DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
COMMONWEALTH OF PUERTO RICO
DEPARTMENT OF NATURAL RESOURCES

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I–863

DEFINITIONS AND STRATIGRAPHY

The Ponce quadrangle is underlain by a sequence of Upper Cretaceous to Miocene volcaniclastic rocks of marine and probable nonmarine origin, extrusive and intrusive rocks, and limestone. Volcaniclastic rocks are the most widespread and persist throughout the sequence. They include conglomerate-breccia of the Achiote, Maravillas, Coamo, and Guayo Formations; autoclastic breccia of the Cotorra, Lago Garzas, and Anón Formations; and siltstone, mudstone, and sandstone of the Yauco, Monserrate, and Anón Formations.

Volcaniclastic rocks, that is, rocks composed of clasts of material of volcanic origin, are commonly divided on the basis of origin and clast size (Fisher, 1961); and, although there is general agreement on definitive characteristics of autoclastic rocks, there is less agreement on definitive characteristics of epiclastic volcanic rocks, pyroclastic rocks, and reworked pyroclastic rocks. Volcaniclastic rocks here described as epiclastic are those in which a preponderance of lithic and mineral clasts, especially the coarser sizes, show a considerable degree of rounding, and in which rocks with bogen structure and shards are largely absent. Rocks here described as pyroclastic are those in which bogen structure-curved, concave or convex planes meeting at sharp points-and the sharply angular form of mineral clasts have been preserved. Bogen structure is commonly present in fine-grained lithic and vitric clasts as well as in shards, and it is generally observable in the hand specimen and thin section in even the most argillized pyroclastic rock. Reworked pyroclastic rocks and volcaniclastic rocks derived from demonstrably coeval source material, lithified or not, are considered epiclastic if the characteristics of pyroclastic rocks noted above have been obliterated by sedimentary-erosional processes. In most volcanic terranes epiclastic and pyroclastic volcanic rocks intergrade and interbed on both a local and possibly regional scale. The presence of minor quantities of pyroclastic debris in an otherwise epiclastic rock is not, therefore, considered sufficient to characterize the rocks as pyroclastic. This point is particularly important in Puerto Rico, where volcanism has been the dominant source of rock-forming material throughout the known history of the island.

Cretaceous rocks in the Ponce quadrangle are extensively faulted and accordingly the stratigraphic sequence has been determined in other areas. The sequence is, older to younger: Cotorra Tuff, Achiote Conglomerate, Maravillas Formation, and Coamo Formation. The Coamo and Maravillas Formations are in part lateral equivalents. The stratigraphic positions of the Yauco Mudstone, Lago Garzas Formation, and the limestone of Cerrillos are not yet definitely known. Work in progress in the Peñuelas quadrangle to the west indicates that the Yauco and Lago Garzas are interbedded. The structurally isolated limestone of Cerrillos is early Maestrichtian in age (Pessagno, 1960, p. 53), and it may be equivalent to limestone in the Yauco or Lago Garzas to the west.

The Cuevas Limestone forms the basal unit of the Tertiary sequence in the Ponce quadrangle. It is conformably overlain by the Monserrate Formation, which is overlain and interbedded with the Anón Formation. The stratigraphic relationship of the Monserrate-Anón with the Guayo Formation is not definitely known, but the presence in the Guayo of rounded boulders and cobbles of the Cuevas, Monserrate, and Anón strongly suggests that the Guayo was originally deposited disconformably or unconformably over the Cuevas-Monserrate-Anón. The Juana Díaz Formation unconformably overlies both the Monserrate and Guayo, and it is conformably overlain by the Ponce Limestone.

A thin sequence of rock beneath the Cuevas Limestone and above the Achiote Conglomerate at Quebrada Indalacia was named by Pessagno (1960, p. 71) the Miramar Member of the Naranjo Formation. Glover and Mattson (1967, p. 33), on the basis of mapping in the Río Descalabrado and Jayuya quadrangles, retained the name and raised it to formational status as the basal unit of their Jacaguas Group. The rock beneath the Cuevas Limestone on the Quebrada Indalacia is sheared and brecciated (see below) and was originally derived predominately from the underlying Achiote Conglomerate, but a few tens of metres farther west and elsewhere on the northern border of the Ponce quadrangle the brecciated rock below the Cuevas is derived chiefly from the Maravillas Formation. In both places the breccia contains clasts of Cuevas-like limestone. Mattson (1966, p. 50) suggested that this sequence could be a talus deposited along a Tertiary shore. However, because of the brecciated character of the strata and the mixing of material from units above and below, the brecciated rock has been mapped in the Ponce quadrangle as fault breccia. It is in continuous outcrop with rock mapped as Miramar Formation in the Jayuya and Río Descalabrado quadrangles. The breccia in the Ponce quadrangle is thought to have been produced by gravity gliding and to be of Tertiary age. Megabreccia mapped by Glover (1971, pl. 2) in the Río Descalabrado quadrangle is possibly equivalent in mode of origin and time of formation to the gravity glide breccia. Descriptions of the "Miramar" by Glover (1971, p. 52) in the Coamo and Río Descalabrado quadrangles suggest that the "Miramar" there is composed of two different lithologic materials. The Miramar south of Cerro de las Cuevas resembles the gravity-glide breccia, and it and the continuous areas of outcrop in the Ponce quadrangle may have been derived from the Coamo Formation which lies a few hundred metres to the north. Other "Miramar" in the Coamo quadrangle and locally in the Río Descalabrado quadrangle appears from Glover's descriptions to be lithologically identical to volcaniclastic mudstone and massive oyster-bearing limestone of the Lago Garzas Formation in the Peñuelas quadrangle to the west. Because of the uncertainty of mode of origin of the "Miramar Formation" and application of the term in areas other than the type section, the name Miramar Formation will not be applied in the Ponce quadrangle.

The age of stocks and dikes of hornblende porphyry in the quadrangle is not certain. Three of the smaller stocks and the two major dikes cut the Monserrate Formation, and they appear on the bases of similar lithology and chemistry to have been the source of the lavas of the Anón Formation. The generally more propyllitized stock of hornblende porphyry near Guayabal and the coarsely porphyritic Tibes stock and associated fine-grained border facies in the west-central part of the quadrangle intrude only Cretaceous rocks. All of the intrusives may be of Tertiary age, as the youngest rocks intruded are Tertiary, but they may also be of two different ages. Although clasts definitely ascribable to the intrusives have not been found in Cretaceous rocks in the Ponce quadrangle, Glover (1971, p. 78) notes that some blocks in the Maravillas Formation of the Coamo area are similar to rock in the Los Panes laccolith. From descriptions by Glover (1971, p. 78), it appears that the Los Panes intrusive and those in the Ponce quadrangle may be lithologically similar. All but one of the stocks and the two thick dikes in the Ponce quadrangle are too highly altered to permit radiometric age dating. Radiometric age determination of the fresh-appearing Tibes stock will be attempted in the future.

GRAVITY GLIDE PLATES

The Cuevas, Monserrate, and Anón Formations form, at least locally, an allochthonous plate that lies on strata resembling the Maravillas Formation (Upper Cretaceous). Evidence is in the form of a hematitized red slickenside-riddled clayey fault gouge at the base of the Cuevas in the Ponce quadrangle. The Cuevas-Maravillas contact north of the Río Guayo on the north-central border of the quadrangle consists of breccia of angular clasts of calcareous mudstone like that of the immediately underlying Maravillas Formation with sparse angular clasts of algal calcarenite like that in the overlying Cuevas held in a slickensided red clay matrix. The lower Cuevas surface shows in places as much as 1 m of vertical relief in 1 m horizontally, and the clast-rich breccia is pastered up into the irregularities and fractures in the Cuevas. The breccia is best seen along Quebrada Indalacia on the north-central border of the Ponce quadrangle. There it consists of a hematitized slickenside-riddled clay matrix enclosing abundant sharply angular and tabular slickenside-surfaced clasts of resistant rock types like those in the immediately underlying Achiote Conglomerate. Angular to well rounded clasts of algal calcarenite like that at the base of the overlying Cuevas are also present. These clasts show sharp, nongradational contacts with the clayey breccia. The calcarenite clasts commonly include some minor volcanic constituents and the rock is pale red or pink-orange like the basal few metres of the Cuevas as exposed here and to the south. A third exposure of breccia at the base of the Cuevas lies beneath the cliff of Cuevas in the ridge south of Semil. There angular clasts of the Cuevas, as much as 1 m on a side, are suspended in a clayey matrix. A fourth exposure 250 m southwest of the east end of the Guayabel Dam also shows slickensided red clayey breccia plastered up into irregularities in the lower Cuevas surface. The large quantity of clay matrix, the tabular nature of most of the clasts, the presence of rock from the overlying formation, and the slickensided nature of clasts and matrix would suggest that the material is a fault gouge, in which clasts of both the autochthonous Achiote-Maravillas plate and the allochthonous Cuevas-Monserrate-Anón plate were sloughed off during emplacement, probably by gravity sliding. The amount of linear displacement is unknown as the Cuevas and overlying Tertiary rocks do not crop out to the north of the quadrangle. Comparison of this allochthon with those in the Río Descalabrado quadrangle to the east strongly suggest a common origin.

A poorly exposed gravity-glide fault or thrust fault cuts the ridge south of the Quebrada Chorrera southwest of Guayabal. The allochthonous plate (olistolith) lies locally at its eastern end, over irregularly distributed gravity-glide breccia like that beneath the Cuevas Limestone on the Quebrada Indalacia; the fault plane dips moderately to the north, and the dip becomes steeper toward the west. Chert of the Monserrate Formation, in the hanging wall, locally dips steeply into the fault plane. Although this fault has no demonstrable physical connection with the fault at the base of the Cuevas on the Quebrada Indalacia they may be two segments of a recurved gravity-glide fault which to the north dips south at a high angle, flattens to the south, and eventually dips north as at Quebrada Chorrera (see diagram for plan view).

Glover suggests (1971, p. 87) that movement of the allochthonous plates in the Coamo area was toward the north on the basis of the following lines of evidence: 1) southward-dipping imbricate allochthonous plates, 2) the only known source of more highly metamorphosed rock in the megabreccia lies to the south, 3) northeastern edges of allochthonous plates are crumpled where they abut more resistant rock types, and 4) paleoslopes were northward dipping. However, southward-dipping imbricate allochthonous plates can also be explained by a southward movement and the mechanism suggested above. A southerly dip and northward movement would occur only in a rooted thrust in which the plates had been moved against the force of gravity. The presence of metamorphic rocks in the megabreccia is not dependent on a southern source as they could also have been derived from metamorphic zones surrounding intrusives rocks that cut the Coamo Formation. Crumpling of allochthonous plate edges that abut resistant rocks would occur in either southward- or northward-moving plates. Penecontemporaneous low-amplitude folds overturned and in one case overthrust by 1 m or so toward the south (850 m north of Real Arriba and south of Collores on the Quebrada Indalacia) suggest that paleoslopes in the Monserrate-Anón were southward dipping in the Ponce quadrangle. Paleoslopes in the Jacaguas Group are also indicated as southward dipping (Glover, 1971, pl. 4) in the diagram illustrating Jacaguas Group stratigraphic relations in the Río Descalabrado quadrangle. In addition, a landmass as a source of gravity-glide plates was and is present to the north, and there is no evidence for the existence of a southern highland from which northward-directed gravity glides or rooted thrusts could have been derived. Although a southern highland is theoretically possible, present tectonic arrangement of the southwest part of Puerto Rico suggests that such a mass would be a southeastward-moving wrench fault block from which it would be difficult to generate northward-directed thrusts. Gravity-glide plates could move northward off such a mass, but the present attitude of the fault planes indicates that these plates would have had to move against the force of gravity for most of their extent. Additionally the superposition of Monserrate over Guayo indicated near Quebrada Chorrera could not be achieved by gravity-glide plate movement from the south. Emplacement of the glide plate in the Ponce quadrangle postdates deposition of the Anón Formation, and, if the superposition of Monserrate over Guayo is correct, gliding postdates deposition of the Guayo.

Three structurally isolated blocks of the limestone of Cerrillos crop out between the hill north of Vayas and Lago Número 2 in about the center of the quadrangle. Bedding in the limestone dips at 50° to 58° into a virtually horizontal contact with the underlying Lago Garzas Formation. The contact is best seen in the quarry on the north side of the westernmost block and in the re-entrant between the two center blocks. The geometric relationship of steeply-dipping beds abuting virtually horizontal contact strongly suggests a gravity-glide or thrust. The relationship in time and origin, if any, with the glide plate of Tertiary rocks is unknown.

Examination of broad areas of the Tertiary sequence and part of the Cretaceous sequence indicates a generally concordant homoclinal dip to the south-southwest. Attitudes are best seen in larger fault blocks away from bordering wrench faults and associated folds, and away from converging wrench faults. The general concordance of the homoclinal structure over many blocks suggests that it was imposed prior to wrenching. The relationship in time to the emplacement of a Tertiary gravity glide plate is unknown.

SOUTHWEST PUERTO RICO FAULT ZONE

The southwest Puerto Rico fault zone is, in the Ponce quadrangle, a series of wrench faults and associated high-angle cross faults and minor folds. The zone crosses the quadrangle from the northwest to the southeast and obscures but does not completely conceal the general south-southwest homoclinal dip of the Tertiary rocks, and the allochthonous nature of part of the Tertiary sequence. Although proof of relative movement on individual northwest-trending wrench faults is generally lacking, some indication of left-lateral movement is seen in quartz filled tension fractures distorted into "S"-shaped curves. It is generally assumed (Glover, 1971, p. 84; D. H. McIntyre, 1973, written commun.) that the entire zone has undergone left-lateral wrenching with some unprovable amount of vertical movement.

Eight northwest-trending high-angle wrench faults cut the Cretaceous and Tertiary sequences. They are, from the north, the Santo Domingo, Paraíso, San Patricio, Maraguez, Real Abajo, Chiquito, Santas Pascuas and Yuca.

Three additional faults in the west-central part of the quadrangle, the northwest-trending Bayagán, and the east-west-trending Machuelo and Portugués faults may also be wrench faults, but their nature and extent are unknown as the area to the west has not been mapped in detail and possible extensions to the east have been cut by younger faults and covered by alluvium. Lateral movement apparently exceeds the length of any wrench fault with in the quadrangle as neither structures, intrusions, nor detailed sequences can be matched across any wrench fault but one. That exception, the Santo Domingo fault, may show lateral movement of only about 100 m. Traces of the wrench faults are commonly marked by clayey gouge as much as 10 m wide; closely-spaced wrench faults like those 1 km northeast of Maraguez and the Cerrillos-Yuca block in the Machuelo Arriba area show clay gouge and breccia in excess of 50 m wide. Healed fractures along the Río Inabon in the Monserrate Formation show "S"-shaped curves compatable with left-lateral movement.

Impersistent high-angle north-, northeast-, and some northwest-trending faults cut both the Cretaceous and Tertiary sequences, and are commonly confined to major wrenched blocks. A few also cut probable wrench faults. Commonly these faults show no fault gouge, rather a conspicuous powdering with calcite on and between clasts in narrow (1-2 m) fault zones. These faults may have formed as a result of wrenching and may be compared to tension fractures in a couple between the central and southwestern blocks of the island. Time of formation of these faults is not precisely known, but they may locally postdate wrenching as they cut probable wrench faults.

Fold axes in the Ponce quadrangle can be traced for as much as 2 km although most die out in less than 1 km along strike. They are confined within major wrenched blocks, and their axes range from subparallel to 45° to the direction of wrenching. Axes plunge both to the northwest and southeast. The folds may have been produced by drag on wrench faults with the axes pulled into subparallel position by vertical movement on those same faults. Movement suggested is left-lateral with the eastern end of the southern block moving down and the western end of the northern block moving up in any particular couple. Locally in the Real Arriba and Corozal areas penecontemporaneous folds are overturned and one is overthrust to the south. These folds plunge west. As they die out rapidly laterally and are not reflected in the overlying rocks or contacts, they are considered nontectonic in origin. The folds north of Real Arriba suggest deformation of the unconsolidated Monserrate by the southward and downslope-moving lavas of the Anón.

Timing of wrenching and thus of the formation of the southwest Puerto Rico fault zone is not precisely known. Wrench faults cut the Juana Díaz of Oligocene and Miocene age in the Ponce quadrangle and to the west in the Penuelas quadrangle, and clearly juxtapose rocks of Eocene and late Oligocene-Miocene age. Wrenching also postdates gravity gliding as glide plates are cut by wrench faults. Glover (1971, p. 84-85) considers the Río Jueyes a wrench fault, and suggests that wrenching may have begun in the Early Cretaceous. He uses as evidence the thin sequence of Cuevas Limestone deposited disconformably on the block of Coamo Formation north of the Río Juyes fault (Glover, 1971, pl. 2—incorrectly as RÍO JUVES FAULT) as opposed to its deposition south of the Río Juyes fault in a sequence of several pre-Cuevas and post-Coamo formations. The rationale may be correctly applied to a dip-slip fault, but it has no application to a wrench fault in which deposition on the southern block of the couple may have taken place more than 5, 10, or 20 km to the northwest of deposition on the northern block. Although wrenching may have begun in the Cretaceous and may have been reactivated in the Tertiary, there is presently no known evidence that would substantiate pre-Tertiary wrench fault movement.

APPLIED GEOLOGY

Limestone and intrusive rocks are presently the chief mineral resources in the Ponce quadrangle. Limestone crops out near the northern border and near the center of the Ponce quadrangle. All major outcrop areas of limestone are presently being quarried for road metal and concrete aggregate. Both the Cuevas Limestone and the limestone of Cerrillos would be suitable for polished "marble" of commerce. Intrusive igneous rocks crop out in numerous areas within 5 km of Ponce. Both the fine-grained rock would be suitable for road metal and concrete aggregate. Four quarries have been developed in the predominantly fine-grained intrusive rock north of Ponce, three appear to have been abandoned, and the fourth appears sited chiefly in slightly baked rock of the Monserrate Formation. Gravel is taken from alluvial-fan deposits near Aguilita near the center of the southwest quarter of the quadrangle.

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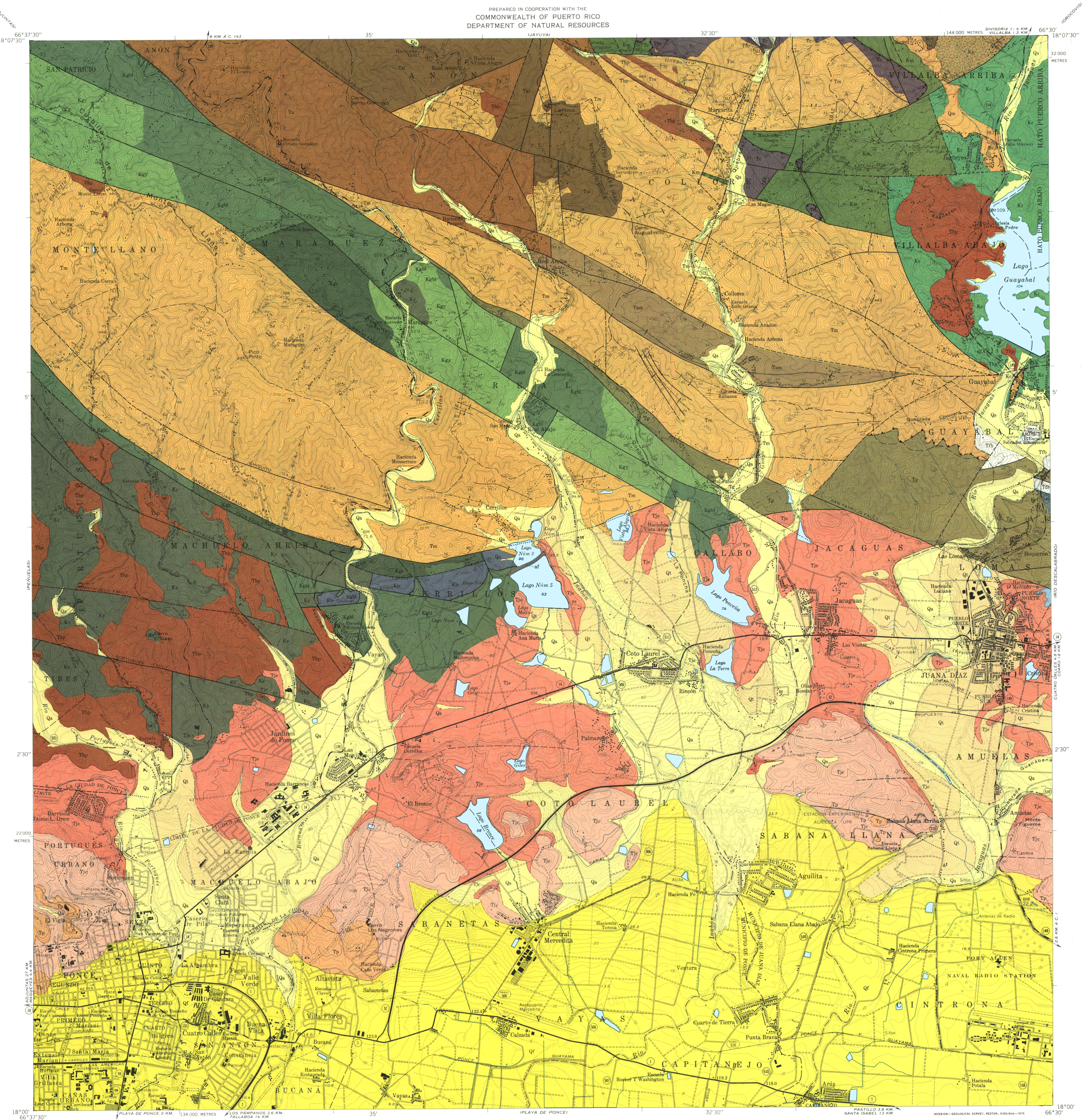
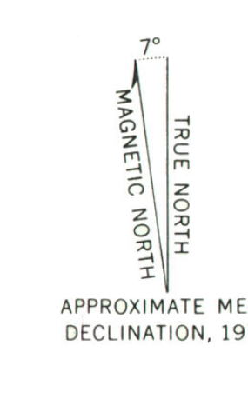


Base from U.S. Geological Survey, 1970
2,000 metre grid based on Puerto Rico coordinate system

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1975

Geology Cretaceous, Eocene, and some Oligocene rocks by R. D. Krushensky, 1970–71; geology of Oligocene, Miocene, and Quaternary units by W. H. Monroe 1969–1971



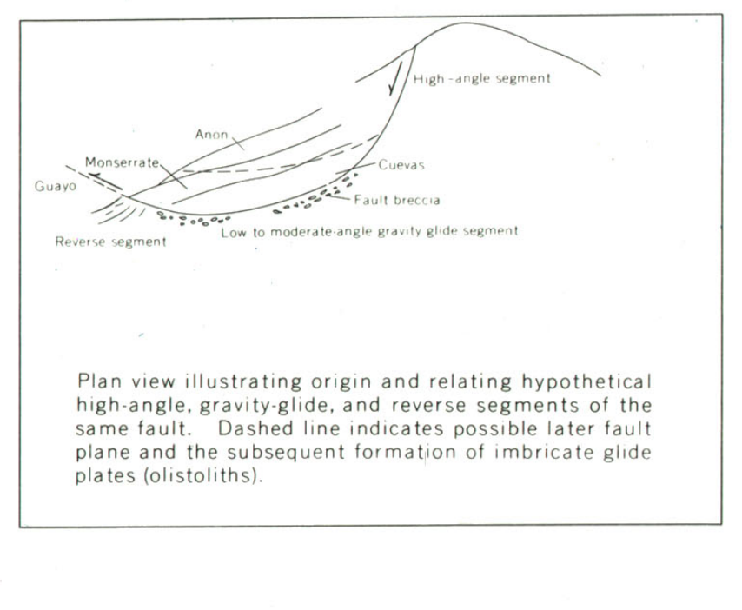
APPROXIMATE MEAN DECLINATION, 1970

SCALE 1:20 000

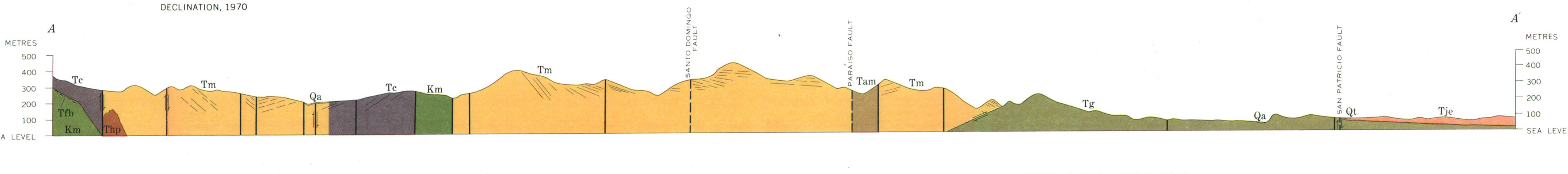
1 .5 0 1 2 3 KILOMETRES

1 ½ 0 1 MILE

CONTOUR INTERVAL 10 METRES
DASHED LINES REPRESENT 5-METRE CONTOURS
DOTTED LINES REPRESENT 1-METRE CONTOURS
DATUM IS MEAN SEA LEVEL



Plan view illustrating origin and relating hypothetical high-angle, gravity-glide, and reverse segments of the same fault. Dashed line indicates possible later fault plane and the subsequent formation of imbricate glide plates (olistoliths).



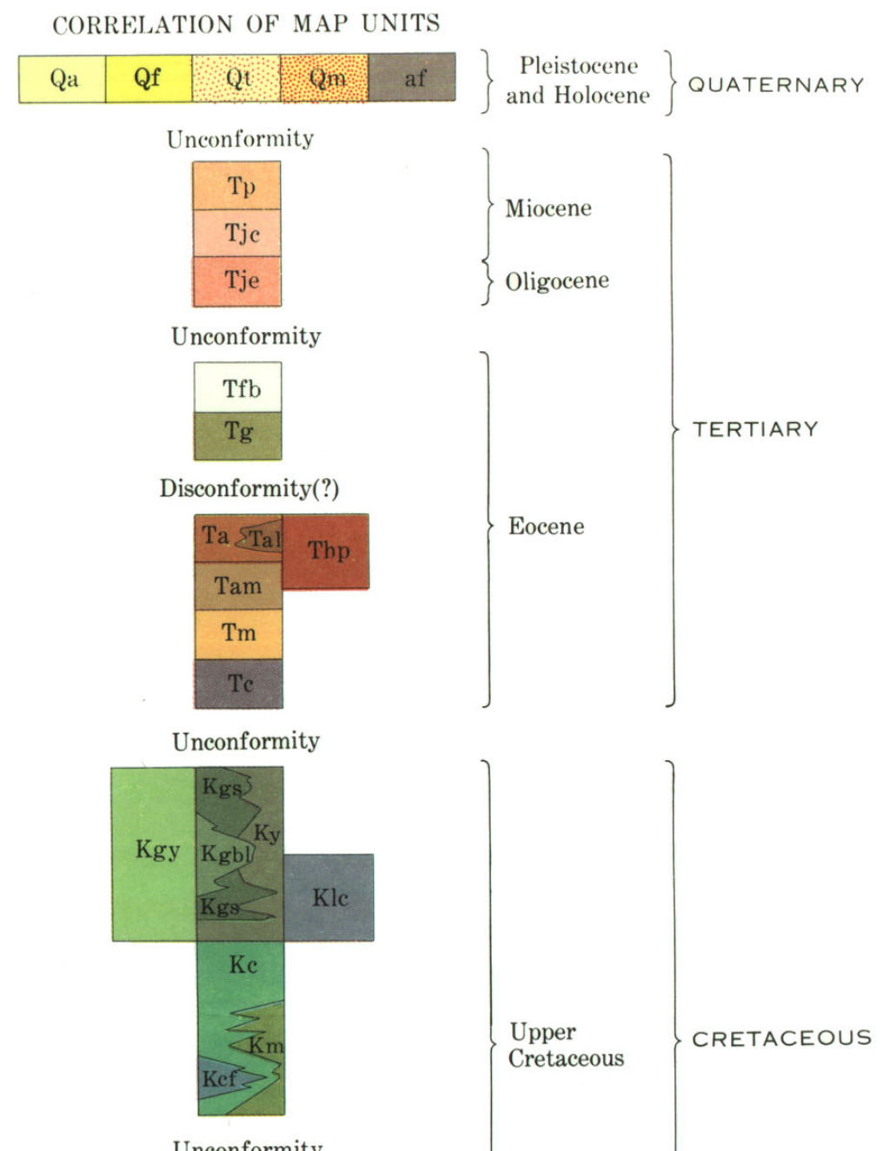
GEOLOGIC MAP OF THE PONCE QUADRANGLE, PUERTO RICO

By

Richard D. Krushensky and Watson H. Monroe

1975

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

af ARTIFICIAL FILL

Qa **Qf** **Qt** ALLUVIUM, ALLUVIAL FANS, AND ALLUVIAL TERRACES (PLEISTOCENE AND HOLOCENE)—Crudely and irregularly bedded, fresh to moderately weathered, gravel, sand, silt, and some clay; includes terrace deposits above present valley floors, valley-floor alluvium, and alluvial-fan deposits

Qm MUDFLOW DEPOSITS (PLEISTOCENE AND HOLOCENE)—Unsorted and nonbedded bouldery and sandy clay; composed chiefly of weathered volcanic rock from the Cotorra Tuff and the Achiote Conglomerate; forms irregular, hummocky, boulder-strewn surface

Tp PONCE LIMESTONE (MIOCENE)—Crudely and thickly bedded, rubbly, light grayish-orange calcarenite containing abundant fossils, including *Clypeaster cubensis*, *Flobellum* sp., and molds of mollusks. Thickness estimated at somewhat more than 100 m

JUANA DÍAZ FORMATION (OLIGOCENE AND MIOCENE)

Tjc Calcareous unit—Lenticular calcareous sandstone overlain by chalk and chalky limestone. About 150 m thick

Tje Detrital unit—Light blue-gray calcareous sandy clay, sand, and sandy gravel; gravel chiefly present in the lower 100 m. Commonly contains cobbles of volcanic rock more than 10 cm in diameter. *Lepidocyclina undosa* common except in gravel. Thickness, estimated by projection of dips, as much as 700 m

Tfb FAULT BRECCIA (EOCENE)—Dark hematite-red, slickenside-riddled, clayey breccia; composed chiefly of angular clasts of porphyritic volcanic rocks, calcareous mudstone, and algal calcarenite in an abundant clay matrix. Clasts in the Quebrada Indalacia area are porphyritic volcanic rocks, some volcaniclastic sedimentary rocks from the immediately underlying Achiote, and algal calcarenite from the overlying Cuevas Limestone. Clasts in the Río Guayo area are thinly laminated calcareous mudstone from the underlying Maravillas and algal calcarenite from the overlying Cuevas. Both clasts and matrix show abundant slickensides and clasts are coated with shiny thin films of hematite

Tg GUAYO FORMATION (EOCENE)—Thickly (4 m+) and crudely bedded, very coarse, poorly sorted, epiclastic volcanic conglomerate, sandstone, and mudstone. Predominant coarse facies appears characteristically speckled, and contains abundant and conspicuous, rounded to angular clasts of volcanic porphyries like those in the Coamo, Maravillas, Lago Garzas, and Anón Formations; algal calcarenite like that in the Cuevas and Monserrate Formations; clasts of moderate-green and blue-green tuff and volcanic mudstone like that in the Monserrate Formation, and clasts of light-green tuff with flow- or fiamme-texture like that of the Robles Formation. Outcrops in the Juana Díaz area contain larger quantities of clasts from the Cuevas, Monserrate, and Anón Formations. Some of the Anón-like clasts may be from stocks and dikes that intrude the Monserrate and are petrographically identical with the lava of the Anón. Lithic clasts range from about 1 m on a side to less than 0.05 mm in diameter; shards and bogen structure are absent; cement is chiefly calcite and minor clay. Mineral clasts range from angular to subrounded, unaltered to argillized and epidotized, and consist of plagioclase, hornblende, clinopyroxene, and sparse quartz. Local epiclastic volcanic sandstone lenses in the conglomerate are thin bedded (<1 cm), and composed of lithic and mineral clasts like those described above. Mudstone outcrops on the Río Jacaguas near Juan Díaz contain beds of red-brown and gray-green fine-grained epiclastic rock. Shards are absent. Thickness of the Guayo is estimated to be at least 500 m

Thp STOCKS AND DIKES (EOCENE)—Light greenish-gray and light-gray dacitic hornblende-plagioclase porphyry; consists chiefly of plagioclase and hornblende phenocrysts as much as 6 mm long and sparse phenocrystic quartz in a very fine grained groundmass of smaller crystals of plagioclase, hornblende, magnetite, and altered, apparently chloritized, glass. Contact zones consist of an abundant fine-grained light-brown groundmass of plagioclase in altered glass and sparse phenocrysts of plagioclase, hornblende, and rare large (as much as 1.5 cm) augite. Border zones of the stocks near Guayabal and Margarita show intrusion breccia in which clasts of rock are mineralogically similar to the bulk of the stocks but differ greatly in crystal size. The Tibes stock west of Escuela Río Chiquito on the western border of the quadrangle is mineralogically like the other stocks, but phenocrysts are much coarser and they compose as much as 90 percent of the rock. Coarser crystalline facies of all of the stocks, except the Tibes, are chloritized and locally zones of autoclastic intrusion-breccia are zeolitized

ANÓN FORMATION (EOCENE)—Massive lava, volcanic breccia, and minor volcanic sandstone and mudstone

Ta Breccia, mudstone, and lava—Medium- to thick-bedded (5 cm-3 m) volcanic breccia composed of angular clasts of light-green, greenish-gray, and brownish-gray hornblende-plagioclase porphyry, and light- to dark red-brown aphyric volcanic clasts in a fine-grained, dark-green volcanic sandstone matrix; interbedded with greenish-gray porphyritic hornblende-plagioclase lava flows (trachyandesite to rhyodacite) and dark-gray, fine-grained, medium- to thick-bedded volcanic mudstone. Mudstone contains aphyric red, brown, and dark-green lithic clasts like those in the volcanic breccia; and sparse plagioclase and hornblende. The matrix is dark-gray clay. Pebbles of algal calcarenite like that in the Cuevas and thinly laminated volcanic siltstone and fine sandstone like those in the Monserrate are present in local lenses in the mudstone. The lack of shards and bogen structure, the massive character of the breccia beds, and the clayey nature of the matrix suggest that the breccias may be mudflow deposits. Locally interbedded with Monserrate Formation

Tal Lava flows—Light greenish-gray porphyritic dacite (analyses range from trachyandesite to rhyodacite) with abundant phenocrysts of plagioclase and hornblende and sparse quartz in a dense to fine-grained microporphyritic groundmass of plagioclase, hornblende, and chloritized glass. Cores of some plagioclase and most hornblende phenocrysts are chloritized. Amygdules of crystalline quartz and chalcedony are locally common. Weathers over wide areas to light yellow-brown saprolite that retains the texture of the original rock. Locally texture of the saprolite suggests autobrecciation of flows

Tam INTERBEDDED ANÓN AND MONSERRATE FORMATIONS (EOCENE)—Locally interbedded volcaniclastic sandstone-siltstone of the Anón Formation and Monserrate Formation

Tm MONSERRATE FORMATION (EOCENE)—Moderate-green and blue-green volcanic siltstone-tuff and sandstone irregularly interbedded with dark-green tuff, intraformational conglomerate, pale-brown calcarenite, and pale-purple to white chert are characteristic and widespread. Light-green or light blue-green, thin- to medium-bedded (3-25 cm), and internally thinly laminated, erosion-resistant beds of volcanic siltstone regularly interbedded with greenish-brown, internally massive, fine- to medium-grained, thin (3-5 cm) beds of volcanic sandstone are common. Shards are absent in both the sandstone and siltstone, and X-ray analysis indicates that the siltstone consists of quartz, calcite, and minor mordenite and calcic plagioclase. The siltstone is commonly crowded with microscopic foraminifers. Conglomerate beds consist chiefly of tabular, rounded pebbles of the thinly laminated siltstone and thin-bedded fine-grained sandstone. Coarser sandstone beds consist of angular clasts of plagioclase, hornblende and minor quartz in a clayey matrix. Shards are absent. Dark-green, very dense (almost glassy), massive and thick-bedded (2-4 m) tuff beds with abundant devitrification centers crop out along the Río Inabon and the Río Guayo. Shard structure is partly obscured by alteration, but it is clearly partly to completely collapsed, and the rock resembles a welded to partly welded ash-flow tuff. X-ray analyses indicate that this rock also consists of quartz and calcite. It is therefore possible that the volcanic siltstone described above may be a tuff in which all evidences of pyroclastic origin have been destroyed by processes of devitrification. Calcarenite beds are lens-like, pale-brown, and composed of angular to rounded clasts of calcareous algae, large foraminifers, some coral clasts, and minor volcanic debris in a fine- to coarse-crystalline matrix. The type area near Hacienda Monserrate consists chiefly of dark-green intraformational conglomerate and dark-gray, pyritic, fine-grained, calcareous mudstone. Pale-purple and opaque white chert are interbedded with volcanic sandstone in the ridges west of Guayabal. The basal few meters of the formation consist of abundant, angular, medium-green and yellowish-green vitric clasts and subordinate clasts of plagioclase and hornblende in an abundant algal calcarenite matrix. Thickness of the formation is estimated at more than 2000 m

Tc CUEVAS LIMESTONE (EOCENE)—Chiefly massive calcarenite-calcirudite with 80 percent or more of white to pale-gray calcareous algae clasts in a pale-brown, or locally near the base, pale-pink calcilutite matrix. Upper 5-10 m is medium-bedded and composed of abundant large foraminifers, clasts of calcareous algae, and sparse to common yellowish-green vitric clasts like those in the base of the Monserrate. Locally includes two thin (15-20 cm) beds of hematite-red volcaniclastic breccia in the outcrops between Hacienda Las Megas and Hacienda Guayo. Maximum thickness known is about 50 m

LAGO GARZAS FORMATION (UPPER CRETACEOUS)—Massive lava, volcaniclastic breccia, sandstone, and tuff

Kgs Tuff, sandstone, and conglomerate—Predominantly thin- to very thin-bedded, pale-yellow, light-green, and light- to pale-brown air-fall tuff, with subordinate light- to dark-green volcaniclastic sandstone and conglomerate, interbedded locally with dark red-brown or purple volcaniclastic breccia; interbedded with and overlies lava at the top of Kgbl

Kgbl Lava, breccia, volcaniclastic sandstone, and tuff—Dark red-brown, and purple amygdaloidal and porphyritic lava, dark-red volcanic breccia, and coarse-grained red and red-brown volcaniclastic sandstone-tuff. Lava consists chiefly of dark-red or purple fine-grained groundmass with sparse, large (as much as 1 cm) and conspicuous phenocrysts of plagioclase and augite. Amygdules of crystalline quartz and chalcedoney are abundant, locally composing as much as 60 percent of the rock. Volcaniclastic breccia and coarse volcanic sandstone in the Vayas area contain red-brown and purple lithic clasts of the lava described and light-green and light-gray porphyritic rocks like those in the Maravillas. Some of the volcanic sandstone has very angular and abundant augite and plagioclase clasts, and the rock may be pyroclastic in origin

Kgy INTERBEDDED LAGO GARZAS AND YAUCO FORMATIONS (UPPER CRETACEOUS)—Either formation may compose from 20 to as much as 80 percent of the unit

Ky YAUCO MUDSTONE (UPPER CRETACEOUS)—Light yellowish gray-brown weathering, dark blue-gray and greenish-gray where fresh, chiefly siltstone, fine-grained sandstone, claystone, mudstone, and sparse conglomerate, all are calcareous. Distinguished from the Lago Garzas with which it is interbedded to the west by the absence of distinctive red or purple lithic volcanic clasts and the absence of augite-rich crystal tuff

Klc LIMESTONE OF CERRILLOS (UPPER CRETACEOUS)—Thick (1-3 m) beds of dark-gray or dark gray-brown calcirudite separated by thin to medium (2 mm-20 cm) beds of calcarenite. Calcirudite consists of abundant white clasts of radiolitid rudist fragments in a dark-gray calcilutite matrix; calcarenite beds are nonfossiliferous and contain abundant pyrite and carbon. The calcarenite beds have a fetid odor when freshly broken

Kc COAMO FORMATION (UPPER CRETACEOUS)—Massive dark red-brown volcanic breccia; contains abundant well-rounded to angular, dark red-brown, light-gray, and gray-green porphyritic volcanic rocks, augite-plagioclase andesite, in a very clayey volcanic sandstone matrix. The admixture of abundant rounded resistant rock types with angular rocks of the same type, the predominance of clay in the matrix, and the absence of shards or fine-grained or vitric clasts with bogen structure suggest that the deposit is a flanglomerate composed of mudflows. The Coamo typically weathers to a red-brown saprolite in which clast outlines and rock textures are well preserved

Kcf Lava flows—Dark greenish-brown andesite(?) with sparse pseudomorphs of calcite and clay after plagioclase phenocrysts and common pseudomorphs of chlorite after mafic minerals in a fine-grained groundmass of microporphyritic plagioclase and chlorite. Generally massive, but locally flow banded; sparse vesicles. Weathers to dark-brown or reddish-brown fine clayey soil

Km MARAVILLAS FORMATION (UPPER CRETACEOUS)—Medium- to thick-bedded (15-60 cm), dark red-brown to dark reddish-purple volcanic conglomerate, conglomeratic sandstone, and locally calcareous mudstone and well sorted plagioclase-hornblende crystal tuff. Conglomerate and sandstone contain abundant, rounded, porphyritic dark red-brown, light-gray, and light gray-green augite-plagioclase andesite lithic clasts, some very fine grained dark red-brown, aphyric volcanic lithic clasts, and abundant angular to subrounded, smaller clasts of plagioclase, augite, some quartz, and sparse but conspicuous detrital magnetite in a dark-red clay matrix. The conglomerate-sandstone facies weathers to a dark red-brown saprolite. Outcrops on the north border of the quadrangle consist of thinly laminated calcareous mudstone with angular lithic clasts of fine-grained volcanic rocks, chiefly red, green, and gray. Westernmost outcrops are largely replaced by pistacite, calcite, quartz, and chlorite, but the original rock appears to be a well-sorted plagioclase crystal-tuff with sparse hornblende

Ka ACHIOTE CONGLOMERATE (UPPER CRETACEOUS)—Interbedded massive (2-5 m) dark gray-green epiclastic volcanic conglomerate and medium- to thick-bedded (3-40 cm) epiclastic volcanic sandstone, mudstone, and siltstone. Conglomerate is composed of as much as 60 percent of well-rounded boulders of porphyritic volcanic rock, generally augite andesite, in a clayey epiclastic volcanic sandstone matrix. Finer grained facies are composed of lithic clasts like those described in a clayey matrix

Kct COTORRA TUFF (UPPER CRETACEOUS)—Very dark gray, massive autoclastic volcanic breccia composed of angular, porphyritic, fine-grained, to dense basalt clasts with abundant phenocrystic and autoclastic augite and some plagioclase. Some dense porphyritic pillowed basalt flows like the clasts described. Both lithic and mineral clasts and pillows held in a calcareous and locally zeolitized matrix. Rock is a typical hyaloclasite

Contact—Long dashed where approximately located; short dashed where inferred

Fault—Long dashed where approximately located; short dashed where inferred; dotted where concealed. D, downthrown side; U, upthrown side; wrench faults and relative directions of movement shown by arrows

Gravity glide fault—Sawteeth on upper plate. Dashed where approximately located

Gravity glide fault or thrust fault—Sawteeth on upper plate

Folds showing crestline or troughline and direction of plunge or plunge where known—long dashed where approximately located; short dashed where inferred; dotted where concealed

- Anticline
- Syncline
- Overturned syncline

Bearing and plunge of minor fold axis

- Anticline
- Syncline

Bearing and plunge of minor overturned fold axis

- Anticline
- Syncline

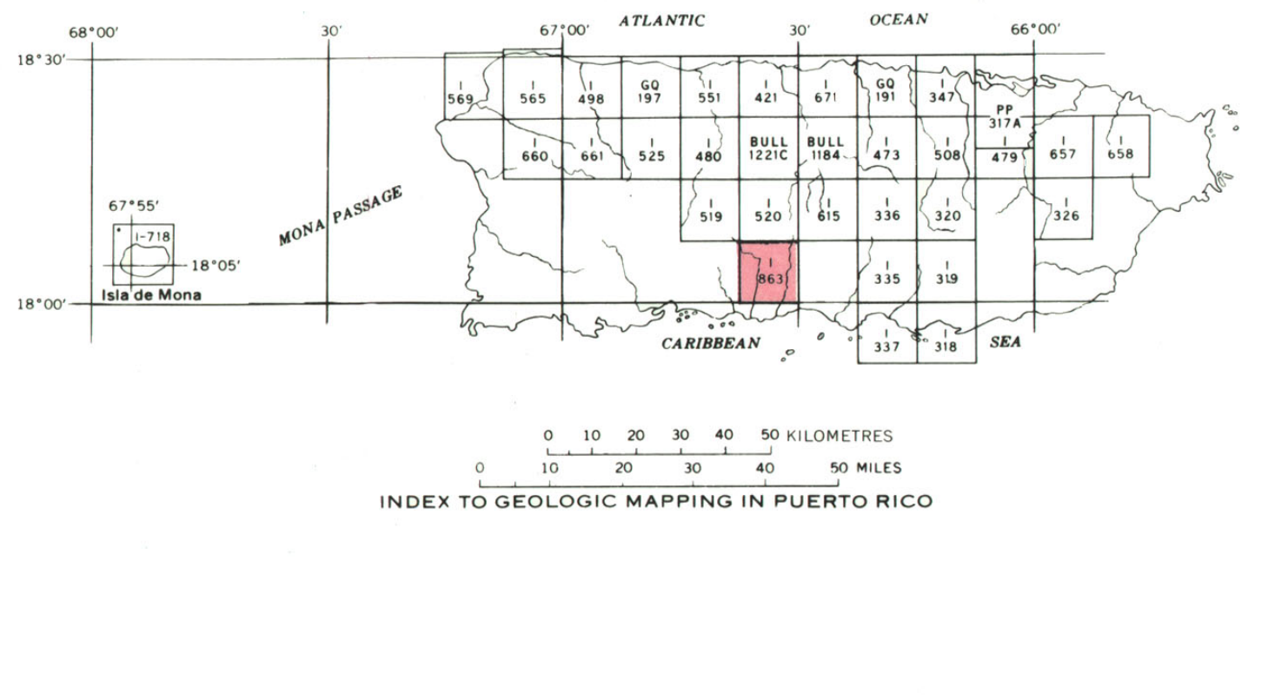
Shear zone

S-shaped quartz-filled fracture

Strike and dip of beds

- Inclined
- Overturned
- Vertical
- Horizontal

Top determination from graded bedding or crossbedding



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