**

Tecs

Limestone and igneous-rock debris, shallow water facies, undifferentiated—In some cases we can distinguish shallow water facies rock units in Cuba, Dominican Republic and Jamaica; additional analysis may allow reassignment of some units from unit **Tec** to either subunits **Tecs**, the shallow water facies or **Tecd**, the deepwater facies. In western Cuba, from Matanzas and west, the lower Eocene Universidad Group consists of marl, siliceous shale, biogenic limestone, and basal conglomerate, locally containing chert nodules (IGP, 2011). It is commonly associated with the Loma Candela of unit **Tec**. Pardo (2009) reported that volcanic glass is a detrital component of this unit. The lower Eocene Caibarien Formation is exposed on the north coast of Cuba in the vicinity of Sagua La Grande (IGP, 2011). A Caibarien Formation was described by Puscharovsky and others (1988) as limestone, marl, and carbonate breccia. Pardo (2009) indicated that this unit is not the same as, although it is similar to, the Caibarien Formation as defined by Gulf Oil Company prior to 1959 and indicated that the Caibarien Formation of Puscharovsky and others (1988) is lithologically related to his (Pardo’s) middle to lower Eocene San Martin Formation. The Lesca Formation, as described by Puscharovsky and others (1988), is apparently equivalent to the Caibarien Formation of Pardo (2009); the Lesca Formation consists of about 100 m of conglomerate and cherty limestone. The Lesca Formation (IGP, 2011) as defined here is middle Eocene bioclastic limestone, calcirudite, clay-rich limestone siltstone, sandstone, and chert. The El Embarcadero Formation, which is exposed in the same area as the Lesca Formation, is a calcareous breccia containing clasts of limestone, dolostone, chert and conglomerate, and has interbeds of bioclastic limestone and polymictic breccia-conglomerate containing abundant clasts of igneous rocks (IGP, 2011). Pardo (2009) considered the [El] Embarcadero Formation to be essentially his San Martin Formation, which he defined as “tan, fine to coarse calcarenite containing abundant igneous-rock grains, interbedded with pebble conglomerate containing abundant chert fragments and with dull light-gray argillaceous limestone, which is typically shattered in splinters.” Where present, the Embarcadero Formation (that is, the San Martin Formation of Pardo, 2009) represents the first influx of igneous-rock detritus. The Charco Redondo Formation was described by Pardo (2009) as consisting of “50–200 m of compact, varicolored (white, beige, yellowish brown, pinkish yellow, and yellowish red), bioclastic limestones. Intraformational limestone breccias and thickly bedded white limestones characterize its lower part. In the upper part, the brownish colors predominate, the bedding is thinner, and the bioclastic texture is dominant; some horizons consist entirely of large-Foraminifera coquinas.”

In Dominican Republic, shallow water algal limestone and detrital reef limestone was formerly considered part of the Loma Caballero Formation (Toloczyki and others, 1991). Small areas of this limestone are exposed scattered through northern and eastern Dominican Republic. In Jamaica, rocks mapped by McFarlane and others (1984) as the Gibraltar-Bonny Gate Formation of the White Limestone Group are present in Mitchell's (2013a) Montpelier belt, and they correspond to Mitchell's Somerset Formation; Mitchell formally rejected the name "Gibraltar Limestone." The Somerset Formation is thin and "consists predominantly of pink to grey to cream foraminiferal grainstones and packstones, which locally contain a rich mollusk and coral fauna. Thin units of wackestones and carbonate mudstones may also be present * * * Bedding ranges from 30 cm up to 2 to 5 m" (Mitchell, 2013a). Mitchell (2013a) reported a late Eocene age that was based on Sr-isotope values from *Kuphus* tubes reported by Robinson (2004, as cited in Mitchell [2013a]). McFarlane and others (1984) mapped a composite unit, the Troy/Claremont-Somerset-Swanswick Formation. The Troy Formation reflects the earliest units of the shallow-water White Limestone Group and is generally of middle Eocene age. McFarlane and others (1984) inclusion of the Somerset Formation, of late Eocene age in this assemblage, is at variance with usage of Mitchell (2013a). Stratigraphically, listed from lowest to highest, these formations are the Troy, Swanswick, and Claremont Formations, which are unconformably overlain by the Somerset Formation, which, in turn, locally rests directly on the Troy Formation. The Troy Formation is pink or brown, locally white or gray, massive to medium-bedded limestone and dolostone; in general, dolostone and recrystallized limestone dominates; dolostone is either brown, sugar-textured dolomite or pink dolomicrite. Most of formation is crystalline calcium carbonate and was interpreted by Mitchell (2013a) as dedolomitized dolostone because thin sections show replaced dolomite textures; locally, original limestone depositional fabrics, consisting of micritic limestone, are preserved (Mitchell, 2013a). The Swanswick Formation is dominantly pale white, but, locally, it is pink or brown grainstone and subordinate packstone; bedding thickness ranges from tens of centimeters to meters, but bedding is not recognizable in many outcrops; in general, thinly bedded units are common on the platform margin, whereas thickly bedded to massive units dominate in the platform interior; bioclasts are well sorted, suggesting high-energy deposits (McFarlane and others, 1984; Mitchell, 2013a). The Claremont Formation is dominantly pale-pink to white calcareous mudstone and wackestone and a few thin packstone beds. Bedding thickness ranges from medium to very thick or massive; mudstone and wackestone layers are commonly very hard and brittle, whereas packstone layers are commonly softer. Dolomitization is limited for most of the formation but becomes more significant in the platform interior. Exposures of the Claremont Formation that have extensive dolomitization cannot be distinguished from exposures of the Troy Formation, other than by stratigraphic position. The presence of *Fabularia verseyi* suggests a probable late Eocene age (Robinson and Mitchell, 1999, as cited in Mitchell, 2013a)

Tecd

Limestone and igneous-rock debris, deepwater facies, undifferentiated—This subdivision of the Eocene carbonate unit is primarily distinguished in Cuba, though a small area in Haiti is clearly a deepwater facies as well as the limestone of the Rio Descalabrado Formation in Puerto Rico (Glover and Mattson, 1973). Exposed in western Cuba, just west of Havana, the Punta Brava Formation is microcrystalline limestone, chalk, clay-rich limestone breccia, sandstone, clay-rich calcarenite, and claystone (IGP, 2011). According to Pardo (2009), the Punta Brava Formation has an estimated maximum thickness of about 200 m of well-bedded, chalky limestone and fine-grained, argillaceous calcarenite showing graded bedding and contains igneous-rock grains. Some limestone breccia is present. Pardo (2009) stated that the Punta Brava Formation is, in part, equivalent with (and similar to) the Nazareno Group (termed the Nazareno Formation in this report, included in the mixed clastic and lesser carbonate rocks unit Tes), although it has less igneous-rock-derived material. The Punta Brava Formation was deposited in deepwater, and it unconformably overlies the Capdevila Formation (unit Tecd) (Pardo, 2009). Located in close proximity with the Punta Brava is the Jabaco Formation, which consists of marl and clay-rich limestone containing interbeds, lenses, and blocks of biogenic, clastic limestone and subordinate sandstone (IGP, 2011). The Florida Formation, exposed in central Cuba around the community of Florida, is carbonate breccia, calcirudite, limestone, and clay-rich marl, and siltstone of middle Eocene age. It is about 60 m thick and partially equivalent to the Vertientes Formation (Pardo, 2009) (unit Tecd). Two small areas of upper Eocene pelagic limestone are mapped in southern Haiti (MMER, 1989), both are associated with the limestone we show as unit Tec. Limestone of the Rio Descalabrado Formation (Glover and Mattson, 1973) occurs as thin-bedded, partially laminated equivalents of planktonic oozes, which are rare to common in the Rio Descalabrado Formation (Glover, 1971)

Mixed clastic and carbonate rocks, undifferentiated (Tertiary, Eocene)—Consists of various mixtures of conglomerate, sandstone, claystone, limestone, siltstone, and marl. This unit reflects erosion of older volcanic rocks both prior to and concurrently with development of the Eocene carbonate-rock units such as the limestone containing igneous-rock debris unit and its shallow and deepwater subunits (**Tec**, **Tecs**, and **Tecd**, respectively). In Cuba, many widely distributed, formal geologic formations are represented by this map unit. Exposed in central Cuba, the upper to middle Eocene Arroyo Blanco Formation is “100 and 150 m thick, is moderately well exposed, especially in the eastern part of Sancti Spiritus and north-east of Sierra de Jatibonico in Sancti Spiritus Province. It is composed of a terrigenous and clastic-carbonate series of polymictic sandstones, conglomerates, calcarenites, biocalcarenes, limestones and marls deposited on a surface of unconformity atop the Remedios Group, the Taguasco Olistostrome and the Vega and Zaza Formations” (Torres-Silva and others, 2019).

In the vicinity of Havana, the uppermost Eocene Consuelo Formation is finer grained than most of these units, consisting of interbedded white and beige marl and claystone. The middle Eocene Peñón Formation, consists of breccia, conglomerate, and limestone. It is spatially associated with ultramafic rocks and serpentinite of units **Mzum** and **Mzs**, respectively, near Cardenas in northcentral Cuba. The combined upper Eocene Jicotea Formation and lower Eocene Blanquizar, Ochoa, and Ranchuelo Formations centered north, east, and south of Santo Domingo in central Cuba, consist of mixtures of polymictic sandstone and conglomerate, marl, limestone and subordinate claystone and siltstone (IGP, 2011). Exposed in central Cuba between the Trinidad and Sancti Spiritus Domes, the lower Eocene Meyer Formation is a breccia containing metamorphic rock fragments and thick limestone containing shale fragments. Its upper part is flysch consisting of marl and argillaceous and detrital limestone grading to calcareous sandstone (IGP, 2011). The upper and middle Eocene Saramaguacán Formation and middle Eocene Maraguán Formation are found between Camagüey and Holguín in southern Cuba. The Saramaguacán Formation is bioclastic limestone, claystone, and marl whose upper part contains sandstone, siltstone, and claystone. Chert and radiolarian chert lenses are interbedded between the marl and limestone. The Maraguán Formation is about 100 m of interbedded conglomerate, sandstone, siltstone, and marl (Pardo, 2009) and is likely derived from erosion of Cretaceous granitic rocks (that are mapped as unit **Kgu** in this report) and the tectonites of unit **KJmm** that are composed of metamorphosed ultramafic rocks. In southeast Cuba, near the community of Banes, the upper to middle Eocene Banes Formation consists of calcilutite, limestone, chalk, pebble conglomerate, and sandstone (IGP, 2011). Widely exposed between San Germán and Guantánamo, the middle and upper Eocene Mucal Formation is marl that contains interbeds of clay-rich limestone, polymictic sandstone and conglomerate, siltstone, and tuff (IGP, 2011). The middle Eocene to lower Oligocene Nazareno Formation, originally defined as a group by Albear Franquiz and Iturralde-Vinent (1985) because it is lithologically variable and according to them possibly could be divided into discrete formations. According to Pardo (2009), the unit consists of possibly as much as 700 m of interbedded gray argillaceous marl, fine-grained argillaceous limestone, minor pink to reddish-brown laminated siltstone to fine-grained sandstone, and gray shale. The distribution of lithologic components is variable, but limestone and limestone-siltstone-shale sequences dominate. As described here, the upper and middle Eocene Loma El Añil Member (see also units **Tols** and **Tecr**), is stratified marl, argillaceous and clay-rich-detrital limestone, grayish-greenish siltstone and clay-rich calcite-cemented polymictic sandstone (IGP, 2011). The upper to middle Eocene San Luis Formation exposed north of the Sierra Maestra in southern Cuba, was described by Pardo (2009) as 700 m of a wide variety of clastic and carbonate rocks; thin- to medium- and well-bedded, gray, brownish-gray, and brown, fine- to medium-grained sandstone constitutes 90 percent of the formation, where most fragments are derived from volcanoclastic rocks of the El Cobre Group and Guamá Formation (unit **Tvep**). Also found in the unit are green to greenish-gray or brown, poorly sorted and polymictic conglomerate consisting mostly of volcanic-rock fragments and limestone and calcareous siltstone, which contains sparse carbonized plant fragments. White, laminated, marly limestone is found generally at the base of the formation but can be found higher stratigraphically in the formation as well. The lower and middle Eocene Zaza and lower Eocene Siguaney Formations are exposed north of Sancti Spiritus Dome. The Siguaney is calcareous breccia, bioclastic and argillaceous limestone, marl, calcareous polymictic sandstone and conglomerate, and claystone, whereas the Zaza is a turbidite sequence consisting of sandstone, siltstone, conglomerate, sandy limestone, marl, and clay (IGP, 2011). In Dominican Republic, small areas of sandstone and marl of middle Eocene age are exposed west of San Cristóbal along the west shore of the lake at Presa Valdesia and about 40 km to the north (Toloczyki and others, 1991). In Jamaica, the Chapelton Formation of the Yellow Limestone Group has been divided into

multiple members; the uppermost member is middle Eocene, impure, fossiliferous limestone, which overlies a middle and lower Eocene, gypsum-bearing clay member or sandstone and clay member. Limestone, arkosic sandstone, and conglomerate members are interbedded with the lower members (Donovan, 2002). The Font Hill Formation (or Font Hill Limestone) is a cream-colored, thinly bedded, marly limestone that contains interbedded clastic limestone. Coarse breccia, present in the upper part of section, is commonly graded, containing blocks of the Richmond Formation (mapped as the volcanic clast-bearing rocks unit **Tpcv** in this report) as large as 60 cm, as well as local exotic masses of the Richmond Formation, some more than 15 m across, and local exotic fragments of the Wagwater Formation (called the Wagwater Conglomerate by James, 2005); breccia represents olistostrome deposits. Locally subdivided into units **Tecr**, **Tech**, and **Tvcv**

Tecr

Mixed clastic and volcanic rocks, undifferentiated—In Cuba, Jamaica, and Puerto Rico. The lowermost Eocene Capdevila Formation, exposed in northernmost Cuba, is a well-bedded rhythmic sequence of sandstone, siltstone, clay, calcarenite, marl, limestone, graywacke, and conglomerate (IGP, 2011). According to Pardo (2009), it is 450–600 m thick (locally as much as 1,680 m thick) of polymictic graywacke sandstone interbedded with sandy calcarenite, shale, marl, and conglomerate. The lower part of formation consists of sandy and argillaceous rocks that have a few marl interbeds. Overlying these are polymictic sandstone, argillite, conglomerate, and minor pebbly mudstone as much as 500 m thick. Conglomerate is poorly sorted and is commonly strongly bimodal, having well-rounded boulders up to 3 m in diameter that mostly consist of volcanic rocks in a siltstone matrix, though some pebbles of leucocratic gneiss and limestone are also present. Rarely present are tuff, agglomerate, and pink to cream, bioclastic limestone that contains abundant algae, gastropods, pelecypods, corals, and foraminifera. The uppermost part of section is sandstone, siltstone, shale, and thin interbeds of marl; graded bedding and flow structures are common, reflecting flysch deposition. In more complete sections, marl becomes more abundant toward the top where the unit grades into the overlying Universidad Formation (mapped as subunit **Tecs** in this report) (Pardo, 2009). The upper Eocene Marroqui Formation of central Cuba west of Morón, is breccia-conglomerate, sandstone, calcarenite, limestone, and marl (IGP, 2011). The lower Eocene Vertientes Formation of the Camagüey region is medium- to fine-grained calcareous sandstone with clay-calcareous cement, medium- to thick-bedded volcanoclastic sandstone, marl, limestone and polymictic conglomerate (IGP, 2011). The upper Eocene Camarones Formation of southern Cuba is 500 m of green, greenish-gray, and brown, poorly sorted, poorly stratified, massive, polymictic conglomerate and associated coarse-grained sandstone. Rounded to subrounded conglomerate clasts in it are predominantly volcanic rocks, which are commonly silicified, 20 percent of which are felsic volcanic rocks. Subordinate limestone clasts are also present. Conglomerate is calcite cemented, and clasts range in size from about 10 to as much as 60 cm (Pardo, 2009). The Farallon Grande Formation of southwestern Cuba is 50 to 1,250 m of polymictic, conglomeratic breccia that has angular to subangular clasts 2 to 10 cm in diameter and interbeds of coarse-grained sandstone and well-sorted conglomerate. Sorting is poor at the base, improving upward in the section where rhythmic bedding is observed. Most clasts are derived from volcanic rocks of the El Cobre Group and Guamá Formation (unit **Tvep**) (Pardo, 2009). The San Ignacio Formation, which lies unconformably over metamorphic rocks (unit **Kmv**), is equivalent to the Farallon Grande Formation (Pardo, 2009). Pardo (2009) described the San Ignacio Formation of southeastern Cuba as 200 to 700 m of monomictic breccia that consists of fragments of greenschist and phyllite, and a serpentinite breccia is present in the upper part of formation. Blocks in the unit, are mostly angular and are commonly 2 to 40 cm in diameter, though some blocks are as much as 4 m in size. The matrix consists of sand and silt derived from rocks of greenschist facies. In the Sierra de Los Organos of northern Cuba, the lower Eocene to upper Paleocene Manacas Formation arkosic sandstone, shale, siltstone, calcarenite, micritic limestone, flint, and rare conglomerate and breccia is structurally interleaved with rocks of the Cretaceous to Jurassic Artemisa and Guasasa Formations, which are dominantly limestone, minor chert, and incidental shale (Pardo, 2009). The upper part of the Manacas Formation consists of chaotic polymictic deposits with sand to clay or silty matrix (IGP, 2011). Another member of the Nazareno Formation (see unit **Tes**), the middle Eocene El Cangre Member, is a flyschoid sequence of fine- to medium-grained polymictic clastic rocks (shale to sandstone) and minor marl and limestone. The Playa Molino Formation, which is exposed along the south coast of Cuba, consists of grayish-brown to greenish, fine-grained, finely laminated, carbonate-cemented sandstone, which may be locally metamorphosed (IGP, 2011). North of the Sierra Maestra and overlying rocks of the Sabaneta Formation (unit **Tvep**) are small areas of quartzite whose age is not reported; although lithologically distinct from the San Luis Formation (unit **Tes**). This quartzite may be Eocene and is therefore included here with this map unit. In southeasternmost Cuba, the upper

Eocene Sierra de Capiro Formation consists of siltstone and marl containing interbeds of conglomerate that contains clasts of reef limestone, serpentinite, and volcanic rocks (IGP, 2011). The Richmond Formation of the Wagwater Group of Jamaica is apparently lower Eocene (Mann and Burke, 1990) and at least 1,000 m thick. Mann and Burke (1990) described the lower Port Maria Member as about 250-m-thick, clast-supported conglomerate, thought to represent slump deposits in a submarine-fan complex. The middle Roadside Member is about 800 m of thin-bedded sandstone, siltstone, and mudstone, in graded beds and is extensively bioturbated. The Nutfield Volcanics, a subunit within the upper part of the Roadside Member, is correlated with the Newcastle Volcanic Formation (mapped as the intermediate and mafic flows and tuff unit Tv). The Albany Beds, also a subunit of the Roadside Member, consist of clast-supported conglomerate like the Port Maria Member and are also interpreted as submarine slump deposits, and they include sandstone and shale blocks that are typical of the Roadside Member. The uppermost Langley Member is about 200 m of soft, evenly bedded, alternating dark-gray and greenish-gray, organic-rich, laminated mudstone and siltstone (Mann and Burke, 1990). In Puerto Rico, the Guayo Formation of the Jacaguas Group (Glover and Mattson, 1973; Krushensky and Monroe, 1975) is exposed in southern Puerto Rico in the Rio Descalabrado and Ponce quadrangles. It consists of very coarse, poorly sorted, epiclastic volcanic conglomerate, sandstone, and mudstone having crude and thick (>4 m) bedding and is at least 500 m thick. Clasts in the coarse facies range from about 1 m on a side to less than 0.05 mm in diameter and are abundant rounded to angular clasts of volcanic porphyry, algal calcarenite, moderate-green and blue-green tuff and volcanic mudstone, and clasts of light-green tuff with flow- or fiamme-texture (Krushensky and Monroe, 1975). In the northwest part of Puerto Rico, the Rio Culebrinas Formation of the Jacaguas Group has a distinctive and persistent chert called the Guacio Member (unit Tech) at its base. However, the bulk of the formation is “very thick bedded tuff breccia, very thick to thick-bedded coarse crystal-lithic tuff, and thin-bedded volcanic sandstone and mudstone. * * *. The relative proportions of these three rock types vary greatly from place to place” (McIntyre and others, 1970)

Tech

Guacio Member of the Rio Culebrinas Formation—Chert of the Rio Culebrinas Formation is the basal Guacio Member of the formation and is exposed in northwest Puerto Rico. McIntyre (1971) defined the member and described it as primarily, siliceous and lesser calcareous, mudstone or chert. The rock is thin-bedded to laminated and has variable proportions of organic detritus, chiefly recrystallized planktonic foraminifera and Radiolaria(?), and silt-size volcanic debris. Fresh rock ranges from dark greenish gray to light gray, and weathers to a light-brown or brownish-gray, brittle, blocky chert-like material interbedded with reddish-brown, reddish-orange, or white clay (McIntyre, 1971; Tobisch and Turner, 1971). J.M. Aaron (U.S. Geological Survey, unpublished data, 1968) described the Guacio Member as thin-bedded volcanic sandstone and siltstone; thick-bedded sparse crystal-lithic tuff; massive tuff breccia with pebbles, cobbles, and boulders of porphyritic hornblende andesite; thin-bedded chert and siliceous and calcareous mudstone in the Rincon quadrangle; however, this description is more appropriate for the Rio Culebrinas Formation as a whole

Tvcv

Mixed carbonate and clastic rocks and tuff, undifferentiated—In Cuba, two units are included in this unit, the Alto de Villalón Member of the Chorrerón Formation, and the Barrancas Formation. The Alto de Villalón Member in southeastern Cuba on the north side of the Sierra Maestra, consists of tuffaceous calcareous sandstone, limestone, tuff, tuffite, bauxite, rhyodacitic welded tuff, and basaltic-andesite sills (IGP, 2011). To the west, but still on the north side of the Sierra Maestra, the Barrancas Formation is 60 to 100 m of crystal-vitric and vitric, rhyolite-rhyodacite tuff. Lesser white marl, cream-colored, well-sorted, tuffaceous, and calcareous sandstone, white bioclastic limestone, and calcilutite also are present (Pardo, 2009; IGP, 2011)

Tesv

Volcaniclastic and clastic rocks, undifferentiated (Tertiary, Eocene)—Restricted to Puerto Rico except for two areally restricted units in Cuba, these Eocene rocks are transitional between the clastic and volcanic rocks of unit Tecr and tuff and breccia of unit Tvc. In central Cuba, the Jucillo Formation, associated with the Escambray Massif (Complex) of Lewis and Draper (1990) is volcanic-clast pebble-conglomerate that ranges in thickness from 0 to 900 m (Pardo, 2009); mapping by IGP (2011) considered it lower Eocene; however, although it is barren of organisms, Pardo (2009) considered it Maastrichtian because of its stratigraphic position and because reef limestone in its upper part grades into the Maastrichtian Isabel Formation (mapped as the limestone and limestone conglomerate subunit Klc in this report). However, it is most closely associated with the Eocene Zaza Formation mapped in this report within unit Tes. In southern Cuba in the Sierra Maestra, the Chorrerón Formation consists of siltstone having interbedded sandstone, andesitic lava, limestone, and conglomerate, its El Escandel Member of welded tuff is included here in pyroclastic rocks of unit Tvc. In northwest Puerto Rico and stratigraphically lower than the Guayo Formation (unit Tecr), the Raspaldo Formation, also of the

Jacaguas Group is thin- to medium-bedded, dacitic and andesitic tuff and mudstone commonly having graded bedding and some small-scale crossbedding, 600 m or more, thick. It contains a plankton-rich fauna and rudistids reworked from older formations are rare to common (Glover and Mattson, 1973). As originally defined by Glover and Mattson (1967), the unit was thought to be lower Eocene to lower Paleocene but was revised to middle Eocene by Glover and Mattson (1973). In the Ponce quadrangle, as well as the adjacent Jayuya, Adjuntas, and Penuelas quadrangles, the Monserrate Formation (Mattson, 1968a, b; Krushensky and Monroe, 1975, 1978) is estimated to be at least 2,000 m thick and consists of tuffaceous siltstone and sandstone irregularly interbedded with tuff, intraformational conglomerate, calcarenite, and chert. The siltstone is rich in foraminifers. Conglomerate beds consist chiefly of tabular, rounded pebbles of the thinly laminated siltstone and thin-bedded fine-grained sandstone. Coarser sandstone beds consist of angular clasts of plagioclase, hornblende, and minor quartz in a clay-rich matrix. Dense (almost glassy), massive and thick-bedded (2–4 m) tuff beds resemble welded to partly welded ash-flow tuff. The tuffaceous siltstone may possibly be tuff in which all evidence of pyroclastic origin have been destroyed by devitrification. Calcarenite is in lens-like beds and is composed of angular to rounded clasts of calcareous algae, large foraminifers, some coral clasts, and minor volcanic debris in a fine- to coarse-crystalline matrix. Thickness of the formation is estimated at more than 2,000 m (Krushensky and Monroe, 1975). Locally, the Monserrate Formation is weathered to saprolite. Exposed to the northwest of the Monserrate Formation, the tuffaceous mudstone and sandstone of the Anón Formation is chiefly medium-bedded, calcareous tuffaceous mudstone and volcanic sandstone and subordinate feldspathic tuff (Mattson, 1968a, b). Breccia, tuff, and flow members of the Anón Formation are included in the andesite and basalt flows and tuff subunits Tfv and Tvc. The Milagros and Matilde Formations, from the San Sebastian quadrangle of northwest Puerto Rico, are fine-grained bedded tuff and grayish-brown fine-to medium-grained volcanic sandstone and siltstone and subordinate andesite (Tobisch and Turner, 1971). As mapped in the Bayaney quadrangle (Nelson and Tobisch, 1968), these formations contain a higher proportion of volcanic rocks and are included here in unit Tvc. Both were originally mapped as upper Paleocene and Eocene(?) (Nelson and Tobisch, 1968), they were subsequently determined to be middle Eocene (McIntyre and others, 1970, Tobisch and Turner, 1971).

Tepc

Clastic rocks, limestone, and breccia, undifferentiated (Tertiary, lower Eocene to Paleocene)—Unit contains the products of erosion of the Cretaceous volcanic arc and consists of sandstone, conglomerate, claystone, marl, limestone, and locally, calcareous breccia. It commonly includes (or consists entirely of) olistostrome deposits; and is primarily exposed in Cuba, particularly northern Cuba. The Ancón Formation consisting of limestone, schistose limestone, argillite, marl, and calcareous breccia with fragments of limestone and flint, and the Mariel Group composed of flysch-like sequences of polymictic sandstone, siltstone, shale, claystone, polymictic conglomerate, biogenic limestone, marl, calcilutite, calcareous gravels and calcarenite are present in northern Cuba. However, the most areally extensive of these units in northern Cuba, the Manacas Formation, consists of arkosic sandstone and calcarenite, siltstone, shale, micritic limestone, flint, and rare conglomerate and breccia. Its upper part consists of chaotic polymictic deposits in a sandy-clayey and silty matrix (IGP, 2011). Pardo (2009) described the Manacas Formation as tens of meters to as much as 500 m of shale, sandstone, and limestone in its lower part and chaotic mega-conglomerate and breccia (olistostrome) in the upper part. The Mercedes Formation, exposed southeast of Havana is biogenic and clastic biogenic limestone, marl, and minor calcareous and polymictic sandstone, claystone, and conglomerate. South of Cardenas, a single exposure of the Hatillo Formation consists of clastic and bioclastic limestone and fine- to medium-grained calcareous sandstone having interbeds of marl, calcilutite, siltstone, calcarenite and limestone breccia. The El Recreo Formation found north of Holguín in southern Cuba, consists of clay-rich limestone, calcareous marl, and marl containing nodules and chert lenses. It also contains thin beds of siltstone and sandstone, which have cracks filled with bitumen, which is unusual (IGP, 2011). In central Cuba, breccia and limestone of the Grande Formation is exposed in a thin, linear belt along the contact between mélange of unit Tmo and Cretaceous limestone of unit Kcr (IGP, 2011). In eastern Dominican Republic, Paleocene limestone is found locally in fault-bounded slivers or as isolated exposures surrounded by Cretaceous andesitic volcanic rocks of unit Kevi. Small exposures of Eocene or Paleocene limestone are also found in southern Dominican Republic on the west side of the Cordillera Central (Toloczyki and others, 1991). Widely exposed rocks of this map unit in Haiti include conglomerate and volcanogenic sandstone of the Massif de la Selle (Marigot Formation) in southern Haiti; and marl, sandstone, and marly limestone of the Montagnes Noires (Abuillot Formation) in more northern Haiti (MMER, 1989). In Jamaica, the Halberstadt Limestone is light-gray reef limestone, in bodies as much as 100 m thick (Mann and Burke, 1990); the Halberstadt Limestone (Good Hope Limestone) and the equivalent Chepstow Formation and Woodford Limestone, the latter of which is hard, splintery, gray to black,

impure limestone, are members of the Wagwater Formation², which is thought to represent a transverse intra-arc rift zone (Mann and Burke, 1990; Hastie, 2007). In northcentral Puerto Rico, the Corozal Limestone consists of lenticular beds of light-gray limestone and grayish-red limestone breccia, about 150 m thick (Nelson, 1967a). In the vicinity of San Juan in northeastern Puerto Rico, at the base of the Guaracanal Formation, medium- to very thick-bedded limestone lenses as much as 75 m thick contain abundant algal fragments, orbitoid foraminifera, and less abundant volcanoclastic debris (Seiders, 1971b). Also present is about 50 m of thin- to medium-bedded calcareous and volcanic mudstone in the Guaracanal Formation. Another limestone lens is present in the Ortiz Formation, which overlies the Guaracanal Formation (Seiders, 1971b). In the same general area, tuffaceous limestone of the Rio Piedras Siltstone can be as much as 120 m thick (Pease, 1968b). West of these limestone lenses, other fragmental limestone lenses that are massive and only faintly stratified occur in the Yunes Formation in the Florida and Utuado quadrangles (Nelson and Monroe, 1966; Nelson, 1967b).

Tpcv

Clastic and volcanic clast-bearing rocks, undifferentiated (Tertiary, lower Eocene to Paleocene)—Mixed clastic and volcanic rocks exposed in Cuba, Jamaica, and Puerto Rico. In northern Cuba, these include the Madruga Formation, graywacke sandstone, calcareous shale and siltstone, marl, clay and polymictic conglomerate; according to Pardo (2009) conglomerate clasts are as much as 2 m in size and consist of Cretaceous sedimentary and volcanic rocks. Pardo (2009) described it as a deepwater flysch deposit. East of it, is the Apolo Formation, a rhythmic sequence of clay, siltstone, sandstone, and polymictic conglomerate, calcarenite, limestone, and marl, which Pardo (2009) also described as a deepwater flysch deposit. At the western end of the Sierra Maestra in southern Cuba, the Ojo del Toro Formation is described as sandstone and conglomerate (IGP, 2011). The Pílon Formation, exposed in same general area, was described by Pardo (2009) as more than 2,000 m of a lower banded calcareous tuff overlain by graywacke and medium-grained sandstone or conglomerate composed of volcanic-rock fragments, in turn overlain by massive limestone containing volcanic-rock fragments in its upper part; Pardo (2009) stated that it is reported to contain abundant Turonian-Cenomanian reworked clasts. The Vigía Formation, exposed near Holguín in southeastern Cuba, is described by Pardo (2009) as being as much as 700 m of mostly igneous-rock-derived clastic rocks, detrital limestone, and tuff. Lower part of this formation has interbedded beds of green to grayish-green mafic tuff, limestone, and well-bedded, fine- to coarse-grained graywacke and mudstone; the upper part is white to grayish-white, thin-bedded, well-bedded, calcareous, commonly silicified or zeolitized tuff and radiolarian-bearing marl and bentonite, as well as white to grayish-white, porphyritic rhyodacite and greenish-gray, dense rhyodacitic tuff (Pardo, 2009). The unit contains a rich foraminiferal fauna that suggests a middle Eocene to upper Paleocene age. In Jamaica, the Wagwater Formation has been divided into several members (Mann and Burke, 1990). Lowermost, the Ginger River Member, is very poorly sorted, purple, polymictic clast-supported conglomerate that contains metamorphic- and volcanic-rock clasts ranging in size from pebbles to boulders as much as 3 m in diameter, all in a muddy-sand matrix and in beds as much as 10 m thick (Mann and Burke, 1990). Locally, conglomeratic limestone beds are present. Also present are the Halberstadt (Good Hope) and Woodford Limestone (described in unit Tpec). Another major member is the Pencar River Member, 300 m of brownish-dark-gray to green, coarse sandstone and conglomerate, which has ripple marks present on some bedding surfaces (Mann and Burke, 1990). The uppermost Dry River Member, of the Wagwater Formation, consists mainly of poorly sorted, purple, polymictic conglomerate; lithologically similar to conglomerate of the Ginger River Member, being clast supported and having a poorly sorted, muddy-sand matrix. In contrast to the Ginger River Member, however, Dry River Member clasts include granodiorite, which is not present in the Ginger River Member. “Bedding is rarely seen except where lenses of coarse sandstone weakly define bedding” (Mann and Burke, 1990). The Garlands/Summerfield Formations (McFarlane and others, 1984) or the Summerfield Group of Hastie (2007) is exposed in fault blocks in the White Limestone Group (mapped in this report as the limestone and igneous-rock debris, shallow water facies subunit Tecs). As described by Hastie (2007), the Summerfield Group is a shallowing-upward succession of marine to terrestrial volcanoclastic sedimentary rocks that has been interpreted as a prograding braided delta (Mitchell, 2000, as cited in Hastie, 2007). Mitchell and Blissett (2001, as cited in Hastie, 2007) recognized four formations in ascending order: the Green River Formation, evenly and thinly bedded volcanoclastic sandstone; the Peckham Formation, massive sandstone; the Mahoe River Formation, volcanoclastic sandstone and conglomerate; and the Waterworks Formation, thick ash-flow tuff or ignimbrite. Hastie (2007) also reported a second, thick, ignimbrite

²Some sources, such as McFarlane and others (1984), called this formation the Wagwater Group; however, Mitchell and others (2016) reported the abandonment of the Wagwater Group name and formal acceptance of the Wagwater Formation name. Additionally, the Halberstadt Limestone was abandoned as a formation name; the Good Hope Limestone was suggested as an alternative (Mitchell and others, 2016).

within the Mahoe River Formation that he called the Bronte Tuff Member; McFarlane and others (1984) mapped the Garlands/Summerfield unit as being Maastrichtian, whereas Hastie indicated it is Paleocene. In Puerto Rico, the Palmarejo Formation in the northcentral part of the island consists of volcanic sandstone interbedded with siltstone as much as 370 m thick (Nelson, 1967a). The Rio Piedras Siltstone in the northeastern part of the island consists of well-stratified, thin-bedded, partly laminated, mostly fine-grained tuffaceous siltstone and sandstone (Monroe, 1973, 1977; Pease and Monroe, 1977) as much as 800 m thick. The unit was divided into a coarse-grained volcanic wacke member and a siltstone member by Pease (1968b, c). The volcanic wacke is very thick-bedded olive-gray volcanic pebble conglomerate and coarse-grained wacke interbedded with thick-bedded coarse-grained volcanic sandstone and siltstone, whereas the siltstone member is thin-bedded laminated siltstone containing thin layers of claystone and commonly contains fragments of glass altered to celadonite(?) (Pease, 1968b, c). The Carreras Siltstone in northcentral Puerto Rico, is medium-dark-gray to olive-black siltstone that contains thin- to medium-bedded, light-colored bands or laminae of mixed reworked ash and epiclastic particles. Unit is dense and highly calcareous, such that some beds might be considered impure limestone. The Carreras locally grades downward into an arkosic conglomerate consisting of granodiorite clasts and has a maximum estimated thickness of 600 m (Berryhill, 1965; Nelson, 1967a). East of the Carreras exposures, the Ortiz Formation “consists of calcareous, thick-bedded coarse sandstone with interbeds of dusky-red shale at the base, overlain by thin conglomerate and varicolored volcanic sandstone and siltstone and pale-green tuff” (Nelson, 1966, 1967b). It conformably overlies the Corozal Limestone (mapped as the brecciated carbonate and clastic rocks unit **Tepc** in this report); because its upper part is not exposed due to faulting, the maximum thickness is estimated at 600 m. The Jicara Formation of southwest Puerto Rico is very fine-grained, siliceous, volcanic siltstone and mudstone and basal lithic sandstone that can be locally calcareous. Chiefly, it has a cherty matrix containing scattered minute grains and veinlets of calcite and anhedral clasts of feldspar. Bedding ranges from 5–30 cm thick and is well displayed by a strong bedding plane parting. The rock is extremely well indurated and fractures conchoidally in directions other than along parting. Thickness is approximately 220 m (Volckmann, 1984c). Sandstone beds range from well- to poorly sorted and are composed of subangular volcanic rock fragments. The rocks in the Jicara Formation are turbidites that show partial Bouma sequences (M.M. Colon and P.A. Llerandi Roman, University of Puerto Rico-Mayagüez, written communication, 2004)

TKfs **Flysch (lower Tertiary to Upper Cretaceous)**—Exposed in northwestern Cuba, flysch-like rocks of the Cacarájicara and Peñalver Formations consist of calcareous and clastic megaturbidites that fine upward from calcirudite to calcarenite and calcilutite (IGP, 2011); clasts are largely calcareous but contain minor igneous-rock debris. Age of this unit is lowermost Tertiary to uppermost Cretaceous

TKvc **Mixed volcanic and clastic rocks, undifferentiated (lower Tertiary? to Cretaceous, Campanian or older?)**—Exposed in southern Cuba and Puerto Rico. In Cuba, the Micara Formation consists of undivided clastic sedimentary rocks that include siltstone, breccia, sandstone, clay, conglomerate, subordinate felsic bentonite tuff, tuffite, and limestone (IGP, 2011); according to Pardo (2009), the formation is dark-gray, greenish-gray, and dark-green, fine- to medium-bedded sandstone and siltstone and interbeds of conglomerate and dolomitized limestone; graded bedding and crossbedding are common. The sandstone, which is fine to coarse grained, consists of subrounded rock fragments, plagioclase, quartz, chalcedony, calcite, and ultramafic rock fragments, in a calcareous matrix. The siltstone, which is gray, is made up of rock fragments, plagioclase, quartz, and calcite, in a fine-grained matrix. Contact between sandstone and siltstone is commonly sharp, erosional, and wavy. Conglomerate clasts, which are rounded to subangular and as much as 20 cm in diameter, consist of volcanic rocks, gabbro, diorite porphyry, limestone, and, locally, serpentinite, in a sandy matrix. A rich nannoplankton assemblage suggests a Campanian to Maastrichtian age. The Micara Formation, which appears to have been deposited as flysch in open water as a result of erosion of an advancing thrust front (Pardo, 2009), is found under the major ultramafic thrust sheet that covers a large part of southeastern Oriente region (Pardo, 2009). In northcentral Puerto Rico, the Cibuco Formation, as much as 2,000 m thick, consists of massive conglomerate and breccia containing pebbles of lava, tuff, and quartz diorite. It grades upward into conglomerate interbedded with volcanic-clast sandstone, siltstone, and tuff (Nelson, 1967b). The Miramar Formation in Puerto Rico, the stratigraphically lowest member of the Jacaguas Group, is coarse, red volcanic-wacke conglomerate containing abundant reworked dacite tuff. It locally contains lenses and beds of limestone, some described as oyster-rich limestone at the top (Glover and Mattson, 1973) or reddish algal limestone at the base (Mattson, 1968b). It is greater than 600 m thick. According to Glover and Mattson (1967), the Miramar Formation may be a transgressive unit that ranges in age from Eocene in the Jayuya quadrangle to the northwest (Mattson, 1968b) to Maastrichtian in the Rio Descalabrado quadrangle in the southeast (Glover and Mattson, 1973). Included in this report is a combined unit of

Krushensky and Curet (1984) in the Monte Guilarte quadrangle. Their unit “TKaym” (the interbedded Anón, Yauco, and Maricao Formations) is described as “Pale-greenish and pale-gray weathering hornblende-bearing tuff, tuffaceous sandstone, and breccia composed generally of hornblende dacite, all characteristic of the Anón Formation (unit TvC), irregularly interbedded with pale-yellowish-gray-brown weathering lithic sandstone, siltstone, and claystone of the Yauco Formation (unit Ku), and subordinate generally dark-green breccia composed of angular clasts of augite trachybasalt in which the augite phenocrysts are abundant, conspicuously large (1–2.5 cm), and characteristic of the Maricao Formation (unit TKmv). The breccias are commonly massive, unsorted, and non-graded. Sparse interbeds of tuff and tuffaceous sandstone and siltstone, chiefly of the Anón, are thin to very thick bedded (3 cm to 4 m)” (Krushensky and Curet, 1984).

In the Florida quadrangle, Nelson and Monroe (1966) mapped a unit “TKu,” defined as small inliers within the Lares Limestone consisting of undivided Yunes (Tvep) and Pozas Formations (Kip or Kcls)

TKI

Limestone, marl, and tuff, undifferentiated (Tertiary, Paleocene and Cretaceous, Maastrichtian)—

Several dominantly limestone units of Late Cretaceous to Paleocene age are present in small outcrop areas throughout Cuba (IGP, 2011). Four of the five units are found in the vicinity of Trinidad Dome in central Cuba. Among these are the Cocos Formation, which consists of marl, micritic and detrital limestone, fine-grained polymictic sandstone, and bentonitic clay; the Fomento Formation, of marl, siltstone, and fine-grained, clay-rich limestone interbedded with clay-rich and zeolitized tuff; the Santa Clara Formation, of limestone, marl, calcareous conglomeratic breccia, and tuff; and the Vaquería Formation, of marl interbedded with thin layers of clay and tuff, micritic and fragmental limestone, and locally silicified, sandstone and breccia-conglomerate. In the Santa Clara Formation and also in the Vaquería Formation, the Tertiary-Cretaceous boundary has been identified, and impact-generated material has been found (Pardo, 2009). The Gran Tierra Formation, exposed to the south near Moa and La Jaiba, consists of carbonate-cemented volcanic-clast conglomerate that grades into fragmental limestone and interbeds of calcareous volcanoclastic and tuffaceous sandstone, siltstone, tuffite, marl, and tuff (IGP, 2011). In Haiti, as mapped, this unit is somewhat variable. In the Massif de la Selle at the eastern end of the southern peninsula, the Beloc Formation consists of marl and marly limestone, whereas at the western end of the peninsula, the Riviere Glace Formation is volcanoclastic rocks and clay. In between these two extremes, the remainder of the unit on the southern peninsula is described as pelagic limestone (MMER, 1989)

TKsl

Sedimentary rocks of Central Aguirre (Tertiary, Paleocene? or Upper Cretaceous)—Exposed in southern Puerto Rico at Central Aguirre are sedimentary rocks of unknown but, presumed Late Cretaceous or early Tertiary age. The rocks were mapped as two units by Berryhill (1960) and consist of a unit of interbedded light olive-gray sandstone, light olive-gray to yellowish-gray siltstone, light olive-gray to light brownish-gray limestone and a second, less extensive unit of thin layers of shale, and medium-dark-gray and white chert which is cut by many calcite veinlets (Berryhill, 1960)

Klsv

Sedimentary and volcanic rocks, undifferentiated (Upper Cretaceous, Maastrichtian and Santonian)—Present in Cuba, Dominican Republic, Puerto Rico, and possibly Jamaica, this unit includes a wide variety of volcanic and sedimentary rocks that are commonly interbedded. In northcentral Cuba, to the northwest of Trinidad Dome, the La Rosita Formation consists of tuff, andesitic lava, volcanic breccia and subordinate sandstone and conglomerate (IGP, 2011). Exposed to the east of the La Rosita but still associated with Trinidad Dome, the Cotorro Formation is volcanic-derived sandstone and conglomerate, calcarenite, tuffaceous sandstone, and crystal vitric tuff, (Pardo, 2009); bioclastic limestone and marl are also reported (IGP, 2011). Continuing east and closely associated with the Cotorro, the Hilario Formation consists of zeolitized tuff, subordinate sandstone, shale, tuffite, and scarce tuffaceous limestone beds. Along the south coast of Cuba, exposed in limited areas, the Manacal Formation is sandstone, polymictic and tuffaceous siltstone, shale, limestone, basaltic-andesite tuff, and conglomerate (IGP, 2011). These units are Campanian and Maastrichtian. Spatially associated with the Manacal Formation is quartzite shown by IGP (2011); no further description or age is provided, and the single polygon is included on map sheet 2. In the Camagüey region of Cuba, the Campanian to Santonian Piragua Formation consists of about 500 m of breccia, tuffaceous conglomerate, shale, tuffaceous sandstone, tuffite, and tuff (IGP, 2011). The lower part of the formation has been divided into two members (not shown) representing different facies of the formation. The Loma Yucatan Member consists of a basal conglomerate overlain by thick, massive, dark-gray limestone interbedded with tuff and is considered Santonian. The San Francisco Member consists of cream to pink calcareous tuff and has no basal conglomerate; it is thought to be a deepwater equivalent of the Loma Yucatan Member (Pardo, 2009). In Dominican Republic, Toloczyki and others (1991) reported a poorly defined unit of “Late Cretaceous volcano-sedimentary rocks”

in the eastern part of country. We also include in this report a co-located unit defined by Toloczyki and others (1991) simply as “flysch.” McFarlane and others (1984) show a unit in western Jamaica, they labelled “Ku” that they infer is the Garlands Formation. They describe it as undifferentiated red sandstone and conglomerate; (Hazel and Kamiya, 1993) described the Garlands Formation as volcanic shale, conglomerate, and tuff that is Maastrichtian age. In the Central Inlier of Jamaica, the Summerfield Formation was raised to Group status and four units are defined, being from the bottom, the Green River, Peckham, Mahoe River and Waterworks Formations (Mitchell and Blissett, 2001). They range from thinly bedded coarse-, medium-, and fine-grained sandstone and interbedded mudrock (Green River Formation) to thick, predominantly massive coarse- and medium-grained sandstone, also interbedded with mudstone (Peckham Formation) to interbedded matrix and clast supported volcanic clast conglomerate and alternating massive sandstone beds, where mudstones are largely absent (Mahoe River Formation), finally succeeded by the Waterworks Formation consisting of pumiceous hornblende-bearing ignimbrite (Mitchell and Blissett, 2001). In Puerto Rico, several formal stratigraphic units are included in this map unit; common among them are andesitic to basaltic, volcanoclastic sandstone, siltstone, and breccia, as well as flows that may be pillowed; less common are conglomerate, tuff, calcarenite, limestone, and limestone conglomerate. In southwestern Puerto Rico, this unit includes the Sabana Grande Formation (note that the Sabana Grande Formation of Cuba [unit Koba] is similar in age but is more dominantly volcanic). In Puerto Rico, the Sabana Grande Formation consists of light- to dark-gray to light-reddish-brown, polymictic, massive, volcanoclastic breccia and subordinate conglomerate, sandstone, siltstone, claystone, and limestone (Curet, 1986). In northeastern Puerto Rico, the Guaynabo Formation is found to the west, south of San Juan. It is rhythmically interbedded thin-bedded volcanic wacke and tuffaceous siltstone, which are interstratified with volcanic conglomerate of well-rounded cobbles of lava, limestone, and quartz in a matrix that contains red and green finely scoriaceous pumice fragments. Unit has an estimated maximum thickness of 1,200 to 1,600 m (Pease, 1968b; Pease and Monroe, 1977)

Kcr

Limestone and chert, undifferentiated (Cretaceous)—Dominantly consists of limestone; includes carbonate units of broadly defined Cretaceous age. In southern Cuba, includes the Gibara Formation of Aptian to Maastrichtian age consisting of generally highly folded and fractured, biomicritic and bioclastic limestone, dolomitized limestone, and dolostone; locally, karst is well developed on this formation (IGP, 2011). Pardo (2009) described the formation as being 700 to 800 m of limestone where the lower Albian to Aptian part of formation is brownish-white, compact, medium-bedded, crystalline limestone and interbedded yellowish-white, sometimes laminated, hard, microcrystalline limestone. A slight angular discordance separates the upper (possibly Maastrichtian to Turonian) part of formation, which consists of massive, crystalline, medium- to coarse-grained, yellowish-gray limestone, that contains abundant rudist remains. This upper section transitions upward to yellowish-white, dense, microcrystalline pelagic limestone; beds of dolostone and dolomitic limestone are present (Pardo, 2009). Most widespread of Cretaceous limestone units included in this map unit, the Remedios Group (IGP, 2011), assigned an Maastrichtian to Aptian age, was mapped as the Remedios Formation by Puscharovsky and others (1988); however, Pardo (2009) indicated that, as mapped, that group or formation includes all Cretaceous and Jurassic carbonate rocks, in what Puscharovsky and others (1988) called the “Remedios structural zone” of central Cuba. As traditionally defined, the Remedios Formation is of Maastrichtian age and consists of about 470 m of dolostone overlying about 260 m of porcelaneous limestone. As defined by Puscharovsky and others (1988), the formation ranges in age to Albian, although it also includes rocks mapped as the Vinas Group that range from Upper Jurassic to Cenomanian (Pardo, 2009). In a small area in central Cuba is the Guanay Formation (IGP, 2011), defined as yellow sandy to clay-rich biomicrite in beds between 0.5 and 2 m thick as well as containing calcareous marl and chert; karst is intensely developed, and the unit has manganese dendrites on its surfaces. Within central Cuba, IGP (2011) mapped many lenses and bodies of limestone, uniformly associated with Cretaceous sedimentary units; although no age or stratigraphic position was assigned to these rocks, they are included here. In central Dominican Republic, very small exposures of Cretaceous limestone were mapped by Toloczyki and others (1991). Limestone described as being upper Lower Cretaceous is exposed in eastern Dominican Republic. Locally, divided into subunits Klc, Kelc, and Kec

Klc

Limestone and limestone conglomerate, undifferentiated (Upper Cretaceous, Maastrichtian and Campanian)—Many Upper Cretaceous carbonate units are common and well exposed in the Greater Antilles, including central Cuba, Haiti, eastern Dominican Republic, Jamaica, and Puerto Rico and on Saint Croix in the U.S. Virgin Islands. In Cuba, there are multiple units; northernmost is the Amaro Formation consisting of conglomeratic breccia containing poorly sorted fragments of calcareous sandstone, detrital limestone, chert, and claystone (IGP, 2011) and assigned a Cretaceous to Tertiary

“limit” age. Pardo (2009) described it as about 60 m of thickly bedded “gray, medium heterogeneous limestone with bright-green igneous grains and small, green clay pellets interbedded with light-gray to white or pink, very dense, porcelaneous, pure limestone with a characteristic network of tiny calcite-filled cracks.” Pszczółkowski (1986; as cited in Pardo, 2009) considers the Amaro Formation a mega-bed representing one major turbidite event caused by one large earthquake possibly related to the Chicxulub meteorite impact at the K-T boundary. However, Pardo (2009), while accepting the turbiditic origin, discounts the idea that the unit represents a single event. The Lutgarda Formation, exposed in the same general areas as the Amaro Formation, consists of 55 m of “thin- to medium-bedded calcarenite and calcirudite, bright red and brown chert beds and nodules, very fine, detrital to porcelaneous white limestone, greenish-blue clay, and characteristic sugary-white limestone or coquina consisting exclusively of small, broken rudist fragments” (Pardo, 2009). The basal limestone of the Lutgarda Formation is strongly stained with manganese, yielding a pink to black color (Pardo, 2009). IGP (2011) defines this unit as late Maastrichtian, whereas Pardo (2009) extends it to the Santonian. Exposed to the northwest of Trinidad Dome in central Cuba, the Cantabria Formation is described as micritic, clastic, clastic foraminifera-bearing, or nodular limestone, marl, and lenses of reef limestone that is late Maastrichtian (IGP, 2011). Exposed in much the same area, the very limited exposures of the Carlota Formation are white to gray, massive, bioclastic and biohermal limestone of Maastrichtian to Campanian age. Exposed north of Sancti Spiritus Dome, the Isabel Formation is as much as 90 m of reef limestone containing large rudists, corals, and orbitoid foraminifera. Igneous-derived grains are common to abundant (Pardo, 2009). A basal conglomeratic breccia is present (IGP, 2011). Considered equivalent to the Isabel Formation, the Presa Jimaguayú Formation is widespread and contains thin-bedded biogenic, bioclastic, micritic limestone that grades to calcareous breccia, marl and has interbeds of polymictic and silty sandstone (IGP, 2011). IGP (2011) describes a Las Parras Member, consisting of bioclastic, biogenic, oolitic and silicified limestone gradational to chert and marl. It is unclear which formation the Las Parras Member is a member of; possibilities include the Piragua or the Crucero Contramaestre Formations. Another central Cuban limestone, the Purio Formation (IGP, 2011) of locally dolomitized micritic and bioclastic limestone was mapped by Puscharovsky and others (1988) as part of the Remedios Formation. Several dozen meters of silicified, porcelaneous limestone of the Lindero Formation was considered the Lindero Member of the Iberia Formation by Pardo (2009) (the Iberia Formation of Cuba is mapped as subunit Kvib in this report). Also considered part of the Iberia Formation by Pardo (2009), the Tinajita Formation (Member) is bioclastic, biogenic, and oolitic limestone, and marl, which is locally silicified and grades to chert (IGP, 2011). In southeastern Cuba, very small exposures of the Yaguaneque Formation, consists of limestone reef deposits; these rocks overlie metamorphosed rocks and tectonized ultramafic rocks. In Haiti, the Macaya Formation (MMER, 1989; unit “c” of Vila and others, 1985) forms massive karst cliffs of Upper Cretaceous (Coniacian to Maastrichtian) epipelagic, biomicrite limestone that is associated with green and red radiolarian chert and thin siliceous interbeds (Butterlin, 1960, as cited in Vila and others, 1985). In eastern Dominican Republic, Toloczyki and others (1991) reported Upper Cretaceous limestone overlying rocks of the intermediate-composition volcanic rocks subunit Kevi. In Jamaica, there are quite a few Upper Cretaceous limestone units. McFarlane and others (1984) mapped the Rio Grande Limestone as part of the Bellevue Formation and indicated it is Maastrichtian; however, Hastie (2007) indicated that the Rio Grande Limestone is the upper member of the underlying Back Rio Grande Formation and is Campanian. The Guinea Corn Limestone (or the Guinea Corn Formation) has a lower part composed of interbedded greenish-gray mudstone, siltstone, and rubbly limestone, succeeded by massive, rubbly limestone that has a few siltstone beds; the upper part is mudstone and graded sandstone (Hastie, 2007). Arden (1975) described the Clifton Limestone of the Hanover Formation as being “of reef origin and is composed largely of corals and rudists. Among the rudists are species of *Barrettia*, indicative of early Campanian age.” Arden (1975) described four limestone formations, separated by mudstone and siltstone, that are present in the Calton Hill and Maldon Inliers in western Jamaica; we believe that these include the Calton Hill Limestone, the Maldon Limestone, the Stapleton Limestone, and the Titanosarcolithes Limestone. In Puerto Rico, the most extensive exposures of Upper Cretaceous limestone are in the extreme southwest of the island. The Melones and Parguera Limestones are found south of the Lajas valley in the southernmost part of this exposure area. The Melones Limestone characteristically consists of four units, the lowest is reddish-brown, olive-brown, or tan, medium- to coarse-grained, thin- to medium-bedded, thinly laminated, locally crossbedded, weakly cemented, tuffaceous sandstone consisting of subrounded to subangular plagioclase, and volcanic rock fragments that contain common limy concretions, and rounded fragments of worm-bored wood replaced by calcite. Sandstone is interbedded with gray shaly limestone, dark-brown calcareous mudstone and locally with thinly

laminated, red-maroon, blackish-red, or dark-brown siltstone. Overlying this is light- to dark-gray, thin-bedded, fossiliferous carbonaceous shaly limestone and limy shale that contains numerous fossils including larger foraminifera, and the mollusks *Pseudocuculea* sp. and *Lopha* sp. Overlying this is a massive phase, locally mapped separately, consisting of light- to dark-gray, massive or thick-bedded, bioclastic calcarenite consisting of calcareous fossil fragments, mostly mollusks, foraminifera, and pellets in a sparry to micritic cement; characteristic fossils are the rudists *Barrettia gigas*, *Parastroma gutarti*, and *Titanosarcolithes* sp. Outcrops of this subunit commonly show karren features (solution features produced through karsitic weathering). The uppermost phase is reddish-orange or yellowish-orange, massive, locally thick-bedded, cherty calcarenite containing zones of abundant gastropods; chert locally replaces calcite (Volckmann, 1984a, b). The co-located Parguera Limestone, also described by Volckmann (1984a, b) and Krushensky and Monroe (1979) has two members. The lower member is thick- to medium-bedded conglomerate containing rounded to angular clasts of volcanic rocks and chert, and minor serpentinite and amphibolite, which grades upwards to medium- to thin-bedded volcanoclastic calcarenite. The member locally contains glauconitic beds, thin beds of silicified mudstone, interbeds of calcareous mudstone, and sparse lenses of coarse-grained, light-gray bioclastic limestone. The limestone lenses grade upwards to thin- to medium-bedded, calcilutite. The lower member is as much as 1,000 m thick. The lower part of the upper member consists chiefly of volcanoclastic conglomerate containing abundant sand- to pebble-sized clasts of basalt and coarse-grained skeletal debris consisting chiefly of mollusk fragments and larger foraminifera. The upper member locally has interbeds of thin lenses of coarse-grained massive bioclastic limestone, which may contain *Barrettia gigas*. The upper part of the upper member consists of coarse-grained, thick-bedded to massive bioclastic limestone chiefly made up of mollusk fragments including radiolitic rudists and *Barrettia gigas*, larger foraminifera, calcareous algae fragments, and other skeletal debris. Between the Lajas and Hormigueros valleys, another three limestone units are associated with the ultramafic rocks; these are the Cotui Limestone, and limestone members associated with the Sabana Grande and El Rayo Formations. The Cotui Limestone (Volckmann, 1984a, c) is thick-bedded to massive, dense bioclastic limestone; generally composed of rudist fragments in micritic to sparry cement, it locally contains fecal pellets, sparse larger foraminifera, and rare oolites. The rudists are principally *Barrettia gigas* and *Radiolitiidae* and the Cotui locally contains concentrations of the large gastropod *Trochaeteon* sp. (Volckmann, 1984c). Limestone lenses in the Sabana Grande Formation are massive, discontinuous lenticular bodies of calcarenite and calcirudite made up of mollusk fragments, fecal pellets, and echinoid spines typically in a sparry cement, which near the base of the formation contain *Barrettia gigas* (Volckmann, 1984d). Limestone lenses in the El Rayo Formation are thin-bedded to massive bioclastic limestone that is commonly argillaceous. The lenses typically consist of predominantly rudist fragments in a sparry to micritic matrix. The rudists are most commonly of the genera *Titanosarcolithes*, *Distefanella*, and *Parastroma* (Volckmann, 1984b). The lenses may locally contain scattered fecal pellets and (or) abundant larger foraminifera (Volckmann, 1984c). In the Mayagüez and Rosario quadrangles to the north are fragmentary exposures of limestone in the Lago Garzas Formation, informally called the limestone of Las Marias and a few small outcrops of the Penones Limestone. The limestone of Las Marias is “light-gray to pinkish-gray, fine- to coarse-grained limestone composed of angular to subrounded fossils and fragments of fossils (pelecypods) and carbonate intraclasts in a micritic, or rarely sparry matrix” whereas the Penones Limestone is pale-gray, massive, thick-bedded, fossil-bearing limestone and limestone breccia (Curet, 1986). According to Curet (1986), the Penones Limestone is locally intruded by a small stock. Most other Upper Cretaceous limestone exposures tend to be fragmentary or lenses within other formations, as follows. In the Ciales quadrangle of central Puerto Rico, a reef limestone apparently was deposited on a shallowly submerged volcanic island that is part of the Avispa Formation of the Rio Orocovis Group (Berryhill, 1965). In the Orocovis and Rio Descalabrado quadrangles, limestone members of the Maravillas Formation, include the Santa Ana and Sabana Hoyos Limestone Members. The Sabana Hoyos Limestone Member was originally considered part of the Cariblanco Formation and the Santa Ana Limestone Member part of the Coamo Formation, but they were reassigned to the Maravillas Formation (Glover, 1971). The Sabana Hoyos Limestone Member is “very thick and thick-bedded recrystallized calcilutite, calcarenite, and calcirudite and thin- to thick-bedded calcarenite, tuffaceous calcarenite, and calcareous tuffaceous sandstone” (Briggs, 1971). Also similar are the Botijas Limestone Member of the Pozas Formation, the Flor de Alba Limestone Lenticle and unnamed limestone of the Pozas Formation (Nelson and Monroe, 1966), and unnamed limestone lenses in the Maravillas and Cariblanco Formations in the Rio Descalabrado quadrangle (Glover and Mattson, 1973) and Jayuya quadrangle (Mattson, 1968b). The Botijas Limestone Member was originally mapped as a member of the Coamo Formation (Briggs and Gelabert, 1962) but was later reassigned to the Pozas Formation (Glover, 1971). In the Ponce quadrangle,

Krushensky and Monroe (1975) mapped thick beds of dark-gray or dark-gray-brown calcirudite separated by thinner beds of calcarenite enclosed within interbedded Lago Garzas and Yauco Formations (unit TKmv). The limestone of Santo Domingo is a massive, very fine crystalline, dark-gray, argillaceous limestone bed within unit Ku (Krushensky and Monroe, 1978, 1979). Krushensky and Monroe (1979) also report thin limestone lenses of thin pale gray-brown to light-brown, pale-gray weathering biosparite “composed of generally angular fragments of rudists, other pelecypods, calcareous algae plates, and large foraminifers in a generally sparry matrix. Angular volcanic lithic and crystal clasts range from abundant to sparse in the thinner lenses.” Similar limestone lenses in the Maricao quadrangle were reported by McIntyre (1975) in what was mapped as the now abandoned Rio Blanco Formation, rocks of which are now considered Lago Garzas or Yauco Formation. In eastern Puerto Rico, the Trujillo Alto Limestone Member of the Monacillo Formation is a richly fossiliferous dark-gray calcarenite, locally as much as 100 m thick exposed in the San Juan, Aguas Buenas, and Gurabo quadrangles (Pease, 1968b, Seiders, 1971b; Pease and Monroe, 1977). Lenses of limestone are present in the Rio de la Plata Sandstone and Santa Olaya Lava in the Naranjito quadrangle (Pease, 1968c), commonly associated with volcanic rocks. A hard, gray limestone of likely Late Cretaceous age is sparsely exposed on the eastern part of Isla de Vieques (Vieques Island) and on other smaller offshore islands (Learned and others, 1973). On northern Saint Croix in the U.S. Virgin Islands, a thin (15 m), resistant limestone and volcanic-clast pebble-conglomerate bed, known as the Clairmont Member of the Judith Fancy Formation, is exposed, and it can be mapped for about 3 km and is considered Campanian (Whetten, 1966)

Kelc

Limestone and minor calcarenite, undifferentiated (Cretaceous, Santonian to Albian)—Largely only exposed in Cuba, the largest exposure of this unit is in central Cuba as the Mata, Quiñones, Carmita, and Palenque Formations (IGP, 2011). The Palenque Formation of biogenic and detrital limestone, dolostone, calcarenite, and intraformational breccia was deposited in Zone 1 of what Lewis and Draper (1990), considered a relatively shallow-water environment. Also, in central Cuba, interbedded with the Palenque Formation, the Vilató Formation is biogenic, bioclastic, and calcirudite limestone, characterized by the rhythmic laminar sedimentation (IGP, 2011). In northwestern Cuba, the Quiñones Formation (IGP, 2011) was described as red chert having traces of manganese, interbedded with siltstone, shale, limestone, sandstone, conglomerate, basalt, and minor tuffite. Pardo (2009) described it as about 600 m of interbedded sandy limestone, siltstone, shale, and chert. The percentage of shale and chert increases upward in the unit although sandstone and breccia are present at top. The limestone has abundant planktonic microorganisms, as well as terrigenous and pyroclastic material (Pardo, 2009). The similar and age equivalent Carmita Formation consists of micritic, siliceous, and detrital limestone containing interbedded brown and red chert, as well as shale, siltstone, calcareous sandstone, sandy limestone, and marl. The Mata Formation, exposed in the same general area of Cuba consists of limestone, chert, flint fragments, calcareous clusters and occasionally clay-rich conglomeratic breccia. The Carmita and Mata Formations are in Zone 2 of Lewis and Draper (1990), which they considered the deepwater equivalent of Zone 1. South of the Carmita Formation in the Escambray Massif (which includes Trinidad and Sancti Spiritus Domes), are small exposures of the Moscas Member of the Arimao Formation, nodular, biogenic, detrital, reef limestone containing abundant rudists fossils, conglomerate, calcareous sandstone, and sandy marl (IGP, 2011). Outcropping to the north of Trinidad Dome, is the Provincial Formation of finely crystalline limestone containing interbeds of marl, calcareous conglomerate, sandstone, tuff, and tuffite (IGP, 2011). Pardo (2009) indicated that the Provincial Formation was a combination of three formations, the Gomez, Casanova, and Cristobal Formations. Lowest is the Cristobal Formation, about 150 m of interbedded thin- to medium-bedded limestone, thin-bedded shale, and calcarenite; the limestone is oolitic, dense, fragmental, and contains Radiolaria. The calcarenite can be coarse, and it contains mollusk remains and reworked oolites of Late Jurassic age (Pardo, 2009). The Casanova Formation was described by Pardo (2009) as about 180 m of argillaceous, dense to fragmental, yellowish-brown limestone interbedded with thinly bedded shale and containing in the middle of the section a 45-m-thick, dark-gray porphyry flow; upper part of formation contains tuffaceous sandstone and conglomerate, as well as a rudist reef. The Gomez Formation is correlative with the Casanova Formation; however, Pardo (2009) considered it distinctive because it is detrital and not associated with volcanism, saying that it is about 150 m “of black to dark-brown, thin-bedded, sometimes nodular, shaly limestone with interbedded dark-gray shales toward the base. Toward the top, the limestones are lighter colored and occasionally fragmental and interbedded with yellowish marls. Some calcareous, fine-grained sandstones are present, containing basic plagioclase, green hornblende, apatite, chlorite, volcanic grains, and bands of heavy minerals” (Pardo, 2009). In northern Cuba, the Guajaibon Formation is exposed in a narrow linear belt and consists of massive, locally dolomitized limestone and biomicritic calcarenite (Puscharovsky

and others, 1988; IGP, 2011). Exposed in the same area of northern Cuba, the Pinalilla Formation is also massive to thickly bedded biomicrite; it locally contains thin interbeds of siltstone and shale (IGP, 2011). A limestone lens and limestone breccia in the El Ocho Formation (unit Ksv) (Pease, 1968c) of northeast Puerto Rico and a limestone lens in the Carraizo Breccia (unit Kvib) (Pease, 1968c) are the only mapped exposures of this unit outside of Cuba

Kec

Carbonate rocks, including biomicritic limestone (Lower Cretaceous)—Exposed in Cuba, Haiti, Jamaica, and Puerto Rico these rocks are similar to units Kelc and Klc though older. In Cuba, the unit is represented by two formations, the Margarita and Paraiso Formations. The Margarita Formation is exposed in central Cuba in Zone 2 of Lewis and Draper (1990) and is microcrystalline, argillaceous limestone and minor chert and breccia. The co-located more chert-rich Paraiso Formation and Margarita Formation were both considered by Pardo (2009) to be synonymous with Captolio Formation of dense, biomicrite, with thin, yellow-orange, wavy laminae, interbedded with brown and black thin-bedded banded vitreous chert of Berriasian to Hauterivian age. Included here are very small exposures of calcarenite and red marl on the southern peninsula of Haiti of presumed Early Cretaceous age (MMER, 1989). In Jamaica, the Devil's Race Course Group includes several limestone formations, such as the Benbow, Copper-Phillipsbury, and Jubilee Limestones (McFarlane and others, 1984). More recent mapping indicates that the Copper-Phillipsbury Limestone is now considered to be the same formation as the Jubilee Limestone (Brown and Mitchell, 2010). According to Brown and Mitchell (2010), the Jubilee Limestone consists of compact, very hard, dark- to medium-gray limestone containing interbedded mudstone and volcanically derived sandstone and conglomerate and a single lava flow near the base of the formation. The limestone is generally massive or has poorly developed bedding and ranges from micrite and biomicrite upward to wackestone and packstone. The Benbow Formation (previously Benbow Limestone) is the thickest limestone unit of the Devil's Race Course Group and consists of very hard, compact dark blue-gray biomicrite that is rich in rudists, gastropods, and corals, with smaller numbers of chondrodonts and columnar stromatolites (Brown and Mitchell, 2010). In southeast Puerto Rico, several thin limestone lenses and beds are associated with volcanic rocks. Southernmost of these are four limestone units mapped by Berryhill and Glover (1960) in the Cayey quadrangle. Mapped before much of the stratigraphic nomenclature was established for Puerto Rico, only one of these was assigned to a defined formation as the Rio Matón Limestone Member of the Robles Formation. This unit was also mapped in the Comerio quadrangle (Pease and Briggs, 1960) and in the Barranquitas quadrangle (Briggs and Gelabert, 1962) where it was described as medium-dark-gray massive crystalline limestone, generally in thin lenses near the base of the formation. In the Jayuya quadrangle, Mattson (1968b) described limestone lenses in the Robles Formation that have been contact metamorphosed to a white, coarsely crystalline marble due to proximity to the Utuado batholith (unit TKgm). Briggs and Gelabert (1962) described a lithologically similar limestone as part of their formation L. Also included here is the Aguas Buenas Limestone Member of the Torrecilla Breccia (Caguas quadrangle; Rogers, 1979), originally mapped as the Aguas Buenas limestone of informal formation K of the Comerio quadrangle (Pease and Briggs, 1960) and of formation D in the Cayey quadrangle (Berryhill and Glover, 1960). Best defined by Rogers (1979), the Aguas Buenas Limestone Member where not metamorphosed, is aphanitic, medium-gray to medium-dark-bluish-gray limestone that locally is laminated to thickly bedded though generally massive. Near the Caguas pluton, "it is light gray (locally mottled), recrystallized, and fine to medium grained." It characteristically forms karst topography. Lenses of impure limestone, tuff, and limestone breccia were also mapped as part of formation K as well as a limestone lens in formation J by Pease and Briggs (1960). East of this area in the Humacao quadrangle M'Gonigle (1978) mapped "limestone" within the Pitahaya Formation. Described as marble beds as much as a meter thick that are found scattered throughout the section; locally skarn has formed replacing the marble. "Lenses as much as 30 cm thick and massive bodies of fairly pure magnetite (m) locally replace the carbonate beds; magnetite was once mined at the Island Queen mine, located 600 m southeast of Cerro Colores" (M'Gonigle, 1978)

Ku

Undifferentiated clastic rocks (Upper Cretaceous, Maastrichtian to Turonian)—Widely exposed throughout the Greater Antilles, these clastic rocks range from shale to conglomerate. In northwestern Cuba, the Bacunayagua Formation of Campanian age consists of graywacke, arkosic sandstone, and conglomerate containing lenses and interbeds of carbonaceous claystone (IGP, 2011). It overlies metamorphosed ultramafic rocks of unit KJmm. Northwest of the Escambray Massif, polycrystalline sandstone, siltstone, and marl and a basal polymictic conglomerate of the Monos Formation is associated with the Arroyo Grande Formation (unit Kcls), lacking its carbonate and the La Rosita Formation (unit Klsv), lacking its volcanic and volcanoclastic components (IGP, 2011). North of the exposures of the Monos Formation in the vicinity of Embalse Palma Sola (Palma Sola Reservoir)

the data from IGP (2011) show several small polygons labelled “Ksmt,” but otherwise undescribed. We infer them to belong to this map unit. In eastern Cuba, the La Picota Formation consists of polymictic conglomerate containing interbeds of poorly sorted polymictic sandstone and breccia-conglomerate interbedded with shale (IGP, 2011). In the eastern and southern parts of Dominican Republic, Toloczyki and others (1991) report scattered outcrops of Upper Cretaceous polymictic conglomerate that is locally carbonate cemented rocks of the Don Juan Formation(?) and locally overlying andesitic volcanic rocks (unit Kevi) in the more northern exposures and associated with mixed clastic and carbonate rocks of unit Kcls in the southern exposures. Several units in Jamaica are included here; in western Jamaica, several defined units are exposed in the Lucca (or Hanover) and Saint James (or Sunderland) Inliers of Hastie (2007). The Hanover Formation (or Hanover Shale), exposed in the Lucca Inlier, is divided into lower and upper units (Arden, 1975). The lower unit is calcareous mudstone containing thin interbeds of limestone and calcareous sandstone; the Clifton Limestone (mapped as the limestone and limestone conglomerate subunit Klc here) is found at the top of the lower unit. The upper unit is sandy and contains conglomeratic and shaly lenses. Arden (1975) indicated that the Hanover Shale was Campanian, whereas McFarlane and others (1984) considered it to be Coniacian to Santonian. The Green Island, Jerusalem Mountain, Masemure, and Morland Formations, which all lie within the Lucca and Westmoreland Inliers of western Jamaica, may be encompassed by the Hanover Shale of Arden (1975). The Newman’s Hall Formation, gray shale that contains calcareous concretions, and the Sunderland Formation, brown-weathering shale and sandstone, are found in the Saint James Inlier (Jiang, 1993). Jiang (1993) indicated that the Newman’s Hall and Sunderland Formations are Campanian based on nanofossils, whereas McFarlane and others (1984) considered them Coniacian to Santonian. In eastern Jamaica, the Ginger House Member of the Bellevue Formation is purple to gray, polymictic conglomerate that has a sandy tuffaceous matrix along with clasts of porphyritic andesite and bright-green, chloritized pelitic rocks (Hastie, 2007). Also, in eastern Jamaica, the Bowden Pen Member of the Blue Mountain Formation is a coarse-grained “slump” conglomerate (McFarlane and others, 1984; Hastie, 2007). In northcentral Jamaica, the Cascade Formation of McFarlane and others (1984) is exposed in a fault block in Saint Anne’s Inlier. The Shepard’s Hall Formation, consisting of conglomerate and tuff, is not dated but is tentatively considered Campanian by Arden (1975). The Saint Anne’s Great River Formation (called the “Diozoptysis shale” by McFarlane and others, 1984) was described by Mitchell and others (2011) as 48 m of dark-gray, silty shale that has common shallow-water fossils and no obvious marker beds; however, because the upper part of formation is terminated by a fault, its true thickness is not known (Mitchell and others, 2011). The Veniella Shale was described by Chubb (1955) as about 750 m of largely nonfossiliferous shale and conglomerate, though the uppermost approximately 45 m is richly fossiliferous, purple, brown, and gray shale and siltstone that contains indurated sandy beds; some shale is nodular or concretionary. The Windsor Shale, exposed in Saint Anne’s Inlier on the northcentral coast of Jamaica, is Campanian, according to Arden (1975). Exposed in two general areas in Puerto Rico, rocks of this map unit are generally composed of the Yauco Formation in the west and the Monacillo Formation in northeastern Puerto Rico, near San Juan. The Yauco Formation is widely exposed southwest of the Great Southern Puerto Rican Fault Zone (GSPRFZ). Locally, it has been lumped with the more volcanoclastic Maastrichtian (and younger?) Lago Garzas Formation or the Eocene Anón Formation. The Yauco Formation is defined as dark-bluish-gray to dark-gray to dark-greenish-gray, calcareous, volcanoclastic sandstone, siltstone, mudstone, claystone, limestone, and subordinate breccia and conglomerate (in contrast with the Lago Garzas, which is as much as 90 percent breccia). The Yauco is characteristically thin- to medium-bedded and fine- to medium-grained. Some beds show evidence of extreme bioturbation, and microfossils as well as clasts of megafossils are common. The Yauco characteristically weathers to a light-orange-brown saprolite that preserves the texture and structure of the original rock. Volcanoclastic sandstone, which makes up as much as 40 percent of the formation, is composed of angular to subrounded volcanic, lithic, and crystal clasts, glass shards, and pumice in a groundmass of dark-brown clay, chlorite (after glass?), and iron oxides, and locally a sparry calcite cement. Clasts range from relatively fresh, easily identified volcanoclastic rocks, to clasts composed of calcite, chlorite, epidote, and quartz. Finer grained beds contain greater quantities of microfossils, chiefly foraminifera, and crystal clasts are predominant over lithic clasts. Limestone in the Yauco Formation is chiefly dark gray, thin to medium bedded, and consists of angular to subrounded, poorly sorted macrofossil clasts, some larger foraminifera, and carbonate intraclasts in a micritic matrix. Crystalline clasts and fecal pellets locally compose as much as 25 percent of the rock. Very minor breccia and conglomerate consist chiefly of clasts of volcanoclastic rocks and some clasts of limestone, siltstone, mudstone, and chert. The matrix is composed of similar but smaller sand-sized

lithic clasts and plagioclase, augite, and hornblende clasts and clay (Krushensky and Monroe, 1979; Curet, 1986). The unit is exposed as far southeast as Ponce (Krushensky and Monroe, 1975) and as far northwest as the Rincon quadrangle. Locally, a massive purple-weathering coarse lithic-crystal tuff is present in the Adjuntas quadrangle (Mattson, 1968a). The Monacillo Formation consists of “reddish-gray poorly indurated volcanic conglomerate and dusky-reddish-brown mudstone interstratified with yellowish-gray thin-bedded siltstone and sandstone” (Pease, 1968b; Pease and Monroe, 1977); and tuffaceous clastic rocks that range from conglomerate to mudstone, and it locally contains a limestone member, the Trujillo Alto Limestone Member (subunit Klc in this report; Pease, 1968b). Locally, divided into subunits Kvss and Kso

Kvss

Volcaniclastic sandstone and mudstone, undifferentiated—In the Holguín area of southern Cuba, the La Jiquima Formation was described by Pardo (2009) as 300 m of thin- to medium-bedded, well-sorted, fine- to medium-grained, brownish-gray to creamy-brown sandstone that commonly contains carbonized plant fragments. It is commonly associated with metamorphosed ultramafic rocks. In the Adjuntas quadrangle of western Puerto Rico, mudstone, volcanic sandstone, and siltstone were mapped in limited areas of the Lago Garzas Formation (Mattson, 1968a). It is likely that these rocks are present, but undivided in the Lago Garzas in other quadrangles where the undivided unit is shown here as unit TKmv. The Cariblanco Formation thin-bedded sandstone and shale facies in the Coamo quadrangle of southcentral Puerto Rico (Glover, 1961a) tends to be tuffaceous and locally contains white and black chert in thin laminae in its lower parts. In the northern Barranquitas quadrangle, rocks originally mapped as the Cariblanco Formation (Briggs and Gelabert, 1962) are reassigned in this report to the Magueyes Formation (unit Ksv), in common with rocks in the southern Corozal quadrangle (Nelson, 1967a). Like the Cariblanco, these rocks consist of greenish-gray or light brownish-gray, fine- to coarse-grained, massive to thin-bedded volcanic sandstone interbedded with dark-gray thin-bedded siltstone and water-laid lapilli tuff. In the northern Corozal quadrangle (Nelson, 1967a), adjacent Naranjito quadrangle (Pease, 1968c) and farther east in the Aguas Buenas quadrangle (Pease, 1968b), tuffaceous and locally calcareous sandstone of the Rio de la Plata Sandstone outcrops along the margins of Mamey Lava Member of the Camarones Sandstone, a Late Cretaceous basalt and andesite (unit Klmv). The Coniacian Camarones Sandstone was originally included in the Hato Puerco Formation but was separated and defined by Pease (1968a). Consisting of thin-bedded dark-gray calcareous siltstone that is possibly carbonaceous, and thicker bedded dark-gray volcanic wacke as well as minor volcanic pebble conglomerate, it overlies the Hato Puerco Formation (Pease, 1968b) (unit Kvib). Interbedded in the andesitic rocks of the Avispa Formation are thin, but mappable horizons of sandstone and siltstone (Nelson, 1967a); a similar siltstone is interbedded with the Tortugas Andesite in the central Aguas Buenas quadrangle (Pease, 1968b). Small pods of limestone are also present in the Tortugas Andesite in the Aguas Buenas quadrangle. The Frailes and Guaynabo Formations have somewhat overlapping definitions; in a sense, the Frailes Formation might be considered the upper part of the Guaynabo Formation. For both, the Leprocomio Mudstone Member is part of their formal definition. Of the source maps for this compilation, the Leprocomio Mudstone Member as assigned to the Guaynabo Formation is only mapped in the San Juan quadrangle (Pease and Monroe, 1977). In the adjacent Aguas Buenas (Pease, 1968b), Gurabo (Seiders, 1971b), Carolina (Monroe, 1977) and Rio Grande (Pease and Briggs, 1972) quadrangles, the Frailes Formation is the map unit shown. In eastern Puerto Rico, the Frailes Formation has thin, calcareous, foraminiferal mudstone beds, which are most abundant near its base and also in the Leprocomio Mudstone Member at its top; the thick, middle part is interbedded grayish-green, andesitic to dacitic volcanic-clast sandstone, pebbly volcanic-clast sandstone, fine-grained volcanic-rock breccia, fine- to medium-grained breccia-conglomerate, and less abundant volcanic-clast mudstones; in eastern exposures, two units of pillow-basalt flows are included (Seiders, 1971b). A 650-m-thick unit of siltstone, sandstone, thin-bedded tuffaceous siltstone, and fine-grained sandstone is assigned to the Los Negros Formation in the southwest corner of the Aguas Buenas quadrangle (Pease, 1968b). Pease (1968a) describes this as a 400-m-thick siltstone member. The Canovanas Formation underlies the Frailes-Guaynabo Formation rocks in the Gurabo (Seiders, 1971b), El Yunque (Seiders, 1971a), and Rio Grande (Pease and Briggs, 1972) quadrangles. Likely the oldest of the units included here, the Canovanas Formation, is about 450 m of marine-deposited, medium- to dark-gray, medium- to thick-bedded, basaltic volcanic sandstone and less abundant medium-dark-gray calcareous mudstone. Sandstone is relatively rich in clinopyroxene and generally calcareous, composed chiefly of angular volcanic rock and mineral grains and less abundant rounded grains and pebbles of the same composition (Seiders, 1971a, b; Pease and Briggs, 1972). Over much of Saint Croix in U.S. Virgin Islands, a series of Campanian to Maastrichtian volcaniclastic sandstone units are exposed. One of the oldest, the Allandale Formation of Campanian age is only exposed on western Saint Croix; it is about 600 m of most

commonly green, tuffaceous sandstone and lesser mudstone, volcanic-breccia, lapilli tuff, flows, and fragmental limestone (Whetten, 1966); volcanic-rock debris is primarily pyroclastic andesite and dacite and minor epiclastic keratophyre and spilite fragments. Of equivalent age, the Caledonia Formation consists of about 30 percent sandstone composed chiefly of keratophyre and spilite debris and 60 to 70 percent mudstone; beds are typically graded from sandstone to mudstone, are 7 to 8 cm thick, and have sharp, distinct lower contacts. Locally, chert beds are present between the mudstone and the overlying sandstone beds (Whetten, 1966). The formation is at least 2,700 m thick and may be as much as 5,400 m thick. The East End Member of the Caledonia Formation, exposed in eastern Saint Croix, is composed of tuffaceous sandstone and volcanic breccia, both of which become coarser eastward, and is about 275 m thick (Whetten, 1966). The Cane Valley Formation, which overlies the Allandale Formation, is divided into three members, the upper Springfield Member and the lower Hope Member, both largely mudstone, and the middle Robe Hill Member, which is largely tuffaceous mudstone (Whetten, 1966). Overlying all these formations on Saint Croix is the Judith Fancy Formation, composed of tuffaceous rocks about 4,570 m thick. The Judith Fancy Formation is present over a wide area of western and central Saint Croix; rocks of the formation are variable in composition. On the western part of island, the formation varies from west to east from fine- to coarse-grained tuffaceous sandstone to breccia and lapilli tuff to tuff and lapilli tuff. On the eastern part of the island, the Judith Fancy Formation is characterized by tuffaceous sandstone, lapilli tuff, and mudstone, as well as a few thin beds of interbedded fossiliferous, fragmental limestone (Whetten, 1966)

Kso

Siltstone and local olistostrome deposits, undifferentiated (Upper Cretaceous, Maastrichtian to Campanian)—Commonly siltstone, this unit is distinctive because of included olistostrome deposits. In northern Cuba, the Via Blanca Formation is as much as several hundred meters of reddish-green shale, graywacke siltstone, sandstone, and sparse interbeds of white marl. Conglomeratic olistostrome deposits are common and consist of two types, (1) those consisting mostly of igneous-rock material, and (2) those consisting of carbonate-rock fragments, including a high percentage of limestone fragments that contain rudists probably derived from the underlying San Juan y Martinez Formation (mapped as unit Kcls in this report). The formation was deposited in shallow- to relatively deepwater conditions. Its source of material appears to have been from the south-southwest (Pardo, 2009). In southern Haiti, Vila and others (1985) described calcareous olistostrome deposits within a tuffaceous matrix. These deposits are rich in basaltic debris but also contain various other clast lithologies including dark chert, radiolarian chert, siliceous and sandy limestone, and diabase. In Dominican Republic, Upper Cretaceous flysch consists of marly sandstone containing interbedded conglomerate and olistoliths and gray to violet, thin-bedded pelagic limestone exposed in the central part of the country, as well as adjacent to the border with Haiti (Toloczyki and others, 1991). In Haiti, adjoining the flysch unit in the Dominican Republic, is a unit that Vila and others (1985) called the flysch du Massif du Nord (North Massif flysch) (mapped there as “cF”) and that MMER (1989) called the Trois Rivières Formation, their unit “Cf.” Vila and others (1985) described their “cF” flysch unit as mostly schistose argillite, mudstone, sandstone, conglomerate, and limestone turbidites of Late Cretaceous age. It is distinct from another Haitian flysch consisting of calcareous olistostrome of presumed older Cretaceous age mapped by Vila and others (1985) as unit “cbl,” on the southern peninsula in the Jacmel road area. The “cF” flysch unit of Vila and others (1985) constitutes a northwest-southeast-trending band that extends into the Dominican Republic. Vila and others (1985) also mapped (conterminous with their unit “cF”) a low-grade metamorphic-rock unit (their unit “Ms”) that they described as a polyphase schistose complex (shale, sandstone, schist) derived from sandy and clay-rich pelitic rocks by weak dynamic metamorphism

Kcgl

Volcaniclastic conglomerate (Upper Cretaceous, Maastrichtian to Santonian)—Though exposed in Cuba and Jamaica, most extensive exposures of this unit are in Puerto Rico. In central Cuba, the Las Gordas Member of the Crucero Contramaestre Formation (IGP, 2011) is volcanic-clast conglomerate that has a tuffaceous sandstone and volcaniclastic gravel matrix. In Jamaica, the Slippery Rock Formation, exposed in the Central Inlier, is red, brown, or gray conglomerate and sandstone, in poorly defined beds that range in thickness from a few tens of centimeters to as much as several meters. The conglomerate is predominantly poorly to moderately sorted and contains rounded, predominantly andesitic and mafic volcanic-rock clasts in sandy matrix. Conglomerate grades upwards into sandstone and pebbly sandstone, locally with carbonate concretions, and subordinate red sandstone and siltstone (Mitchell and Blissett, 2001). The Slippery Rock Formation is a terrestrial unit deposited by braided streams and coalescing alluvial fans (Mitchell, 2003). In Puerto Rico, the Santonian to Maastrichtian Achiote Conglomerate, exposed in the central part of island, is as much as 1,800 m of massive, red volcanic-rock conglomerate of well-rounded clasts of red and green andesite and chert, in a red

mudstone matrix, as well as interbedded green tuffaceous conglomeratic sandstone (Mattson, 1967, 1968b; Briggs, 1971; Glover, 1971; Glover and Mattson, 1973; Krushensky and Monroe, 1975). The Cariblanco Formation, also in central Puerto Rico, has a maximum estimated thickness of 1,000 m of volcanoclastic conglomerate, sandstone, and siltstone. It is divided into four members, consisting of a flow member at its base, a massive tuff member, and two limestone members (included in subunit **Klc** in this report) in its upper part. The conglomerate is dominantly composed of hornblende dacite, welded ash-flow tuff, amygdaloidal plagioclase-pyroxene biotite andesite, and subordinate sandstone, siltstone, and limestone clasts (Berryhill and Glover, 1960; Glover, 1961a, 1971; Briggs and Gelabert, 1962; Glover and Mattson, 1973). In the Barranquitas quadrangle, only the southern exposures of the Cariblanco as mapped by Briggs and Gelabert (1962) are included in this unit; the finer grained northern exposures are here reassigned to the Magueyes Formation and shown as part of subunit **Ksv**. The Achiote Conglomerate is the approximate stratigraphic equivalent of massive conglomerate of the Cariblanco Formation. Within the Avispa Formation, a conglomerate unit (Berryhill, 1965; Nelson, 1967a) tends to separate it from the basaltic tuff of the Cotorra Tuff (unit **Kbt**). A conglomerate occurs near the middle of the Rio de la Plata Sandstone in the Naranjito quadrangle of northcentral Puerto Rico (Pease, 1968c). Two units of conglomerate are found in southwest Puerto Rico. Volckmann (1984b, c) mapped a conglomeratic phase of the Yauco Formation in the San German and Puerto Real quadrangles generally consisting of rounded clasts of volcanic rock, siltstone and claystone, and rare limestone in a generally noncalcareous sand or silt matrix with local variations including serpentinite and chert clasts in a calcareous matrix. Addarich-Martínez (2009) described a hydrothermally altered orthoconglomerate in the Guánica quadrangle. Informally named the Cienaga conglomerate, it is composed of well-sorted, well-rounded basaltic to andesitic rock fragments in a matrix of quartz and barite

Kcls

Mixed clastic and carbonate rocks, undifferentiated (Upper Cretaceous, Maastrichtian to

Campanian)—Predominantly exposed in central Cuba, this unit consists of variety of clastic sedimentary rocks that are always associated with limestone and marl. The Moreno Formation of northern Cuba consists of a lower marly and detrital limestone succeeded upward by slate, shale, and sandstone (IGP, 2011). In central Cuba, the Durán Formation is about 100 m of volcanoclastic conglomerate and sandstone and siltstone that contains interbeds of marl reef-limestone (Pardo, 2009; IGP, 2011). Pardo (2009) considered it as equivalent to the Jimaguayú Formation (mapped as the limestone and limestone conglomerate subunit **Klc** in this report). South of the Durán Formation, the Rio Yaquimo Formation is a mixture of interbedded sandy marl and sandy, clay-rich, saccharoidal limestone, calcareous and polymictic sandstone, which is often volcanoclastic, and subordinate clay, shale, and conglomerate (IGP, 2011). Exposed to the north of the Durán and Rio Yaquimo Formations and north and primarily northwest of Trinidad Dome, the Arroyo Grande Formation tends to be richer in carbonate rocks, consisting of clastic and bioclastic limestone, porcellanite, clay-rich breccia, conglomerate, marl, siltstone, and chalk (IGP, 2011). Also, north of Trinidad Dome, the Palmarito Formation is a biostrome or reef limestone containing fragments of rudists, corals, mollusks, echinoderms, and large foraminifera intermixed with conglomerate and sandstone made up of fragments of volcanic rocks and volcanoclastic sedimentary rocks. A unit that was informally defined by the IGP (2011), the Bacuranao limestone is exposed east of Havana and is composed of calcareous siltstone grading upward to calcareous marl and claystone. The last of the Cuban units, the Sao Redondo Formation is exposed northeast of Holguín and is simply defined as conglomerate, volcanoclastic sandstone, and limestone of Maastrichtian to Campanian age (IGP, 2011). In southern Dominican Republic, Toloczyki and others (1991) mapped two units, (1) a sandstone, marl, and limestone unit; and (2) a marl and calcarenite unit. In Puerto Rico, the La Muda Formation was originally considered the La Muda Limestone Member of the Frailes Formation (subunit **Kvss**; Pease (1968b) mapped it as a distinct formation that he defined as being mostly well-bedded arkosic sandstone and siltstone containing lenticular, massive limestone beds. Pease (1968b) also described interbedded pebble- to cobble-conglomerate primarily composed of volcanic clasts but locally having “almost exclusively limestone” clasts. The Reves Member of the Pozas Formation in the Orocovis quadrangle (Briggs, 1971) and rocks originally assigned to the El Reves Member of the Coamo Formation (now reassigned to the Pozas Formation as the Reves Member) consist of thin- to thick-bedded calcareous feldspathic sandstone containing lenses of calcirudite and recrystallized calcilutite. Also included here is the Rio Bauta Member of the Pozas Formation whose age may extend into the latest Santonian; it is a thin- to medium-bedded calcareous volcanic sandstone, which locally has interstratified lenses of recrystallized calcilutite and calcarenite and impure calcirudite as much as 10 m thick (Briggs, 1969). Rocks mapped as Formation L of Briggs and Gelabert (1962), consisting of tuffaceous sandstone and siltstone and including water-laid lapilli tuff, are likely reasonably assigned to the Pozas Formation and are included here

Klcv	Mixed clastic, carbonate, and volcanic rocks, undifferentiated (Upper Cretaceous, Campanian to Coniacian)—The most extensive exposure is in Cuba, but this unit is also present in Jamaica and Puerto Rico. In central Cuba, northwest of Trinidad Dome, rocks of the Arimao Formation of basalt, andesite, dacite, tuff-breccia, and containing interbedded limestone, conglomerate, sandstone and marl (IGP, 2011), are associated with the basalt of the Las Calderas Formation (unit Kmvm). The most extensive exposure of this unit, the Crucero Contramaestre Formation is exposed in the southern part of the Camagüey region. It consists of tuffaceous sandstone, conglomerate, felsic to intermediate-composition tuff, siltstone, argillite, silicified limestone, basalt, basaltic andesite, andesite, marl, and breccia. The Crucero Contramaestre Formation as mapped by IGP (2011) may correspond to the Guaimaro Formation of Puscharovsky and others (1988) and Contramaestre Formation of Pardo (2009). Pardo (2009) says the Contramaestre Formation has been found to be a structural mixture of Camujiro and Piragua Formations (units Koba and Klsv, respectively), which are exposed together just to the north of the Crucero Contramaestre Formation exposures. In northeast Jamaica, this unit includes the Cross Pass Shale of the Blue Mountain Formation, which includes shale, as well as tuff and conglomerate. In southcentral Puerto Rico, south of the town of Coamo, the Coamo Formation sedimentary facies in the Ciales quadrangle as defined by Berryhill (1961) were reassigned to the Pozas Formation by Berryhill (1965) and Briggs (1969) and shown in this report as part of unit Kva. Whereas, rocks of the Coamo Formation in the Salinas quadrangle (Glover, 1961a) and Central Aguirre quadrangle (Berryhill, 1960) were assigned to the Maravillas Formation by Mattson (1967) and included in this report in unit Klcv. In southcentral Puerto Rico, rocks of the Maravillas Formation, including the Toyosa Member, are medium- to thick-bedded, dark-red-brown to dark-reddish-purple volcanic conglomerate, conglomeratic sandstone, and locally calcareous mudstone and well-sorted plagioclase-hornblende crystal tuff. Conglomerate and sandstone contain abundant, rounded, porphyritic augite-plagioclase andesite lithic clasts, some very fine-grained dark-red-brown, aphyric volcanic lithic clasts, and abundant angular to subrounded, smaller clasts of plagioclase, augite, some quartz, and sparse but conspicuous detrital magnetite in a dark-red clay matrix. The conglomerate-sandstone facies weathers to a dark-red-brown saprolite. Outcrops on the north border of the Ponce quadrangle, consist of thinly laminated calcareous mudstone containing angular lithic clasts of chiefly red, green, and gray fine-grained volcanic rocks (Krushensky and Monroe, 1975); the westernmost outcrops are largely replaced by epidote, calcite, quartz, and chlorite. In the adjacent Jayuya quadrangle, Mattson (1968b) reports that locally, the formation has been silicified and (or) epidote and pyrite have been introduced; the original rock appears to be a well-sorted plagioclase crystal-tuff
Kue	Older undifferentiated clastic rocks (Upper Cretaceous, Santonian to Cenomanian)—Present in Jamaica and Puerto Rico, this is a lithologically diverse clastic unit. In western Jamaica, the unit includes several defined units exposed in the Lucca (or Hanover) and Saint James (or Sunderland) Inliers of Hastie (2007). Conglomerate of the John's Hall Formation is found in both the Lucca and Saint James Inliers (Jiang, 1993); Jiang (1993) placed the John's Hall Formation stratigraphically below the Sunderland Formation of late early Campanian age, which suggests that it could be as young as Campanian, whereas McFarlane and others (1984) considered it Coniacian to Santonian. Exposed in the Central Inlier, the Peter's Hill Formation consists of conglomerate overlain by rudist-bearing limestone that yielded a late Santonian fossil age for the unit (Hastie, 2007). Two formations from the Benbow Inlier of Jamaica are also included in this unit. The Tiber Formation, younger of the two, consists of volcanoclastic(?) conglomerate and minor andesitic flows (Brown and Mitchell, 2010). Lacking fossil control, they report an age based on stratigraphic grounds of early Turonian or Cenomanian, whereas Hastie (2007) reports an Albian age. The Rio Nuevo Formation is at least 1,150 m of dark-gray shale and minor conglomerate and tuffaceous sandstone (Brown and Mitchell, 2010). Age is suggested by Brown and Mitchell (2010) to be late or middle Cenomanian, whereas Hastie (2007) reports an Albian age. In Puerto Rico, the Pina Siltstone Member included in this report in the El Ocho Formation (unit Ksv) consists of thin-bedded to laminated calcareous siltstone and interbedded volcanic wacke; locally it grades to a carbonaceous impure limestone. The age of the Pina Siltstone Member is defined as Late and Early Cretaceous based on stratigraphic correlation (Pease, 1968a)
Ktu	Tutu Formation (Cretaceous, Santonian to Albian)—Consists of mixed volcanoclastic sedimentary rocks and their metamorphosed equivalents, in the Virgin Islands. The unit is roughly 3,000 m thick; about 1,800 m thick in the U.S. Virgin Islands (Donnelly, 1966), and an additional about 1,100 m is present in the British Virgin Islands (Helsley, 1960). As mapped in the British Virgin Islands by Helsley (1960) and in the U.S. Virgin Islands by Donnelly (1966) and Rankin (2002), the unit consists of volcanoclastic wacke, shale, conglomerate, calcareous siltstone, sparse limestone, and rare basalt and andesite, or their metamorphosed equivalents. Rankin (2002) divided the Tutu Formation into two members, the Mandal and Picara Members on Saint John Island that have yet to be extended to other islands. Helsley

(1960) described unit as “thin bedded fine-grained tuffaceous wacke interbedded with coarser grained materials of about the same character. Graded bedding is present in the finer units but is reported to be absent from the coarser units. Considerable variation is present in both size of material, varying from silt to cobbles, and in thickness of individual beds, varying from less than an inch in the finer wackes to more than thirty feet in conglomeratic units. Numerous fragments of limestone and of underlying beds are incorporated in the finer sediments suggesting the presence of currents capable of carrying large fragments of material originally formed or deposited nearer to the shore. Slump structures are present showing transport to the north and indicating deposition on a northward sloping surface.”

In the British Virgin Islands, the Tutu Formation surrounds the informal Coki Point megabreccia, which Helsley (1960) and Donnelly (1966) described as consisting of large (some more than 30 m long) blocks of shallow-water limestone mixed with andesitic volcanic rocks and tuffaceous wacke of the Tutu Formation at its base, thought to represent a massive slump deposit. Near the top of the Tutu Formation, the Congo Cay Limestone Member is coarsely crystalline limestone that contains gastropod molds (Helsley, 1960). As shown here, the Tutu Formation includes the Picara and the Mandal Members, which consist of porphyritic meta-andesite and medium- to thin-bedded, metamorphosed sandstone, siltstone, shale, and limestone, respectively, on Saint John (Rankin, 2002)

Ksv

Older mixed clastic, carbonate, and volcanic rocks, undifferentiated (Cretaceous, Turonian to Albian)

—Exposed both in Cuba and Puerto Rico, in northernmost Cuba, the La Trampa Formation consists of glassy lithocrystalline and crystalline basaltic-andesite tuff, andesitic to dacitic flows, conglomerate containing andesitic and rhyolitic clasts, coarse-grained tuffaceous sandstone and argillite (IGP, 2011). Northwest of Trinidad Dome in central Cuba, the Guaos Member of the Las Calderas Formation consisting of tuff, tuff breccia, and thin layers of biogenic, bioclastic, microgranular limestone represents the pyroclastic, clastic, and carbonate phase of the otherwise igneous Las Calderas Formation (shown here as part of unit Kmvm). On the north side of the Sierra Maestra in southern Cuba, this unit Ksv, includes the andesitic tuff and breccia, dacite, tuffite, shale, volcanic siltstone, basaltic lava, rhyodacite, conglomerate, and limestone of the Santo Domingo and Téneme Formations. Small bodies of porphyritic diorite, andesite, and diabase intrude the formations (IGP, 2011). Pardo (2009) considered these as part of his Bucney Formation and considered them potentially correlative with the Iberia Formation (unit Kvib). In a very limited area along the south coast of Cuba, the Palma Mocha Formation was described as mafic tuff and agglomerate having interbeds of shale and tuffaceous sandstone, as well as limestone, which is dominant in the upper part of unit (IGP, 2011), whereas Pardo (2009) described the Palma Mocha Formation as about 200 m of thin- to medium-bedded, black to dark-gray limestone containing local interbeds of crystal-lithic tuff, clearly focusing on only the upper part of the unit. The exposures of the unit are in a window through surrounding largely Tertiary volcanic rocks. Other rocks assigned to this map unit are in Puerto Rico and include an important unit in southcentral and southeast Puerto Rico, the Robles Formation. The Robles Formation is widely distributed in the Barranquitas (Briggs and Gelabert, 1962), Caguas (Rogers, 1979), Cayey (Berryhill and Glover, 1960), Comerio (Pease and Briggs, 1960), Jayuya (Mattson, 1968b), and Orocovis (Briggs, 1971) quadrangles and to a lesser extent in the Coamo quadrangle (Glover, 1961a). Divided into a several members and informal units, it has a dominantly tuffaceous phase (unit Kwt), a dominantly volcanic phase (unit Koba), a dominantly sedimentary and volcanoclastic phase (this unit), a chert unit (unit Kch), and a limestone and marble phase, which includes the Rio Matón Limestone Member (unit Kec). The sedimentary phase described here includes two defined members, the Cayey Siltstone Member and Collao Member. The Cayey Siltstone Member overlies the Rio Matón Limestone Member and is a thick sequence consisting principally of siltstone. The siltstone is about 300–350 m thick in the northcentral part of the Cayey quadrangle but thins toward the southwest, where it intertongues with the Lapa Lava Member (unit Kwt). It consists of three tongues: an upper tongue overlying the Lapa Lava Member, another between flows in the Lapa Lava Member, and one below the Lapa Lava Member. The middle and lower tongues pinch out southwestward within the quadrangle. Laminated siltstone is the chief component of the member, but it also includes layers of sandstone and volcanic breccia. Locally, at the top is a distinctive conglomerate (Berryhill and Glover, 1960). The Collao Member is higher in the Robles Formation, overlying the Las Tetras Lava Member of the Robles Formation (unit Kwt), and consists of siltstone and fine-grained sandstone, lenses of conglomerate, a unit of limestone, and a unit of lapilli tuff that is characterized by its reddish-brown color. A thin andesite lava flow is interstratified with the siltstone. Laminated siltstone like that of the Cayey Siltstone Member is the principal constituent of the member. The thickness of the Collao Member could not be measured accurately because of numerous displacements caused by faulting and deformation adjacent to igneous intrusions; an assumed maximum thickness is about 200 m. Adjacent to intrusions, the siltstone is contact metamorphosed and

pyritized. Locally, the siltstone contains lenses of conglomerate mainly in the basal part of the member. Most of the conglomerate is only poorly stratified and consists mainly of tightly compacted, subangular blocks and subrounded pebbles, cobbles, and boulders of porphyritic andesite. It also locally includes blocks of siltstone and thin interbedded lenses of sandstone. The limestone unit of the Collao Member consists of several massive layers of limestone and interbedded volcanic rocks about 6 to 7 m thick. Locally, the limestone is represented by almost pure epidote, which formed by contact metamorphism during the intrusion of the nearby igneous rocks (Berryhill and Glover, 1960). Other siltstone and conglomerate units occur within the Robles Formation, for example, associated with the Las Tetas Lava Member (Berryhill and Glover, 1960). West of the Cayey quadrangle, fewer distinctions are made within the Robles Formation; the sedimentary and volcanoclastic phase is described generally as dominantly medium-gray to light-brown thin-bedded tuffaceous sandstone; medium-gray to light-brown tuffaceous siltstone and medium-dark-gray to brownish-gray water-laid lapilli tuff common (Briggs and Gelabert, 1962; Briggs, 1971). Two other formations of central Puerto Rico are also assigned here. The El Ocho Formation (Pease, 1968c), exposed in the Naranjito quadrangle is mostly massive to thick-bedded volcanic breccia, coarse-grained tuff, interbedded lenticular bodies of tuffaceous wacke and siltstone, and having andesitic lava flows and flow breccias near its base. The unit is as much as 825 m thick although according to Pease (1968a) the formation is not completely exposed anywhere due to faulting. Pease (1968b) also mapped a bedded calcareous sandstone member in the upper part of the El Ocho Formation. A 180-m-thick basal siltstone, of the El Ocho Formation named the Piña Siltstone Member is assigned here to unit **Kue**. A somewhat more widely exposed unit, the Magueyes Formation of the Ciales and Corozal quadrangles (Berryhill, 1965; Nelson, 1967a) is similar lithologically consisting of chiefly greenish-gray, fine- to coarse-grained, massive to thin-bedded volcanic sandstone interbedded with dark-gray thin-bedded siltstone and subordinate dark-gray to greenish-black basaltic tuff and gray to dark-gray andesite flows (Nelson, 1967a)

- Kmm** **Martin Mesa Formation and similar formations, undivided (Cretaceous, Turonian to Aptian)**—Exposed in a linear belt in northwestern Cuba, the Martin Mesa and Pons Formations and the Buenavista Group are biomicritic limestone, calcarenite, polymictic sandstone, slate or argillite, chert, and clayey calcareous rocks (IGP, 2011). Pardo (2009) considered the Martin Mesa Formation, the easternmost of these units, a tectonic complex, consisting of thin-bedded, sometimes massive, gray, micritic limestone associated with medium-grained brownish-gray sandstone and calcareous slate; locally, sandstone is the dominant lithology (Pardo, 2009). West of the Martin Mesa Formation, the Buenavista Group consists of chert, breccia, limestone, and subordinate lenses of argillite and sandstone; Pardo (2009) subdivided the Buenavista Group into the Santa Teresa Formation (unit **Kch**) and the Carmita and Pinalilla Formations (subunit **Kelc**); and the Moreno Formation (unit **Kcls**). The Pons Formation, the westernmost of these units, is dark-colored micrite containing gray to black lenses and nodules of chert. Pardo (2009) suggested an age of Turonian to Hauterivian, but the units were considered Turonian to Aptian by IGP (2011)
- KJcm** **Mariquita Chert and Mate Prieto Unit (Upper Cretaceous, middle Turonian? to Upper Jurassic, lower Tithonian to upper Kimmeridgian)**—The Mate Prieto unit in Cuba is a small exposure of chert and metachert within tectonites of unit **KJmm**, exposed in the Camagüey region (IGP, 2011). In southwestern Puerto Rico, the Mariquita Chert is laminated, fine-grained, dark-gray chert that is locally interbedded with recrystallized and largely silicified limestone and nonmetamorphosed amygdaloidal pillow basalt (Krushensky and Monroe, 1979; Volckmann, 1984b, c, d). Radiolaria and locally foraminifera are abundant constituents and locally, the Radiolaria are completely recrystallized and may be selectively stained by iron oxide (Volckmann, 1984b). Mattson and Pessagno (1979) reported the radiolarians ranged in age from late Aptian to early Tithonian. The unit is found on both sides of the South Lajas Fault (Piety and others, 2018) in what is likely the upper part of a thrust sheet
- Kch** **Chert (Cretaceous, Cenomanian to Aptian or lower)**—Chert of this age is exposed in Cuba, Jamaica, Puerto Rico, and the U.S. Virgin Islands, although most widely exposed in northern and central Cuba. The Santa Teresa Formation is chalcidonic chert, green and brown radiolarian chert, siliceous shale, claystone, siltstone, limestone, and marl (IGP, 2011). Pardo (2009) described Santa Teresa Formation as a monotonous succession of thin, 3- to 6-cm-thick, beds of primary chert interbedded with dark, fissile, carbonaceous and sometimes marly or clayey shale, of probable volcanic origin. It is mineralized and stained with manganese oxides. Pardo (2009) described it as a characteristically noncarbonate unit and considered it a deepwater deposit that received strong influx of silica and fine detritus from contemporaneous submarine volcanism to the south. Pardo (2009) made the case that the Cenomanian age was a time of essentially no volcanic activity in central Cuba and that the stage separates older mafic submarine volcanism from younger, more felsic, arc-volcanic rocks. Thus, if the Santa Teresa Formation is related to volcanism, it should not be Cenomanian, but instead, it should be either younger or older

than Cenomanian. In view of its association with the underlying Constancia and Ronda Formations, and also taking into account that its lithology suggests an association with submarine volcanism and not arc volcanism, Pardo (2009) suggested it is more likely Albian through upper Aptian and not younger than lower Cenomanian. As mapped in this report, this unit **Kch** also includes quartzite of undefined age in Cuba (IGP, 2011). In eastern Jamaica, the Mount Charles Formation of the Above Rocks Inlier consists of metamorphosed conglomerate, banded chert, and mudstone along with intercalated andesitic tuff and flows, which dip westward (Hastie, 2007). In the Barranquitas quadrangles of Puerto Rico, yellowish-brown; dark-reddish-brown, or dark-gray chert occurs at the base of the Robles Formation (unit **Ksv**) (Briggs and Gelabert, 1962). On the southernmost part of Saint John in the U.S. Virgin Islands, Rankin (2002) mapped a very small exposure of light-blue-gray to dark-gray, bedded radiolarian chert of the Water Island Formation (see also map units **Kwi**, **Kvm**, and **Kkp**). Rankin (2002) also implied the presence of other areas of chert where radiolarians were not visible

- Kevc** **Volcaniclastic rocks, undifferentiated (Lower Cretaceous, Albian)**—Located in northeast Puerto Rico, this unit includes rocks of the Tabonuco and Fajardo Formations. The Fajardo Formation was divided into multiple units including an upper unit that is chiefly thin- to medium-bedded bluish-gray to black cherty tuffaceous siltstone and sandstone and noncalcareous thin-bedded tuffaceous siltstone and sandstone (see also unit **Kbb** for more tuffaceous phases of the Fajardo Formation). It locally contains some thick-bedded coarse tuff beds, which are more common and possibly thicker in the lower unit. The lower thin-bedded cherty siltstone is proximal to the Eocene Rio Blanco stock (unit **Ted**) and the chert may be a result of silicification due to emplacement of the stock. The two units of the Fajardo Formation are 300 to 500 m thick (Briggs and Aguilar-Cortes, 1980). The Tabonuco Formation contains calcareous thin- to thick-bedded dark-gray to bluish-black tuffaceous siltstone and sandstone (60 percent) interbedded with subordinate calcareous mudstone (30 percent) and breccia. Sandstone is moderately sorted and composed of angular, nonvesicular to moderately vesicular volcanic rock fragments and mineral grains. The Tabonuco Formation also includes a basal volcaniclastic breccia and a breccia composed chiefly of fragments of calcareous siltstone a few centimeters across in a calcareous sandstone matrix. In the contact zone of the Rio Blanco stock, the Tabonuco Formation has been metamorphosed such that near the contact, calcareous beds have been converted to calcsilicate hornfels. The top of the formation contains a few lava flows. The formation ranges from about 800 to 1,000 m thick (Seiders, 1971a; Briggs and Aguilar-Cortes, 1980). Also included in unit **Kevc** is a dark-gray to pale-green, cherty mudstone, which Seiders (1971a) placed stratigraphically below the Tabonuco Formation
- Kwi** **Water Island Formation, volcanic-clast wacke (Lower Cretaceous)**—In the U.S. and British Virgin Islands, this unit consists of volcanic wacke of subrounded to angular clasts of keratophyre, basalt, and trondhjemite, in a matrix that is probably comminuted keratophyre but includes xenocrysts of quartz and plagioclase (Rankin, 2002). Clasts are poorly sorted and may be more than 1 m across; bedding generally is poorly defined, though graded bedding is present but rare. Pumiceous keratophyre clasts are rare except where submarine pumice flows may be present. Trondhjemite clasts as large as boulder size (likely from the trondhjemite and keratophyre unit **Kqt** in this report) are found locally (Rankin, 2002)
- Kpf** **Polier Formation (Lower Cretaceous, Albian to Valanginian)**—Exposed in northern Cuba, Pardo (2009) and IGP (2011) described this formation as thin-bedded micritic limestone interbedded with sandstone and shale as much as 200 to 300 m thick and decreasing to less than 30 m thick southward. The lower part of formation is thin-bedded, gray, micritic limestone interbedded with claystone and sandstone. Calcareous-cemented sandstone is gray to dark-gray, hard, fine-grained, and generally thin bedded, but locally, has beds as much as 1 m thick. Beds have organic and inorganic markings at their base, and they have graded bedding and horizontal- and cross-laminations; clasts are dominantly poorly rounded quartz and subordinate plagioclase and muscovite; Pardo (2009) considered the sandstone to be a turbidite deposit
- KJcl** **Chert-rich limestone (Lower Cretaceous to Upper Jurassic)**—Widely exposed in northern and central Cuba are several formations of limestone, chert, and clastic sedimentary rocks. The Esperanza Formation in westernmost Cuba has a lower terrigenous unit consisting of limestone and subordinate sandstone and siltstone and contains intercalated bodies of diabase or tholeiitic basalt. The upper terrigenous unit consists of sandstone and quartz-rich siltstone with beds of claystone and limestone (IGP, 2011). Pardo (2009), describing a Spanish translation of a Russian paper reports that the Esperanza “group” has 3 groups of lithologies that from the bottom are (1) a sandy shaly-carbonaceous carbonate-terrigenous package, (2) a sandy shaly-carbonaceous terrigenous package, and (3) a carbonate package. Pardo (2009) reports that “In general, the section of the Esperanza Group contains several types of limestones: micrites; biomicrites; sandy, nodular, dolomitized limestones; dolomites with terrigenous material represented by calcareous sandstones; quartz-rich sandstones; and thin clay beds.” He relates the Tithonian part

of the Esperanza Formation to the Artemisa and Guasasa Formations and the upper parts to the Polier Formation (unit Kpf) and possibly in part with overlying Santa Teresa Formation (unit Kch). The Esperanza Formation as mapped here apparently does not include Pardo's (2009) upper unit. Exposed just south of the Esperanza Formation, the Guasasa Formation is bedded to massive, medium-gray to black, bituminous, sometimes dolomitized limestone. Locally, a sedimentary breccia is present at the base that consists mostly of Guasasa fragments but also contains fragments of Jagua Formation (unit Jjg). The Guasasa Formation has chert nodules in its lower sections, and chert beds in the upper part of the unit. The limestone of the Guasasa Formation is responsible for the characteristic rugged mogotes landscape that is a mature stage of karst topography. Streams flow uninterruptedly underground through the limestone hills and ridges. The Guasasa Formation ranges in age from upper Oxfordian to early Valanginian (Pardo, 2009). The Artemisa Formation, exposed west of Havana, is composed of micrite, calcilutite, calcarenite, and minor calcirudite and contains interbeds of chert as well as incidental beds of siltstone and fine-grained sandstone (IGP, 2011). In central Cuba, north of the Escambray Massif, the Constancia Formation is calcareous sandstone, sandy limestone, conglomerate, calcareous siltstone, marl, and claystone (IGP, 2011). The Trocha Formation, exposed in the same general area is composed of micrite, clay-rich, oolitic, pisolitic, and dolomitized limestone, and like the Guasasa Formation, it contains lenses and chert nodules. It also has dolostone interbeds as well as isolated beds of calcareous breccia (IGP, 2011). Pardo (2009) considered it part of a group and based on fossils present, suggested it was a largely shallow water unit. The Veloz Formation is also in central Cuba and is the most widespread of these Cuban formations. It is a thin-bedded, clay-rich micritic limestone containing chert nodules and ammonites. Pardo (2009) considered the unit distinct because of the thin tuff and glassy laminae interbedded in the unit. He also described the unit as being allochthonous

Jjg **Jagua Formation of Cuba (Upper Jurassic)**—Exposed in thin linear belts in northwestern Cuba, which underlie the Guasasa Formation, the Jagua Formation is composed of micritic, bioclastic, and marly limestone, and coquina. It contains interbeds of shale that have fossil-bearing calcareous concretions (Puscharovsky and others, 1988; IGP, 2011). Similar to the Guasasa Formation, the Jagua Formation is 30 to 160 m of dense, black, bituminous, medium-bedded limestone that contains thick beds of oyster coquina and purple-black shale that has limestone concretions containing a rich fauna of ammonites, fish, and reptile bones (Pardo, 2009)

Jpa **Punta Alegre Formation of Cuba (Upper Jurassic)**—Composed of gypsum-cemented breccia containing clasts of limestone, slate, siltstone, sandstone, and tuffite. Pardo (2009) indicates that the formation name applies to a breccia of heterogeneous rock fragments in a gypsum matrix. He states that the breccia has been subdivided into four varieties based on the number, size, and abundance of exotic clasts and the red, blue, yellow, or brown color of the gypsum matrix. The exotic clasts, which form most of the rock, vary from a few centimeters to more than 100 m. The clasts consist of blocks of black, dark-gray, or dark-red medium-grained limestone, which is locally oolitic as well as dolomitized limestone and dolostone, purple slate, red shale, argillite, blue quartzite, quartz-rich sandstone, and tuff. The carbonate clasts form most of the clasts in the unit. The age of the Punta Alegre Formation is considered Tithonian or older based on abundant *Favreina joukowskyi* that is found in the dolostone exotic clasts; it is the only identifiable fossil in the unit. Though globally *Favreina joukowskyi* appears to range from Tertiary to Upper Jurassic, it is considered an important Upper Jurassic fossil in the Caribbean region (Pardo, 2009)

Jff **Francisco Formation (Upper Jurassic, upper to middle Oxfordian)**—Exposed in small areas in northern Cuba where it is closely associated with the San Cayetano Formation, the Francisco Formation consists of dark shale and siltstone, micritic limestone, and calcareous and quartzose sandstone. Locally, calcareous concretions are present in shale of the unit. According to Pardo (2009), the formation has a maximum thickness of 25 m and represents a transition between the underlying San Cayetano Formation (unit Jvs) and the overlying Artemisa Formation (unit KJcl). Pardo (2009) also reported ammonites as well as fossil fish and plant remains have been found in the formation. *Globochaetes* sp. has been identified in the formation. The fauna indicates a late middle Oxfordian age

VOLCANIC ROCKS

Qv **Alkali basalt (Quaternary)**—In east-central Dominican Republic, consists of “alkaline basalt” (Toloczyki and others, 1991). In northern Haiti, consists of nepheline basalt of the Mome La Vigie and of the eastern part of Chaîne des Matheux, which is accompanied by ash and scoria (Vila and others, 1985; MMER, 1989). The 200-m-high scoria cone of Mome La Vigie features fresh deposits of scoria, ash, and tuff and has numerous associated cracked bombs; its crater is 250 m in diameter (Butterlin, 1960, as cited in Vila and others, 1985; Wadge and Wooden, 1982). Wadge and Wooden (1982) described five centers of Quaternary volcanism on the island of Hispaniola. In Haiti, they consist of nepheline basalt; in Dominican Republic,

	they are alkali olivine basalt and basanite. In Dominican Republic, flows can be as much as 10 km long, originating from several vents marked by small cinder cones (Wadge and Wooden, 1982). Wadge and Wooden (1982) reported a 1.1 ± 0.5 Ma K/Ar age on basanite from the San Juan volcanic field in Dominican Republic and a 1.8 ± 0.9 Ma K/Ar age on nephelinite from the Thomazeau field in eastern Haiti
QTV	Volcanic rocks of Dos Hermanos and Valle Nuevo (Quaternary, Pleistocene and Tertiary, Pliocene)—In Cordillera Central of Dominican Republic, rocks of this unit consist of trachyandesite domes, flows and pyroclastic rocks, rich in biotite and hornblende, latite containing hornblende, augite andesite, olivine basalt and subordinate alkaline basalt (Toloczyki and others, 1991). In Dos Hermanos volcanic field, volcanic products include numerous domes, flows, and dikes; in Valle Nuevo field, products are of more variable compositions that include rhyolite, andesite, trachyandesite, and phlogopite-bearing basalt (Wadge and Wooden, 1982). K/Ar ages vary between about 0.3 and 2.8 Ma (Vespucchi, 1986)
Thb	Hypabyssal dikes and intrusions, undifferentiated (Tertiary)—In Cuba and Puerto Rico, includes hypabyssal rhyolite and syenite, porphyritic rhyodacite and dacite dikes, and hypabyssal intrusions. The Cuban Institute of Geology and Paleontology (IGP, 2011) mapped multiple occurrences of rhyolite, rhyodacite, and dacite in southern Cuba in the Sierra Maestra. Neither age or descriptions other than rock-type were provided and most occurrences are in very small bodies except for a large complex west of Guantanamo Bay and north of El Verraco. An Eocene age can be inferred for these bodies. Also, in the Sierra Maestra, numerous small diabase and diorite bodies were mapped, all west of the complex just described (IGP, 2011). In eastern Puerto Rico, several diorite, diabase, or hornblende andesite dike complexes of inferred Tertiary (Eocene?) age were mapped in the Aguas Buenas (Pease, 1968b), Cayey (Berryhill and Glover, 1960), Central Aguirre (Berryhill, 1960), Rio Grande (Pease and Briggs, 1972), and San Juan (Pease and Monroe, 1977) quadrangles. Pease (1968c) mapped a small pyroxene diorite dike in the Naranjito quadrangle and assigned it a Tertiary age. He reported that though the dike cuts no strata younger than Late Cretaceous, it closely resembles dikes that cut strata of Paleocene age in the San Juan quadrangle. In Puerto Rico, dacitic stocks and dikes are apparently restricted to the western part of the island and southwest of the GSPRFZ. Generally inferred to be of Eocene age, they are found in the Adjuntas (Mattson, 1968a), Central La Plata (McIntyre, 1971), Jayuya (Mattson, 1968b), Maricao (McIntyre, 1975), Moca and Isabela (Monroe, 1969b), and Monte Guilarte (Krushensky and Curet, 1984) quadrangles. On Virgin Gorda, British Virgin Islands, Helsley (1960) also mapped several north-trending lamprophyre dikes that cut the batholith, which he inferred were middle Eocene. On Saint John, in the U.S. Virgin Islands, the unit includes a Tertiary(?) mafic dike (not shown on map sheet 1 or 5) 15 to 20 cm thick and about 20 m long that contains 60 percent or more xenoliths of keratophyre, greenstone, gabbro, and tonalite and inferred to represent an explosion breccia (Rankin, 2002). Shown at the southernmost tip of Saint John, is a small magnetite-bearing, aphanitic dike that has prominent hornblende phenocrysts as large as 3 cm by 1 cm and, locally, clinopyroxene phenocrysts as large as 1 cm (Rankin, 2002). This unit also includes the informal Red Hook tonalite porphyry of Rankin (2002), which is characterized by large bipyramidal quartz and barrel-shaped biotite phenocrysts, in aphanitic to fine-grained and locally spherulitic groundmass; phenocrysts may constitute as much as 45 percent of rock that consists of quartz, plagioclase, biotite, less commonly hornblende, and prominent apatite (Rankin, 2002). Where age is reasonably well controlled, rocks of this map unit are thought to be Eocene; however, in many cases, an age of Tertiary is as precise as can be defined
Tv	Volcanic rocks including Low Layton Lavas of Jamaica (Tertiary, early Pliocene to Oligocene)—Largely on Hispaniola, but also Jamaica, consists of submarine basalt and subordinate andesite. As described, includes some tuff and agglomerate. In both Haiti and Dominican Republic, its exposure areas are limited and are in generally linear belts through central Haiti and southern Dominican Republic and northern Dominican Republic (Toloczyki and others, 1991). In Haiti, the unit is alkaline basalt of the Chaîne des Matheux (MMER, 1989). In Dominican Republic (in Sierra de Neiba and Sierra de Baoruco), it includes subaerial and submarine basalt, tuff, and agglomerate (Toloczyki and others, 1991). In Jamaica, it includes the Miocene Low Layton Lavas (McFarlane and others, 1984), which resulted from a submarine-fissure eruption that produced a modest volume of alkaline basalt at Low Layton, on Jamaica's north coast ($18^{\circ}12.99' \text{ N.}, 76^{\circ}35.77' \text{ W.}$). The eruption, which occurred in no more than a few hundred meters of water, produced a series of hyaloclastite, pillow-basalt breccia and flows, massive flows, and dikes that have east-northeast-trending, en echelon structural grain; the volcanic center lies on strike with the Duanvale Fault Zone, one of that island's major east-west-striking strike-slip fault zones (Wadge, 1982)
Tve	Basalt to andesite, undifferentiated (Tertiary, Eocene?)—Primarily exposed in southern Cuba, with outlier exposures in northern Cuba; basalt, basaltic-andesite, and andesite bodies were mapped and included in this map unit. No age assignment is reported or further description provided in previous publications (IGP, 2011); however, based on setting, we inferred an Eocene age for these rocks

Tab	Andesite and basalt, undifferentiated (Tertiary, Eocene)—Exposed in eastern Jamaica are three volcanic-rock formations of Eocene age, the Halberstadt Volcanics, the Nutfield Volcanics, and the Newcastle Volcanics (McFarlane and others, 1984). These are all associated with the Wagwater Formation (unit Tpcv). The Newcastle Volcanics, the most extensive of the three volcanic-rock formations, is porphyritic andesite, dacite, and quartz keratophyre flows and their sedimentary derivatives (Roobol, 1972, as cited in Mann and Burke, 1990). “The Newcastle Volcanics are most abundant in the Dry River Member of the Wagwater Formation, but are also found in the Ginger River and Pencar River Members of the Wagwater Formation and the Roadside Member of the Richmond Formation” (Mann and Burke, 1990). The basalt pillow lavas of the Halberstadt Volcanics, 200 to 300 m thick, are contained within the Pencar River Member. The Nutfield Volcanics are a thin sheet of basaltic pillow-lava flows conformably overlain by a dacite flow (Roobol, 1972, as cited in Mann and Burke, 1990). In Haiti, dacite and basalt are known from the west part of the southern peninsula, these small exposures are largely associated with Paleocene to Eocene volcanoclastic rocks included in unit Tcpc. In the British Virgin Islands, Helsley (1960) reported small areas of Tertiary (middle Eocene?) basalt on Guana, Scrub, and Necker Islands
Tfv	Felsic volcanic rocks (Tertiary, Eocene)—A Puerto Rican unit, these felsic rocks are largely associated with the GSPRFZ. Within the fault zone, this unit is inconsistently identified between quadrangles; therefore, its depiction on the map does not fully reflect its extent. In its northernmost mapped extent in the Adjuntas quadrangle, the unit, mapped as part of the Anón Formation, consists of massive greenish- or bluish-gray dacite porphyry containing sparse to common phenocrysts of feldspar and hornblende, minor pyroxene, and rare quartz (Mattson, 1968a). Mattson (1968a) indicates that as mapped, the unit includes lesser amounts of other volcanic rocks, and that minor amounts of dacite also occur in other Anón Formation map units. To the south in the Penuelas and Punta Cuchara quadrangle, several varieties of dacite were mapped by Krushensky and Monroe (1978), all of which were hydrothermally altered. The varieties, all porphyritic, have varying amounts of hornblende and augite. In the adjacent Ponce quadrangle to the east, Krushensky and Monroe (1975) described very similar dacite, which they assigned to the Anón Formation and in addition, described it as saprolite. It is possible that all the dacite described here is altered to saprolite
Tvc	Pyroclastic rocks (Tertiary, Eocene)—Found in Cuba, Puerto Rico, and the Virgin Islands, compositionally, this unit is more dominantly volcanic than the more sedimentary unit Tesv, though the distinction is not everywhere unequivocal. In southern Cuba in the Sierra Maestra, several formal stratigraphic units have been assigned to this map unit. Most extensive are the El Caney and Berracos Formations. The El Caney Formation consists of air-fall tuff, tuffite, calcareous tuff, lapilli tuff, tuffaceous limestone, and interlayers of flows and agglomerate; associated with similar, but slightly older rocks of the Cobre Formation (unit Tvep) (IGP, 2011). The Berracos Formation consists of tuffaceous sandstone and siltstone, fragmental tuff, and agglomerate ranging in composition from andesite to rhyodacite. Andesitic and rhyodacitic flows are also present. The Gran Piedra Member of the Berracos Formation is composed of rhyolitic and rhyodacitic welded tuff, rhyolitic breccia, ignimbrite deposits, tuffaceous sandstone and chert, tuffaceous calcareous conglomerate, clay-rich limestone, and minor basaltic-andesite flows (IGP, 2011). Note that the Berracos Formation was mapped on seven separate sheets by the IGP (2011). On five of the sheets, the unit is assigned an early Eocene age, whereas on the other two sheets, it is assigned an early Pliocene to late Miocene age; we have accepted the Eocene age determination as it fits better with the spatially associated geologic units. The El Escandel Member of the Chorrerón Formation is composed of felsic welded tuff and subordinate intermediate to mafic tuff, tuffaceous sandstone and interbeds of limestone and calcareous sandstone (IGP, 2011). In Puerto Rico, rocks of this unit are restricted to the GSPRFZ. These rocks interfinger with the sedimentary and volcanic rocks of unit Tesv, and available mapping does not allow unequivocal assignment of source map units to Tesv or Tvc. Formation names as well as included members and lithology within a formation vary along the GSPRFZ, roughly from south to north, including the Rio Descalabrado Formation in the south, the Anón and Rio Culebrinas Formations toward the middle and the Milagros and Matilde Formations in the north. The tuff of the Rio Descalabrado Formation is dacitic to andesitic and is interbedded with mudstone. It tends to be thin- to medium-bedded and may show graded bedding or small-scale crossbedding (Glover and Mattson, 1973). The Anón Formation consists of volcanic breccia and flows and subordinate tuff, tuffaceous sandstone, siltstone, and mudstone. Compositionally, it generally ranges from dacite to andesite (Mattson, 1968a, b; Krushensky and Curet, 1984). The Anón Formation, as mapped by Krushensky and Curet (1984) in the Monte Guilarte quadrangle, which they considered Eocene to Late Cretaceous, has an outlier, outside of the GSPRFZ. We consider that part of the Anón Formation

within the GSPRFZ is Eocene, and the outlier, based on context, is possibly Cretaceous, part of map unit TKmv. The tuff and volcanic sandstone of the Rio Prieto Formation of the Adjuntas and Jayuya quadrangles (Mattson, 1968a, b) are also included in this unit Tvc. In northwest Puerto Rico, the tuff and breccia of the Rio Culebrinas Formation is largely tuffaceous breccia, but contains fragments of limestone, algal materials, foraminifera, and blocks of coarse tuff (McIntyre, 1971). This unit is largely saprolitized; as described and mapped, it is transitional between units Tesv and Tvc. The tuff breccia of the Rio Culebrinas Formation is very thick bedded and based on the description is difficult to distinguish from the breccia member of the Milagros Formation. In the adjacent San Sebastian and Central La Plata quadrangles to the north (McIntyre, 1971; Tobisch and Turner, 1971), the Rio Culebrinas Formation is described as primarily thin-bedded crystal or lapilli tuff, volcanic sandstone, and subordinate massive tuff breccia. The Matilde and Milagros Formations from the Bayaney quadrangle (Nelson and Tobisch, 1968) of northwest Puerto Rico, are fine-grained bedded tuff, grayish-brown, fine-to medium-grained volcanic sandstone and siltstone, and subordinate andesite (Tobisch and Turner, 1971). They are shown as part of unit Tesv. However, as mapped in the Bayaney quadrangle (Nelson and Tobisch, 1968), these formations contain a higher proportion of volcanic rocks and are included as part of unit Tvc. The breccia member of the Milagros Formation in the Maricao quadrangle, is primarily tuff breccia and has local intercalations of thin-bedded coarse-grained tuff (McIntyre, 1975). The now abandoned Santas Pascuas Member of the Lago Garzas Formation was mapped by Krushensky and Monroe (1978) and subsequently abandoned by Krushensky and Curet (1984) as they considered it a facies of the Anón Formation. The unit (facies) was described as at least 350 m thick, consisting of a variety of pumiceous tuff as well as subordinate porphyritic lava and minor limestone. "Rock in most areas is deeply saprolitized. Pumiceous beds commonly show reverse grading; pumice clasts of the tube type are concentrated near the top, and lithic clasts are concentrated near the base of any one bed" (Krushensky and Monroe, 1978). Lithic clasts in welded ash-flow tuff, locally show perlite structure. The clasts are "chiefly of glass shards, not flattened or showing any sign of diagenetic compaction, but finely shattered as though they were hot when they entered water. Included plagioclase, hornblende, and augite crystal clasts are finely shattered and unaltered" (Krushensky and Monroe, 1978). In the British Virgin Islands, the undivided Tortola Formation and its Shark Bay, Hans Lollik, and Sage Mountain Members consist of light- to dark-green andesite and augite-andesite breccia, tuff, and volcanic-lithic sandstone about 6,000 m thick. Note that, in the U.S. Virgin Islands, the Hans Lollik Member was considered a formation, part of the Virgin Island Group (Donnelly, 1966) and subsequently the Hans Lollik Formation was abandoned, and the rocks assigned to the Louisenhoj Formation (Rankin, 2002), are shown as unit Kip in this report. The Tortola Formation is a sequence of andesitic breccia, tuff, and reworked tuffaceous sedimentary rocks that are well exposed on northern Tortola and on Jost Van Dyke Islands and are exposed as roof pendants on Virgin Gorda Island. It is deformed, having dips as high as nearly 90°; locally, moderately to intensely contact metamorphosed adjacent to the Narrows pluton (U.S. Virgin Islands name, on Saint John) or Virgin Gorda batholith (British Virgin Islands name); these are the same pluton and are mapped as the granite and granodiorite unit Tegr in this report (Helsley, 1960; Donnelly, 1966). In addition to volcanic-rock lithologies, several minor limestone and limestone-breccia units are present, which have yielded foraminifera of Eocene age. The Shark Bay Member is distinctive because of its characteristic whitish-green color and abundant fragments of dark-green glass fragments; in its upper part, it also includes the Mount Healthy shallow-water limestone lentil (mapped as the limestone containing igneous-rock debris unit Tec in this report). The Shark Bay Member conformably overlies, and interfingers with, the Sage Mountain and Hans Lollik Members. Donnelly (1966) indicated that the Hans Lollik Formation of the Water Island Group is Albian; however, available foraminifera and radiometric dates (Alminas and others, 1994) support an Eocene age, as indicated by Helsley (1960). It appears quite likely the Hans Lollik Member of Helsley (1960) is a different but lithologically similar unit relative to Donnelly's (1966) Hans Lollik Formation and Rankin's (2002) reassignment of the rocks on Hans Lollik Island to the Louisenhoj Formation. It is locally divided into subunit Tn

Tn

Necker Formation—In British Virgin Islands, light-green to tan, subaerial tuff and breccia; it includes welded tuff in lower part of the formation, always near Virgin Gorda batholith (unit Tegr). The tuff is fine grained and interbedded with breccia, as well as with tuffaceous volcanic-clast sandstone whose typical development and excellent exposures on Necker Island led to formation's name. The unit also crops out on small islands north of Virgin Gorda and on Guana Island and Great Camanoe Island. Exposed on these three island groups, the unit varies from island group to island group. In the first island group, which includes Necker, Prickly Pear, Eustatia, and Mosquito Islands, pyroclastic rocks resemble the upper part of the Tortola Formation (unit Tvc), the major

difference being they are dominantly fine tuff rather than breccia and are much less deformed; having a maximum dip, about 40° and an average dip being near 20°, compared to the near 90° dip of the Tortola Formation (Helsley, 1960). Low-grade metamorphism has yielded epidote as the only probable metamorphic mineral. The basal part of the exposed section, 500 m of subaerial ash, is on Prickly Pear Island; the lower approximately 150 m is light-blue-green to green, very fine grained tuff that has poorly developed bedding, interbedded with a few moderately well sorted, coarse, green lithic tuff layers. The approximately 350 m of the upper part is green, coarse, lithic and lithic-lapilli tuff and a few interbedded layers of breccia and vitric(?) fine tuff that dominantly consists of andesitic and felsic fragments. The second island group includes Seal Dogs (West Seal Dog and East Seal Dog), Cockroach Island, and George Dog. On Cockroach Island and George Dog, all exposures are amphibolite, and virtually no original textures or structures remain, whereas in the Seal Dogs, the unit is only mildly metamorphosed. On Seal Dogs, it consists of breccia and lithic-lapilli tuff, much of which shows evidence of reworking as large slump blocks, several more than 3 m long, of very poorly bedded to massive, fine-grained, thin-bedded tuff layers within the lapilli tuff. As in first island group, alteration has developed epidote minerals throughout section. The presence of fragmentary quartz crystals on Cockroach Island and George Dog, as well as a dioritic fragment on West Seal Dog that is very similar to the fine-grained intrusive rocks on West Dog (unit **Tegr**), is the only slight evidence available for grouping these rocks with the Necker Formation (Helsley, 1960). Other than this slight evidence, and their location in the islands, these rocks are more closely related to the Tortola Formation (unit **Tvc**) and may actually belong with unit **Tvc** on the basis of their degree of metamorphism, which is not otherwise observed in the Necker Formation. The third group, on Guana and Great Camanoe Islands, consists of “a wide variety of rock types all of which were deposited subaerially with the possible exception of one thin bedded to laminated very fine-grained porcelaneous tuff, which may have been either a subaqueous or a subaerial deposit. The breccia, lapilli tuff and tuff were all weathered shortly after deposition without reworking, except for probable slumping. Some of the breccia units could be mudflow deposits, however. Several flow units were recognized varying from extensive welded tuffs with columnar jointing to flow breccia of very local development. The entire section, including the later porphyritic basalt dikes and sills, has undergone considerable alteration with replacement of the original rocks by quartz, chlorite, calcite, epidote and sericite. Calcite, chlorite, and quartz are found as replacements throughout the section while epidote and sericite are restricted to local units. The sericite is restricted to the welded tuffs, flows and late basaltic intrusive rocks and may in part be related to metamorphism by the batholith and/or the basaltic intrusive rocks. At least some of this widespread alteration is later than the basaltic intrusive rocks, which cut the entire section, and thus the alteration is probably associated with late magmatic and hydrothermal activity associated with the intrusion of the batholith rather than with the basaltic intrusive rocks themselves. Some of the alteration probably took place very shortly after deposition particularly in the case of the welded tuffs which are much more altered than the surrounding lithic tuffs” (Helsley, 1960)

TKrd

Dacite and keratophyre, undifferentiated (Tertiary, Eocene? to Late Cretaceous)—Small exposures of dacite and trachyte of indeterminate age are found south of Havana in northern Cuba and west of Holguin in southern Cuba (IGP, 2011). They are inferred in this report to be Late Cretaceous or Tertiary and are commonly associated with other Cretaceous rocks. Exposed in the Monte Guilarte, and Penuelas quadrangles of Puerto Rico is dacite associated with unit **TKmv** that is light- to pale-greenish-gray porphyritic dacite, which is widely saprolitized to a pale-gray clay. Where less altered, the dacite contains phenocrysts of plagioclase, hornblende, quartz, and rarely augite in a microgranitic to xenomorphic-granular groundmass of albite, quartz, potassium feldspar (orthoclase?), and accessory magnetite and apatite (Krushensky and Curet, 1984). The dacite is commonly associated with Late Cretaceous mafic volcanic rocks of unit **TKmv**, which are also saprolitized. Four dacite bodies which were originally mapped as part of this unit in the northern part of the Monte Guilarte quadrangle have been reassigned to map unit **Ted** as there was age control suggesting they were Eocene (two age determinations of sample 31–1, K/Ar hornblende at 42.8 ± 5.6 and 45.3 ± 4.0 Ma [Cox and others, 1977]; age recalculated using constants of Steiger and Jager [1977]). In the Parguera quadrangle of southwestern Puerto Rico, Volckmann (1984a) described a pinkish-gray, very light gray, and pale-yellowish-brown massive intrusive dacite body containing plagioclase and sparsely present indeterminate chloritized mafic mineral phenocrysts. Plagioclase phenocrysts of andesine (An_{38}) composition are blocky, zoned, commonly embayed, and partly sericitized. Quartz occurs as small, 0.2 to 1 mm, anhedral grains in a microcrystalline matrix of poorly oriented plagioclase laths and hematite, magnetite, and epidote grains

TKmd	Mafic dikes and sills, undifferentiated (Tertiary, Eocene to Late Cretaceous) —Primarily exposed in central and eastern Puerto Rico, the dikes and sills are typically andesite, which is locally porphyritic. Locally, they are dioritic or gabbroic. In eastern Puerto Rico, in the Fajardo and Cayo Icacos quadrangles (Briggs and Aguilar-Cortes, 1980), they range in thickness from 10 to 160 m, though typically are about 80 m thick. In central Puerto Rico, the dikes tend to be deeply weathered (Glover, 1961b). In the Adjuntas and Jayuya quadrangles Mattson (1968a, b) described the dikes as basalt, andesite, and dacite and as generally less than 10 m thick, though they may locally be as much as 50 m thick; he also included in his map unit a diabase plug
TKfd	Felsic dikes and sills, undifferentiated (Tertiary, Eocene to Late Cretaceous) —These felsic dikes, commonly dacite, are more sparsely distributed than the mafic dikes (unit TKmd) described above. In eastern Puerto Rico, they are described as aplite or pegmatite in the Humacao and Naguabo quadrangles (M'Gonigle, 1978, 1979), whereas in the Orocovis quadrangle of central Puerto Rico they are described as commonly porphyritic dacite or andesite (Briggs, 1971) and in the Rio Descalabrado quadrangle (Glover and Mattson, 1973) of southcentral Puerto Rico they were described as dacite and quartz-micro-diorite dikes. M'Gonigle (1978, 1979) also described medium-grained hornblende quartz diorite and hornblende granodiorite dikes (that locally bear bipyramidal quartz phenocrysts) and fine-grained quartz-bearing dacite dikes. On eastern Saint Thomas in the U.S. Virgin Islands, several quartz-andesine porphyry dikes that trend northeastward and, to lesser extent, northwestward, cut unit Kkp, keratophyre of the Water Island Formation (Donnelly, 1966); age of these dikes is only inferred
TKmp	Porphyritic andesite-diorite (Tertiary, Eocene to Late Cretaceous) —Restricted to western Puerto Rico in the Mayagüez, Rosario, and northern San German quadrangles, this unit constitutes massive, porphyritic andesite that grades into diorite (Volckmann, 1984b; Curet, 1986). A second phase largely exposed on the southern margin of the intrusion, “weathers to a pale-purple-gray saprolite that locally preserves the texture of the original rock. Remnants of fresh rock preserved in the saprolite are rare” (Curet, 1986). Volckmann (1984c) mapped a basaltic andesite unit along the northeastern border of the San German quadrangle. The western block of this basaltic andesite corresponds to this andesite-diorite unit, whereas the eastern block of the basaltic andesite appears to correspond well with the two-pyroxene basalt units it adjoins in the Rosario quadrangle (Curet, 1986) and Sabana Grande quadrangle (Llerandi Roman, 2004) and shown in this report as unit Klmv. The unaltered rock typically “consists of 20–40 percent euhedral to subhedral plagioclase (An_{46}) phenocrysts (1–3 mm long); 5–10 percent poikilitic, euhedral to subhedral, generally altered augite phenocrysts (1–3.5 mm long); and 0–5 percent euhedral to subhedral, dark-green to olive-brown, poikilitic, and commonly altered hornblende phenocrysts (1–1.5 mm long) in a pilotaxitic to intersertal groundmass. * * * Olivine is present in trace amounts only. Magnetite makes up as much as 10 percent of the rock” (Curet, 1986). The body appears to be largely intrusive with brecciated margins
TKmv	Andesite and basalt flows and tuff, undifferentiated (Tertiary, Eocene to Late Cretaceous, Campanian) —Restricted to Puerto Rico, and generally to southwest Puerto Rico, this unit is dominantly volcanic-rocks. The only exposure of this unit outside of southwest Puerto Rico is black basalt of the Guaynabo Formation in the Aguas Buenas quadrangle (Pease, 1968b), which is distinct from the Martin Gonzales Lava Member of the Guaynabo Formation (shown in unit Klmv in this report). This basalt, no more than 5 m thick, consists of dark-gray to black glassy lava containing small phenocrysts of plagioclase and pyroxene. Pease (1968b) considered it possibly younger than Guaynabo Formation as it is similar to the vitrophyre in Guaracanal Formation (unit Tpv); this single exposure extends into the adjacent Gurabo quadrangle (Seiders, 1971b). In western Puerto Rico, rocks of the abandoned Mal Paso and Palma Escrita Formations were mapped by J.M. Aaron (U.S. Geological Survey, unpublished data, 1968), McIntyre and others (1970), McIntyre (1971, 1975), and Tobisch and Turner (1971). Subsequently, these formations were formally abandoned by Krushensky and Curet (1984), who considered them interbedded facies of Anón and Lago Garzas Formations. As originally mapped, the Mal Paso Formation consisted of grayish-red-purple amygdaloidal, basaltic pillowed flows and breccia, greenish-gray celadonite tuff and coarse vitric tuff of Eocene age. The Palma Escrita Formation was mapped as concordantly underlying the Mal Paso Formation and consisted of thick to thin-bedded green and greenish-gray pumice-rich rhyodacitic lapilli tuff, coarse-to fine-grained vitric tuff, and oxidized mafic volcanic rock fragments. Basaltic flows are locally present. The tuff weathers readily to reddish-brown, yellowish-brown, and yellow soil (McIntyre, 1971). As mapped by Krushensky and Curet (1984), rocks they described as interbedded Lago Garzas and Anón Formations in the Monte Guilarte quadrangle are included in this unit. The Yauco Formation (unit Ku) defined as an Upper Cretaceous unit, was commonly mapped interbedded with the Lago Garzas and locally, even mapped with the Anón Formation (Krushensky and Curet, 1984).

More commonly, the Lago Garzas and the Yauco Formations were mapped together (Krushensky and Monroe, 1975, 1978). Included in this unit are map units where the Lago Garzas appears to be the dominant formation. Also included in this unit are areas mapped as simply the Lago Garzas Formation, which is characteristically dark-purple, massive, polymictic, volcanoclastic breccia and flows, making up as much as 90 percent of the unit, and subordinate conglomerate, tuff, volcanoclastic sandstone, and limestone. Only the fine- to medium-grained sandstone and tuff show bedding. Clasts in the breccia consist of gabbro, and various porphyritic rocks (Mattson, 1968a, b; Krushensky and Monroe, 1975, 1978, 1979; Curet, 1986). These rocks of the Lago Garzas Formation (former Mal Paso Formation?) are irregularly interbedded with pale-gray, pale-gray-green, pale-yellow-brown, and uncommonly medium-green porphyritic hornblende dacite flows, volcanoclastic breccia, tuffaceous sandstone and mudstone, and tuff characteristic of the Anón Formation (former Palma Escrita Formation?). In part due to extensive saprolization, it appears that Krushensky and Curet (1984) could not readily distinguish the abandoned Mal Paso, Palma Escrita, and Anón, and Lago Garzas Formations, resulting in them placing them in a combined unit of Eocene to Maastrichtian age. The rocks of the abandoned Rio Blanco Formation (McIntyre and others, 1970; Tobisch and Turner, 1971; McIntyre, 1971, 1975) were reassigned locally to the Eocene Anón Formation or the interbedded Upper Cretaceous Lago Garzas and Yauco Formations. The Rio Blanco name was abandoned by Mattson (1967) and Krushensky and Monroe (1978). Fossil control, as reported by Krushensky and Curet (1984), indicate definitive Maastrichtian and Eocene ages for parts of the combined units; conspicuous is the absence of definitive Paleocene rocks. As all these units are proximal to the GSPRFZ, could the apparent interbedding of likely Upper Cretaceous and Eocene rocks be fault imbrication, rather than an indication of long-term volcanic activity? Available data do not allow resolution of this problem. Additional exposures of this unit west of the GSPRFZ, are offset by an east-west trending fault cutting across the Rosario and Maricao quadrangles. North of the fault in the Rosario quadrangle, the rocks were mapped as early Tertiary to Cretaceous (Maastrichtian) porphyritic augite basalt (Curet, 1986) consisting of dark-bluish-gray, dark- to light-gray massive basalt, which Curet (1986) considered cogenetic with the Maricao Formation, which he considered to be Late Cretaceous, Maastrichtian and Campanian age. The Maricao Formation consists of dark-green volcanoclastic breccia (clasts contain augite and plagioclase phenocrysts), thick-bedded to massive, coarse-grained basaltic tuff and tuff breccia, and thin-bedded, coarse-grained tuff (McIntyre and others, 1970; Krushensky and Curet, 1984). According to Krushensky and Curet (1984), the Robles Formation as mapped in the Bayaney and Adjuntas quadrangles is actually the Maricao Formation and is included in this map unit. Included in this unit are massive or amygdaloidal pillowed lava flows from the Maricao quadrangle, for which McIntyre (1975) inferred a Late(?) Cretaceous age; these were mapped by McIntyre (1975) as the “Rio Loco formation of Slodowski (1956) and Mattson (1960).” Volckmann (1984a, c) abandoned the Rio Loco in the San German and Parguera quadrangles, but it is not clear that the hypabyssal rocks in the San German and Parquera quadrangles were equivalent to the pillow flows mapped by McIntyre (1975); these rocks have been assigned to unit Klmv. Volcanic rocks in the Rosario, Maricao, and adjacent quadrangles are challenging to assign to geologic units and some or all of the rocks in this map unit might alternatively belong to map unit Klmv, though it is quite likely that the more northern exposures are Eocene. Massive basalt flows of the redefined Concepción Formation (McIntyre, 1974) and basalt flows and tuff where exposed in the Maricao and San Sebastian quadrangles (Tobisch and Turner, 1971; McIntyre, 1975), are Late Cretaceous. Plagioclase-augite andesite in the Yauco and Penuelas quadrangles shows some evidence of low-grade metamorphism; these rocks quite likely should be associated with the Lago Garzas Formation, though they apparently do not show the extensive saprolization of the rest of this unit

Tvep

Tuff and breccia, undifferentiated (Tertiary, early Eocene and late Paleocene)—Primarily exposed in southern Cuba, consists of volcanoclastic rocks, undifferentiated tuff, tuffite, andesite, basaltic andesite, tuffaceous sandstone, and beds of limestone. Subdivided into five stratigraphic units, the most widely exposed is the Guamá Formation in the western Sierra Maestra. It consists of coarse agglomeratic deposits, poorly sorted and sandy, fine- to coarse-grained andesitic and rarely dacitic-andesite tuff; siltstone, limestone, and subordinate andesite flows (IGP, 2011). Exposed to the east of the Guamá Formation, the El Cobre Group, which according to Pardo (2009), consists of 5,000 to 6,000 m of dominantly porphyritic andesitic flows, agglomerate, crystal-lithic, vitroclastic, and calcareous tuff, and lenses and beds of bioclastic and tuffaceous limestone. Porphyritic dacite and rhyolite are also present in lesser amounts; rhyolite locally being sulfide-bearing. Well-bedded, well-sorted graywacke is present in western exposures. Various lithologies grade into each other laterally and vertically, making it extremely difficult to subdivide the unit. Numerous dioritic intrusive

bodies cut rocks of the El Cobre Group, causing extensive contact metamorphism of intruded rocks. Exposed south of the El Cobre Group, the Jobo Formation and its Sevilla and La Lirer Members, exposed east of the undivided formation, consist of agglomeratic tuff, tuffaceous sandstone, siltstone, shale, limestone, basaltic-andesite flows and in the La Lirer Member, rhyodacitic ignimbrite deposits (IGP, 2011). Southwest of the Jobo Formation, the similar Uvero Formation is exposed. In the northeast part of the Sierra Maestra, the tuff, tuffite, tuffaceous sandstone, limestone, tuffaceous conglomerate, siltstone, marl, and volcanoclastic conglomerate of the Sabaneta Formation is exposed. It also includes small bodies of basalt, andesite, basaltic andesite, and dacitic andesite. The rocks are locally altered to bentonite and zeolite (IGP, 2011). The Pérodin Formation of northern Haiti of basalt, andesite, and tuffaceous rocks is not dated but is inferred to be Eocene or Paleocene (Kesler, 1971). In Bayaney, Utuado, and Florida quadrangles of northcentral Puerto Rico, rocks of the Puerto Rican Jobos Formation (distinct from the Jobo Formation of Cuba, but lithologically similar) consist of as much as 1,700 m of mostly volcanic breccia and subordinate conglomerate, volcanic sandstone, and lava. South of, but adjacent to the Jobos Formation (Nelson, 1967a; Nelson and Tobisch, 1968), the Yunes Formation consists of a maximum of 1,200 m of pale-green to pale-bluish-green tuff and grayish to brownish-green quartz-bearing, thin- to thick-bedded, volcanic sandstone and siltstone and containing interbedded light-buff-gray fragmental limestone and minor massive dark-brownish-gray volcanic breccia (Nelson and Monroe, 1966, Nelson, 1967b). Exposed in the southwestern part of the Bayaney quadrangle, is an area of undivided volcanic rocks consisting of light-gray to yellowish- to reddish-brown volcanic breccia, lapilli tuff, lava, and volcanic sandstone and siltstone. According to Nelson and Tobisch (1968), “most of these rocks have been hydrothermally altered (sericitized and silicified). Commonly rock types cannot be satisfactorily divided, and locally only a soft sericite or hard siliceous material is all that remains.” These rocks are intruded by small granitic stocks (see unit Ted)

- Tbt Intermediate to felsic biotite tuff (Tertiary, early Eocene to early Paleocene)**—In Puerto Rico, consists of the Los Puertos Formation, a reworked, typically massive or thick-bedded andesitic volcanoclastic breccia as much as 350 m thick, locally interbedded with quartz-bearing dacitic tuff, the presence of which distinguishes it from the underlying Cretaceous Coamo Formation (Glover, 1971; Glover and Mattson, 1973) (mapped as part of unit Kva in this report). “Interbeds of graded fine-grained tuffaceous mudstone contain many coalified wood fragments as well as planktonic foraminifera of Paleocene age” (Glover, 1971). As a reworked unit, the Paleocene foraminifera may only provide a maximum age; a later publication of Glover and Mattson (1973) indicates an early Paleocene to early Eocene age for the unit
- Tpv Extrusive rocks, flows, tuff, and breccia (Tertiary, Paleocene)**—Restricted to eastern Puerto Rico are the Guaracanal and Naranjito Formations. The Guaracanal Formation was originally named the Guaracanal Andesite; however, it consists of massive tuff, volcanic breccia, and poorly stratified tuffaceous wacke and conglomerate up to 600 m thick (Pease, 1968b). Locally, it is coarse purplish- or reddish-gray flow breccia in its southeasternmost exposure, which may be products of a nearby vent; the formation becomes finer grained and more stratified away from that area. Fresh crystals of black hornblende are characteristic. Locally, the Guaracanal has volcanic and calcareous mudstone at its base that contains planktonic foraminifera (Seiders, 1971c) and with other data Seiders assigned a Paleocene age to the unit. Cox and others (1977) reported a K/Ar age of 61.8 ± 1.2 Ma (sample 23–8 in Cox and others [1977]; age recalculated using constants of Steiger and Jäger [1977]) on andesite from the Guaracanal Formation in the Gurabo quadrangle. In the same region but farther west is the Naranjito Formation, which consists of crystal-tuff, tuffaceous mudstone, coarse-grain volcanic conglomerate and tuff breccia, and, locally, flows. Pease (1968a) reported that about 300 m of the Naranjito Formation is exposed in the Naranjito quadrangle; however, both top and bottom have been cut out by faulting. No fossils have been collected from the Naranjito Formation; because of its resemblance to the Guaracanal Formation, Pease (1968a) considered it stratigraphically equivalent and therefore considered it Paleocene
- TKrr Rhyodacite and rhyolite, undifferentiated (Tertiary, Paleocene to Late Cretaceous)**—In central Dominican Republic, near Valle Nuevo, this unit consists of lava and tuff of rhyolitic composition having a porphyritic texture with plagioclase phenocrysts in a fine-grained quartz matrix. Near San Juan, the unit consists of porphyritic rocks containing phenocrysts of quartz and plagioclase in an altered microcrystalline matrix. K/Ar age determinations were reported for samples near Valle Nuevo of 71.5 ± 3.6 and 85.1 ± 4.3 Ma (Toloczyki and others, 1991); however, little data is available to evaluate these dates. Toloczyki and others (1991) suggest that at least some of these rocks are Late Cretaceous

Kvr

Volcanic rocks, undifferentiated (Cretaceous)—In Cuba, Dominican Republic, Jamaica, and Puerto Rico, the unit consists of undivided volcanic rocks of loosely defined Cretaceous age, which range in composition from rhyolite to basalt. In northern Cuba, a unit of basalt and diabase (IGP, 2011) had been simply defined as Cretaceous basalt by Puscharovsky and others (1988). In central Cuba, just east of the Trinidad Dome area, the Aguilar and Jarao Formations consist of well stratified cinder-rich tuff that is locally zeolitized, interbedded with chert, tuffite, calcareous tuffite, biomicritic limestone, and subordinate sandstone and volcanoclastic conglomerate and rare interbedded andesite flows (IGP, 2011). In southern Cuba, units mapped as andesite and dacitic andesite are mapped west of Holguín (IGP, 2011). In Dominican Republic, small outcrops of altered basalt near Dajabón and on the Samaná Peninsula are exposed under Eocene limestone, which is the only control on their age (Toloczyki and others, 1991). In the Blue Mountain block of eastern Jamaica and the Hanover block of western Jamaica³, McFarlane and others (1984) mapped small bodies of andesitic volcanic rocks. In the Maricao quadrangle of western Puerto Rico, McIntyre (1975) mapped black chert, tuff, and brecciated altered formerly glassy lava containing olivine pseudomorphs in a fault sliver within serpentinite (unit **Mzs**) at the south edge of the quadrangle. McIntyre (1975) also described, but largely did not show small intrusions of highly altered rocks of probable basaltic composition within the serpentinite. He reported that no correlatives of either of these rocks were known elsewhere in the quadrangle. Rogers and others (1979) described small bodies of amphibolitic hornfels peripheral to the San Lorenzo batholith (unit **Kgd**) in Yabucoa and Punta Tuna quadrangles of southeastern Puerto Rico. They are dark-gray to greenish-gray, predominantly fine-grained hornfels having granoblastic texture, which locally grades to hornblende schist. The southernmost of the bodies, near Punta Tuna Lighthouse “* * includes porphyritic flow rocks and laminated to thin-bedded volcanoclastic rocks; other bodies largely massive, and nature of primary rock uncertain” (Rogers and others, 1979). In the San German quadrangle of southwest Puerto Rico, Volckmann (1984c) described altered volcanic rocks (possibly andesite) of presumed Cretaceous age. These rocks are surrounded by serpentinite and Volckmann could not find correlative rocks in the quadrangle. A sample (18PWs008) of similar rock from north of the larger serpentinite body in the Maricao quadrangle of southwest Puerto Rico, yielded inherited Proterozoic zircons with ages between 1.89 and 2.5 giga-annum (Ga). Volckmann (1984a) also mapped a sliver of tuff and conglomerate in the Parguera quadrangle associated with rocks of the Mabujina complex and Mariquita Chert of Jurassic or Cretaceous age (units **KJmc** and **KJcm**, respectively). Locally, unit **Kvr** is divided into subunits **Kfp**, **Kva**, **Klmv**, **Kfv**, **Kbt**, **Koba**, **Kip**, **Kvib**, **Kwt**, **Kmvm**, **Kbb**, **Kevi**, **Kib**, **Kvm**, **Kkp**, **Kspf**, and **Kevf**, which have more closely defined ages

Kfp

Felsic pyroclastic rocks (Late Cretaceous, Maastrichtian and Campanian)—The Pozas Formation’s Blacho Tuff Member in central Puerto Rico is a resistant dacitic ash-flow deposit that also contains subordinate fluvial conglomerate, volcanic sandstone, and siltstone. First described by Berryhill (1961), the ash-flow deposits are lenticular and very dense, and their reddish color distinguishes them from all other volcanic rocks in northcentral Puerto Rico. The ash-flow deposits range in thickness from 10 to 40 m and extend at least 4 km in discontinuous outcrops. They “consist primarily of plagioclase crystals, devitrified glass shards, fragments of feldspathic oxidized lava, pumice, and a very fine ash matrix containing iron oxide dust. The plagioclase crystals are highly fragmented, the microscopic glass shards are altered, mostly to quartz and clay, and the flattened pumice bombs and much of the matrix have been altered to a clay mineral (nontronite?), quartz, and zeolites. A concentration of plagioclase crystals is common at the base of the deposits” (Berryhill, 1961). Also described in the Orocovis quadrangle, its ash-flow deposits are “commonly interbedded with medium- to thick-bedded, generally fine volcanic breccia, medium to coarse tuff, and mudstone. The upper parts of ash-flow deposits locally have been removed by penecontemporaneous erosion; where present they consist of non-welded moderately indurated rubbly mixtures of ash, bombs (chiefly andesitic and dacitic lava), and lithic fragments. The center parts are welded, showing flattening of inclusions and parallel orientation of pumiceous and glassy fragments. Lower parts of ash-flow deposits consist of fine breccia and muddy tuff, and commonly rest on mudstone. Welded parts commonly are dense and resistant to weathering” (Briggs, 1971). It is also exposed in the Ciales (Berryhill, 1965), Corozal (Nelson, 1967a), and to a limited extent in the Florida quadrangle (Nelson and Monroe, 1966). Map patterns suggest it is likely more extensively exposed in the Florida and Corozal quadrangles, where it likely is included in the mapped Pozas Formation (unit **Kva**). In the Adjuntas quadrangle, a coarse crystal-lithic tuff that weathers purple was mapped as part of the then defined Yauco Mudstone (now Yauco Formation) (Mattson, 1968a); in this quadrangle, other parts of the Yauco Formation include subordinate tuff as well

³Block names from Hastie (2007).

Andesitic volcanic rocks and volcanoclastic sedimentary rocks, undifferentiated (Late

Cretaceous, Maastrichtian to Santonian)—In Jamaica, the Arthurs Seat Formation consists of a thick succession of volcanic and sedimentary rocks consisting of a lower sequence of tholeiitic andesitic flows and dikes succeeded upward by very poorly sorted, massive conglomerate and rare graded sandstone and porphyritic calc-alkaline basalt and andesite (Mitchell, 2006). According to Mitchell (2013b) age control is lacking, but he infers a Santonian age for the Arthurs Seat formation. In eastern Jamaica, the Border Formation in the Above Rocks Inlier is mainly andesitic tuff, flows, and volcanic bombs; Hastie (2007) indicated that the unit was Late Cretaceous (Campanian), likely on the basis of a $^{40}\text{Ar}/^{39}\text{Ar}$ date of 80.3 ± 0.5 Ma (sample AHC139 from Hastie [2007]) on altered andesite, whereas McFarlane and others (1984) described it as early Barremian to Albian. Several units in Puerto Rico are represented in this map unit. Other than on Isla de Vieques (Vieques Island), all are in the central part of the island. In Ciales and Corozal quadrangles of Puerto Rico, the Avispa Formation consists of greenish-gray to dark-gray lenticular and commonly pillowed andesite flows and interbedded volcanic sandstone and siltstone, and subordinate dacite flows (Berryhill, 1965; Nelson, 1967a). The lenticular Cuchillas Member of the Avispa Formation is dark-grayish-green massive andesitic volcanic breccia as well as interbedded volcanic sandstone and siltstone lenses (Nelson, 1967a). The 2,220-m-thick Manicaboa Formation is intertongued with the upper part of the Avispa Formation and consists largely of tuff, tuffite, and volcanic breccia; Berryhill (1965) described it as a waterlaid cyclic sequence of massive grayish volcanic breccia and breccia-conglomerate beds generally 1 to 30 m thick alternating with laminated gray reworked fine and coarse tuff in layers generally 1 to 25 m thick. In northcentral Puerto Rico, the Pozas Formation, consists of very thick- and thick-bedded volcanic breccia and tuff and subordinate medium- to thick-bedded mudstone and sandstone and local andesitic dacite flows. Breccia is made up of largely subrounded to subangular andesite fragments in a tuffaceous matrix (Briggs, 1971). In the Barranquitas quadrangle, rocks originally mapped as part of the Coamo Formation (Briggs and Gelabert, 1962) were later reassigned to the Pozas Formation (Briggs, 1969). In southcentral Puerto Rico, this unit is represented by two formations, the Coamo and Maravillas Formations. The Coamo overlies the Maravillas and the definitions of the two units have been modified with time. The Coamo, originally defined in 1961 (Glover, 1961a), had its description modified, whereas the lower heterogeneous part of the Coamo Formation was included in the underlying Maravillas Formation and its massive upper 70 percent became the redefined Coamo Formation. As a result, the San Diego Lapilli Tuff and Santa Ana Limestone Members were assigned to the Maravillas Formation (Glover, 1971) as the San Diego Member and Santa Ana Limestone Member, respectively. As redefined, the Coamo Formation consists of massive andesitic volcanic breccia at least 1,500 m thick. The Maravillas Formation is primarily pyroclastic rocks and tuff and has more common quartz-bearing tuff than the generally similar San Diego Member. Within the Maravillas Formation, locally, augite-andesite pyroclastic rocks are more dominant than hornblende andesite flows. The pyroclastic rocks of the Maravillas Formation are coarser than those in the underlying Cariblanco Formation (unit Klmv); nor do they seem to contain the sanidine or biotite of the tuff of the Cariblanco Formation. Pyroclastic rocks in the Maravillas are commonly mottled by secondary zeolites (laumontite, analcime) and albite (Glover, 1971). In northcentral Puerto Rico, there are three units; in stratigraphic sequence, the Alonso, Tetuán, and Mameyes Formations. The Alonso Formation is the uppermost, about 1,000-m-thick, and consists of tuff, which is locally welded, breccia and lahar deposits, minor andesite flows, and volcanic sandstone (Nelson and Monroe, 1966; Nelson, 1967b). Below this is the 1,500-m-thick Tetuán Formation, generally fine-grained tuffaceous mudstone and sandstone and subordinate crystal and crystal-vitric tuff; rare basalt or andesite flows are present (Nelson and Monroe, 1966; Nelson, 1967b; Mattson, 1968b; Briggs, 1971). The lowermost of the three units, the Mameyes Formation is about 600-m-thick and is dominantly andesite flows and subordinate volcanic sandstone and siltstone (Nelson and Monroe, 1966; Nelson, 1967b). Equivalent rocks, described as volcanic breccia and andesite fragments and volcanic sandstone were also mapped in the Corozal quadrangle (Nelson, 1967a). The Cerro Bravo Andesite of the Rio Grande quadrangle (Pease and Briggs, 1972) and correlative mafic dikes and sills in the Carolina (Monroe, 1977) and El Yunque quadrangles (Seiders, 1971a) may reflect a relatively widespread hypabyssal igneous event in northeast Puerto Rico. Krushensky and Monroe (1979) mapped small exposures of andesite flows in the Punta Verraco quadrangle of southwest Puerto Rico in an outlier of this unit. On Isla de Vieques, Learned and others (1973) mapped Late Cretaceous andesite, tuff, and breccia, intruded by a large quartz diorite batholith (unit TKqt)

Klmv

Basalt, pillowed and nonpillowed flows, breccia, and tuff, undifferentiated (Late Cretaceous, Maastrichtian to Santonian)—In Jamaica, the Bullhead Volcanics or Main Ridge Volcanics of the Central Inlier are largely basalt flows overlain by volcanoclastic conglomerate (Mitchell, 2013b). In Puerto Rico, multiple formations are mapped as part of this unit. Generally, nonpillowed rock units typically are basaltic or basaltic andesite flows, locally containing lenses of limestone and tuffaceous beds. These include the Boquerón Basalt (Volckmann, 1984b) and El Rayo (Volckmann, 1984d; Llerandi Roman, 2004) and Lajas Formations (Volckmann, 1984b, d; Colon, 2003), as well as an unnamed olivine basalt in southwestern Puerto Rico (Krushensky and Monroe, 1979; Krushensky and Curet, 1984) and the Martin Gonzales Lava Member of the Guyanabo Formation (Pease, 1968b; Seiders, 1971a, b; Pease and Briggs, 1972; Monroe, 1977; Pease and Monroe, 1977) in northeastern Puerto Rico. Also, in Puerto Rico, are many pillowed formations, which typically contain, in addition to andesitic pillow flows, interbedded tuffaceous sandstone, and some volcanic-rock breccia and conglomerate. Some of these map units are more tuff or breccia than flows. In the Mayagüez, Rosario, and Sabana Grande quadrangles (Curet, 1986; Colon, 2003), and likely also present in the adjacent Maricao quadrangle is two-pyroxene basalt closely associated with the ultramafic complex, locally known as the Monte del Estado Peridotite belt (Llerandi Roman, 2004). Unnamed basalt and basaltic andesite in the Cabo Rojo and Parguera quadrangles (Volckmann, 1984a) and the adjacent Guánica quadrangle (Addarich-Martínez, 2009) are highly altered, with the potential development of laterite. South of these outcrops, porphyritic basalt forms an arcuate outcrop belt around the community of Parguera. Though presumed to be Late Cretaceous, the rocks there do not show alteration or development of laterite. Whereas, andesitic and felsic volcanic rocks in Puerto Rico appear to be limited to the northeast of the GSPRFZ, mafic rocks appear largely limited to southwest of or within the fault zone. Outliers to this are small dikes and other hypabyssal exposures of basalt and basaltic andesite in the Ciales quadrangle (Berryhill, 1965), the basaltic tuff and andesite (andesite shown in unit Kva) of the Los Negros Formation in the Corozal and Naranjito quadrangles (Nelson, 1967a; Pease, 1968c), the basalt porphyry of the Martin Gonzalez Lava Member of the Guyanabo Formation, which is locally pillowed and exposed in Aguas Buenas, Rio Grande, San Juan, Carolina, Gurabo, and El Yunque quadrangles (Pease, 1968b; Pease and Briggs, 1972; Seiders, 1971a, b; Monroe, 1977; Pease and Monroe, 1977), and basalt to andesite pillow flows and breccia of the Frailes Formation in the Carolina, Gurabo, and El Yunque quadrangles of northeast Puerto Rico, which are exposed in a very limited area (Seiders, 1971a, b; Monroe, 1977)

Kfv

Intermediate and felsic volcanic rocks (Late Cretaceous, Campanian to Coniacian)—Exposed in Cuba, Dominican Republic, and Puerto Rico, this unit reflects slightly older volcanic activity. In central Cuba, the unit is represented by three formations that consist of rhyolite to andesite flows, tuff, and domes; all three formations contain zeolitized tuff. The La Pelao Formation is a very small exposure of welded trachyandesite tuff in central Cuba. The Bruja Formation is exposed north of the Escambray Massif and is pyroxene-bearing andesite, dacite, rhyodacite, perlite, tuff, tuffite, sandstone, siltstone, and marl (IGP, 2011). Southeast of the Bruja Formation, are outcrops of the Dagamal Formation of tuff, rhyodacitic and dacitic flows and flow-breccia and subordinate andesite, and limestone (IGP, 2011). The Caobilla Formation in the Camagüey region is dacite to rhyolite and subordinate silicic andesite, tuffaceous agglomerate, and limestone (IGP, 2011). The Caobilla is locally hydrothermally altered. West of the Holguín area, the Marti Formation is felsic flows, tuff, volcanoclastic sedimentary rocks and limestone, thought to be of Campanian age; its thickness is not reported (Pardo, 2009). Exposed in the same general area, IGP (2011) mapped small areas of rhyolite and rhyodacite of indeterminate age, which we have included in this unit. In the Holguín area of southern Cuba, the Loma Blanca Formation consists of felsic to intermediate composition flows, pyroclastic and volcanoclastic sedimentary rocks, and limestone (IGP, 2011). In Haiti, basaltic andesite, andesite, dacite, and calc-alkaline rhyodacite of the Massif du Nord, the Massif de Terre Neuve, and the North-West Peninsula lie on an extension of the Cordillera Central of the Dominican Republic and may be equivalent to part of the Tireo Formation (MMER, 1989). In Dominican Republic, a subunit of the Tireo Formation consists of dacite, rhyolite flows, and rhyolitic domes in the Central Cordillera; another subunit was a volcanoclastic member of the Tireo Formation (Toloczyki and others, 1991)

Kbt

Cotorra and Jayuya Tuffs, undivided (Late Cretaceous, Santonian to Turonian)—In Puerto Rico, the Cotorra Tuff is massive dark-green and greenish-black, coarse basaltic tuff and lapilli tuff and interbedded subordinate volcanic breccia and basalt pillow flows. Calcite, chlorite, and zeolite cement the grains; some chlorite probably is devitrified volcanic glass. Basalt contains phenocrysts of augite and altered olivine(?) in a felty or trachytic matrix of feldspar, chlorite, and pyroxene (Mattson,

1968b). Briggs (1971) and Krushensky and Monroe (1975) describe the tuff as a typical hyaloclastite. The Jayuya Tuff is massive, dark, pyroxene-rich coarse crystal- and lapilli-tuff and rare basalt flows and feldspathic crystal tuff. It also contains subordinate laminated and medium-bedded greenish-gray silicified mudstone and thin-bedded tuffaceous sandstone (Mattson, 1968a, b). Where intruded by the Utuado pluton (unit TKgm), it has been contact-metamorphosed to feldspar-hornblende hornfels, gneiss, and schist. Locally, the tuff has been hydrothermally altered to quartz and clay and has some introduced sulfide minerals (Mattson, 1968a)

Koba

Older basalt and andesite flows, breccia, and tuff, undifferentiated (Cretaceous, Santonian to

Albian)—Exposed on the northwest coast of Isla de la Juventud of Cuba, the Sabana Grande Formation consists of basalt, basaltic andesite, and tuff, which are cut by diabase dikes and bodies of diorite and quartz diorite (IGP, 2011). Age control on this formation suggests it may be as young as Campanian and as old as Albian. The most widely exposed of the Cuban units, the La Rana Formation, is exposed in central Cuba, northeast of the Escambray Massif (IGP, 2011). Consisting of agglomerate, andesite, and basaltic andesite flows and tuff, the La Rana Formation is Santonian to Coniacian. In southern Cuba, small areas of undated basaltic andesite and trachybasaltic andesite in the vicinity of Las Tunas are included in this unit (IGP, 2011). In southcentral Cuba, the Guaimaro Formation is composed of basaltic flows and flow-breccia, as well as trachyandesite, trachybasalt, and andesite flows. Subordinate tuffaceous agglomerate and other thin beds of friable pyroclastic rock units and minor conglomerate and limestone is present (IGP, 2011). The Guaimaro Formation may be as old as Aptian but, is certainly at least as old as Coniacian to Albian. Exposed adjacent to and north of the Guaimaro Formation is the similar Camujiro Formation consisting of flow-breccia, flows, agglomeratic flows (aa-aa?), tuff, tuffaceous andesitic, and basaltic andesitic agglomerate, trachybasalt and shoshonite to trachyandesite flows, and lesser sandy and detrital limestone (IGP, 2011). In Puerto Rico, several defined map units are represented in this unit. In contrast to unit Klmv, these map units are all in central and eastern Puerto Rico, east of the GSPRFZ. The Coniacian(?) Mamey Lava Member and other flows of the Camarones Formation, exposed in the Naranjito and Aguas Buenas quadrangle (Pease, 1968b, c) are basalt flows and are as much as 350 m thick. Also, in the Aguas Buenas quadrangle, the Campanian to Coniacian Tortugas Andesite consists of andesite flows and volcanic breccia that overlie the Camarones Formation; it contains minor tuff breccia and volcanic wacke and conglomerate (Pease, 1968b). Among the easternmost of these units, is the thin Toma de Agua Vitrophyre Member of the Turonian Cambalache Formation consisting of massive andesite having glomeroporphyritic plagioclase and lesser clinopyroxene in a groundmass that is in partly black glass but is widely devitrified to grayish-green felsite (Seiders, 1971a, b; Pease and Briggs, 1972). Also, in eastern Puerto Rico, south of the Cambalache Formation, are the Celada and Lomas Formations. The Santonian to Turonian Celada Formation consists dominantly of basaltic pillow lava and breccia and subordinate volcanic sandstone and mudstone in the Gurabo quadrangle (Seiders, 1971b). Adjacent to the Celada Formation in the adjoining Aguas Buenas quadrangle (Pease, 1968b) and continuing into the Naranjito quadrangle (Pease, 1968c) is the Santa Olaya Lava, which has a virtually identical definition to the Celada Formation, although it is described as locally converted to greenstone by pervasive intrusion of quartz diorite stocks and dikes (unit TKqt). Pease (1968b) mapped an informal andesite member of the Guaynabo Formation (250 m thick) of scoriaceous andesite, which he pointed out resembled the Santa Olaya Lava. Separated from the Celada by faulting, the Lomas Formation is thickly bedded, poorly sorted, andesitic to basaltic volcanic breccia and sandstone and subordinate moderately sorted volcanic sandstone. Minor pillow lava is locally present (Seiders, 1971a, b; M'Gonigle, 1978). In more southeastern exposures of the Lomas Formation, it is commonly hydrothermally altered and pyrite-bearing. M'Gonigle (1978) mapped an informal Mambiche sequence exposed adjacent to and south of the Lomas Formation in the Humacao quadrangle. It is a more volcanoclastic-rich facies of this map unit, containing tuff, breccia, sandstone, and conglomerate as well as lava flows. It is commonly hydrothermally altered; according to M'Gonigle (1978) intensely altered areas are "grayish yellow to white, and have a soft, clayey to a hard siliceous aspect," suggesting sericitic alteration. The Perchas Formation of the Rio Orocovis Group is widely exposed in central Puerto Rico [included in this map unit as part of the Perchas Formation is Formation L of Pease and Briggs (1960) and Briggs and Gelabert (1962)]. Commonly described as basalt flows that are locally pillowed, it also includes tuff and volcanic sandstone and siltstone. Formation L conforms well to the description of the Perchas Formation. Eastern exposures are hydrothermally altered (Pease, 1968b). As originally described by Berryhill (1965), the Perchas Formation was considered early Campanian or Santonian(?) to Turonian(?). In the southcentral part of the exposure area, the La Guaba Lava Member of the Coniacian Cariblanco Formation in the Coamo quadrangle (Glover, 1971), consists of about 50 m of pillow basalt, and the Hacienda Larga Tuff Member is crystal tuff that represents an end member of the volcanoclastic

components of the Cariblanco Formation. Crystal tuff forms about 35 percent of the volcanoclastic rocks of the Cariblanco Formation. The Santonian(?) to Albian Robles Formation, widespread in southcentral Puerto Rico, contains several formally defined volcanic members, including the Cañabón Lava, the Las Tetas Lava, and the Lapa Lava Members; the Lapa Lava Member is the most widespread of these. Glover (1971) described the Lapa Lava Member, which he called a porphyritic trachyandesite, pointing out that it and the lavas of the Rio Orocovis Group (Perchas Formation) “are unique in some ways among the Puerto Rican volcanic rocks. They are potassium rich and are intermediate between calc-alkalic and alkalic suites (Mattson, 1968b). Inasmuch as most other Puerto Rican rocks belong to the calc-alkalic (Mattson, 1968b) “orogenic” suite, the Robles-Rio Orocovis sequence is unusual in its setting. Discovery of the potassic nature of these lavas suggests the possibility that the small syenite intrusive bodies of the Ciales (Berryhill, 1965) and Barranquitas (Otálora, 1961) quadrangles are of Robles age also. Lidiak (1965) noticed the high potassium content of Rio Orocovis lavas in north-central Puerto Rico” (Glover, 1971). [Note that Glover (1971) considered the Robles Formation to be Cretaceous, Albian to Santonian.]

The Lapa Lava Member is about 370 m thick at the type locality in the Cayey and Coamo quadrangles (Berryhill and Glover, 1960), but reaches a maximum thickness of 650 m in the Barranquitas quadrangle (Glover, 1971). Pillows in the lava are about 1 to 3 m in greatest dimension, and red and gray siliceous interpillow mudstone and chert are common (Glover, 1971). The Las Tetas Lava Member is typically 100 to 400 m above the Lapa Lava Member in the Robles Formation, is also trachyandesite, potassium-rich, commonly pillowed, and as much as 400 m thick (Glover, 1971). Less extensive than the Lapa Lava Member, it tends to be exposed in the central part of the Robles Formation in the Coamo area (Glover, 1971). The least extensive of the Robles Formation lava members, the Cañabón Lava Member overlies the Las Tetas Lava Member; its limited description is “principally grayish-black to dark-bluish-gray augite phenocryst lava” (Briggs and Gelabert, 1962). The Malo Breccia is considered stratigraphically equivalent to the Robles Formation; it consists of thickly bedded andesite and basaltic andesite breccia interlayered with subordinate very thick bedded tuff, hyaloclastic tuff and breccia, and thin- to thick-bedded tuffaceous sandstone and siltstone (Briggs, 1971). Locally, andesite was mapped separately (Briggs, 1971). Poorly exposed in the Jayuya quadrangle, the Malo Breccia is commonly hydrothermally altered (Mattson, 1968b). Basalt flows and lesser basaltic tuff of the Vista Alegre Formation in northcentral Puerto Rico, are Santonian(?) to Albian (Nelson and Monroe, 1966; Mattson, 1968b; Briggs, 1971)

Kip

Intermediate and silicic pyroclastic rocks (Late Cretaceous, Santonian to Cenomanian)—In Cuba, Puerto Rico, and Virgin Islands, consists of largely andesitic to dacitic tuff and tuffaceous sedimentary rocks; locally includes basalt, marl, and limestone. The Orozco Formation of coastal northwestern Cuba is dacitic tuff, tuffite, tuffaceous sandstone, basalt, and agglomeratic basaltic tuff (IGP, 2011). The Seibabo Formation of central Cuba, exposed just north of the Escambray Massif, consists of coarse tuff containing abundant dark-green pumice fragments, marl, tuffaceous sandstone, and rare black limestone (Pardo, 2009). Aphanitic lava flows are found in the middle part of the section (IGP, 2011). Pardo (2009) suggested this unit was deposited under deepwater conditions. In northeastern Puerto Rico, the Turonian Cambalache Formation, largely of pumiceous volcanic sandstone and breccia, is distinctive because of as much as 50 m of vitrophyre at its top (Seiders, 1971a, b) (shown within unit Koba in this report). It also contains subordinate calcareous and volcanic mudstone and is distinctive because the “volcanoclastic rocks are characterized by variable amounts of altered vitric debris, especially long-tube pumice and perlite * * *” (Seiders, 1971a, b). Also, in northeastern Puerto Rico, the Cancel Breccia is as much as 2,000 m of andesitic tuff breccia and flows. The formation is composed mostly of tuff breccia and coarse-grained lapilli tuff; however, present in the lower part of the unit are flow breccia and flows. Lenses of stratified tuff occur throughout but are not mappable units. An oxidizing environment and subaerial deposition are suggested for the unit due in part to a pervasive reddish-gray to purplish-gray color of the rocks. The stratified tuff may represent episodes of marine deposition within this otherwise predominantly nonmarine unit (Pease, 1968a). The nearby Carraizo Breccia, at least 1,200 m thick, is similar, consisting of massive coarse- to fine-grained volcanic breccia, coarse-grained volcanic wacke and lapilli stone, and lenses of thin-bedded tuffaceous wacke (Pease, 1968b). In many respects, like the Cambalache Formation, the volcanoclastic rocks of the Infierno Formation (flows of the Infierno Formation assigned to unit Kvib in this report) range from moderately to poorly sorted, mudstone to breccia in thin to very thick beds. Sandstone and finer grained breccia contain abundant altered pumice with bold globular and attenuated vesicles and less abundant altered perlite, lithic volcanic-rock fragments, plagioclase, and clinopyroxene grains. In all respects, these rocks are quite like the volcanoclastic rocks of the Cambalache Formation including scattered clasts included in finer breccias that are texturally identical with its Toma

de Agua Vitrophyre Member (Seiders, 1971c). Nelson (1967a) mapped a small area of reddish, deeply weathered volcanic breccia in the Corozal quadrangle, which was presumed to be Late Cretaceous. We have tentatively correlated it with the Cancel Breccia. In U.S. Virgin Islands, the Louisenhoj Formation is widely exposed on Saint Thomas and Saint John Islands, as well as on outlying islands north and west of Saint Thomas. The Louisenhoj Formation is possibly slightly older than other formations of this map unit because its age may extend into the Albian. The Louisenhoj Formation is volcanic breccia, tuff, and minor conglomerate and varies in mode of deposition from pyroclastic to epiclastic (Donnelly, 1966). Rankin (2002) locally mapped separate flow units within the Louisenhoj Formation, which are included in the mafic volcanic rocks subunit (Kmvvm) in this report. This formation is thickest on western Saint Thomas, where it is nearly 4 km thick (Donnelly, 1966), and it thins to as little as 500 m on eastern Saint Thomas, according to Rankin (2002). Deposition was clearly more distal in the west. In the east, the formation may have calcareous cement in conglomeratic beds (Rankin, 2002). In the type section on Saint Thomas, the formation consists dominantly of coarse, water-laid andesitic tuff beds 2 to 4 m thick, having “fair” grading and showing evidence of laminar slumping (Donnelly, 1966). Locally, soft-sediment deformation and broken, finer grained beds are present (Rankin, 2002). Donnelly (1966) defined a Hans Lollik Formation, which Rankin (2002) abandoned reassigning those rocks to the Louisenhoj Formation. On Salt Island in the British Virgin Islands, Helsley (1960) tentatively correlated exposures of metamorphosed andesitic breccia and tuff with the Louisenhoj Formation.

Kvib

Iberia Formation of Cuba, Hato Puerco Formation of Puerto Rico, and similar rocks (Cretaceous, Turonian to Albian)—The Iberia Formation of the Holguín area of southern Cuba is described as andesite flows, diabasic andesite and basalt, diabase dikes, mafic and intermediate tuff and agglomerate, conglomerate, sandstone, limestone, and marl (IGP, 2011). Pardo (2009) considered the Iberia to be a “wastebasket” because it consists of a large variety of rock types that range in age from Maastrichtian to Albian, in which pyroclastic rocks are 80 percent of the formation, flows and dikes are 15 percent, and conglomerate, sandstone, and limestone are only 5 percent of the unit. Mapping by IGP (2011) restricted the distribution of the unit relative to the mapping of Puscharovsky and others (1988) and refined its age to Turonian to Aptian. The Cerrajón Complex of dikes and diabasic gabbro is associated with the ultramafic rocks north of Guantánamo; its age is not well controlled. Also included in unit Kvib are several small exposures of andesite and trachyandesite that IGP (2011) did not assign an age. These exposures are distributed around Cuba, with the bulk of them to the north of Guantánamo, in the Holguín area or south of Camagüey. The Turonian(?) to Cenomanian Hato Puerco Formation in eastern Puerto Rico, consists of marine-deposited thick-bedded to massive, moderately sorted, coarse-grained, volcanic sandstone and breccia and minor thin-bedded sandstone and calcareous tuffaceous mudstone (Seiders, 1971b; Pease and Briggs, 1972; Briggs and Aguilar-Cortes, 1980). Unit contains sparse fragments of shallow-water limestone (Seiders, 1971a, b). At Cabeza Chiquita, a small exposure of pillowed andesitic lava is interbedded with and assigned to the Albian Tabonuco Formation (Briggs and Aguilar-Cortes, 1980). Pease (1968b) in mapping in the Aguas Buenas quadrangle, defined the Carriazo Breccia and described it as different than the Hato Puerco Formation. Subsequent mapping by Seiders (1971b) in the adjacent Gurabo quadrangle, showed that these are likely the same unit. Underlying the Hato Puerco Formation, the Barrazas Formation is lithologically similar though finer grained and more calcareous (Seiders, 1971c). Flow members of the Infierno Formation consist dominantly of pillow flows of andesitic to basaltic composition but do contain subordinate breccia and minor mudstone. Volcaniclastic facies of the Infierno Formation are assigned to unit Kip. Andesite flow subunits of the Vista Alegre Formation (Nelson and Monroe, 1966; Mattson, 1968b; Briggs, 1971) are assigned to this map unit. The Vista Alegre Formation is dominantly a volcaniclastic unit and those components of the formation are assigned to unit Kwt. In northeastern Puerto Rico, in the Naranjito quadrangle, the Cerro Gordo Lava, consists of as much as 1,100 m of basaltic andesite flows, flow breccia, and minor tuff and tuff breccia (Pease, 1968c). The unit was defined by Pease (1968c) and overlies the Pájaros Tuff (unit Kwt); both are only exposed in the Naranjito quadrangle. Age control is lacking; the Cerro Gordo Lava may be early Late Cretaceous. Flows and breccias of the Cerro Gordo Lava, which conformably overlie the Pájaros Tuff, are almost identical lithologically with flows and breccias that interfinger with and overlie the Robles Formation in the northern parts of the Comerio and Barranquitas quadrangles. These volcanic rocks are Formation L on the geologic map of the Barranquitas and Comerio quadrangles (Pease and Briggs, 1960; Briggs and Gelabert, 1962) and are included in unit Koba in this report; they probably correlate with the lower part of the Río Orocovis Group. The volcanic members of the Magueyes Formation, the lower formation of the Río Orocovis Group consist of andesitic to basaltic tuff and flows in the Corozal and Ciales quadrangles (Berryhill, 1965; Nelson, 1967a).

Kwt	Intermediate and mafic pyroclastic deposits (Cretaceous, Turonian to Aptian)—Mapped in Cuba and Puerto Rico; the unit consists of volcanoclastic rocks that range in composition from dacite to basaltic andesite but are largely andesite. In northernmost Cuba, the Turonian to Albian Chirino Formation is about 1,000 m of predominantly vitric and crystalline tuff and tuffaceous chert, medium- to coarse-grained lithic tuff, andesite and basaltic andesite sills and dikes, graywacke, tuffaceous shale, and argillaceous limestone (Pardo, 2009; IGP, 2011), a somewhat mixed unit. In central Cuba, north and east of the Escambray Massif, the Albian Cabaiguán Formation consists of andesitic and dacitic tuff, sandstone, tuffaceous and volcanoclastic siltstone, tuffite, and andesite and dacite flows (IGP, 2011). In Puerto Rico, the Robles Formation has been divided into two formal tuff members, the Barranquitas and the Helechal Tuff Members; however, neither appears on published maps. Several published maps do show tuff units in the Robles Formation (Berryhill and Glover, 1960; Briggs and Gelabert, 1962; Glover, 1971). Age is not well controlled on the Robles Formation; Norman F. Sohl (USGS, written communication, 1962, as cited in Pease, 1968c) assigned an early middle Albian age because of the presence of the ammonite <i>Oxytrupidoceras</i>, collected from near the base of the Robles Formation north of Comerio. The upper age limit of the Robles Formation has been assigned to the Cenomanian (Berryhill and Glover, 1960) or Santonian (Glover, 1971). Rogers (1979) mapped a unit of dominantly ash- to lapilli-tuff (grading locally into breccia) containing subordinate andesitic lava and scarce thin sequences of siltstone and sandstone that he inferred might be Robles Formation in the eastern Caguas quadrangle. The poorly exposed Pájaros Tuff in the northern Naranjito quadrangle (Pease, 1968c), consists of thin-bedded tuff and tuffaceous sedimentary rocks and is nowhere in contact with any rocks defined as the Robles Formation. Pease (1968c) described these as closely resembling tuffaceous rocks of the Robles Formation, exposed in the northern part of the Comerio quadrangle (Pease and Briggs, 1960). However, there is little stratigraphic control on the Pájaros Tuff; if the correlation with the Robles Formation is accepted, then the Pájaros Tuff may be as old as Albian or as young as the early part of the Late Cretaceous
Kmvm	Mafic volcanic rocks (Cretaceous, Cenomanian to Barremian)—Only in Cuba and the U.S. Virgin Islands. In northern Cuba, this includes the Cenomanian to Albian Encrucijada Formation, which largely consists of tholeiitic basalt flows and breccia and, subordinate sedimentary rocks, dominantly chert, limestone, and lesser argillite and siltstone (IGP, 2011). East of Havana, the Cenomanian to Aptian Margot Formation consists of porphyritic and aphanitic basalt, limestone, chert, including radiolarian chert in thin strata, shale, tuff, and schist. Northwest of Trinidad Dome in the Escambray Massif, basalt, olivine basalt, basaltic-andesite, andesite, dacite, and “plagioryholite” of the Los Calderas Formation of Cenomanian to Albian age is mapped (IGP, 2011). The Santa Lucia Formation, having the longest defined age span among the units in Cuba, Cenomanian to Barremian, is lithologically like the Margot Formation, consisting of aphanitic basalt, chert, including radiolarian chert, and limestone (IGP, 2011). It is exposed in the Holguín area of southern Cuba. Several small exposures of basalt and basaltic andesite in Cuba were not described nor had ages assigned; these are scattered throughout Cuba and are tentatively assigned to this unit (IGP, 2011). On Saint John in the U.S. Virgin Islands, this unit includes separately mapped flow units of the Louisenhoj Formation of Rankin (2002). As mapped by Rankin (2002), flow units of the Louisenhoj Formation consist of porphyritic basalt, some of which has pillows, and andesite, both of which may be locally metamorphosed to greenschist facies
Kbb	Tuff of the Fajardo Formation (Early Cretaceous, Albian)—Located on the most northeastern part of the island of Puerto Rico, the Fajardo Formation consists of volcanoclastic sedimentary rocks (unit Kevc) and tuff. The tuff, which is as much 1,100–1,500 m thick, has several phases, including thick-bedded coarse, very dark to light-bluish gray and dark-greenish-gray, olive-gray-weathering tuff, which is interbedded with thick-bedded to massive tuff breccia. Most common is crystal-vitric tuff, but lithic andesite clasts are also commonly present, and the upper part contains some pumice and red scoria (Seiders, 1971a; Briggs and Aguilar-Cortes, 1980). Also present is subordinate thin- to thick-bedded pale-brown-weathering tuffaceous sandstone and siltstone. Where the sedimentary phases of the formation can be mapped separately, they are shown in unit Kevc
Kevi	Intermediate-composition volcanic rocks (Early Cretaceous, Albian to Barremian?)—Exposed in Jamaica, Dominican Republic, and Puerto Rico, this unit primarily consists of pillowed or brecciated andesitic flows, interbedded with tuff, tuffaceous sandstone, and chert. In Jamaica, the Devil’s Race Course Formation of the Benbow Inlier of McFarlane and others (1984) was elevated to the Devil’s Race Course Group status by Brown and Mitchell (2010), who then divided it into nine distinct formations (table 3) that have a total thickness exceeding 4,000 m; they thought it was the oldest rock unit in Jamaica. In eastern Dominican Republic, Toloczyki and others (1991) mapped the widely exposed Peralvillo Formation that, according to Bowin (1975), is pyroxene andesite and tuff. In Puerto

Rico, several related units are included here in this map unit, all in eastern Puerto Rico or on Culebra Island. The Dagua Formation (M'Gonigle, 1978, 1979), 1,000 to 1,500 m thick, and the Figuera Lava (Briggs, 1973; M'Gonigle, 1979; Briggs and Aguilar-Cortes, 1980), at least 1,200 m thick, are locally interbedded and are exposed in the easternmost part of the island of Puerto Rico. These formations consist of massive andesite flows that are locally pillowed, and are interlayered with minor volcanic-rock breccia, tuffaceous sandstone, siltstone, tuff, and hyaloclastite breccia. In a large area west of the San Lorenzo batholith (unit Kgd), poorly defined andesitic volcanic rocks are assigned to several informal units defined primarily in the early period of modern geologic mapping in Puerto Rico. These were variously called formations "A," "B," "C," "D" (Berryhill, 1960; Berryhill and Glover, 1960; Glover, 1982), and "J" and "K" (Pease and Briggs, 1960; Rogers, 1979). Rogers (1979) indicated that his formation "J" was the same unit as formation "A" of the other authors. Formation "A" (or "J") is "predominantly volcanic breccia interlayered with massive to poorly stratified tuff, a few thin lava flows, and scarce siltstone and sandstone. The tuff is dark-gray to dark greenish gray and is composed chiefly of abundant granule-sized andesitic lava fragments, which in places are highly pumiceous, in an aphanitic to fine-grained generally calcareous matrix. * * * The breccia resembles the tuff except for the size of the sparse to abundant, subangular to subrounded lava blocks, which may range up to a meter or more in diameter but, are mostly much smaller. The section contains a few thin sequences of laminated to medium-bedded siltstone and fine-grained sandstone, also scarce impure limestone in thin lenticular layers" (Rogers, 1979).

In northern exposures, "* * * tuff and breccia also predominate, but toward the top, the formation contains abundant lava (forming a few dikes as well as flows), some flow breccia, and scattered thin layers of siltstone and sandstone" (Rogers, 1979). A diagnostic feature of formation "A" that is, Rogers formation "J," is the cyclic repetition of its clastic members and the uniform gradation upward from coarse to fine particle size within each cycle of deposition (Berryhill, 1960). Formation "B" (Berryhill, 1960; Berryhill and Glover, 1960), in the southern part of the area in Cayey and Central Aguirre quadrangles, is hard to distinguish from the other units based on available description. Described as "Predominantly coarsely stratified volcanic breccia; includes a few andesite flows and flow breccias, and sandstone and siltstone mainly in basal part of formation. Rocks are chiefly dark greenish gray but oxidized flows are reddish brown" (Berryhill, 1960). Formation "B" is distinguished from "A" because of its different strike (N. 30° W. for "B" versus N. 30° E. for "A"), and "In contrast to the volcanic siltstones of formation A, however, the siltstones of formation B were deformed by penecontemporaneous slumping and show marked evidence of deposition by turbidity currents" (Berryhill, 1960). Formation "C" has essentially the same description, though it may contain a higher proportion of flows and flow breccias. According to Berryhill (1960) the informal units "A" to "D" represent a sequence where "A" is the oldest. Formation "K" of Pease and Briggs (1960) and Formation "D" of Berryhill and Glover (1960) are each apparently equivalent to the Albian Torrecilla Breccia of Briggs (1971) and Rogers (1979); similar to the other units included in this unit it consists of crudely stratified volcanic breccia, which locally transitions to massive tuff, subordinate andesite flows, and some siltstone and sandstone that may be as much 1,000 m thick. As a unit, The Torrecilla Breccia is distinctive because of the presence of the Aguas Buenas Limestone Member (unit Kcc) at its base (Rogers, 1979). In the Coamo and Barranquitas quadrangles (Glover, 1961a; Briggs and Gelabert, 1962) a unit described as "Pre-Robles rocks" appear to be similar and likely equivalent to the Torrecilla Breccia. As described, these pre-Robles rocks appear to grade upward from more dacitic to andesitic composition (Glover, 1971). In southeasternmost Puerto Rico, Rogers and others (1979) mapped metavolcanic rocks derived from lava flows, flow(?) breccia, tuff, and tuffaceous siltstone and sandstone that are engulfed in the plutonic rocks of the San Lorenzo batholith (unit Kgd) and older plutons. On Isla de Culebra (Culebra Island) and most of the surrounding islets, Banks (1962) described the informally named Culebra andesite as more than 700 m of pillowed and massive andesite flows and interbedded tuff and breccia. Banks (1962) distinguished an informally named Playa Sardinias breccia member as thick-bedded andesite in the lower part of the Culebra andesite. Locally subdivided into unit Kib

Kib

Intrusive breccia of the Dagua Formation—A subset of the Dagua Formation, the breccias are hypabyssal intrusive rocks of medium-dark-gray brecciated andesite (M'Gonigle, 1979) in Puerto Rico. They contain subangular clasts of dark-gray andesite having large plagioclase and clinopyroxene phenocrysts in a brecciated matrix of the same composition. The clasts seem to be lithologically identical to andesite clasts in the tuff breccias and autoclastic lavas of the Dagua Formation. The clasts of the two intrusive bodies in the Naguabo quadrangle east of Dagua range from 3 to 15 cm in length. On Isla Piñeros in the Punta Puerca quadrangle (M'Gonigle, 1979), blocks as large as 90 cm in

length are found in an intrusive(?) body making up a small hill on the northwest corner of the island. The intrusive rocks are locally much epidotized and silicified; the epidote and quartz occur in veins and in irregular patches. In a quarry in the intrusive body that is south of the Roosevelt Roads airfield, some pod-shaped zones several meters long have been largely replaced by epidote and quartz, yet the original texture of the porphyritic andesite breccia is discernable. An exposure of massive andesite lava about 100 m wide and 200 m long on the crest of the ridge to the northwest of Naguabo may also be an intrusive body. The lava is lithologically similar to the other intrusive breccias; although it is only partly brecciated, it does show some near vertical banding (flow lines)

Kevm

Basalt and basaltic andesite, undifferentiated (Early Cretaceous)—In Cuba, Dominican Republic, eastern Puerto Rico, and U.S. Virgin Islands. In central Cuba, the Albian to Aptian Mataguá Formation is found on the north side of the Escambray Massif and consists of flows, flow breccia, and tuff of andesitic, basaltic-andesitic, and basaltic composition. Subordinate tuffite, limestone, sandstone, and siltstone are also present (IGP, 2011). In central Dominican Republic, basalt and minor tuff, wacke, and chert of the Siete Cabezas Formation was described by Toloczyki and others (1991); however, the formation does not appear on their map. In southeast Puerto Rico, northeast of the San Lorenzo batholith (unit Kgd), the Pitahaya Formation (M'Gonigle, 1978), Rio Abajo Formation (M'Gonigle, 1978), and a unit of undifferentiated and contact metamorphosed volcanic rocks (Broedall, 1961) consists of a mixture of flows, breccia, and tuff as well as minor siltstone conglomerate, and limestone (converted to marble). On Saint John in the U.S. Virgin Islands, Rankin (2002) distinguished pillows of amygdaloidal basalt, pillow breccia, and hyaloclastite within the Water Island Formation (mapped as units Kwi and Kkp in this report)

Kkp

Keratophyre (Early Cretaceous)—Keratophyre is exposed in Dominican Republic, the Virgin Islands, and Puerto Rico. In Dominican Republic, rocks of the Los Ranchos Formation are exposed in the central and eastern part of the country and is composed of a variety of volcanic rocks, significantly that include keratophyre and spilite flows, as well as tuff and black lacustrine siltstone and mudstone (Draper and Lewis, 1991b; LeBron and Mann, 1991). Several informal units have been defined within the Los Ranchos; the Zambrana fragmental unit consisting of lithic welded-tuff of quartz keratophyre and spilite, the Quita Sueno member of agglomeratic quartz keratophyre and keratophyre, and the Pueblo Viejo member, which is a maar-diatreme complex consisting of breccia, tuff, and carbonaceous lacustrine mudstone (Draper and Lewis, 1991b). Other spilite-rich members of the Los Ranchos are included in unit Kspf in this report. The Water Island Formation is well exposed on Saint Thomas and Saint John of the U.S. Virgin Islands and also on Norman, Peter, Salt, and Cooper Islands of the British Virgin Islands. Described by Helsley (1960) as “Predominately light tan to reddish brown keratophyre flows, flow breccia, and tuff interbedded with thin flows of dark green to almost black spilite flows and minor radiolarites.” The spilite is assigned to unit Kspf, spilitic basalt in this report. Donnelly (1966) added “A few of the fine-grained tuffaceous beds contain well-preserved Radiolaria of undetermined age”; and quartz keratophyre dikes and plugs are present in many parts of unit. Both Donnelly (1966) and Rankin (2002) commented that the unit is an oceanic deposit; Donnelly (1966) suggesting that it was erupted prior to the existence of the trench or island platform. On Saint Thomas, metamorphic grade increases to the north and east, and spherulites in the groundmass of the keratophyre are recrystallized and stand out as ovoids, some as large as 4 cm on weathered surfaces (Rankin (2002). Helsley (1960) pointed out that “in the British Virgin Islands * * * the formation has undergone greater metamorphism. The rocks described above are now amphibolite and quartz-mica schist.” Alminas and others (1994) reported several K/Ar ages on rocks of the Water Island and Louisenhoj Formations, most yielding Eocene ages and in Puerto Rico on Cayo Norte and nearby islands, Banks (1962) described the informally named Cayo Norte formation as being albite-rich pillow flows, which we tentatively correlate with the Water Island Formation

Kspf

Spilitic basalt (Early Cretaceous)—In Dominican Republic, Draper and Lewis (1991a) mapped the Platnal and Naviza spilite unit of the Los Ranchos Formation consisting of massive amygdaloidal spilite the contains lenses of agglomeratic breccia. Neocomian fossils are found in limestone at the base of this unit. Pillow lava forms the Cotui, another informal spilite unit mapped by Draper and others (1991). In U.S. Virgin Islands, spilite flows, which vary greatly in thickness from a few meters to about 100 m, make up about one fifth of the thickness of the Water Island Formation. Flows generally are massive and lack columnar joints; though they commonly lack pillow structures, pillows are locally well developed (Donnelly, 1966). On Isla de Culebra in Puerto Rico, Banks (1962) described about 360 m of spilitic lapilli tuff as his informally named Cerro Balcon formation; the lower about 60 m consists of well-bedded, fine-grained, tan tuff that he (Banks, 1962) defined as the informal Playa Resaca member of the Cerro Balcon formation

- Kevf Felsic volcanic rocks (Early Cretaceous, Barremian to Berriasian)**—In central Cuba, north of Trinidad Dome, the felsic volcanic rocks of the Los Pasos Formation are exposed in a belt between the Early Cretaceous mafic volcanic rocks of unit **Kevm** and the middle Cretaceous granitic rocks of units **Kmgd** and **Kqt** (IGP, 2011). The Los Pasos consists of rhyodacite, dacite, plagioryholite, and tuff of those same compositions, and subordinate aphyric basalt, basaltic-andesite, andesite, sandstone, and siltstone. This corresponds to the stratigraphically lower part of the Mataguá Formation of Puscharovsky and others (1988), which lumped the felsic and mafic volcanic rocks into one unit
- Khk Hypabyssal rocks, keratophyre porphyry (Early Cretaceous)**—On Saint John and on nearby islands in the U.S. Virgin Islands, Rankin (2002) described the Careen Hill Intrusive Suite, which consists of variety of keratophyre dikes and plugs that intrude the Water Island Formation (**Kwi**). Dikes and plugs vary from coarsely porphyritic to phenocryst-poor bodies and minor diabase is present
- KJb Zurrupandilla Formation and Cajul Basalt (Early Cretaceous to Late Jurassic)**—Exposed in Cuba (Zurrupandilla Formation) and Puerto Rico (Cajul Basalt). In central Cuba, a linear belt of diabase and basalt, rare siltstone, and limestone constitutes the Zurrupandilla Formation (IGP, 2011). It is exposed to the northeast of the Escambray Massif. Pardo (2009) inferred that this unit is his (Pardo's) Cumbre Formation, consisting of at least 300 m of spilitic basalt, diabase, chert, and possible tuff. Pardo (2009) also suggested that it may include a unit traditionally mapped as the Old Volcanics by the Gulf Oil Company, consisting of basalt, porphyritic basalt, and associated sedimentary rocks that overlie the Cumbre Formation. The Sagua la Chica Formation, exposed in the same general area was described as aphanitic basalt, diabase, and agglomeratic breccia and gray to black chert (IGP, 2011). In northern Cuba, a small area of basalt and diabase is associated with serpentinite of unit **Mzs**. These rocks are not dated but, in this report are inferred to be of Cretaceous to Jurassic age. In southwestern Puerto Rico, the Cajul Basalt, consisting of amygdaloidal, pillowed, porphyritic basalt flows associated with the Mariquita Chert (unit **KJcm**) of Jurassic age (Volckmann, 1984a, b, c). The flows are typically altered, where the larger plagioclase phenocrysts are altered to calcite or sericite, calcite, and magnetite. Rare olivine phenocrysts are altered to calcite and iddingsite. The groundmass consists of nearly opaque glass containing abundant granules and microlites of magnetite and hematite; glass has been altered to epidote and locally, chlorite; amygdules are filled with calcite; thin veins are filled with calcite and (or) epidote (Volckmann, 1984c). North of the Cajul Basalt outcrop area, in the Mayagüez and Rosario quadrangles, spilitic basalt is associated with serpentinite (unit **Mzs**) (Curet, 1986). It is dark-greenish-gray to light-gray, aphanitic, locally vesicular and generally massive basalt. Fifty-five to sixty percent of the rock contains twinned plagioclase that has been pervasively replaced by sodic plagioclase (An_{10} or less), calcite, sericite, kaolinite, and minor chlorite. Clinopyroxene, originally 20–25 percent of the rock, is pervasively altered to epidote, chlorite, and green hornblende. The groundmass is largely chlorite and accessory magnetite-ilmenite (Curet, 1986)
- Jdb Diabase and basalt flows and marine sedimentary rocks, undifferentiated (Jurassic, late Oxfordian)**—Diabase and basalt having interbedded limestone, dolostone, quartzose sandstone, volcanoclastic shale, and chert of the El Sábalo Formation of northcentral Cuba (IGP, 2011); associated with the Artemisa Formation (unit **KJcl**)

PLUTONIC ROCKS

- Tgb Gabbro and diorite, undifferentiated (Tertiary, Miocene to Eocene)**—In the Sierra Maestra and Guantanamo areas of Cuba several diabase, gabbro, or diabasic gabbro occurrences that are undated nor described further are shown (IGP, 2011). Also shown are occurrences called a gabbro-diorite association, a gabbro-plagiogranite association and a monzodiorite association. Given their setting, we presume these are Tertiary and likely Eocene
- TKq Quartz keratophyre (early Tertiary? or Late Cretaceous)**—Includes stocks of medium-dark-gray to medium-bluish-gray porphyritic rock with an aphanitic matrix in the Naguabo and Punta Puerca quadrangles of Puerto Rico (M'Gonigle, 1979). Also included are dikes of dark-greenish-gray to pale-yellowish-brown dike rock with sparse altered feldspar phenocrysts in the Coamo and Naranjito quadrangles of Puerto Rico (Glover, 1961a; Pease, 1968c). These rocks contain oligoclase and distinctive bipyramidal quartz phenocrysts. The interior of the stocks is massive in aspect, although the rock is commonly much jointed and locally shattered. The borders of the stocks are irregular, there being numerous apophyses and dikes extending into the country rock. M'Gonigle (1979) describes the groundmass as an intricate intergrowth of quartz, albite, and oligoclase. X-ray diffraction analysis indicates that more than 10 percent of the rock is potassium feldspar, but he could not confirm this optically. Phenocrysts of plagioclase are about 1–4 mm in length. Quartz phenocrysts, about 3 mm

long, tend to be resorbed and rounded, although the bipyramidal shape is plainly evident in many of them. Epidote is common as patches and stringers throughout the rock. The dikes in the Naranjito and Coamo quadrangles have a similar composition, containing chlorite rather than epidote (Glover, 1961a; Pease, 1968c)

Tegr

Granite and granodiorite, undifferentiated (Tertiary, Eocene?)—In the Sierra Maestra mountains of southern Cuba, several small granite to granodiorite, and quartz monzonite plutons, locally, intrude quartz diorite and tonalite plutons or intrude rocks of the Cobre Formation (unit Tvep) (IGP, 2011). These plutons are not dated but are consistently associated with other Eocene rocks. On Salt Island in the British Virgin Islands, a pegmatite dike cuts the Tutu Formation (unit Ktu); the pegmatite is likely an offshoot from the Virgin Gorda batholith (unit Ted)

Ted

Diorite and tonalite, undifferentiated (Tertiary, Eocene and Paleocene)—These plutons are small bodies in the Sierra Maestra mountains of southern Cuba, a few small plutons in Dominican Republic, larger plutons in southern Puerto Rico, and similar plutons form much of the British Virgin Islands and a small part of the U.S. Virgin Islands. In Cuba, many small diorite and tonalite plutons intrude rocks of the Cobre Formation (unit Tvep) (IGP, 2011). Kysar and others (1998) and Rojas-Agramonte and others (2004, 2006) reported U/Pb zircon ages that generally range from 60.2 ± 2.6 to 46.9 ± 0.1 Ma on quartz diorite, tonalite, and trondhjemite. Each sample was from a more mafic phase within bodies mapped as granite, granodiorite, or monzonite. However, some age determinations yielded outlier dates as young as 32 ± 3 Ma (fission-track age on zircon; Rojas-Agramonte and others [2006]) to as old as 310.8 ± 3.4 Ma (likely inherited zircons or laboratory contamination; Rojas-Agramonte and others [2006]). Also included in the unit in Cuba, are rocks described as plagiogranite, which are associated with tonalite. In eastern Dominican Republic, several small medium-grained pyroxene diorite plutons, which were considered part of the Duarte Complex (unit Kmgb) intrude the Maimon Formation (unit Kmv) (Toloczky and others, 1991). Despite being considered part of the Duarte Complex of Cretaceous or possibly Jurassic age, these plutons were considered “modern” or post-Eocene by Toloczky and others (1991). In the Central La Plata (McIntyre, 1971), adjacent Rincon (J.M. Aaron, U.S. Geological Survey, unpublished data, 1968), and San Sebastian (Tobisch and Turner, 1971) quadrangles in northwest Puerto Rico, small diorite and quartz diorite stocks and dikes have a near hypabyssal character. No dating is available on these but, their age is inferred to be Eocene. Several of these bodies intrude latest Cretaceous sedimentary rocks of unit Ku. These are spatially associated with numerous porphyritic bodies in the Central La Plata quadrangles mapped as part of unit Thb, hypabyssal felsic and intermediate intrusions. In the Adjuntas quadrangle, several quartz diorite to granodiorite bodies are mapped (Mattson, 1968a). The Vivi Quartz Diorite Porphyry is extremely hydrothermally altered and is the host of several ore bodies. Cox and others (1977) and Barabas (1982) dated several phases of the quartz diorite from drill holes and surface sample collections that yielded ages ranging from 34.8 ± 0.7 to 45.6 ± 2.6 Ma. Virtually all of these samples were hydrothermally altered rocks and in particular, the biotite dates must be considered suspect due to having potassium values lower than should be expected for biotite. A much larger quartz diorite to granodiorite body to the northeast of the Vivi Quartz Diorite Porphyry, yielded several Eocene K/Ar ages as well as one highly discordant K/Ar age (biotite 49.2 ± 1.2 and hornblende 66.8 ± 1.3 Ma; sample 32–129, Cox and others [1977]). Mattson (1968a) had mapped this as Late Cretaceous or early Tertiary; however, the age determinations point to Eocene. The quartz diorite stock in the Cuyon Formation in the Cayey quadrangle of Puerto Rico (Berryhill and Glover, 1960), yielded hornblende and biotite K/Ar ages of 48.3 ± 1.0 and 49.4 ± 1.3 Ma (Cox and others, 1977⁴), respectively. In the Ponce and adjacent Penuelas quadrangles, Krushensky and Monroe (1975, 1978) assigned an Eocene age to hornblende diorite and quartz diorite bodies, including the Tibes Diorite stock; these were described in the Ponce quadrangle as dacitic porphyries that may include groundmass devitrified glass. In the Monte Guilarte and adjacent Bayaney quadrangles, rocks variously described as hornblende diorite and quartz diorite (Nelson and Tobisch, 1968; Krushensky and Curet, 1984) have yielded late and middle Eocene hornblende K/Ar ages of 42.8 ± 5.6 and 45.3 ± 4 Ma on the Torrecilla stock (Cox and others, 1977; Barabas, 1982) and 34.7 ± 3.3 and 43.2 ± 4.5 Ma on an unnamed stock to the east (Barabas, 1982). These intrusions are surrounded by extensive zones of hydrothermal alteration of the surrounding Tertiary volcanic rocks. In the Maricao quadrangle (McIntyre, 1975), a small highly altered granodiorite to quartz monzonite pluton is offset along the left-lateral Cordillera Fault, which trends east-west, traversing the Monto Guilarte, Maricao, Rosario, and Mayagüez quadrangles. A small extension of this pluton extends into the Rosario quadrangle (Curet, 1986). In eastern Puerto Rico, the relatively large stock of quartz diorite and outliers near Rio Blanco (Seiders, 1971a, b; M’Gonigle, 1978, 1979) yielded K/Ar ages of 46.8 ± 2.2 and 47.3 ± 1.1 Ma on biotite and hornblende, respectively (Cox and others, 1977). It has a small extension into the Fajardo

⁴All K/Ar ages have been recalculated using constants of Steiger and Jager (1977).

quadrangle (Briggs and Aguilar-Cortes, 1980). In the British Virgin Islands, Helsley (1960) described the Virgin Gorda batholith, which is exposed on many islands in the British Virgin Islands and on Saint John in the U.S. Virgin Islands, where it is locally known as the Narrows pluton. The batholith is assumed to underlie much of the underwater area between the islands. Helsley (1960) conservatively estimated that its area is about 264 square kilometers (km²), including 57 km² in its western extension, the Narrows pluton. Several other major plutons in the batholith include Jost Van Dyke, Peter Island, and Cooper plutons. Helsley (1960) described tonalite as being the most abundant rock type and having considerable textural and compositional variation; however, the batholith also includes granodiorite and gabbro, as well as late pegmatite and granite dikes (Helsley, 1960). Multiple U/Pb zircon ages range from 30.64±0.46 Ma for the Peter Island pluton and 37.62±0.05 to 43.56±0.08 Ma for the plutons on Beef Island (British Virgin Islands) and Virgin Gorda (Schrecengost, 2010). Potassium-argon age determinations vary somewhat more widely, from 23.7±0.3 to 42.80±2.14 Ma (as well as one outlier age of 60.36±3.02 Ma) for gabbro on Virgin Gorda (Cox and others, 1977; Kesler and Sutter, 1979; Vila and others, 1986; Rankin, 2002). On Saint John in the U.S. Virgin Islands, the multiphase Narrows pluton consists of very-light- to medium-light-gray, medium-grained, nonfoliated biotite-hornblende tonalite and minor gabbro, diorite, granite, and pegmatite (Rankin, 2002). The pegmatite is locally copper stained, and the pluton as a whole contains many xenoliths of stratified country rock, as well as pockets of skarn that contain massive sulfides and have copper staining; the pluton produces a contact-metamorphic aureole as wide as 2 km (Rankin, 2002). Reported ⁴⁰Ar/³⁹Ar plateau ages range from 38.67±0.22 to 39.29±0.22 Ma (Rankin, 2002); Kesler and Sutter (1979) and Rankin (2002) also reported (and discussed) a 24.3-Ma hornblende K/Ar age (recalculated as 23.7±0.3 Ma, using constants of Steiger and Jager [1977]) on the Narrows pluton that Rankin (2002) considered to be “the most puzzling anomaly” and indicated that its meaning was unresolved. As the description of or location of the sample was not disclosed by any of the sources, it is difficult to evaluate the analysis

Tgn

Gabbronorite, norite, and diorite, undifferentiated (Tertiary, Eocene)—Exposed primarily as small plutons and dikes, these mafic rocks are exposed in the Virgin Islands and in Puerto Rico. In Puerto Rico, several small plutons intrude mafic volcanic rocks of the andesite and basalt flows and tuff subunit (TKmv). These were described by McIntyre (1971, 1975) in the Central La Plata and Maricao quadrangles as dark-greenish-gray, holocrystalline, equigranular or porphyritic rocks containing plagioclase, clinopyroxene, and magnetite, and minor chlorite, prehnite, and epidote. Weathering products range from reddish-orange soil to brown grus; both may contain spheroidal boulders of fresh rock as much as several meters in diameter. Composition is moderately variable from high-alumina gabbro to alkali gabbro. McIntyre (1975) thought these bodies most likely were younger than the middle Eocene stratified rocks exposed in the Maricao quadrangle. In the southwest Adjuntas quadrangle, Mattson (1968a) described several small plutons of medium-grained diorite, gabbro(?), and minor granodiorite. The plutons there are locally rich in hornblende, some samples containing more than 40 percent; Barabas (1982) reported a 42.4±1.4 Ma K/Ar date on hornblende. “These rocks weather to a light-colored clayey soil” (Mattson, 1968a). On Saint John in the U.S. Virgin Islands, Rankin (2002) described nearly vertical gabbroic dikes that range in thickness from a few centimeters to several tens of meters, as well as complex dike swarms, some having internal layering parallel to dike walls; these dikes, which are widely scattered across island, typically have chilled margins, and they vary in color index, grain size, and texture. On the north half of Saint John, dikes are progressively metamorphosed to amphibolite-facies mineral assemblages. Also, toward the north, many dikes have the same penetrative cleavage as enclosing stratified rocks and, locally, are broken into segments aligned parallel to cleavage, although other dikes postdate cleavage. Larger bodies commonly contain epidote nodules and disseminated epidote (Rankin, 2002). Rankin (2002) thought that, on Saint John, the unit includes dikes of more than one age; some are intrusive equivalents of extrusive rocks in enclosing or overlying stratified units. Other of these dikes are part of Rankin’s (2002) tonalite intrusive event (unit Ted); and a very few cut lamprophyre dikes of unit Thb. In the British Virgin Islands, Helsley (1960) mapped a small body of banded gabbro on Salt Island that he assigned to the Virgin Gorda batholith. Vila and others (1986) and Rankin (2002) reported a 60.36±3.02 Ma whole-rock K/Ar age on gabbro associated with the Virgin Gorda batholith on Virgin Gorda; however, because the pluton is interpreted as Eocene and because this is a whole-rock age on gabbro, we discount the anomalously old age

TKgs

Alkali syenite (Tertiary, Paleocene to Late Cretaceous, Maastrichtian)—In the Ciales quadrangle of central Puerto Rico, (Berryhill, 1965) mapped a small body of alkali syenite, which consists of potassium feldspar and augite in a chloritized matrix. It intrudes the Late Cretaceous andesitic rocks of unit Kva. A much larger body of augite syenite, also in the Ciales quadrangle may be significantly older and is described in unit Kas

TKga	Granite and aplite, undifferentiated (Tertiary, Paleocene to Late Cretaceous, Maastrichtian) —In the Comerio quadrangle of central Puerto Rico, small, apparently intrusive bodies of “Light-colored weathered rock whose original mineral constituents cannot be recognized” (Pease and Briggs, 1960) intrude Early Cretaceous intermediate composition volcanic rocks of unit Kevi. These weathered rocks are associated with hornblende diorite, also assumed to be Tertiary or Cretaceous, though not dated. On Isla de Vieques in Puerto Rico, Learned and others (1973) mapped several very small aplite and porphyritic bodies associated with a large batholith as well as abundant quartz veins cutting the pluton
TKgm	Granodiorite and quartz monzonite, undifferentiated (Tertiary, Paleocene to Late Cretaceous, Maastrichtian) —Present primarily in Puerto Rico but also present in eastern Jamaica and, to a lesser extent, on Saint Thomas in the U.S. Virgin Islands. Small granodiorite stocks are present in eastern Jamaica (McFarlane and others, 1984). Chubb and Burke (1963) reported a 64 ± 5 Ma U/Pb sphene date (likely a Pb-alpha date, which should be considered spurious as the method was based on invalid assumptions), a 64 ± 5 Ma Rb/Sr biotite date, and a 66.7 ± 5.0 Ma K/Ar biotite date on the Zion Hill Bridge body, as well as a 55.4 ± 5 Ma K/Ar feldspar date on the Hall Green pluton that likely is a minimum age. Chubb and Burke (1963) also reported a 75.5 ± 5 Ma K/Ar feldspar date on the Troja pluton. Lewis and others (1973) reported discordant whole-rock K/Ar and hornblende dates of 48.2 ± 1.8 and 74.3 ± 2.0 Ma, respectively, on the Ginger Ridge granodiorite (the whole-rock date is likely spurious and the hornblende date is most likely a minimum age). In Puerto Rico, the largest exposure of this unit is granodiorite to quartz diorite of the Utuado batholith, in the west-central part of island; generally, it is pale-gray-brown to pale-pink, massive, locally porphyritic, medium- to fine-grained granodiorite and subordinate quartz diorite, quartz monzonite, and diorite. The batholith is widely and deeply weathered to very-pale-yellow-brown, sandy saprolite (Adjuntas and Jayuya quadrangles, Mattson, 1968a, b; Bayaney quadrangle, Nelson and Tobisch, 1968; Florida quadrangle, Nelson and Monroe, 1966; Utuado quadrangle, Nelson, 1967b). Several radiometric ages have been reported for the pluton including K/Ar hornblende ages between 62 ± 2.6 and 70.6 ± 3.3 Ma (Cox and others, 1977; Barabas, 1982); alunite at 62.7 ± 3.2 Ma (Barabas, 1982), biotite 72.3 ± 1.7 Ma (Cox and others, 1977), and 66.7 ± 3.25 Ma (Mattson, 1968b). There were also several Pb-alpha ages, now considered spurious. An older, 76.1 ± 1.5 Ma hornblende K/Ar age from quartz diorite exposed in a southern outlier of the batholith may represent a distinct igneous episode (Cox and others, 1977; Barabas, 1982). Small stocks in eastern Puerto Rico in the Humacao and Naguabo quadrangles are quartz diorite to granodiorite, none of which have been dated (M’Gonigle, 1978, 1979)
TKtm	More mafic granitic rocks, tonalite, monzonite, quartz diorite, and granodiorite (Tertiary, Eocene to Late Cretaceous, Maastrichtian) —Main exposure of the unit is granodiorite and tonalite in a northwest-trending belt across the island of Hispaniola. Mapped as tonalite in the Dominican Republic (Toloczyki and others, 1991) and as granodiorite and tonalite in Massif du Nord in Haiti (Vila and others, 1985); also includes small outlier plutons in eastern Dominican Republic. Radiometric ages, by either K/Ar or $^{40}\text{Ar}/^{39}\text{Ar}$ methods, range from 33 ± 2 to 83.0 ± 9.2 Ma; however, most analytically reliable ages are between 56 ± 2 and 70.5 ± 0.8 Ma. The outlier age determinations are suspect, owing to abnormal K_2O contents, discordance, or low-quality analyses. Several of these plutons in Dominican Republic, especially the eastern outlier bodies, yielded age determinations indicating that more likely they belong to either the quartz diorite and diorite unit (TKqt), the granodiorite subunit (Kgd), or the granodiorite and tonalite unit (Kmgd), and they have been reassigned here as appropriate. On the island of Vieques in Puerto Rico, small “mafic” intrusive bodies intrude the larger quartz diorite batholith (Learned and others, 1973)
TKqt	Quartz diorite and diorite, undifferentiated (Tertiary, Paleocene to Late Cretaceous, Maastrichtian) —In western Puerto Rico, small porphyritic hornblende diorite or quartz diorite plutons or stocks are widely scattered across the Rosario and Mayagüez quadrangles (Curet, 1986). No radiometric dates are available for the bodies, which intrude several of the older map units of the quadrangle including units as young as Maastrichtian. In the Orocovis quadrangle of central Puerto Rico, Briggs (1971) mapped several quartz diorite and diorite intrusions. These tend to be equigranular and medium grained, though the bodies in the western part of the quadrangle can be porphyritic with large plagioclase and less common hornblende phenocrysts. Some of these may transition to granodiorite in the adjacent Jayuya quadrangle (Mattson, 1968b). Very similar intrusions were mapped by Briggs and Gelabert (1962) in the Barranquitas quadrangle to the east. Several elongate quartz diorite to granodiorite intrusions in the Corozal (Nelson, 1967a) and adjacent Naranjito quadrangles (Pease, 1968c) intrude Late Cretaceous mafic volcanic rocks of unit Klmv. As above, no radiometric dates are available for these rocks. Intruding Early Cretaceous volcanic rocks of unit Kevi are several small plutons and stocks of porphyritic hornblende diorite as well as several pyroxene diorite dikes; age is inferred (Pease and Briggs, 1960). In the Aguas Buenas (Pease, 1968b), Naranjito (Pease, 1968c), and Gurabo (Seiders, 1971b) quadrangles, are many exposures of diorite and quartz diorite.

This area is cut by many faults, which in some cases juxtapose the intrusions against Paleocene to Eocene sedimentary rocks; however, the youngest rocks that appear to be intruded are early Late Cretaceous. In the western Aguas Buenas and eastern Naranjito quadrangles, there is a dike swarm radiating from one pluton, suggesting it might reflect a volcanic center; if it is related to the enclosing volcanic rocks, this might suggest these bodies are early Late Cretaceous in age. These plutons likely extend into the northern Juncos quadrangle (Broedall, 1961) where they also interfinger with medium-grained gabbro. Several small stocks of medium- to fine-grained quartz diorite and granodiorite in the Naguabo and Punta Puerca quadrangles (M'Gonigle, 1979) intrude Early Cretaceous volcanic rocks of the Dagua Formation (unit Kevi). Other small porphyritic diorite and quartz diorite bodies occur in the Salinas quadrangle (Glover, 1961b), Utuado (Nelson, 1967b), and Yauco quadrangles (Krushensky and Monroe, 1979). Banks (1962) mapped an undated diorite pluton on Isla de Culebra. In the U.S. Virgin Islands, small diorite plutons are present on the east end of Thatch Cay, on Buck and Capella Islands, and on Frenchman Cap (Donnelly, 1966); Donnelly (1966) also mapped several andesine-hornblende porphyry dikes on Saint Thomas that we include in unit TKqt. Whetten (1966) mapped a hornblende diorite pluton called the Southgate diorite on eastern Saint Croix in the U.S. Virgin Islands that yielded a K/Ar age of 66.0 ± 3.2 Ma (Speed and others, 1979).

TKgb

Gabbroic rocks, including Fountain Gabbro (Tertiary, Paleocene or Late Cretaceous,

Campanian)—Nelson and Monroe (1966) mapped several small intrusive bodies of diorite to gabbro in the Florida quadrangle of Puerto Rico that intrude Late Cretaceous volcanic and volcanoclastic rocks of unit Kva. In the Corozal quadrangle, also in Puerto Rico, a small body of olivine gabbro (Nelson, 1967a) intrudes early Late Cretaceous sedimentary rocks of unit Ksv. To the south in the Barranquitas quadrangle (Briggs and Gelabert, 1962), mafic intrusive rocks (likely of gabbroic composition), intrude Late Cretaceous volcanoclastic conglomerate (Kcgl). On Isla de Vieques, mafic bodies intrude the island batholith and are likely of gabbroic composition (Learned and others, 1973). The Fountain Gabbro is a two-pyroxene gabbro that has accessory biotite, magnetite, and apatite (Whetten, 1966) on northwestern Saint Croix; the gabbro body is about 3.5×2 km in size, and it intrudes the volcanoclastic sandstone and mudstone subunit (Kvss)

Kd

Dikes, granite to diorite (Cretaceous)—In the Holguín area of southern Cuba, several small diabase bodies are associated with flows of the Loma Blanca Formation, shown in this report as part of unit Kfv (IGP, 2011). No age control is available. In Puerto Rico, restricted to the southcentral and southeastern part of the island, these dikes include andesite and diorite porphyry. Rogers (1979) reports numerous dikes in the Caguas quadrangle of Puerto Rico, many too small to map. They dominantly trend north to northeast and are most common in the east-central part of the quadrangle where they intrude Late Cretaceous rocks. Rogers and others (1979) describe a similar group of diorite porphyry dikes in the Yabucoa and Punta Tuna quadrangles of Puerto Rico, all of which cut phases of the San Lorenzo batholith. In the Punta Guayanes quadrangle, Rogers (1977) describes a single large curving diorite porphyry dike and a mafic dike (representative of many others), that he suggests indicates an arcuate fracture. These dikes cut a phase of the San Lorenzo batholith that has yielded an approximately 80 Ma K/Ar date (see discussion of unit Kqd). Berryhill and Glover (1960) show several dikes and a small porphyritic andesite stock that intrude early Late Cretaceous volcanic rocks of unit Kevi in the Cayey quadrangle. Farther west in the Rio Descalabrado quadrangle, Glover and Mattson (1973) show several pyroxene andesite dikes, having apparently random orientations, cutting tuff of the Coamo Formation (unit Kva)

Kgb

Gabbro (Cretaceous?)—This unit includes many gabbroic occurrences in Cuba, a few in northern part of the island and the majority in Cuba's Camagüey region (IGP, 2011). In many cases, an age was not reported for the bodies mapped as gabbro. Also included in this unit are units mapped as gabbro-plagiogranite complexes and syenitic gabbro complexes and assigned a Cretaceous age

Kgu

Granitic rocks, undifferentiated (Cretaceous)—In Cuba and Puerto Rico, there are several granitic intrusions for some of which, at best, only a Late Cretaceous age can be inferred (IGP, 2011). Included in this unit are some small granite bodies on Isla de la Juventud in Cuba intruding muscovite schist that has yielded Campanian metamorphic ages (Laverov and Cabrera, 1967). In central Cuba, several small granodiorite intrusions and a larger body in the northern Camagüey region are inferred to be Cretaceous; the larger body is on trend with a series of intrusions of Coniacian to Albian age (IGP, 2011). A small quartz diorite body along the Cuban coast near Trinidad Dome is inferred to be Cretaceous (IGP, 2011). In Puerto Rico, on the border of the Humacao and Naguabo quadrangles, a small area of hydrothermally altered rocks, which have been inferred to have originally been granodiorite (M'Gonigle, 1978, 1979) is inferred to be Cretaceous. The nearest intrusions to these rocks are 4 to 6 km away and are not dated but are recorded as Tertiary or Cretaceous (M'Gonigle, 1978, 1979). Granophyre in the Patillas quadrangle,

consists of a porphyritic rock of granitic composition that contains phenocrysts of quartz and plagioclase and minor hornblende and biotite in a graphic-textured groundmass. It is associated with the quartz diorite of plutonic complex of Punta Guayanes (Glover, 1982). Locally, divided into subunits Kdi, Klq, Kgd, Klqm, Kqd, Kpd, Kmgd, Kgr, and Kas

Kdi **Diorite**—Diorite in small intrusions in central and southern Cuba (IGP, 2011). Reported age is Cretaceous
Klg **Granite (Late Cretaceous, Maastrichtian or Campanian)**—In central Cuba, small granite bodies are associated with the plutonic phase of the Camagüey volcanic-intrusive arc (IGP, 2011). No radiometric age determinations have been reported for these bodies; however, Hall and others (2004) reported biotite $^{40}\text{Ar}/^{39}\text{Ar}$ total-fusion and plateau ages of 60.1 ± 0.3 and 65.8 ± 0.6 Ma, respectively, on syenitic facies of Camagüey batholith, which they (Hall and others, 2004) interpreted as indicating emplacement age of 70 Ma or older. These syenitic facies were not mapped separately by IGP (2011). Other biotite, hornblende, and K-feldspar plateau age determinations on the Camagüey batholith varied between 63.2 ± 2.5 and 79.9 ± 0.5 Ma (Hall and others, 2004)

Kgd **Granodiorite (Late Cretaceous, Maastrichtian and Campanian)**—In southern Cuba, a “granodiorite complex” (IGP, 2011) assigned to the Camagüey volcanic-intrusive arc yielded $^{40}\text{Ar}/^{39}\text{Ar}$ ages in the range of 63.2 ± 2.5 to 79.9 ± 0.5 Ma (Hall and others, 2004; Kesler and others, 2004); the 63.2 Ma age is an outlier; replicate age determination on the sample were 72.3 ± 0.2 and 73.0 ± 0.5 Ma (Hall and others, 2004). This complex is dominantly granodiorite but, also includes a syenite facies. In Puerto Rico, this subunit and subunit Klqm represent the main part of San Lorenzo batholith complex of southeastern Puerto Rico. The main part of the batholith is mapped as granodiorite, which occurs in two phases. As mapped, the dominant phase, the granodiorite of San Lorenzo, is a medium-dark-gray rock. It has a hypidiomorphic-granular texture and is largely nonfoliated but, locally has simple planar arrangement of hornblende and biotite grains. Scattered small subrounded autoliths that are darker and more mafic than the host rock are present, as are a few areas of older diorite that are too small or too poorly defined to be mapped. Several radiometric age determinations have been made, all along the periphery of the batholith. A K/Ar age determination on granodiorite from the southeastern part of the batholith yielded discordant ages of 67.3 ± 1.6 and 76.0 ± 1.5 Ma on biotite and hornblende, respectively (Cox and others, 1977; Rogers, 1977). A U/Pb zircon analysis from the northern part of the batholith yielded an age of 70.1 ± 2.0 Ma (table 4, sample 18PWs020) and contained several inherited zircons yielding roughly 106 Ma ages (see Wilson and others [2024]). A second granodiorite phase, locally mapped as the granodiorite of Punta Guayanes is light- to very-light-gray, dominantly medium-grained, nonfoliated rock having hypidiomorphic-granular to allotriomorphic-granular texture. It commonly weathers to light red or pink, is highly fractured and friable, and in some areas is extensively epidotized along fractures. Compared to the granodiorite of San Lorenzo, it is relatively free of autoliths and metavolcanic xenoliths (Rogers, 1977). A K/Ar age determination on this phase in the Punta Guayanes quadrangle yielded concordant ages of 67.2 ± 1.6 and 67.8 ± 2.9 Ma on biotite and hornblende, respectively (Cox and others, 1977; Rogers, 1977). A locally mapped quartz monzonite phase is described in subunit Klqm. A quartz diorite phase is included in unit Kqd and a much older associated quartz diorite is included in unit Kqt

Table 4. Uranium-lead zircon radiometric ages from Puerto Rico determined in this study.

[Ages from Wilson and others (2024). Age uncertainties are plus or minus ($\pm$). Sample analysis by Paul O’Sullivan (GeoSep Services, Inc., Moscow, Idaho). Latitude and longitude in decimal degrees, World Geodetic System of 1984 (WGS 84) datum. Ma, mega-annum (million years before present); N, north; n.a., not applicable; W, west]

Sample number	Latitude, in decimal degrees N	Longitude, in decimal degrees W	Rock type	Age (Ma)	Uncertainty (Ma)	Map unit
18PWs008	18.1872	67.0626	Andesite	n.a.	see text	TKmv
18PWs010	17.9920	65.8895	Granitic rock	109.3	1.3	Kqt
18PWs012	18.0137	65.8692	Diorite	69.3	1.1	Kqd
18PWs013	18.1608	65.8534	Granodiorite	69.3	1.0	Kgd
18PWs020	18.2170	65.9120	Granodiorite	70.1	2.0	Kgd
18PWs022	18.1137	65.5197	Granitic rock	69.6	1.0	Kqd
18PWs026	18.0997	65.5004	Granodiorite	68.2	1.4	Kqd
18PWs029	18.0958	65.4769	Quartz diorite	69.7	1.1	Kqd

Klqm	Quartz monzonite (Late Cretaceous, Maastrichtian and Campanian)—In Puerto Rico, quartz monzonite of the plutonic complex of Punta Guayanes occurs in several small bodies and one larger one within the larger Late Cretaceous San Lorenzo batholith and are not dated. Mapping of these rocks was limited to only the Yabucoa quadrangle (Rogers and others, 1979), and presumably these rocks are more extensive in the batholith, though possibly not as mappable units. K/Ar age determinations on quartz monzonite from parts of the batholith in the Juncos quadrangle yielded slightly older ages than the granodiorite including concordant ages of 74.4 ± 2.0 and 75.2 ± 1.5 Ma on biotite and hornblende, respectively (Cox and others, 1977; Rogers, 1977) and discordant ages of 63.2 ± 1.5 and 72.2 ± 3.2 Ma on chloritized biotite and hornblende, respectively (Cox and others, 1977)
Kqd	Quartz diorite and tonalite, undifferentiated (Late Cretaceous, Maastrichtian to Santonian)—Exposed in Cuba, Haiti, Dominican Republic, and Puerto Rico. In central Cuba, several small quartz diorite bodies are associated with the plutonic phase of the Camagüey volcanic-intrusive arc (IGP, 2011). No radiometric age determinations have been reported for these quartz diorite bodies in Cuba. U/Pb SHRIMP zircon age determinations on tonalite from the San Andres body yielded an age of 74.8 ± 0.7 Ma, and granite from the same body yielded an age of 76.3 ± 0.5 Ma (Rojas-Agramonte and others, 2010). This small pluton is shown on map sheet 2. The Tres Guanios body, described as trondhjemite yielded a U/Pb SHRIMP age of 76.6 ± 0.4 Ma (Rojas-Agramonte and others, 2010). On Hispaniola, is a large plutonic complex, the bulk of which is exposed in Haiti. In Haiti, it consists of tonalite, quartz diorite and lesser granodiorite of the Massif du Nord (MMER, 1989), and in Dominican Republic, the Loma de Cabrera batholith appears to be an extension of the same unit. Originally mapped as part of their unit “ks-tpg’to” by Toloczky and others (1991), this batholith was separated in this report based on available radiometric dates. There are fourteen available dates which used $^{40}\text{Ar}/^{39}\text{Ar}$, K/Ar, and Rb/Sr methods. The youngest of the dates, a 33.0 ± 2.0 and 49.4 ± 0.6 Ma K/Ar age on biotite (Kesler and others, 1991), may represent an unmapped phase or younger intrusion. Other age determinations ranged from 68.4 ± 0.9 Ma on hornblende (Kesler and others, 1991) to an 87.9 ± 2.5 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ plateau age on hornblende (Escuder-Viruet and others, 2006a). The Rb/Sr whole rock composite dates were 85 ± 17 and 87 ± 19 Ma, reflecting 7 and 4 samples, respectively (Feigenson, 1977). Unfortunately, we do not have precise location information for any of these samples. In southeastern Dominican Republic, the tonalitic Medina stock has several reported K/Ar dates, which are 81.4 ± 2.0 Ma on biotite from one sample and 79.9 ± 2.0 Ma and 81.6 ± 2.0 Ma on biotite and hornblende from another sample (Bowin, 1975; Kesler and others, 1991). In southeastern Puerto Rico, peripheral to the main San Lorenzo batholith are several tonalite plutons. Generally, southwest of the main pluton, these tonalite plutons intrude the older volcanic rocks of unit Kevi and an apparently older tonalite facies of the San Lorenzo batholith (Rogers, 1977, 1979; Rogers and others, 1979; Glover, 1982). No radiometric dates are available for the rocks of this unit; the older facies is mapped as part of unit Kqt. Learned and others (1973) mapped a large quartz diorite, diorite, and granodiorite batholith on Isla de Vieques. Recent U/Pb dates on zircon from the batholith on Isla de Vieques ranged from 68.2 ± 1.4 to 69.7 ± 1.1 Ma (table 4, samples 18PWs026, 18PWs022, and 18PWs029)
Kpd	Porphyritic diorite (Late Cretaceous, Maastrichtian and Campanian)—In Cuba and Puerto Rico. In central Cuba, includes several small diorite bodies including the Tres Guanios pluton, which Rojas-Agramonte and others (2010) reported a U/Pb SHRIMP zircon age determination on zircon of 71.1 ± 0.4 Ma on seven grains (one grain from the sample yielded a highly anomalous age of 536 ± 3 Ma, suggesting that zircon was inherited). In the San German quadrangle of western Puerto Rico, the Las Tunas stock is an isolated body that intrudes the Late Cretaceous Lajas Formation mafic volcanic rocks (unit Klmv). It consists of porphyritic diorite near the western border of the quadrangle that is strongly altered to sericite, chlorite, and epidote, and locally completely replaced by calcite (Volckmann, 1984c). Volckmann (1984c) suggested the Las Tunas stock and the Lajas Formation possibly were derived from the same source. He further suggested that “if the two rock types are related, the Las Tunas stock is a hypabyssal intrusive unit which was emplaced during the late stages of development of the Lajas Formation and therefore is probably Campanian in age.” The small Zanja Blanca stock in the Rio Descalabrado quadrangle (Glover and Mattson, 1973) intrudes the Coamo Formation, and Glover (1971) inferred that it reflects the site of a vent for the volcanic rocks. The diorite is altered and is surrounded by an albite-epidote hornfels. Glover and Mattson (1973) also mapped a small area of hornblende diorite to the west of the Zanja Blanca stock for which they did not assign an age; we tentatively place that small body in this map unit (Kpd). In the adjacent Coamo quadrangle, porphyritic hornblende diorite occurs in several small bodies and in a larger body (3 km in diameter) known as the Los Panes intrusion (Glover, 1961a); these are not dated and intrude Cretaceous volcanic and volcanoclastic rocks. Glover (1961a) called these Tertiary(?), but subsequently Glover (1971) described these as Late Cretaceous. In southeastern Puerto Rico, several small diorite plutons are associated with and on the periphery of the

San Lorenzo batholith (unit **Kgd**) and the satellite Caguas pluton. These diorite intrusions are typically described as heterogeneous, medium- to coarse-grained hornblende-pyroxene diorite that is locally rich in magnetite, particularly in the Humacao quadrangle (M'Gonigle, 1978). The bodies are also present in the Patillas and Guayama quadrangles (Glover, 1982), and the Punta Guayanes, Caguas, and Yabucoa quadrangles (Rogers, 1977, 1979; Rogers and others, 1979). In the Punta Guayanes quadrangle, two K/Ar age determinations yielded 79.7 ± 1.6 and 80.2 ± 1.6 Ma on hornblende (Cox and others, 1977; Rogers, 1977), indicating that some of these bodies predate the larger batholith, whereas in the Patillas quadrangle, Cox and others (1977) reported a 102.5 ± 16.0 Ma K/Ar age on actinolite; the large reported analytical error is due to the low potassium content of the actinolite, whereas Cavosie and others (2007) reported a U/Pb zircon age of 79.0 ± 2.1 Ma on apparently the same intrusion

Kmgd

Granodiorite and tonalite, undifferentiated (Cretaceous, Santonian to Albion)—In Cuba, Dominican Republic, and Puerto Rico. In central Cuba, peripheral to the Escambray Massif are several large granodiorite and tonalite plutons mapped as part of a “granodiorite-granite complex” by IGP (2011). Reported U/Pb SHRIMP zircon age determinations yield a tight range of ages between 83.1 ± 0.8 and 88.7 ± 0.7 Ma and thermal ionization mass spectrometry (TIMS) multigrain ages between 89.3 ± 2.0 and 93 ± 10 Ma (Bibikova and others, 1988; Hatten and others, 1988; Rojas-Agramonte and others, 2011; Stanek and others, 2019). The age determinations suggest these are multiphase plutons, as reported lithologies include tonalite, diorite, trondhjemitic diorite, quartz monzonite, and monzodiorite. Hatten and others (1988) reported a hornblende K/Ar age of 85 ± 1 Ma from a weakly foliated quartz monzonite from drill core and a muscovite K/Ar age of 84 ± 1 Ma from a pegmatite that is likely associated with the plutons and cuts amphibolite in the metamorphic country rocks. Hatten and others (1988) also report several K/Ar ages on orthogneiss ranging between 69 ± 2 and 78 ± 3 Ma. In eastern Dominican Republic, plutons mapped by Toloczyki and others (1991) as their unit “ks-tpg-to” yielded a wide range of K/Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ radiometric ages. Those plutons (and their nearby neighboring plutons) that yield ages less than 80 Ma were assigned to unit **Kqd** in this report; older plutons yielding ages between 84.6 ± 0.5 and 109.8 ± 2.2 Ma (Bowin, 1975; Escuder-Viruet and others, 2006b) and U/Pb ages ranging between approximately 89.73 ± 0.15 and 115.5 ± 0.3 Ma (Escuder-Viruet and others, 2006b, 2013a; Torró and others, 2017a, b, 2018a, b) were assigned to this map unit (**Kmgd**). In central Puerto Rico, the Morovis and Ciales stocks are granodiorite (Berryhill, 1965). A K/Ar age on hornblende from quartz monzonite of the Morovis stock was 90.2 ± 1.8 Ma (Cox and others, 1977; Lidiak, 1990). A spurious Pb-alpha age of 70 ± 20 Ma on zircon was reported by Berryhill (1965)

Kgr

Older granite (Cretaceous, Coniacian to Albion)—In Cuba, associated with the plutons (described previously for **Kmgd**) near the Escambray Massif is a small body of granite, which has not been dated (IGP, 2011). In Dominican Republic, Toloczyki and others (1991) mapped a small area of granite enclosed within tonalite of the granitic rocks, granodiorite, and tonalite unit (**Kmgd**); this may be a distinct body or, alternatively, simply a different compositional phase of the larger pluton. Hernaiz-Huerta and others (2012) report a $^{40}\text{Ar}/^{39}\text{Ar}$ plateau age of 95.4 ± 1.2 Ma on a leucogranite intrusion in the Los Canos Formation as part of Puerto Plata basement complex

Kas

Augite syenite (Cretaceous, Coniacian to Albion)—In the Ciales quadrangle of central Puerto Rico, a small body of augite syenite intrudes the Perchas Formation of the Rio Orocovis Group (unit **Koba**), and it is in close proximity to Cretaceous quartz monzonite of the Morovis stock (Berryhill, 1965). No date is available on this body of augite syenite, but it may be the same age as that of the nearby Morovis stock, which yielded a 90.2 ± 1.8 Ma hornblende K/Ar age (Cox and others, 1977; age recalculated using constants of Steiger and Jager [1977])

Kqt

Quartz diorite, tonalite, and trondhjemitic, undifferentiated (Cretaceous, Santonian to Albion)—Found in Cuba, Puerto Rico, and the U.S. Virgin Islands. In Cuba, just north of the Escambray Massif the unit is exposed in what IGP (2011) described as a plagiog-rhyolite-plagiogranite complex of Cretaceous or Tertiary age. Closely associated with plutons of unit **Kmgd** that yielded U/Pb SHRIMP ages between 83.1 ± 0.8 and 88.7 ± 0.7 Ma on zircon (Rojas-Agramonte and others, 2011), it is likely that this body is similar in age. In southeast Cuba, a quartz diorite body located west of Baracoa is described as fine- to medium-grained quartz diorite that is associated with the Cretaceous volcanic arc; $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations, which may be dating this body were reported by Lázaro and others (2009) (sample locations are uncertain) on amphibole from trondhjemitic were between 85.7 ± 1.5 and 94.8 ± 2.3 Ma. In Puerto Rico, rocks of this map unit are found in two locations, southwest and southeast Puerto Rico. In southwest Puerto Rico, quartz diorite of the Maguayo Porphyry in the Bermeja Complex intrudes the Mariquita Chert (unit **KJcm**). The quartz diorite is porphyritic, containing sparse to abundant phenocrysts of plagioclase (sodic andesine), hornblende, biotite, and locally, quartz set in a fine-grained, granular matrix of plagioclase, quartz, and chloritized mafic minerals (Volckmann, 1984a). Cox and others (1977)

reported a hornblende date of 88.2 ± 2.1 Ma on diorite porphyry from this unit. In southeast Puerto Rico, peripheral to the San Lorenzo batholith on its south and southwest sides, Rogers (1977) and Rogers and others (1979) mapped a unit they called the tonalite facies of the San Lorenzo batholith. It is a “light- to medium-dark-gray, predominantly medium-grained rock having hypidiomorphic-granular texture. It is largely nonfoliated but has a faint suggestion of foliation locally near diorite contacts” (Rogers, 1977) (unit **Kpd** in this report). A single K/Ar age on hornblende yielded an age of 111.4 ± 9.0 Ma, which is significantly older than other phases of the San Lorenzo batholith (Cox and others, 1977). A U/Pb age determination on zircon of a sample from the northern part of the San Lorenzo batholith yielded an age of 70.1 ± 2.0 Ma (table 4, sample 18PWs020; see Wilson and others [2024]); this sample also contained 2 zircons, which were assumed to be inherited, that yielded ages between of 105 and 107 Ma and may reflect intrusion through an older phase or pluton. Southwest of Saint John, on Leduck and Flanagan Islands in the U.S. Virgin Islands, Rankin (2002) mapped small trondhjemite and intrusive keratophyre bodies as part of the Careen Hill Intrusive Suite. The hypabyssal keratophyre is included in the hypabyssal rocks and keratophyre porphyry unit (**Khk**). The trondhjemite is fine- to medium-grained, commonly porphyritic, and has quartz and twinned non-zoned albite phenocrysts, in a groundmass that typically is a granophyric intergrowth between quartz and albite. On Leduck Island, columnar jointing is prominent (Rankin, 2002). Rankin (2002) suggested an Early Cretaceous age for the trondhjemite of Saint John and Leduck Island; however, no radiometric ages are available on this map unit. Rankin (2002) mapped trondhjemite on Flanagan Island, which is located east of Saint John, assigned it an Early Cretaceous age, and included it with the trondhjemite of Saint John and Leduck Island. Helsley (1960) had considered Flanagan Island as part of the Tertiary Virgin Gorda batholith (unit **Ted**)

Khg Hornblende gabbro and diorite, undifferentiated (Late Cretaceous, Coniacian to Cenomanian)—Associated with the Rio San Juan Complex of northeastern Dominican Republic is hornblende gabbro, diorite, and tonalite and their metamorphic derivatives of the Rio Boba Metaplutonic Complex (Escuder-Virue and others, 2013a). In subordinate amounts ultramafic cumulates (wehrlite and websterite) are also present. A U/Pb TIMS multigrain zircon age (90.1 ± 0.2 Ma) indicates Late Cretaceous intrusion of hornblende-bearing tonalite and diorite (Escuder-Virue and others, 2013a). Hornfels is developed at the intrusive with the Puerca Gorda mafic schist (unit **KJca**)

Kegb Doña Ruth gabbro and gabbro of the Careen Hill Intrusive Suite of Rankin (2002) (Early Cretaceous)—The Doña Ruth gabbro of Torró and others (2018b) of central Dominican Republic, is a massive body that intrudes basalt and basaltic autobreccia. It is holocrystalline, medium to coarse grained, and has an equigranular texture (Torró and others, 2018b). It is composed of plagioclase (60 modal percent), amphibole (actinolite; 38 modal percent), and incidental quartz (2 modal percent). Torró and others (2017b, 2018b) report a 117.4 ± 1 Ma U/Pb SHRIMP zircon age on the gabbro. The gabbro of the Careen Hill Intrusive Suite (Rankin, 2002) at Bovocoap Point on southwestern Saint John in the U.S. Virgin Islands, is presumed to be Early Cretaceous and is dark greenish gray, fine grained, and porphyritic. Unit **Kegb** also likely includes mafic dikes in the Water Island Formation, which Rankin (2002) indicated are more abundant than what is shown on his map

Jgr Rio Cana Granite (Middle Jurassic)—In Cuba, consists of coarse-grained pink granite that contains perthitic microcline, plagioclase, quartz, biotite, and accessory apatite and zircon (Renne and others, 1989). According to Renne and others (1989), the unit is highly deformed and commonly has cataclastic texture. Somin and Millán (1977) and Renne and others (1989) reported several whole-rock K/Ar dates between 136.6 ± 2 and 146.5 ± 5 Ma; however, the dates are suspect because they are whole-rock dates on granitic rock and the decay constants used are unknown. Renne and others (1989) reported a multigrain U/Pb analysis that yielded a lower intercept age of 172.5 Ma and an upper intercept of about 900 Ma. This upper intercept age is similar to age determinations by Somin and Millán (1977) and Renne and others (1989) for phlogopite in marble (unit **Pm**) that was intruded by this unit whereas the lower intercept age suggests a Middle Jurassic age for the granite

METAMORPHIC ROCKS

Kps Pelitic schist, minor greenstone, and marble, undifferentiated (Cretaceous)—This constitutes two map units in central Cuba. The El Tambor Formation is exposed in the Trinidad Dome area of the Escambray Massif in central Cuba and consists of psammitic and calcareous schist, slate, and foliated marble (Stanek and others, 2006). It was described by Pardo (2009) as a metamorphosed alpine-type flysch consisting of well-bedded, rhythmic, sometimes calcareous, fine-grained chlorite schist to greenschist that includes coarse-grained metasandstone and numerous interbeds of light-colored marble and a few beds of metaquartzite. Pardo (2009) indicates the formation appears to contain olistoliths of older formations. Its San Blas Member shown here is described as psammitic and pelitic

schist, rich in quartz and granitic clasts and having interlayers of quartzite and locally, having mafic metavolcanic greenstone and gray to black marble (IGP, 2011). The bulk of this map unit reflects the Lower Cretaceous La Sabina Formation, exposed dominantly on Trinidad Dome and to a lesser extent on Sancti Spiritus Dome. It consists of quartzite containing interlayers of pelitic schist and local layers of meta-arenite and marble (IGP, 2011)

- Kmgb** **Gabbroic amphibolite and amphibolite, undifferentiated (Cretaceous?)**—Gabbroic amphibolite and amphibolite of the greenschist-facies Duarte Formation (or Complex) of Cordillera Central and Cordillera Septentrional of Dominican Republic. Also includes metamorphosed mafic volcanic rocks including basalt and tuff, locally including sedimentary rock intercalations (quartzite), of pre-Albian age (Bowin, 1966; Toloczyki and others, 1991). Also includes the Cuaba Mafic-Ultramafic unit of the Río San Juan Complex of Escuder-Virue and others (2013a). The Cuaba Mafic-Ultramafic unit is subdivided into two subunits; the Jobito subunit consists of fine-grained amphibolite and mafic schist and metadiorite occurring as intercalated tectonic lenses at the base of serpentinized peridotite. A second subunit consists of banded metagabbro and metadiorite tectonically enclosed in the lower structural levels of the Guaconejo subunit (unit **KJmc**). These rocks were metamorphosed to eclogite and ultrahigh pressure eclogite facies (Escuder-Virue and others, 2013a)
- Kmvs** **Metavolcanic rocks, metasandstone, and blueschist, undifferentiated (Cretaceous, Turonian to Aptian)**—Exposed in the vicinity of Guantánamo in southern Cuba is the Sierra del Purial Formation, consisting of metavolcanic rocks, metasandstone, and including blueschist facies rocks (IGP, 2011)
- Kgs** **Marble and greenschist, undifferentiated (Cretaceous, Turonian or older)**—In both the U.S. and British Virgin Islands, two marble units are recognized, the Outer Brass Limestone (Donnelly, 1966; Rankin, 2002) and the Congo Cay Limestone Lens of the Mandal Member of the Tutu Formation (Rankin, 2002). The Outer Brass Limestone is about 100 m of thin-bedded, partially silicified, radiolarian-bearing limestone that contains about 10 percent interbedded crystal tuff, in beds as much as 1 m thick (Helsley, 1960; Donnelly, 1966; Rankin, 2002). It is common for thin sections of the limestone to contain a small percentage of angular plagioclase and augite crystal shards, likely the product of sporadic eruptions from an unknown source (Donnelly, 1966). The unit is exposed on Outer Brass Island, Saint Thomas, and Saint John, and thins to the east. On northern Saint John, epidote, brown isotropic garnet, diopside, vesuvianite, and wollastonite are developed near the contact of the limestone with the Narrows pluton (Rankin, 2002). According to Helsley (1960), the Outer Brass Limestone is not exposed in the British Virgin Islands and he states that as rock exposures are present in the stratigraphic interval it should occur in, it probably was not deposited there. The Congo Cay Limestone Lens (Helsley, 1960; Donnelly, 1966; Rankin, 2002) is exposed on Congo Cay in the U.S. Virgin Islands and on Great Thatch Island and Tortola in the British Virgin Islands. Rankin (2002) described it as tightly folded, vertical beds of marble, calcsilicate rock, and siliceous hornfels exposed on Congo Cay and Carval Rock. Helsley (1960) placed it near the top of the Tutu Formation in the British Virgin Islands where it is exposed in context, as coarsely crystalline limestone containing poorly preserved gastropod molds. The Congo Cay Limestone Lens varies in thickness. Helsley (1960) reported that its usual thickness is about 120 m in the western part of Tortola. The map unit described here also includes marble conglomerate of the Picara Member of the Tutu Formation on northern Saint John (Rankin, 2002)
- Kmv** **Metavolcanic and meta-volcaniclastic rocks, undifferentiated (Early Cretaceous)**—This unit is exposed in Cuba and Dominican Republic as well as Haiti, but it is not distinguished on the most recent Haitian map (MMER, 1989). In Cuba, the Porvenir Formation is a bimodal volcanic sequence of felsic metavolcanic rocks interlayered with mafic metavolcanic rocks that has been metamorphosed to greenschist facies and is exposed between the granodiorite of unit **Kmgd** and the quartz diorite of unit **Kqt** on the north side of the Escambray Massif (IGP, 2011). The Yaguanabo Formation is part of the Escambray Massif and consists of mafic volcanogenic greenschist, mainly metatuff to meta-agglomerate, and, locally, it contains thin interlayers of gray marble and quartzite (IGP, 2011). It is exposed in both the Trinidad Dome and Sancti Spiritus Dome areas of the massif. Originally mapped as part of the Late Cretaceous Iberia Formation by Puscharovsky and others (1988), the Tejas Formation is exposed in a small area north of the Sierra Maestra in southern Cuba. It consists of metatuff and metasandstone and was assigned an Early Cretaceous to Late Jurassic age by IGP (2011). In Dominican Republic, the Maimon Formation, located on the north side of the Cordillera Central, is metamorphosed keratophyre, quartz keratophyre, tuff, and other volcanic rocks (Toloczyki and others, 1991). It is considered Early Cretaceous and may correlate with the Water Island Formation (unit **Kkp**) of Virgin Islands. A small part of the Río San Juan Complex of the Cordillera Septentrional consists of the El Guineal felsic schist, consisting of porphyritic metarhyolite, felsic metavolcanic

rocks and quartz-feldspathic schist and phyllite (Escuder-Viruete and others, 2013a). These rocks are metamorphosed to blueschist and upper greenschist facies (Escuder-Viruete and others, 2013a). In Haiti, in Massif du Nord, roughly on trend with the Maimon Formation in Dominican Republic, Vila and others (1985) mapped undifferentiated metamorphic rocks consisting of gneiss, mica schist, amphibolite, and chlorite schist. However, those rocks were not shown as a distinct unit on the more recent MMER (1989) map, but rather were lumped in a unit of amphibolite and ultramafic rocks, shown as unit **Mzum** in this report

- KJmc Mabujina complex and equivalent units (Early Cretaceous or Late Jurassic)**—In Cuba, Dominican Republic, and Puerto Rico. The Mabujina complex of Cuba, which structurally underlies nonmetamorphosed volcanic-arc rocks, is composed of gabbro, basalt, basaltic andesite, and pyroclastic rocks that were deformed and metamorphosed to greenschist and amphibolite facies (Somin and Millán, 1981; Blein and others, 2003; Iturralde-Vinent and others, 2016). It is exposed on the north side of the Escambray Massif. Considered autochthonous, Blein and others (2003) indicated that the Mabujina complex rocks are tholeiitic and calc-alkaline basalt, part of an Early Cretaceous and (or) Jurassic intraoceanic island arc, and that their isotopic compositions indicate a depleted mantle source contaminated by sediments. Blein and others (2003) interpreted that the magmatism is not related to classic Early Cretaceous Caribbean tholeiitic series but is similar to the Late Jurassic to Early Cretaceous Guerrero arc terrane from Mexico and may represent its southernmost extension. Their data indicated that two different island arcs were tectonically juxtaposed in central Cuba, (1) the classical Upper and Lower Cretaceous suites of the Greater Antilles arc, and (2) an Early Cretaceous to Jurassic island-arc suite that has a paleo-Pacific Ocean provenance. They additionally interpreted that different tectonic units of central Cuba cannot be easily correlated with those of the island of Hispaniola. The Mabujina complex can be subdivided in several lithologic units, described here. In southernmost Cuba, rocks of the Guira de Jauco Formation are undifferentiated amphibolite, feldspar-epidote-amphibolite schist, gneiss, and metachert (IGP, 2011). Included is pegmatite associated with the Guira de Jauco Formation, which was not described nor had an age assigned (IGP, 2011). In northeastern Dominican Republic, the Guaconejo subunit of the Rio San Juan Complex consists of high-pressure garnet-epidote amphibolite and (coronitic) eclogite including garnet-bearing mafic gneiss, metagabbro, metadiorite, retrograded eclogite, and mylonitic rocks (Escuder-Viruete and others, 2013a). In southwestern Puerto Rico, Mattson (1960) described the Bermeja Complex as mainly serpentinitized peridotite, now serpentinite (unit **Mzs**), and spilitite, amphibolite, and minor silicified volcanic rock and (or) chert. Curet (1986) interpreted the chert to be the Mariquita Chert (described in this report in unit **KJcm**). Included in this unit is amphibolite in the Puerto Real (Volckmann, 1984b), San German (Volckmann, 1984c), Cabo Rojo and Parguera (Volckmann, 1984a), and Punta Verraco (Krushensky and Monroe, 1979) quadrangles. These rocks are generally described as dark-gray to dark-greenish-gray, fine- to medium-grained, weakly foliated to nonfoliated amphibolite composed of plagioclase (andesine) and green hornblende. Foliated varieties exhibit granoblastic texture; nonfoliated varieties exhibit relict(?) ophitic texture. In some localities the rock is cut by abundant veinlets of zoisite. Veinlets of epidote and (or) chlorite are also locally present but are less common (Volckmann, 1984b). Krushensky and Monroe (1979) describe a slightly different rock, of which only a small area is exposed, engulfed in serpentinite. It is also dark-gray, nonfoliated amphibolite but contains 45 percent dark-reddish-brown pleochroic hornblende, about 8–10 percent light-green nonpleochroic anhedral and apparently relict pigeonite, and about 45 percent generally non-twinning plagioclase altered to prehnite, and sparse to rare clear andesine with prominent albite twinning. Locally, subdivided into units **KJba**, **KJam**, **KJgn**, **KJca**, and **KJms**
- KJba Mabujina complex biotite-bearing amphibolite**—Biotite-bearing amphibolite is the most extensive of Mabujina complex subunits. IGP (2011) mapped several phases of this subunit, consisting of (1) commonly well-stratified schistose amphibolite containing fine-grained biotite; (2) commonly banded, biotite-bearing amphibolite; (3) biotite-bearing amphibolite in a stratified sequence; (4) biotite amphibolite, derived from porphyritic basalt; and (5) biotite amphibolite and gneiss
- KJam Mabujina complex amphibolite without biotite**—Tending to be restricted to the northwestern part of the Complex, this amphibolite is commonly fine-grained and locally banded (IGP, 2011)
- KJgn Mabujina complex metagranitic rocks**—Exposed in the northern part of the complex, these metagranitic rocks consist of fine-grained granitic gneiss, composed of quartz, feldspar, generally biotite, and locally containing garnet or hornblende. Rojas-Agramonte and others (2011) reported an Early Cretaceous U/Pb SHRIMP age (sample F68, on six grains) of 132.9 ± 1.4 Ma and a multigrain conventional zircon age of 133 ± 2 Ma on trondhjemitic orthogneiss, indicating that unit is likely Early Cretaceous. Rojas-Agramonte and others (2011) also reported an age of 123.9 ± 0.62 Ma (SHRIMP) on a sample of tonalitic gneiss (sample F77). Earlier, $^{206}\text{Pb}/^{238}\text{U}$ TIMS multigrain age determinations on

the same samples by Bibikova and others (1988), yielded an age of 108 ± 15 Ma on sample F68, which combined with another sample F77 (115 ± 10 Ma), led them to report an interpreted age of 110 ± 10 Ma. Rojas-Agramonte and others (2011) showed that plotting the data from the two samples analyzed by Bibikova and others (1988) on a concordia diagram, shows these analyses to be strongly discordant, and in such cases $^{206}\text{Pb}/^{238}\text{U}$ ages are not geologically meaningful. According to Rojas-Agramonte and others (2011), field relations show that there are several generations of granitoid rocks that are variably foliated and boudinaged and locally, strongly folded, having significant strain gradients. Grafe and others (2001) using the Rb/Sr technique, dated a pegmatite cutting the metagranitic unit, which yielded several isochron ages reflecting different combinations of mineral and whole-rock determinations. The resulting dates ranged from 73 ± 1 to 87.6 ± 0.4 Ma. They also reported $^{40}\text{Ar}/^{39}\text{Ar}$ dates of 72.2 ± 0.6 Ma on white mica from pegmatite and 73.8 ± 0.5 Ma on white mica from granodiorite suggesting Late Cretaceous cooling

KJca

Mabujina complex and Puerca Gorda schist derived from mafic sources—In Cuba, this subunit consists of amphibolite, generally banded, interpreted to have been derived from basalt, basaltic andesite, gabbro, or metamorphosed pyroxenitic hornblendite (IGP, 2011). These bodies surround the perimeter of the Escambray Massif on its north, west, and southwest sides. In northeastern Dominican Republic, the Puerca Gorda mafic schist of Escuder-Viruete and others (2013a), of the Rio San Juan Complex is a greater than 3,000-m-thick sequence of mafic schist and porphyritic metabasalt, with minor intercalated quartz-feldspathic schist (Escuder-Viruete and others, 2013a). It is exposed in the northeastern part of the Rio San Juan Complex

KJms

Mabujina complex amphibolite and Gaspar Hernández and Helechal peridotite associated with serpentinite—In Cuba, this is the most restricted subunit of the Mabujina complex, only exposed on the eastern side of the Escambray Massif. It consists of serpentinitized ultramafic rocks containing coarse-grained amphibolite bands (IGP, 2011). North of there, near the community of Matanzas, a zone described as a “crust mantle transition” consists of serpentinite, harzburgite, dunite, wehrlite, and lherzolite, as well as plagioclase-bearing lherzolite, wehrlite, as well as orthopyroxenite, websterite, and clinopyroxenite. The zone is cut by serpentinitized dikes of pegmatitic gabbro (IGP, 2011). In the Rio San Juan Complex of Dominican Republic, the Gaspar Hernández and Helechal serpentinitized peridotite of Escuder-Viruete and others (2013a) occur in the northern part of the complex and at its extreme southeast limit, respectively. Both units contain serpentinitized harzburgite; the Gaspar Hernández also containing dunite and the Helechal containing lherzolite. Both are metamorphosed, the Gaspar Hernández to amphibolite and upper greenschist facies, and the Helechal to upper to lower greenschist facies (Escuder-Viruete and others, 2013a)

KJsi

Metasedimentary and metaigneous rocks, undifferentiated (Early Cretaceous to Late Jurassic, Tithonian)—In Cuba and Jamaica. On the northern Isla de la Juventud of Cuba, the Sierra de Caballos Formation consists of medium-grained, banded marble, containing thin layers of cherty quartzite, recrystallized dolostone, garnetiferous amphibolite, and calcsilicate rocks (IGP, 2011). On the south side of the metamorphic complex (unit Jm) on the island, the informally defined Dagulla amphibolite consists of schistose, diopside- and almandine-bearing amphibolite, interlayered with metasandstone and diopside-plagioclase-bearing calcsilicate rocks and having inclusions of finely crystalline marble. Restricted to the Escambray Massif are several units of marble or foliated limestone and greenschist. The Loma Quivicán Formation is typically found in the interior of the massif and consists of foliated crystalline limestone having interlayers of psammitic greenschist and intraformational chert and breccia (IGP, 2011). Generally peripheral to this, is the Los Cedros Formation consisting of foliated marble and quartzite interlayered with green volcanogenic schist and micaceous calcschist (IGP, 2011). In the northern part of the Camagüey region of central Cuba, the informal La Suncia metamorphics consist of metagabbro, mylonized metadiabase, volcanogenic greenschist, and metachert. These rocks are closely associated with tectonized ultramafic rocks of unit KJmm (IGP, 2011). In southeastern Cuba, the Sierra Verde Formation (IGP, 2011) is about 80 percent black, graphitic phyllite and metamorphosed shale, which weathers pinkish, violet, creamy, or greenish and contains beds of meta-limestone, metamorphosed mafic volcanic rocks, and metamorphosed chert (Pardo, 2009). Gray, schistose, laminated meta-limestone locally has small remnants of noncrystallized, cream-colored limestone in which microfossils have been found. Fauna consists of *Calpionella* sp., *Nannoconus* sp., and undetermined Globigerinidae (*Ticinella*? sp. and *Hedbergella*? sp.), suggesting a Tithonian to Hauterivian age (Pardo, 2009). Pardo (2009) also reported that “common interbeds of metamorphosed chert and an argillaceous, lustrous (sericitic), meta-silicate schist showing abundant remains of Radiolaria also exist.” In the Blue Mountain Inlier of eastern Jamaica, McFarlane and others (1984) lumped three different schist units together that they called the Westphalia and Mount Hibernia Schist Groups and the Green Bay Metamorphics. Using slightly different terminology, Hastie (2007) described the Westphalia schist as having a sedimentary or volcanoclastic protolith metamorphosed

to amphibolite facies and as having a calc-alkaline affinity. Lewis and others (1973) reported discordant K/Ar ages on the schist of 49.9 ± 1.3 and 54.1 ± 1.4 Ma on biotite and 78.2 ± 2.1 Ma on hornblende. The Green Bay schist located southwest of Kingston, Jamaica, is described as having a similar character to the Westphalia schist (Hastie, 2007). The Mount Hibernia schist is described by Hastie (2007) as having an ultramafic to mafic tholeiitic protolith metamorphosed to blueschist and greenschist facies

KJm

Marble (Early Cretaceous to Late Jurassic)—In Cuba, Dominican Republic, Puerto Rico, and Haiti, though not shown on the most recent Haitian map (MMER, 1989). On the Isla de la Juventud of Cuba, the informal Sierra de Casas marble is massive dark-gray marble containing remnant dolomite crystals (IGP, 2011). Also, on the island, the Gerona Group consists of marble, and dolomitized or silicified marble, and calcsilicate rocks (IGP, 2011). Both units are inferred to be earliest Cretaceous to Late Jurassic. Toloczyki and others (1991) mapped massive or thick-bedded marble on the east end of Peninsula de Samaná, which is locally associated with metasedimentary rocks of presumed Jurassic age (unit Jm) and the metamorphic complexes characterized by glaucophane schist (unit JsCh). Toloczyki and others (1991) considered these rocks equivalent to marble on Isla de la Juventud and similar rocks on the Isla de Tortue in Haiti. Lewis and Draper (1990) described calcareous schist containing a post-Turonian microfauna, silicic metavolcanic rocks, and greenschist on Isla de Tortue, though not shown on the mapping of MMER (1989). Comparison with the mapping of Vila and others (1985) suggests that these units were incorrectly mapped as their unit cf, a unit of slate and flysch (included in unit Kso in this report). However, the correlation of the rocks on the Peninsula de Samaná and the Isla de la Juventud seems reasonable, whereas the rocks on the Isla de Tortue are likely too young. In southwest Puerto Rico, the Mariquita Chert (unit KJcm) includes grayish-red to grayish-yellow limestone lenses in beds 5 to 15 m thick of recrystallized calcite, which has been strongly replaced and veined by silica (Volckmann, 1984a, c)

KJmq

Marble and quartzite, undifferentiated (Early Cretaceous to Late Jurassic)—Closely associated with the marble of unit KJm on the Isla de la Juventud of Cuba, is the informal La Reforma unit consisting of polyminerologic crystalline calcsilicate rocks and boudinaged interlayers of medium-grained gray marble (IGP, 2011). To the east, forming a significant part of the Sancti Spiritus Dome and locally present on Trinidad Dome of the Escambray Massif is the Cobrito Formation, which consists of calcic and graphitic schist containing thin layers of foliated marble and lawsonitic greenschist and eclogite. More common on Trinidad Dome, but also present to a lesser extent on Sancti Spiritus Dome are rocks of the San Juan Group, a dark-colored laminated graphitic marble that has interlayered cherty quartzite (IGP, 2011). Pardo (2009) described the Cobrito Formation as a succession of calcareous schist and schistose marble layers that have fine, rhythmic stratification. “Commonly included in the schists are small boudins, less affected by the metamorphism, of black dolomitic and crystalline limestone, with Radiolaria (*Spumellaria* spp. and *Nassellaria?* spp.) and other organic remains. Some of the fossils have been tentatively identified as the Hauterivian–Upper Jurassic *Globochaetes alpina* and *Cadosina* sp.” (Pardo, 2009). Pardo (2009) described the San Juan Group as about 300 m of well-bedded, black to dark-bluish-gray, commonly graphitic marble and calcareous schist that commonly has a fetid odor. “The formations of the San Juan Group appear to have all been deposited under restricted, anoxic conditions, as indicated by the dark color, abundant graphite, and common hydrogen sulfide odor. Under the proper conditions, they could have served as petroleum source rocks prior to the Late Cretaceous metamorphism” (Pardo, 2009). In the northern part of the Camagüey region, the informal Esmeralda Complex is exposed associated with tectonized ultramafic rocks of unit KJmm. The complex consists of microcrystalline clay-rich limestone, pelitic and calcareous schist, bituminous limestone, phyllite, and quartzite (IGP, 2011)

KJmm

Metamorphosed mafic and ultramafic rocks, undifferentiated (Early Cretaceous to Late Jurassic)—Restricted to Cuba and Dominican Republic, this unit includes several metavolcanic units for which ages were not assigned and therefore whose age is inferred here. The best-defined unit is the informally defined Perea Metamorphics of Late Jurassic age in central Cuba. Exposed in long, linear outcrop belts associated with the ophiolite complex northeast of the Escambray Massif, this unit was described as low-pressure amphibolite derived from gabbro and diabase of the ophiolite complex and is locally cut by folded granitoid dikes. Other metavolcanic rocks (mapped as $\mu\beta$) and metagabbro (mapped as $\mu\nu$) are associated with the Escambray Massif in the Trinidad and Sancti Spiritus Domes (IGP, 2011). A very small exposure of these metavolcanic rocks is also associated with the metasedimentary rocks of unit Jm in northern Cuba. In the Rio San Juan Complex of Dominican Republic, the Cuaba Mafic-Ultramafic unit includes garnet-bearing serpentized harzburgite and minor dunite. This part of the unit is exposed north of the Puerca Gorda mafic schist (unit KJca) and contains many small dunite bodies (unit Mzum). The Cuaba Mafic-Ultramafic unit is metamorphosed to ultrahigh pressure eclogite and eclogite facies (Escuder-Virue and others, 2013a)

KJgm	Garnetiferous amphibolite (Early Cretaceous, Barremian to Jurassic, Tithonian) —Muscovite-garnet amphibolite with occasional interlayers of garnetiferous quartzite exposed on the northeast part of the Sancti Spiritus Dome and associated with the Mabujina complex (IGP, 2011)
Jsch	Metamorphic complexes characterized by glaucophane schist (Jurassic?) —This unit is composed of various metasedimentary schist units, all characterized by the presence of glaucophane and other blueschist-facies minerals in Cuba and Dominican Republic. In each of these units, age is inferred. In Cuba, within the metamorphic rocks that are peripheral to the Trinidad and Sancti Spiritus Domes are small areas mapped as eclogite (IGP, 2011). While these small areas are not in themselves indicative of the presence of glaucophane, they appear in the same area mapped by Puscharovsky and others (1988) as the Algarrobo Schist, a quartz-garnet-mica schist, glaucophane-quartz-garnet-mica schist and, locally, hornblende schist and calcschist. This unit is not shown on the map by IGP (2011); however, north of the Escambray Massif are several small mapped exposures of glaucophane schist within a larger area of ultramafic rocks (unit Mzum). In the northeastern part of the Dominican Republic, Toloczyki and others (1991) mapped micaceous schist on Peninsula Samaná that they described as locally including eclogite and blueschist
Jqp	Quartzite and phyllite, undifferentiated (Jurassic?) —Arenaceous quartzite with layers of sericitic-carbonaceous glossy phyllite of the La Llagueta Formation, largely exposed on Trinidad Dome in central Cuba (IGP, 2011). The map unit also includes quartzite on the flank of Trinidad and Sancti Spiritus Domes whose age was not assigned (IGP, 2011)
Jm	Metasedimentary rocks including marble (Jurassic) —Mapped in Cuba and Dominican Republic, metasedimentary rock units (included in this unit) are similar to those of the metamorphic complexes characterized by glaucophane schist (unit JsCh), except that these rocks do not show indications of blueschist-facies metamorphism. The northernmost of the exposures of these rocks in Cuba is in the Arroyo Cangre Formation, which consists of quartz-rich metasandstone containing white mica and locally chlorite, carbonaceous lenses, and isolated interbeds of recrystallized limestone. Subordinate metagabbro and metadiabase bodies are present (IGP, 2011). The Arroyo Cangre Formation is exposed in a linear belt adjacent to the San Cayetano Formation (unit Jvs). On Isla de la Juventud off the coast of Cuba, the Agua Santa and Cañada Formations (including the Victoria Member of the Cañada Formation) consist of metasedimentary schist and marble. The Agua Santa Formation, on the east side of the island, is pelitic mica schist containing garnet and has locally predominant interbeds of marble and calcsilicate rocks, whereas the Cañada Formation is psammitic quartz-rich and quartz-mica schist, containing interbeds of pelitic muscovite-graphite schist that may contain garnet, kyanite, and staurolite. The Victoria Member of the Cañada Formation, restricted to the west side of the island, is pelitic quartz-mica schist that is commonly graphite-rich and has interlayers of quartzose schist and rare interbeds of marble (IGP, 2011). On the northeast part of the island, the Sierra Chiquita Formation of dolomitized marble, the Playa Bibijagua Formation of black fossiliferous marble, and the Columbo Formation of dolomitized marble and metachert represent a very small part of the island. Pardo (2009) described these rocks as having an antiformal dome-like structure and divided them into five metamorphic-grade zones, the lowest grade being in the center. Pardo (2009) suggested that the Agua Santa and Cañada Formations are equivalent to the San Cayetano Formation. In central Cuba, the Escambray Massif area is the locale of several other presumably Jurassic-age metasedimentary complexes. Rimming the massif on the north and in a large area on southeastern Trinidad Dome, the Boquerones Formation of schistose marble and calcschist contains black dolomitic limestone boudins having abundant radiolarian casts and contains graphite and white mica (IGP, 2011). Most extensive of these metamorphic units as part of the massif is the La Chispa Formation and its Felicidad Member. The La Chispa Formation is quartz-muscovite and muscovite schist, which contains interlayers of metachert and marble and its Felicidad Member of lawsonite-bearing volcanogenic greenschist (IGP, 2011). In extreme southeastern Cuba, the Chafarina Formation consists principally of dark-gray marble that is locally dolomitic, and muscovite-bearing calcschist. Dark-gray to black chert is locally present and may be abundant (Pardo, 2009). In eastern Dominican Republic, on Peninsula Samaná, micaceous schist and marble are widely exposed. Age control is not available for this unit; however, Toloczyki and others (1991) mapped it as Mesozoic(?)
Jvs	Schistose metasedimentary rocks (Jurassic, Oxfordian to Early Jurassic) —The three formations included in this unit are the San Cayetano Formation, widely exposed in northwesternmost Cuba, and the Loma La Gloria and Herradura Formations, which surround the Escambray Massif in central Cuba (IGP, 2011). The undivided San Cayetano Formation has interbeds of quartz and quartz-mica sandstone with carbonaceous shale and siltstone, conglomerate, phyllite, polymictic sandstone, and schist. Its Castellano Member, which tends to be exposed in the northwestern part of formations exposure area, consists of quartz and quartz-mica sandstone interbedded with slaty, laminated, and folded siltstone and shale as

well as interbeds of silicified, almost black limestone. Puscharovsky and others (1988) considered the Castellano Member to be the upper part of the San Cayetano Formation. Pardo (2009) described the San Cayetano Formation as a thick monotonous section of dominantly dark-gray to black shale, sandstone, and siltstone that weathers to white, grayish orange, red, or grayish black. Its upper part has sparse interbeds of conglomerate and limestone. Pardo (2009) reported that “because of the intense deformation and the monotonous nature of the section, no reliable thickness measurements exist”; however, estimates range from 1,500 to as much as 5,000 m thick. The Loma La Gloria Formation, exposed along the northern and northeastern limit of the Escambray Massif, consists of quartz-rich and quartz-muscovite schist, and locally, graphitic schist, as well as subordinate interlayers of marble, eclogitic rocks, polymineral schist, and metachert. The El Algarrobo schist, an informal member of the Loma La Gloria Formation, is the polymineral schist, which can be locally calcareous. However, the actual limit of the massif is formed by the lithologically similar Herradura Formation of quartz-rich and quartz-muscovite terrigenous schist, containing thin layers of muscovite schist, which are locally graphite-rich. A small linear belt of mica schist is on trend with the Perea Metamorphics (unit **KJmm**) north of the Escambray Massif. No age was assigned to these mica schists, which are closely associated with serpentinitic mélange of unit **Mzsm**

Pm

Oldest marble (Proterozoic)—Marble of indefinite age, mapped in the northern part of central Cuba, that is shown by only one map polygon (IGP, 2011). However, locations of radiometric age determinations suggest other small exposures may be present. IGP (2011) described the Sierra Morena Metamorphics in Cuba as medium- to coarse-grained light-colored marble and calcsilicate rocks containing phlogopite, forsterite, and diopside of Proterozoic age. Somin and Millán (1977) and Renne and others (1989) dated phlogopite in the marble. Somin and Millán (1977) obtained two K/Ar ages of 918 ± 25 and 884 ± 25 Ma, and Renne and others (1989) using the $^{40}\text{Ar}/^{39}\text{Ar}$ technique, yielded a phlogopite plateau age of 903.5 ± 7.1 Ma

ULTRAMAFIC ROCK AND OPHIOLITE ASSOCIATED UNITS

Mzum

Ultramafic and associated rocks, undifferentiated (Mesozoic or older)—Widespread in Cuba; also present on the island of Hispaniola, in both Haiti and Dominican Republic, and in southwest Puerto Rico. Subdivided here into several map units, this unit consists of undivided ultramafic rock complexes in Cuba and on Hispaniola. In central Cuba, the Caibarien ophiolite ultramafic rocks were not assigned an age nor further described (IGP, 2011). To the south, in the Holguín and Guantánamo areas, these rocks were assigned a Jurassic or Cretaceous age and described as ultramafic cumulate rocks consisting of dunite, wehrlite, websterite, and serpentinitized lherzolite (IGP, 2011). A similar description was applied to a small area of ultramafic rocks on the east side of Sancti Spiritus Dome in central Cuba (IGP, 2011). IGP (2011) mapped what they described as a cumulate ultramafic-mafic transition zone, which consists of alternating gabbro and ultramafic serpentinites after lherzolite and wehrlite in the eastern part of the Holguín area and in a small area associated with rocks described as tectonites in the Camagüey region. In northeastern Dominican Republic in Cordillera Central and Cordillera Septentrional, rocks of this unit consist of gabbro-norite and gabbroic complexes and pyroxenite that are ophiolite-associated (Toloczyki and others, 1991). An extensive belt, about 90 km long, of ultramafic rocks (described as the Loma Caribe Peridotite) is present along the southeastern margin of Cordillera Central and on the north coast of Cordillera Septentrional (Toloczyki and others, 1991). Within the Cordillera Central, small bodies of pyroxenite and locally hornblende, considered part of the Duarte Formation, are associated with the meta-mafic rocks of unit **KJmu** (Toloczyki and others, 1991). Escuder-Virue and others (2013a) provided more detailed description of the rocks of the Rio San Juan Complex of the Cordillera Septentrional in northern Dominican Republic. A significant part of the complex is the Rio Boba Metaplutonic complex of metagabbro-norite and two pyroxene granulite. These rocks may be genetically related to the hornblende gabbro of unit **Khg**. Exposed in the northern part of the Rio San Juan Complex are numerous small bodies of dunite associated with serpentinitized harzburgite (Escuder-Virue and others, 2013a). The harzburgite is separated from the gabbro-norite by rocks of the Jagua Clara mélange of unit **Kmk**. Age control is lacking; however, rocks are associated with Jurassic and Cretaceous metamorphic complexes. In Haiti, several small ultramafic bodies, also associated with meta-mafic rocks, are present in Massif du Nord, the extension of the Cordillera Central of Dominican Republic (MMER, 1989). A larger area of mixed amphibolite and ultramafic rocks occurs at the westernmost part of northern Haiti (MMER, 1989). Vila and others (1985) mapped more of this unit in the Massif du Nord as they included the laterite equivalent of these rocks. They stated that in the Massif du Nord, the old laterites must correspond to serpentinite in the Dominican Republic and that “their elevated topographic position with respect to the Cretaceous volcanic-sedimentary complexes suggests they are allochthonous.” Subdivided into units **Mzs**, **KJmu**, **KJdg**, **KJv**, and **KJuc**

Mzs	Serpentinite (Cretaceous or Jurassic?)—Present in Cuba, Dominican Republic, Jamaica, and Puerto Rico and likely present in Haiti (though not separately mapped in Haiti). Serpentinite is widely scattered in the older rock packages of Cuba, extensively associated with the San Cayetano Formation in northern Cuba, the Escambray Massif in central Cuba, the Caibarien ophiolite northeast of the Escambray Massif, and in the Holguín region of southern Cuba. In general, no age is reported for the serpentinite, although several occurrences have been assigned a Cretaceous to Jurassic age (IGP, 2011). Much more widely exposed in Cuba is a unit IGP (2011) mapped as “tectonite,” which was defined as metamorphosed mantle ultramafic rocks consisting of serpentinite after harzburgite, dunite, and pyroxenite. Also included in unit Mzs in this report, is a unit in Cuba defined as the ultramafic-mafic cumulate transition zone consisting of alternating ultramafic serpentinite (lherzolite, wehrlite) and gabbro (IGP, 2011). In Dominican Republic, Escuder-Viruete and others (2013b) described serpentinitized harzburgite and minor dunite on the northern part of the island in the lower structural levels of their Guaconejo subunit. In eastern Jamaica, in the southwestern part of the Blue Mountain Inlier (McFarlane and others, 1984), small bodies of serpentinite are found that, according to Arden (1975), are likely of Late Cretaceous age. In southwestern Puerto Rico, a large exposure of serpentinite as well as several smaller exposures are present; these constitute a major component of the Bermeja Complex of Mattson (1960). According to Llerandi Roman (2004), “The serpentinite is predominantly composed of serpentine minerals, including bastite pseudomorphs, minor chlorite, and scarce iron oxides. * * * Actinolite and tremolite are present in some veins that cut the serpentinite. Uvarovite occurs within pale green to white roddingite dikes that cut through the serpentinites. Amphibolite and chert blocks occur as inclusions within serpentinite. Altered volcanic rocks, of intermediate to mafic composition, also occur as blocks within the serpentinite.” Other parts of the Bermeja Complex include a spilite unit, named the Las Mesa Greenstone by Schellekens and others (1990) and a chert unit named the Mariquita Chert by Mattson (1973) both of which are included unit KJcm in this report, and an amphibolite unit, later named the Las Palmas Hornblende Schist and Amphibolite by Mattson (1973), which is commonly not mapped separately as it consists of small tectonic blocks in the serpentinite. Larger blocks are included in the Mabujina complex and equivalent rocks unit (KJmc)
KJmu	Dike complex (Cretaceous or Jurassic)—Diabase dike swarms containing tectonic blocks of diabase, diabasic gabbro, and microgabbro are associated with serpentinite and tectonites of the Caibarien ophiolite and in the Camagüey and Holguín regions of Cuba (IGP, 2011)
KJdg	Gabbro and diorite, undifferentiated (Cretaceous or Jurassic)—These rocks are exposed associated with tectonites or with the ophiolitic complex in Cuba and consist of gabbro, diorite, and diabase. IGP (2011) generally assigned a Cretaceous to Jurassic age to these rocks or, locally, did not assign an age. These rocks are exposed east of La Habana (Havana), in the Sancti Spiritus and Trinidad Domes and most commonly in the Holguín region (IGP, 2011)
KJv	Mixed sedimentary and volcanic component of ophiolite (Cretaceous to Jurassic)—Called the “sedimentary effusive level” by IGP (2011), these rocks consist of aphanitic, subaphyric, and spherulitic basalt, hyaloclastite, chert, including radiolarian chert, tuffite, shale, and limestone. These rocks are exposed in small areas of the Caibarien ophiolite, the Holguín region and north of Guantánamo
KJuc	Mafic cumulate rocks (Cretaceous to Jurassic)—Mafic cumulate rocks including banded gabbro containing olivine, pyroxene, and amphibole, troctolite, gabbroic amphibolite, and subordinate plagiogranite. These rocks are exposed east of La Habana, in the Caibarien ophiolite, the Holguín region and north of Guantánamo (IGP, 2011). In the Rio San Juan Complex of Dominican Republic, ultramafic cumulates (including wehrlite and websterite) occur in small lenses in the metagabbro of the Rio Boba metaplutonic complex (unit Mzum) (Escuder-Viruete and others, 2013a)

TECTONIC MAP UNITS

Tpm	Young mélange (Late Tertiary, Pliocene?)—Consists of the Arroyo Sabana mélange of Toloczyki and others (1991) exposed along the southwest side of the Cordillera Central of Dominican Republic. It is a tectonic mélange and breccia that contains blocks and rock fragments that have been incorporated by tectonic movements into the matrix. The blocks include early Tertiary and Cretaceous limestone (Cerro Las Canitas, Loma la Pelada and Loma del Agua Formations). Blocks also include late Tertiary clastic rocks from the Pliocene to the Lower Miocene (Toloczyki and others, 1991)
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Tmo

Mélange and olistostromes, undifferentiated (Tertiary, Eocene to Paleocene)—In Cuba and Dominican Republic. The Vega Alta Formation, and the Eocene Vega Formation (or the Brecha Sagua Formation of Puscharovsky and others [1988]) are found in a linear belt along the northeast coast of Cuba, north of Trinidad and Sancti Spiritus Domes. The informally defined Vega Alta olistostrome is a chaotic mix of blocks of limestone, serpentinite, and volcanic and metamorphic rocks in a clayey matrix, locally also containing interbeds of conglomerate, sandstone, and polymictic siltstone (IGP, 2011). The Vega Formation (or Brecha Sagua Formation) is a carbonate breccia containing fragments of limestone and dolostone, and subordinate chert, gabbro, and serpentinite, which transitions to or is interbedded with limestone, polymictic breccia, conglomerate, sandstone, siltstone, marl, and clay (IGP, 2011). Pardo (2009) considered these formations as mixes of multiple other formations, including the Sagua, Vega, Camajuani, and San Martín Formations. Pardo (2009) interpreted these as deepwater turbidite deposits. The spatially associated informally defined Taguasco olistostrome consists of olistoliths of Cretaceous sedimentary rocks, and volcanoclastic sedimentary and volcanic rocks in a stratified matrix composed of sandstone, marl, siltstone, clay and rare conglomerate. The base of the unit consists of conglomerate and polymictic breccia (IGP, 2011). Pardo (2009) describes this unit as having highly variable thickness, though probably averaging 75 m of well-bedded, fine-to coarse-grained, sandstone and shale, which is bimodally sorted. The finer grained rocks contain spherical granite and basalt boulders as much as 1 m in diameter. He describes the boulders as very fresh and showing almost no sign of weathering. Although volcanic rocks (other than the basalt boulders) and limestone components are occasionally present, they are surprisingly rare; essentially no ultramafic material is present. The sandstone and shale are interbedded with igneous grain-bearing limestone, marl, and occasional reef limestone (Pardo, 2009). To the south in the Camagüey Province, the informally defined Senado olistostrome (also called the upper Vega or Rosas Formation of Pardo [2009]) is a multicomponent olistostrome containing serpentinite and limestone olistoliths in a conglomeratic breccia matrix having clasts of volcanic rocks, gabbro, limestone, and sandstone (IGP, 2011). Pardo (2009) described “a lower unit of poorly sorted, thick-bedded sandstone, silty shale, and conglomerate and an upper unit of *mélange* that consists of blocks of limestone and serpentinite, in a sandstone and siltstone matrix.” In the Holguín region, the informally defined Paleocene Halicos olistostrome crops out along the southern margin of the ophiolite belt. It consists of blocks of serpentinite, gabbro, gabbro-diabase, diabase, granodiorite, jasper, and magmatic and tuffaceous rocks in a matrix of volcanoclastic sandstone, siltstone, and marl (Pardo, 2009; IGP, 2011). The interbedded tuff contains isolated lithic fragments. The north margin of the ophiolite belt is locally bounded by the informally defined Rancho Bravo olistostrome, which has a lower unit of an olistostrome of conglomerate and polymictic breccia and an upper part of flysch containing polymictic sandstone and siltstone. It has carbonaceous cement and contains interbeds of marl and claystone (IGP, 2011). In Dominican Republic, the San Marcos Olistostrome was thought of as Quaternary by Toloczyki and others (1991). However, Hernaiz Huerta and others (2012) indicated that a middle Eocene age was more appropriate, and they described the San Marcos Formation as an olistostrome that contains exotic blocks of carbonate rocks and clastic rocks, as well as olistoliths of underlying formations

Kmk

Mélange (Cretaceous?)—In Dominican Republic, Toloczyki and others (1991) mapped Cretaceous(?) *mélange* along the southern edge of Cordillera Central and eastern Cordillera Septentrional. Also, along the Cordillera Central, the Arroyo Sabana *mélange* is of late Tertiary age and is described in unit Tpm. In the eastern Cordillera Septentrional, the Jagua Clara *mélange* consists of blocks of amphibolite, fine-grained schist and garnet-glaucophane schist, surrounded by a matrix that is essentially composed of sheared ultramafic rocks (“dismembered ophiolite”). “The age of these tectonic zones can only be deduced from the age of the most recent incorporated rocks; possibly, the *mélange* of the Cordillera Septentrional has been formed along with the emplacement of the ophiolite rocks, during the Tertiary to Cretaceous transition” (translation of Toloczyki and others, 1991; subdivision of their unit ‘Mel’). The ophiolite rocks are shown in unit Kmgb in this report. Escuder-Virue and others (2013a) provided a slightly different description of the Jagua Clara as a *mélange* containing blocks of massive serpentinitized peridotite, eclogite, blueschist, greenstone, metasedimentary rocks, and orthogneiss, which they divided into several units. The Hicotea mafic schist is formed from mylonitic mafic metavolcanic rocks and has minor intercalations of marble and chert. It was mapped by Escuder-Virue and others (2013a) as the upper part of the Jagua Clara *mélange*. The lower part of the *mélange* is a serpentinite-matrix *mélange* containing blocks of massive serpentinitized peridotite, eclogite, blueschist, greenstone, metasedimentary rocks, and orthogneiss (Escuder-Virue and others, 2013a)

Mzsm **Serpentinite mélange (Cretaceous or Jurassic)**—In Cuba, the largest area of this unit is in the vicinity of the Caibarien ophiolite and consists of serpentinite mélange and tectonic breccia containing high pressure-and-temperature blocks (IGP, 2011). A second area of mélange is on the south coast of Cuba near San Antonio del Sur associated with a small area of tectonites (IGP, 2011). A very small area of serpentinite mélange is exposed on Trinidad Dome (IGP, 2011)

OTHER MAP UNITS

TKht **Hydrothermally altered rocks (Tertiary, Eocene or Cretaceous)**—Widely distributed in Puerto Rico, these hydrothermally altered rocks consist of mixed clay, sericite, albite, and pyrophyllite and are locally, pyrite bearing. Where it can be determined, the protolith unit is shown on the map sheets; however, for areas shown as part of this unit, the protolith cannot be readily determined. These areas are limited to central Puerto Rico in the Aguas Buenas (Pease, 1968b), Barranquitas (Briggs and Gelabert, 1962), Naranjito (Pease, 1968c), and Orocovis (Briggs, 1971) quadrangles

Tfg **Fault- or mega-breccia (Tertiary, Eocene)**—Mapped only in the Rio Descalabrado (Glover and Mattson, 1973) and adjoining Ponce (Krushensky and Monroe, 1975) quadrangles of southcentral Puerto Rico is a mega-breccia formed by recurrent movement along the GSPRFZ. The mega-breccia contains fragments and blocks of all units from the Eocene Rio Descalabrado Formation to the Upper Cretaceous Coamo Formation and may possibly contain some fragments as old as the Cretaceous (Albian to Santonian) Robles Formation (Glover and Mattson, 1973). It is likely that this mega-breccia is much more widely distributed along the GSPRFZ though not explicitly mapped. In other areas of the Rio Descalabrado quadrangle (Glover and Mattson, 1973), breccia and (or) clay-rich altered rocks along faults are present but most are too small to map. These exposures tend to be linear and the rocks in them may be cataclastic or mylonitic

bu **Bedrock of unknown type or age**—These are small areas on the Haiti map by MMER (1989) where the color does not match the label, or they used a color not in the legend, or the areas were uncolored and not labelled. These areas are all on the southern coast of Haiti

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Appendix 1. Terranes of the Greater Antilles and Virgin Islands

Table 1.1. Terrane identification codes and characteristic rock units for the Greater Antilles and Virgin Islands.

[BVI, British Virgin Islands; ID, code to identify terrane in geodatabase; K/Ar, potassium/argon; km, kilometers; m, meters; Ma, mega-annum (million years before present); n.a., not applicable; SEDEX, sedimentary exhalative deposits; USVI, U.S. Virgin Islands; VMS, volcanogenic massive sulfide; --, not assigned; ?, questionable ~, approximately]

ID	Terrane name	Characteristic rock units	Age range of units	Timing of boundary structures
--	Overlap sequences	Carbonate and some clastic rocks overlying most of the terranes, suggesting the assembly of most of the terranes was complete during the early Miocene or Oligocene.	Pliocene to Oligocene	n.a.
--	Puerto Rico (overview)	Late Cretaceous (Maastrichtian to Santonian) andesitic volcanic rocks and volcanoclastic sedimentary rocks are common to all Puerto Rican terranes except the San Sebastian terrane, though these rocks are most common in the western Utuado terrane, where they may be potassic. Upper Cretaceous limestone is also common on the islands of Puerto Rico and Vieques; it is most common, however, in the Mayaguez terrane.	Late Cretaceous, Maastrichtian to Santonian	n.a.
GATVI1	Virgin Islands (Virgin Islands and Puerto Rico)	The eastern part of Puerto Rico and Culebra Island contain Early Cretaceous volcanic breccia, lava, and subordinate volcanic sandstone and crystal tuff; although spatially separate, similar rocks are found in the adjacent Utuado terrane. Middle Cretaceous intermediate composition volcanic rocks and the Tutu Formation, a dominantly tuffaceous radiolarian meta-limestone and lesser meta-andesite. Plutonic rocks of middle Cretaceous age, ranging from gabbro to quartz diorite, intrude rocks of the terrane. Distinctive units of this terrane are Early Cretaceous keratophyre and spilitic basalt found in the Virgin Islands, on the island of Culebra and northeast Puerto Rico. The Water Island Formation is a volcanic wacke containing keratophyre clasts. Minor latest Cretaceous andesite and volcanoclastic rocks are found in northeast Puerto Rico. Found in the central part of the terrane, are virtually the only felsic pyroclastic rocks of Late Cretaceous (Maastrichtian to Campanian) age; these are emplaced upon carbonate-rich rocks of Turonian to Albian (middle Cretaceous) age. Undifferentiated Late Cretaceous volcanic clast-rich sandstone is present in the western part of the terrane and locally tracks the terrane boundary. Small exposures of quartz diorite and diorite of Tertiary-Cretaceous age are present locally. A distinctive component of this terrane is the Eocene Virgin Gorda batholith (BVI) or Narrows pluton (USVI), a large diorite to tonalite pluton (batholith) intruding St. John and St. Thomas, Tortola, Virgin Gorda, and outlying islands in the Virgin Islands. Felsic and pyroclastic rocks of Eocene age are also present. The most common mineral occurrences are skarns, however, at the easternmost and westernmost parts of the terrane, several porphyry-type occurrences are present.	Eocene to Early Cretaceous	Great Northern Puerto Rico Fault Zone, younger than Cretaceous(?)
GATVI2	Saint Croix	Characterized by Upper Cretaceous fine-grained tuffaceous sedimentary rocks of the Judith Fancy and Cane Valley Formations, as much as 5,000 meter (m) thick, which overlie the Allandale Formation. The Allandale Formation is most commonly green tuffaceous sandstone, associated with mudstone, volcanic breccia, lapilli tuff, flows, and fragmental limestone. Best exposure consists of a mixture of pyroclastic andesite and dacite debris and minor epiclastic keratophyre and spilite fragments. The oldest unit of the terrane is the Caledonia Formation, composed chiefly of epiclastic fragments of keratophyre and spilite, and mineral grains derived by mechanical breakdown of these volcanic rocks. Twenty to thirty percent of the Caledonia Formation is volcanic sandstone, typically fine grained, but locally, coarse grained or conglomeratic. The average bed is graded, approximately 3 inches thick, and interbedded with mudstone. The Campanian or older Caledonia Formation is as much as 5,500 m thick. The Caledonia Formation has a distinctive member, the East End Member, which consists of 275 m of tuffaceous sandstone and volcanic breccia. The East End Member is a marker bed and helps to indicate the Southgate anticline on Saint Croix. These sedimentary rocks are intruded by the Southgate Diorite (dated at 66.0 ± 3.2 Ma) and the Fountain Gabbro, inferred to be early Tertiary or Late Cretaceous age.	Tertiary, early Paleocene; to Late Cretaceous, Campanian or older	Separated from the rest of the Virgin Islands by the Anegada Passage, likely a major fault structure.

Table 1.1. Terrane identification codes and characteristic rock units for the Greater Antilles and Virgin Islands.

ID	Terrane name	Characteristic rock units	Age range of units	Timing of boundary structures
GATPR1	Utado (Puerto Rico)	Middle Cretaceous quartz diorite and tonalite plutonic rocks are found locally associated with the younger Maastrichtian batholith in southeast Puerto Rico and indicate the presence of Early Cretaceous country rock in the terrane. These rocks, exposed west of the batholith consist of volcanic breccia, lava, and subordinate volcanic sandstone and crystal tuff and are also a component of the Virgin Islands terrane to the northeast. Upper Cretaceous volcanoclastic conglomerate and finer-grained clastic rocks containing minor volcanic rocks and limestone are present in the southwestern part of the terrane. Late Cretaceous basalt and andesite are widely exposed and track the boundary with the Virgin Islands terrane. Further west in the terrane, are early Late and Middle Cretaceous mafic to felsic volcanic rocks. In the western part of the terrane, the Cotorra and Jayuya Tuffs of early Late Cretaceous age are widely exposed. A key component of the terrane is the Paleocene to Maastrichtian Utado batholith in the western part of the terrane. North of the batholith is a small area of early Tertiary tuff and breccia. A wide range of mineral occurrences including skarns, polymetallic veins, manganese, and porphyry-type are present that are Eocene and latest Cretaceous age.	Eocene to Early Cretaceous	Great Northern Puerto Rico Fault Zone between Virgin Islands and Utado terranes, younger than Cretaceous(?); and the Eocene(?) suture zone between Utado and Mayaguez terranes
GATPR2	San Sebastian (Puerto Rico)	This terrane is really a suture zone between Utado and Mayaguez and consist almost entirely of Tertiary (Eocene) intrusive and volcanic rocks that for the most part do not appear in the adjacent terranes. A significant number of mineral occurrences are present within this terrane, including porphyry-type, and polymetallic vein occurrences. A few volcanogenic manganese occurrences are present and appear to be in slivers of the adjacent Mayaguez terrane.	Tertiary, Oligocene and Eocene	post-Oligocene(?) Undifferentiated Eocene to very Late Cretaceous volcanic rocks track the inferred western boundary of this terrane. They define a Tertiary suture zone separating this terrane from the Mayaguez terrane to the southwest.
GATPR3	Mayaguez (Puerto Rico)	This terrane in southwest Puerto Rico, is separated from others by a wide “suture” zone of likely Eocene age from terranes to the northeast, which defined here as the San Sebastian terrane. Two important types of units characterize this terrane. The first type includes the only serpentinite in Puerto Rico and the oldest rocks in Puerto Rico in the Bermeja Complex consisting of amphibolite and marble, the Mariquita Chert, and the Cajul Basalt (basalt and spilite), both of Early Cretaceous or Late Jurassic age. Associated with the metamorphic units are small exposures of early Late Cretaceous (88 Ma) quartz diorite and tonalite. The second type includes widely distributed Late Cretaceous basalt and associated clastic rocks. Latest Cretaceous clastic and carbonate rocks are widespread through the terrane. Small exposures of Eocene gabbro are present along the northwest boundary of the terrane. Primary mineral occurrences in this terrane are laterites associated with the ultramafic rocks and several epithermal occurrences.	Essentially Late Cretaceous and Early Cretaceous or Jurassic (a hiatus in between rock packages)	Post-Oligocene suture zone separates this terrane from the San Sebastian terrane to the northeast.

Table 1.1. Terrane identification codes and characteristic rock units for the Greater Antilles and Virgin Islands.

ID	Terrane name	Characteristic rock units	Age range of units	Timing of boundary structures
GATHS1	Puerto Plata (Dominican Republic)	Ultramafic and serpentinite rocks are found locally through much of the Greater Antilles; in this terrane in northern Dominican Republic there are two areas of these rocks, found in the Rio San Juan Complex and the Gaspar Hernández and Helechal peridotite (Escuder-Viruete and others, 2013a) and the Loma Caribe Peridotite (Toloczki and others, 1991). Age control is poor, but these rocks are mapped as pre-Albian or simply Mesozoic; radiometric ages vary between ~75 to 153 Ma. Both complexes may be allochthonous. At the eastern limit of the terrane, metamorphic rocks characterized by glaucophane and/or marble are presumed Jurassic. Cretaceous(?) amphibolite is present along the southern limit of the Rio San Juan Complex (similar rocks are found in the Armando Bermudez terrane to the south). Associated with the Rio San Juan Complex is Late Cretaceous hornblende gabbro and diorite. Distinctive to this terrane is an area of Cretaceous mélange along the northern limit of the Rio San Juan Complex; age control on this and other mélange complexes in the region is limited. Oligocene andesite is exposed along the southern limit of this terrane; Oligocene to Eocene carbonate and clastic rocks make up the bulk of the terrane. Placer occurrences are most common in this terrane.	Oligocene and Mesozoic (probably Early Cretaceous or Jurassic)	Forms the northern part of Dominican Republic (region described as the Cordillera Oriental and Peninsula de Samana). Separated from the rest of Hispaniola by normal faults and a broad Quaternary basin (~20 kilometers wide)
GATHS2	Armando Bermudez (Dominican Republic and Haiti)	This terrane is the most mineralized of the terranes on Hispaniola; it extends through central Dominican Republic and northern Haiti. Plutonic rocks of early Late Cretaceous age (~75 to 90 Ma) are an important component of the terrane; they intrude intermediate to felsic volcanic rocks of equivalent age as well as gabbroic amphibolite. Limited areas of ultramafic rocks are present in the terrane, most commonly at its southeast end and are only sparsely present in the Haitian part of the terrane. Also present in the southeast part of the terrane, is a small area of Early Cretaceous(?) basaltic volcanic rocks. Country rock includes the Early Cretaceous(?) Amina-Maimon schist of along the northern boundary of the terrane. Turbidites and olistostrome of Late Cretaceous (Maastrichtian to Campanian) age overlie the plutonic and volcanic rocks of the terrane along its southwestern edge. In the central section of the terrane along its north side, late Tertiary continental clastic rocks overlie the terrane and commonly contain placer gold occurrences. The northern part of the terrane, especially in Haiti is overlain by Eocene carbonate deposits and includes Paleocene plutons and associated porphyry occurrences.	The terrane is dominantly early Late Cretaceous. The ultramafic rocks are of uncertain age and may be as old as Jurassic.	Unknown; boundaries of the terrane are overlain by Tertiary and younger rocks
GATHS3	Gonaves (Dominican Republic and Haiti)	This terrane, consisting of a large part of Dominican Republic and northern Haiti is dominantly Tertiary rocks, largely carbonates. However, small areas of Late Cretaceous volcanic and early Tertiary tuff and breccia are present in fault bounded blocks, particularly in Haiti. Present in the southeastern part of the terrane, are the Quaternary and latest Tertiary Dos Hermanos and Valle Nuevo volcanic fields of alkaline and peralkaline rocks. The Cretaceous fault bounded blocks may be faulted sections of the Armando Bermudez terrane. At the extreme northwestern part of the terrane, an area of ultramafic rocks is present along the coast and are unique to this terrane. These rocks are overlain by younger limestone and reef deposits.	Largely Quaternary and Tertiary; however, Late Cretaceous volcanic rocks are present in Haiti	Tertiary; may be an overlap sequence and not truly a terrane

Table 1.1. Terrane identification codes and characteristic rock units for the Greater Antilles and Virgin Islands.

ID	Terrane name	Characteristic rock units	Age range of units	Timing of boundary structures
GATHS4	Jacmel (Haiti and Dominican Republic)	Primarily a Haitian terrane that forms the southern margin of Hispaniola and is separated from the Gonaves terrane by a Quaternary or late Tertiary valley, which is likely a fault zone. Oldest rocks in this terrane are early Late Cretaceous (Turonian to Cenomanian) tholeiitic volcanic rocks. Pillows are present, indicating these rocks are marine. These tholeiitic rocks are overlain by Upper Cretaceous (Maastrichtian to Santonian) limestone and limestone conglomerate, in turn overlain by Eocene limestone. A few nickel (Ni) occurrences and many aluminum (Al) and manganese (Mn) occurrences are associated with the tholeiitic rocks. At the eastern end of the terrane, along the coast in Dominican Republic, Eocene volcanic rocks are associated with several copper occurrences.	Eocene(?) to Late Cretaceous, overlain by younger Tertiary rocks	Tertiary
GATHS5	Punta Cana	Located in eastern Dominican Republic, this terrane largely consists of Early Cretaceous intermediate volcanic rocks, andesite flows, and breccia intruded by Early Cretaceous granodiorite and tonalite (>100 Ma). In the east, the older volcanic rocks are overlain by Upper Cretaceous mixed sedimentary and volcanic rocks including turbiditic sandstone, marl, loamy claystone, subordinate sandy limestone, tuff, agglomerate, and conglomerate. At its western limit, the terrane also includes Early Cretaceous keratophyre and spilite. This and the Virgin Islands terrane are the only terranes to contain keratophyre and spilite. Gold placer deposits are common in this terrane and associated with the older volcanic rocks are epithermal occurrences. In the western part of the terrane, associated with the keratophyre and spilite, skarn occurrences and volcanogenic massive sulfide (VMS) occurrences are present.	Primarily Early Cretaceous	Late Cretaceous or younger
GATJM1	Jamaica A	Jamaica is divided into two subterranees, Jamaica A and Jamaica B, which to some extent are based on age. This subterrane consists of the older rocks of the island. Largely, consisting of Upper Cretaceous clastic rocks in the east, and Late Cretaceous andesitic volcanic and volcanoclastic rocks (intruded by early Paleocene to Maastrichtian granodioritic rocks) in the central part of the subterrane. Farther west, Late Cretaceous mafic and andesitic volcanic rocks are associated with Upper Cretaceous limestone and mixed clastic and carbonate rocks. A small granodiorite body (similar to those in the east of the subterrane) intrudes the Upper Cretaceous sedimentary rocks. Locally, a very small area of serpentinite is present. Mineral occurrence types include porphyries proximal to the plutons, and epithermal and skarn occurrences. Many of the mineralized occurrences are found in the Late Cretaceous rocks intruded by the Tertiary-Cretaceous plutons. Overlying a small part of the terrane are Oligocene carbonate rocks, which have associated bauxite occurrences.	Early Tertiary to Cretaceous	Tertiary, Eocene(?)
GATJM2	Jamaica B	This subterrane comprises the remainder of the island of Jamaica and consists primarily of Miocene to Eocene carbonate rocks. At the western limit of the terrane, are Upper Cretaceous (Santonian to Coniacian) clastic rocks of the Hanover Formation (also referred to as the Hanover Shale) and a very small area of Late Cretaceous intermediate volcanic rocks. Several porphyry-type occurrences are found in this limited region. The primary mineral occurrences in this terrane are bauxite occurrences associated with the Tertiary limestone.	Tertiary, Eocene and younger	Tertiary, Eocene(?)

Table 1.1. Terrane identification codes and characteristic rock units for the Greater Antilles and Virgin Islands.

ID	Terrane name	Characteristic rock units	Age range of units	Timing of boundary structures
GATCU1	San Cayetano (Guanguanico)	Located in westernmost Cuba, this terrane dominantly consists of the Jurassic San Cayetano Formation and its Castellanos Member, overlain by the Cretaceous-Jurassic Artemisa Formation. The San Cayetano Formation consists of low-grade metamorphic quartz and quartz-mica sandstone and carbonaceous shale and siltstone, conglomerate, phyllite, polymictic sandstone, and schist; the Castellano Member tends to be finer grained and contains limestone. The Artemisa Formation is a cherty limestone. The youngest unit of the terrane is the Early Cretaceous Albion to Valanginian Polier Formation consisting of micritic limestone containing interbeds of sandstone, shale, and chert. Structurally the terrane consists of several thrust sheets. The dominant mineral occurrences are lead-zinc (Pb-Zn) sedimentary exhalative deposits (SEDEX) and a variety of copper (Cu) SEDEX(?) occurrences thought to represent feeders to the Pb-Zn occurrences.	Early Cretaceous and Jurassic	Late Cretaceous or younger
GATCU2	Havana	This terrane consists of several allochthonous packages of Cretaceous-Jurassic ultramafic and mafic cumulate rocks, middle Cretaceous intermediate and mafic pyroclastic rocks, and in its western part, sparse Late Cretaceous, Santonian to Cenomanian intermediate and felsic pyroclastic rocks “floating” in Tertiary and latest Cretaceous turbidites of the Cacarajicara Formation. In the western part of the terrane, between the ultramafic and mafic rocks and the turbidites are the tholeiitic flows and breccia of the Encrucijada Formation. This unit contains interbedded flint, micrite, and biomicrite, and minor shale and siltstone. Underlying that is red chert interbedded with siltstone, shale, limestone, sandstone, conglomerate, basalt, and minor tuffite of the early Late Cretaceous Quiñones Formation; and early Late Cretaceous gray to almost black, fine- to medium-grained biomicrite of the Guajaibón Formation. Laterite occurrences are associated with the ultramafic rocks; locally other units; and VMS occurrences are associated with the pyroclastic rock units. In the eastern part of the terrane, podiform chromite occurrences are present, these are lacking elsewhere in the terrane.	Tertiary, Paleocene; Cretaceous; and Jurassic(?)	Tertiary, Paleocene; but in a “sea” of Miocene carbonate rocks

Table 1.1. Terrane identification codes and characteristic rock units for the Greater Antilles and Virgin Islands.

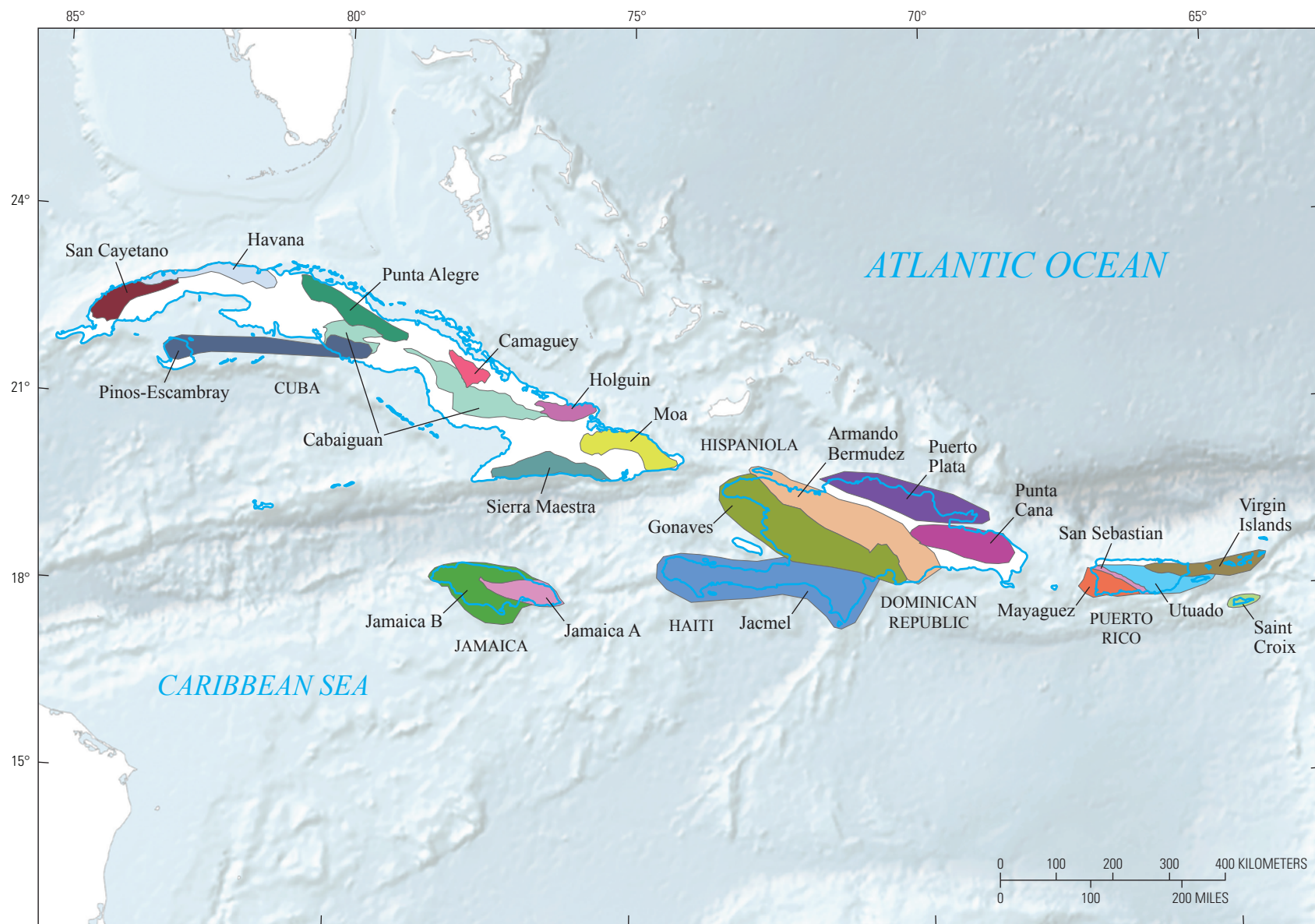
ID	Terrane name	Characteristic rock units	Age range of units	Timing of boundary structures
GATCU3	Pinos-Escambray	This terrane is in two sections, one consisting of the Isla de Juventud and a section consisting of Trinidad and Sancti Spiritus Domes. Rocks of the Isla de Juventud consist of the Jurassic Agua Santa Formation and its Victoria Member. The formation is micaceous pelitic schist containing mica, garnet, and aluminosilicates, and has interlayers of marble and calcsilicate rocks that may be locally predominant. The Victoria Member is also micaceous and quartz-mica pelitic schist, which is commonly graphite-rich and has interlayers of quartzose schist and quartz-mica schist. Marble layers are rare in the Victoria Member. Also present are the Middle to Early Jurassic quartz-rich and quartz-mica psammitic schist of the Cañada Formation. Interlayered(?) with the schist is marble of the earliest Cretaceous to Late Jurassic Gerona Group. Radiometric ages on muscovite from the schist yield ages between 53.7 and 75.9 Ma (early potassium/argon age determinations [K/Ar]). On the northern part of the island, a small, undated granite body is present. Mineral occurrences are not common on the island though several skarn occurrences are present in the Victoria Member on the southern part of the island and an old mine is reported as an orogenic gold occurrence in the Agua Santa Formation on the western part of the island. The Trinidad and Sancti Spiritus dome region consists of similar units as the Isla de Juventud. These units include the middle Oxfordian to Early Jurassic Loma La Gloria Formation, consisting of quartz-rich and quartz-muscovite schist, that are locally graphitic, and muscovite schist and subordinate interlayers of marble, eclogitic rocks, and metachert. Also present is the middle Oxfordian to Early Jurassic La Chispa Formation of quartz-muscovite and muscovite-rich schist, containing interlayers of metachert and lawsonite-bearing volcanogenic greenschist and marble; the Late Jurassic Boquerones Formation of schistose marble and calcschist containing graphite and white mica, and black dolomitic limestone boudins containing abundant radiolarian casts; the Late Jurassic Cobrito Formation consisting of calcic and graphitic schist containing thin layers of foliated marble and layers of lawsonitic greenschist and eclogite; the Early Cretaceous to Late Jurassic San Juan Group of dark-colored laminated graphitic marble having interbeds of cherty quartzite; and the Early Cretaceous La Sabina Formation of quartzite that has pelitic schist interlayers, and local metamorphosed arenite and marble layers. Radiometric ages in the part of the terrane commonly range from about 56.7 to 71.7 Ma (with some questionable outliers). Mineral occurrences are not common in this part of the terrane and include several VMS occurrences as well as several unclassified gold and copper occurrences.	Earliest Cretaceous to Early Jurassic metamorphic rocks (probably a protolith age; several K/Ar dates are Paleocene to Campanian)	Terrane is possibly allochthonous; bounding rocks are middle Cretaceous mafic volcanic rocks of the Las Calderas Formation.
GATCU4	Punta Alegre	Located along the northern shore of Cuba, this highly tectonized terrane contains mafic and ultramafic rocks (and serpentinite) of Cretaceous or Jurassic age in tectonized slivers intermixed with Cretaceous volcanic, clastic, and shallow marine carbonate rocks. Orogenic gold occurrences are common in the southeastern part of the terrane, as are several epithermal occurrences. In the northern part of the terrane, manganese occurrences are tightly grouped. Other types of occurrences locally present include podiform chromite (north) and VMS (southeast).	Primarily Early Cretaceous and Jurassic(?)	post-Turonian

Table 1.1. Terrane identification codes and characteristic rock units for the Greater Antilles and Virgin Islands.

ID	Terrane name	Characteristic rock units	Age range of units	Timing of boundary structures
GATCU5	Cabaiguán	This terrane, sandwiched between the Pinos-Escambray and Punta Alegre terranes is dominated by four, probably related geologic units. Oldest of the four is the Early Cretaceous (Barremian to Berriasian) Los Pasos Formation felsic volcanic rocks; the late Early Cretaceous Mataguá Formation consisting of basalt and basaltic andesite; the middle Cretaceous Cabaiguán Formation of intermediate and silicic pyroclastic deposits in the northeast part of the terrane; and an early Late Cretaceous (~85 Ma) granodiorite to quartz diorite series of plutons. The plutons likely associated with the Los Pasos and Mataguá Formations, intrude the metamorphic rocks of the informally defined Early Cretaceous to Late Jurassic metamorphic rocks of the Mabujina complex and the bimodal greenschist facies metavolcanic rocks of the Porvenir Formation. The Mabujina complex tends to define the boundary of the Pinos-Escambray terrane. Radiometric age determinations associated with the Mabujina complex tend to be between 70 and 85 Ma, possibly reflecting cooling ages associated with intrusion of the plutonic rocks. Between the Los Pasos and Cabaiguán Formations, the Santonian to Coniacian Bruja and Seibabo Formations intermediate and felsic volcanic rocks and pyroclastic rocks appear to form a graben, which also incorporates the limestone and minor calcarenite of the Cenomanian to Albian Provincial Formation. The westernmost part of the terrane, adjacent to the Pinos-Escambray terrane consists of the Late Cretaceous Las Calderas Formation mafic volcanic rocks, the Late Cretaceous El Tambor Formation, San Blas Member of the El Tambor Formation pelitic schist, minor greenstone, and marble that is similar to the La Sabina Formation and the undivided El Tambor Formations found in the Pinos-Escambray terrane. Very Upper Cretaceous clastic and carbonate rocks of the Monos and Cantabria Formations, locally overlie the Cabaiguán terrane. VMS mineral occurrences are associated with the felsic volcanic rocks of the Los Pasos Formation whereas skarn, epithermal, and porphyry-type occurrences are associated with the plutonic rocks. Porphyry-type and VMS occurrences are present in the Cabaiguán Formation.	early Late Cretaceous to Jurassic(?), dominantly Early Cretaceous	Late Cretaceous or younger
GATCU6	Camagüey	This Cuban terrane is dominantly composed of metamorphosed ultramafic rocks that are quite likely allochthonous. Associated and possibly overlying is the Barremian to Tithonian micritic limestone of the Veloz Formation, which suggests some age control on the ultramafic rocks. Upper Cretaceous carbonate rocks are present northeast of the ultramafic rocks in fault contact. Overlying the older rocks are the informally defined Taguasco olistrostromes and Senado olistrostromes of middle Eocene to late Paleocene age. Podiform chromite occurrences are very common in the southern part of the terrane associated with the ultramafic rocks, whereas these are lacking in the northwestern part of the terrane's ultramafic rocks.	Tertiary, Eocene; and Early Cretaceous to Jurassic	Tertiary, Eocene
GATCU7	Holguín	A largely ultramafic and mafic rock terrane in southern Cuba, the rocks are allochthonous and similar to the Camagüey terrane. They are associated with the informally defined Eocene to Paleocene Haticos olistrostromes and Rancho Bravo olistrostromes. These igneous rocks and olistrostromes are most likely in the upper plate of a thrust fault. Also widely exposed, primarily in the northern part of the terrane, is the early Late Cretaceous Iberia Formation of andesite and basalt, diabase dikes, mafic and intermediate tuff, and agglomerate, conglomerate, sandstone, limestone, and marl. Mineral occurrences are mostly reported in the central half of the terrane and include orogenic gold, podiform chromite, and a few epithermal, VMS, and laterite occurrences. Placer occurrences are present in the northern part of the terrane.	Late Cretaceous to Jurassic(?)	Eocene or younger

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ID	Terrane name	Characteristic rock units	Age range of units	Timing of boundary structures
GATCU8	Moa	Located at the eastern end of Cuba, this is another terrane containing significant ultramafic rocks. Ultramafic and metamorphosed ultramafic rocks form as much as 60 percent of the exposure in the terrane. In the easternmost part of the terrane, metavolcanic, metasandstone, and blueschist of the Sierra del Purial Formation cover a large area. Farther west, andesitic tuff and breccia, dacite, tuffite, shale, volcanoclastic siltstone, basalt and rhyodacite flows, conglomerate, and limestone of the Santo Domingo Formation overlies the metamorphosed ultramafic rocks. It is intruded by small plugs of porphyritic diorite, andesite, and diabase. Unlike the nearby and somewhat similar Holguín terrane, no olistrostromes or tectonite units are described associated with this terrane. Distributed through the central part of the terrane, are Late Cretaceous conglomeratic rocks of the La Picota Formation and Paleocene to Late Cretaceous Gran Tierra and Micara Formations of calcareous cemented volcanoclastic conglomerate grading to fragmental limestone, containing interbeds of calcareous tuffaceous sandstone (Gran Tierra) and siltstone, breccia, sandstone, subordinate felsic bentonite tuff, tuffite, and limestone (Micara), respectively. Also present, particularly along the perimeter of the western part of the terrane, is Eocene to Paleocene tuff, this is in common with the Sierra Maestra terrane to the southwest. Mineral occurrences are mostly reported associated with the ultramafic rocks and include podiform chromite and a few epithermal, VMS, and orogenic gold occurrences. Laterite occurrences are also associated with the ultramafic rocks. The Eocene to Paleocene tuff, which overlaps and extends outside of the terrane has many volcanogenic manganese occurrences.	late Early Cretaceous to Jurassic(?) overlain by Maastrichtian and younger volcanic and sedimentary rocks	Eocene or younger
GATCU9	Sierra Maestra	This terrane, also the southern coast of Cuba, is almost entirely comprised of Tertiary, Eocene to Paleocene intrusive and volcanic rocks. Small exposures of Late Cretaceous volcanoclastic rocks and lesser volcanic rocks are locally present. However, by far, the dominant rock unit in the terrane is Eocene to Paleocene tuff of the Jobo Formation. Eocene intrusive bodies ranging from monzodiorite to gabbro (particularly gabbro) are present scattered throughout the terrane. Felsic to intermediate hypabyssal rocks are most common in the eastern part of the terrane, as are felsic welded tuff. Basalt to andesite flows are common in the central part of the terrane. Eocene clastic, carbonate, and tuffaceous rocks are present in small amounts throughout terrane. To the northeast of the terrane, Eocene clastic and carbonate rocks are extensively exposed between this terrane and the Moa terrane. A significant number of mineral occurrences are present within this terrane, including porphyry-type, and polymetallic vein occurrences. Volcanogenic manganese occurrences are common and widely present. Skarn and epithermal occurrences are also common; whereas, there are few VMS occurrences, and porphyry-type occurrences are rare.	Eocene to Paleocene, rare Late Cretaceous rocks	Oligocene(?)



Base from Natural Earth
 Lambert Conformal Conic projection
 World Geodetic System of 1984

Figure 1.1. Map showing the terranes of the Greater Antilles and Virgin Islands.