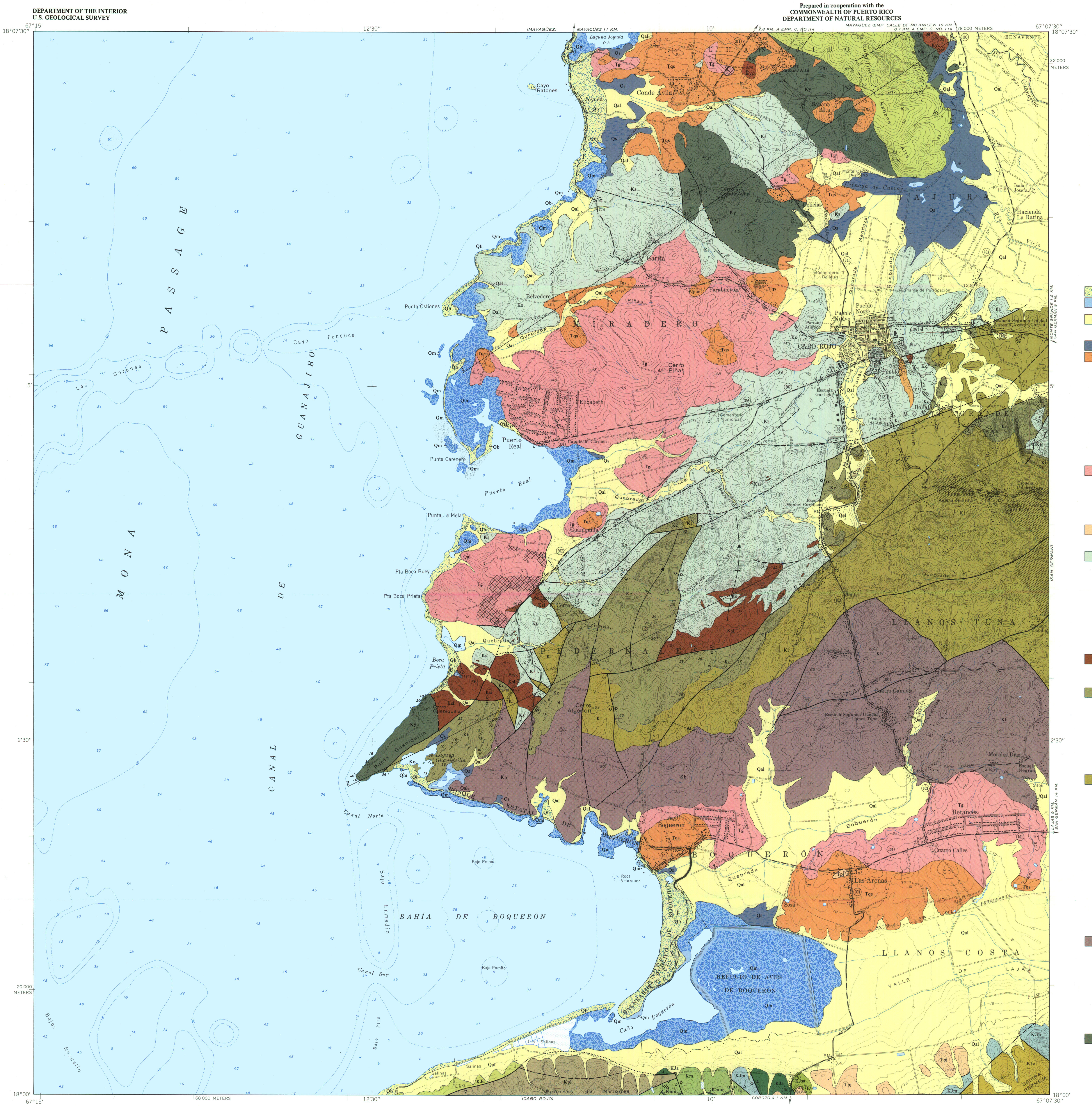
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
COMMONWEALTH OF PUERTO RICO
DEPARTMENT OF NATURAL RESOURCES

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I-1559



Base from U.S. Geological Survey, 1966
Selected hydrographic data compiled from U.S.C. & G.S. Chart 901 (1965)
This information is not intended for navigational purposes
Polyconic projection. Puerto Rico datum, 1940 adjustment
2000-meter grid based on Puerto Rico coordinate system
Barrio and Municipality boundaries by the Puerto Rico
Planning Board

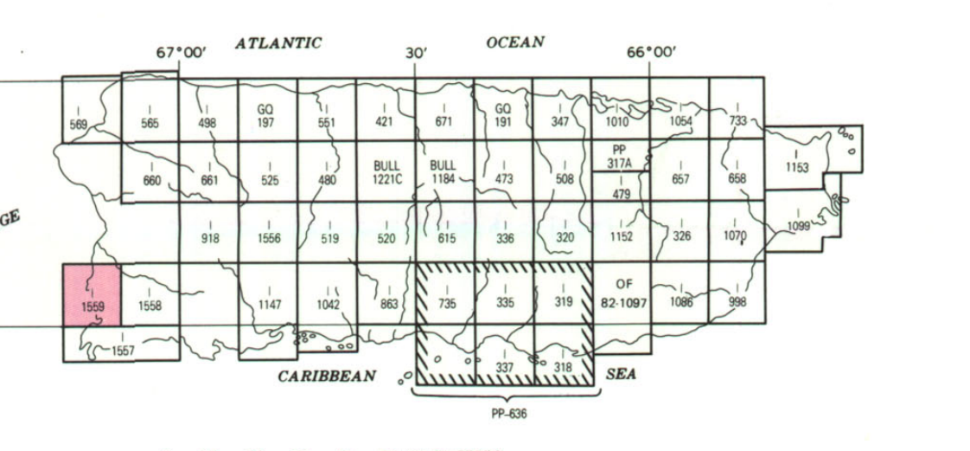
APPROXIMATE MEAN DECLINATION, 1984

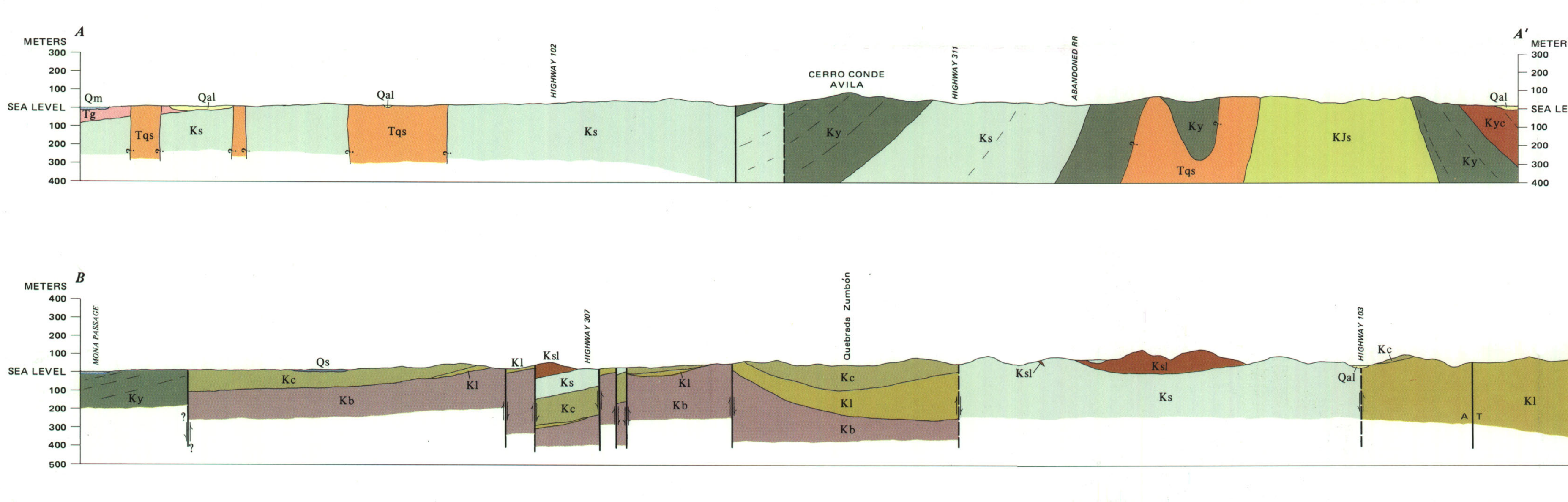
SCALE 1:20 000

CONTOUR INTERVAL 5 METERS
DOTTED LINES REPRESENT 1-METER CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET–DATUM IS MEAN LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 0.2 METERS

Geology mapped in 1973-74
Assisted in 1973 by Widiberto Medina


PUERTO RICO
QUADRANGLE LOCATION


INDEX TO GEOLOGIC MAPPING IN PUERTO RICO

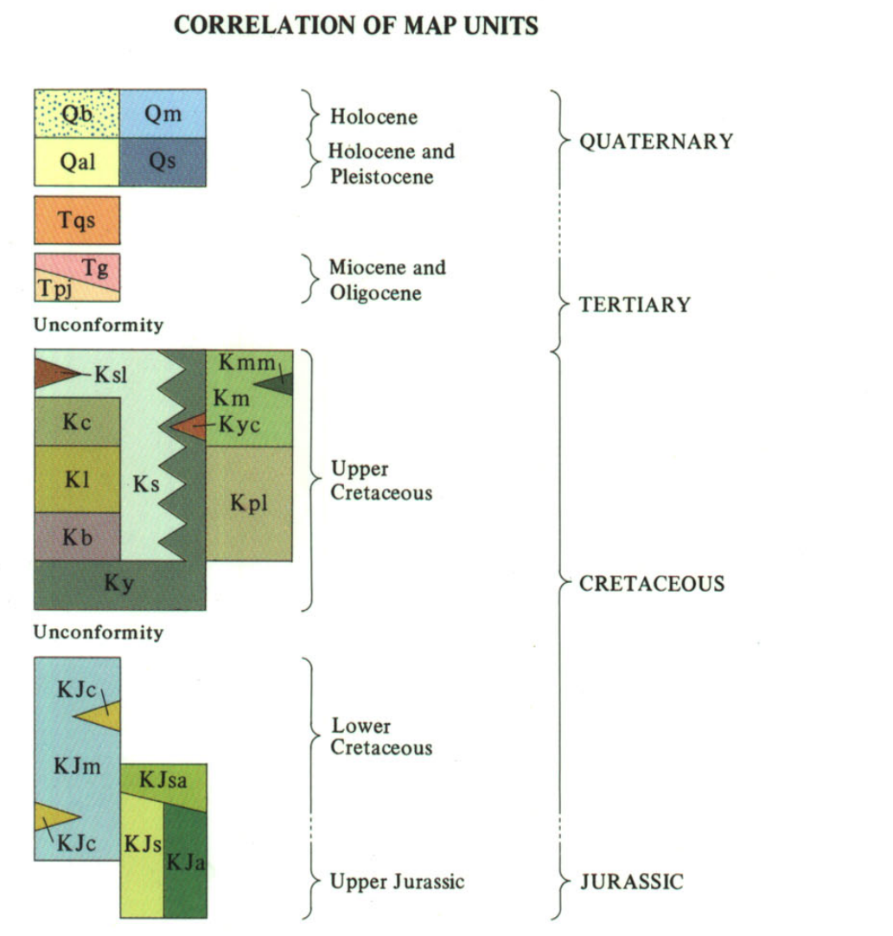


Interior—Geological Survey, Reston, Va.—1984—G83311

GEOLOGIC MAP OF THE PUERTO REAL QUADRANGLE, SOUTHWEST PUERTO RICO

By
Richard P. Volckmann
1984

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qb BEACH DEPOSITS (HOLOCENE)—Sand and minor gravel consisting of rounded shell debris, volcanic rock, chert, and, locally quartz

Qm MANGROVE SWAMPS (HOLOCENE)—Coastal areas containing thick growths of mangroves. Underlain by fine sand and silt trapped by mangrove roots

Qal ALLUVIUM (HOLOCENE AND PLEISTOCENE)—Clay, silt, sand, and gravel in major stream valleys; merges with colluvium along valley walls; Lajas valley deposits consist mainly of silt and clay with fine sand lenses grading into sand and gravel fan deposits on the north and south sides of the valley

Qs SWAMP DEPOSITS (HOLOCENE AND PLEISTOCENE)—Sand, silt, clay and organic material deposited in areas of poor drainage

Tqs QUARTZ SAND DEPOSITS (TERTIARY?)—Irregularly shaped and distributed bodies chiefly consist of quartz grains and minor hematite or limonite and clay; exposures are typically varigaeted in color and range from reddish-brown to reddish-orange to dark-yellowish-orange; colored areas are commonly streaked with pinkish-white to white bleached zones; quartz grains which comprise 85-95 percent of the bodies are extremely angular to sliver-like and moderately sorted; grain size ranges from 90-380 micrometers (um), however, most grains approach an average of 180 um; grains are clear, contain bubble trains, and exhibit undulatory extinction; elongate grains are randomly oriented; grains are typically supported in a matrix of limonite, hematite (or both), and clay. Limonite and manganese nodules 1 mm to 3 cm in diameter occur sparsely within most exposures and are typically concentrated on topographic surfaces; most nodules enclose quartz grains and in some larger nodules the quartz is in the form of rods; upper portions of most exposures appear to be reworked and display vague to well-developed stratification which is defined by alternation of coarser or finer sand laminae, locally by concentration and alignment of manganese and limonite nodules and rarely, by thin (1-3 cm) silt lenses

Tg GUANAJIBO FORMATION (MIOCENE)—(1) Yellowish-white to yellowish-orange loosely cemented, somewhat friable calcirudite and calcarenite containing oyster shells, minor corals, and internal molds of gastropods. Finer grained material contains abundant ostracodes and Foraminifera, including *Marginopora* sp. (2) Reddish-brown to reddish-orange, interbedded sand, and medium- to coarse-grained gravel loosely cemented with calcite and iron oxides. Gravel east and south of Puerto Real consists of clasts of volcanic rock, silicified mudstone and minor limestone; interbedded with thin (1 to 10 cm) layers of limy silt. Thickness estimated to be as much as 30 m.

Tpj PONCE LIMESTONE AND JUANA DIAZ FORMATION, UNDIVIDED (MIOCENE AND OLIGOCENE)—Interbedded chalky limestone and medium- to coarse-grained gravel. Gravel composed chiefly of clasts of Cretaceous limestone, volcanic rocks, and chert. Estimated to be at least 40 m thick

Ks SABANA GRANDE FORMATION (MAESTRICHTIAN AND CAMPANIAN)—Gray, dark-greenish-gray, and purplish-gray andesitic crystal-lithic tuff, tuff-breccia, and conglomerate with minor basaltic lava and breccia. Andesitic rocks typically contain abundant clinopyroxene and calcic andesine crystals in a fine-grained, commonly silicified matrix. Green hornblende or oxyhornblende occur locally in addition to, or in place of, clinopyroxene. Plagioclase is typically strongly altered to sericite or sausserite; mafic minerals are altered to chlorite and epidote. Accessories include magnetite, apatite, and rare quartz and biotite. Fibrous chlorite is very common as a pore filling. Conglomeratic sequences, which occur throughout the formation, are composed of rounded to subangular clasts of tuff, tuff-breccia, and lava in a fine- to coarse-grained matrix typically consisting of plagioclase, clinopyroxene and tuff fragments with interstitial calcite, rare authigenic quartz and, locally zeolites and prehnite. Basalt lava flows contain labradorite, clinopyroxene, and rare olivine phenocrysts in a fine-grained to aphanitic groundmass. Quartz occurs as rare xenocrysts(?). Weathers to a grayish-brown or reddish-brown soil

Ksl Sabana Grande Formation, limestone lenses (Maestrichtian and Campanian)—Chiefly light- to dark-gray, massive, discontinous lenticular bodies of calcarenite and clacirudite made up of mollusk fragments, pellets, and echinoid spines typically in a sparry cement; near base of formation contains *Barrettia gigas;* conglomerate of volcanic and limestone clasts developed at base of some lenses

Kc COTUI LIMESTONE (MAESTRICHTIAN AND CAMPANIAN)—Medium-gray to brownish-gray, thick-bedded (1-2 m) to massive, dense bioclastic limestone; generally composed of mollusk (chiefly rudist) fragments in an abundant micritic to sparry cement; in some places contains abundant pellets, sparse larger Foraminifera, and rare oolites. Other minor constituents include locally, authigenic quartz, glauconite, and very rare hematite. Locally basal beds are conglomeratic containing detritus from underlying Lajas Formation and locally derived limestone rubble. Rudists are principally *Barrettia rusae, Barrettia gigas,* and Radiolitidae. Locally contains concentrations of the large gastropod *Trochacteon* sp. Exposures containing abundant pellets generally show much better developed bedding than those which are primarily made up of skeletal debris. Limestone shows strong solution effects and locally is cavernous. Surfaces of most exposures exhibit well-developed karren. Thickness ranges from 10 to 75 m

Kl LAJAS FORMATION (CAMPANIAN OR OLDER)—Chiefly grayish-purple, light- to dark-maroon to reddish-maroon, rarely grayish-green seriate-porphyritic basalt flows and minor tuffs consisting mainly of euhedral to subhedral plagioclase (labradorite, An_{52-57}) and oxyhornblende phenocrysts, as much as 5 mm in length, within an aphanitic to glassy matrix. Locally, pseudomorphs of olivine and phenocrysts of partially to completely altered clinopyroxene and orthopyroxene occur in various combinations with plagioclase and oxyhornblende. Accessory minerals are apatite, zircon, biotite, and rare quartz (xenocrysts?). Plagioclase phenocrysts are commonly zoned, show resorption effects, locally display reaction borders of fine-grained magnetite or hematite, and are altered to sausserite and, locally, to calcite. Oxyhornblende phenocrysts are strongly poikilitic with inclusions of plagioclase, apatite, and, rarely, zircon, and are typically altered to magnetite or hematite. Olivine is altered to iddingsite and serpentine, and clinopyroxene to chlorite, calcite and (or) fine-grained magnetite. All mafic phenocrysts are bordered by ferric iron. The matrix consists chiefly of fine needles and laths of plagioclase, which commonly exhibit trachytic texture, accompanied by minute granules and octahedra of magnetite, needles of hematite, and locally, needles of actinolite(?). In some localities, much of the matrix consists of devitrified glass; in other localities, glass is subordinate to absent. Formation locally contains zones of very coarse grained agglomerate consisting of rounded clasts, from about 5 cm to as much as 1.5 m in diameter, in an igneous matrix. Both clasts and matrix have the same mineralogical composition as the Lajas Formation. Grain size and color range from one clast to another in any given exposure; grain size from medium- to coarse-grained and color from pinkish-white to dark-red-maroon. Fractures in some clasts are filled with matrix material

Kb BOQUERON BASALT (CAMPANIAN? OR OLDER)—Dark-grayish-brown, dark-greenish-gray, and very dark gray, porphyritic locally amygdular lava with minor breccia and tuff; contains abundant phenocrysts of plagioclase (labradorite, An_{52-57}), clinopyroxene and olivine in a fine-grained to aphanitic matrix; plagioclase phenocrysts occur as twinned laths and as strongly zoned equant crystals; clinopyroxene crystals are euhedral to subhedral and commonly occur as intergrown crystal aggregates; olivine is typically in the form of skeletal crystals which are altered to serpentine and iddingsite; accessories are apatite, magnetite and hematite; matrix consists of a mixture of plagioclase needles, chlorite, epidote, and abundant hematite granules. Trachytic texture is well developed; vesicles are principally filled with calcedonic silica - some weathered outcrops display silica amygdules as much as 3 cm in diameter; other vesicle fillings are chlorite (penninite?), calcite and epidote. Tuffs and breccias occur near top of unit; at very top of unit tuffs are interbedded with grayish-red amphibole-rich tuffs of the same composition as the rocks of the overlying Lajas Formation

Ky YAUCO FORMATION (MAESTRICHTIAN AND CENOMANIAN)—Brownish-gray, dark-gray, to black where fresh, yellowish-brown to yellowish-orange where weathered, thin- to medium-bedded variously interbedded calcareous siltstone, argillaceous limestone, claystone, fine-grained tuff, and conglomerate (Kyc described below). Siltstone and claystone are the most abundant and are composed of fragments of pelagic foraminifera, subordinate shell debris, and angular to rounded mineral clasts, mainly plagioclase. The matrix is generally an argillaceous micrite locally containing finely disseminated pyrite. In some localities, siltstone-claystone sequences have been silicified to thin-bedded yellowish-orange, reddish-orange, or very dark gray chert. The chert zones, which range from 0.5 m to 10 m in thickness, appear to be laterally discontinuous and are interbedded with non-silicified siltstone and claystone. Sandstones contain a higher percentage of mineral clasts and locally are non-calcareous. Tuffs are generally brown to dark-brown, thinly bedded and laminated units within siltstone-claystone sequences; locally show graded bedding

Kyc Yauco Formation, conglomerate phase—Generally consists of rounded clasts of volcanic rock, siltstone and claystone, and rare limestone in a generally non-calcareous sand or silt matrix. Stratification is generally poor; conglomerate intervals range from about 5 m to more than 20 m thick. Conglomerate on east and west side of Cordillera Sabana Alta contains abundant rounded to angular clasts of chert and amphibolite with minor volcanic rocks and limestone

Km MELONES LIMESTONE (MAESTRICHTIAN AND CAMPANIAN)—Consists of a series of units, which are locally interbedded, but which can be roughly separated from the top of the formation to the bottom as: (1) Reddish-orange, yellowish-orange, massive, rarely thick-bedded, cherty calcarenite containing zones of abundant actionellid gastropods; chert occurs as replacement of calcite but it is unclear if replacement is diagenetic or post-diagenetic; (2) Massive phase (Kmm described below); (3) Light- to dark-gray, thin-bedded, fossiliferous carbonaceous shaly limestone and limy shale; bedding typically wavy with well-developed bedding plane parting; exposures commonly cut by numerous small calcite veins; contains numerous fossils including larger Foraminifera, and the mollusks, *Pseudocuculea* sp. and *Lopha* sp.; (4) Reddish-brown, olive-brown, or tan, medium- to coarse-grained, thin- to medium-bedded, thinly laminated, locally crossbedded tuffaceous sandstone consisting of subrounded to subangular plagioclase, and volcanic rock fragments weakly cemented by hematitie and (or) calcite; crossbedding and laminae well-displayed by concentrations of magnetite; contains common limy concretions as much as 20 cm in length, and rounded fragments, as much as 25 cm in diameter, of worm-bored wood, now replaced by calcite; interbedded commonly with gray shaly limestone, dark-bown calcareous mudstone and locally with thinly laminated, red-maroon, blackish-red, or dark-brown siltstone

Kmm Melones Limestone massive phase—Light- to dark-gray, massive to thick-bedded, bioclastic calcarenite consisting of calcareous fossil fragments, mostly mollusks, Foraminifera, and pellets in a sparry to micritic cement; many shell fragments recrystallized to sparry calcite; outcrops commonly show karren features; characterized by the rudists *Barrettia gigas, Parastroma guitarti,* and *Titanosarcolites* sp.

Kpl PARGUERA LIMESTONE, LOWER MEMBER (CAMPANIAN TO SANTONIAN)—Chiefly consists of thin- to medium-bedded, grayish-orange to pale-yellowish-brown volcaniclastic calcarenite, thin beds of silicified mudstone, and dark-gray to dark-bluish-gray, thin- to medium-bedded, laminated to non-laminated calcilutite which weathers grayish-orange or pale-yellowish-orange. Contains abundant planktonic Foraminifera. Locally partially silicified. Bedding is planar to wavy, generally with well-developed bedding plane parting; beds locally graded. As much as 300 m thick

KJm MARIQUITA CHERT (LOWER CRETACEOUS AND UPPER JURASSIC)—Yellowish-red, brownish-red, grayish-green, black or white, fine- to medium-grained bedded chert with rare amygdular basalt and silicified limestone. Chert is generally fractured or brecciated and typically consists of an interlocking mosaic of micro-crystalline quartz which in many areas has been partially to completely recrystallized. Quartz and (or) calcite and limonite-hematite commonly fill fractures and voids between breccia fragments. Radiolaria and locally Foraminifera are abundant constituents. Locally the radiolaria are completely recrystallized and may be selectively stained by iron oxide. Bedding is 2-30 cm thick but is commonly obscured or indistinct because of intense brecciation; characteristically lenticular; the lenses range from 1-4 m in length and are separated by clay partings. Locally beds are deformed by small-scale slump-folding. Amygdular basalt occurs as black to greenish-black flows 1-3 m thick and consists of felted plagioclase needles in an opaque, hematite-rich glassy matrix; amygdules are filled with calcite, much of which is replaced by microcrystalline silica. Limestone is grayish-red to grayish-yellow; occurs in beds 5-15 m thick; consists of highly recrystallized calcite, which has been largely replaced and veined by silica

KJc CAJUL BASALT (LOWER CRETACEOUS? AND UPPER JURASSIC?)—Blackish-red-purple to brownish-black porphyritic amygdular basalt; chiefly composed of plagioclase (labradorite-An_{55-59}), which occurs as sparse blocky untwinned phenocrysts, 1-3 mm in length, and as abundant smaller twinned laths; larger phenocrysts are zoned and are commonly selectively altered to calcite along preferred zones; some large phenocrysts are strongly sausseritized; plagioclase laths exhibit felted to trachytic texture and are altered to sausserite, calcite and hematite. Olivine occurs as rare, corroded phenocrysts altered to calcite and iddingsite. Matrix consists of nearly opaque glass that contains 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. In the extreme southeast corner of the quadrangle, the basalt has been intruded by small dikes of coarse-grained plagioclase-hornblende porphyry that are too small to show at map scale; they are probably related to the Maguayo Porphyry, which occurs extensively in the Sierra Bermeja of the San Germán quadrangle to the east (Volckmann 1984a; Mattson, 1973)

KJs SERPENTINITE (LOWER CRETACEOUS AND UPPER JURASSIC)—Black, blackish-green, pale-green, bluish-green, grayish-red, pervasively fractured rock consisting primarily of serpentine minerals. Vague outlines of pyroxene and olivine grains are visible in some specimens. Pyroxene grains are serpentinized in a characteristic boxwork texture and persist as pseudomorphs (bastite), which display megascopic reflective surfaces of relict cleavage planes. Accessories are magnetite and chromite. Outcrops are characterized by extreme brecciation and shearing that locally produce a strong foliation. Angular to tectonically rounded breccia fragments range from less than 1 cm to several meters in diameter. Slickensides are typically well developed on all fragment surfaces. Some outcrops are intruded by highly altered dikes of probable andesitic-basaltic rock. These dikes are too small to show at map scale. The serpentinite is cut locally by thin veins of magnesite

KJa AMPHIBOLITE (LOWER CRETACEOUS AND UPPER JURASSIC)—Dark-gray to dark-greenish-gray, fine- to medium-grained, weakly foliated to non-foliated metamorphic rock; principal constituents are plagioclase (andesine) and green hornblende. Foliated varieties exhibit grano-blastic texture; non-foliated exhibit relict(?) ophitic texture. Plagioclase is moderately sericitized or completely sausseritized. Hornblende occurs as mineral aggregates, is locally poikiloblastic, and is commonly unaltered. Common accessories include quartz, sphene, magnetite, ilmenite(?), apatite, epidote, chlorite, and rarely, actinolite. 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

KJsa SERPENTINITE AND AMPHIBOLITE, UNDIFFERENTIATED (LOWER CRETACEOUS AND UPPER JURASSIC)—Areas underlain by both serpentinite and amphibolite, individual bodies of which are too small to resolve at map scale. Consist of blocks of amphibolite in an abundant serpentinite matrix and probably represent areas of tectonic mixing of the two rock types

GEOLOGIC SYMBOLS

Contact—Dotted where concealed; queried where inferred (contacts of Quaternary units are shown by a solid line by convention; placement ranges from assured to inferred

U ? T / D · A Fault—Dashed where approximately located, dotted where concealed, queried where existence uncertain. Arrows show relative strike-slip movement. T, movement toward observer; A, movement away from observer. D, downthrown side; U, upthrown side

Axis of syncline—Showing direction of plunge

45 Strike and dip of beds

⊕ Horizontal beds

45 Strike and dip of foliation

▨ Zone of hydrothermal alteration

Zone of surface concentration of silica blocks

⚒ Quarry

INTRODUCTION

The Puerto Real quadrangle is underlain by serpentinite, amphibolite, chert, and basalt of Late Jurassic to Early Cretaceous age, volcanic rocks, mudstone and limestone of Late Cretaceous age, and limestone and gravel to Tertiary age. Irregularly distributed bodies of quartz sand are suspected to be the weathered surfaces of intrusive rocks, which may be Tertiary in age. Layered rocks in the central part of the quadrangle are offset by two principal sets of high-angle faults, one trending dominantly northeast and a subsequent set trending north-northwest. Serpentinite has been emplaced against Upper Cretaceous rocks along the northern and southern borders of the quadrangle. The Lajas Valley, a flat-floored alluvium-filled valley, trends east-west across the lower part of the quadrangle.

Special acknowledgment is due to N. F. Sohl, U.S. Geological Survey, for his instructive comments on rudist assemblages, to Widiberto Medina, San Juan, Puerto Rico, for his assistance in the field, and to R. J. McEwen, Parguera, Puerto Rico, for his advice and helpful criticism during the progress of geologic mapping.

UPPER JURASSIC AND LOWER CRETACEOUS ROCKS

SERPENTINITE

Serpentinite crops out in the Cordillera Sabana Alta on the northern border and in the Peñones de Melones on the southern border of the quadrangle. The northern exposure, which is larger, is flanked on the northeast and southwest by the Yauco Formation, which dips steeply away from both sides of the serpentinite mass. The serpentinite has been strongly and pervasively sheared; shear attitudes are approximately parallel to contacts between serpentinite and the Yauco Formation.

There exists some question as to the mode of emplacement of the serpentinite in its present position. The serpentinite may have been uplifted, horst-like, along high-angle normal faults, which now might represent the serpentinite-Yauco contacts. However, these contacts are quite sinuous and unlike the character of other faults in the Puerto Real area.

The sinuosity of the serpentinite—Yauco contacts, the pervasive shearing in the serpentinite, and the absence of shearing in the Yauco Formation suggest that the serpentinite was emplaced by protrusion (Lockwood, 1971, p. 920) either as a single event or as a series of events spaced out over a long period of time. The steep dips shown in the Yauco could represent arching over the protruding serpentinite. The age of the serpentinite is unknown, and there exists no evidence to indicate the time of formation from its parent ultramafic rock. The maximum age of emplacement of the serpentinite is limited by the age of the Yauco Formation. Attitudes in the Yauco attest to the fact that final emplacement of the serpentinite at least postdated Yauco deposition in that area. The Yauco on Rio Viejo has been dated as Late Cretaceous (Mattson, 1960, pl. 1, pl. 6). Therefore the latest protrusive event is Late Cretaceous or younger.

AMPHIBOLITE

Amphibolite crops out only in the Peñones de Melones along the southern border of the quadrangle. It occurs in fault blocks and as fragments in a tectonic breccia supported in a serpentinite matrix. The amphibolite is weakly foliated to non-foliated and rarely shows compositional layering.

MARIQUITA CHERT AND CAJUL BASALT

The Mariquita Chert crops out in the Sierra Bermeja in the southeast corner of the quadrangle where it is in fault contact with the Cajul Volcanic Rocks described by Mattson (1973, p. 22) from an outcrop in Quebrada Cajul in the Cabo Rojo quadrangle. From exposures of these volcanic rocks in the Puerto Real, San Germán, Parguera, and Cabo Rojo quadrangles, it is evident that they are entirely basalt and that they are, in part, interbedded with the Mariquita Chert (Volckmann, 1984b). It is here proposed that the name Cajul Volcanic Rocks be redefined as Cajul Basalt in order to more accurately depict their nature and be adopted for use by the U.S. Geological Survey. The Mariquita Chert has been dated in the Sierra Bermeja, on the basis of identification of Radiolaria, as Tithonian to Aptian (Upper Jurassic to Lower Cretaceous) (Mattson and Pessagno, 1974; E. A. Pessagno, Jr., personal commun. 1978). Interbedding of the Cajul Basalt with the Mariquita indicates rough age equivalency although it is not known at what stratigraphic interval in the Mariquita the interbedding occurs.

UPPER CRETACEOUS ROCKS

YAUCO FORMATION

The Yauco Formation (Krushensky and Monroe, 1979) crops out in the northern part of the quadrangle and on Punta Guaniquilla north of Bahía de Boquerón. In the northernmost exposures, the Yauco is in (apparent) depositional contact with serpentinite, that contact having subsequently been disturbed by diapiric intrusion of the serpentinite. Near Cerro Conde Ávila, the Yauco is interbedded with volcanic rocks of the Sabana Grande Formation. Exposures on the southwest side of the Cordillera Sabana Alta and on Cerro Conde Ávila have been deeply saprolitized, but locally, unsaprolitized rock is exposed, notably in the small fault wedge immediately west of Cerro Conde Ávila. Also, at Cerro Conde Ávila the Yauco contains beds, 0.5 to 2.0 m thick, of reddish-orange or black chert.

Foraminifera from the Yauco where it overlies detrital serpentinite on Highway 2 in the San Germán quadrangle yield an age of Cenomanian (E. A. Pessagno, Jr., written commun. 1967). Yauco interbedded with the Sabana Grande Formation north of the Guanajibo Valley may range from Turonian to Campanian (Mattson, 1960, p. 332). In the vicinity of Cerro Conde Ávila the Yauco has been dated as Campanian to Maestrichtian (Mattson, 1960, pl. 4). Thus, the areal age range of the Yauco is Cenomanian to Maestrichtian; however, in the Puerto Real quadrangle it is restricted to Campanian to Maestrichtian.

SABANA GRANDE FORMATION

The Sabana Grande Formation, redefined by (Volckmann, 1984c, p. A78), is interbedded with the Yauco Formation in the northern part of the quadrangle and overlies the Cotuí Limestone in the central part of the quadrangle. The top of the Cotuí contains *Barrettia gigas,* a rudist which indicates the Campanian-Maestrichtian boundary (N. F. Sohl, personal commun. 1974). Also, limestones which occurs within the Sabana Grande Formation contain *B. gigas.* Mattson (1960, pl. 4) reports an age of Campanian to Maestrichtian in a conglomeratic(?) facies of the Sabana Grande west of Cerro Conde Ávila, and in that same area, Yauco Formation which is interbedded with the Sabana Grande has been dated as Campanian and Maestrichtian. North of the Guanajibo Valley the Sabana Grande may range from Turonian to Campanian (Mattson, 1960, p. 332). Thus, areally the Sabana Grande may range from Turonian to Maestrichtian, but that part of the formation exposed in the Puerto Real quadrangle is Campanian and Maestrichtian.

PARGUERA LIMESTONE

Thin-bedded volcaniclastic calcilutite and calcarentite, which occur in the Peñones de Melones along the southern border of the quadrangle, are tentatively correlated with the Parguera Limestone (Volckmann, 1984b). The portion of the Parguera here exposed was considered by Almy (1965) to consist of his Bahia Fosforescente and Punta Papayo Members. These members have been referred to collectively and informally as the lower member of the Parguera Limestone (Volckmann, 1984b). Dates obtained by E. A. Pessagno indicate the lower member has a possible age range of late Santonian to late Campanian and possibly early Maestrichtian (Almy, 1965, p. 131-150).

BOQUERON BASALT

The Boquerón Basalt was named (Volckmann, 1984c, p. A82) for exposures of dark-greenish-gray to very dark gray porphyritic lava north of the town of Boquerón. Although many outcrops show crude layering which may represent original stratification, the lack of pillow lava indicates that the basalt was deposited subaerially. In the area east of Cuatro Caminos, the Boquerón consists of basalt lava and tuff interbedded on a scale of several meters. North of the town of Boquerón, a line of thin (5 to 10 m thick) dark-gray massive bioclastic limestone lenses occurs at the top of the basalt. The limestone is overlain by coarse-grained, medium-bedded volcanic wacke composed of detritus of the same composition as the basalt. This volcanic wacke occurs consistently at the top of the Boquerón along strike and is locally as much as 150 m thick. The upper part of the volcanic wacke is locally interbedded with hornblende-rich volcanic wacke of the same mineralogical composition as the overlying Lajas Formation. Above the interbedded interval, the Lajas consists of subaerial lava flows and tuffs.

The limestone and volcanic wacke at the top of the lava flows in the Boquerón attest to a period of local submergence following deposition of the basalt. The interbedding of Boquerón- and Lajas-type volcanic wacke indicates simultaneous erosion of areas of Boquerón and Lajas volcanic rocks. Thus, Lajas volcanism apparently commenced during the period of erosion of the Boquerón, initially contributed sediment to the area of submergence, and, upon reemergence of that area, covered it with subaerial flows and tuffs.

The overlying Lajas Formation has been approximately dated as early Campanian or older. Inasmuch as diagnostic fossils have not been found in the limestone lenses at the top of the Boquerón Basalt, the Boquerón must also be dated as early Campanian or older.

LAJAS FORMATION

The Lajas Formation has been named, in the San Germán quadrangle (Volckmann, 1984c, p. A80), for amphibole-rich porphyritic lava and tuff that constitute the lower part of the San Germán formation of Mattson (1960, p. 340). The Lajas in the Puerto Real quadrangle overlies the Boquerón Basalt and underlies the Cotuí Limestone. Its thickness decreases rapidly toward the western part of the area where it pinches out locally between the Boquerón and the Cotuí. For example, the Lajas is absent 0.5 km west of Cerro Algodón; there the Cotuí Limestone lies directly on the Boquerón Basalt.

Coarse breccia occurs in the Lajas Formation in the approximate area from Highway 103 southwest for a distance of about 1.5 km. Clasts in the breccia are as much as 1.5 m in diameter, are typically rounded, mineralogically identical to lavas of the Lajas, and are enclosed in a primary igneous matrix. Matrix material is the same composition, is medium to coarse grained, and penetrates fractures in some clasts. The origin of this breccia is uncertain; however, it is suggested that the breccia was formed in a series of volcanic pipes or conduits by the process of "fluidization" (Reynolds, 1954).

The Lajas Formation can be dated only on the basis of the overlying Cotuí Limestone which locally contains, near its base, the rudist *Barrettia rusae. B. rusae,* according to N. F. Sohl (written commun., 1974), indicates a middle Campanian Age; thus the Lajas Formation is early Campanian or older.

COTUI LIMESTONE

The Cotuí Limestone, is sharply disconformable above the Lajas Formation in most places. Locally the contact is gradational, consisting of 3 to 10 m of stratified detrital material derived from the Lajas formation which becomes calcareous near the top and merges into a zone of limestone rubble 1 to 5 m in thickness. This rubble zone is overlain by the massive to thick-bedded limestone typical of the Cotuí. West of Cerro Algodón the rubble zone overlies the Boquerón Basalt indicating that the Lajas Formation was either completely eroded before deposition of the Cotuí or, may not have been deposited at all, perhaps being near the feather-edge of its westward extent.

The Cotuí contains several species of rudists, the most biostratigraphically significant of which are *Barrettia rusae* in the lower part of the formation and *Barrettia gigas* in the upper part. *B. gigas* is an indicator of the Campanian-Maestrichtian boundary. Additionally, from a locality in the lower part of the Cotuí, N. F. Sohl has tentatively identified the rudist *Pseudovaccinites,* a form which occurs with *B. rusae* in Jamaica (N. F. Sohl, written commun., 1974). Thus the Cotuí ranges from probable middle Campanian to Campanian and Maestrichtian in age.

MELONES LIMESTONE

The Melones Limestone was named by Mattson (1960, p. 335) for "dark argillaceous limestone with banded tuff or volcanic wacke" which occurs in the Peñones de Melones (Melones Hills) along the Cabo Rojo-Puerto Real quadrangle border. Mattson correlated the Melones with limestones which are interbedded with the El Rayo Formation near Lajas Arriba in the San Germán quadrangle. The Melones Limestone has since been redefined (Volckmann, 1984c, p. A81) to include only those exposures in the Peñones de Melones and to exclude the limestones within the El Rayo Formation.

A small area of the Melones Limestone occurs along the southern border of the Puerto Real quadrangle where it is in fault contact with the lower member of the Parguera Limestone on the west and the Mariquita Chert on the east. Mattson (1960, pl. 1) mapped the Melones exposures in the Puerto Real quadrangle as occupying the northern limb of a syncline overturned to the south. However, crossbeds in volcanic wacke exposed some 100 m to the south in the Cabo Rojo quadrangle (Volckmann, 1984b) show that the Melones is a right-side-up sequence dipping north.

Barrettia gigas occurs in the lower part of the massive phase of the Melones Limestone indicating that part is late Campanian to early Maestrichtian in age, and *Pseudocuculea* sp. in the shaly beds immediately below the massive limestone is compatible with that age. *Parastroma guitarti* and *Titanosarcolites* have been collected from the upper part of the massive limestone unit in the Cabo Rojo quadrangle. *P. guitarti* occurs in the upper range zone of *B. gigas* upward into the lower range zone of *Titanosarcolites.* Because *Titanosarcolites* occurs in the upper half of the Maestrichtian (N. F. Sohl, written commun., 1974), the upper part of the Melones Limestone is assumed to be middle Maestrichtian in age. The age range of the Melones is thus late Campanian to middle Maestrichtian.

OLIGOCENE AND MIOCENE ROCKS

Deposits of Tertiary gravel and limestone occur principally east and south of the town of Puerto Real and on both sides of the Lajas Valley. The deposits south of the valley are tentatively correlated with the Juana Díaz Formation and the Ponce Limestone (Oligocene and Miocene) because they are continuous with those formations along the south coast of Puerto Rico. The deposits near Puerto Real and on the north side of the Lajas Valley are tentatively correlated with the Guanajibo Formation, as suggested by Monroe (1973, p. 1092-1093). On the basis of microfossils, chiefly ostracodes and Foraminifera, the Guanajibo has been dated as Miocene in age (Gordon, 1961, p. 619).

TERTIARY(?) ROCKS

QUARTZ SAND DEPOSITS

Scattered throughout the Puerto Real quadrangle are several deposits of nearly pure quartz sand. The largest of these are in the northern part of the quadrangle at Conde Ávila and in the southern part at Las Arenas and Boquerón. Although surface exposures are crudely stratified probably by aeolian reworking, deeper (1 to 4 m below the surface) in most exposures the material is massive and consists of quartz grains in a matrix of iron oxide and a clay mineral. The megascopic textural appearance of some deeper exposures is suggestive of saprolitized fine-grained igneous rock in which all constituents have been weathered except the quartz. The vertical extent of these bodies is unknown; the deepest cut extends to a depth of about 4 m, and other rock types have not been observed below the quartz-rich material.

The origin of these quartz-rich bodies is unknown. They do not appear to share the same characteristics as "blanket sands" described by Briggs (1966) along the north coast of Puerto Rico. The blanket sands fill longitudinal depressions in limestone and have flat to rolling surfaces unlike these quartz-rich bodies, which are not restricted to depressions but which occur on the sides and tops of hills as well. Additionally, the blanket sands seem to be related to nearby streams that have eroded intrusive bodies of quartz diorite and granodiorite, whereas a major factor in the determination of the origin of the Puerto Real quartz-rich bodies is the lack of any known source for the large amount of quartz they contain. The silica in the Mariquita Chert can be ruled out because it is typically microcrystalline and not clear like the quartz grains in the deposits. No known intrusive igneous bodies are either large enough or near enough to have supplied the quartz, and the volcanic rocks of the area are essentially quartz-free.

Considering the lack of source and the curious topographic position of the quartz sands, it is suggested that the bodies may be deeply saprolitized quartz-rich intrusive rocks. The extreme angularity of quartz grains may be due to the weathering out of anhedral, interstitial quartz. The clay matrix, found in the lower parts of exposures may have resulted from the weathering of feldspar. The obvious drawback to this suggestion is the fact that no unweathered or even partly weathered rock specimen has yet been discovered which would answer the description of such an intrusive in the area mapped.

STRUCTURE

The major structural features are a set of northeast-trending high-angle faults which offset Upper Cretaceous rocks. Although fault planes are not well exposed, distribution of lithologic units indicates offset probably resulted from a combination of vertical and lateral displacement. In the northern part of the quadrangle, serpentinite has been emplaced against the Yauco Formation which dips steeply off both sides of the serpentinite mass. Contacts between the Yauco and the serpentinite are parallel to beds within the Yauco and probably represent depositional surfaces which have been disturbed by emplacement of the serpentinite. In a sense, the contacts are faults, in that the serpentinite has undoubtedly moved along them; in still another sense they are protrusive contacts if it is assumed that the serpentinite was diapirically intruded. A similar feature occurs at the western end of the Peñones de Melones where serpentinite has been emplaced against the Parguera Limestone.

A major high-angle fault truncates the western end of the Sierra Bermeja. The fault zone is as much as 60 m wide and nearly vertical and extends to the southwest into the Cabo Rojo quadrangle.

Brittle failure rather than folding has been the predominant response of the rocks of the Puerto Real quadrangle to tectonism. Most stratified units dip generally west, although in the Pedernales area rocks of the Lajas Formation, Cotuí Limestone, and San Germán Formation of Mitchell (1922) occur in two faulted, shallow synclines, which plunge gently north. Small, steep folds occur locally in the Mariquita Chert and the Yauco Formation. These are considered to represent penecontemporaneous slump folding because they occur within sequences of non-folded sediments.

HYDROTHERMAL ALTERATION

A zone of hydrothermal alteration occurs in the Lajas Formation in the area of Llanos Tuna. The rocks have been silicified, with the development of kaolinite, hematite, limonite, and locally, pyrite. Alteration occurred prior to the deposition of the Cotuí Limestone as the limestone and overlying Sabana Grande Formation are unaffected. Structural control of the alteration is unknown. It may be related to the emplacement of the Las Tunas stock, a small intrusive body located near the western border of the San Germán quadrangle (Volckmann, 1984a).

Zones of what appear to be the result of near-surface hydrothermal activity occur locally throughout the quadrangle. These zones are typified by abundant float blocks of yellowish-brown or yellowish-orange, commonly milky-appearing, porcellainoid silica. Some float blocks are as much as 2 m in diameter. Most blocks contain randomly oriented cavities which range from a few millimeters to several centimeters in size. These cavities are commonly lined with drusy quartz. Some blocks are internally brecciated, and the spaces between the breccia fragments are filled with silica. The silica blocks occur most commonly in association with Tertiary gravels; the most significant occurrence is on the wedge of gravel south of Puerto Real harbor. Because a local source for the silica blocks is lacking, because the large size of many blocks precludes deposition with the gravels, and because of the apparent physical differences, the blocks are interpreted as having been derived from *in situ* break-up of silica deposits formed by hot springs within the gravels. The silica blocks may have been concentrated as a lag deposit on the gravels, because the blocks are too large relative to the gravels to have been affected by erosion at the same rate.

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