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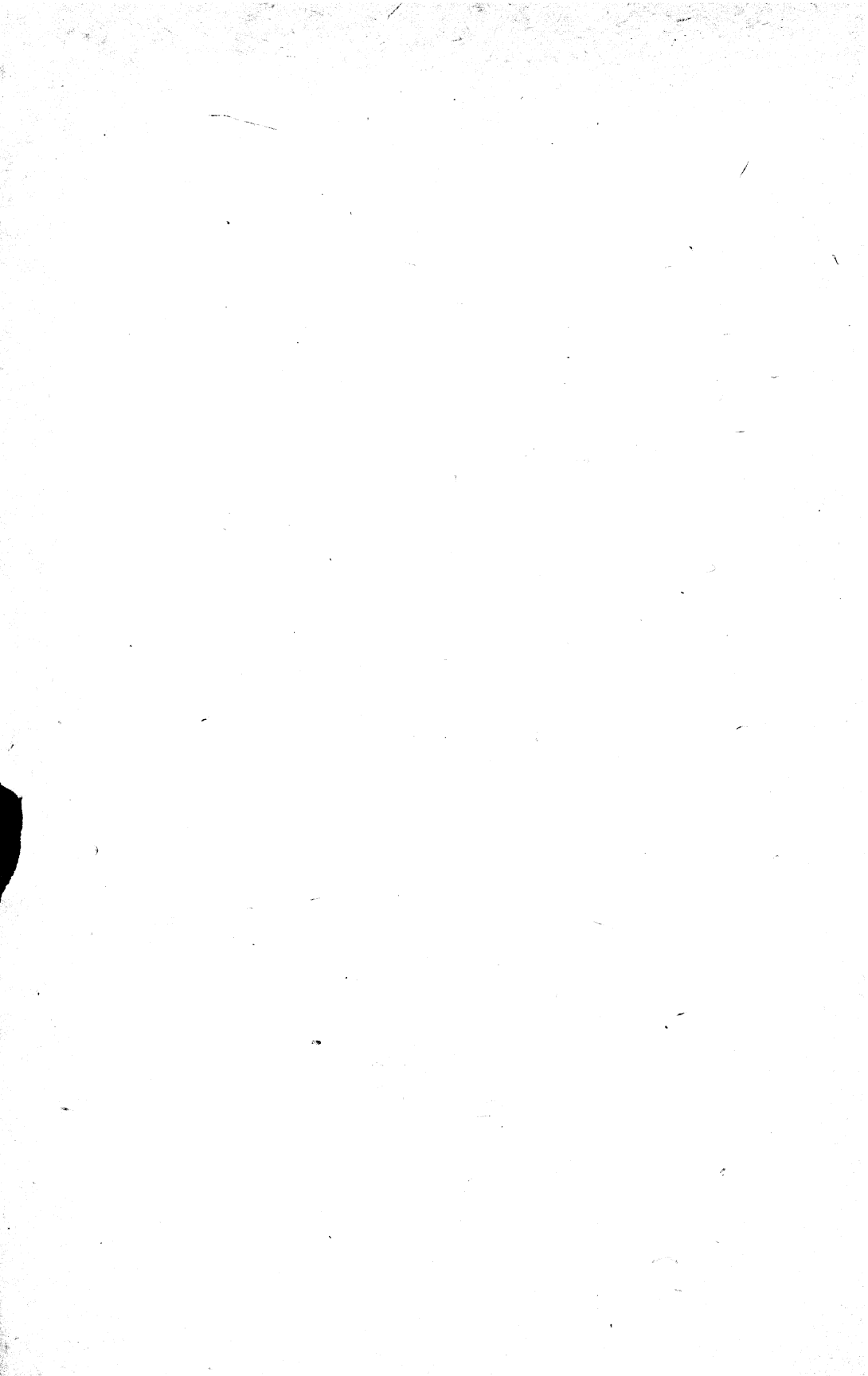
VOLUME II—Part 2

The Geology of the Humacao District, Porto Rico—

Charles R. Fette



NEW YORK:
PUBLISHED BY THE ACADEMY
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BY CHARLES R. FETTKE

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INTRODUCTION

LOCATION OF THE DISTRICT

The district described in this report covers an area of approximately 400 square miles in the extreme southeastern portion of Porto Rico. It has been arbitrarily bounded on the north by the parallel of $18^{\circ} 15'$ north latitude and on the west by the meridian of $65^{\circ} 5'$ west longitude. The Caribbean Sea lies to the south and east. The district has been named after the town of Humacao, the capital of the Department of Humacao, the southern half of which is included within the area described.

Important towns along the coast, starting at the southwestern end, are Arroyo, Patillas, Maunabo, Yabucoa, Humacao, and Naguabo. Interior towns in the northern portion of the area are Caguas, San Lorenzo, Juncos, and Las Piedras. The interior portion of the district is a rugged mountainous area in which only small villages are located. Caguas, in the northwestern corner, is connected with San Juan, the capital of Porto Rico, by an electric and steam railroad. In 1916 construction work was under way to similarly connect Humacao with Caguas. The only other railroad lines in the district have been built along the playas and interior valleys to furnish transportation facilities from the sugar-cane fields to the *centrals* or sugar mills. These are of only light con-

struction and are not connected with one another. Good roads connect the coastal towns and those of the northern portion of the district, but the interior is only accessible by native trails which have to be traversed on horseback or afoot.

FIELD WORK AND ACKNOWLEDGMENTS

The geological survey of the Humacao district was made during the summer of 1916 under the auspices of the New York Academy of Sciences and the Insular Government of Porto Rico. Field work on the area was commenced on July 8 and completed on September 3. A map of the Island of Porto Rico, compiled by the Bureau of Public Works of the Porto Rican Department of the Interior under the direction of John A. Wilson, Commissioner of the Interior, and dated May 13, 1912, upon which the locations of the principal streams, roads, railroads, towns, and villages are shown, was available as a base. The charts of the United States Coast and Geodetic Survey, which accurately show the configuration of the coast, were also used. In the southwestern corner of the district, the Arroyo-Patillas sheet of the Porto Rico Irrigation Service, drawn to a scale of $\frac{1}{12,000}$, covers a small area in great detail.

The various towns along the coast and in the northern portion of the district were used as headquarters as the work progressed. Pace and compass traverses were made along all of the roads and also along the greater portion of the coast, as well as along many of the trails which follow the principal valleys into the interior. Two north and south traverses were run across the eastern extension of the Sierra de Cayey in the western part of the district. On account of the limited time available and the fact that much of the work was done during the rainy season, heavy tropical showers being encountered nearly every day, no attempt was made to sketch the topography. Seven hundred ninety-six rock specimens were collected during the course of the investigation, from 394 of which thin sections were later cut and examined under the microscope. All the data gathered have been assembled on a map drawn to a scale of $\frac{1}{62,500}$.

The office and petrographic work in connection with the preparation of this report has been carried on in the geological and mineralogical laboratories of the Carnegie Institute of Technology at Pittsburgh, Pennsylvania. Its completion has been unduly delayed, first, by the entrance of the United States into the World War which attracted the writer's

attention to other imperative calls, and later, by an investigation started at an earlier date for the Pennsylvania Bureau of Topographic and Geological Survey, for whose completion funds became available.

The present investigation was undertaken at the suggestion of Professor Charles P. Berkey, of Columbia University, who furnished the writer with much valuable information derived from his own experience in making a reconnaissance survey of the whole island. Dr. E. T. Hodge, who had made a geological survey of the Coama-Guayama district, which adjoins the Humacao area on the west, during the previous summer, also gave helpful advice. The writer is also indebted to Colonel George R. Shanton, Chief of the Insular Police. The hearty co-operation of the insular police of the various towns of the district, obtained through his letter of introduction, did much toward facilitating the work. Eduardo Martinez, of Comerio Falls, acted as assistant and interpreter during the entire field season. His faithful and intelligent service was an important factor in enabling the field work to be brought to a successful completion within the limited time available.

PREVIOUS WORK

Berkey's (1915) report on the general geology of Porto Rico, based upon a reconnaissance survey made by him and C. N. Fenner in 1914, was found an invaluable aid in carrying on detailed work in the Humacao area, and frequent reference to it was made in the field. Other articles dealing with the geology of Porto Rico, published prior to this, make only casual reference to the geology of the southeastern portion of the island and give very little information of a specific nature. A list of such articles is included in the bibliography attached to Berkey's paper.

Since 1916, detailed reports on the geology of the San Juan (Semmes, 1919), Coamo-Guayama (Hodge, 1920), Ponce (Mitchell, 1922), and Lares (Hubbard, 1923) Districts and the Physiography of Porto Rico (Lobeck, 1922) have been published by the New York Academy of Sciences. The information contained in these has been very helpful in interpreting some of the data obtained on the geology of the Humacao district.

PHYSIOGRAPHY

The Humacao district, taken as a whole, has a mountainous aspect. It is a region of rugged relief. A considerable portion of the west central part is occupied by the eastern end of the Sierra de Cayey, some of whose peaks reach an elevation of 3000 feet. To the north lie the

Luquillo mountains which rise to still greater elevations. Their southern slopes are included in part within the boundaries of the district.

The Tertiary coastal plain, which is prominently developed along the northern and southern coasts of the island, is absent in the Humacao district, the coast line being characterized instead by bold headlands separated by broad alluvial filled valleys. In the northwestern part of the district the Caguas valley, a broad interior lowland, forms a rather striking topographic feature.

UPLAND AREA

The upland area, which comprises the major portion of the Humacao district, is underlain largely by a complex mass of folded volcanic tuffs,



FIG. 1.—Divide between Patillas and Del Espino drainage systems

breccias, and lava flows intruded by large bodies of quartz diorite and granite. It has reached a mature stage of erosion and hence exhibits an extremely rugged aspect. The humid tropical climate has brought about the development of a fine textured topography. Weathering nearly everywhere has proceeded to considerable depths so that outcrops of the bed-rock formations are scarce even in the extremely mountainous portions of the district, except where the streams have cut through the soil mantle. Prominent talus slopes, so characteristic of mountainous regions where more rigorous climates prevail, are practically absent. Figure 1 shows the appearance of the ridge in the Sierra de Cayey which forms the divide between the Patillas and Del Espino drainages. Only in a few places along it do any outcrops of the underlying formations appear.

Chemical decomposition rather than mechanical disintegration has been the prevailing process of weathering. Rocks like quartz diorite frequently show etched surfaces, where the soil has been removed, similar to those ordinarily associated with the outcrops of more soluble rocks such as limestone. Outcrops of quartz diorite affected in this manner appear in figures 2, 3, and 4. As may be seen in figure 2, the luxuriant tropical vegetation probably plays an important rôle in the development of these weathered surfaces which are so unusual for quartz diorite. Very tenacious clayey soils are formed. Steep slopes, ranging from 30 to 45 degrees with *cuchillo* or knife-edge divides, are characteristic of

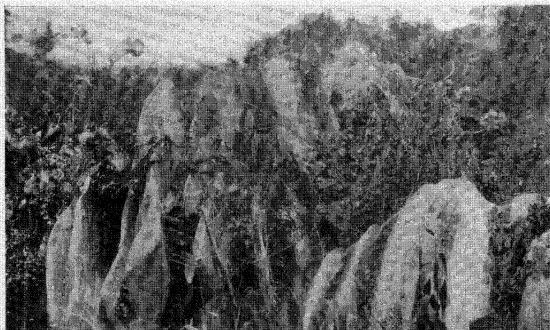


FIG. 2.—Outcrop of quartz diorite along Del Espino River

the mature topography developed, and the striking feature is that the soil clings to them and frequently they are under cultivation. Figure 5, taken near the headwaters of the Turabo River where the bedrock is largely an andesitic tuff, is typical of this kind of topography. Native huts with little patches of cultivated ground around them can be seen at numerous places along the steep hillsides. Figure 6 shows a trail in the quartz diorite area in the region of the Ingenio valley, which started originally on the surface of the soil mantle overlying the quartz diorite but has now been worn down nearly to bedrock by the surface run-off which flows along the depression started by the traffic over it. The steep walls on either side are very characteristic of the manner in which the residual soils of Porto Rico stand up.

Berkey (1915, p. 35) believes that the three factors that are largely

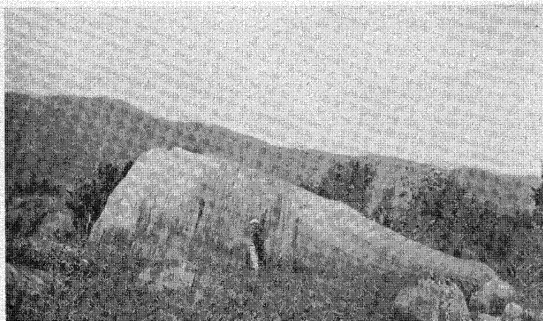


FIG. 3.—*Fluted quartz diorite boulder along divide at head of Del Espino River*

responsible for the remarkable stability of the soil mantle are the clinging character of much of the vegetation which tends to bind the soil together, the small range of temperature variation which reduces mechanical disintegration or disruption tendencies to a minimum, and the low content of inert or refractory materials, such as quartz, in the rocks

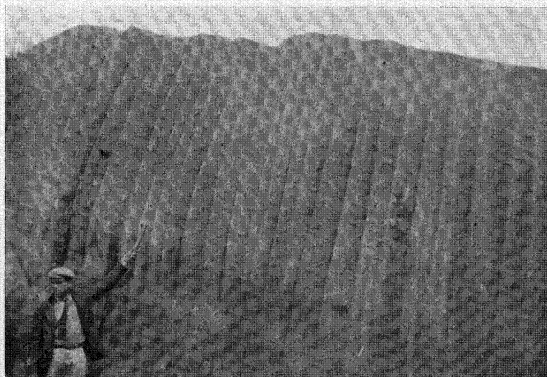


FIG. 4.—*Detail of fluting shown in figure 3*

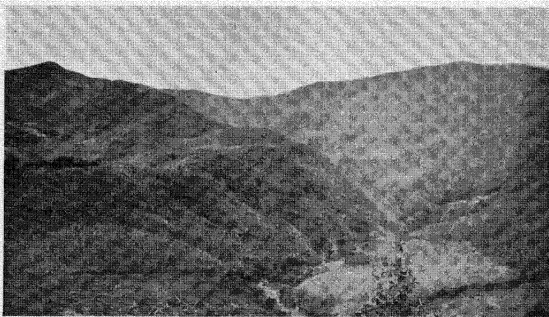


FIG. 5.—*Mature topography at head of Turabo River*

whose destruction has furnished the soils. Lobeck (1922, p. 308) thinks that another factor is the short duration and torrential character of the rainfall which results in an exceedingly heavy and rapid run-off over the surface of the impervious soil.

In my opinion, the character of the weathering process under conditions such as prevail in an extremely humid tropical climate, which brings about a chemical decomposition rather than a mere mechanical disintegration of the exposed rocks and, as a result, produces a very tenacious impervious clayey soil, is in a large measure responsible for

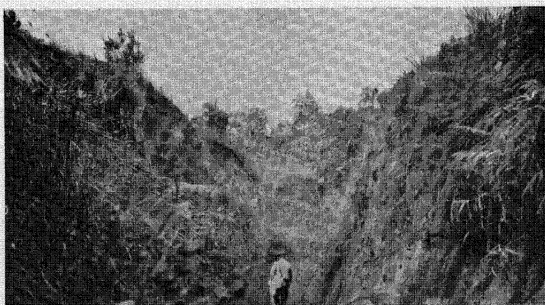


FIG. 6.—*Trail worn into a gully. Ingenio valley region*

the behavior noted. This soil is not subject to the action of frost which is such a potent factor in bringing about slumping in colder climates. Its impervious nature causes much of the rain which falls upon it to run off readily over its surface. As a result, true springs are of comparatively rare occurrence in the district. The absence of quartz from many of the rocks undoubtedly is also an important factor, although the author observed many steep slopes under cultivation and saw soil-covered knife-edge ridges in the quartz diorite area. Outcrops of the bedrock forma-

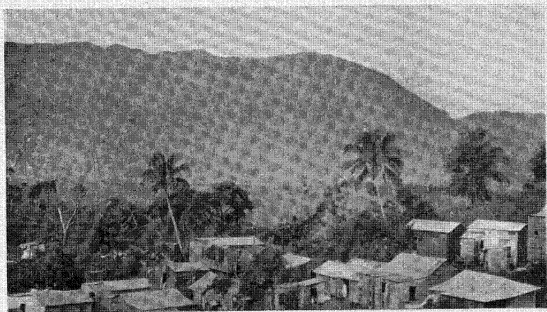


FIG. 7.—Panduras Ridge, a portion of Yabucua shows in the foreground

tions along the divides, however, are of much more common occurrence in the region underlain by this rock.

The drainage system developed upon the upland area is of the typical dendritic type. In general it may be said that the character of the underlying formations and their structure has had very little influence upon the directions in which the streams now flow. Much of the area underlain by quartz diorite has been worn to a somewhat lower level than those portions of the district in which indurated volcanic tuffs and breccias and andesites constitute the bedrock. On the other hand, Panduras Ridge, shown in figure 7, which constitutes one of the most imposing physiographic features along the southern coast, is underlain by quartz diorite.

THE UPPER PENEPLAIN

Over much of the western portion of the upland area the even crest line, formed by the general accordance of the summit levels of the innumerable ridges, is a particularly striking feature. Rocks, including



FIG. 8.—Even crest line formed by upper peneplain at headwaters of Del Espino River

indurated volcanic tuffs and breccias, andesites, quartz diorites, and monzonites are beveled alike at this level. Apparently this region was at one time reduced to a peneplain which has since been elevated and maturely dissected. The area over which this old erosion surface can be recognized comprises that portion of the upland of the Humacao district extending from its western border to a line east of the Del Espino River, running approximately from San Lorenzo to Yabucoa. On the north it is bounded by the Caguas lowland and on the south it extends nearly to

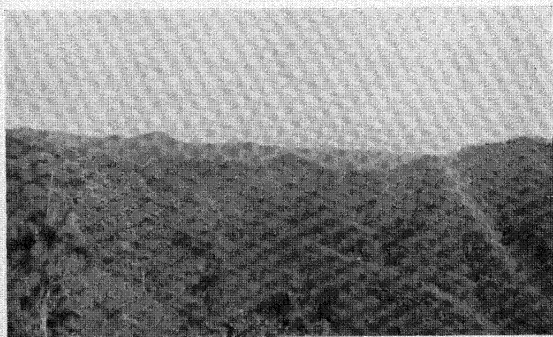


FIG. 9.—Maturely dissected upper peneplain in vicinity of Mulas barrio

the coast. The even crest line produced by the erosion remnants of this old peneplain can be seen in figure 8 which was taken looking eastward across the headwaters of the Del Espino River and in figure 9, taken in the vicinity of Mulas barrio. In the central portion of the area, this peneplain level has an elevation of approximately 2000 feet. No distinct traces of it were recognized along the southern slopes of the Luquillo mountains within the limits of the Humacao district.

The peneplain described above is undoubtedly the one which Berkey (1915, p. 50) recognized in his reconnaissance study of Porto Rico in 1914. Lobeck (1922, pp. 312-320) has referred to it as the first or higher peneplain to distinguish it from a second or lower one which was developed over portions of the island and which is also represented in the Humacao district.



FIG. 10.—Looking across lower peneplain toward upper, northwest of Yabucoa

MONADNOCKS

Along the divide between the Del Espino and La Plata Rivers on the north and the streams that flow southward into the Caribbean Sea, portions of the Sierra de Cayey stand out as monadnocks above the level of the upper peneplain. Some of the higher peaks rise nearly 1000 feet above the peneplain level. The Luquillo mountains, which extend into the northeastern portion of the district, have a similar relationship to this old erosion surface.

THE LOWER PENEPLAIN

A lower erosion surface also marked by concordant summit levels occurs between the Guayanes and Humacao drainage areas. The rela-

tionship of this lower peneplain to the upper one can be seen in figure 10, which is a view taken about 4 miles northwest of Yabucoa looking northwest across the lower erosion surface toward the upper which forms the crest of the escarpment seen in the background. This lower peneplain lies about 1000 feet below the upper.

CAGUAS BASIN

An extensive lowland, practically surrounded on three sides by high hills whose crests rise to the level of the upper peneplain, has been developed by erosion in the northwestern portion of the Humacao district. Its average elevation above sea-level is about 550 feet. On the north it extends beyond the limits of the district. On the west and south it is bounded by an upland whose summit represents the level of the upper



FIG. 11.—*Caguas lowland as developed west of Caguas*

peneplain. On the southeast a low divide separates it from the lower peneplain area previously described. Figure 11 is a photograph taken in the western portion of the lowland along the Caguas-Aguas Buenas road. The upland area on the south can be seen in the background.

The Caguas basin is drained by the Turabo, De Espino, and Gurabo Rivers which unite to form the Grande de Loiza. The latter stream leaves the basin at its northwest corner where it has cut a valley into the upland area. The Grande de Loiza and its tributaries have developed broad flood plains along their courses which lie from 200 to 300 feet below the level of the lowland.

Lobeck (1922, p. 318) believes that the Caguas lowland was developed at the same time as the lower peneplain. It stands at a somewhat lower



FIG. 12.—Wave cut terraces in the vicinity of Quebrada Honda Point

level, however, than the surface of this peneplain as developed in the eastern portion of the island between the Guayanes and Humacao Rivers.

COASTAL AREA

The coast line of that portion of Porto Rico included within the limits of the Humacao district is one produced by drowning in which the submerged valleys have been filled with alluvium. Wave erosion upon the headlands and the filling of the drowned valleys, particularly the latter, have to a considerable extent obliterated the more pronounced



FIG. 13.—Wave cut terrace in vicinity of Naguabo Playa

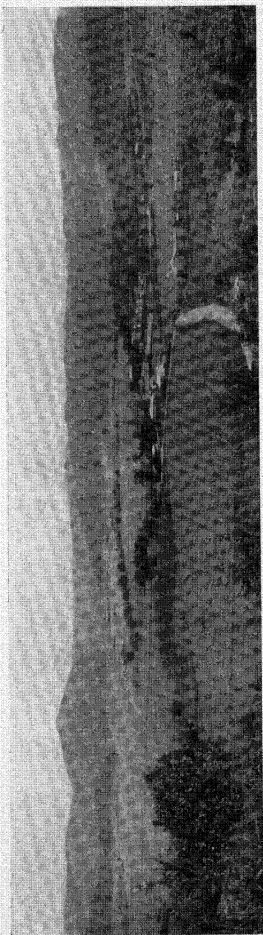


FIG. 14.—Panorama view of Patillas Playa

irregularities so that, with the possible exception of Ensenada Honda, there are no good harbors.

PROMONTORIES

At numerous places along the southeast coast of Porto Rico, headlands made up of the older formations of the upland area or igneous rocks intrusive in them extend to the sea where they terminate in wave-cut cliffs. Amongst the most impressive of these is Panduras Ridge between Maunabo and Yabucoa. Other prominent ones occur southeast of Patillas and southwest of Maunabo, also between Yabucoa and Candelero playas, Candelero and Humacao playas, and southeast of Naguabo.

In places the headlands are notched by what are probably remnants of marine terraces. Two such terraces in the vicinity of Quebrada Honda Point are shown in figure 12. The upper of these is approximately 280 feet above sea-level, while the lower one occurs at an elevation of 160 feet. Figure 13 shows another of these terraces in the vicinity of Naguabo Playa which is of much more recent origin and stands only a short distance above sea-level.

PLAYAS

The broad alluvial plains sloping gently toward the sea that occur along the lower courses of all the major streams along the southeastern coast are locally known as playas. For the most

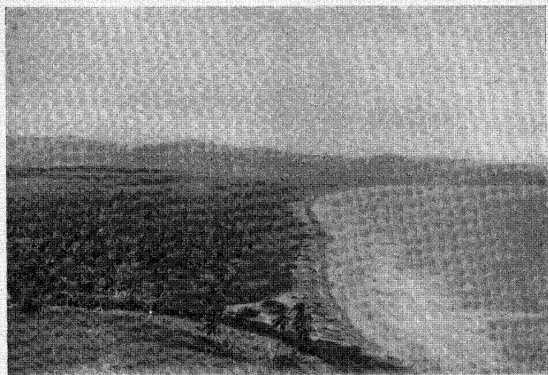


FIG. 15.—*Lower portion of Yabucoa Playa*

part, they represent estuaries formed by drowning that have been filled with alluvium brought down by the streams. Inland they often grade into typical flood plains developed by the widening out of the river valleys. Figure 14 is a panorama view of the Patillas playa, while figure 15 shows the lower portion of the Yabucoa playa between Quebrada

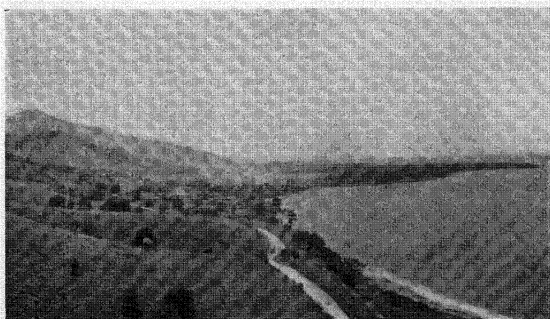


FIG. 16.—*Marginal playa in the vicinity of Viento Point*



FIG. 17.—Sea cliff in playa deposits west of Arroyo

Not all of the playas are of the estuarine type. Along the south coast some, such as the one upon which the town of Arroyo is built and the one developed in the vicinity of Viento Point shown in figure 16, are marginal and more in the nature of alluvial fans often possessing a pronounced seaward slope.

While in most cases the playas are not terminated by any pronounced cliff along their seaward margins, one striking exception was noted. Figure 17 shows a cliff 25 feet high cut by the waves into the unconsolidated playa deposits along the coast just beyond the western limits of the Humacao district. The upper 3 feet of the alluvial deposit, as may

Honda and Yabucoa Points. In the former, the upper peneplain level is readily recognizable along the crests of the hills which border the broad valley. One of the outstanding topographic features along the southern coast is the abruptness with which the mountains rise to this level. In the case of the Yabucoa playa, there is an absence of a pronounced wave-cut cliff along the shore line. This is characteristic of most of the playas. The sandy beach marking the playa margin is usually bordered by a zone of coconut palms, back of which frequently occur small areas of salt marsh, and beyond which in turn lie fertile fields planted in sugar cane.

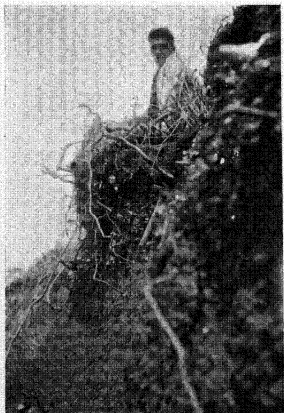


FIG. 18.—Fossiliferous upper 3 feet of cliff shown in figure 17

be seen in figure 18, are extremely fossiliferous. Abundant shells of many recent species of gastropods, pelecypods, as well as coral remains in every way identical with those accumulating along the present beach, are present. Indian pottery fragments occur in the lower portion of this fossiliferous horizon, which are associated with the shells in such a manner as to lead one to the conclusion that they were deposited contemporaneously. The great variety of genera and species and the lateral extent of the shell bed seem to indicate that the deposit does not represent an Indian shell heap, but rather that there has been along this portion of the coast an uplift of from 25 to 30 feet since the region first became inhabited by the early Indians.

DRAINAGE

The northwestern one-third of the Humacao district is drained by the Gurabo, Valenciano, Del Espino, and Turabo Rivers, tributaries of the Grande de Loiza which enters the Atlantic Ocean along the north coast east of San Juan. Some of the headwater tributaries of the La Plata, which enters the Atlantic west of San Juan, also rise within the western limits of the district. The rest of the area is drained by streams flowing southward and eastward into the Caribbean Sea.

One of the outstanding features of the drainage is the unsymmetrical position of the divide between the streams which flow northward into the Atlantic and those that flow southward and southeastward into the Caribbean. As an example, the Del Espino River, which rises on the northern slopes of the Sierra de Cayey, and its continuation, the Grande de Loiza River, have a total length of 36 miles, while the Patillas River which rises on the southern slopes of the same range opposite it has a length of only 8 miles. Berkey (1915, pp. 39-41) and Mitchell (1922, pp. 266-269) have traced a prominent fault of late Tertiary age along the southern margin of the island extending from the vicinity of Juana Diaz to a point 5 miles east of Point Melones on the west coast. According to Mitchell, the displacement in the vicinity of Juana Diaz is at least 900 feet and probably considerably more. The presence of this fault and the unsymmetrical arrangement of the drainage, as well as the comparatively abrupt manner in which the island is terminated at both the east and west ends, has led Berkey to conclude that Porto Rico is probably bounded roughly on three sides by faults (the east, west and south) and is a block tilted gently to the north. This would explain the drainage phenomena noted. Lobek (1922, pp. 304-305), on the other hand, believes that the greater length of the streams flowing northward is due to the fact that the precipitation is much greater on that side of

the island. He attributes the phenomena along the south coast, ascribed by Berkey and Mitchell to indicate faulting, to be the result of the sagging and collapse of cavern roofs in the Tertiary limestones. If the unsymmetrical drainage is due entirely to differences in rainfall, however, it is difficult to explain why the lofty Luquillo mountain group, with very short streams flowing northward to the sea, should be located in the extreme northeastern portion of the island where the rainfall is heaviest. The character of the rocks that underlie this area does not appear to be essentially different from those of the rest of the island.

Stream terraces occur along most of the major valleys of the Humacao district. Particularly good ones may be seen along the Gurabo, Valenciano, Del Espino, and Turabo Rivers. In most instances these can be explained by the fact that the rivers have changed from aggrading to degrading streams within comparatively recent times and they do not necessarily indicate that an uplift has taken place.

GENERAL GEOLOGY

The interpretation of the bedrock geology of a large portion of the Humacao district is difficult on account of the thick mantle of residual soil which covers most of it. In the lowlands, outcrops are extremely scarce; while in the mountainous areas, where they are more plentiful, they are frequently so badly decomposed as to make the determination of the exact nature of the original rock almost impossible. Formational boundary lines can, therefore, in many instances be traced only approximately.

The best exposures are found along stream beds as shown in figure 19, along the cliffs which the waves have cut back into the headlands, along road cuts, and occasionally at or near the crests of the ridges. Often residual boulders in the thick mantle of soil furnish the only clues available in regard to the character of the underlying rock over large areas. The formations have been folded and invaded by numerous intrusives, but strike and dip measurements can rarely be obtained on account of the massive character of most of the rocks involved and the scarcity of outcrops.

FORMATIONS PRESENT

The oldest formations exposed in the Humacao district belong to what Berkey has called the Older Series. Berkey (1915, p. 10) considers the whole series to be of Cretaceous age, using the term to include both the Upper Cretaceous and Lower or Comanchean.¹ Later workers in other

¹Op. cit., p. 58.

parts of Porto Rico concur with him pretty well in this correlation.² Semmes concludes from foraminiferal remains found in the upper portion of the older series in the San Juan district, northwest of the Huma-

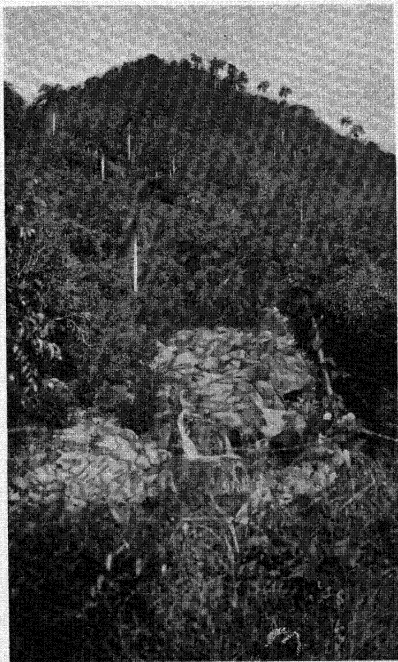


FIG. 19.—Outcrop of quartz diorite along Maunabo River

² Semmes, D. R. Geology of the San Juan district. Scientific Survey of Porto Rico and the Virgin Islands, New York Academy of Science, Vol. I, Part 1, pp. 72-75.

Hodge, E. T. Geology of the Coamo-Guayama district. Idem., Vol. I, Part 2, pp. 192-194.

Mitchell, G. J. Geology of the Ponce district. Idem., Vol. I, Part 3, pp. 285-287.

Hubbard, Bela. The geology of the Lares district. Idem., Vol. II, Part 1, pp. 34-35.

cao area, that some beds of Eocene age may also be present. In the Coamo-Guayama district which adjoins the Humacao on the west, Hodge has come to a similar conclusion, basing his belief on a specimen of *Venericardia alticosta* and large numbers of foraminifera, radiolarians, and diatoms which he found in its uppermost beds. He thinks that the lower portion is of Comanchean age. Mitchell and Hubbard, on the other hand, working in the western part of the island, found no evidence of Eocene sediments in the older series. All fossils discovered by them point toward an Upper Cretaceous age for the whole series. In the Humacao district, unfortunately the writer was not able to find any fossils that would throw further light upon this problem.

The older series of southeastern Porto Rico are made up predominantly of volcanic rocks. They consist chiefly of tuffs and andesites, the former predominating in the western half of the district and the latter in the eastern.

The tuffs are largely andesitic in composition, but latite varieties are also present. In texture, some of them are sufficiently coarse to be classed as volcanic breccias. Others contain sufficient amounts of calcareous material to be classified as calcareous tuffs and these sometimes grade into tuffaceous limestone.

The andesites show a rather wide range in texture and mineralogical composition and include some dacites and latites. More siliceous felsites are also present over limited areas. Augite and hornblende andesites are of most frequent occurrence and a porphyritic texture is usually developed in them. Both extrusive and intrusive types are undoubtedly represented but it is difficult to differentiate these in the field. In many instances, a parallel alignment of the plagioclase laths of the ground-mass, indicating a flowage structure, is revealed in them under the microscope.

Sandstones, true shales, and limestones make up only a very minor portion of the older series in the Humacao district.

On account of the scarcity of outcrops, the rapid alternation from one type of rock to another, both vertically and horizontally, and the complexity of structure, it was not found possible to subdivide the older series in the Humacao district into a number of distinct formations, such as has been attempted in some of the other districts. Much more detailed work, than was possible in the limited time at the writer's disposal, will have to be done to make such a subdivision justifiable.

The older series in southeastern Porto Rico has been cut by a great number of intrusive bodies of igneous rock. One of these, a quartz diorite batholith, underlies the major portion of the Humacao district.

Smaller bodies in the form of stocks, bosses, intrusive sheets, and dikes, ranging in texture from granitoid to felsitic and in mineral composition from gabbro and augite andesite to granite and rhyolite, are also present. In many instances the areas covered by their outcrops are too small and too numerous to show on the geologic map. All of these intrusives are older than the oldest of the Tertiary beds that overlie the older series unconformably along the north and south coasts of the island as they are nowhere found to intersect them.

The Tertiary limestones and shales, that are so extensively developed along the western portion of the north and south coasts of the island and which according to Hubbard (1923, p. 66) are of middle and upper Oligocene age, are absent from the Humacao district. The recent alluvial deposits of the coastal playas and the flood plains and terraces of the interior valleys are the only representatives of Berkey's (1915, p. 10) "Younger Series" within the limits of the Humacao district.

OLDER SERIES

Tuffs and volcanic breccias—The formations of the older series in the Humacao district consist primarily of volcanic ashes, tuffs, and breccias of andesitic composition, tuffs being the most common. In the western half of the district the major portion is made up of materials of this character, while in the eastern part andesites predominate. As a rule, the fragmental igneous rocks are thoroughly indurated so that in many instances they resist weathering even better than some of the associated massive types.

Over much of the area igneous rocks, also largely of andesitic composition, are so intimately associated with the tuffs that separate mapping is impossible. On the geologic map, therefore, those areas in which the former predominate are indicated as being underlain by andesite; while those portions where the andesites constitute only minor portions of the formation are shown as tuff. It was not found possible to map the volcanic ashes, tuffs, and breccias separately on account of their intimate association with one another. Gradations from one type to the other, both vertically and horizontally, are of too frequent occurrence.

In the southwestern portion of the Humacao district in the area drained by the Llaunel River, beds of consolidated ash alternate with tuff. Occasionally volcanic breccias are also present. A thin section cut from a greenish gray specimen of the latter type occurring near the head of the west fork proved to consist largely of fragments of andesite. These have a felsitic texture and consist of an interlocking mass of plagioclase laths with occasional phenocrysts of augite. Some have a trachytic type of groundmass developed in them. Chlorite and epidote

are the chief secondary minerals present. The matrix consists largely of secondary quartz and chlorite. Microscopic examination of a specimen obtained near the head of the east fork showed it to be a latite tuff. Grains of orthoclase, plagioclase, and augite can be identified in it. Abundant epidote has developed from augite and feldspar, and large quantities of secondary quartz as well as a little sericite are present in the matrix. The tuffs of the Patillas River drainage north of the reservoir are also thoroughly indurated and much altered. Grains of plagioclase and orthoclase, however, can still be recognized under the microscope. Epidote, chlorite, and sericite are abundantly developed, as well as large amounts of secondary quartz.

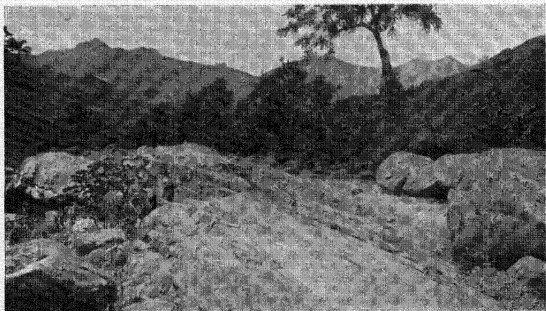


FIG. 20.—Outcrop of indurated volcanic ash and tuff along upper portion of Turabo River

A dark greenish gray volcanic breccia, containing fragments up to 11½ centimeters in diameter from the northern slopes of the Sierra de Cayey, was also found to be of the andesitic type. The fragments are felsitic in texture and consist largely of plagioclase laths in more or less parallel alignment. Small amounts of needle-like amphibole are also present. The andesite is an amygdaloidal variety, the amygdules consisting of secondary quartz and occasionally epidote. Besides the fragments of andesite, a few feldspar crystals occur in the matrix which is composed largely of secondary quartz and epidote.

Thoroughly indurated fine-grained volcanic ashes, alternating with coarser tuffs, form very prominent outcrops along the upper portion of the Turabo valley, as shown in figure 20. Some of these are almost identical in appearance with the Swedish *höllefinta*. Under the micro-

scope, they are seen to consist of minute grains of quartz, orthoclase, and plagioclase together with a little pale green amphibole, probably developed through metamorphism. The coarser tuffs are made up largely of andesite fragments with felsitic texture and trachytic structure. Occasional plagioclase phenocrysts appear in them. Some fragments that are composed of a fine mosaic of quartz grains are also present. The fragments range up to 2 millimeters in diameter. The matrix consists

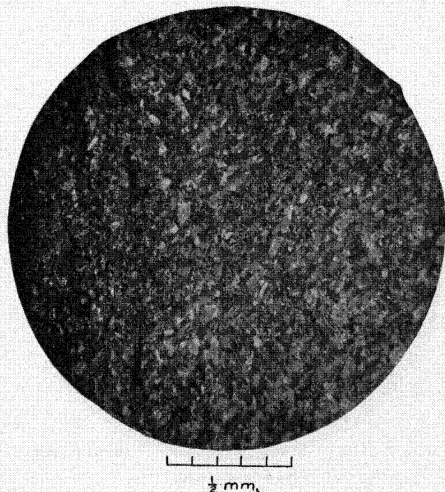


FIG. 21.—Photomicrograph of volcanic ash (*halleftinta*). Upper portion of the Turabo valley

largely of secondary quartz and epidote. Figure 21 is a photomicrograph of the ash and figure 22 of the tuff.

Andesite tuffs are well exposed in cuts and quarries at a number of places along the military road running southwest between Caguas and Cayey. At K. 40.9 such a tuff crops out along Quebradillas creek. It contains fragments up to $3\frac{1}{2}$ millimeters in diameter. Under the microscope they are seen to consist of andesites, varying in texture and number of phenocrysts as well as in the degree of alteration which they

have undergone. Most of them contain plagioclase phenocrysts which in some instances have been largely replaced by secondary quartz. Occasional hornblende phenocrysts are also present in them. Numerous needles of pale green amphibole have developed in all of them. Secondary quartz has been abundantly deposited between the fragments. A short distance beyond K. 44 a quarry for road rock has been opened in a coarse tuff containing fragments of andesite up to 5 millimeters in diameter, most of which show some rounding. Microscopic examination

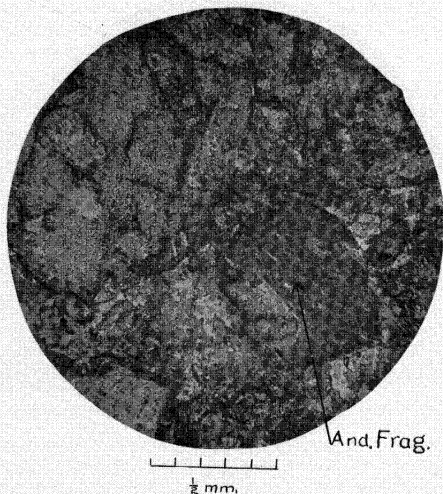


FIG. 22.—Photomicrograph of andesite tuff from upper portion of Turabo valley

reveals a felsitic texture and trachytic structure in them with occasional phenocrysts of plagioclase. Much chlorite and a little epidote and sericite have developed as alteration products. Beyond K. 46 very much similar tuffs are exposed. The fragments of andesite range in diameter up to 7 millimeters. In texture and structure they vary somewhat. Some contain numerous plagioclase phenocrysts imbedded in a ground-mass of feldspar laths. Considerable epidote and calcite have developed as secondary minerals in them. Others have a felsitic texture and a

typical trachytic structure. All are amygdaloidal, chlorite usually filling the original vesicular openings. Much epidote and calcite occur between the fragments.

Good exposures of tuff and volcanic breccias may also be seen along the Caguas-Juncos road, particularly in the vicinity of Gurabo, which lies just to the north of the Humacao district. A thin section cut from a specimen obtained southwest of K. 6 consists of numerous grains of plagioclase, augite, and brown hornblende imbedded in a fine matrix.

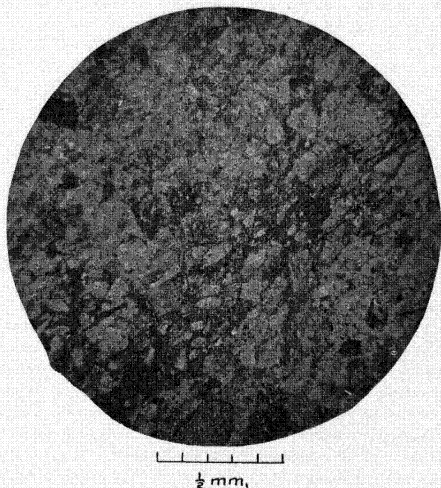


FIG. 23.—Photomicrograph of latite tuff southwest of magnetite deposit No. 5, south of Torres

Epidote has partially replaced the feldspar grains. Between K. 12 and K. 13, a small quarry has been opened in a tuffaceous limestone interbedded with the andesitic tuffs. About 30 feet of the former are exposed.

Southwest of the magnetite deposit, south of Torres, a thin bed of latite tuff occurs associated with dacites and andesites, a photomicrograph of which is shown in figure 23. It is composed of ragged and

rounded grains of plagioclase, orthoclase, and a little augite imbedded in a fine matrix in which some pale green amphibole and chlorite can be distinguished. A little magnetite is also present.

In the eastern portion of the district the greatest area of predominatingly tuffaceous rocks lies to the north of the Humacao playa. Some of these consist of consolidated ash beds. Numerous grains of plagioclase are usually present, some representing broken fragments while others are complete crystals. Small amounts of orthoclase and quartz also occur in them. In many instances the feldspar has been more or less completely altered to epidote, chlorite, calcite and sericite. The matrix, as a rule, is extremely fine and consists of sericite, kaolinite, and calcite—the latter often being very abundant. Coarser fragmental volcanic rocks are interbedded with the ashes. The fragments in almost every instance consist of andesitic material.

Thoroughly indurated volcanic ashes of the *hállefinta* type, resembling those along the upper portion of the Turabo valley, also occur along the Santiago valley, north of Naguabo. Plagioclase grains and minute fragments of well-rounded andesite can be recognized in them under the microscope. Epidote and needle-like crystals of amphibole can be distinguished in the fine matrix.

Where the tuffs come in contact with the major intrusive of southeastern Porto Rico, the San Lorenzo quartz diorite batholith, they are usually metamorphosed into hornblende schist. Similar changes have also taken place in them in the vicinity of the magnetite deposits of the Juncos-Torres region. These are described under contact metamorphism.

Andesites.—Andesites rank next to the tuffs in order of abundance in the older series. They show a rather wide range in texture and mineralogical composition and include some dacites and latites. Augite and hornblende varieties are of most frequent occurrence, but some that are largely feldspathic in composition are also present. A porphyritic texture is commonly developed in them. Both extrusive and intrusive types are undoubtedly represented but it is difficult to differentiate these in the field. In many instances a parallel alignment of the plagioclase laths of the groundmass, indicating a flowage structure, is revealed in them under the microscope. Andesites are almost everywhere associated with the tuffs, but on the geologic map an attempt has been made to show only the larger areas.

Andesites crop out along the headwaters of the west fork of the Patillas River along the southern slopes of the Sierra de Cayey. These range in texture from felsitic to porphyritic, the former type predominating. When phenocrysts are present they consist of plagioclase. Feld-

spar laths are the chief constituents of the matrix and magnetite is the most important accessory mineral. Chlorite, sericite, and uraltite are the principal secondary minerals along with occasional nests or bunches of epidote. Here and there the andesites are cut by veinlets of secondary quartz. Some pyrite has been introduced. An andesite of the hornblendic variety occurs on the opposite slopes of the Sierra de Cayey, with an area of tuff intervening. Plagioclase and a light green hornblende occur as phenocrysts in it. The matrix consists chiefly of plagioclase

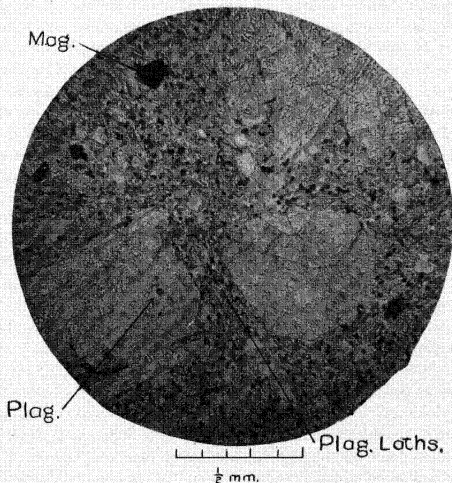


FIG. 24.—Photomicrograph of hornblende andesite porphyry from Kilometer Post 41, Caguas-Cayey road

laths with minor amounts of magnetite and exhibits a typical trachytic structure.

East of the bridge at K. 41, along the road southwest of Caguas, a hornblende andesite porphyry crops along the bed of a small stream. A photomicrograph of this rock appears in figure 24. The phenocrysts consist chiefly of plagioclase, now almost completely altered to sericite and chlorite. Occasional crystals of bluish green hornblende, in part altered to chlorite, are also present. The groundmass is made up of

plagioclase laths and hornblende in more or less parallel alignment. Magnetite and a little quartz are the chief accessory constituents. About 850 feet southwest of K. 41 a trachyte occurs on the south side of a small stock of quartz monzonite that intervenes. It contains occasional phenocrysts of orthoclase. Plagioclase and quartz are only sparingly present. The groundmass consists mostly of orthoclase feldspar, together with a little plagioclase and occasional flakes of biotite. Numerous spherulites of orthoclase occur in it. Between K. 41 and K. 42, a short distance up Quebradillas Creek, a quarry for road rock has been opened in a hornblende latite. Phenocrysts of orthoclase and plagioclase are prominent, the latter in part altered to epidote. Crystals of pale green hornblende, almost completely altered to chlorite, are also present. The matrix is made up of innumerable small feldspar laths. Epidote, chlorite, and a little calcite occur as secondary minerals. A short distance further up the creek a fine-grained rock with only occasional phenocrysts of orthoclase and plagioclase and with some quartz besides feldspar and occasional biotite in the matrix crops out. On up Quebradillas Creek outcrops of andesites, dacites, and latites may be seen interstratified with tuffs and volcanic breccias.

Andesites and andesite porphyries occur along the road between Caguas and San Lorenzo. A thin section of a specimen obtained a short distance west of K. 5 contains numerous plagioclase phenocrysts which show maximum extinction angles of 21 degrees at right angles to the albite lamellæ, and are, therefore, probably andesine. The groundmass consists principally of feldspar laths arranged in trachytic fashion. A little chlorite and occasional nests of epidote occur in it.

Andesites predominate in the older series in the northeastern portion of the Humacao district. Many different types are present representing feldspathic, hornblende, and augite varieties. Some have felsitic textures while others are porphyritic. In many instances they show under the microscope a parallel alignment of the plagioclase laths of the groundmass, indicating a flowage structure.

An augite andesite comprises the footwall of the magnetite deposit east of Juncos at its west end. It possesses a felsitic texture with a tendency for the many feldspar laths of the groundmass to be in parallel alignment. A few phenocrysts of plagioclase of an andesine or acid labradorite variety and a little augite are present. The groundmass consists chiefly of plagioclase. Titanite is an accessory mineral. Pale green amphibole aggregates occur along small fractures as well as in places once occupied by augite phenocrysts. The plagioclase phenocrysts are clouded by alteration products. Beyond the andesite tuff, adjoining the

magnetite deposit on the northwest, there is an occurrence of hornblende andesite porphyry. Augite phenocrysts with reaction rims of hornblende are prominent. The groundmass is made up predominantly of a brownish green hornblende with only minor amounts of plagioclase. It is coarse in texture. A little magnetite and apatite are present.

North of the calcareous andesite tuff that overlies the second magnetite deposit southeast of Juncos an augite andesite with felsitic texture crops out. Under the microscope a few large phenocrysts of augite can still be recognized. Others have been altered into aggregates of epidote or brownish green biotite and secondary quartz. The groundmass is composed of plagioclase laths in more or less parallel alignment, biotite, and augite. The limestone, with which the third magnetite deposit is associated, is also overlain by an andesite. Southwest of this deposit, between it and the quartz diorite batholith, a hornblende andesite porphyry occurs. Plagioclase and pale green hornblende are present in it as prominent phenocrysts. The groundmass consists of plagioclase, hornblende, and magnetite. The lath-like crystals of the former show a slight tendency toward parallel alignment.

A feldspathic andesite comprises the hanging wall of the fourth magnetite deposit southeast of Juncos. In thin section, it is seen to possess a felsitic texture and distinct flowage structure brought out by the parallel alignment of the plagioclase laths. A few phenocrysts of plagioclase and a little light green hornblende derived possibly from augite are present. Occasional aggregates of epidote also occur. The matrix consists predominantly of plagioclase laths. Skeleton crystals of iron oxide, possibly magnetite, are prominent. A little hornblende is also present. South of the magnetite deposit at the head of the Anton Ruiz valley prominent outcrops of an augite andesite porphyry occur over a considerable area. The phenocrysts in it consist of pale green augite and plagioclase. The matrix is composed of plagioclase laths, showing some tendency toward parallel alignment and magnetite. A little pale green hornblende and epidote have developed in it as alteration products from the augite. Andesites and dacites occupy the belt between the above magnetite deposit and the one south of Torres.

A hornblende andesite crops out on the south side of the Gurabo valley in the vicinity of Torres. This contains a few phenocrysts of greenish brown hornblende imbedded in a groundmass of plagioclase, hornblende, and magnetite. A faint flowage structure is noticeable. Small amounts of epidote and calcite have formed as alteration products from hornblende and a little sericite from the feldspar.

An augite andesite and a latite occur between a bed of limestone and

the outcrop of magnetite south of Torres. Whether these are extrusive or intrusive sheets could not be determined from their field relations. The andesite which immediately overlies the limestone, in thin section, shows a parallel alignment of its plagioclase laths indicating a flowage structure. The latite contains phenocrysts of plagioclase and orthoclase in a groundmass consisting chiefly of plagioclase laths and a little hornblende. Small amounts of epidote occur as alteration products in the groundmass and also along fractures.

Cuts along the road up Pena Pobre valley expose feldspathic andesites at several places. One of these has plagioclase laths, small amounts of hornblende, and a little magnetite imbedded in a partly glassy matrix. The rock, in thin section, shows a pronounced flowage structure, due to the parallel alignment of the feldspar crystals. The rock contains numerous small fragments of a pre-existing andesite imbedded in it. The latter contain feldspar phenocrysts in a somewhat finer textured groundmass than the main rock. Very similar andesite may be seen along the Blanco valley above its junction with the Pena Pobre. Here also in one instance, small fragments of pre-existing andesite were observed in a feldspathic augite andesite. Hornblende and feldspathic andesites are the predominating rocks along the Santiago valley.

At El Morillo Point a feldspathic andesite forms the low hill rising above the playa level. It contains occasional phenocrysts of andesine feldspar and hornblende in a groundmass of plagioclase laths and hornblende. The former are in more or less parallel alignment. Similar andesites occur along the Humacao-Naguabo road to the north.

Along the shore southeast of Naguabo Playa, andesite porphyries form the rather prominent cliffs that have been cut back by the waves. An augite variety contains prominent phenocrysts of augite and labradorite in a groundmass of feldspar. Uralite has developed along the borders and cleavage cracks of the augite and epidote occurs along numerous minute fractures that intersect the rock in all directions. It shows only a faint flowage structure. A feldspathic hornblende variety contains numerous phenocrysts of plagioclase and a few of bluish green hornblende in a groundmass made up chiefly of minute feldspar laths. Both the plagioclase phenocrysts and laths are in parallel alignment. Some epidote has developed from the feldspar and epidote and secondary amphibole occur along minute fractures in the rock.

Andesites and andesite porphyries crop out at a number of places along the road leading northeast from Naguabo Playa. At K. 62.2 a quarry for road rock has been opened in andesite. It has a felsitic texture and a flowage structure. The groundmass contains not only occasional

phenocrysts of plagioclase but also small fragments of pre-existing andesite.

Felsite.—At several widely separated localities in the Humacao district small areas of dense usually light-colored felsitic rocks, more siliceous than the andesites described, occur in the older series. Their exact relationship to the other members of the series could not be determined. They may represent intrusive bodies or possibly they are lava flows interstratified with the tuffs and andesites. The more prominent of these occurrences are shown under the heading of felsites on the geological map. They crop out on both sides of the Patillas valley south of Patillas and along the coast west of Naguabo Playa, as well as at several places along the road leading northeastward from the latter point.

Along the west bank of the Patillas River where the road from Patillas to Arroyo crosses it, a quarry for road material has been opened in a rock of this character. It possesses an extremely fine felsitic texture and light color. Fractures intersect it in all directions and it is cut by several dikes of rhyolite porphyry showing prominent phenocrysts of quartz. Under the microscope, occasional small phenocrysts of orthoclase are noticeable in a fine groundmass composed chiefly of orthoclase and quartz. A little plagioclase is present as a minor accessory. The feldspar is cloudy from alteration. This rock apparently is a rhyolite. South of this locality along the west side of the Patillas valley a number of outcrops of very similar rock may be seen. Microscopic examination shows them to range in composition from rhyolite, through trachyte and latite to dacite.

On the east side of the road leading southeastward from Patillas, about half way to the coast, the contact between a dacite and rhyolite, in many respects similar to those noted above, can be seen in a small quarry. The dacite which overlies the rhyolite has a felsitic texture with a few small phenocrysts of plagioclase imbedded in a groundmass composed essentially of plagioclase and quartz. Minor amounts of magnetite occur as an accessory constituent. A little sericite and chlorite are present in the groundmass as secondary minerals. The rhyolite is considerably more brecciated. It also has a fine felsitic texture but contains no phenocrysts. Under the microscope, it is seen to consist of an allotriomorphic intergrowth of quartz and orthoclase. The orthoclase in part has been converted into sericite by alteration.

West of Naguabo Playa along the coast a fine-grained dense dacite forms the cliffs. Under the microscope it is seen to consist of plagioclase and quartz. Chlorite, calcite, and epidote have been developed in it by alteration. Along the road to the northeast of Naguabo Playa between

K. 67 and K. 68, a light colored, dense, badly fractured rock, very similar to that west of Patillas, crops out. A few scattered phenocrysts occur in a groundmass composed essentially of orthoclase and quartz. Titanite, plagioclase, and hornblende are accessory constituents. A photomicrograph of this rock is shown in figure 25. Between K. 60 and K. 61 a very similar rock has been exposed in a small quarry for road material. It contains a few small phenocrysts of orthoclase in a groundmass consisting of an allotriomorphic intergrowth of orthoclase and quartz.

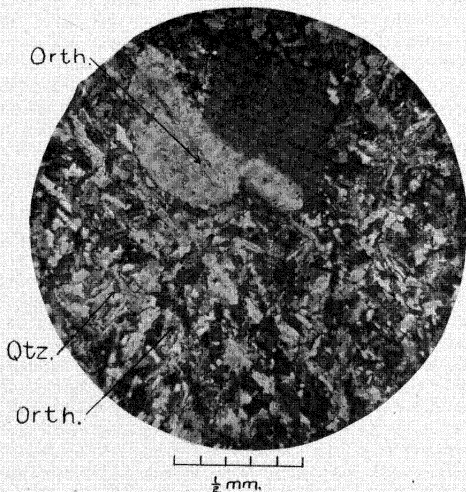


FIG. 25.—Photomicrograph of rhyolite from vicinity of Kilometer Post 68, Naguabo-Fajardo road. Crossed nicols

Plagioclase, biotite, magnetite, and apatite are present as minor accessories.

Limestones.—True limestones are of comparatively rare occurrence in the older series of the Humacao district. Those that were encountered during the course of the present investigation, had recrystallized to such an extent that all traces of organic remains were obliterated. Even in these limestones, in some instances, small amounts of tuffaceous ma-

terial can be detected. In many cases the tuffaceous material predominates so that the rock becomes a calcareous tuff, which may in turn grade into an ordinary andesitic tuff. In still other instances, andesitic tuffs have been so completely altered to carbonate that they may readily be mistaken for true limestone.

Collores limestone.—The most conspicuous outcrops of limestone observed in the Humacao district occur along two belts; one of which begins $1\frac{1}{2}$ miles east of Juncos and extends S. 53° E. for a distance of about 6 miles. It has been called the Collores limestone on account of its typical development in the barrio of Collores de Piedras. The dip is toward the northeast and ranges from 32 to 41 degrees. The second belt was traced for only a short distance. It lies about $7/10$ of a mile northeast of the southeast end of the first and apparently dips toward the southwest, although the character of its outcrop is such as to make it impossible to determine this positively. This makes it appear that a syncline is present and that the two belts may be formed by outcrops of the same bed.

Along the southwest belt, the best development of the limestone appears in the barrio of Collores de Piedras. The limestone has a strike of N. 50° W. and dips 32° toward the northeast. Prominent ledges of gray and white crystalline limestone, in some instances 40 feet thick, crop out. The total thickness is estimated to be 250 feet. A thin section of the crystalline gray limestone, a photomicrograph of which is shown in figure 26, reveals an interlocking mosaic of calcite crystals of medium texture with only occasional minute grains of iron oxide amongst them and a little chlorite. Qualitative analyses indicate a very pure limestone. There is very little residue after treatment with cold dilute hydrochloric acid and only slight amounts of iron and alumina and a trace of magnesium carbonate are present. In the vicinity of the magnetite deposit, which occurs in its upper portion, the limestone has been converted into an aggregate of calcite, garnet, pyroxene, chlorite, quartz, magnetite, and specular hematite. These changes in the limestone are referred to again under contact metamorphism.

At the northwest end of the belt, just southeast of the Juncos magnetite deposit, the limestone has been completely metamorphosed into an aggregate of garnet, pyroxene, amphibole, epidote, chlorite, and talc. Only minor amounts of calcite are still present in it. At the southeast end, 1500 feet northwest of the most southeasterly of the magnetite deposits shown on the geological map, prominent ledges of white crystalline limestone can also be seen. Some garnet rock is associated with them.

Along the northeast belt, outcrops of limestone were observed at only

one locality about 9/10 of a mile south of Torres. It is a dark gray, fine grained variety which has not been metamorphosed to the extent that the limestone of the first belt has. In thin section, it is seen to consist principally of calcite, but occasional grains of quartz, augite, and plagioclase are also present. The latter undoubtedly represent tuffaceous material deposited simultaneously with the calcareous constituents. A few small grains of pyrite are also present. Figure 27 shows a photomicrograph of this limestone. Southeast of this limestone along the

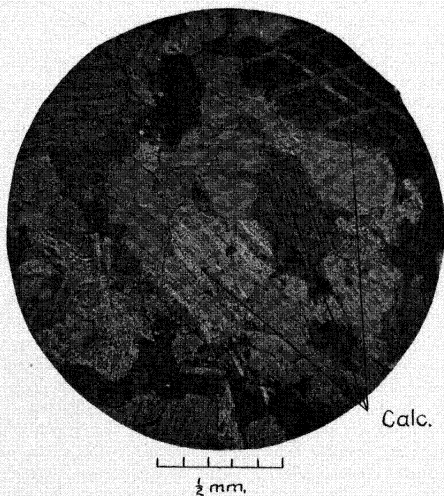


FIG. 26.—Photomicrograph of Collores limestone from Collores de Piedras.
Crossed nicols

strike, a prominent ledge of metamorphosed rock was noticed at one place, which, under the microscope, was found to consist almost entirely of an aggregate of garnet grains. A little pale green amphibole and deep brown biotite occur between the former. This rock apparently represents metamorphosed portions of the limestone.

Tuffaceous limestones and calcareous tuffs.—Southeast of K. 12, along the Juncos-Caguas road northwest of the town of Juncos, a small

quarry has been opened in a tuffaceous limestone interbedded with calcareous tuffs. The formations strike N. 42° E. and dip 75° toward the southeast. About 30 feet of limestone are exposed in the quarry. The upper beds consist of a light greenish-gray fine-grained fragmental rock which, under the microscope, is seen to be made up chiefly of calcite, sericite, chlorite, and kaolinite. Occasional remnants of plagioclase can be detected in it. This rock may be classified as a tuffaceous limestone or perhaps better, a calcareous ash. Below it occurs a somewhat coarser

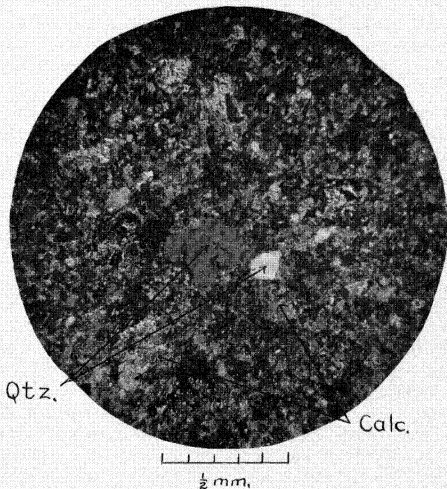


FIG. 27.—Photomicrograph of limestone south of Torres. Crossed nicols

greenish-gray brecciated tuff. Calcite has replaced almost the entire matrix of the tuff, but original structures can still be detected in it. Chlorite now occupies the space where feldspar grains were originally present. Only occasional remnants of plagioclase crystals can be seen.

Similar calcareous tuffs were observed in the tuff areas south of the Anton Ruiz valley near its lower end and north of Arroyo and Patillas.

Shales.—Shales are of practically negligible importance in the older series of the Humacao district. All of those examined by the writer

contained so much material that is clearly of volcanic origin and were so intimately associated with tuffs that no attempt was made to map them separately. They are included with the latter on the geological map.

Sandstones.—Sandstones are of only minor importance. An occurrence was observed at the east end of the Patillas dam. The rock has a mottled dark brown color and, under the microscope, is seen to be made up chiefly of quartz grains reaching a maximum diameter of .32 millimeter and an occasional fragment of some pre-existing rock. The bond between the grains consists of chlorite, hematite, and sericite. The outcrop is not extensive and probably represents a small lens interstratified with the volcanic tuffs and breccias which crop out at other places near by. At the dam, the contact between it and a monzonite porphyry is exposed.

Along the upper portion of the west fork of the Patillas River, prominent ledges of medium-grained quartzite crop out along the creek bed. Microscopic examination reveals quartz to be the chief constituent but orthoclase and plagioclase are also present. A little chlorite, calcite, and sericite occur between the grains of the former minerals.

INTRUSIVES IN THE OLDER SERIES

Numerous intrusives, ranging in composition from augite andesite and gabbro on the one hand and to rhyolite and granite on the other, occur in association with the older series of the Humacao district. Some of these are present as intrusive sheets or sills varying from a few inches to several hundred feet in thickness, while others are in the form of stocks and bosses, ranging from a small fraction of a mile to several miles in largest horizontal dimension. One of the latter type has a sufficiently large areal extent to be called a batholith. Innumerable dikes of widely different mineralogical composition cut across, not only the formations of the older series itself, but many of the igneous rocks intrusive in it as well. As has already been pointed out, all of these manifestations of igneous activity antedate the middle Oligocene.

INTRUSIVE SHEETS AND SILLS

The numerous intrusive sheets and sills, that are interstratified with the tuffs, lavas and sedimentary rocks of the older series, are, for the most part, composed of augite, hornblende, and feldspathic andesites and andesite porphyries. Somewhat more siliceous varieties, such as dacite and latite, are of only minor importance. They range from a few inches to several hundred feet and perhaps more in thickness. In the field, on account of the limited occurrence and extent of outcrops, it is

very difficult and often impossible to distinguish them from extrusive types of similar mineralogical composition with which they may be associated and they have, therefore, not been mapped separately. It is believed that these igneous masses were intruded into the older series contemporaneously with their deposition or at least very shortly thereafter while the beds were still in a nearly horizontal position and before the orogenic movement set in that produced the present folded structure.

STOCKS, BOSSES, AND BATHOLITHS

The stocks, bosses, and batholiths of granitoid igneous rocks that have invaded the older series of the Humacao district are clearly of later origin than the intrusive sheets and sills just described, as they intersect the latter as well as the tuffs, lavas, and sediments with which they are associated. They, therefore, belong to a somewhat later period of igneous activity, probably contemporaneous with the period of folding and uplift or else closely following it. The more important types represented in this group are gabbro, quartz diorite, granite, and quartz monzonite—the gabbro being the oldest and the quartz monzonite the youngest.

Juncos gabbro.—A small intrusive mass of gabbro apparently in the form of a stock, occurring $1\frac{1}{4}$ miles northeast of Juncos, is the oldest of the second group of intrusives. Its outcrop covers an area of probably not more than 4000 feet in maximum and 2000 feet in minimum dimensions. The rock has a medium granitoid texture and under the microscope is found to consist chiefly of plagioclase of the labradorite variety and augite. A little greenish-brown hornblende occasionally occurs as reaction rims around the augite. Titanite is the chief accessory constituent. The Juncos locality is the only place where a rock of this type was observed.

San Lorenzo quartz diorite.—The major intrusive of the Humacao district consists of a medium to moderately coarse granitoid rock possessing the mineralogical composition of a quartz diorite. The largest outcrop underlies a rudely rectangular block approximately 15 miles long and 12 miles wide, which extends from Juncos on the north to Maunabo on the south and from the mouth of the Humacao River on the east to the headquarters of the Del Espino on the west. Exposed over a continuous area of over 180 square miles, it is evidently of sufficient size to be called a batholith (Daly, 1914) rather than a stock and will, therefore, be designated hereafter as the San Lorenzo batholith, since typical exposures occur in the vicinity of that town, particularly along the highway leading eastward toward Las Piedras and along the Del Espino valley to the south. The bed of the latter stream is strewn with great

boulders of the quartz diorite on some of which appear crude designs, as shown in figure 28, carved upon them by the aboriginal inhabitants of Porto Rico. Huge rounded monoliths, such as are shown in figure 29, form conspicuous outcrops in the quartz diorite area. The highway leading across Panduras Ridge from Maunabo to Yabucoa also affords excellent opportunities to examine the quartz diorite at close range.

A similar quartz diorite crops out along the Gurabo valley northeast of Juncos and also along the upper portions of the Blanco and Pena Pobre valleys in the northern portion of the Humacao district. These areas are a part of a large stock which underlies a considerable portion of the Luquillo Range and which is undoubtedly connected at no great

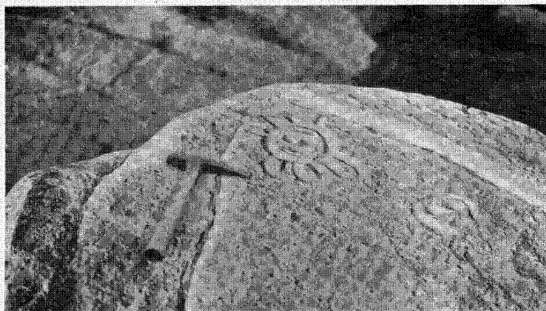


FIG. 28.—Boulder of quartz diorite along Del Espino valley, south of San Lorenzo

depth with the main San Lorenzo batholith. Another similar but somewhat smaller stock occurs in the vicinity of Caguas. Much smaller satellite stocks of from $\frac{1}{4}$ to $\frac{3}{4}$ of a mile in diameter were observed along the east fork of the Llaunel River, along the military road about 3 miles southwest of Caguas, and about $\frac{1}{2}$ mile east of the main batholith east of Las Piedras.

Under the microscope, the San Lorenzo quartz diorite is seen to be composed principally of plagioclase of an andesine or acid labradorite variety, quartz, and a dark brownish-green hornblende. Orthoclase, biotite, occasionally augite, magnetite, titanite, and apatite are the chief accessory constituents. The rock, as a rule, possesses a moderately coarse granitoid texture. This phase is by far the predominating type, but sometimes quartz drops out almost entirely so that the rock becomes a

diorite; in a few other instances orthoclase takes the place of plagioclase producing a hornblende granite; and in rare cases augite replaces hornblende so that the rock is a gabbro. Occasionally, in the case of the smaller satellitic stocks, the texture is porphyritic.

Figure 30 shows a photomicrograph of the quartz diorite from a specimen obtained from an outcrop south of the San Lorenzo-Las Piedras road about 2½ miles southeast of the former town. Plagioclase, quartz, and hornblende are the three chief constituents present. The plagioclase shows maximum extinction angles of 25 degrees in sections at right angles to the albite lamellæ and frequently exhibits pronounced zonal growth. The hornblende is markedly pleochroic, ranging from yellowish brown through greenish brown to deep brownish green. Orthoclase,

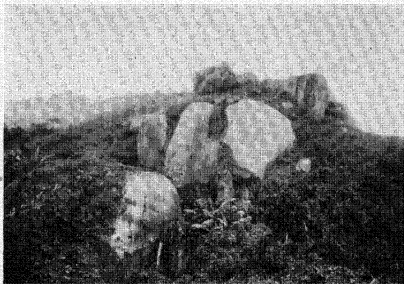


FIG. 29.—Quartz diorite outcrops in Guayanes valley region

biotite, magnetite, titanite, and apatite are the chief accessory constituents. The order of crystallization of the various minerals appears to have been apatite, magnetite, titanite, hornblende, plagioclase, orthoclase, and quartz. A little sericite has developed from the plagioclase and small amounts of chlorite and epidote from the biotite.

An augite diorite phase of the San Lorenzo quartz diorite occurs along the northern slopes of Panduras Ridge about 2 miles east of Yabucoa. Figure 31 shows a photomicrograph of this rock. Hornblende, plagioclase, and augite are the principal constituents. The hornblende is intensely pleochroic, ranging from yellowish brown through greenish brown to brownish green. The plagioclase shows maximum extinction angles of 35 degrees in sections at right angles to the albite lamellæ. The augite frequently is enveloped by reaction rims of hornblende. Basal

sections of augite surrounded by hornblende may be seen in thin section, each with its typical prismatic cleavage developed. Intergrowths of augite and hornblende are also present. Plagioclase appears to have crystallized before hornblende, inclusions of the former occurring in the latter. The latter also frequently fills the space between plagioclase crystals. Magnetite, orthoclase, titanite, and apatite are the principal accessory constituents.

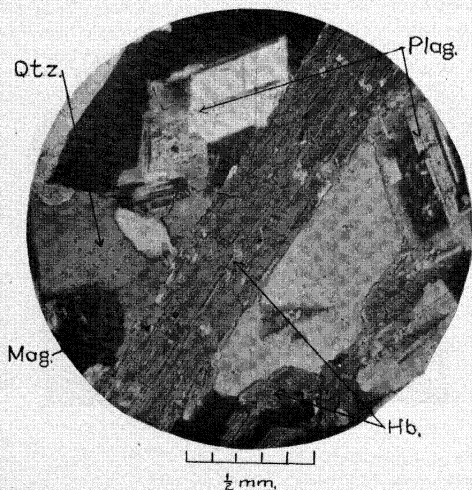


FIG. 30.—Photomicrograph of quartz diorite $2\frac{1}{2}$ miles southeast of San Lorenzo.
Crossed nicols

South of Humacao, $1\frac{1}{2}$ miles, a diorite phase developed. At this point the chief constituents are plagioclase, frequently showing zonal growth with maximum extinction angles of 26 degrees in sections at right angles to the albite lamellæ, and an intensely pleochroic brownish green hornblende. Quartz is only a minor constituent. The other accessory minerals are orthoclase, biotite, magnetite, apatite, and titanite. A little sericite has developed from the feldspar and chlorite and epidote from the biotite. One mile south of Humacao a gabbro phase occurs. Plagioclase and augite are its main components. The plagioclase shows

maximum extinction angles of $33\frac{1}{2}$ degrees in sections at right angles to the albite lamellæ. The augite is a pale greenish-gray non-pleochroic variety. It sometimes contains internal growths of dark brownish green hornblende in parallel orientation with one another, and is occasionally surrounded by narrow rims of the same mineral. Magnetite and orthoclase are the other accessory minerals besides hornblende. The order of crystallization appears to have been magnetite, augite, and plagioclase,

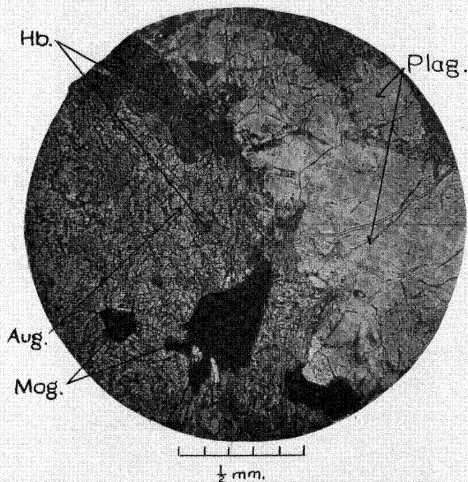


FIG. 31.—Photomicrograph of augite diorite 2 miles east of Yabucoa

although occasional inclusions of small plagioclase crystals in the augite indicate that some of the former antedates the augite.

Along the headwaters of the Ingenio River, in the vicinity of Teja Piedras barrio, the quartz diorite passes into a hornblende granite. Microcline, orthoclase, quartz, hornblende, and biotite are its chief constituents. Graphic intergrowths of quartz and orthoclase occur in it. Plagioclase is of only minor importance. The other accessory minerals are magnetite, titanite, and apatite. A little chlorite and epidote have developed from the biotite.

All of the above varieties are merely different phases of the San Lorenzo quartz diorite. Nowhere is there evidence that they were intruded as distinct units. On the other hand, transitional changes from

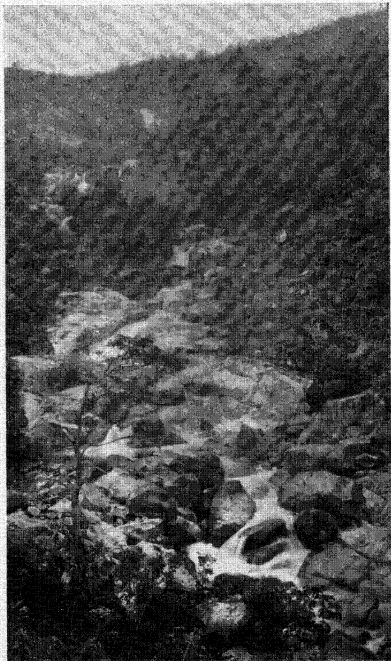


FIG. 32.—Falls of the Blanco River

one type to the other may frequently be seen. They represent segregation or differentiation phenomena that took place in the main mass after it had been intruded in its present position.

The Luquillo stock consists of a quartz diorite almost identical in mineral composition and texture with the main San Lorenzo mass. It

is particularly well exposed at the Falls of the Blanco River, shown in figure 32. Plagioclase, quartz, hornblende, and biotite are its principal constituents, while orthoclase, magnetite, apatite and titanite occur as accessory minerals. The plagioclase shows maximum extinction angles of $30\frac{1}{2}$ degrees in sections at right angles to the albite lamellæ. Zonal banding is common in it. The hornblende exhibits pronounced pleochroism, ranging from yellowish-brown through greenish-brown to brownish-green. Biotite is not always an essential constituent. Along the north side of the Pena Pobre valley it is practically absent in places.

The Caguas stock is composed of a grano-diorite phase of the San Lorenzo quartz diorite. Plagioclase, quartz, hornblende, and orthoclase are its essential constituents. The plagioclase possesses maximum extinction angles of 24 degrees in sections at right angles to the albite lamellæ and frequently exhibits zonal growth. Biotite, largely altered to chlorite, magnetite, apatite and titanite, are the principal accessory minerals.

The San Lorenzo batholith has produced pronounced contact metamorphic changes in the tuffs of the older series in many places where it has come in contact with them. In some instances, all traces of original structures have been obliterated with their conversion into hornblende schists. These changes are further discussed under contact metamorphism. The fact that the San Lorenzo quartz diorite is a younger intrusive than the Juncos gabbro is clearly shown northeast of Juncos where small tongues of quartz diorite, which are part of the Luquillo stock, project into the gabbro along its contact with the latter.

Yabucoa granite.—Around the borders of the San Lorenzo batholith and frequently in contact with it, there are a number of small stocks of coarse granitoid, frequently almost pegmatitic granite, which will hereafter be designated as the Yabucoa granite on account of the excellent exposures that may be seen in the vicinity of Yabucoa Point. The largest outcrop, which includes the above exposures and which covers an area roughly 4 miles long and $1\frac{1}{2}$ miles wide, occurs along the coast between the Yabucoa and Candelero playas. Other localities along the south coast where the granite is exposed are Point Yeguas, Cape Mala Pascua, and Patillas Landing. In the interior the only occurrence observed lies about 1 mile northeast of Las Piedras in the form of a strip $\frac{1}{4}$ of a mile wide and 2 miles long adjacent to the San Lorenzo batholith.

The Yabucoa granite possesses a very coarse granitoid, in some instances almost pegmatitic texture. Under the microscope, the two chief constituents are found to be orthoclase and quartz, the former sometimes being light pink in color. Only minor amounts of plagioclase, rarely

showing maximum extinction angles greater than 13 degrees in sections at right angles to the albite lamellæ, and a little biotite occurs in it. Hornblende is practically absent. Other accessory minerals are apatite, magnetite, and zircon.

A thin section of the granite from the vicinity of Yabucoa Playa consists chiefly of orthoclase and quartz in allotriomorphic intergrowths. Its accessory constituents are plagioclase, dark brown biotite, magnetite, and apatite. Figure 33 represents a photomicrograph of the granite.

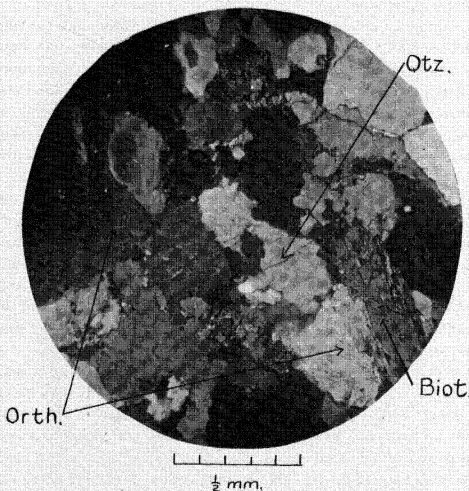


FIG. 33.—Photomicrograph of Yabucoa granite from Yabucoa Playa. Crossed nicols

In the vicinity of Fraile Point the granite still has a very much similar composition. A little zircon appears in sections of the rock from this locality. At Patillas Landing a micrographic intergrowth of orthoclase and quartz is a prominent feature in the rock which was not noted elsewhere. The coarse, almost pegmatitic Yabucoa granite 1 mile north-east of Las Piedras consists largely of light pink orthoclase and quartz. Plagioclase and biotite are its chief accessory constituents. The structure on the whole is allotriomorphic. Micropertthitic intergrowths of

orthoclase and plagioclase of minor importance are noticeable in some of the sections of this rock.

In the vicinity of Yabucoa Playa the contact between the Yabucoa granite and the San Lorenzo batholith is exposed. The fact that the Yabucoa granite represents a later intrusion is plainly evident, as it ramifies the quartz diorite in all directions in the form of dikes. The latter has also, in part, been converted into gneiss in the vicinity of the contact. These metamorphic effects are described in more detail under contact metamorphism.

Patillas quartz monzonite.—A third group of stocks intersecting the older series of the Humacao district is made up of granitoid rocks of the mineralogical composition of quartz monzonite. Such stocks are particularly well developed along the Patillas valley and the name Patillas quartz monzonite will, therefore, be applied to this type of intrusive hereafter. Similar stocks also occur along the Llaurel valley north of Arroyo, along the military road southwest of Caguas, along the Turabo valley, along the road leading from Caguas to Juncos, along the contact between the San Lorenzo batholith and the older series 3 miles east of Juncos, and in the vicinity of Naguabo. The areas covered by their outcrops are usually small, in most instances being less than $\frac{1}{2}$ mile in diameter. The largest of these intrusive bodies, that in the vicinity of the Patillas reservoir, however, is nearly 4 miles long and has a maximum width of about 2 miles.

In most instances plagioclase, orthoclase, hornblende, and quartz are the main constituents of the Patillas quartz monzonite, while magnetite, apatite, and titanite are the principal accessory minerals. While the texture is usually granitoid, it is considerably finer than that developed in the San Lorenzo quartz diorite and Yabucoa granite. Occasionally along the borders of the larger stocks or throughout in the case of some of the smaller ones it is porphyritic.

The Patillas quartz monzonite at the southeastern end of the stock, which occurs along the Patillas valley in the vicinity of the Patillas reservoir, is a fine granitoid dark greenish-gray rock in which feldspar, hornblende, and a little quartz are visible. In thin section the chief constituents are found to be orthoclase, plagioclase, green pleochroic hornblende, and quartz. Magnetite is an abundant accessory mineral. The feldspar is cloudy from the development of kaolinite and sericite. The hornblende has altered in part to epidote and chlorite. Along the southern margins of the stock the texture is porphyritic. Phenocrysts predominate over groundmass. They consist chiefly of plagioclase with maximum extinction angles of 18 degrees in sections at right angles to

the albite lamellæ, indicating andesine, a ferromagnesian mineral now completely altered to epidote and chlorite, and a little orthoclase. The groundmass consists of an allotriomorphic intergrowth of plagioclase, orthoclase, and quartz. Micrographic intergrowths of quartz and feldspar are common. Considerable sericite has developed from the feldspar. At the northeastern end of the Patillas reservoir the rock possesses a fine granitoid texture. Plagioclase, orthoclase, augite frequently surrounded by rims of green hornblende, and quartz in part in micrographic intergrowth with orthoclase, are the principal constituents. Magnetite in abundance and apatite are the accessory minerals. Considerable sericite and kaolinite as well as some chlorite have developed from the feldspar by alteration. The augite and hornblende have also in part been altered to chlorite and epidote.

A small stock of the Patillas quartz monzonite on the west side of the Llaunel valley along the playa border consists of a fine granitoid gray rock in which feldspar, hornblende, and quartz are likewise visible. Under the microscope, plagioclase, orthoclase, quartz, and pale green hornblende are seen to be the important constituents. Almost colorless cores of augite surrounded by pale green hornblende are also present. The quartz occurs in part as micrographic intergrowths with the orthoclase. Magnetite in abundance and apatite occur as accessory minerals. Some kaolinite and a little sericite have developed from the feldspar. The hornblende has partially altered to chlorite and epidote.

The two small intrusive masses of Patillas quartz monzonite occurring 3 miles east of Juncos along the contact between the San Lorenzo batholith and the older series possess a porphyritic texture with phenocrysts in excess. The predominating minerals are plagioclase, orthoclase, and a dark greenish-brown hornblende. The groundmass is made up largely of feldspar and quartz occurring in part as micrographic intergrowths. Magnetite, apatite, and titanite are the principal accessory constituents. Abundant sericite has developed from feldspar. Small amounts of chlorite and epidote also occur in the rock as alteration products.

The other areas of Patillas quartz monzonite, shown on the geologic map, are very similar in texture and mineralogical composition to those described.

The relationship of the Patillas quartz monzonite to the Yabucoa granite is shown along the coast, 2 miles southeast of Patillas where their contact is exposed, as shown in figure 34. The rock at the left is the quartz monzonite and that at the right the granite. The point of the hammer rests upon the contact. The quartz monzonite 15 feet from the contact possesses a fine granitoid texture. Orthoclase, plagioclase, augite,

and quartz are its main constituents. Some of the quartz occurs in micrographic intergrowth with the orthoclase. A little green hornblende is present in the form of reaction rims around the augite. Magnetite, apatite, and biotite are accessory minerals. Sericite has developed from feldspar, chlorite from augite, and a little epidote occurs along minute fractures in the rock. Approaching the contact the texture becomes finer and finer until at the contact it is felsitic and the rock becomes a quartz latite. The intrusion of the quartz monzonite appears to have had no effect upon the Yabucoa granite, which is clearly the older rock.



FIG. 34.—Contact of Patillas quartz monzonite at left with Yabucoa granite at right. Southeast of Patillas

DIKES

Dikes of igneous rocks, cutting not only the older series itself but also the major intrusives in it, are prominent geologic features in the Humacao district. They range in thickness from a fraction of an inch up to 55 feet and perhaps more in some instances. On account of their great abundance and the small thickness of many of them, no attempt has been made to show them upon the geologic map. For purposes of description, they can be divided into two types, namely, those of a siliceous character and those of intermediate to basic composition. The major period of dike formation appears to have commenced soon after the intrusion of the San Lorenzo batholith and continued until shortly after the appearance of the Patillas quartz monzonite.

Siliceous dikes.—The siliceous dikes consist of granite, granite pegmatite, aplite, granite and rhyolite porphyry, and rhyolite. These are

undoubtedly closely related to the Yabucoa granite and the first two are probably identical with it. They were found cutting only the San Lorenzo quartz diorite. The aplites and granite and rhyolite porphyries, on the other hand, occur not only in the San Lorenzo quartz diorite but are also intrusive in the Yabucoa granite itself, and, in one instance, an aplite dike was found cutting a quartz monzonite porphyry that is probably the equivalent of the Patillas.

Granite and granite pegmatite dikes.—In the vicinity of Quebrada Honda Point, the San Lorenzo quartz diorite is cut by a dike of granite 1 foot 10 inches wide that splits as shown in figure 35. The texture is granitoid and the important mineral constituents are orthoclase, microcline, quartz, and plagioclase of the albite variety, showing maximum



FIG. 35.—Granite dike in San Lorenzo quartz diorite, Quebrada Honda Point

extinction angles of $13\frac{1}{2}$ degrees in sections at right angles to the albite lamellæ. Small amounts of biotite and a very little magnetite, apatite, and zircon are accessory minerals. This rock is undoubtedly identical with the Yabucoa granite, a stock of which may be seen about 1000 feet south along the coast.

Pegmatite dikes cut the San Lorenzo batholith at a number of places along its borders. Such a dike, 1 foot in thickness, may be seen along the Juncos-San Lorenzo road about $\frac{4}{5}$ of a mile southwest of Juncos. Orthoclase in crystals up to 4 centimeters in length and soda plagioclase are its chief constituents, but some quartz and biotite are also present. It resembles rather closely some of the coarser phases of the Yabucoa granite and is thought, therefore, to be identical with it.

Aplite dikes.—Aplite dikes are of much more frequent occurrence than the pegmatite varieties and are not confined to the San Lorenzo quartz diorite areas but also occur in the Yabucoa granite, and in one place along the military road southwest of Caguas in the vicinity of K. 41, a 12-foot dike of this type cuts a quartz monzonite porphyry that has been correlated with the Patillas. Figure 36 shows a number of aplite dikes cutting the Yabucoa granite in the vicinity of Yabucoa Point. The majority of these dikes do not exceed 1 foot in thickness and usually they are considerably thinner. They always possess a rather fine granitoid texture and are composed principally of orthoclase and quartz. Plagioclase, biotite, muscovite, and magnetite are only very minor constituents.

Granite and rhyolite porphyry dikes.—The granite and rhyolite porphyry dikes are the most abundant and important of the siliceous group. The two differ from one another only in the relative abundance of the phenocrysts present in them and the texture of their groundmasses. In the former phenocrysts predominate, while in the latter the groundmass is in excess. Granite and rhyolite porphyry dikes are rather widely distributed



FIG. 36.—Aplite dikes cutting Yabucoa granite in the vicinity of Yabucoa Point

throughout the Humacao district. They cut the formations of the older series as well as the San Lorenzo quartz diorite and the Yabucoa granite, but were nowhere found intersecting the Patillas quartz monzonite. It is probable, therefore, that they followed closely after the intrusion of the former and before the appearance of the latter.

The granite and rhyolite porphyries can be studied to good advantage in the vicinity of Yabucoa Point where their intrusive relation to the Yabucoa granite is well shown. The dikes of this locality consist of a light gray coarse porphyritic rock in which abundant euhedral as well as anhedral crystals of both orthoclase and quartz and occasional flakes of biotite are visible. The phenocrysts of orthoclase frequently reach lengths

of $2\frac{1}{2}$ and diameters of $1\frac{1}{2}$ centimeters. They consist of simple crystals bounded by a prism and basal and clinopinacoids. Carlsbad twins with the same forms developed on them may also be seen. The euhedral crystals of quartz sometimes reach lengths of 2 centimeters and diameters of 1.2. They consist of combinations of the hexagonal prism with the positive and negative rhombohedrons. One instance was noted where two crystals occurred in parallel growth in the form known as scepter

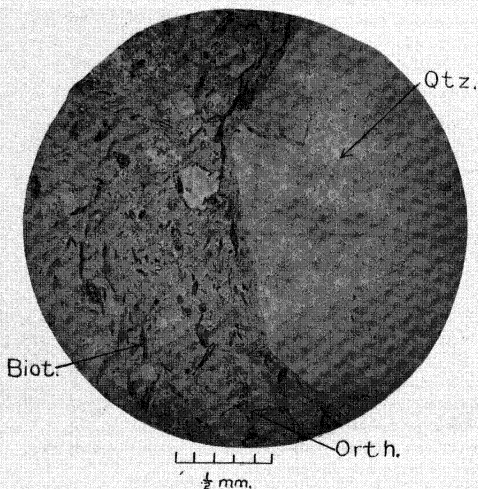


FIG. 37.—Photomicrograph of rhyolite porphyry cutting San Lorenzo quartz diorite in the vicinity of Quebrada Honda Point

quartz. While numerous phenocrysts of quartz are euhedral, the majority are rounded at least at the corners. Biotite is not a conspicuous constituent. Oligoclase, magnetite, titanite, and zircon are minor accessories. The groundmass consists of a fine mosaic of orthoclase and quartz. A little chlorite and epidote have developed from the biotite and sericite from the feldspar.

A photomicrograph of the rhyolite porphyry from a dike 26 feet thick cutting the San Lorenzo quartz diorite in the vicinity of Quebrada Honda

Point is shown in figure 37. It possesses a coarse porphyritic texture. The phenocrysts consist of euhedral and anhedral orthoclase and quartz. The orthoclase occurs in simple crystals and as Carlsbad twins. Oliogoclase and minute flakes of biotite are accessory constituents. The latter indicate a flowage structure by their parallel alignment around the larger phenocrysts. The groundmass is cryptocrystalline. A little sericite has developed from the feldspar and chlorite and epidote from the biotite.

Several dikes of rhyolite porphyry, cutting a felsite, may be seen in a quarry for road rock along the west bank of the Patillas River where the road from Patillas to Arroyo crosses it. The phenocrysts consist principally of orthoclase and quartz but the rock is particularly exceptional in that occasional small trapezohedrons of garnet up to 1 millimeter in diameter occur in it. Sometimes the garnets appear in the groundmass but often they are present as inclusions in the orthoclase. Occasional plagioclase phenocrysts may also be seen. The groundmass consists of a fine allotriomorphic intergrowth of orthoclase and quartz. Sericite in abundance has developed from the feldspar.

Rhyolite.—About $\frac{1}{4}$ mile up the Quebradillas valley from the military road southwest of Caguas, a dike of rhyolite about 10 feet thick occurs in the rocks of the older series. In thin section only occasional small phenocrysts of orthoclase are visible. The groundmass, which consists largely of orthoclase and quartz, is extremely fine. A little epidote and chlorite are present in it.

Dikes of intermediate and basic composition.—The dikes of this group range in mineralogical composition from latites and monzonites on the one hand to augite and andesites and diabase on the other, and possess textures ranging from felsitic through porphyritic to granitoid, the felsitic and porphyritic types being the more common. They are encountered most frequently in the older series, but are also abundant in the marginal portions of the San Lorenzo batholith and are occasionally present in the Yabucoa granite and Patillas quartz monzonite. While some of these dikes may be older than the San Lorenzo quartz diorite, it is believed that the majority followed shortly after the intrusion of that rock.

Latite and monzonite dikes.—Dikes of the mineralogical composition of latite and monzonite were found cutting the older series, the San Lorenzo quartz diorite, and the Yabucoa granite.

A latite dike about 20 feet thick cuts the volcanic breccias of the older series along the west fork of the Llaunel River. Macroscopically it is a dark gray almost black felsitic rock. Under the microscope a few phenocrysts of plagioclase and orthoclase may be observed. Magnetite

occurs as an accessory constituent. The groundmass is composed largely of minute interlocking feldspar crystals and a little augite.

Southeast of Naguabo Playa, latite and monzonite porphyries are present amongst the numerous dikes that cut the andesitic rocks of the older series in that vicinity. A thin section from a latite porphyry dike only $1\frac{1}{2}$ inches wide contains numerous phenocrysts of plagioclase, orthoclase, and hornblende in an extremely fine crypto-crystalline groundmass. Biotite, quartz, and magnetite are accessory constituents. Flowage is indicated by the parallel alignment of the phenocrysts, particularly the smaller ones. Near by, a thicker dike of monzonite porphyry, with phenocrysts predominating over groundmass, has almost an identical mineralogical composition.

In the vicinity of Quebrada Honda Point, a quartz monzonite porphyry dike only 8 inches wide cuts the San Lorenzo quartz diorite. Plagioclase of the andesine variety, orthoclase, microcline, quartz, and biotite are its prominent constituents. Magnetite, apatite and titanite occur in it as accessory minerals.

Along the coast near Patillas Landing, a dike of latite porphyry, 20 feet thick, cuts the Yabucoa granite. The phenocrysts consist of orthoclase and plagioclase of the oligoclase variety. The groundmass shows a spherulitic structure. Apatite is present as an accessory mineral. Chlorite, sericite, and epidote occur as alteration products.

Dacite and quartz diorite dikes.—Dacite and quartz diorite dikes are not very abundant. Along the coast west of Naguabo Playa, a dacite dike, 12 feet thick, intersects a felsite belonging to the older series. In thin section, the rock shows a felsitic texture. Plagioclase and quartz can be identified in it. Chlorite, calcite, and epidote are present as alteration products.

At one place along the Guayanes valley, a dike of quartz diorite porphyry, 3 feet thick, was found cutting the San Lorenzo quartz diorite. Labradorite, quartz, hornblende, and biotite are its predominating minerals. Orthoclase, a little magnetite, and apatite occur as accessory constituents.

Andesite and diorite dikes.—Dikes of andesitic composition are the ones most frequently encountered in the Humacao district. Hornblende and augite varieties are about equally abundant. They are mostly confined to the older series and the San Lorenzo quartz diorite, but instances were also noted where augite andesites cut the Yabucoa granite and the Patillas quartz monzonite. In texture they range from felsitic to porphyritic.

A hornblende andesite porphyry with very prominent large crystals

of hornblende cuts the older series near the crest of the Sierra de Cayey at the head of the west fork of the Patillas River. In thin section, phenocrysts of greenish-brown hornblende and lesser amounts of plagioclase are prominent. Magnetite is present as a minor accessory. The groundmass consists principally of plagioclase and hornblende. Some epidote has developed as an alteration product from the hornblende.

Along the coast in the vicinity of Naguabo Playa, a hornblende andesite dike, 3 feet thick, cuts andesitic rocks belonging to the older series. Its texture is felsitic and under the microscope the structure is seen to be diabasic, but bluish-green hornblende containing inclusions of biotite occupies the space between the plagioclase laths instead of augite.

In the vicinity of Quebrada Honda Point, a felsitic hornblende andesite dike, 2 feet thick, cuts the San Lorenzo quartz diorite. A greenish-brown pleochroic hornblende and plagioclase are its chief constituents. Magnetite is abundant. An occasional grain of augite and a little titanite are also present. A flowage structure is indicated by the parallel alignment of the amphibole crystals.

A 55-foot dike of augite andesite intersects the volcanic rocks of the older series along the Llaunel River a short distance below the forks. It is a dark gray, almost black porphyritic rock in which phenocrysts of plagioclase and augite are visible. In thin section, plagioclase phenocrysts of the labradorite variety are seen to predominate but pale brownish-green non-pleochroic crystals of augite are also prominent. The groundmass contains abundant microlites of plagioclase. A little magnetite is also present. Small amounts of sericite have developed from plagioclase and chlorite and calcite from augite.

Near the northeastern end of the Patillas reservoir, a felsitic dike of augite andesite, 15 feet wide, cuts the San Lorenzo quartz diorite. Its chief constituents are plagioclase and augite. A little magnetite is also present. Some calcite, chlorite, and epidote have developed by alteration from the plagioclase.

Along the coast not far from Patillas Landing, a 15-foot dike of augite andesite cuts the Yabucoa granite. It is felsitic in texture and plagioclase and augite are its main components. Magnetite occurs as a minor constituent. Some chlorite is present as an alteration product.

On the point which projects into the Patillas reservoir at the east end of the dam, a dike of augite andesite cuts the Patillas quartz monzonite. It is a felsitic dark gray, almost black rock. Under the microscope, a few phenocrysts of labradorite feldspar and augite are visible. The groundmass is made up largely of feldspar laths with augite inter-

spersed between. Abundant magnetite also occurs in it. A little chlorite associated with augite and calcite are present as alteration products.

A diorite porphyry dike, 2 feet thick, cuts the San Lorenzo quartz diorite in the vicinity of Quebrada Honda Point, as shown in figure 38. It consists chiefly of labradorite feldspar and hornblende. Orthoclase, magnetite, titanite, and apatite are minor accessory constituents. A little epidote has developed by alteration from the plagioclase.

Diabase dikes.—Only two occurrences of diabase dikes were noted in the Humacao district, in both of which the diabase cuts Patillas quartz monzonite stocks in the Llaunel valley region. The diabase ranges from fine granitoid to porphyritic in texture. Labradorite feldspar, frequently zonal, and a pale green non-pleochroic augite are its chief constituents, the latter filling the space between the feldspar laths. Magnetite and highly pleochroic brown biotite are the accessory minerals.

CONTACT METAMORPHISM

Contact metamorphic phenomena in the older series are confined principally to the immediate vicinity of the San Lorenzo batholith. The metamorphism has resulted largely in the conversion of the tuffs and associated andesites of the former into schists and gneisses, chiefly of a hornblendic variety. This has been brought about by a recrystallization of the original constituents of the former and the development of a foliated structure in the resulting rock. Apparently, no new material has been added from the outside. The pressure exerted by the invading magma upon its walls as it was making room for itself appears to have been responsible for the development of the foliated structure. The schistosity everywhere is parallel to the contact.

The conversion of portions of the Collores limestone into an aggregate of lime iron silicates is also believed to have been the result of the intrusion of the quartz diorite magma of the San Lorenzo batholith, but in this case emanations from the magma itself reacted with the calcium carbonate of the limestone to produce the metamorphic minerals.

In the vicinity of Yabucoa Playa, the intrusion of the Yabucoa granite has converted the San Lorenzo quartz diorite into a gneiss just as the invasion of the latter converted the tuffs and andesites into schists.

HORNBLLENDE SCHISTS AND ASSOCIATED ROCKS

The Maunabo River, along a considerable portion of its course, follows rather closely the contact of the San Lorenzo quartz diorite with the tuffs of the older series and the effects of this intrusive upon the

latter can, therefore, be studied to good advantage at many places along its course. Outcrops of metamorphic rock appear about $2\frac{1}{2}$ miles above the town of Maunabo and continue at intervals for nearly 3 miles. Go-

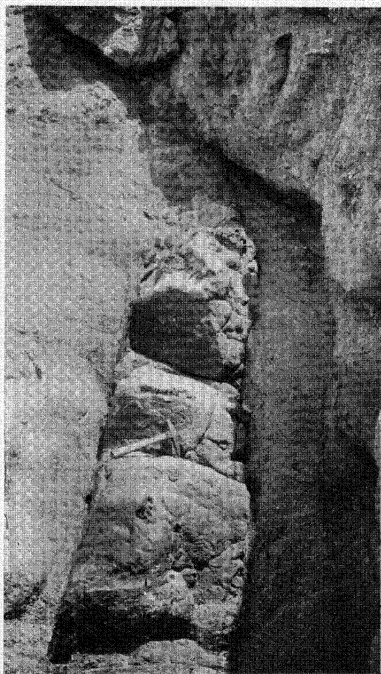


FIG. 38.—Diorite porphyry dike cutting San Lorenzo quartz diorite in the vicinity of Quebrada Honda Point

ing up stream the first outcrops encountered possess a dark gray color and fine crystalline texture. The foliated structure is not very noticeable to the naked eye. Under the microscope, the rock is seen to consist of an interlocking mosaic of augite, orthoclase and a little quartz. Small

grains of magnetite are fairly abundant and a little muscovite is also present. The augite is a pale brownish-green non-pleochroic variety full of inclusions of orthoclase and quartz as well as magnetite. Often considerable patches of individual augite grains behave as single units optically. A slight indication of a foliated structure may be observed, due to the greater concentration of augite grains along certain bands and their parallel orientation. A photomicrograph of this pyroxene schist is shown in figure 39. A little further upstream plagioclase and a little

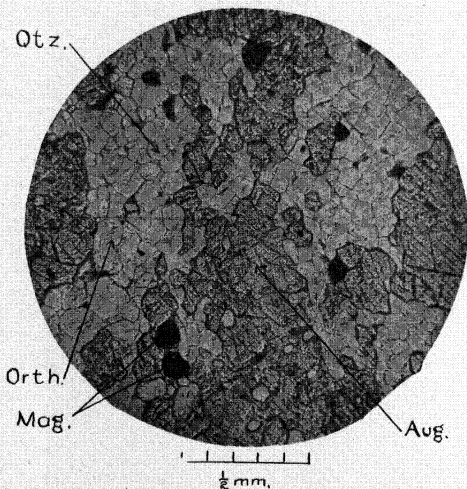


FIG. 39.—Photomicrograph of pyroxene schist along Muunabo River 2½ miles above Maunabo

hornblende also appear in the schist. About a mile above the first locality, typical hornblende schists make their appearance. These also possess a fine to medium crystalline texture and show a slightly foliated structure due to the more or less parallel alignment of the hornblende grains. In thin section, the rock is found to consist of a mosaic of hornblende, plagioclase, orthoclase, and quartz grains. Some magnetite is also present. The hornblende is a deep green, highly pleochroic variety. Compared with the augite grains of the pyroxene schists it is rela-

tively free from inclusions. Occasional larger grains of orthoclase and plagioclase with ragged borders also occur in the rock. There was encountered a fine grained quartzite $2\frac{1}{2}$ miles above the first locality. This consists principally of a fine mosaic of quartz with only occasional grains of orthoclase and plagioclase. Now and then a cluster of pyroxene grains may also be observed in it. In patches, chlorite and sericite occur between the quartz grains.

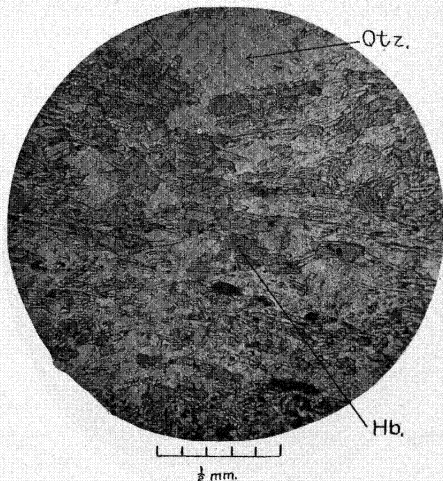


FIG. 40.—Photomicrograph of hornblende schist from Tuna Point

In the vicinity of Tuna Point, southeast of Maunabo, a small area of hornblende schist and associated quartzite is exposed along the coast. The hornblende schist possesses an extremely fine crystalline texture and a pronounced foliated structure due to the concentration of the hornblende in bands between the quartz grains. The rock consists principally of hornblende and quartz, the former being relatively free from inclusions as are the quartz grains. A little orthoclase showing Carlsbad twinning and plagioclase exhibiting albite twinning are also present. Pyrite and magnetite in little grains also occur in the rock. A photomicrograph of this schist is shown in figure 40. The quartzite associated

with it is an extremely fine-grained variety, a photomicrograph of which appears in figure 41. It consists of a fine mosaic of granular quartz in which a little hornblende in parallel alignment may be observed. Some magnetite grains are also present.

Metamorphosed tuffs also appear at the headwaters of the Guayanes River and along the divide between that stream and the Del Espino River. A dark gray fine crystalline specimen from the latter locality exhibiting a distinctly foliated structure was found under the microscope

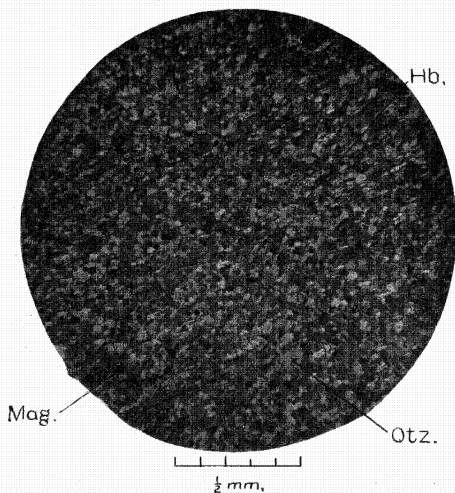


FIG. 41.—Photomicrograph of quartzite from Tuna Point. Crossed nicols

to be made up of alternate bands of augite, feldspar and quartz, and hornblende. The augite is nearly colorless in thin section. Considerable patches of its grains behave optically as single units. The lighter colored bands consist principally of plagioclase, orthoclase, and quartz. The hornblende is a dark brownish-green pleochroic variety. While its grains are also in more or less parallel alignment along certain bands, patches of them do not behave optically as units when viewed between crossed nicols. Occasional larger ragged crystals of augite full of magnetite

inclusions and having hornblende developed along their borders, as well as in their interiors, are also present. These may represent augite crystals of the original tuff from which the schist has been derived.

Along the Caguas-San Lorenzo road northwest of San Lorenzo, in the vicinity of K. 8, the metamorphic belt is approximately 2000 feet wide. The metamorphosed tuff still contains original ragged and cloudy crystals of plagioclase and orthoclase. The recrystallized portions consist of a mosaic of green pleochroic hornblende, plagioclase, orthoclase, and quartz. The latter feldspars are clear.

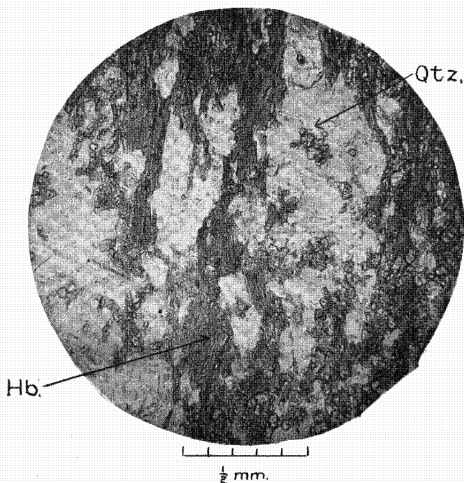


FIG. 42.—Photomicrograph of hornblende schist from hill south of Humacao

A specimen of hornblende schist obtained 2 miles southwest of Juncos, in the vicinity of the San Lorenzo quartz diorite contact, contains fairly numerous large ragged crystals of plagioclase, clouded by the development of sericite in them, imbedded in a recrystallized matrix composed largely of dark bluish-green hornblende and smaller amounts of plagioclase, quartz, and possibly orthoclase. The foliated structure is due to the parallel alignment of the hornblende crystals along their long axes.

A narrow belt of schists borders the San Lorenzo quartz diorite along the south side of the Humacao Playa. A photomicrograph of a specimen obtained from a small hill which projects above the playa level south of Humacao, is shown in figure 42. It is a dark gray fine-grained foliated rock consisting of bluish-green pleochroic hornblende, quartz, plagioclase, and a little pale green non-pleochroic augite. The latter sometimes has rims of hornblende around it, particularly in the case of the larger crystals. The schistose structure is due chiefly to the parallel alignment of the longer axes of the hornblende.

Inclusions of metamorphosed tuff and andesite are of rather common occurrence in the marginal portions of the San Lorenzo quartz diorite. They vary in diameter from a few inches up to many feet in some instances.

METAMORPHOSED LIMESTONE

The Collores limestone, whose outcrop occurs along a belt trending S. 53° E. for a distance of nearly six miles about $\frac{1}{4}$ mile northeast of the San Lorenzo batholith, has been recrystallized into a gray to white crystalline rock of medium texture, in which all fossil remains that may have occurred in it originally have been obliterated. In places, this limestone has been converted into an aggregate of lime iron silicates by contact metamorphism. It is with these metamorphosed portions that the magnetite deposits of eastern Porto Rico are associated.

Contact metamorphic phenomena in the Collores limestone can be studied to good advantage in the vicinity of the third magnetite deposit southeast of Juncos in the barrio of Collores de Piedras. Northwest of this magnetite deposit, which occurs very near the top of a northwest-southeast ridge, prominent ledges of the limestone crop out that range in mineral composition all the way from crystalline calcite associated with only small amounts of silicates to those in which silicates are the predominant constituents present. A thin section of the least altered rock consists mostly of calcite and a little garnet intersected by fractures along which quartz, specular hematite, and possibly magnetite have been introduced, replacing the calcite. This was followed by the development of chlorite along fractures and between calcite grains, replacing the latter in part. The final stage was the deposition of later calcite in the form of minute veinlets cutting the other minerals. In the more altered rock, a photomicrograph of which is shown in figure 43, garnet, showing pronounced optical anomalies, is the predominant mineral, having almost completely replaced the original calcite of the limestone. Magnetite and specular hematite have been introduced along fractures, accompanied by the development of chlorite. Later, veinlets of calcite and quartz cut

the other minerals. The limestone is overlain by an andesite at this locality. Only the upper portion directly underneath the andesite has been effected, as above described.

Toward the southeast, the magnetite deposit east of Juncos is succeeded by a belt of metamorphic rock which is believed to have been derived from the Collores limestone, perhaps a tuffaceous phase. Numerous prominent ledges crop out along the hillside. Large vugs occur

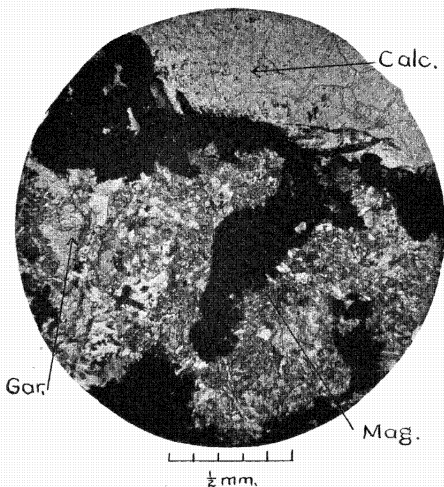


FIG. 43.—Photomicrograph of contact metamorphosed limestone. Barrio of Collores de Piedras

in it in places. A microscopic examination of the rock reveals that it consists largely of pyroxene and garnet, the garnet having developed after the pyroxene. Calcite, epidote, quartz, and talc are present in minor amounts. Chlorite has developed along minute fractures. Another specimen taken from the walls of one of the vugs consists largely of garnet and amphibole, together with some talc. The garnet apparently formed first, then the amphibole, and finally the talc. Hornblende and pyroxene schists, undoubtedly derived from andesitic tuffs, overlie and underlie the metamorphosed limestone.

Garnet rock, associated with the Collores limestone, was also observed at one locality near the southeast end of the limestone belt.

Quartz diorite gneiss.—In the vicinity of Yabucoa Playa, the San Lorenzo quartz diorite has been converted into a gneiss by the intrusion of the Yabucoa granite. The gneiss itself is cut by numerous tongues of the coarse Yabucoa granite and by aplite dikes. The rock possesses a medium crystalline texture and a greenish-gray color. It shows a distinctly gneissoid structure. In thin section, it is seen to consist princi-

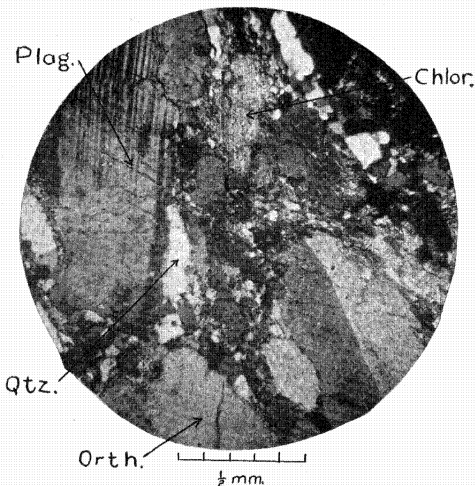


FIG. 44.—Photomicrograph of quartz diorite gneiss from Yabucoa Playa. Crossed nicols

pally of plagioclase, quartz, some orthoclase, and brownish-green hornblende. Magnetite, titanite, biotite, now mostly altered to chlorite, and apatite are the chief accessory constituents. The hornblende has been affected most by the shearing produced by the pressure exerted by the invading granite magma, but the quartz also shows a pronounced cataclastic structure. The feldspars have been affected the least. Sericite and kaolinite have developed from the feldspar, the plagioclase having been altered more than the orthoclase. The hornblende has been con-

verted in part into chlorite, epidote, and calcite. A photomicrograph of this rock is shown in figure 44.

FOLDING

The structure of the formations belonging to the older series is complex. The uplift which followed their deposition and which was accompanied by the intrusion of the San Lorenzo batholith and numerous closely related stocks, produced a folded structure in them that is rather difficult to unravel on account of the relative scarcity of outcrops and the massive character and weathered condition of a large percentage of those that do exist. Reliable strike and dip observations can be obtained at only rare intervals. For this reason it has been possible to show the trend of the folds only in a general way on the geologic map.

In the western portion of the district the folds have a northwesterly and southeasterly trend. Starting at the south, a syncline, followed by an anticline and another syncline, occur. Another anticline starts near the headwaters of the Turabo River and trends slightly east of north, just east of the Turabo valley. As has already been pointed out in connection with the description of the Collores limestone, a syncline apparently exists northeast of the San Lorenzo batholith, between it and the Luquillo stock, which also trends in a northwesterly-southeasterly direction.

FAULTING

No direct evidence for the occurrence of faulting on a major scale was found within the limits of the Humacao district, although in some instances the abrupt change in character of the formations within comparatively short distances along their general strike and some of the topographic features of the district would seem to indicate that there is a possibility that displacements of considerable magnitude, due to faulting, may exist. In the few cases where faults were actually observed in outcrops under conditions that made a measurement of the displacement possible it was always found to be small.

ALLUVIAL DEPOSITS

Unconsolidated alluvial deposits form the broad plains, known as playas, that occur along the lower courses of all the major streams of the Humacao district. For the most part, these have accumulated in estuaries formed by the drowning of the river valleys, but in some instances, particularly along the south coast, they represent alluvial fans that have been built out into the sea by the streams issuing from the

channels into these deposits and thereby forming terraces along their valleys. Such dissected alluvial deposits are sometimes encountered almost at the head of a stream, as is the case with the exposure shown in figure 47, which occurs along Pena Pobre Creek.

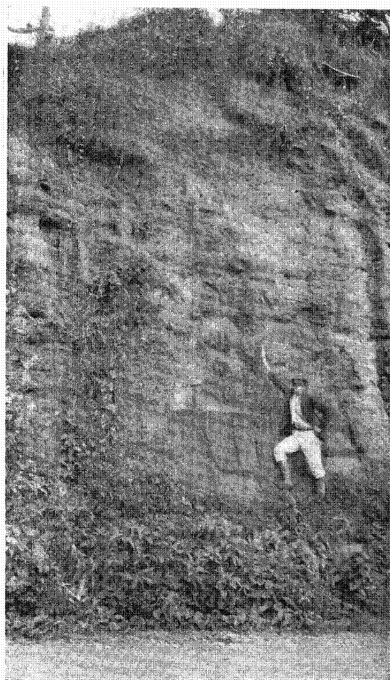


FIG. 47.—Alluvial deposits near head of Pena Pobre Creek.

HISTORICAL GEOLOGIC SUMMARY

The oldest rocks exposed within the limits of the Humacao district are essentially young from a geologic standpoint. While no fossils were

discovered in the older series in southeastern Porto Rico by the author, sufficient evidence has been gathered by other investigators in adjacent areas to lead to the conclusion that this series is largely confined to the upper Cretaceous, although there is a possibility that a portion of the lower part may be lower Cretaceous in age and some Eocene sediments may be included in its uppermost members.

During Cretaceous times, Porto Rico was the scene of intense volcanic activity, largely of the explosive type. Enormous quantities of fragmental material were extruded, chiefly of an andesitic character, that built up the great beds of volcanic tuffs and breccias that now comprise the major portion of the older series of the Humacao district. A portion of the eruptions, however, was of a quieter type and resulted in the lava flows, also largely andesitic, that are interbedded with the fragmental rocks. Not all of the latter, however, reached the surface, as some are clearly of an intrusive character, having forced themselves as sheets and sills amongst the layers of tuff and breccia extruded by previous eruptions.

Much of this volcanic debris, perhaps the major portion of it, undoubtedly accumulated under sub-aerial conditions. The occurrence of occasional beds of limestone, such as the Collores, interstratified with the volcanic rocks, however, indicates that the district did not stand above sea-level throughout the Cretaceous period, but that oscillation with respect to sea-level took place from time to time, which resulted in at least partial submergence of the area at intervals.

Toward the close of the Cretaceous, a general uplift took place which was accompanied by the folding of the volcanic and associated sedimentary rocks that comprise the older series. Fresh accessions of magmatic material appeared which invaded the Cretaceous formations, and in the Humacao district resulted in the formation of the San Lorenzo batholith and the Luquillo and Caguas stocks.

While practically all of the volcanic rocks, both massive and fragmental, are either andesites or closely related types, the later intrusions show a much wider range in chemical and mineralogical composition. Apparently, the primary magmas from which the various igneous rocks of the Humacao district have been derived were of an andesitic or dioritic character. During the earlier stages of igneous activity, when comparatively free communication with the surface prevailed, very little differentiation occurred in this magma. Later on, however, when new accessions of igneous material became largely of an intrusive character, such differentiation did take place. As a result, quartz diorites are followed by granites and quartz monzonites in the form of batholiths and stocks.

The dike rocks accompanying this period of igneous activity show even greater variation, ranging all the way from aplites and granite pegmatites at the one extreme to diabase at the other. The diabase dikes that are occasionally found cutting the quartz monzonite stocks appear to be the last manifestations of igneous activity in the Humacao district.

After the uplift which marked the close of the Cretaceous, there is no direct evidence that any extensive portions of the Humacao district, with the exception of the playa areas, again become submerged below sea-level. The later geological history of this area must, therefore, be interpreted from its physiographic development and from what took place in other portions of the island. From the fact that nowhere are there any igneous rocks found associated with the Tertiary sediments that occur along the north and south coasts outside the Humacao district, it appears that volcanic activity came to an end with the uplift that marked the close of the Cretaceous.

During the early Tertiary, erosion wore a large portion of the Humacao district down to a peneplain. It was at this time that the extensive erosion surface, referred to as the upper peneplain in the early part of this report, was developed. This was followed by another uplift of perhaps 1000 feet. Erosion again set in and developed a lower peneplain over that portion of the Humacao district lying between the Guayanes and Humacao drainage areas and that portion occupied by the Caguas lowland, the rest of the region reaching a mature stage of erosion. A slight submergence followed the second partial peneplanation, which affected the western portion of the island in particular, for along the northern and southern coasts extensive marine deposits of middle and upper Oligocene (Hubbard, 1923, p. 66; Lobeck, 1922, p. 318) age rests upon an erosion surface that is contemporaneous with the lower peneplain of the Humacao district. There is no direct evidence, however, that any of the Humacao district itself was submerged, as nowhere within its borders are there any Tertiary sediments.

The submergence of a portion of the northern and southern coastal margins during Oligocene time was followed by another uplift which, in the case of the Humacao area, resulted in a rejuvenation of the streams and a marked increase in their eroding power. Somewhat later, a drowning of the entire coast line occurred which resulted in the formation of numerous large estuaries that are now filled with alluvial debris and constitute the playa areas of the southeastern coast. Lobeck (1922, pp. 346-348) attributes the drowning of the coast to a rise of sea-level, due to the melting of the ice stored up in the great continental glaciers of North America and Europe at the close of the Pleistocene epoch.

Recent changes in the Humacao district have consisted in the deposition of alluvium along stream valleys and in drowned bays and as alluvial fans along the south coast. Evidence for a local emergence of perhaps 25 to 30 feet along portions of the coast also exist in the form of wave cut terraces, raised beaches, and cliffs cut into recent playa deposits containing marine fossils.

ECONOMIC GEOLOGY

MAGNETITE DEPOSITS

Magnetite deposits that have attracted some attention as possible future sources of iron ore occur at a number of localities in the older series of the Humacao district. The principal ones, which have already been described by the writer in a previous paper (Fettke, 1924) occur in association with the belt of Collores limestone, trending approximately S. 53° E. which begins 1½ miles east of Juncos and can be traced for a distance of about 6 miles toward the coast. Four outcrops of magnetite were observed along it, which are designated as Nos. 1, 2, 3, and 4, respectively, starting at the northwestern end on the geological map accompanying this report. Others are probably present but escaped notice on account of the thick mantle of residual soil which in most places conceals the bed rock formations. One deposit, 9/10 mile south of Torres, designated as No. 5, lies outside the main belt, being about 7/10 mile northeast of it. Other deposits of a similar character occur in the older series, 3 or 4 miles west of Juncos, a short distance south of the Juncos-Caguas road, and in the hills north of Arroyo. The writer did not have an opportunity to examine these personally, but was informed by Professor James F. Kemp that they are very similar to those lying east of Juncos.

The outcrop at locality No. 1 east of Juncos makes the most prominent showing and this deposit is probably the largest of those examined. Inasmuch as there are no fuels available in Porto Rico for the establishment of a local iron industry, the ores, if exploited, will have to be shipped. The two nearest harbors at which shipping facilities are at present available are San Juan and Fajardo Playa. Of these, San Juan is by far the better. By way of the Gurabo and Rio Grande de Loiza valley, the Juncos deposit is 31 miles distant from San Juan. The electric and narrow gauge steam railroad from San Juan to Caguas covers the distance to the mouth of the Gurabo River. From there it is 10 miles up the Gurabo valley to the magnetite deposit. Along the greater portion of the latter distance a light narrow gauge track has already been con-

structed for the transportation of sugar cane from the fields to the central "Juncos."

By way of the headwaters of the Gurabo River, across the divide to the Rio Blanco valley, down it to Naguabo, and thence parallel to the coast to Fajardo Playa, the distance is about 27 miles. Ensenada Honda,

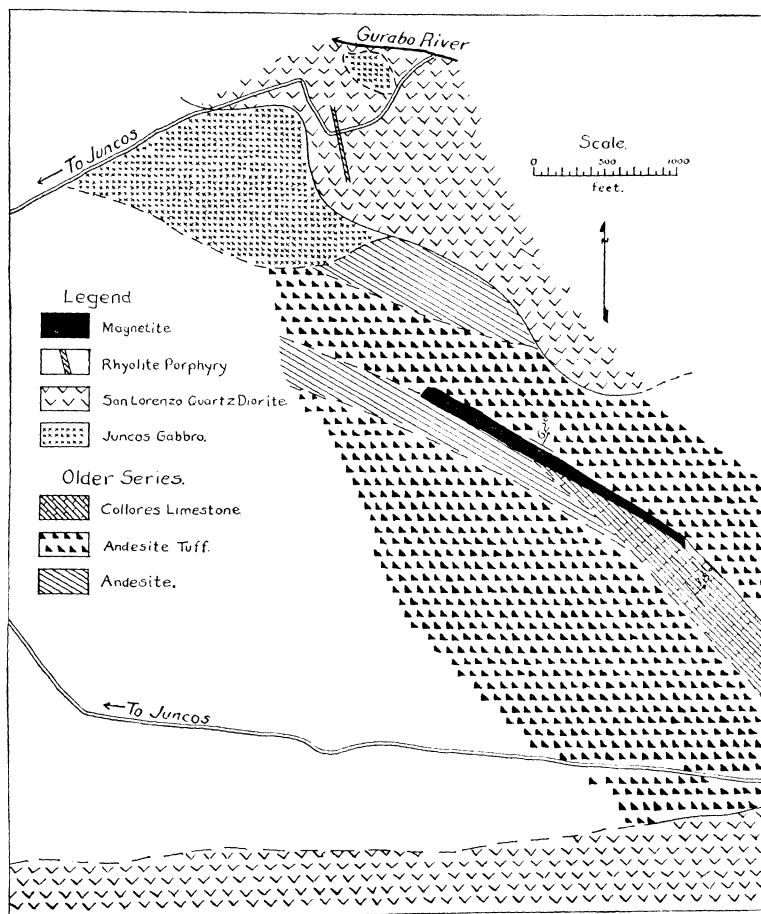


FIG. 48.—Relation of magnetite outcrop No. 1 to surrounding formations

south of Fajardo Harbor, is 7 miles nearer, but no shipping facilities are at present available. Along all but the first 9 miles of this distance light narrow gauge tracks are already in existence for the hauling of cane. The only steep grades along this route occur after leaving the headwaters of the Gurabo River and going down Peña Pobre Creek, a tributary of the Rio Blanco. Along this the haul would be down grade.

The magnetite deposit at locality No. 1 lies $1\frac{1}{2}$ miles east of Juncos along the crest of a ridge, south of the Gurabo valley, that rises approximately 375 feet above the lowlands to the north and south. Figure 48 consists of a sketch map, based upon field notes, which shows the relationship of the outcrop to the surrounding formations; while figure 49 is a photograph of the ridge as it appears from the south looking north.

The outcrop has a strike of N. 60° W. and apparently dips 62° toward the northeast. It can be traced for a distance of 2000 feet along the crest of the ridge, but the best development of magnetite occurs at the northwest end, where large boulders and prominent ledges of nearly pure magnetite make a very conspicuous showing. Much of the magnetite

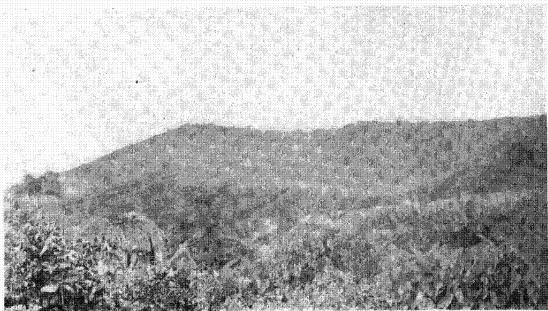


FIG. 49.—Ridge with magnetite deposit east of Juncos

appearing in the outcrop at the northwest end is fine grained and nearly pure. It possesses a porous structure, due undoubtedly to the leaching out of silicates and perhaps small amounts of sulphides by weathering. Octahedral crystals of magnetite are sometimes seen lining drusy cavities. Part of the magnetite is sufficiently magnetic to pick up small tacks. Occasionally a fine grained intergrowth of magnetite and specular hematite occurs. Qualitative analyses show only traces of titanium. In several places, a little malachite was noticed. This is presumably derived from a sulphide, such as chalcopyrite, and indicates that in depth small amounts of sulphides are probably present in association with the magnetite. Garnet occurs with the magnetite at the west end of the deposit. Under the microscope, it exhibits pronounced optical anomalies and complex twinning. A little fibrous amphibole has been formed from it by

alteration. At the east end, the magnetite occurs with much larger amounts of silicates. A thin section of a specimen shows epidote to be the predominant mineral with which the magnetite is associated, but small patches of garnet are also present. Figure 50 is a photomicrograph showing the association of magnetite and garnet; while Figure 51 shows that of magnetite and epidote.

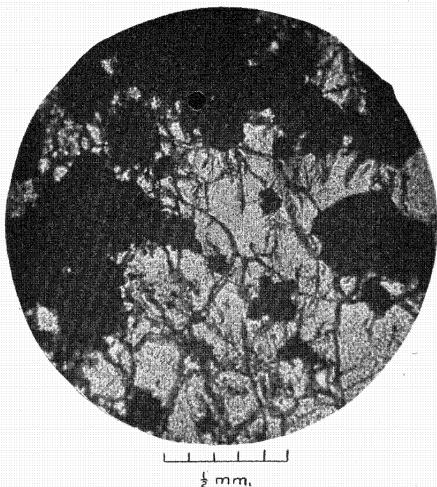


FIG. 50.—Magnetite ore from western end of Juneos deposit; black mineral is magnetite, light mineral is garnet

Toward the southeast, the magnetite is succeeded by a belt of metamorphic rock which is believed to have been derived from the Collores limestone, perhaps a tuffaceous phase. Numerous prominent ledges crop out along the hillside. At one place about 400 feet beyond the ore body, the strike is N. 37° W. and the dip 38° N. E. Large vugs occur in the metamorphosed rock in places. A microscopic examination of the rock reveals that it consists largely of pyroxene and garnet, the garnet having developed after the pyroxene. Calcite, epidote, quartz, and talc are present in minor amounts. Chlorite has developed along minute frac-

tures. Another specimen taken from the walls of one of the vugs consists largely of garnet and amphibole with some talc. The garnet apparently formed first, then the amphibole, and finally the talc.

Hornblende and pyroxene schists undoubtedly derived from andesite tuffs, overlie and underlie the metamorphosed limestone. A thin section of a specimen obtained from above the limestone possesses a distinctly foliated structure. It is made up chiefly of plagioclase, quartz, orthoclase, and a deep green hornblende. A little pyroxene is also present.

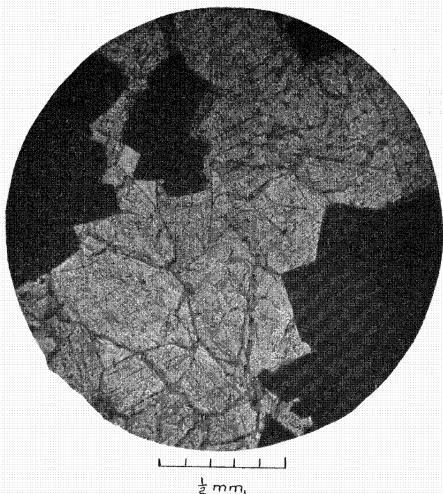


FIG. 51.—Magnetite ore from eastern end of Juncos deposit: black mineral is magnetite, light mineral is epidote

The outlines of a few original feldspar crystals, now completely altered to kaolin, sericite, and epidote, can still be recognized. Magnetite and titanite are present as minor constituents. Another specimen taken from a point some distance below the limestone also possesses a schistose appearance. It is composed of an interlocking mosaic of pale green pyroxene, plagioclase, orthoclase, and a little dark green hornblende. A few large crystals of pyroxene full of inclusions, including smaller

pyroxene grains, are present. Magnetite occurs in minor amounts. Epidote has developed along minute fractures.

At the west end, an augite andesite occurs as the footwall of the magnetite deposit. It possesses a felsitic texture with a tendency for the many feldspar laths of the groundmass to be in parallel alignment, indicating a flowage structure. A few phenocrysts of plagioclase of an andesine or acid labradorite variety and a little augite are present. The matrix consists chiefly of plagioclase. Titanite is an accessory mineral. Pale green hornblende aggregates occur along small fractures, as well as in places once occupied by augite phenocrysts. The plagioclase is clouded by alteration products.

In one place north of the deposit, an outcrop of metamorphosed andesite tuff was observed. It possesses a fine texture and exhibits a slight tendency towards a schistose structure. Grains of augite, plagioclase, and orthoclase up to .4 millimeters in length, are present. The matrix consists chiefly of an allotriomorphic intergrowth of quartz and pale green hornblende. A little chlorite has developed from hornblende.

Beyond the andesite tuff toward the northwest, there is an occurrence of hornblende andesite porphyry. Augite phenocrysts with reaction rims of hornblende are prominent. The matrix is made up predominant of a brownish-green hornblende with only minor amounts of plagioclase. It is coarse in texture. A little magnetite and apatite are present.

The Juncos deposit lies about 2,500 feet north of the San Lorenzo quartz diorite batholith. An off-shoot of the latter, which is part of the Luquillo stock, crops out 500 feet north of the magnetite occurrence.

The magnetite deposit at locality No. 2 is situated about $3\frac{3}{4}$ miles southeast of No. 1 on the south side of a ridge about 160 feet below its crest and 365 feet above the valley at its base. The outcrop strikes N. 50° W. and can be traced for a distance of 335 feet. The dip appears to be 72° toward the northeast.

Magnetite is the chief ore mineral present but some fine grained specular hematite also occurs. Garnet is the predominating gangue mineral appearing in the outcrop. Drusy cavities lined with trapezohedrons of garnet and sometimes small octahedrons of magnetite as well as crystals of quartz are of common occurrence. Veinlets of magnetite and quartz are seen cutting massive garnet rock. The garnet possesses a reddish-brown color. A qualitative analysis indicates that it is the andradite variety—silica, iron oxide, and lime being the chief constituents. Alumina occurs in only small amounts and magnesia is absent.

A green brecciated rock forms the north or hanging wall of the deposit. The dark green portion is intersected in all directions by streaks

of light colored material. Under the microscope, the dark green portions are found to consist chiefly of pyroxene associated with small amounts of garnet. The light portions represent an allotriomorphic intergrowth of plagioclase, orthoclase, quartz, and some pyroxene. It is thought that this rock represents a metamorphosed andesite tuff, probably a calcareous one.

North of the tuff along the crest of the ridge, an augite andesite crops out. This has a felsitic texture. Under the microscope, the plagioclase laths of the groundmass are seen to be in more or less parallel alignment, indicating a flowage structure. A few large phenocrysts of augite can still be recognized. Others have been altered into aggregates of epidote or brownish-green biotite and secondary quartz. The matrix is composed of plagioclase laths, biotite, and augite.

The above magnetite deposit is located about $\frac{1}{3}$ mile northeast of the San Lorenzo batholith.

The outcrop of the magnetite deposit at locality No. 3, which is $\frac{1}{2}$ mile southeast of No. 2, while it does not make a very conspicuous showing at the surface, is of considerable interest because the relationship of the magnetite and contact metamorphic minerals associated with it to the Collores limestone is brought out more clearly than at any of the other localities. The magnetite associated with the metamorphosed limestone occurs very near the top of a northwest-southeast ridge. Numerous outcrops of nearly pure crystalline light gray and white limestone appear on the southwest flank of this ridge. The strike of the formations is N. 54° W. and the dip is 32° N. E. It is estimated that the limestone has a thickness of at least 250 feet. A small quarry has been opened in it at one place from which limestone has been taken for burning into lime for local use. Qualitative analyses of the limestone indicate that it should yield a good grade of lime.

A thin section of the crystalline gray limestone below the magnetite, reveals an interlocking mosaic of calcite crystals of medium texture with only occasional minute grains of iron oxide amongst them and a very little chlorite. A specimen of the metamorphosed limestone from the hanging wall of the deposit is composed of garnet, pyroxene, and calcite—garnet being the most abundant. Garnet seems to have developed somewhat later than pyroxene, and some of the calcite in the form of little veinlets cuts all three. Northwest of the deposit proper, prominent ledges crop out that range in mineral composition all the way from crystalline calcite associated with only small amounts of silicates, to those in which silicates are the predominant constituents present. A thin section of the least altered rock consists mostly of calcite and a little

garnet intersected by fractures along which quartz, specular hematite, and possibly magnetite have been introduced, replacing the calcite. This was followed by the development of chlorite along fractures and between calcite grains, replacing the latter in part. The final stage was the deposition of later calcite in the form of minute veinlets cutting the other minerals.

The limestone is overlain by an andesite at locality No. 3 and underlain by a metamorphosed and much altered andesite tuff. The magnetite deposit occurs in the upper portion of the limestone just below its contact with the overlying andesite. The San Lorenzo batholith lies about $\frac{1}{3}$ mile to the southwest.

The outcrop of the magnetite deposit at locality No. 4 occupies nearly the entire crest of a hill about $1\frac{1}{2}$ miles southeast of No. 3. It has a length of nearly 200 feet and a maximum width of 80 feet at the western end. At this end some coarse micaceous hematite, associated with quartz, as well as massive magnetite, are present. The outcrop, while not very large in area, makes a very prominent showing. Great boulders of massive magnetite derived from it are strewn along the hillside to the south and have accumulated in the little valley at the base.

A feldspathic andesite comprises the hanging wall of the deposit. In thin section, it is seen to possess a felsitic texture and distinct flowage structure, brought out by the parallel alignment of the plagioclase laths. A few phenocrysts of plagioclase and a light green hornblende derived possibly from augite are present. Occasional aggregates of epidote also occur. The matrix consists predominately of plagioclase laths in more or less parallel alignment. Skeleton crystals of iron oxide, possibly magnetite, are prominent. A little hornblende is also present. Three hundred feet south of the deposit there is a small outcrop of a sericite phyllite, probably representing a metamorphosed volcanic ash or shale, which has a strike of N. 59° W. and a dip of 41° N. E. Sericite, quartz, and iron oxides are its chief constituents. One thousand five hundred feet N. 73° W. from the deposit prominent outcrops of gray crystalline limestone and associated garnet rock were observed. The main San Lorenzo batholith lies $\frac{3}{4}$ mile to the southwest, while a small offshoot from it crops out only $\frac{1}{3}$ mile away.

The magnetite deposit at locality No. 5, $9/10$ mile south of Torres and about the same distance north of No. 4, does not belong to the same belt as the four deposits already described. The outcrop, which is not very conspicuous, being traceable only for about 50 feet, occurs on the north side of a ridge just below its crest, which rises 410 feet above the

Gurabo valley. Figure 52 is a photograph of the ridge as it appears from the north.

On the northeast side of the ridge, 220 feet below the magnetite prospect in elevation, outcrops of limestone are exposed, one ledge having a thickness of 10 feet. On account of the massive character of the rock, no strike and dip measurements on the limestone itself were possible. It is overlain, however, by an augite andesite, showing flowage structure under the microscope, outcropping ledges of which occur in such relation to the limestone as to lead one to conclude that the strike of the contact of the two is N. 48° W. and the dip 52° S. W. This makes it appear that a syncline occurs between the deposits of Nos. 4 and 5 and that the limestone at locality No. 5 may be the same bed that the other four deposits are associated with.



FIG. 52.—Ridge with magnetite deposit south of Torres

A microscopic examination of the limestone reveals a rather fine-grained rock composed chiefly of an interlocking mosaic of calcite crystals with occasional grains of quartz, augite, and plagioclase distributed amongst them. The latter undoubtedly represent tuffaceous material deposited contemporaneously with the calcareous constituents. One hundred and seventy feet southeast of the limestone outcrops along the hillside a prominent ledge of garnet rock, developed from the limestone, was noticed. The garnet, which is apparently an andradite variety, shows birefringence and is optically negative. It was at first mistaken for vesuvianite in thin section, but possesses a higher index of refraction than the latter mineral.

Going in the direction of dip, augite andesite and latite occur between the limestone and magnetite outcrops over a belt about 350 feet wide. Whether these are extrusive or intrusive sheets could not be determined from their field relations. The andesite which immediately overlies the limestone, in thin section, shows a parallel alignment of its plagioclase laths, indicating a flowage structure. The wall rocks of the magnetite deposit itself are not exposed. A latite tuff overlies the magnetite, but it was not observed in direct contact with it. This in turn is succeeded by dacites and andesites toward the southwest. The magnetite deposit lies $1\frac{1}{3}$ miles northeast of the San Lorenzo batholith contact and $1\frac{1}{2}$ miles southeast of the Luquillo stock.

The magnetite deposits described are clearly of the type ordinarily termed contact metamorphic deposits. In each case they possess mineral associations and occur in such relation to the surrounding rocks as to lead one to conclude that they have been formed by the replacement at high temperatures and pressures of either a nearly pure limestone, a tuffaceous limestone, or a calcareous tuff. A study of the geology of southeastern Porto Rico leads one to the conclusion that the magma, which gave rise to the San Lorenzo quartz diorite batholith, as well as the Luquillo and other smaller satellitic stocks, and from which the later intrusions that surround, and in some instances penetrate the quartz diorite, were derived by magmatic differentiation, was also responsible for the emanations that formed the magnetite deposits in the more calcareous portions of the older series of eastern Porto Rico. The proximity of the San Lorenzo batholith and the Luquillo stock, as well as smaller offshoots, to the magnetite deposits, indicates that the quartz diorite undoubtedly underlies them at no very great depth.

The metamorphism produced by the intrusion of the quartz diorite into the older series was of two kinds. In one case it involved simply a recrystallization of constituents already present in the original rock with very little change in chemical composition. The heat of the intrusive and probably the escaping water vapor, as well as the pressure exerted by the invading mass, were largely responsible for these changes. Hornblende schists were in many instances developed from andesite tuffs along the contact, as has already been pointed out. In a few places, where the intrusions came in contact with shales and sandstones, phyllites and quartzites were formed. The conversion of an ordinary limestone into a crystalline one, such as now occurs in the vicinity of the magnetite deposits, with the obliteration of all traces of organic remains, can likewise be attributed to the same cause.

In the case of the formation of the magnetite deposits and their asso-

ciated silicates, on the other hand, emanations from the magma itself introduced large amounts of mineral matter, consisting chiefly of silica and iron oxides, which re-acted with and to a great extent replaced the original calcite of the limestone and calcareous tuff with which the deposits are associated.

The mineralized emanations from the cooling quartz diorite magma rose along fractures through the surrounding rocks in the immediate vicinity of the intrusive until they came to places where the fractures intersected the nearby limestones and calcareous tuffs. The latter re-acted with the ferro-siliceous emanations much more readily than the andesites and ordinary tuffs with which they are interbedded and replacement occurred. In making an exploration of the Humacao district for

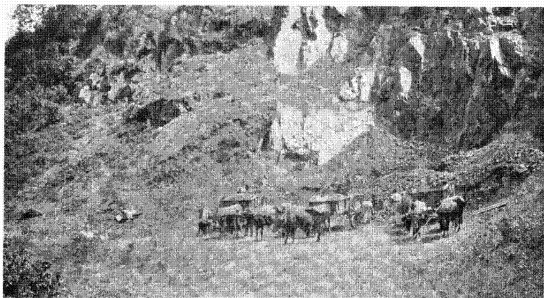


FIG. 53.—Road rock quarry along Quebradillas Creek southwest of Caguas

iron ore deposits, therefore, the belts along which the calcareous portions of the older series crop out, in the vicinity of the San Lorenzo batholith and its satellitic stocks, are the ones which should be prospected most thoroughly.

ROAD METAL

Rock suitable for road construction is abundantly distributed throughout the Humacao district. Amongst the various types that have been used for this purpose are included felsite, rhyolite, latite, dacite, andesite, quartz diorite, andesitic tuffs and breccias, and calcareous tuffs. The andesites and latites are probably the best for macadam road construction. Figure 53 shows a view of one of the larger quarries located along the military road southwest of Caguas, a short distance up the Quebradillas valley. The rock obtained here is a hornblende latite.

LIMESTONE

The Collores limestone was the only one encountered within the borders of the Humacao district that is of sufficient purity to be suitable for burning purposes. The best development was observed in the vicinity of the barrio of Collores de Piedras, where it has a strike of N. 54° W. and dips 32° toward the northeast. Prominent ledges of gray and white crystalline limestone, in some instances 40 feet thick, crop out. The total thickness is estimated to be 250 feet. Qualitative analyses indicate a very pure limestone. There is very little residue after treatment with cold dilute hydrochloric acid, and only slight amounts of iron oxides and alumina and a trace of magnesium carbonate are present. A small quarry has been opened in it at one place from which limestone has been taken for burning into lime for local use.

BRICK CLAY

While the residual soils of the upland area of the Humacao district are predominatingly of a plastic ferruginous clayey nature, they are not suitable for making a good grade of building brick. The writer did not come across a single locality in the district where bricks were being made from them.

KAOLIN

At several places along the military road southwest of Caguas and west of K. 45, rhyolite porphyry dikes are exposed that have been almost completely altered to kaolin. In some instances these are almost pure white in color, while in other cases they are badly stained by limonite. The quartz phenocrysts of the original rhyolite porphyry are still plainly visible in the white kaolin. These could probably be removed by careful washing. There is a possibility that commercial deposits of kaolin may be present in this locality.

THERMAL SPRINGS

One thermal spring, the Virella, located out on the playa northwest of Arroyo, lies within the borders of the Humacao district. Hodge (1920, pp. 225-226) quotes the following analysis made by Mr. Louis Hernandez, of the Porto Rican Service of Sanitation, of the waters of this spring:

Quantitative analysis

	Parts per million.	Amount of water used, Cubic centimeters.
Nitrates	.02	100
Free ammonia.....	.0432	
Albuminoid ammonia.....	.048	
Total ammonia.....	.0912	1000
Potassium	.0697	500
Sodium	.819	500
Lithium	.00287	10000
Sulphates	.4598	1000
Magnesium	.0012	1000
Calcium	1.6877	1000
Chlorine	1.35796	100
Silicon dioxide.....	.3678	1000
Carbonates as CO ₂	1.06577	100
Ferric oxide.....	.00402	

5.94702

	Parts per million.
Sodium nitrate.....	.0739
Ammonium chloride.....	.1374
Lithium chloride.....	.00343
Potassium chloride.....	.1469
Sodium chloride.....	2.1991
Magnesium sulphate.....	.004
Calcium sulphate.....	1.1088
Ferric carbonate.....	.00759
Silicon dioxide.....	.3678
Calcium carbonate.....	1.7721
	5.82102
Total solids.....	5.8242

Qualitative analysis

Bromine	negative
Iodine	negative
Hydrogen sulphide.....	negative
Carbonic anhydride (free).....	negative
Free sulphurous anhydride.....	negative
Phosphoric anhydride.....	negative
Boric acid.....	negative
Lithium (spectroscopically).....	positive

Specific gravity..... 1.006

Temperature 30° C. |

Alkaline to litmus and phenolphthalein.

Hodge attributes the high chloride content of the water from this spring to wind-carried salt spray from the near-by coast and to the fact that the waters issue through recent coastal plain deposits, which have not as yet been completely freed of their connate sodium chloride.

Several small bath houses were at one time erected at the Virella Spring, but these have now fallen into a state of disrepair.

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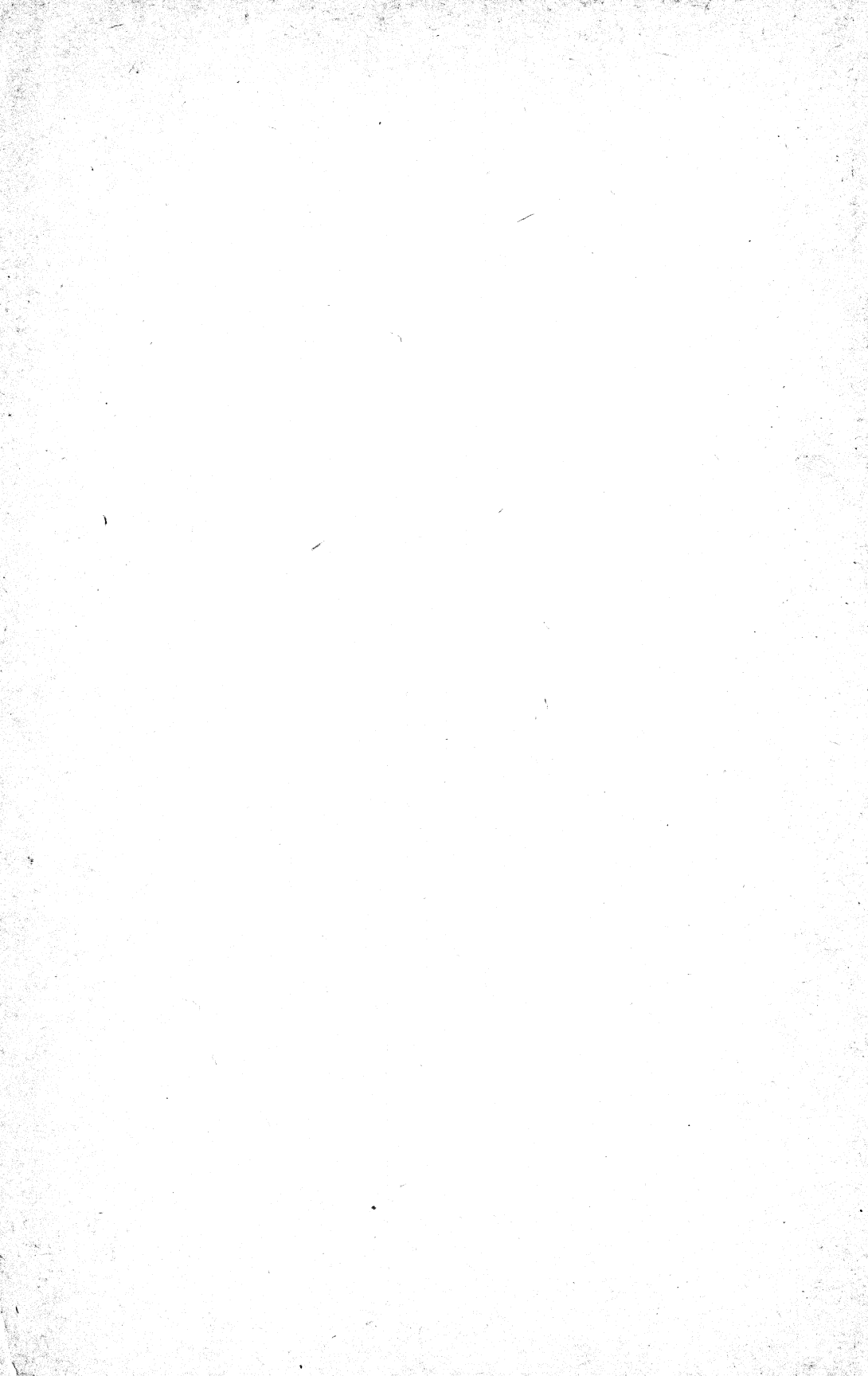
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New York Academy of Sciences

Porto Rico and the
Virgin Islands

Vol. 7, pt. 1-3

1923-31

