UNITED STATES GEOLOGICAL SURVEY

PLAGIOCLASE AUGITE ANDESITE (MAESTRICHTIAN AND CAM-

PANIAN?) - Dark- to medium-bluish-gray, porphyritic augite ande-

site that weathers to very dark red or dark brownish red. Composed

of abundant plagioclase (labradorite to andesine) and conspicuous

sparse to common augite phenocrysts (to 1.5 cm long) in a generally

sparse groundmass of smaller plagioclase phenocrysts, plagioclase

STRATIGRAPHY

YAUCO FORMATION The Yauco Formation as here defined consists predominantly of siltstone and claystone. Rocks included in the formation were originally named the Río Yauco shale (Mitchell, 1922, p. 249) for "strongly bedded shale" exposed along the road (now Puerto Rico Routes 128 and 372) north of Yauco and along the Rio Yauco in the Yauco quadrangle. Hubbard (1923, p. 29) used the term Río Yauco Series to describe "predominantly shale often interbedded with ash and tuff, and with occasional andesite flows and intrusives." Mattson (1960, p. 331) redefined the Río Yauco Series as the Yauco Mudstone, a unit composed of "mudstone, minor tuff, and rare conglomerate." The lithic modifier is here dropped and the word formation substituted because the Yauco includes significant quantities of various rock types. In addition the type locality of the Yauco Mudstone (Mattson, 1967, p. 29) in the Yauco quadrangle includes volcanic breccia that we would include in another formation. The Yauco Formation consists predominately of volcaniclastic siltstone and claystone and quantitatively important but lesser amounts of mudstone and sandstone, sparse limestone, and rare conglomerate. Although the claystone appears chiefly epiclastic, the other clastic rocks contain variable amounts of pyroclastic debris. A few are composed almost completely of pyroclasts, but examination in thin section is generally necessary to establish the pyroclastic or epiclastic origin of the rock. The Yauco Formation as exposed in the type area of Mitchell (1922, p. 249) and in that of Mattson (1967, p. 20) is intruded by stocks, cut by numerous faults, and interbedded with volcanic breccia of the Maricao Basalt. Because these conditions are widespread in south-central Puerto Rico, the original type area of Mitchell (1922, p. 249) is probably as useful as any other available. It is clear that the conditions noted prevent any one area from adequately representing the Yauco. A number of reference locations are suggested.

Excellent exposures of the Yauco are present in Barrio Jaguas, Barrio Ceiba, and in the western part of Barrio Rucio in the Penuelas quadrangle. The sequence 350 m south of Corozal on the Quebrada Ceiba consists predominantly and characteristically of calcareous dark-blue-gray volcaniclastic siltstone and claystone that typically weather to a light- to mediumout in a small fault block 0.5 km east of Santas Pascuas on the northern yellowish-gray brown. The claystone invariably lacks the fissility character- border of the Penuelas quadrangle and extends into the Adjuntas quadistic of shale. In an interbedded claystone-siltstone sequence, the claystone weathers into negative relief and the siltstone into low ledges. The sequence here is about 750 m thick. Higher in the sequence in the same area the siltstone and claystone are interbedded with fine-grained tuffaceous sandstone that contains abundant angular plagioclase clasts. Farther north along the valley of the Quebrada Ceiba and apparently higher in the same section, the sequence includes increasing amounts of fine- to coarse-grained volcaniclastic sandstone of epiclastic origin and tuffaceous sandstone; beds are thicker (15 - 20 cm), rarely to 2 m thick, locally graded, and commonly crossbedded. Small-scale tabular and trough-shaped small-ripple bedding (Reineck and Singh, 1973, p. 87) is extremely common in the siltstone and somewhat less so in the sandstone facies of the Yauco. "Ripple bedding with numerous mud flasers" characteristic of flaser

bedding (Reineck and Singh, 1973, p. 98) is common in the Yauco in southcentral Puerto Rico; apparently similar structures have been reported widely in the upper part of the Pastillo Member. A Crassos (Mattson, 1960, p. 331) as common in the Yauco of southwestern and western Puerto Rico. Graded bedding, although less commonly seen, is widely present in the tuffaceous sandstone facies of the Yauco. The sequence exposed in roadcuts in the major ridge east of Jaguas consists chiefly of thin- to medium-bedded (1 – 30 cm) calcareous siltstone. thin- to medium-bedded fine-grained sandstone, and thinly laminated (<2 mm) claystone. In the southeast-trending large spur off the main ridge, eight or more soft sediment slump structures are exposed in a northise exposed in the core of a small anticline. Pastillo breccia is overlain by west-striking roadcut. The sequence dips to the south-southwest. In the roadcut the slumped rocks are separated from the nonslumped rock by high-angle faults. Apparent dip of the faults in the roadcut is to the south-

east, but true dip is to the southwest. Breccia, 15 - 20 cm thick, composed tuff and dark-red claystone. of subangular clasts of siltstone and claystone in a massive mudstone matrix lies along the traces of the fault planes. Traces of the high-angle faults extend for only a few meters in the roadcut before their angle decreases and they become décollement or bedding-plane faults. Typically beds in the heads of the slumps are dragged upward and beds in the nonslumped rock are dragged downward by slump movement. Subjacent to one slump, where the high-angle fault becomes a décollement, a 4-cm-thick bed of mudstone has been "plowed up" by the slumped beds and folded into a recumbent syncline, overturned to the south. Beds within the bases of the slump structures are also folded into hook structures or recumbent anticlines and overturned to the south. Movement indicates that the direction of the paleoslope was to the south-The sequence exposed in the fault block west of Salto Garzas Central Hydroelectrica No. 1 is a monotonous succession of deeply weathered

siltstone, claystone, and mudstone that becomes progressively more saprolitized toward the north. Outcrops in the Cordillera Central in the northwest corner of the quadrangle are so deeply saprolitized that fresh exposures are not available. The saprolitized Yauco Formation ranges from a pale-yellow to hematite-red or dark-orange clay. Study of thin sections indicates that rocks of the Yauco Formation are commonly tuffaceous, but uncommonly tuffs. Only the coarser grained sandstone can be identified consistently and correctly in the field as tuffaceous. The finer grained rocks consist largely of clay-sized particles, variable amounts of angular to subrounded clasts of fresh and weathred plagioclase and lithic materials, but rarely of fresh and angular augite. The claystone contains as much as 15 percent very fine grained fresh and angular plagioclase that is invisible in hand specimen. Claystone commonly has a minor tuffaceous component, but the lack of shard structures in the finer clasts suggests that it is chiefly epiclastic. Pumice has not been verse-graded bedding. identified in the Yauco either in the field or in thin section, and shard structures have not been seen in any thin section of the formation. Thin sections examined also included only rare to sparse microscopic Foramini-Coarser grained rocks of the Yauco may contain conspicuous pyro-

clastic plagioclase and augite, but they consist predominantly of subroundtalline volcanic lithic clasts in variable amounts of clayey matrix. Hand specimens of coarse-grained volcanic sandstone commonly appear to consist of fresh and angular plagioclase set in a dark-colored matrix. Thin sections of the same specimens, however, show that the matrix consists of caniclastic breccia of the Pastillo lithofacies. Mineral clasts are sparse to sparse clay matrix. The siltstone-sandstone beds rarely include rocks composed of 80 to 90 percent fresh angular plagioclase clasts and sparse whole plagioclase crystals in a clayey matrix. These relatively uncommon rocks

Limestone lenses are irregularly interbedded with the sandstone-siltstone facies of the Yauco. Lenses are commonly only a few meters thick and a few tens of meters long. Dark-gray argillaceous limestone crops out in the ridge north of Santo Domingo on the Yauco-Penuelas quadrangle of Santo Domingo Lack of graded bedding, the generally well-winnowed character of the matrix, the presence of large (to 15 cm long) plates of coralline algae, and the shallow-water fauna suggest that the limestone lenses in this area are not turbidites (Pessagno, 1962, p. 353; Slodowski, 1956, p. 77 - 78), but calcarenites deposited in place in shallow water. Similarly, the lack of graded bedding not related to emplacement of tuffs, the widespread presence of small-ripple bedding in most of the siltstone-sandstone facies, and the presence of features (Mattson, 1960, p. 332; Slodowski, 1958, p. 68, 70; Berkey, 1915, p. 21 - 22) now recognized as flaser bedding over wide areas in the claystone-mudstone facies of the Yauco, suggest that within the mapped area the formation is the product of deposition in shallow intertidal areas, probably in restricted basins similar to that west of Punta

The Yauco and Lago Garzas Formations are interbedded over wide areas, the nature of the contacts is discussed after the description of the Lago Garzas Formation Foraminifera of Late Cretaceous age (Mattson, 1960, p. 332, pl. 6; Slodowski, 1958, p. 71 - 76; Pessagno, 1962, p. 353, chart 4, p. 355) have been widely reported from the Yauco Formation, and suggest an early Campanian(?) to early Maestrichtian Age for the formation.

Ballena on the south coast of Puerto Ricco

LAGO GARZAS FORMATION The Lago Garzas Formation crops out over the northeastern third of ne Penuelas quadrangle, where it consists chiefly of volcaniclastic breccia, sandstone, tuff, claystone, mudstone lava, and limestone. The formation was named by Mattson (1967, p. 22) for outcrops in the Lago Garzas-Cerro El Gigante area in the southeast corner of the Adjuntas quadrangle, pordering the Penuelas quadrangle on the north. Mattson (1968) informally divided the formation into three members, a lower predominantly fine-grained epiclastic unit, a middle tuffaceous unit, and an upper unit of lava. Equivalents of the lower and middle units crop out widely in the Penuelas quadrangle where they interbed with each other and with the Yauco Formation. Pessagno (1960, p. 48) mapped this interbedded sequence as the Río Blanco Formation, but the lithofacies are those of the Yauco and Lago Garzas Formations, and are sufficiently different to map separately in most areas. Because of the inclusion of Cretaceous and Tertiary rocks of highly varied types, Mattson (1967, p. 23 - 25) has suggested that the name Río Blanco be abandoned in favor of names appropriate to specific areas. We agree, and the name is herein abandoned for use in Puerto Rico. The upper member of the Lago Garzas has not been separated and mapped in the Penuelas quadrangle even though Mattson 1968) mapped it as abutting the Adjuntas-Penuelas quadrangle boundary. Rock in continuous outcrop with the "upper member" as mapped in the Adjuntas quadrangle consists, predominantly of volcaniclastic breccia and only a few thin (5 - 10 cm) lava flows in the Penuelas quadrangle. The sequence is indistinguishable from equivalents of Mattson's lower member exposed in the Penuelas quadrangle.

PASTILLO MEMBER The lower member of Mattson (1968), here named the Pastillo Member of the Lago Garzas Formation consists chiefly of volcaniclastic breccia, sandstone, mudstone, claystone, and lesser amounts of lava and minor limestone. The Pastillo Member is named for the Río Pastillo; its type area is near the headwaters of that river The sequence in the type area near Marueño on the Río Pastillo consists of conspicuous dark-red epiclastic sandstone irregularly interbedded with dark-red and purple volcaniclastic breccia. Farther north on the ridge between the Río Pastillo and the Río Tallaboa, southwest of Haci-

enda Batiz, the same sandstone-breccia sequence is overlain by a massive pale-gray biosparite that contains abundant fragments of rudists, other mollusks, and large Foraminifera. Higher and apparently in the same sequence along the Rio Cañas in Barrio Guaraguao, the rock consists of dark-red and purple volcaniclastic breccia overlain by alternating thick beds (2.3 m) of hematite-red claystone and coarse-grained locally crossbedded tuffaceous sandstone. The lowest sandstone in the section contains, near its base, much admixed red claystone like that in the underlying claystone bed; upward in the sequence the claystone decreases, and the sandstone consists of a light- to medium-green tuffaceous sandstone. A second thick claystone bed overlies the tuffaceous green sandstone and is overlain by another 3 - 4 m thick bed of massive sandstone which grades upward into a massive (2 - 3 m) biosparite. Overlying beds of red sandstone and claystone are thinner (10 - 15 cm); and higher in the sequence they alternate with light- to medium-yellowish-gray-brown-weathering, thin-bedded to laminated siltstone and claystone similar to the Yauco lithofacies. The lowest massive claystone described is intensely sheared, and locally injected as clastic dikes into fractures in the overlying sandstone. Shear planes appear roughly concordant with the attitude of the enclosing beds and are apparently not related to any nearby high-angle faults. The limestone shows irregular and impersistent claystone and sandstone partings; it contains abundant large Foraminifera, angular fragments of Crassostrea sp., and rudists in a sparry matrix. Along the upper course of the Rio Tallaboa near Hacienda Esperanza in the fault block that includes the Cerrote de Peñuelas and in fault blocks to the southeast of Cerrote de Penuelas, the Pastillo Member consists characteristically of coarse-grained, dark-red, red-brown, purple, and darkgreen volcaniclastic breccia and a few thin (5 - 10 m) interbedded nonpillowed andesitic lava flows. The top of the Cerrote de Peñuelas consists of about 30 m of massive lava flows. Clasts in the breccia sequence are probably all andesitic; but they have different colors or shades of the same color and different textures, amounts, and kinds of phenocrysts. Commonly clasts are angular and as much as 25 cm across, rarely 40 cm across; most are dense, and contain phenocrysts of augite, plagioclase, and accessory magnetite; augite phenocrysts are commonly larger and generally more abundant. Some clasts contain only phenocrysts of augite. Only rarely do the clasts show flow foliation; the breccia matrices are never foliate, as in autoclastic lava flows, but rather detrital. Matrices of the breccias are poorly sorted mixtures of sand- to clay-size lithic clasts like the coarser breccia fragments. Shard structures are not present in the matrices. The larger clasts are often texturally and mineralogically like the enclosing lava flows, and are commonly isolated by the matrix. The breccias may have been emplaced subaerially as mudflows or the nearshore marine equivalent

ded with and overlain by dark-red and purple augite-bearing breccia of the Pastillo Member of the Lago Garzas. West of Rucio along the Rio Tallaboa, siltstone and sandstone of the Yauco are conformably overlain by 15 m thick beds of Lago Garzas breccia. About 400 m south of Rucio, outcrops in the road cut at the crest of the small ridge include thick (5.8 m) beds of coarse-grained light-greenish-gray hornblende-augite-plagioclasebearing tuffaceous sandstone interbedded with light-yellowish-gray-brownweathering thin-bedded siltstone and fine-grained sandstone, the latter is a typical lithofacies of the Yauco. The tuff sequence exposed there is typical of the Santas Pascuas Member of the Lago Garzas Formation. Dark-red volcaniclastic breccia, characteristic of the Pastillo Member, rops out in the same fault block to the north, stratigraphically above The fault block immediately east of the Cerrote de Penuelas includes the tuff sequence, and to the south, stratigraphically below the tuff seoutcrops of a distinctive Crassostrea-bearing limestone described in detail quence. It is apparent that a unique upper contact cannot be described for the Yauco Formation, but that the Yauco and the Santas Pascuas and below. This limestone characterizes the upper part of the Pastillo Member of the Lago Garzas Formation. The breccia sequence 0.4 km north Pastillo Members of the Lago Garzas are interbedded through an apparof Hacienda Esperanza includes distinctive light-green augite-hornblendeently thick vertical sequence and over a wide area. bearing tuffaceous sandstone interbeds similar to the Santas Pascuas Mem-Ongoing work of Krushensky and Monroe suggests that the pale-yellowber of the Lago Garzas. It is indicated by a special pattern, but not sepbrown and light-gray Cretaceous limestone southeast of Peñuelas and at arated in mapping of the Pastillo Member. The Crassostrea-bearing lime-Hacienda Oliva on the western border of the Penuelas quadrangle correstone also crops out over wide areas in the fault blocks north of Hacienda late in lithology and in time with the Parguera Limestone. Batiz in the north and western parts of Barrio Guaraquao. The southern half of the Penuelas quadrangle and the Punta Cuchara A massive limestone (20+ m thick) composed predominantly of Crasquadrangle are underlain by sedimentary rocks of Oligocene to Holocene sostrea sp., minor quantities of turriculate but otherwise unidentified age (Monroe, 1973) which rest with angular unconformity on epiclasticgastropods, and a subordinate very argillaceous dark-gray matrix, crops volcaniclastic rocks of Cretaceous age, and probably (Krushensky and Monroe, 1975) on lower Tertiary rocks. rangle. It is not separated on the map. This rock was mapped by Mattson

monly, as in the northeast corner of the quadrangle, thick sequences of

the Yauco contain major quantities of the Lago Garzas interbedded

Lajas valley are also intrusive (Volckmann, oral commun., 1975).

Yauco, direction of movement indicated by slump structures in the

contact of the Yauco is not exposed in the Penuelas quadrangle.

JUANA DÍAZ FORMATION (1968a) and described by him (1967, p. 9) as Robles Formation in the The Juana Díaz Formation, formally named by Maury (1929) for ex-Adjuntas quadrangle. Examination of outcrops along the Río Cañas and posures in the Juana Díaz area (Ponce and Río Descalabrado quadrangles) and later revised by Monroe (1973 p. 1092 - 1093) consists of lenticular along roadcuts west and southwest of Guaraguao in the Adjuntas and Penuelas quadrangles indicates, however, that the Crassostrea-bearing and intertonguing beds of conglomerate, sandstone, mudstone, limestone, limestone is in fault contact with adjacent rock. A few meters east of and chalk. The base of the unit in the eastern part of the quadrangle con-Río Canas-Guaraguao road intersection, southwest-dipping Crassostreasists chiefly of interlensing conglomerate and mudstone and contains a bearing limestone is in vertical contact with northeast-dipping dark-bluefew thin lenses of coralline limestone and abundant specimens of the large gray siltstone-mudstone described by Mattson (1968) as the Robles Forforaminifer Lepidocyclina undosa and the echinoid Clypeaster oxybaphon. mation. Farther west on the same road, and a few tens of meters before The lower member ranges in age from the early Oligocene (Moussa and the road rises to the ridge crest, is a second vertical contact between a Seiglie, 1970, p. 1891 – 1892) to early Miocene. It is overlain by chalk northeast-dipping vivid-green tuff-breccia-sandstone-lava sequence and the and limestone of early Miocene age. The uppermost part of the unit is a Crassostrea-bearing limestone. The contacts are faults; and both can be lenticular deposit of crossbedded sand, gravel, carbonaceous clay, and caltraced into the valley of the Río Cañas in the Adjuntas quadrangle. The stone, apparently the same as that in the Pastillo Member, has been rewater, but the presence of crossbedded sand and gravel and carbonaceous ported by Glover (1971, p. 52) 1.9 and 2.3 km east of Juana Diaz from clay in a channel suggest even more strongly that the unit was deposited the so-called "Mirimar Formation," a slickenside-riddled fault breccia near shore in shallow water. Moussa and Seiglie (1970) consider this up-(Krushensky and Monroe, 1975) per member the basal unit of the overlying Ponce Limestone. Contact of the Pastillo and the overlying Santas Pascuas Member is In the central part of the quadrangle, a tongue of coralline limestone seen about 1.5 km southeast of the village of Santas Pascuas. There the divides the lower conglomerate-mudstone sequence into two tongues, and characteristically dark-red and purple volcaniclastic breccia of the Pastillo west of the Río Tallaboa the sequence consists of a basal member of gravel and mudstone overlain by coralline limestone which, in turn, is overlain a 3 - 4 m thick unit of Crassostrea-bearing limestone which is, in turn, by chalk. A 10-m-thick lens of gravel and cobbles occurs within the coraloverlain by a sequence of interbedded dark-red epiclastic volcanic sandline limestone 6 km west of the plaza in Penuelas. The chalk west of the Río Tallaboa, 800 m north of Puerto Rico Route 2, is overlain by a brown sandy calcareous clay containing many oysters; it grades downward into

(1970) to contain planktonic foraminifers similar to those in the upper sand SANTAS PASCUAS MEMBER and gravel member in the eastern part of the quadrangle. Rock equivalent to the middle member (Mattson, 1968a) of the Lago The Juana Díaz Formation is overlain disconformably by the Ponce Garzas Formation, here named the Santas Pascuas Member, consists pre-Limestone, a pale-yellowish-orange to dark-yellowish-orange, compact, dominantly of light- to medium-green pumiceous lapilli tuff, pumiceousindurated, and very fossiliferous limestone. lithic lapilli tuff, dark-greenish-brown vitric and vitric-crystal tuff, medium-Limestone units in the Juana Díaz and the Ponce Limestone are comgreen porphyritic lava, and minor limestone. It is named for the village monly overlain by a mantle of secondary chalk or caliche, a meter or more of Santas Pascuas which lies on the northern border of the Penuelas quadthick. The caliche is generally banded white and light-brown, and at most rangle. The type area extends from the first east-flowing unnamed tribuplaces the uppermost 10 - 30 cm is slightly indurated. Although the calitary on the Rio Cañas 1.3 km north of Hacienda Batiz to the village of che is mostly soft chalk, it contains sparse small blocks of the underlying Santas Pascuas. The member also crops out in the fault block adjoining limestone and scattered grains of quartz. It so effectively blankets the the type area on the southwest, in two fault blocks and 0.58 km west of limestone units that outcrops of limestone bedrock are scarce except in Puerto Rico Route 10 on the northern border of the quadrangle, and in stream channels and in roadcuts. No fossils indigenous to the caliche have a fault block 0.5 km northeast of Hacienda Batiz. The Santas Pascuas been found, but its stratigraphic position suggests that it is of Holocene Member is also extensively interbedded with the upper part of the Pastillo age. It is not shown as a separate unit on the map. Member in fault blocks that lie east and west of the fault block that in-River valleys that cross the quadrangle contain thick masses of alluvial cludes the Cerrote de Peñuelas, in the fault block west of Hacienda Batiz, cobbles, sand, and pebbles, similar material is locally present as terrace and in three fault blocks in the extreme northeast corner of the quaddeposits as much as 10 m above the stream channels. rangle. These interbeds are indicated, but not separated in mapping. The lower part of the Santas Pascuas Member, in the type area, contains dark- to medium-green coarse-grained thin- to very thin-bedded Five varieties of intrusive rock have been separated in mapping the (10 - 1 cm) vitric tuff irregularly interbedded with subordinate medium Penuelas quadrangle. Of these, four, all probably Tertiary in age, are minbedded (10 - 30 cm) dark-red volcanic siltstone and mudstone, and with eralogically and chemically similar; but they differ in color, texture, the rare dark-red thick (1+ m) beds of fine-pebble conglomerate of the Pastillo presence or absence of augite, and the degree of alteration. They are all

dacite-diorite-quartz diorite and comagmatic. The fifth rock type is an Member. Coarse-grained vitric tuff predominates in the upper part. The Pastillo lithofacies is absent, and the sequence includes some light-green andesite of Cretaceous age. medium- to thin-bedded (30 - 10 cm) pumiceous lapilli tuff. The vitric tuff is locally crossbedded, and the pumiceous tuff commonly shows repart of the quadrangle and locally elsewhere. Two texturally different rock types are recognized. One, an augite andesite which is present only About 0.9 km east of Santas Pascuas on the Guaraguao-Santas Pascuas in a single fault block in the northwest corner of the quadrangle, consists road the vitric-pumiceous tuff sequence includes a very fine crystalline of conspicuous (to 1.5 cm long) augite phenocrysts in an abundant dense medium- to dark-green porphyritic lava. The glassy and apparently dacitic dark-blue-gray matrix composed of plagioclase microlites and glass. The lava contains conspicuous plagioclase, augite, and rarely hornblende phenosecond, an augite andesite, consists of abundant (40 - 60 percent) plagiocrysts as much as 5 mm long, in an abundant matrix composed of plagioclase and sparse to common coarse augite phenocrysts and relatively abundant (40 - 60 percent) plagioclase and sparse to common coarse augite ed to subangular weathered plagioclase and weathered extremely fine cryssection, but flow foliation is not apparent in the outcrop or hand specimen. phenocrysts and relatively abundant well-crystallized accessory magnetite In the immediate area of Santas Pascuas, the sequence consists largely in a dark-red or purple matrix. This latter rock is mineralogically and of laminated to thin-bedded (0.3 - 10 cm) very fine grained (<0.5 mm) chemically similar to extrusive and volcaniclastic rocks in the Pastillo Memdark-greenish-brown vitric tuff and some coarse interbeds of dark-red volber of the Lago Garzas and to larger clasts of plagioclase-augite andesite that forms major parts of the Coamo and Maravillas Formations, and the well-sorted, dark-colored, and weathered lithic clasts in a similarly colored common and consist chiefly of plagioclase, augite, and hornblende. The fault gouge called the "Miramar Member" by Pessagno (1960, p. 71), and matrix is devitrified; lithic clasts are very rare. The Santas Pascuas sequence contains reverse-graded pumiceous lapilli (1971, p. 51 - 52) in the Ponce and Río Descalabrado quadrangles to the east. The augite-plagioclase andesite intrusive rocks are probably comagtuff and silificified vitric tuff in the fault block 0.5 km northeast of Hacienda Batiz. Platy clastic tube-type pumice is abundant in the lapilli matic with the volcanic rocks of those units. Extrusive correlatives of the

tuff; the matrix, composed chiefly of glass shards, is sparse. Platy surfaces augite andesite are not known in the Penuelas quadrangle nor in areas to the east, but work in progress by Krushensky and Monroe indicates that of the pumice clasts commonly parallel the direction of tube elongation and bedding. Uncommonly some platy clasts lie at high angles to the bedextrusive and coarse volcanic clasts in the Marico Basalt in the central part ding direction. Those pumice clasts which lie parallel to bedding show of the Yauco quadrangle are petrographically and mineralogically identical boundary. The unit has been separated in mapping, but it has not been given moderate to slight compaction and molding around nearby mineral clasts with rocks of this intrusive a formal member name. It may be conveniently referred to as the limestone held in the matrix; those in which the tubes lie at high angles to bedding The greatest concentration of larger Tertiary and Cretaceous intrusive show little or no compaction rocks is in the east-central part of the quadrangle. Generally smaller stocks Reverse grading, good sorting, the general absence of lithic clasts, the of Tertiary and Cretaceous age also crop out in the central and western relative rarity of shards, and the discordance of pumice clasts with bedding parts of the Penuelas quadrangle, but there they are more widely separated. Except for the diorite-quartz diorite, Pessagno (1960) included all the indicate that the pumiceous lapilli tuff is not a welded ash-flow tuff, but an aqueous tuff, probably marine. Bubble- and tube-type pumice were rocks here mapped as stocks, as lava flows of the Rio Blanco Formation. sorted from each other and partly from shards and lithic-mineral clasts The rock mapped as aphyric dacite is predominately very fine crystalat the water surface; foliation developed as a result of sediment-rock load line. Rarely the aphyric dacite contains plagioclase phenocrysts. Characduring diagenesis. The rocks are similar to those described by Fiske (1969). teristically it contains abundant small (2 - 4 mm) round calcite amygdules. Locally in the interior of the stock 0.7 km north of Ponce, the aphyric The presence of only tube-type pumice in reverse-graded beds suggests that the tube-type pumice sinks more rapidly than bubble-type pumice dacite grades into a coarse-crystalline plagioclase-augite porphyry. The at about the same rate as the matrix shards and mineral clasts in the same coarse-crystalline facies is too restricted areally to map separately in the eruption. Reverse grading also suggests that a single graded bed should Penuelas quadrangle; the relationship of the two textural facies and the become progressively enriched in shards and mineral-lithic clasts toward country rock is well exposed in the Cerro El Gato area and in the ridge the eruptive source, as the pumice is diluted in a larger quantity of non-0.8 km east of that peak in the Ponce quadrangle. Both rock-types are floating relatively dense clasts. It was impossible to prove this thesis in the intersertal, but the aphyric dacite consists of 85 - 90 percent plagioclase Santas Pascuas area as outcropping rocks are widely separated by areas of microlites suspended in a chloritized glass, whereas the porphyry consists

mapped (Mattson, 1968a) and described (Mattson, 1967, p. 9) as Robles

Formation in the Adjuntas quadrangle. Although the area mapped as

Robles Formation in the southwest quarter of the Adjuntas quadrangle

generally replaced by green chlorite (celadonite). As welded ash-flow tuffs

the Santas Pascuas is indicated by these probably cognate lithic clasts.

Dark-red to purple and dark- to light-green volcaniclastic sandstone

breccia and pumiceous tuff characteristic respectively of the Pastillo and

Santas Pascuas Members of the Lago Garzas are widely interbedded with

the Yauco in the Penuelas quadrangle. Where these beds make up con-

are known to have been deposited only in a subaerial environment (Rankin,

1960), emergence of the land during and probably preceding deposition of

has not been extensively checked (by R. D. Krushensky) that part west in the Penuelas quadrangle, the relationship is best seen in the El Gato area of the Ponce quadrangle where the Yauco overlies the intrusive, is silicified of Guaraguao is lithologically identical and apparently equivalent to the to 40 cm, and baked to as much as 4 m beyond the contact. Foraminifera Santas Pascuas Member of the Lago Garzas Formation. Much of the remaining "Robles" in the southwest part of the Adjuntas quadrangle has are recrystallized, but detrital lithic clasts and pyroclasts of plagioclase been metamorphosed to hornfels by the intrusion of stocks of Tertiary appear little affected. Clearly the aphyric dacite is a chilled contact facies age, and the original rock type is obscure. The rock is deeply saprolitized of the coarse-crystalline porphyry, and not a sequence of lava flows. over wide areas, except locally in cores of joint blocks. Exposures in road Hornblende dacite crops out in one large and four small stocks in the cuts between Santas Pascuas and Guaraguao in the Adjunats quadrangle fault block north of Jaguas, in the western part of the Penuelas quadrangle. It is distinguished from the hornblende-augite dacite only by the absence indicate that vertical changes in the sedimentary sequence are abrupt and closely spaced as in the Santas Pascuas type area. The sequence along the of augite. Deeply embayed and resorbed quartz phenocrysts are present road consists of pale-yellowish- or bluish-green coarse-grained vitric tuff, in the major part of the stocks, but quartz is absent in the chilled contact zones. The absence of quartz there suggests that the mineral is phenocryspumiceous lapilli tuff, vitric-crystal tuff, and a pumiceous-lithic lapilli tuff. A dark- to medium-green porphyritic lava crops out 1.22 km east of Santas tic rather than xenocrystic. Pascuas on the Guaraguao-Santas Pascuas road. It is identical to the lava Hornblende-augite dacite and diorite-quartz diorite stocks differ chiefly exposed 1 km east of Santas Pascuas in the type area of the Santas Pascuas in texture. Mineralogically both contain abundant plagioclase, hornblende, Member. Pumiceous-lapilli tuff exposed in the larger fault block near the and augite as well as sparse quartz and accessory sphene and magnetite. Pastillo-Santas Pascuas contact about 1.4 km east of Santas Pascuas is iden-The granitic-textured rock also contains biotite. Augite in both rock types is commonly jacketed with hornblende, and only very rarely occurs as tical to that exposed near the base of the Santas Pascuas Member in the type area, and in the fault block northeast of Hacienda Batiz. The sequence discrete crystals. The diorite-quartz diorite has a porphyritic appearance in the fault block 0.3 km east of Santas Pascuas also includes reverse-graded as the mafic minerals and magnetite form aggregates. The dacite-diorite quartz diorite stocks in the Penuelas quadrangle are pumiceous-lithic lapilli tuff beds which contain clasts of welded ash-flow tuff with moderate to extreme flattening and molding of shards around considered Eocene in age because mineralogically and chemically similar included mineral clasts. Commonly the densely welded clasts show wellstocks in the Ponce quadrangle (Krushensky and Monroe, 1975) intrude rocks of Eocene age, and because no extrusive or detrital rocks of a similar developed perlitic structure. Clasts of lava like those described above are also present in small amount. These lithic clasts are concentrated near type thus far have been found in the Cretaceous sequence. Although the granitic rocks have no extrusive equivalent in the immediate area, the hornthe base of a single bed, and tabular wispy clasts of compacted pumice are concentrated in the upper part of the bed. As in the other pumiceous-Formation of Eocene age (Krushensky and Monroe, 1975). lapilli tuff beds present in the Santas Pascuas, pumice is devitrified and

Rock in two fault blocks 3 and 6 km west of Puerto Rico Route 10 on augite suspended in a microlite-rich glass. Neither the aphyric dacite nor

STRUCTURE A major southwestern Puerto Rico fault zone, chiefly a zone of wrench faults, crosses the quadrangle northwest-southeast and slices the area into spicuous but subordinate parts of the stratigraphic sequence, they are indiacted by pattern, but not separated in mapping of the Yauco. Uncomcross faults. Major fold structures do not cross the fault zone within the

are not known to intrude rocks of Tertiary age.

The augite andesite and plagioclase-augite andesite stocks are considered

canic rocks in bedded units that contain extensive Cretaceous faunas. They

Andesite stocks of Cretaceous age crop out chiefly in the east-central

Miramar Formation" by Glover and Mattson (1967, p. 33) and by Glover

of about 80 percent coarse (3 - 8 mm) phenocrysts of plagioclase and

the porphyry show flow foliation in outcrop or hand specimens, and thin

Although the contact of the aphyric dacite and Yauco is exposed locally

sections of both rock types show only randomly oriented microlites or

strike of the fault zone and individually discontinuous. Structure is simithroughout. These are mapped as interbedded Lago Garzas and Yauco. lar to that present in the Ponce quadrangle (Krushensky and Monroe, 1975) Slodowski (1956, p. 63) has described the lower contact of the Yauco and the east-central part of the Rio Descalabrado quadrangle of (Glover as disconformably(?) overlying the "Río Loco Formation." He named and Mattson, 1975) to the east. Although the Yauco and Lago Garzas the "Río Loco" (1958, p. 53); characterized it as composed of hypersthene Formations crop out across the quadrangle, the direction of relative movebasalt flows and crystal and vitric tuffs; and suggested that the contact of ment on faults is generally unknown. These formations interbed through the Yauco and pillowed "Rio Loco" was well exposed on the east side of a thick sequence over wide areas, and generally they are internally undisthe hill on which the town of Yauco was built. However, moderate to steep south-southwest dips in the Yauco both north and south of the body Some long, persistent, high-angle faults in the southwestern Puerto Rico of hypersthene porphyry exposed there, together with truncation of the fault zone are assumed to be wrench faults, probably with left-lateral dis-Yauco by at least 10 small stocks of identical hypersthene porphyry inplacement; others are probably simple normal faults. Proof of the direccluding that cited by Slodowski, strongly suggests that the so-called "Rio tion and extent of movement is commonly lacking or unconvincing. The Loco" basalt flows are, in at least that area, intrusive. In addition nonextensive width of shearing (to 80 m) in the northwest end of the fault pillowed "Río Loco basalt flows" mapped by Almay (1969) south of the block between the Lago Garzas and Bartolomei faults and zones (to 5 m) of crushed and sheared rock along the faults farther to the southeast sug-Slodowski (1958, p. 63) suggested that the sea in which the Yauco was gest wrenching on those faults. Left-lateral movement on the Bartolomei deposited transgressed from the northeast to the southwest. The direcfault is supported by the presence of a small overturned syncline southtion of currents indicated by ubiquitous small-ripple bedding the the west of the Bartolomei fault. S-shaped quartz-filled fractures, present in in the Monserrate Formation in the Ponce quadrangle (Krushensky and Penuelas and Ponce (Krushensky and Monroe, 1975) quadrangles, the Monroe, 1975), adjacent to faults that extend into the Penuelas quadrangle, progressive reduction of coarse-grained epiclastic and volcaniclastic sedialso suggest left-lateral wrenching in the Penuelas quadrangle. Glover nentary rocks toward the south southwest and the increase in these rock (1971, p. 85 – 86), Glover and Mattson (1967, p. 363 – 364; and 1973), types as well as the increase in reefoid limestone toward the north-northand McIntyre (1976) have illustrated left-lateral wrenching in widely sepeast suggest that the reverse is true, that is, that the sea depositing the arated areas in the southwestern Puerto Rico fault zone. Mattson (1968) Yauco was transgressive southwest to northeast. The lower stratigraphic also reports widespread left-lateral shears in central and southwestern Puerto Rico. Vertical movement, especially in those fault blocks contain-Contacts between the Yauco and Lago Garzas appear parallel and thus ing lithologically distinctive beds, is apparent on many of the northwestconformable everywhere exposed. Outcrops on the west-trending unrending faults; but the presence and magnitude of vertical movement in named tributary of the Río Pastillo 2.7 km north of Marueño are typical those fault blocks lacking such beds is problematic. of the contact zone. There, light-yellowish-gray-brown-weathering silt-The age of wrenching is unknown. Glover (1971, p. 84) suggests that stone and fine-grained sandstone of the Yauco are conformably interbedit may have begun in the Cretaceous, but the evidence cited is ambiguous or inappropriate (Krushensky and Monroe, 1975). McIntyre (1976) suggests that wrenching in the Maricao area ceased before deposition of the San Sebastian Formation of middle to late Oligocene age. However, extension of the Lago Garzas and Bartolomei faults south and along the alluvium-floored valley of the Rio Cañas suggests wrenching of the upper part of the Juana Diaz Formation. In that area wrenching was probably of early Miocene age. Although the presence of faults beneath the alluvium in the valley of the Rio Canas is unproven, the absence of the San Marcos fault west of the Rio Cañas valley suggests that extension of the Lago Garzas and Bartolomei faults to the south is valid. METAMORPHIC ROCKS

mapped area, rather fold axes are commonly parallel or subparallel to the

Calcareous Yauco sandstone in contact with the hornblende-augite stock s metamorphosed to a fine-crystalline marble that contains scattered blebs of hydrogrossularite and apparently unaffected original detrital lithic and plagioclase clasts. In contrast, calcareous sandstone and arenaceous and gillaceous limestone of the Pastillo Member of the Lago Garzas in the ault block west of the diorite-quartz diorite stock has been metamorphosed to a calc-silicate hornfels of the amphibolite facies. The centraleastern part of the fault block consists of diopsidic augite in a matrix of plagioclase and quartz. More calcareous rocks in the northern part of the same fault block were metamorphosed to a coarse-crystalline marble with abundant vesuvianite, hydrogrossularite, pistacite, and quartz. Locally, along the Río Portugués in the same fault block, and near the small stock of hornblende dacite 1 km to the northeast, the rock is a skarn containing pods of coarse-crystalline magnetite-pistacite-quartz as much as 3 m long. Skarn formation and amphibolite-grade metamorphism around the small fornblende-dacite stock suggest that a larger intrusive body may be present at depth. Roadcuts northeast of the gaging station on the Rio Portugués expose a biotite-rich calc-silicate hornfels developed in the matrix of a pebble conglomerate of the Pastillo Member. The volcanic pebbles appear structurally unaltered and mineralogically only slightly altered by the

ECONOMIC GEOLOGY Copper in the form of lumps and veins of malachite, azurite, native copper, and cuprite occurs sparingly but in many locations in the plagioclase-augite andesite stock between the Marueno, Portugués, Reconciliación faults in the central part of the quadrangle. Mineralization, where careous clay that apparently fills a channel eroded in the underlying chalky observed, is in or near fault or shear zones. A ridge and spur geochemical limestone. An abundance of planktonic foraminifers have led Moussa and soil survey was run by R. D. Krushensky to test the presence of copper, the stocks sampled by Learned and Boissen (1973) in the Piedra Hueca and Cala Abajo areas of the Río Vivi district, soils on the plagioclase-augite- andesite stock are poorly developed; the A, B, and C horizons are compressed into a thin layer. Samples collected consisted chiefly of grus of the C horizon. Samples were analyzed for 30 elements by semiquantitative spectrographic methods of Grimes and Marranzino (1968). Copper, silver, lead, and zinc were determined by atomic absorption methods of Ward and others (1969), and gold was determined by atomic absorption methods developed by Thompson, Nakagawa, and Van Sickle (1968). Analyses indicate that: (1) gold in even the most copper-rich samples is less than 0.02 ppm, the limit of detection of the method, and (2) that copper varrubbly light-gray limestone. This outcrop is reported by Moussa and Seiglie ies from as much as 65,000 ppm in one specimen from a fault zone to an average of 119 ppm for specimens collected in areas other than faults. The analyses suggest that mineralization is fault controlled and not disseminated, and that the deposit is of no economic interest. A vein which consists of coarsely crystallized calcite, galena, sphalerite, and chalcopyrite lies within the zone of the Machuelo fault where that fault crosses the Río Cañas a few meters south of Coral Veijo. The vein is about 40 cm wide and appears to extend along the fault no more than a few meters. A composite sample taken across the vein was analyzed by the methods noted above. Results follow:

The Puerto Rico Cement Company extracts the chalky limestone and the upper clastic beds of the Juana Diaz from a quarry on Route 10 within the Ponce city limits, between Ponce and the Magueyes Urbano. Similar material is widely available in the southern half of the Penuelas quadrangle and in the Punta Cuchara quadrangle.

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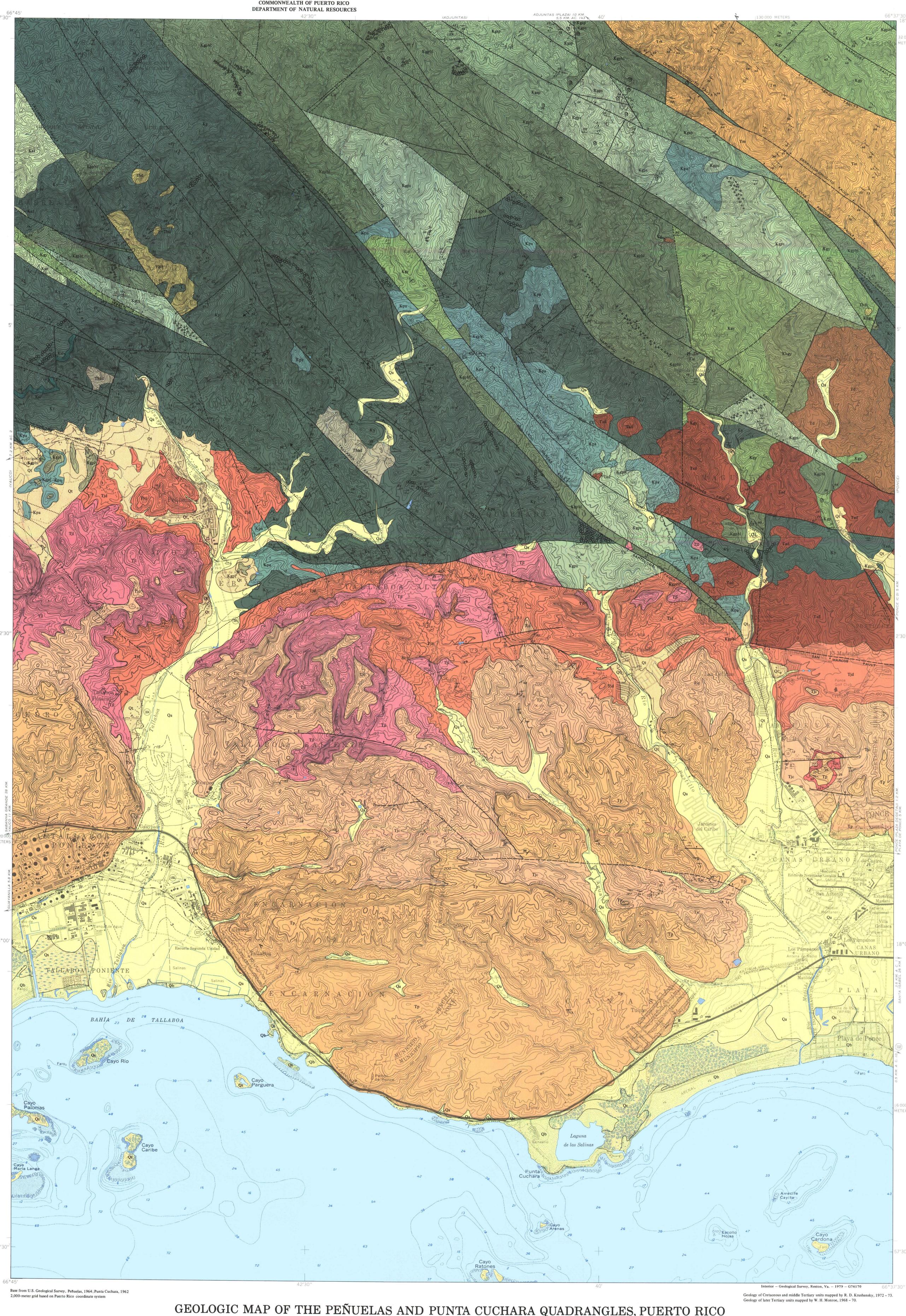
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**CORRELATION OF MAP UNITS** 

DESCRIPTION OF MAP UNITS

SWAMP DEPOSITS (HOLOCENE) - Largely mangrove swamps, a mixture of sand, clay, and carbonaceous debris from mangrove BEACH DEPOSITS (HOLOCENE) - Sand, locally containing cobbles, commonly crossbedded ALLUVIUM (HOLOCENE) - Cobbles, pebbles, sand, clay, and sandy clay. Thickness variable, but probably as much as 50 m in the area southwest of Ponce and in the southern part of the Rio

TERRACE DEPOSITS (HOLOCENE AND PLEISTOCENE?) – Like alluvium above; includes some alluvial fan deposits of similar composition along the Río Tallaboa LANDSLIDE DEPOSITS (HOLOCENE) - Unsorted and nonbedded rubble of angular limestone fragments, sand, and clay; derived chiefly from the Ponce Limestone and Juana Diaz Formation PONCE LIMESTONE (MIOCENE) — Very pale orange to grayishorange generally crystalline calcarenite. Contains abundant internal molds of fossils, especially mollusks and solitary corals; also contains shells of the echinoid Clypeaster cubensis, oysters, and the tests of Foraminifera such as Marginopora sp. and Gypsina sp. Thickness is more than 200 m and may be as much

as 850 m near the southwest corner of the Penuelas quadrangle UANA DIAZ FORMATION (MIOCENE AND OLIGOCENE) UPPER CLASTIC BEDS - Gray to light-brown, fine- to coarsegrained sand; conglomerate of angular fragments of limestone, calcite, and sandstone in a matrix of medium-grained sand; and carbonaceous sandy clay. Oysters are present in the lower part, and some beds contain abundant planktonic Foraminifera (Moussa and Seiglie, 1970). Brown sandy clay (4 m thick) of the same age on the west side of the Rio Tallaboa is mapped with the rlying member. These upper clastic beds are a channel-f deposit that has a maximum thickness of 46 m and pinches out at sides of the old channel CHALK MEMBER - White to very pale orange clayey chalk and bedded chalky limestone; contains many small Foraminifera; ranges in thickness from about 50 m in the western part of the quadrangle, where it overlies a reef limestone, to about 300 m

sandy mudstone as much as 10 m thick; intertongues toward the east with typical sandy mudstone and basal conglomerate member. In addition to reef-building corals, it contains Lepidocyclina undosa and Clypeaster oxybaphon. Small lenses of similar limestone are present within the mudstone-conglomerate member in the eastern part of the quadrangle. Thickness ranges from 0 to about 400 m. MUDSTONE AND BASAL CONGLOMERATE MEMBER - Grayish-orange weathering, light blue gray where least weathered; calcareous, silty to sandy, slightly carbonaceous clay interbedded with calcareous sandstone; at many places basal beds consist of sandy clay, sand, and sandy gravel, commonly with cobbles of volcanic and intrusive rock. Fossils abundant in scattered lenses,

LIMESTONE MEMBER - White to grayish-orange limestone,

mostly crystalline and coralline; contains lenses of cobbles and

especially Clypeaster oxybaphon, 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 HORNBLENDE DACITE (EOCENE) — Medium- to light-greenishgray or yellowish-gray-green porphyritic dacite. Sparse to common phenocrysts of hornblende, subordinate smaller phenocrysts of plagioclase (oligoclase to andesine), and corroded phenocrysts of quartz are suspended in an abundant microgranitic groundmass of anhedral plagioclase, quartz, and chloritized glass. Hornblende is commonly completely replaced by chlorite and epidote; plagioclase is thoroughly albitized and locally replaced by calcite, chlorite (penninite and an unidentified yellow-green chlorite), and epidote. Locally near intrusive contacts, chilled border facies contain smaller phenocrysts of hornblende and plagioclase suspended in an abundant glassy matrix, but quartz is absent. Com-

monly dacite in the stock (at 121,045 - 28,600) is so completely

saussuritized that only vague outlines of the original minerals are HORNBLENDE-AUGITE DACITE (EOCENE) - Medium-gray to light-yellowish-gray-green porphyritic dacite with abundant hornblende and subordinate augite, plagioclase (oligoclase-andesine), and corroded quartz phenocrysts in a microgranitic groundmass of oligoclase, hornblende, and sparse quartz. Hornblende occurs as irregular rims around corroded augite and as well-formed twinned prisms as long as 4 cm. It is commonly replaced by chlorite and epidote. Augite occurs only as corroded masses rimmed with hornblende or actinolite; it is commonly replaced by chlorite and epidote. Plagioclase is thoroughly albitized, and partly replaced by calcite, chlorite, and epidote. Sphene is a sparse accessory

APHYRIC TO SPARSELY PORPHYRITIC DACITE (EOCENE) ommonly aphyric abundantly amygdaloidal, generally deeply weathered medium-gray-green dacite. Microlites of plagioclase are enveloped in an abundant crystallized glass that is partly replaced by chlorite. Both microlites and glass are also locally replaced by calcite. Sparse phenocrysts of plagioclase (andesine to labradorite) or very rarely of augite are largely replaced by calcite, chlorite, and epidote. Amygdules are round and composed of calcite or chalcedony. Microlites are unoriented, and flowfoliation, alinement of phenocrysts, or elongation of vesicles or amygdules is not present. Microlites in one small stock (127, 645 - 26,265) have a conspicuous trachytic texture in the border zone. Locally the dacite is dense and without vesicles or

HORNBLENDE-AUGITE DIORITE AND QUARTZ DIORITE (EOCENE) - Medium-gray to light-greenish-gray, speckled coarsecrystalline, intergranular diorite to quartz diorite. Composed of abundant nearly equigranular subhedral to anhedral twinned plagioclase (oligoclase to labradorite), common pale-green diopsidic augite, green hornblende, sparse brown biotite, quartz, and accessory magnetite and sphene. Augite, hornblende, biotite, and magnetite commonly occur as aggregates of crystals. Augite is invariably corroded, and locally only discrete optically alined blebs scattered through enclosing plagioclase or hornblende indicate the presence of a former single crystal. Irregular masses of augite are commonly enclosed by hornblende, biotite, or acting lite or by all three. Hornblende is anhedral in the dioritic phase Commonly it is partly replaced by chlorite and actinolite. Brown biotite encloses magnetite; it is partly replaced by chlorite. Accessory sphene is enclosed by biotite, hornblende, and plagioclase. Minor quartz is present as anhedral masses or rarely as myrmekitic intergrowths with sodic plagioclase

MONSERRATE FORMATION (EOCENE) - Light- to mediumgreen tuffaceous siltstone commonly interbedded with tuffaceous sandstone is characteristic and widespread; interbeds of intraformational conglomerate, calcarenite, and carbonaceous siltstone are rare. Thick sequences of medium-green, light-bluish-green, or light-grayish-green (celadon green), thinly laminated to mediumbedded (0.2 to 30 cm), dense and erosion-resistant beds of veryfine-grained vitric tuff are common and characteristic throughout the outcrop area. Many of the thicker beds are massive and dense; the rock shows a prominent conchoidal fracture. Both massive and laminated siltstones are partly to largely replaced by calcite and contain abundant microscopic Foraminifera. Locally, beds of tuffaceous siltstone show graded bedding. Interbedded laminated to medium bedded (0.3 to 30 cm), fine- to mediumgrained volcanic sandstone consists largely of angular lithic and vitric clasts and sparse broken angular plagioclase and hornblende clasts. The tuffaceous sandstone commonly weathers into negative relief, giving the interbedded fine-grained tuff-tuffaceous sandstone sequences a flaggy appearance. Rare intraformational conglomerate beds are composed of small (less than 1 cm) moderately rounded, tabular pebbles of tuffaceous siltstone in a generally silty matrix. Local lenses of medium- to dark gray-brown, medium-bedded biosparite-biomicrite consist largely of rounded algal clasts and large Foraminifera in a matrix of very fine grained sparry calcite or less commonly of argillaceous or possibly tuffaceous microcrystalline ooze. The Monserrate is extensively saprolitized to a very fine grained pale-yellow or lightgreen clay that retains evidences of bedding. The unit shows a minimum thickness of 1100 m in the northeast part of the Penuelas

once glass

AUGITE TRACHYBASALT (MAESTRICHTIAN) - Dark-blue-green abundantly porphyritic augite trachy basalt characteristically contains abundant, conspicuous, large (to 1 cm long) augite phenocrysts and sparse, small (0.5 cm), tabular labradorite-andesine phenocrysts held in an abundant dark-blue-green matrix of finecrystalline plagioclase and generally chloritized material, probably

microlites, regularly crystallized and fairly abundant magnetite, and chloritized glass. Plagioclase is generally albitized and to a minor extent replaced by chlorite and locally by calcite. Augite is generally fresh-appearing and commonly contains inclusions of apatite. Rarely augite and plagioclase phenocrysts show conspicuous compositional zoning. Groundmass glass is largely chloritized, and locally vesicles are filled with medium-green chlorite (penninite?) and rimmed with pumpellyite. Locally (125,660 - 27,920) plagioclase is thoroughly albitized; augite is replaced by pseudomorphs of chlorite and an unidentified granular material, possibly epidote rimmed with magnetite HORNFELSED LAGO GARZAS AND YAUCO FORMATIONS (MAE-STRICHTIAN AND CAMPANIAN?) – Generally light-greenish or brownish gray, fine- to coarse-crystalline marble and bright-green pelitic or arenaceous calc-silicate hornfels. West of the largest dioritequartz diorite fault block, the rock is a coarse- to fine-crystalline marble with abundant bright-green anhedral diopsidic augite; in the northern part of the same fault block are locally abundant massive lightbrown irregular masses of hydrogrossularite-grossularite and vesuvianite and sparse pods of massive coarse-crystalline magnetite with subordinate epidote and quartz. Other borders of the diorite-quartz diorite have hornfelsed the clastic facies of the Lago Garzas and Yauco so that the mineralogy and texture of the clasts are unchanged but the matrix calcite and clay have been converted to epidote, chlorite, and recrystallized quartz. On the northern border of the dioritequartz diorite block, a narrow zone of conglomerate of the Yauco (?) Formation has been metamorphosed to a biotite-plagioclase hornfels; the matrix is a biotite-rich hornfels, but the original pebbles have been little affected LAGO GARZAS FORMATION (MAESTRICHTIAN AND CAMPAN-IAN?) - Volcanic breccia, lava, volcanic sandstone, siltstone, claystone, tuff, limestone, and volcanic conglomerate SANTAS PASCUAS MEMBER - Widespread and thick sequences commonly consist of pumiceous lapilli tuff, pumiceous-lithic lapilli

tuff, vitric and vitric crystal tuff, porphyritic lava, and minor lime-

stone. Commonly light bluish green, light medium green, or pale

yellowish brown. Sequences show abrupt and closely spaced changes

in lithology. Rock in most areas is deeply saprolitized. Pumiceous

type are concentrated near the top, and lithic clasts are concentrated

near the base of any one bed. Pumice is commonly tabular and lies

beds commonly show reverse grading; pumice clasts of the tube

parallel or subparallel to bedding; it is commonly partly collapsed, but the enclosing shard matrix shows no flattening or moulding around contained lithic and crystal clasts. Lithic clasts of welded ash-flow tuff with prominent perlitic structure are common in the area of Santas Pascuas. These consist 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. Tuff of the Santas Pascuas is interbedded with the top of the Pastillo Member in the type area and with the Yauco Formation in the northeastern corner of the quadrangle. Dacitic (?) lava of the Santas Pascuas crops out in only two areas. It is lithologically like the enclosing tuffaceous siltstone and tuff. The glassy matrix is light-green, abundant, and composed of plagioclase microlites in glass. Phenocrysts of plagioclase, augite, and hornblende are sparse. The unit is a least 350 m thick PASTILLO MEMBER – Breccia and lava; very thick bedded (1+ m) to massive volcanic breccia composed of abundant dark-red-brown and subordinate dark-green and purple angular, large (commonly 3 - 6 cm, rarely to 25 cm) clasts of porphyritic (augite, plagioclase) dense to vesicular andesite in an unsorted coarse-sandstone matrix of the same lithic types. Commonly the breccia is interbedded with lava flows and minor fine-grained marine sedimentary rocks. Lava is dark red brown and purple and consists of an abundant, finegrained dense to vesicular, and locally amygdaloidal groundmass with common to sparse, conspicuous (to 1 cm long) augite phenocrysts and generally sparse smaller plagioclase (andesine-oligoclaselabradorite) phenocrysts. Single flows range from 5 - 15 m thick; none display pillow structure. Commonly the breccia and lava are deeply saprolitized in the area bordering the northern boundary of the quadrangle. The Cerrote de Penuelas consists of about 150 m of thick-bedded nonpillowed lava flows over interbedded lava and breccia. The Pastillo Member is at least 1,000 m thick VOLCANICLASTIC AND PYROCLASTIC ROCKS - Very thin to thick-bedded dark-red-brown siltstone, fine- to coarse-grained sandstone containing abundant rounded to subangular lithic clasts like the breccia and lava described above, and sparse to abundant angular to subrounded clasts of augite and plagioclase crystals. Beds with abundant angular mineral and (or) lithic clasts are assumed to be pyroclastic. The origin is best established in finer grained sequences

where not diluted by coarse clasts. Typically thicker sequences of

the Pastillo show mixtures of pyroclastic and epiclastic rocks. Thick

red claystone and calcarenite crop out over much of the north cen-

tral part of the quadrangle. The unit is at least 750 m thick in indi-

vidual fault blocks. Limestone (not differentiated in mapping) is a

massive very dark gray and commonly composed chiefly of Cras-

sostrea sp., subordinate turriculate gastropod molds, and black car-

bonaceous clay. As all limestone in the Lago Garzas is fossiliferous,

sequences of epiclastic volcanic sandstone interbedded with hematite-

the fossil symbol is used only to indicate conspicuous Crassostrea YAUCO FORMATION (MAESTRICHTIAN AND CAMPANIAN?) -Dark bluish gray where freshest, light to medium yellowish gray brown where weathered; generally interbedded abundant calcareous siltstone, claystone, subordinate fine- to coarse-grained sandstone, mudstone, minor limestone, and rare intraformational conglomerate Thick sequences commonly consist of irregularly alternating beds of well-sorted calcareous siltstone, claystone, and fine-grained sandstone; however, over wide areas thick sequences may consist predominantly of siltstone or claystone with only very minor amounts of the other lithic types. Generally the siltstone and claystone are thinly laminated to thin-bedded (0.3 – 10 cm) and less commonly medium-bedded (10 - 30 cm). Siltstone consists of lithic clasts and subordinate mineral clasts, uncommonly it contains abundant angular plagioclase clasts and appears pyroclastic and tuffaceous. Microscopic Foraminifera range from abundant to very sparse in the siltstone and claystone facies. Claystone is commonly very dark brownish gray or black and locally carbonaceous. It characteristically weathers into polyhedral tabular clasts that show conchoidal surfaces. Sandstone ranges from very fine to coarse-grained and from lithic and epiclastic to plagioclase rich and tuffaceous. Bedding is thin to medium (2 - 10 cm), and finer grained sandstone beds interlayered with claystone and siltstone are commonly laminated to thinly laminated (0.3 to 1 cm). Limestone consists of dark- to me dium-grayish-brown biomicrite and biosparite lenses as much as 3 - 4 m thick composed of rounded shell, algal, coral(?), and rudist fragments and sparse large Foraminifera in a dark-brown clayey tuffaceous ooze or a pale-gray sparry matrix. Rare conglomerate is intraformational, and consists of rounded tabular clasts of siltstone or claystone in a matrix of the same type. Uncommonly the coarser sandstone beds are pebbly. Interbedded tuffaceous sandstone, volcaniclastic breccia, and conglomerate of Lago Garzas Formation are described under that heading. The Yauco has a minimum thickness of 1,200 m in a single fault block

LIMESTONE OF SANTO DOMINGO (MAESTRICHTIAN AND CAMPANIAN?) - Massive, very fine crystalline, dark-gray, argillaceous limestone. The unit is about 20 m thick PARGUERA LIMESTONE(?) (MAESTRICHTIAN AND CAMPAN-IAN?) - Pale-gray to pale-brown, thin- to very thick-bedded (3 cm -1 m) calcarenite composed of subrounded clasts of shells, algae. rudists, and large Foraminifera in a predominately sparry matrix. Locally recrystallized by intrusion of plagioclase-augite andesite LAGO GARZAS AND YAUCO FORMATIONS INTERBEDDED (MAESTRICHTIAN AND CAMPANIAN?) - In the northeast quarter; typical light-yellowish-gray-brown weathering thin- to mediumbedded claystone, siltstone, and minor mudstone of the Yauco irregularly interbedded with dark-red-brown volcaniclastic breccia and round pebble conglomerate, dark-red-brown and purple vesicular and amygdaloidal lava, and pale-yellowish-green and medium-green thinto very thin bedded tuffaceous siltstone of the Lago Garzas Formation. The tuffaceous siltstone is like that at Santas Pascuas. In the

central area; interbedded typical siltstone, fine-grained sandstone,

and claystone of the Yauco and thick sequences of coarse-grained

augite-bearing tuffaceous sandstone of the Lago Garzas Formation

Contact - Dotted where concealed; queried where inferred (contacts of Quaternary alluvial units are shown by a solid line by convention; placement ranges from assured to inferred) Fault – Long dashed where approximately located; short dashed where inferred; dotted where concealed; ball and bar on downthrown side; wrench fault and relative directions of movement shown by arrows; A, away from observer; T, towards observer Folds - Showing crestline or troughline, direction and amount o plunge if known and direction of dip of limbs; long dashed where

approximately located; dotted where concealed ◆ U Overturned syncline

Bearing and plunge of small closely spaced folds Dikes of unspecified composition Strike and dip of beds \_\_\_\_\_\_Inclined

> Overturned Top determined from graded bedding or crossbedding

Cu Copper-bearing minerals Pb Lead-bearing minerals

+++++ Conspicuous beds of Ky in Kgpbl or Kgps

Zn Zinc-bearing minerals O Zones or beds of abundant Crassostrea sp. △△△△ Conspicuous beds of Kgsp in rock chiefly Kgpbl or Kgp OOOOO Conspicuous beds of Kgpbl or Kgps in Ky

10 20 30 40 50 MILES INDEX TO GEOLOGIC MAPPING IN PUERTO RICC

1 1/2 0 1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 METERS DASHED LINES REPRESENT 5-METER CONTOURS 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

GEOLOGIC MAP OF THE PEÑUELAS AND PUNTA CUCHARA QUADRANGLES, PUERTO RICO Richard D. Krushensky and Watson H. Monroe