U. S. Geological Survey.

REPORTS-OPEN FILE SERIES, no. 76-126:

Open File 76-126

Contains text, explanation, + description of units.

Preliminary geologic map of the Humacao quadrangle, Puerto Rico

by John M'Gonigle

Introduction

The Humacao quadrangle is underlain by a Lower to Upper Cretaceous volcanic sequence of intrusive, extrusive, and volcaniclastic rocks, by part of the Upper Cretaceous San Lorenzo batholith, and smaller stocks and intrusive bodies ranging to Lower Tertiary in age. Quaternary surficial deposits cover about a third of the quadrangle, and soil or saprolite has formed on most of the upland areas.

TM
TWonroe

Two major northwest-trending transcurrent fault zones divide Puerto Rico into northeast, central, and southwest tectonic-stratigraphic blocks. The Cerro Mula fault zone separates the northeast block from the central block. Volcanic units to the north or to the south of the Cerro Mula fault zone can be correlated laterally with units in other areas within their respective blocks, but not across the fault zone. The San Lorenzo Batholith, the largest of two granodiorite batholiths occurring in the central block, underlies much of the western part of the quadrangle.

Early references to the general geology of the region are those by Lobeck (1922), Fettke (1924a), and Meyerhoff (1933), and to the magnetite deposits in the area by Fettke (1924a and b), Jackson (1934), and Colony and Meyerhoff (1935). The Humacao quadrangle was investigated by J. P. Owens and R. B. Guillou during 1954-1955 as part of a mapping program in southeastern Puerto Rico. Limited investigations of surficial deposits in the quadrangle were made after 1955 by W. H. Monroe.

Reproducible only in map drawer

The terminology for volcaniclastic rocks used in this report is largely that of Fisher (1960, 1961, 1966), and for bedding thickness, that of Ingram (1954). The classification of plutonic rocks is principally that of the International Union of Geological Sciences (Streckeisen, 1973), modified as proposed by Lyons (1976).

Volcanic rocks

The Pitahaya (Kp) and Río Abajo (Kra) Formations (M'Gonigle, in press) south of the Cerro Mula fault zone are correlated, respectively, with formation K and formation J of the Comerío quadrangle (Pease and Briggs, 1960), and also to formations D and A of the Cayey quadrangle (Berryhill and Glover, 1960). These quadrangles lie about 17 km west of the Humacao quadrangle. Formations K and D are now considered to be equivalent to the Torrecilla Breccia, according to Briggs, 1969. While the San Lorenzo batholith largely forms a barrier to eastward extension of units from central Puerto Rico, M'Gonigle and Rogers were able to trace upper portions of the Torrecilla Breccia from the Comerío quadrangle eastward across the Caguas and Juncos quadrangles to the Humacao quadrangle. These volcanic facies, undivided on the west (Broedel, 1961), trace into a narrow zone of the upper Pitahaya Formation in the Humacao quadrangle along the north side of the batholith. The upper part of the Pitahaya Formation is, therefore, thought to represent an eastern facies of the Torrecilla Breccia. Limestone beds in the Pitahaya near Melillas do not correlate with the Aguas Buenas Limestone of the Caguas quadrangle, but rather are discontinuous beds higher within the section, and are similar to those found elsewhere in the easternmost outcrops of the Torrecilla Breccia (Briggs, 1969).

The Río Abajo formation could not be traced around the batholith, but as the crystal tuffs, conglomerates, sandstone, and particularly the polymict tuff-breccia units of formation A in the Cayey quadrangle are very similar to those of the Río Abajo Formation in the Humacao quadrangle, the Río Abajo is tentatively correlated with formation A. The Río Abajo and Pitahaya Formations are in fault contact in the Humacao area, but it is postulated that the regional unconformity between the Torrecilla Breccia and underlying formations such as formation A (Briggs, 1969) probably extends this far eastward, and is present between the Pitahaya and the underlying Río Abajo Formation.

The Daguao Fromation (Kd) is best developed directly east of the Humacao quadrangle in the Naguabo quadrangle, where it largely underlies, but also interfingers in its uppermost parts with the Lower Cretaceous Figuera Lava (M'Gonigle, in press). The Figuera Lava is structurally missing in the Humacao quadrangle, and the Daguao Formation is the oldest unit in the Humacao quadrangle north of the Cerro Mula fault zone. As the Lomas Formation is in fault contact with other units in the Gurabo, El Yunque, and Humacao quadrangles, its exact stratigraphic position is unknown, but presumably it is Upper Cretaceous in age (Seiders, 1971 a, b). The much altered Mambiche sequence is tentatively correlated with the Lomas Formation.

Rocks of the San Lorenzo Batholith

The San Lorenzo batholith is exposed over an area of about 500 square km in southeastern Puerto Rico. In the Humacao area, it includes rocks ranging in composition from gabbro to quartz monzonite. The oldest and most heterogeneous part of the batholith is that of a diorite-hornblendite complex south of Humacao; while it contains a larger amount of coarse-grained hornblendite, it otherwise resembles a diorite pluton mapped by Rogers in the Punta Guayanés quadrangle to the south. That pluton gave potassium-argon ages of about 78 million years (Rogers, in press; Cox and others, in press). Both of these dioritic masses were engulfed and presumably reheated by the granodiorite of San Lorenzo, and the radiometric age might be minimal. Several relative ages may be recognized within the Humacao dioritic complex. The medium light gray, medium-grained hornblende diorite in the northern part of the ridge is complexly intermixed with the dark, fine-grained hornblendite, and the two rock types are contemporaneous over all; they may be somewhat younger than the dark diorite and coarse hornblendite, which in at least one location form xenoliths in the medium light gray diorite; lastly, a dark gray hornblende gabbro intruded the medium light gray hornblende diorite and fine-grained hornblendite mass along the northeastern corner of the ridge. The various rock types of the diorite-hornblendite complex are, however, more akin to one another than to any of the other plutonic rocks in the batholith, and it is felt that their age differences are slight.

The granodiorite of San Lorenzo (Kl), informally named by Rogers (in press), makes up the greater portion of the San Lorenzo batholith and is the dominant plutonic rock in the Humacao quadrangle. It is broadly homogeneous, being mostly of granodiorite with only local gradations to quartz diorite and quartz monzonite in the Humacao quadrangle. Presumably the pluton would, therefore, be approximately the same age throughout. Potassium-argon ages for three widely separated samples from the pluton give an average age of 73 million years on hornblende crystals, but in two of these samples biotite ages are discordant (younger), which is interpreted as an effect of reheating of the rock by local younger intrusives (Rogers, in press; Cox and others, in press). Contacts of the granodiorite with volcanic rocks are farily well defined in the quadrangle and seem to be intrusive. Dikes of aplite, pegmatite, and basic materials and quartz veins are common throughout the granodiorite but only the larger ones were plotted on the map.

The granodiorite of the Punta Guayanés plutonic complex (Kg), informally named by Rogers (in press), forms the youngest plutonic masses in the batholith. A sample of the granodiorite from the Punta Guayanés quadrangle gave a potassium-argon age of 66 million years (Rogers, in press; Cox and others, in press). The absolute age of the stock north of Las Piedras that is correlated with this granodiorite is unknown.

Stocks

The exposures of granodiorite centered around the town of Río Blanco are thought to be part of one stock, as indicated on the map by the buried contact symbol. It may have been emplaced after movements along the Peña Pobre fault zone as discussed in the section on structural geology. Diorite and granodiorite dikes cutting the hydrothermally altered Mambiche sequence and the altered granodiorite(?) stock (Khag) along the eastern border of the quadrangle are possibly related to the stock around Río Blanco and to similar dikes north of that stock. The dikes cutting the altered rocks seem unaffected by the hydrothermal alteration and presumably are younger. A sample from the El Yunque quadrangle of the Río Blanco quartz diorite stock, the southern part of which is exposed along the northern border of the Humacao quadrangle, gave a potassium-argon Eocene age of 46 million years (Cox and others, in press). The age of the other stocks in the northern Humacao quadrangle is uncertain; the granodiorite one around the town of Río Blanco is probably Late Cretaceous, as is the hydrothermally altered granodiorite(?), whereas the small hornblende quartz diorite intrusions north of Maizales may well be Tertiary, emplaced about the same time as the Río Blanco stock along the northern border of the quadrangle.

Structure

In the Humacao quadrangle, as in other parts of eastern Puerto Rico, folding seems to be minor and subordinant to faulting, although good outcrops providing reliable observations on stratigraphic attitudes are too widely spaced to make this statement unequivocally. Some normal faults in the quadrangle seem to predate both the emplacement of plutons and related dikes and the latest movement along transcurrent faults which displace the faults or against which they terminate.

South of the Cerro Mule fault the north-trending Pitahaya fault juxtaposes the Pitahaya and the underlying Río Abajo formations; the stratigraphic displacement on this fault is probably several hundred meters. Locally dikes of dioritic material were intruded along the fault zone. A parallel fault with minor displacement lies about a kilometer to the west.

The overall configuration and topographic expression of the Pitahaya and Río Abajo formations is suggestive of a fracture pattern with northeast to north-northwest trends. As an example, the north-northeast trend of the valley past Melillas suggests structural control; to the south a straight contact of the batholith with the Pitahaya Formation east of Las Piedras is in alignment with this valley, enhancing the impression of a structural trend.

The portion of the Pitahaya Formation in the northwest-trending ridges east and north of Melillas is possibly a repeated section. This is suggested by a repetition of lithologies in these ridges with those found in the ridge called Cerro Collores to the south. Fettke (1924) suggested a repetition of the stratigraphy in this area by synclinal folding, but the rocks dip northward rather uniformly, and I postulate repetition along a normal fault that trended westerly past Melillas. There is no evidence that the northern part of the San Lorenzo batholith has been faulted here or in the Juncos quadrangle, so the normal faulting would predate emplacement of the pluton.

Most of the faults with northeast to northwest trends north of the Cerro Mula fault seems to be normal, with relatively moderate displacements, although Seiders (1971 a and b) found evidence for right-lateral movement along the fault between the Lava and volcaniclastic parts of the Lomas Formation which extends into the northwestern corner of the Humacao quadrangle.

A north-trending normal fault which bounds the west side of an uplifted and northward-thrust block of the Daguao Formation has been offset by differential movement along the Maizales and Peña Pobre faults. Northwest of Maizales the Lower Cretaceous Daguao and Fajardo Formations are juxtaposed along the north-trending fault, while to the south the Daguao and Upper Cretaceous Lomas Formations are inferred to abut beneath the alluvial cover along the offset north-trending fault. Hence movements along the Maizales fault include both normal faulting, with a considerable but unknown amount of vertical stratigraphic displacement between the Lomas and Fajardo Formations, and also 500 to 700 m of left-lateral offset.

The Peña Pobre fault zone merges westward into the Cerro Mula fault ; between 2 and 3.5 km left-lateral movement along the Peña Pobre fault is estimated from the offset of the inferred western limit of the Daguao south of the fault, a short distance (0.3 to 1 km) to the east in the Naguabo quadrangle.

Movement on the Peña Pobre fault is interpreted as having preceded the emplacement of the granodioritic stock around the town of Rio Blanco; although the Lomas Lava and Mambiche sequence south and west of the stock are locally much sheared, no comparable shearing was found in the granodiorite or along its southern contact with the volcanics. To the east in the Naguabo quadrangle, another granodiorite stock, apparently unsheared, lies athwart the zone where the Peña Pobre fault might have extended; perhaps the emplacement of the stocks, which are elongated in an east-west direction, tended to extend along this linear structure.

The Peña Pobre fault is subsidiary to the Cerro Mula fault, along which, from a consideration of regional stratigraphic facies, left-lateral displacement is estimated to have been at least 33 km in northern Puerto Rico (Briggs and Pease, 1968; personal communication, 1976). Earlier regional maps (Briggs, 1964; Briggs and Akers, 1965; Cox and Briggs, 1973) showed an inferred eastward extension of the Cerro Mula fault across the Humacao quadrangle through the center of the hydrothermally altered area along the Quebrada de las Mulas. The present study suggests that major movement took place south of the hydrothermally altered area, although additional undetected faults may well be present in the altered area, for where less altered, the surrounding Mambiche sequence commonly shows a fair amount of shearing. Regionally, structural control of hydrothermal alteration in northern and central Puerto Rico is indicated by the distribution of alteration along belts of structural weakness, largely adjacent to the Cerro Mula and nearby transcurrent faults (Pease, 1960; Hildebrand, 1961; Cox and Briggs, 1973). The altering fluids were probably derived from the magmas that gave rise to the batholiths and stocks in the region (Hildebrand, 1961).

Slight to moderate dislocations of the hydrothermally altered rocks in north central Puerto Rico indicate that some transcurrent movements took place after the alteration, dated by one sample from the Naranjito quadrangle which gave a potassium-argon age of 75 million years (Cox and others, in press). There is no direct evidence concerning the age of transcurrent faulting along the Cerro Mula fault in the Humacao quadrangle. If, however, the dioritic dike north of Antón Ruíz which is cut by the Cerro Mula fault is related to the San Lorenzo batholith, as seems likely, then some of the movement along the fault may be younger than the batholith. Transcurrent faulting in Puerto Rico probably took place over a considerable period of time, judging from the amount of dislocation that has taken place, and very probably the majority of the structures in the Humacao quadrangle and environs formed in response to the large-scale regional stresses that also caused the transcurrent movements.

Little structural deformation related to the emplacement of the San Lorenzo batholith is recognizable in the quadrangle. As previously noted, normal intrusive contacts seem to prevail; the granodiorite has a strongly gneissic texture and shows shearing parallel to the foliation and to the contact with metavolcanic schists (Kram) in only one area, southeast of Humacao. Within the main body of the batholith the scattered primary foliations and lineations show no particular structural pattern. North of the Río Humacao the volcanic cover was probably not far above the present erosional surface of the batholith; a remnant of this roof can be seen in the northwest-trending ridge (Cerro Collores) south of Melillas, where the plutonic rocks underlie rocks of the Pitahaya Formation in an almost horizontal contact (see cross-section A-A'). South of the Río Humacao the plutonic rocks attain higher elevations than that contact, which may reflect primary doming or a higher level of intrusion towards the central part of the batholith. Uplift to the south may also have taken place along an inferred fault along the Río Humacao and along a 15 meter wide mylonite zone, which plunges steeply southwest and trends northwest at a small angle to the river valley. Slickensides on surfaces of parallel small faults in and immediately adjacent to the mylonite zone suggest a reverse and southeastward movement for the block on the southwestern side of the mylonite zone.

Economic Geology

Appreciable quantities of magnetite are present in the quadrangle in deposits in the diorite-hornblendite complex (Kdh) and in the Pitahaya Formation (Kp), locally associated with marble and limestone beds. The diorite-hornblendite complex was apparently explored in 1899 and several exploratory tunnels were driven in search of ore, but these were abandoned after 1902 (Colony and Myerhoff 1935). Cadilla (1963) made a further study and a magnetic survey of the iron deposits of the complex; it is not known if any other evaluations or development of the deposit have since been attempted by commercial interests.

The deposits in the Pitahaya Formation have been intermittently investigated since the early 1900's; Knoerr (1952) states that an exploratory adit was made in 1905 in the deposit that is 600 meters directly southeast of Cerro Collores, although Fettke (1924 a,b) makes no mention of this. The deposit was developed (open pit) in 1951-1952 as the Island Queen mine (Knoerr, 1952) and apparently some ore was shipped; the mine is not being worked at the present time. Abandoned equipment and excavations are present along the magnetite deposits on the southwest side of Cerro Collores, but there seems to be no information available about these operations. Apparently the magnetite deposits in the quadrangle are too small and irregularly distributed to be profitably mined at present.

Hildebrand (1961) suggested that alunite and pyrophyllite, found locally in the hydrothermally altered rocks in the quadrangle, might have several commercial uses, but the deposits have not been developed.

Volcanic rocks have been excavated from small borrow pits and quarries throughout the quadrangle for use as fill and road metal, and there are two fairly large quarries in the granodiorite (Klg) along the Río Humacao west of Humacao which produce fresh crushed rock for various construction purposes. The volcanic rocks vary so in make up that it is difficult to characterize their behavior for different applications, but in general the more easily excavated materials tend to be weathered and have a high clay content, and so would make poor aggregate. Fill made of such material drains more poorly than fill made from fresh volcanic rocks such as lava flows, crystal tuffs, and tuff breccias which often need to be crushed before use.

Sand and aggregate for concrete is much sought after in Puerto rico, but mining the obvious source of supply- beach sand- is curtailed by law. Quartz-rich sand and gravel derived from plutonic rocks of the San Lorenzo batholith could be obtained from the alluvial deposits along the lower reaches of the Río Humacao. The younger granodiorite (Kg) is quartz-rich, rather friable, and hence could probably be fairly easily crushed to produce good aggregate; the unit is, however, much more widespread in the Punta Guayanés quadrangle.

Engineering Geology

Areas covered by extnesive alluvial deposits should be investigated fairly carefully for bearing strength and subsurface drainage characteristics if construction of heavy structures are being considered, as these factors can vary considerably over short distances. The possibility of flooding and erosion of the alluvial material is, of course, always a problem to be considered in selecting construction sites along major streams.

Weathering has locally produced a deep soil and saprolite cover on all rocks units in the quadrangle, which, in combination with steep slopes, can produce unstable conditions for construction. Where fresh bedrock can be reached by removal of cover or by footings, the various rock units would provide adequate bearing strength for most purposes.

The Pitahaya Formation appears to be the unit most prone to landsliding. For example, an old, relatively large slide or mudflow deposit appears to underlie part of the town of Melillas. It originated in a valley on the northern side of Cerro Collores. It is not known if climatic conditions were different from those of the present when this slide developed, but as a precaution, and as the city of Humacao expands, it might be well to investigate the stability of earth materials in the head and walls of valleys in the Pitahaya Formation prior to locating major structures or housing developments in such areas.

Excavations expsoing relatively unweathered lava in the Pitahaya Formation may give the impression that solid bedrock has been reached. Locally such lava may, however, occur in a relatively thin layer over weathered tuff beds, and a cut may ultimately prove unstable.

References

Berryhill, H. L., Jr., and Glover, Lynn, 3d, 1960, Geology of the Cayey quadrangle, Puerto Rico: U.S. Geol. Survey Misc. Geol. Inv. Map I-319.

Briggs, R. P., 1964, Provisional geologic map of Puerto Rico and adjacent islands: U.S. Geol. Survey Misc. Geol. Inv. Map I-392.

_____, 1969, Changes in stratigarphic nomenclature in the Cretaceous System, east-central Puerto Rico: U.S. Geol. Survey Bull. 1274-0, 31 p.

Briggs, R. P., and Akers, J. P., 1965, Hydrogeologic map of Puerto Rico and adjacent islands: U.S. Geol. Survey Hydro. Inv. Atlas HA-197.

Briggs, R. P., and Pease, M. H., Jr., 1968, Large- and small-scale wrench faulting in an island-are segment, Puerto Rico [abs.]: Geol. Soc. America Spec. Paper 115, p. 24.

Broedel, C. H., 1961, Preliminary geologic map showing iron and copper prospects in the Juncos quadrangle, Puerto Rico: U.S. Geol. Survey Misc. Geol. Inv. Map I-326.

Cadilla, J. F., 1963, Geology of the Humacao titaniferous iron deposit: Caribbean Jour. Sci., v. 3, no. 4, p. 243-247.

Colony, R. J., and Meyerhoff, H. A., 1935, The magnetite deposit near Humacao, Puerto Rico: Am. Inst. Mining Metall. Eng. Trans., v. 115, p. 247-272.

Cox, D. P. and Briggs, R. P., 1973, Metallogenic map of Puerto Rico: U.S. Geol. Survey Misc. Geol. Inv. Map I-721.

Cox, D. P., Marvin, R. F., M'Gonigle, J. W., McIntyre, D. H., and Rogers, C. L., in press, Potassium-argon geochronology of some metamorphic, igneous, and hydrothermal events in Puerto Rico and the Virgin Islands: U.S. Geol. Survey Jour. Research.

Fettke, C. R., 1924a, The geology of the Humacao district, Porto Rico: New York Acad. Sci., Sci. Survey Porto Rico and Virgin Islands, v. 2, pt. 2, p. 117-197.

____________ 1924b, Magnetite deposits of eastern Porto Rico: Am. Inst. Mining Metall. Eng. Trans., v. 70, p. 1024-1042.

Fisher, R. V., 1960, Classification of volcanic breccias: Geol. Soc. America Bull., v. 71, no. 7, p. 973-982.

____________ 1961, Proposed classification of volcaniclastic sediments and rocks: Geol. Soc. America Bull., v. 72, no. 9, p. 1409-1414.

____________ 1966, Rocks composed of volcanic fragments and their classification: Earth-Sci. Rev., v. 1, no. 4, p. 287-298.

Hildebrand, F. A., 1961, Hydrothermally altered rocks in eastern Puerto Rico: U.S. Geol. Survey Prof. Paper 424-B, p. B219-B221.

Ingram, R. L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: Geol. Soc. America Bull., v. 65.

Jackson, C. F., 1934, Informe sobre depósitos minerales en Puerto Rico: Revista Obras Públicas Puerto Rico, año 11, no. 6, p. 655-667.

Knoerr, A. W., 1952, Minnesota mining men open up rich Puerto Rico iron mine: Eng. Mining Jour., v. 153, no. 8, p. 74-79.

Lobeck, A. K., 1922, Physiography of Porto Rico: Sci. Survey of Porto Rico and the Virgin Islands, v. 1, pt. 4.

Lyons, P. C., 1976, IUGS classification of granitic rocks - a critique: Geology, v. 4, p. 425-426.

Meyerhoff, H. A., 1933, Geology of Puerto Rico: Puerto Rico Univ. Mon., ser. B., no. 1, 306 p.

M'Gonigle, J. W., in press, The Río Abajo, Pitahaya, and Daguao Formations in eastern Puerto Rico: U.S. Geol. Survey Bull.

Pease, M. H., Jr., 1960, Structural control of hydrothermal alteration in some volcanic rocks in Puerto Rico: U.S. Geol. Survey Prof. Paper 400-B, p. B360-B363.

Pease, M. H., Jr., and Briggs, R. P., 1960, Geology of the Comerio quadrangle, Puerto Rico: U.S. Geol. Survey Misc. Geol. Inv. Map I-320.

Rogers, C. L., in press, Geologic map of the Punta Gayanés quadrangle, Puerto Rico: U.S. Geol. Survey Misc. Inv. Map I-998.

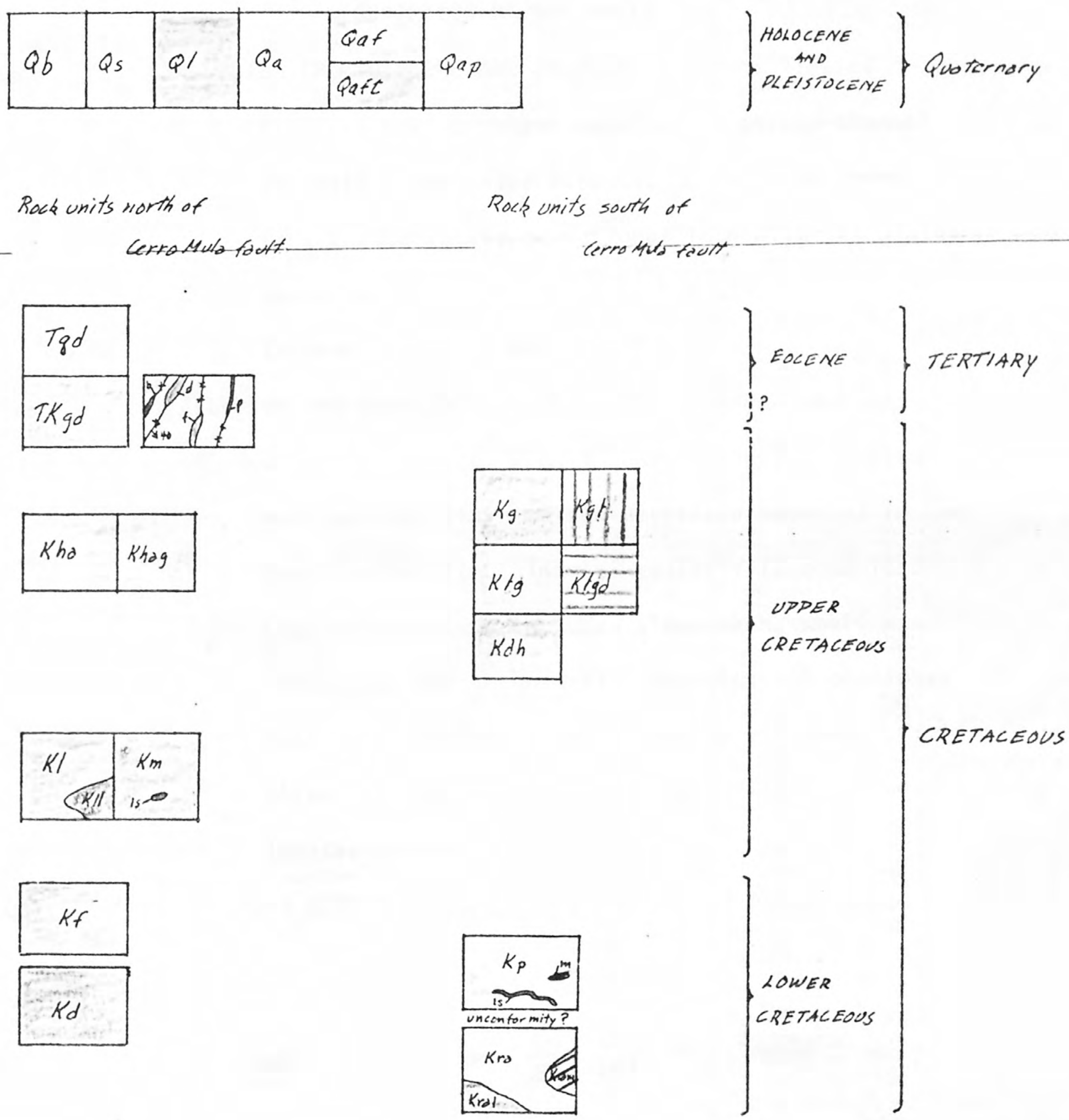
Seiders, V. M., 1971a, Geologic map of the El Yunque quadrangle, Puerto Rico: U.S. Geol. Survey Misc. Geol. Inv. Map I-658.

_____ 1971b, Geologic map of the Gurabo quadrangle, Puerto Rico: U.S. Geol. Survey Misc. Geol. Inv. Map I-657.

Streckeisen, A. L., Chairman, 1973, International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks, Plutonic Rocks. Classification and nomenclature recommended by the IUGS Subcommission on the Systematics of Igneous Rocks: Geotimes, v. 18, no. 10, p. 26-30.

Open File 76-126

U. S. Geological Survey
OPEN FILE MAP 76-126
This map is preliminary and has not been edited for conformity with Geological Survey standards or nomenclature.



Humacao Quadrangle

M'Gonigle

DESCRIPTION OF MAP UNITS

Qa ALLUVIUM (PLEISTOCENE AND HOLOCENE)--Unconsolidated clay- to boulder-sized material in stream-channel deposits along major streams. Locally includes fans and terraces; gradational into alluvial plains deposits.

Thickness locally exceeds 10 m

Qaf ALLUVIUM AND FANGLOMERATE (PLEISTOCENE AND HOLOCENE)--Unconsolidated to weakly consolidated, poorly-to well-sorted, clay- to boulder-sized material in fans and in stratified alluvial valley-fill deposits. Locally terraced; includes slope wash, small landslides and channel-fill deposits. Gradational into units mapped as predominantly alluvium, alluvial plain, and terraced deposits. Thickness locally more than 25 m

Qaft TERRACED DEPOSITS--Terraced alluvium and fanglomerate

Qap ALLUVIAL PLAIN DEPOSITS (PLEISTOCENE AND HOLOCENE)--Unconsolidated to consolidated stratified alluvial deposits on broad, seaward-sloping plains. Composed of clay- to boulder-sized detrital material; interfingered with and overlying Holocene (surficial) beach deposits, and may include older beach and other marine materials at depth. Gradational into units mapped as alluvium and as alluvium and fanglomerate. Thickness probably more than 30 m locally

Ab BEACH DEPOSITS (PLEISTOCENE (?) AND HOLOCENE)--Unconsolidated fine- to coarse-grained sand and pebble deposits mainly of quartz and feldspar grains and plutonic and volcanic rock fragments. Locally includes shell, algal, and coral fragments and considerable magnetite. Gradational into, and partly overlain by, alluvial plains deposits. Thickness probably more than 10 m locally.

Qs SWAMP DEPOSITS (HOLOCENE)--Black to dark brown organic-rich soil and much in poorly drained part of alluvial plains. In large part covered with mangrove. Thickness probably as much as 5 m

Ql LANDSLIDE DEPOSITS (PLEISTOCENE(?) AND HOLOCENE)--Slumps and earthflows on weathered slopes involving masses of soil and rock fragments of varied sizes, including boulders and blocks. Thickness locally more than 10 m

Tqd QUARTZ DIORITE (TERTIARY)--Light gray, medium- to coarse-grained unfoliated rock along northern border of quadrangle, a part of the Rio Blanco stock which is centered in the El Yunque quadrangle. Seiders (1971 a) found the typical mineral composition to be 26.0 percent quartz, 5.0 percent orthoclase, 55.8 percent plagioclase, 7.3 percent hornblende, 3.6 percent biotite, 0.7 percent iron oxides, 0.2 percent apatite, and 1.4 percent fine-grained alteration products and accessory minerals; he considered the rounded to angular more mafic segregations that are common in the unit to be xenoliths

Tkgd GRANODIORITE AND QUARTZ DIORITE--(UPPER CRETACEOUS AND TERTIARY(?)--Light gray to light olive gray, medium-grained unfoliated rock with hypidiomorphic-granular texture in stock(s) north of the Pena Pobre fault (zone). Composition ranges from granodiorite to quartz diorite, with hornblende the predominant mafic mineral. Rounded mafic xenoliths are scattered throughout the rock. The stock(s) centered around the town of Rio Blanco are weathered and altered, to chlorite, epidote, sericite, and minor carbonate and clay. The small intrusions just north of Maizales are of largely unaltered hornblende quartz diorite

DIKES (UPPER CRETACEOUS AND TERTIARY(?)--(b), Dark gray fine-grained adnesitic dikes, locally porphyritic with plagioclase and/or pyroxene phenocrysts; (f) light-gray, fine- to medium-grained aplite dikes and associated quartz veins; (d), light to medium light gray and brownish medium-grained hornblende diorite and hornblende granodiorite dikes, and fine-grained quartz-bearing dacite dikes; (p), light gray pegmatitic dikes.

Kha
Khag

HYDROTHERMALLY ALTERED ROCK (UPPER CRETACEOUS)--Kha-Hydrothermally altered volcaniclastic rocks and lavas. Light gray to white to yellowish-gray rock; ranges from very siliceous and hard to locally earthy, clay-rich and soft. Where more intensely alterated, original textures are destroyed. Contacts often fairly sharp and well-defined, but also gradational. Near the town of Río the mineral assemblages include quartz, alunite, pyrophyllite, diaspore, zunyite, and barite; near Junio include quartz, sericite, alunite, zunyite, and jarosite (Hildebrand, 1961). Khag - light yellowish gray altered granodiorite(?)

Kg GRANODIORITE OF THE PLUTONIC COMPLEX OF PUNTA GUAYANES (UPPER CRETACEOUS)--Light-gray to yellowish-gray, medium-grained unfoliated and rather friable rock with a hypidiomorphic-to allotriomorphic-granular texture. Average composition of the complex in the Punta Guayanés quadrangle to the south is granodiorite, ranging to quartz monzonite and to tonalite (Rogers, in press). Along the southern border of the Humacao quadrangle the unit is a quartz monzonite (adamellite), with 33% plagioclase (oligoclase to andesine), 25% potassic feldspar, 39% quartz, about 2% chloritized biotite, and minor magnetite and apatite. Some of the quartz is in graphic intergrowth with the feldspars. A characteristic feature of the unit is that some of the quartz occurs as embayed to rounded dipyramidal crystals, particularly along contacts with the older granodiorite (Kgl). North of Las Piedras is a stock of grayish-orange-pink, medium- to coarse-grained granodiorite that is tentatively correlated with the granodiorite of the plutonic complex of Punta Guayanes. The plagioclase in this rock is largely oligoclase, generally microperthitic; the quartz in part is in graphic intergrowth with the feldspars

Kgl MIXED ROCK (GRANODIORITE OF THE PLUTONIC COMPLEX OF PUNTA GUAYANES AND GRANODIORITE OF SAN LORENZO) (UPPER CRETACEOUS)--A locally intricate intermixture of the two granodiorites.

Klg GRANODIORITE OF SAN LORENZO (UPPER CRETACEOUS)--Light gray, medium-grained, hornblende-biotite rock with hypidiomorphic-granular texture. Foliation commonly not developed or faint; where present hornblende and biotite grains are usually randomly arranged within planes, but locally hornblende crystals are parallel and give a lineation to the rocks. A fairly well-developed gneissic texture extends inward for a few hundred metres from the contact of the unit with metavolcanic rocks southeast of Humacao. Rounded, elongate concentrations of mafic minerals (zenoliths) averaging 10 cm in length are scattered throughout the unit; no pattern to their distribution was noted, but they tend to be aligned with any local foliations or lineations. The average modal compoisiton of the unit is that of a granodiorite, with about 14% potassic feldspar, 47% plagioclase (andesine), 25% quartz, 12% hornblende, and 2% biotite. The potassic feldspar (mostly orthoclase, some microcline) frequently tends to occur in patches one to several cm across and be very poikilitic. These patches can be seen megascopically on fresh rock surfaces as glancing light flashes from the overall cleavage plane of the orthoclase. Locally the rock is quartz diorite and

Klg quartz monzonite in compoistion, but these masses were not mapped.

Klgd MIXED ROCK (GRANODIORITE OF SAN LORENZO AND DIORITE-HORNBLENDITE COMPLEX) (UPPER CRETACEOUS)--Intricately intermixed zones of granodiorite and diorite-hornblendite. The larger areas delineated on map have very gradational boundaries with adjacent plutonic units

Kdh DIORITE-HORNBLENDITE COMPLEX (UPPER CRETACEOUS)--Medium light-gray to dark-gray, medium-grained to very coarse-grained heterogeneous rock complex. Locally hornblende crystals have a parallel alignment or a planar arrangement. Exposed in semi-circular ridge south of Humacao. Western and central parts of the ridge largely of dark gray to dark greenish gray coarse- to very coarse-grained hornblende-pyroxene diorite, gabbro, and hornblendite. Clinopyroxene is present in variable amounts but subordinate to hornblende. It occurs as patches within hornblende crystals and locally as anhedral grains. At least some of the hornblende is a replacement of the pyroxene. Large hornblende crystals - mostly 9 cm but as much as 16 cm long-can be seen in some exposures along a north-trending road which corsses the western part of the complex. Plagioclase in the diorite varies from andesine to labradorite, in general becoming more clacic from the base towards the crest of the ridge; concomitantly it decreases upwards in amount; rocks along the crest are mostly pyroxenites. Magnetite grains are largely concentrated in hornblende, average 1-2mm in size and commonly compose 5-10% of the rock; locally magnetite occurs in bands 1 to 10 cm wide in hornblendite.

Kdh

solid pieces of magnetite float are common on north-facing slopes in the central and western part of the ridge. Colony and Meyerhoff (1935) and Cadilla (1963) mention several abandoned exploratory tunnels that exposed veins of magnetite, but these could not be located during this study. Medium-light-gray, generally medium-grained hornblende diorite is widespread in the northern part of the ridge, and is well-exposed in a quarry on the north end and in road cuts along the northeast side of the ridge. The rock contains some light-green clinopyroxene largely replaced by hornblende and some chlorite; most mafics are hornblende. Plagioclase is mostly andesine, with minor labradorite. The diorite is intermixed in a complex manner with dark, fine-grained, flow banded hornblendite; generally the hornblendite has intruded the diorite as dikes and large masses, but the reverse situation also occurs.

A dark-gray, medium-grained hornblende gabbro intruded the medium gray diorite along the north-eastern corner of the ridge. This gabbro has a distinctive mottled texture, wherein the plagioclase (labradorite) tends to be concentrated in 5-to 1-cm wide clusters

Kl LOMAS FORMATION (UPPER CRETACEOUS)--medium-gray, dark-gray, and brownish-gray, very thick-bedded volcaniclastic breccia, crystal-lithic tuff, and sandstone; minor lava. Thickness uncertain; estimated to be more than 1000 m. Matrix of volcaniclastic rocks generally pumiceous and usually with a large amount of plagioclase and/or clinopyroxene, rarely orthopyroxene, crystals. Locally the finer-grained tuffs and sandstones show medium and graded bedding. Subrounded to subangular clasts include porphyritic and amygdaloidal lava, pumice with minute to large spherical amygdules, and a variety of tuffs. Many volcaniclastic breccias aremoderately coarse, with lava clasts more than 20 cm in diameter. Thin dark-gray and brownish-gray flows and dikes with feldspar and pyroxene phenocrysts are scattered throughout the formation, and are mapped as a separate unit (Kll) where prevalent. Most rocks of the formation are altered to chlorite, epidote, carbonate, zeolites, and clays. Most feldspar grains are saussuritized.

Kll Lava flows, medium to very thick bedded, greenish gray, dark gray, and dark brownish gray. Most flows are basaltic andesites which are fine grained, pilotaxitic, with scattered plagioclase phenocrysts, and locally amygdaloidal. Commonly much altered and pyritized in places

Km MAMBICHE SEQUENCE (UPPER(?) CRETACEOUS)--Medium dark gray to moderate brown, medium- to thick-bedded altered volcaniclastic tuff, breccia, sandstone, conglomerate, and lava flows which crop out in the zone of extensive hydrothermal alteration between the Cerro Mula and Peña Pobre faults. Rocks are commonly much sheared and locally foliated; calcite veinlets are common along shear planes. Matrix of volcaniclastic units commonly of plagioclase crystals and pumice fragments, with minor pyroxene and amphibole crystals. Clasts consist of tuff, pumice, and porphyritic lava (as large as 20 cm across in some breccia beds). Most lavas are aphanitic to porphyritic andesites with plagioclase phenocrysts; some have pyroxene and amphibole phenocrysts. One solitary block of marble (ls) about a meter thick and 1 1/2 meters long enclosed in a fine-grained calcareous tuff was found in the hills east of Junio. Epidote, chlorite, carbonate, and probable zeolites replace some original constituents in most units of the sequence; extensively hydrothermally altered areas are grayish yellow to white, and have a soft, clayey to a hard siliceous aspect. Probably correlative with the Lomas Formation; thickness uncertain

Kf FAJARDO FORMATION (LOWER CRETACEOUS).--Principally medium-gray to grayish-brown, laminated to thinly-bedded, graded, fine-grained volcanic sandstone and tuff . Interbedded with thick to very thick-bedded volcaniclastic breccia with clinopyroxene-bearing tuff matrix; 4-200 mm-sized clasts of fine-grained tuff and, occasionally, fine-grained lava . Many of the finer-grained tuffs and sandstones are pyritized and silicified and metamorphosed to hornfelses near the Rio Blanco stock. ABout 1100 m exposed in the quadrangle

Kd DAGUAO FORMATION (LOWER CRETACEOUS)--Interbedded volcanic breccia, lava, and minor volcanic sandstone and crystal tuff. The volcanic breccia is medium gray, massive, and contains dark gray irregularly shaped subangular to subrounded granule- to pebble-size andesitic lava clasts in a medium gray, coarse-grained plagioclase and clinopyroxene crystal tuff matrix. The breccia units are commonly cut by fine-grained and by porphyritic lava dikes. Breccia beds are poorly exposed, generally only in artificial excavations; float seen on natural slopes is largely of lava clasts. Lavas are principally medium-dark-gray andesites with a pilotaxitic texture and andesine-clinopyroxene phenocrysts; they are locally amygdaloidal. Some of these lavas are autoclastic breccias, with porphyritic andesite clasts locally ranging to more than 5 cm in diameter, in a matrix of macerated andesite. Some dark greenish gray, very fine-grained flows are also autobrecciated. Volcanic sandstones and tuffs form dark- to medium-gray units seldom more than a few meters thick, are usually laminated to thin-bedded and graded, and are locally cross-bedded. A few crystal tuffs are hornblende-rich; most sandstones and tuffs have compositions like the matrix of the massive volcanic breccias. Thickness estimated to be at least 600 m

Kp PITAHAYA FORMATION (LOWER CRETACEOUS)--Interbedded lava, autoclastic breccia, tuff, and tuff breccia, with minor conglomerate, marble and magnetite. Lava flows appear to be more abundant in the upper half of the formation. These are dark greenish gray to olive or brownish black andesites, locally thick bedded to massive. Varieties include lava with many clino-phroxene phenocrysts, amygdaloidal lava, fine-grained lava, and autoclastic lava breccias. The lavas most commonly occur as irregular layers, lenses, pods, and fragments within coarse-grained, massive to thick-bedded pyroxene-rich cyrstallithic tuffs. This lava and tuff mixture forms a distinctive and characteristic lithology of the formation. Flows with coarse (1 cm) plagioclase phenocrysts in a dark aphanitic matrix are randomly distributed throughout; a few lenses and pods of hornblende andesite are present; and massive pillow lava is found at several intervals near the top of the exposed section. Most lavas are altered; plagioclase crystals are saussuritized, and secondary minerals include epidote, chlorite, tremolite-actinolite, and iron oxide. Local limestone fillings between lava pillows are recrystallized to marble.

Kp

Crystal tuff and volcanic sandstone, largely of clinopyroxene and plagioclase cyrstals, are medium to brownish gray, thin to medium bedded, and locally graded. Lapilli tuff, tuff breccia, and infrequent conglomerate are similarly colored, and generally thicker bedded. Clasts are polymict, largely of various lavas as described above, but tuff fragments are not uncommon; a few units have some pumice or vitrophyre clasts. Volcaniclastic units are usually epidotized and chloritized; some clay-rich (?) tuffs are phyllitic. Limestone (marble) beds (ls), as much as a meter thick, are found scattered throughout the section on Cerro Collores and in the hill east of Melillas; in a few places skarns have formed. Lenses up to 30 cm thick and massive bodies of fairly pure magnetite (m) locally replace the carbonate beds; magnetite was once mined at the Island Queen mine, located 600 meters southeast of Cerro Colores. Thickness of the formation is estimated to be approximately 2000 m

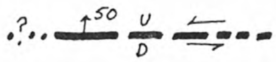
Kra RIO ABAJO FORMATION (LOWER CRETACEOUS)--Tuff and volcanic sandstone, irregularly interbedded with volcanic breccia; minor conglomerate, siltstone, and lava. Coarse, light-colored feldspar crystals in both matrix and clasts give a characteristically speckled aspect to most volcaniclastic rocks of the formation. Coarse- to fine-grained crystal and crystal-lithic tuffs predominate; they are medium gray to brownish gray, commonly massive, but also medium-bedded and graded. Lithic clasts are principally of tuff, less commonly of fine-grained lava and lava with feldspar phenocrysts. The matrix is mainly of plagioclase (andesine) grains; hornblende is the usual mafic mineral, and clinopyroxene is less common. The rocks are commonly altered with epidote, chlorite, calcite, and zeolites the secondary minerals. Less prevalent sandstones are lithologically similar to the tuffs; bedding is generally thin to thick. Minor siltstones are reddish brown and thin-bedded. Widespread polymict breccia units are purplish and medium gray to light olive or brownish gray, and thick bedded to massive. Clasts are subrounded to subangular, composed of tuffs, dark porphyritic andesites, and light-colored lavas with hornblende-pyroxene phenocrysts. Clasts are locally more than

20 cm in diameter. Pumice and vitrophyric clasts are rare. The matrix is generally tuffaceous, and lithologically like the tuff units, but sometimes is wholly epiclastic. Minor medium gray to brownish gray pebble to cobble conglomerates are thick to very thick bedded, have clasts like those of the breccias, and a volcanic sandstone matrix. Some thin dark gray aphanitic lavas, lavas with plagioclase phenocrysts, and autoclastic lava breccias are interbedded with the volcaniclastic units; in the relatively thick lava unit (Kral) near the base of the exposed section, clinopyroxene phenocrysts are replaced by amphibole in an epidotized and chloritized matrix.

Clay-rich volcaniclastic units are locally phyllitic. Along the San Lorenzo batholith they have been metamorphosed to hornblende and mica schists, in which bedding and clastic textures remain discernible. Thickness of the Río Abajo Formation is uncertain, but at least 600 m are exposed in the quadrangle

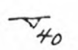
Symbols used

CONTACT--moderately to well-exposed between arrows, dotted where concealed, queried where inferred. Quaternary-deposit contacts approximately located or gradational

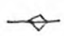


FAULT--long dashed where approximately located; short dashed or queried where inferred; dotted where concealed. U, upthrown side; D, downthrown side; number and arrow shows dip of fault; wrench faults and relative directions of movement shown by parallel arrows on map, by T (toward) and A (away) in cross-sections

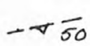
Strike and dip of primary foliation in plutonic rocks. Shown by planar arrangement of mafic minerals and autoliths.



Inclined



Vertical



Inclined, faint

Strike and plunge of lineation of mafic minerals. Dot at point of observation. May be combined with foliation symbol

Inclined

Vertical

Horizontal

Strike and dip of foliation in metavolcaniclastic rocks,

Inclined

Vertical

Strike and dip of beds

Inclined

Overturned

Top determined from graded bedding or cross-bedding

Uncertain if rocks undisturbed
(in place)

Mylonite zone

Dip of foliation in mylonite zone

Shear, showing dip where known

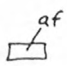
Vertical shear

John W. M'Gonigle

*39-1 Location and field number of sample used for potassium-argon age determination. Hornblende = 74.3 million years; biotite = 65.7 million years (Rogers, in press; Cox and others, in press)

EPIDOTIZED ROCKS--Yellowish-gray to pale olive altered volcaniclastic rocks and lavas. Tremolite-actinolite fibers seen in former vesicles; mafic minerals bleached light-colored; in general original rock textures visible. Most common in the Pitahaya formation around border of San Lorenzo batholith; many altered areas too small to plot on map occur throughout quadrangle.

PILLOW LAVAS--Zones of locally pillowed lavas in the Pitahaya Formation



ARTIFICIAL FILL

QUARRY OR BORROW PIT