NEW YORK ACADEMY OF SCIENCES

SCIENTIFIC SURVEY OF PORTO RICO AND THE VIRGIN ISLANDS

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OF

Porto Rico and the Virgin Islands

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Geology of the Ponce District—*G. J. Mitchell*

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GEOLOGY OF THE PONCE DISTRICT, PORTO RICO

By Graham John Mitchell

CONTENTS

INTRODUCTION

Nature of Investigation

A geological study of the Ponce District, an area of about 850 square miles, in the southwest corner of the island, was undertaken with the expectation that in this less humid section some points in the geology—for example, the structure and age of the Older Series and the question of recent changes of level—might be determined. The relation of this area to other parts of Porto Rico may be seen by reference to the Outline Map.[1]

The field-work occupied the period from June 1 to September 8, 1917, and the report was completed in the Geological Laboratory of Columbia University during the succeeding winter. Field-work was carried on from the principal cities and towns as headquarters, saddle-horses being the chief means of transportation. The formations along all roads, numerous trails, and many stream courses were studied, and it was along such routes that the best exposures and decipherable structures were found, especially in the Cretaceous rocks. Seven main traverses were

[1] Scientific Survey of Porto Rico and the Virgin Islands, I, pt. 1, p. 26.

made from north to south, with many detours into adjoining territory, thus making it possible to examine all formations of any consequence.

Geological and Topographical Map

The base map for the region was compiled from maps of the United States Coast and Geodetic Survey and of the Insular Government, supplemented by the writer's field-notes. The scale used, 1 : 50,000, or approximately one and a quarter inches to one mile, makes it possible to show areally small intrusive bodies which could not have been represented on the available smaller-scale maps. The topography is generalized, but care has been taken to depict the surface features in as much detail as time would allow.

Routes of Travel

On the Geological Map an attempt has been made to differentiate the first-class macadam roads from those of second grade. All important trails are also shown on this map, but the innumerable local paths of the natives have been omitted.

Climate and Vegetation

The climate is tropical, but modified by the trade winds and by the land and sea breezes. The district as a whole has less rainfall than other parts of Porto Rico. In fact, the extreme southwest corner borders on aridity. The mountains along the northern boundary of the district receive a copious supply of moisture from the sudden downpours, which were observed to be a daily event during the period spent in the district.

Tropical vegetation is rank in most of the higher mountains. It forms a tangled mass, through which it is often necessary to chop one's way unless roadways or streams are followed. However, all the mountain slopes are not so heavily coated with plant growth, some being comparatively barren; for example, the serpentine ridges north of Sabana Grande and some of the hills of Tertiary limestone along the south coast.

Acknowledgments

The many courtesies extended by residents throughout the island and the material assistance given by not a few of its people not only added pleasure and comfort throughout the work, but were in a measure responsible for the satisfactory completion of the field investigation.

Among those who rendered special service were Col. George R. Shanton, Chief of Insular Police. Governor Yager's suggestions of a general nature and his assistance in getting the field-work started were highly appreciated. Dr. Lippitt, of the Bureau of Sanitation, gave information concerning sanitary conditions and also furnished letters to residents in the district. To Señor Manuel Gonzales, of Salinas, the writer is indebted for the loan of saddle-horses, the securing of which made it possible to cover the area in much greater detail than could otherwise have been done. Deputy United States Marshal George Trautman, of Ponce, spent one day in the field with the writer, pointing out features of interest in the vicinity of the manganese deposit north of Juana Diaz. The efficient service of Señor Fernando Oliver, Jr., as interpreter was a considerable aid in the field-work.

The field-work and preparation of the report have been under the general direction of Dr. Charles P. Berkey, whose interest has been a source of inspiration. Dr. Amadeus W. Grabau has made valuable suggestions in stratigraphical and paleontological matters, as has also Dr. J. J. Galloway.

Dr. T. W. Stanton, of the United States Geological Survey, determined the *Radiolites* sp. and *Actaconella* sp., and thus made it possible to place the age of the oldest rocks as Upper Cretaceous. Dr. Robert Tracy Jackson identified the *Clypeaster rosaceus* and the new species *Hemiaster berkeyi*. He has also kindly furnished a description for the latter. Lastly, the writer wishes to express his acknowledgments to the New York Academy of Sciences, which institution made it possible to carry on the investigation.

PHYSIOGRAPHY

Introductory Statement

The broader relief features of the Ponce District may be grouped as follows:

(1) A complex mountainous area, the westward continuation of the central Cordillera, which is characterized by angular ridges and deep, narrow valleys cut several hundred feet below the general level of the mountain surface, the altitude of which rises to over 3600 feet in the highest peaks, in the region to the southwest of Adjuntas. These mountains stand on the north side of the district, and their southerly and westerly slopes stretch toward the coast with more or less uniformity and pass beneath the remnants of Tertiary coastal plain sediments which border the south coast. The southwestward continuation of this "old land" surface is broken by two conspicuous, broad valleys, one extending from Yauco on the east to Boqueron, on the west, and the other occupy-

ing the triangular lowland from San German to Cabo Rojo. The most rugged section extends along the northern side of the region from the eastern boundary, east of Villalba, to the vicinity of Maricao, the hills becoming lower and the valleys broader as one approaches the south and west coasts.

(2) A much-dissected coastal plain of Tertiary sediments, which at one time lapped over the eroded surface of these complex mountains, but is now faulted down against the older rocks and forms a border along the south coast. These coastal-plain deposits are cut into isolated remnants by streams flowing through to the Caribbean Sea.

(3) Lowland areas, some quite extensive, occupy present and former river valleys and stretch along the coast in broad, gently seaward sloping plains, called playas. The most striking of such lowlands are the valleys between Yauco and Boqueron and the valley of the Guanajibo River. The most extensive playas are Ponce, Guayanilla, Cape Rojo and Mayaguez.

In the following pages the physiographic details of these broader relief features will be presented, together with a discussion of minor surface configurations.

Complex Mountains

EXTENT

The complex mountains occupy over three-fourths of the region. They extend beyond the district boundaries on the east and north and reach the sea on the west. The southern limit is marked by the fault separating the Tertiary and Upper Cretaceous rocks.

RELIEF

The relief is rugged along the northern border, whereas the ridges become more rounded and the valleys broader as the southern and western boundaries are approached. When viewed from the hills south of Yauco, the upland surface has a gradual slope southwestward from the main drainage divide north of Yauco to the low hills of the west coast, extending from Mayaguez on the north to Cape Rojo Playa (Fig. 1). On closer inspection the intensive dissection which progresses daily under the tropical showers greatly impresses the observer. The steep slopes of the higher mountains turn the waters into narrow gorges, where, after heavy storms, raging torrents are ever deepening and widening their valleys. The heavy coat of tropical vegetation checks the rapid run-off, but the impervious character of the surface soil facilitates it. Such valleys as the upper Rio Yauco, Rosario, Guayanilla, Tallaboa, Canas Bucana, Guanajibo, Guaba and Preito are typical of this mountain region.

The evidence of peneplanation of the older rocks before the deposition of the Tertiary is not so conclusive as on the north side of the island. There the old erosion surface, developed at the close of the Cretaceous and early Eocene, is plainly visible (Berkey, 1915, p. 41). In the Ponce District the only locality where this old erosion surface appears to be preserved is on the "Mesas" near Mayaguez.

RELATION OF TOPOGRAPHY TO ROCKS AND ROCK STRUCTURE

The influence which different rocks and rock structures have exerted in the development of surface features is shown in many instances. The formations most resistant to weathering are the San German and Guayabal limestones, the igneous intrusives, and the highly indurated tuff. One need only see the white ridges of the San German and Guayabal formations, surrounded by lower-lying areas of tuff and shale, to

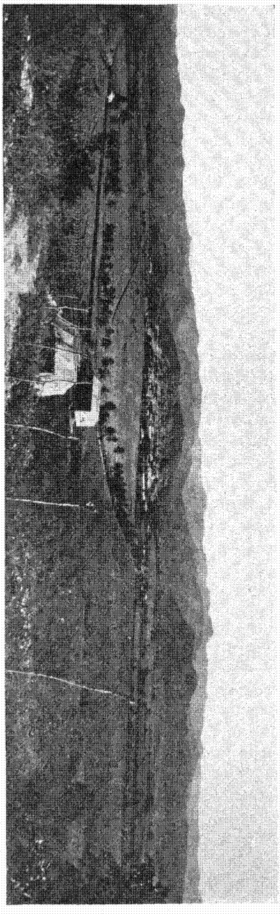


FIG. 1.—*Portion of Complex mountain province as seen from the Tertiary hills south of Yauco.* Yauco nestles on the hillside with the Rio Yauco (Lowland) Valley in the foreground.

realize the importance of these highly calcareous beds in the physiography of Porto Rico.

The tuff and ashy shale weather readily, although it must be remembered that the more strongly indurated tuffs are among the rocks most resistant to erosion. The ashy shales are easily disrupted and cut away, and it is along belts of such material that the head-waters of some of the streams are forming deep valleys with sharp ridges between. Shale higher in lime content, as, for example, that at Ensenada, is a good ridge-maker. Reference to the geological and topographical map brings out the fact that the largest valleys, as, for example, Yauco-Boqueron and Guanajibo, are formed principally on tuff. A factor which has accelerated the erosion of tuff in the southwestern part of the district is exfoliation. By this process numerous tuff exposures are undergoing disintegration.

The structural attitude of such rocks as the San German and Guayabal limestone is in part responsible for some of the most striking surface features in the region. The tilted position of these strata, with more easily eroded material both below and above, has given rise to ridges like the one to the east of Guayabal reservoir and those forming the south face of Yauco-Boqueron and Guanajibo valleys.

The development of subsequent valleys by headward erosion along weaker rock-belts can be seen north of Yauco, where the head-waters of the Guayanilla are working back along belts of tuff and shale. Other smaller, subsequent valleys are found along the south coast, as, for example, the one at Ensenada and the extensive lowland between Yauco and Boqueron and the valley along the Guanajibo.

DRAINAGE

The present drainage is divided among fifteen main streams and their tributaries. The area east of a north-south line drawn approximately through Yauco is drained by eight principal rivers, among which are the Jacaguas, Tallaboa, Guayanilla, Bucana, Inabon, Portugues, Canas, Yauco and Susua. These streams, whose head-waters are in the mountains to the north, cross the geological structure approximately at right angles in the lower three-fourths of their course to the Caribbean Sea. Each has cut a deep valley along its upper course, but on reaching the coastal plain the breadth of this valley is considerably increased, and in instances, like the Ponce Playa, the confines of individual streams are lost in the flat coastal lowland. The course of the drainage across the structure supports the idea of superposition from a former more extensive Tertiary coastal plain, and, as will be shown later, this has probably been the case.

The principal westward-flowing streams are the Guanajibo, with its tributaries, the Viejo, Rosario, Hoconuco, Cain, Flores and Mayaguez. The history of the Guanajibo is of special interest, due to its capture of streams to the east of San German. These streams formerly flowed south through the Yauco-Boqueron Valley to Guanica Bay. The original Guanajibo, which drained westward from San German, had a shorter course to the sea than the streams of the Yauco-Boqueron Valley. As a consequence, it pushed back its head-waters, which were then west of San German, to a point east of the city. The Cain and Flores, with their branches, were then following a longer southerly route and developing the Yauco-Boqueron lowland. With the eastward advance of the Guanajibo, this southward drainage was captured and diverted to the west. The water gaps in the hills southeast of San German strongly support this conclusion. Stream gravels are present in some of these gaps.

The north-flowing streams are Mayaguecillo, Guaba, Bucarabones, Prieto, and Blanco, all of which pass into the adjoining area, studied in detail by Mr. Bela Hubbard. These streams are working mostly in shale and tuff and are rapidly cutting back their valley heads along the main drainage divide.

TERRACES

The only terraces found along streams are those formed by the entrenching of formerly deposited river alluvium. Such terraces are more strongly developed along the lower stream courses, but a few examples are found bordering the wider sections of the upper stream valleys. It is my belief that these terraces are connected with the recent changes of level which have affected Porto Rico. A wave-cut terrace has been formed on the Cretaceous rocks making up the point just south of the Reform School, southwest of Mayaguez. The details of the terraces due to wave action will be found in the section describing the Historical Geology.

Tertiary Coastal Plain

EXTENT

What remains of the Tertiary coastal plain along the south coast of Porto Rico extends from a point a short distance east of Juana Diaz to Cape Rojo and Point Aguila, in the southwest corner of the island. This physiographic province is not continuous, but is cut into isolated areas by the rivers traversing southward. The largest portion is confined to the vicinity of Ponce and continues west to the region of Ensenada. The exposures at Cape Rojo and Point Aguila are small and underlie the San Juan formation at the former locality. The northern boundary is determined by the fault, which is discussed later under structure.

RELIEF

In contrast with the complex mountains, the coastal plain has a much smoother aspect. Viewed from a distance, it is seen to approach, with a gentle south slope, the "old land" on the north. The boundary between these two physiographic units is in most cases characterized by an erosion scarp forming the south wall of the discontinuous fault-line valley developed along the fault zone between the Tertiary and Cretaceous areas. The surface is diversified by stream valleys both across and parallel to the strike. The greatest altitude reached is a little over 900 feet, in the area southeast of Peñuelas, and the slope is southward and southwestward from this point.

RELATION OF TOPOGRAPHY TO ROCKS AND ROCK STRUCTURE

The soft, chalky character of much of the strata making up the coastal plain offers little resistance to erosion. Streams have slight difficulty in developing their valleys, and would cut them much faster were it not for the fact that the rainfall in this part of the island is much less than in other sections of Porto Rico where the Tertiary is found. Harder strata, sometimes a foot or more in thickness, have protected the underlying material, thus producing low cliffs. This, however, is a minor feature. On the north coast shaly and harder strata have been in part responsible for the haystack topography (Berkey, 1915, p. 51). None of this type of topography was seen in the Ponce District.

The ease with which water enters and dissolves the limestone is responsible for the pitting of the surface with depressions having no apparent outlet. Such sinks are to be seen in the region of kilometer 67.0 along the Ponce-Peñuelas road. These depressions are very inferior to similar occurrences on the north side of Porto Rico.

DRAINAGE

The principal drainage consists of the main streams, which rise in the mountains to the north and traverse the coastal plain through open valleys bordered by low hills. All of these streams lie to the east of Ensenada, the Tertiary area to the west being void of any but intermittent streamlets. Among even the larger rivers, few maintain a constant flow to the sea. Observations during the three months spent in the district proved most of them to be of torrential habit, at times filled to overflowing, then receding again to dry channels. The amount of rock waste which such torrents transport is large. Boulders several feet in diameter can be found in stream channels during low water.

Gaps in which water-worn gravel is found occur east of Ponce, in the Tertiary limestone ridge along the south face of the lowland between Ponce and Juana Diaz. The largest of these gaps is just southeast of kilometer 127.0, on the road from Ponce to Juana Diaz. Formerly the Bucana River occupied this depression, but has since taken a westward course to the Ponce Playa. Other gaps notch the Tertiary ridges, but conclusive evidence of stream capture in such instances was not found.

TERRACES

Both stream- and wave-cut terraces are present. The former are similar to those described under the complex mountain area, but are more extensive; the latter are represented by old marine levels along the south coast. The stream terraces are best seen along the Bucana River north of the military road from Ponce to Juana Diaz. The successive levels at this locality have cut through alluvium to underlying rock.

Wave-cut benches on the Tertiary along the south coast of the district are well developed on the headlands at the mouth of Guanica Bay and a short distance both east and west of this point. The elevation of these levels ranges from 10 to 200 feet and bevels the south-dipping Tertiary limestone beds. In some instances cliffs at the inner margin are partially preserved, but in most cases the soft character of the chalky limestone has prevented their preservation.

There has been some difference of opinion, among those who have studied the district, concerning the question of recent changes of sea-level in Porto Rico. In the following pages the evidence secured by the writer in the survey of the Ponce District will be presented. The localities listed range from east to west and include terraces cut on the Cretaceous, as well as on the Tertiary rocks. Berkey (1915, p. 48) describes terraces in the region near Guayama, on the south coast, which he attributes to wave action. Their levels range from 100 to 200 feet. The evidences of recent changes of level, together with conclusions on the question, are as follows:

(1) One-half mile southwest of Juana Diaz, on the north bank of the Jacaguas River, the folded Tertiary beds are beveled and a deposit of silt, sand and gravel 2 to 12 feet thick covers the surface. In this surface

covering, at an elevation of 130 feet, are found numerous *Strombus pugilis*.

(2) At kilometer 72.5, on the Ponce-Peñuelas road, recent marine fossils are found in finely stratified material of estuarine character. In this deposit a layer of black mud averaging one foot in thickness occurs at a depth of from 2 to 5 feet below the surface. In this black mud are found *Strombus pugilis, Lucina jamaicensis, Lucina tigrina, Arca tuberculosa,* and *Byssoarca ziebra.* These fossils are also found in other parts of this deposit, the elevation of which is 180 feet.

(3) Across the west branch of the Cañas River, just east of the above locality, the same species of fossils as occur at (2) are found in the stratified sands and gravels at a depth of 3½ feet below the surface and an elevation of 160 feet.

(4) Southeast of Yauco, 1¼ miles, in the Rio Yauco Valley, abundant fossils are found in the surface covering of the river valley at an elevation of 150 feet. The fossils include *Murex elongatus, Arca rhombea, Lucina tigrina, Arca tuberculosa, Turritella imbricata, Pecten nucleus, Venus cancellata, Ostrea virginica, Pterna* sp.

(5) East of Yauco, one-eighth of a mile, the pre-Tertiary rocks are truncated, and in the gravel and sand which cap the beveled strata are found *Arca tuberculosa* and *Lucina tigrina,* occurring at depths of 1 to 2 feet below the surface. The elevation at this point is 200 feet.

(6) On the coast southeast of Yauco a terrace surface bevels the Tertiary limestone at an elevation of 60 to 160 feet, the inner margin being marked in places by a cliff. The following fossils are found on this surface: *Strombus acciptrinua, Fissurella nodosa, Arca rhombea,* and *Turbo pica.*

(7) Just north of the lighthouse at Guanica the Tertiary limestone is beveled by terraces at levels of 10, 50, and 150 feet, and in the surface soil on the two upper terraces are found *Arca tuberculosa, Lucina tigrina* and *Turbo pica.* At the ten-foot level large numbers of these fossils are found in the lime sand and silt which coat this terrace.

(8) East of Guanica one-eighth of a mile, on the east side of the Susua Valley, a terrace at an elevation of 50 feet contains in the surface layers the forms *Lucina jamaicensis, Arca tuberculosa,* and *Turbo pica.*

(9) At the town of Ensenada (Central Guanica) the shale is truncated and a deposit of shells, mud, silt and sand covers the surface to a maximum depth of 5 feet. The fossils occur at an elevation of 45 feet and include the following: *Murex elongatus, Manicina* sp., *Venus cancellata,* Operculum of *Turbo, Arca rhombea, Cerrethium litteratum, Ostrea virginica, Arca tuberculosa, Byssoarca ziebra.*

(10) On the south side of Pardas Bay, south of Ensenada, the Tertiary limestone is again terraced at an elevation of 65 to 100 feet, and the fossils *Arca rhombea, Arca tuberculosa* and *Lucina jamaicensis* are found buried in the soil of the surface.

(11) On Cape Rojo, in the southwest corner of Porto Rico, the San Juan formation, which has been interpreted by Berkey as a lime sand of dune origin, is found at an elevation of 75 feet, overlain by 3 feet of conglomerate consisting of well-rounded pebbles. In the San Juan formation occurs a *Conus* sp. very close to the recent form *Conus portoricanus.*

(12) On Aguilla Point, the extreme southwestern portion of the island, recent gastropod shells are found in consolidated gravels at an elevation of 11 feet. At an elevation of 25 feet they occur on the beveled surfaces of the rocks which make up this point.

(13) Three and three-quarters miles southwest of Mayaguez, on the coast near the Reform School, a terrace is cut on the Cretaceous rocks at an elevation of 50 feet. The inner margin is marked by a cliff, and the following fossils are found in the surface soil: *Arca tuberculosa, Venus cancellata, Lucina jamaicensis.*

The argument has been advanced by Lobeck that where recent fossils have been found in Porto Rico they are associated with Indian mounds. Such an interpretation, however, could not explain the existence of shells buried in stratified material of estuarine character at depths of from 2 to 5 feet. Furthermore, although in each of the thirteen localities cited above the writer made careful search for artifacts, in no instance was evidence found to substantiate the Indian-mound theory.

Based upon the evidence presented in the thirteen above-mentioned cases, the writer draws the following conclusions: With the recent changes of level the old river valleys were embayed, allowing the sea to enter with its marine fauna and to lay down deposits of sand, silt and mud. That these deposits—for example, at localities Nos. 1, 2, 3, 4, 5, 8 and 9—were laid down in Quaternary time is evidenced by the fact that over 95 per cent of the fossils are of the same species as those living at the present time in the adjacent sea. In the remaining instances, Nos. 6, 7, 10, 11, 12 and 13, the truncation of the underlying beds of limestone and other formations along the south and west coasts and the presence of cliffs at the inner margins of some of these terraces, together with the recent fossils found on the surface, are facts hard to explain if they are not connected with the work of the sea.

In considering the question as to which has been the shifting element, the land or the sea, the evidence indicates a change in the elevation of the land. If the sea-level had varied and the land had remained stationary, one should find some uniformity in the terrace levels at particular stages. Such uniformity does not exist. In summing up the conclusions the writer feels justified in stating that there has been differential uplift of the land in Porto Rico in recent time, with a maximum change of at least 200 feet.

Lowlands

VALLEYS

Two of the most interesting valleys from a physiographic standpoint are the lowlands occupied by the Guanajibo River, especially the triangular portion between San German, Cabo Rojo and Hormigueros, and the broad stretch of nearly level area between Yauco and Boqueron. The development of the former has been at the expense of the latter.

The Guanajibo River occupies a valley, the head of which lies just east of Sabana Grande. The lowland extends westward along the river, and narrows north of San German to less than one-quarter of a mile. A short distance westward it again widens into the triangular area already described. In the northwest corner of this triangle the valley is once more reduced in width and finally opens out into the Mayaguez Playa. The history of the development of this valley is intimately associated with the rocks, rock structure, and drainage of the region. The underlying formation is chiefly tuff, with some shale. The strike is in general parallel to the length of the valley. Berkey has suggested that the triangular portion already mentioned is related to an old volcanic vent, where the extremely broken and easily disintegrated rock material would allow rapid removal by streams and at the same time account for the shape of the depression. The evidence in the case is not clear, because a deposit of alluvium covers the valley floor to such an extent that only scattered exposures of the underlying formations could be examined. Where such exposures were seen they were found to be tuff like that exposed in the hills to the east and west. The narrow portions of the valley, for example, north of San German are bordered on the south by peridotite, largely changed to serpentine. In the case of the depression now occupied by the Guayabal reservoir, north of Juana Diaz, the evidence of a former center of volcanic eruption is clear (Berkey, 1915, p. 37). The extremely broken and heterogeneous mixture of volcanic fragmental material has offered comparatively little resistance to erosion, with the result that a similar but much smaller lowland than the one along the Guanajibo has been formed. Whether or not the lowland along the Guanajibo has a similar history to the one marking the site of the Guayabal reservoir, I was not able to determine from the evidence presented. However, it was found that the more easily eroded rocks underlie this area, the chief eroding agents being the Guanajibo and its western branch, the Viejo River. Another factor in controlling the shape and extent of this lowland is the San German limestone, which forms the south wall and has developed an erosion scarp with east-west trend along the southern boundary. The relation of the history of the Guanajibo Valley to that of the Yauco-Boqueron lowland is closely associated with drainage modifications of the Guanajibo. By working eastward, the head-waters of this stream captured those which formerly flowed south through the Yauco-Boqueron depression to Guanica Bay. Further details of this capture will be found in the discussion of this latter valley.

The Yauco-Boqueron Valley, a name suggested by Lobeck, extends from Yauco on the east to Boqueron Bay on the west. It is the most pronounced physiographic feature of its type in the district. Its south wall is formed by the San German limestone and tuff. The northern boundary is less strongly set off from the low hills of the complex mountain province. Its greatest width is approximately three miles, with a length of over 21 miles. Southwest of Lajas the valley narrows; then widens again westward of that point. The elevation ranges from sea-level at Guanica and Boqueron bays to an altitude of 150 feet just south of Lajas. The underlying rock is chiefly tuff, with small patches of shale and two remnants of San German limestone in the hills east of Guanica Lake. Tuff remnants can be found protruding through the alluvium filling. The geologic structure which has influenced the development of this lowland is that associated with the southward-dipping shales and limestones. Reference to geologic cross-section (B. B^1), Plate V, will illustrate the structural habit of the rocks involved. It will be noted that the formations dip south at angles near 45°, and the main depression is cut on the tuff, with the limestone forming the greater part of the ridge to the south. The history of the development of this valley dates back to a period before the capture of its principal drainage by the Guanajibo. At that time the waters of the Cain, Flores and what is now the upper Guanajibo flowed south to Guanica Bay. It was during this period that the valley was carved. Later diversion of the drainage by the Guanajibo left only a few intermittent streams in the eastern portion, which have continued to furnish water for Lake Guanica. The western portion of the valley was formed by the Boqueron River and its branches.

The depression between Ponce and Juana Diaz differs from the two just described, in that it has been formed on the Tertiary marl and limestone which has an anticlinal structure. Structure (Section H. H^1,

Plate VI) is across the eastern part of this valley and shows the relation between structure and topography. The fault along the north side cuts diagonally southwest across the anticline, and in the vicinity of the Ponce-Adjuntas road brings the southern limb, which is composed of chalky limestone, into contact with the Cretaceous rocks. This feature can be seen in Section G. G[1], Plate VI. The south wall is determined by the erosion scarp developed on the south-dipping Tertiary limestone. The surface of this valley does not present the same smoothness which characterizes the depressions at the west end of the district. Low hills are present and stream terraces are cut below the general level of the valley floor.

Other lowlands along the south coast are illustrated by the valleys cut by the Guayanilla, Yauco and Tallaboa rivers. All of these depressions have essentially the same history, having been formed by the streams which now occupy them. Their location and extent are shown on the Geologic Map. Their most conspicuous portions are near the mouths of the streams and are cut in the Tertiary Coastal Plain sediments. In the case of the Rio Yauco and Guayanilla, the valley floors developed on the Tertiary rocks are much wider than along the Tallaboa, but in each case the mouth of the stream is characterized by a coastal flat.

To the east are similar valleys, as, for example, Canas, Inabon, Portugues and Jacaguas, all of which merge seaward into the Ponce Playa.

PLAYAS

Playa is the local name given to gently sloping areas bordering the sea. In other countries similar areas have sometimes been designated as narrow coastal plains, to distinguish them from more extensive tracts of the same character. In Porto Rico, playas are prominent features, especially along the north and part of the south coast. The four most extensive ones in the Ponce District are Ponce, Guayanilla, Mayaguez and Cape Rojo playas.

Ponce Playa, the largest of the four, is over 15 miles long and 3½ miles wide at its broadest point. The gentle seaward slope is traversed by the Canas, Portugues, Bucana, Inabon and Jacaguas rivers, all of which contribute to the gravel, sand and silt which coat the surface of the underlying limestone to depths of 25 feet and over. The topmost layer is generally a black soil, made blacker by fertilization with cane waste from the sugar "centrals."

The formation of Ponce Playa and others to the westward is due to a combination of river flood-plain and delta processes. The detritus from the land has been carried to these lower areas, where it has been spread out by successive floodings. The occurrence of recent marine fossils in the playa material shows the presence, at one time, of the sea over these areas, and its influence in their formation is a factor to be considered.

Guayanilla and Mayaguez playas are smaller than the one at Ponce, but have essentially the same physiographic history. At Mayaguez the underlying rocks are of Cretaceous age, while in the case of Guayanilla the basement formation is of the same geologic age as that at Ponce.

Cape Rojo Playa is of special interest, due to the presence of a thin coating of reddish, siliceous sand which covers the surface. The rock upon which this sand rests is not extensively exposed, but where seen it is tuff of the same general character as that at Ensenada. The origin of the siliceous sand is probably in the numerous quartz veinlets which occur in the shale and tuff; also from chert masses in these rocks. The red color is due to iron oxide coating the grains and preserved in the arid climate which now characterizes the extreme southwest corner of the district. The concentration of sand at this point is most likely the combined work of streams and sea. Conclusive evidence of former streams entering this area from the north was not found, but the gap to the north of the playa suggests the presence at one time of a stream of considerable size. The level character of the surface is in large part the work of the sea when it stood at a higher level.

Minor Physiographic Features

SLUMPING

Slumping has produced minor physiographic changes, especially evident along the sides of river valleys which traverse the Tertiary limestone, and in places the material has been reworked by the estuary waters, which at one time filled the lower portion of these river valleys. The erosion scarp along the north-facing Tertiary has also been modified by the same process. Large quantities of broken Tertiary rock were found in slumped areas, especially along the Ponce-Mayaguez road between Yauco and Ponce. The slumping has covered much of the fault which passes through this section. In the Cretaceous rocks, slumping is best seen in the serpentine northwest of Yauco, near the trail to Maricao. At this locality a large mass of rock has moved a considerable distance down the steep side of the valley. This slide is so recent that the surface along which the movement took place is plainly visible for some distance. Slumping of small areas, especially in road cuts, were encountered on the Mayaguez-Consumo-Maricao road near Maricao. What appeared to be slumping of more ancient date was seen along the steep mountain valleys in the areas of tuff and red shale.

SINK-HOLES

Good examples of sink-holes are far less extensive than elsewhere in Porto Rico. One place where undoubted sink-holes are found is in the vicinity of kilometer 67.0, on the Ponce-Peñuelas road. The field evidence shows that this process has been less important in shaping the present topography of the Ponce District than in the case of the Tertiary on the north side of Porto Rico.

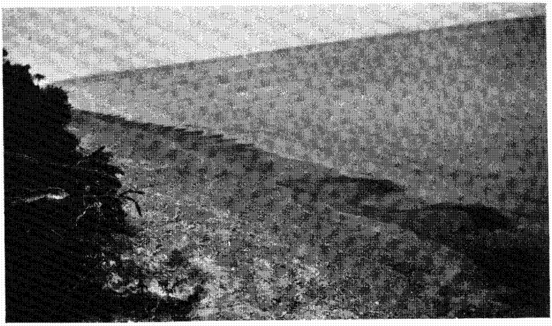


FIG. 2.—*Cuspated beach, west coast, Porto Rico, just south of Melones Point*

DETAILED DESCRIPTIONS OF FORMATIONS

Tuff

Areal Distribution.—Tuff is the most abundant rock in the district. Any north-south traverse of the area will disclose a strong development of this class of material. Typical outcrops may be seen at Ensenada and north of Peñuelas. Yauco is underlain by this rock. Other good exposures may be seen along the Yauco-Lares road north of Yauco. On the Ponce-Adjuntas road, at intervals between kilometer 13.0 and northward, good examples of this rock are to be found. In the broad east-west valley between Yauco and Boqueron occasional remnants of tuff protrude through the alluvial covering of the valley floor.

Thickness.—Due to the pinching and swelling of these beds, whose structure is also very obscure, it is difficult to determine their true thickness. In places where large areas are exposed, it is possible that some duplication exists. The strong folding shown by the shales and limestones would indicate such a possibility. With allowances for such duplication, a conservative estimate of the maximum thickness would be 3600 feet. However, it is possible that sections might be found where this amount would be exceeded.

Lithology.—In general appearance the tuff presents a rather wide variation. Shades of gray, green and chocolate color are common, with yellowish and reddish hues characterizing the weathered material. The texture ranges from very coarse, in which lithic fragments an inch or more in diameter can be plainly seen, to rock so fine that only microscopic study discloses its fragmental habit. The composition is principally andesitic, but trachytic and basaltic varieties have been identified. As these departures from andesitic composition are minor features and are not always apparent in hand specimens, it has been thought best not to attempt separate mapping, but to group all such material under the general head of tuff.

Changes which have been effective since the deposition of the tuff are of two general types:

(1) Induration, which has compacted some beds into a hard, endurable mass which resists weathering even better than some of the igneous types. This induration has involved the formation of carbonitic and epidotitic aggregates, which have acted as a binder for the rock and mineral fragments. The amount of such binding substance is pronounced in some cases and, as can be seen in thin sections, fills the interstitial spaces between the fragments and also replaces rock fragments and crystals.

(2) Weathering, which has disrupted the tuff, thus forming alteration products, chiefly iron oxides and hydroxides, and producing a soft, crumbling mass which can be crushed easily in one's hand. Besides the actual decomposition of the rock constituents, exfoliation has played an important part in the breaking-down process. Large rounded cores of tuff showing exfoliated surfaces are prominent features in the rock toward the southwest end of the area.

Structure is almost entirely absent from rock of this class. Where structure is developed, it is extremely vague and proved of little service in the field. Jointing is pronounced in many exposures, and in places is so well developed that it might easily be confused with bedding. Besides jointing, there are in many exposures a multitude of cross-fractures, some of which have been rehealed with mineral matter, chiefly lime carbonate, giving a veinlike structure to the rock. The gradation of tuff into agglomerate was noted in a few small areas. Rock of this character is made up of somewhat rounded accumulations of rock fragments of the same composition as the tuff proper, bound together by finer material.

In some portions of the mass, attempts at assorting, with the production of partial bedding, could be faintly made out; but massive structure is more characteristic of both the agglomerate and tuff. There are also gradations from tuff into shale, which in some instances is shown by the development of sandy strata. Small, irregular masses of greenish, reddish and grayish chert occur in the tuff, especially in the vicinity of Villalba.

Conditions of Deposition and Age.—The pinching out of beds and the expansion in other areas into deposits of considerable thickness, together with the general lack of stratification which would be expected in water-lain material, are factors which point strongly to deposition upon land of the major part of this rock. The gradation from massive tuff to sandy and ashy beds marks a zone in which the borders of tuff deposits were encroached upon by water bodies and the coarser materials reworked and assorted, with subsequent deposition, into stratified material. The period of tuff deposition ranged throughout the time in which the Cretaceous beds were being formed, deposits of this character being found at the top and bottom and interbedded in the series. There were, however, intervals in which conditions were such as to permit limestone and foraminiferal shales to form.

The geologic age of the Ensenada shale and the San German limestone, as shown by the fossils, is Upper Cretaceous. Since the tuff has an interbedded relation to these formations, and as no unconformity has been found in the series, it is believed that the tuff belongs to the same geologic epoch, namely, the Upper Cretaceous. It is possible that the lowest tuff beds may be Middle Cretaceous or Lower, but there is no evidence to support this view.

Shale

General Statement.—Next to tuff, shale is the most abundant Cretaceous rock in the district. On the basis of composition, a general division may be made into those high in ashy matter and low in lime carbonate, and those high in carbonate of lime and foraminifera remains but low in ashy material. Such a division, although not always applicable in the field, is easily made by microscopic study. A large number of slides from rock of this character, collected in different parts of the district, were studied with this object in mind, and it was found that such a general division like the one mentioned can be made. However, there are gradations between these two main types, and a line of demarkation cannot always be clearly drawn. It was found that the more ashy varieties were confined chiefly to the northern, northeastern and north-western parts of the district, while the more limy members were nearer the southern boundary. The best structure in the region is that exhibited by rock of this character. Strong bedding and fine lamination are exceedingly well developed. This is true of both the limy and ashy shales, but is generally best seen in the more limy beds. The time that could be devoted to the study of the shales was not sufficient to permit correlation of all the different exposures. Those whose relationships have been partially unraveled and whose occurrence is typical will be discussed somewhat in detail. It is possible that the more limy members are equivalent in part to the ashy representatives, but further field study would be required to prove such equivalency.

Rio Yauco Shale.—Along the road leading north from Yauco are excellent exposures of strongly bedded shale. Rock of this character makes up belts of varying breadth, extending northwest-southeast across the northern portion of the district. The section exposed along the Rio Yauco is typical of this class of rock and exhibits very clearly its structural habit. Similar formations to the east and west have been found to be a continuation of these shales, as, for example, the Jayuya Road shales and the red shale around Mayaguez.

The thickness of shale exposed on the upper Rio Yauco measures 1200 feet. The section here is well exposed and can be measured with some degree of accuracy. At other points it was not possible to get sections suitable for measurement; but, from the quantity of this class of material exposed and allowing for some duplication by folding, it is possible that there is a greater thickness than that stated.

The Rio Yauco shale is characterized by a high content of iron-bearing matter which on weathering has produced large areas of reddish and yellowish soil, and by its thin-bedded and laminated structure, blocky fracture, light weight and porous character. The color, as shown by microscopic examination, is due to the oxidation of iron-bearing minerals, chiefly pyrite. All surface outcrops show some shade of red or yellow, but the unweathered rock is a black shale, as seen in the recently opened quarry at kilometer 6.4+, Mayaguez-Consumo-Maricao road. At this locality the red material, as typically exposed around Mayaguez, can be traced downward into black, unweathered shale. The beds at this point dip with a steep angle, and the change from fresh, black rock through yellowish to reddish material is very striking and furnishes conclusive evidence of the origin of the latter. From a petrographic study of the red and dark-colored shales, Berkey (1915, p. 19) concluded that the former was a derivative of the latter through weathering, but he was unable to trace the change in the field, due to excessive soil covering. In places, as much as 20 feet or more of reddish and yellowish earth covers the outcrops, and it is only in stream beds and in recent excavations that one can find the fresh rock. Trails through areas of this formation are steep and exceedingly slippery, especially during a tropical shower, and a journey over one of them during a storm is an experience long to be remembered.

Bedding and lamination are partially destroyed in the weathered rock, but are prominent features in the fresh, black material. The blocky fracture of the weathered shale was seen in some portions of all the outcrops examined. This feature is lost as the shale passes into soil.

The light weight and porous character are due to leaching, which has accomplished weathering. Cavities are present in varying proportions, as seen in thin sections. In some instances these cavities have outlines suggesting foraminifera shells, but in others the shapes are more suggestive of some mineral fragment. In no case could it be positively determined just what had been removed.

The composition of the Rio Yauco shale is given in detail in the section on Petrology. In brief repetition, it may be stated that the most abundant constituent is a fine, dustlike aggregate of the nature of volcanic dust. In some of the coarser portions of the rock a few angular pieces of feldspar crystals and small lithic fragments are present. Other minerals identified are pyrite (abundant), iron oxide and hydroxide, occurring disseminated through the mass, and carbonate of lime, filling veinlets and irregular spaces, as seen in thin section. Rock of this class grades into and forms small lenslike bodies in tuff. In a number of instances, as, for example, just to the south of San German, a patch of the characteristic reddish Rio Yauco shale can be found in the larger mass of tuff. Such occurrences have been mapped with the tuff in order to reduce unnecessary complexities in areal geological representation.

Irregular bodies of chert, in no instance of great extent, are found in these shales. A good example is on the point which forms the north side of Mayaguez Bay. The chert exposed here is strongly jointed and veined with quartz. It is extremely brittle and breaks with a very ragged fracture.

The bedded and laminated structure of the rock shows that it was deposited in water. The lack of any quantity of minerals which characterize typical sediments and the abundance of ashy matter indicate a volcanic source for the material. The presence of some foraminifera remains shows that conditions were favorable for the existence of these animals. The above facts support the conclusion that shale of this character was formed in a region of volcanic activity where heavy showers of ash were prevalent. Streams draining adjoining land areas of pyroclastic material would contribute to the supply of sediment.

The structural relations of the San German limestone, shales and tuff are those of a conformable interbedded series. Since the age of the San German limestone is Upper Cretaceous, the typical Rio Yauco shale, which carries this limestone as an interbedded member, is undoubtedly of the same geologic age.

Peñuelas Shale.—Thin-bedded, finely laminated, bluish gray rocks, which were found on microscopic examination to contain a large proportion of foraminifera shells, are typically exposed along the military road from Ponce to Peñuelas at kilometer 67.+ (10.+ by old numbers). Due to the fact that the lime content, represented chiefly by foraminiferal remains, is so much more prominent than in the shales just discussed, and also to the uncertainty of correlation of the different shale exposures in the district, it has been decided to treat under a separate group shales which have been found to be equivalent to those exposed at the locality noted above. It is possible that these more limy members are equivalent in part to the ashy shales, as represented by the Rio Yauco beds. The Peñuelas shale was followed westward from the type locality at kilometer 67.+ to the vicinity south of Sabana Grande and San German. From this region it continues on to the west. Beds of similar character north of Ponce and farther to the east may belong to this formation, but the fault marking the boundary between the Tertiary and pre-Tertiary cuts off the beds and makes correlation uncertain.

The thickness of this formation is best measured along the road to Lajas, south of San German. At this point beds aggregating 1000 feet are exposed, and this figure probably represents the maximum for the formation.

The most distinguishing field characters of the rock are its perfect thin bedding and lamination, bluish gray color on fresh fracture, and yellowish surface where weathered; also, high lime content, which at first makes one think that the rock might more appropriately be designated a limestone. However, after studying the whole region and noting the variable composition of these shales and their lithological dissimilarity to the limestone, it is believed that to use the term limestone for such material would be confusing and in many cases inappropriate. In this paper, rocks of the character of the Peñuelas shale will be spoken of as limy shale, to distinguish them from the ashy variety exemplified by the Rio Yauco beds. Typical Peñuelas shale is high in lime content. The carbonate occurs replacing the foraminifera shells and as a component of the groundmass. Other constituents are a fine, dustlike aggregate which is not determinable microscopically, and pyrite, which in some instances shows perfect cubical crystals visible in many hand specimens. No other minerals were identified in the extremely fine material which characterizes this formation.

The strike ranges from northwest-southeast to east and west, with local flexures giving strikes beyond these limits. The dip is north or south, at angles ranging from 25° to 80°. The contact with the tuff is not a sharp one, being obscured by excessive weathering and the intergradational habit of the formations. The relation to the San German limestone is also of a transitional nature. In many localities local bodies of tuff are present, but their extent is limited.

The geological conditions under which shale of the Peñuelas type was deposited varied somewhat from those influencing the formation of the Rio Yauco beds. These variations may have been of local nature only, since there is no evidence that any extended time interval or radical change in geological conditions existed between the formation of the Rio Yauco or any other Cretaceous shale member. The presence of the San German limestone (Upper Cretaceous) as an interbedded deposit in the Rio Yauco beds in the northern area, and in the southern part overlain conformably by the Peñuelas shale, suggests the equivalency of the Peñuelas beds with the upper part, at least, of the Rio Yauco shale. The structural relations of the Peñuelas shales to the San German limestone and other Cretaceous beds to the south are such as to place the former in the Upper Cretaceous.

Ensenada Shale.—The small hill just back of the steamer dock at Ensenada is made up of limy shale containing microscopic fragments of radiolites and foraminifera shells and specimens of *Hemiaster berkeyi* n. sp. This rock forms the ridge to the south of the town and can be traced westward to the region just south of Melones Point, on the west coast. The eastward continuation is cut off by the fault between the Tertiary and Cretaceous. Along its westward extension good exposures can be seen just north and also to the west of Parguera. Since the relation of this shale to similar formations in the region is not clear, as will be pointed out later, it is proposed to use a local designation, Ensenada shale, for this rock so well exposed at Ensenada, on Guanica Bay.

The greatest thickness attained by this formation was estimated at 650 feet, but places were found where less than this amount was exposed. The section measured was at the type locality at Ensenada and probably represents the maximum thickness.

The structural habit of this rock is similar to that of the Peñuelas shale, but the fine lamination is not so prominently developed and the color of the fresh material has less of the bluish gray appearance, as seen in the rock at kilometer 67.0, on the Peñuelas-Ponce road. Fragments of foraminifera shells are abundant and sections of *Radiolites* are identifiable. The rock is high in carbonate of lime, which replaces the organic remains, and is also strongly developed in the groundmass. Microscopic examination shows the presence of areas which were at one time volcanic glass and tuff fragments, but are now replaced by lime carbonate.

The strike varies from north 60° west to east and west, with a local flexure at the point where the beds reach Guanica Bay. Toward the west, strikes south 85° west were read, but these were only for short distances. The prevailing strike is nearer east and west. The dip is 42° south at Ensenada, and reaches as much as 85° south north of Parguera. The base of the formation grades into tuff, and the top into sandy, tuffaceous material.

The Ensenada shale was probably deposited under conditions similar to those existing at the time the Peñuelas beds were formed, though the lithologic character of the rock itself would suggest that the water was shallower. It is possible that this shale represents a nearer-shore portion of the Peñuelas beds. Another interpretation, however, would be that the stratigraphic position of the Ensenada shale is higher than that of the Peñuelas. Whatever the stratigraphic relation of the shale at Ensenada may be to other shales in the district, the conditions existing at the time of their formation were not unlike those influencing the formation of such rocks as the Peñuelas shale and similar deposits in the area. There seems little doubt that this shale was formed during the same geologic epoch as the rest of the "Older Series." The structural relations of the rock to those of Upper Cretaceous age and the presence of the *Hemiaster berkeyi* n. sp., whose affinities are with the Cretaceous, lead to the conclusion that this formation is also Upper Cretaceous.

Limestone

San German Limestone.—The areal extent of the San German limestone can best be seen by reference to the Geological Map. It will be noted that the formation has a general east-west trend in places and a northwest-southeast in others; also, that the beds are not continuous, but pinch out. The most typical development of this rock is in the hills southwest of San German, and it is for this locality that the formation has been named. The high erosion scarp which forms the south wall of the San German-Cabo Rojo-Hormigueros Valley partially owes its existence to steeply south-dipping beds of this rock. Exposures of this formation are found at other points in the district, among which are:

(1) Just south of the railroad bridge over the Susua River, on the road to Guanica.

(2) In the limestone quarry at Ensenada.

(3) At kilometers 31.8 and 34.7, on the Yauco-Sabana Grande road.

(4) On the Ponce-Adjuntas road at points shown on the Geological Map.

The greatest thickness determined was 600 feet. In places it pinches to nothing. The best section for measurement is the type locality southwest of San German.

The rock in most cases is a massive, bluish gray, fine-grained limestone, very brittle and showing on weathered surfaces the sieve-like structure of weathered cross-sections of *Radiolites,* so aptly described by Berkey (1915, p. 1) as resembling a piece of loosely woven cloth. In places the rock is filled with fragments of this fossil. Another fossil which was found in the beds southwest of San German, and also north of Yauco and Ponce, is *Actæonella* sp. Both the *Radiolites* and *Actæonella* were identified by Dr. T. W. Stanton, of the United States Geological Survey, who considers them as Upper Cretaceous. In some localities—for instance, at kilometer 14.5, on the Ponce-Adjuntas road—the rock is made up in large part of fragments of *Radiolites* and *Actæonella,* which have given the material a shred-like character. This rock has been called "shred" limestone by Berkey. On many weathered surfaces the mesh form of weathered *Radiolites* can be seen, and was the index by which the beds were traced across the district. The *Actæonella* sp., although occurring in many outcrops, was not found at all points.

Typical exposures of this limestone are generally massive, exhibiting but little of the bedded character. In the massive material, jointing is prominent and weathering has progressed along joints and on the surface, producing a white lime soil resembling very much the powdered Tertiary limestone. This feature is very well shown in the quarry at Ensenada and along the road from the quarry to the "Central"; also on the south side of Yauco-Boqueron Valley. Weathering has also produced pitted surfaces on the exposed rock, the rounded depressions sometimes measuring over two inches in diameter. When examined microscopically, the limestone was found to contain numerous fragments of *Radiolites* and portions of foraminifera shells. Carbonate of lime makes up the remainder of the rock. At some localities, as, for example, along the Yauco-Lares road at kilometer 9.0, the limestone is involved in a crushed zone and has been intensely crushed and broken, inclosing fragments of igneous rock which are chiefly andesite. Other exposures where crushing has taken place are along the Ponce-Adjuntas road at kilometer 16.8 to 16 9 and 18.7; also three miles northwest of Maricao.

During the period of formation of the San German limestone conditions were favorable for the abundant development of *Radiolites,* which grew in reef-like colonies. The character of the rock indicates a decrease of volcanic activity in the region. The lens-like nature of the beds suggests local areas of deposition, and the structural relations of the beds to other formations points to a single period of deposition for all the beds of this limestone. The Upper Cretaceous age of the rock is determined by the presence of *Radiolites* sp. and *Actæonella* sp.

Coama Tuff Limestone.—The best development of the Coama tuff limestone in the Ponce District is in the section exposed along the east branch of the east fork of Jacaguas River, north of kilometer 113.0, Ponce-Juana Diaz-San Juan military road. The structural relation of this rock to the formation associated with it can be seen in cross-section (H. H[1]), Plate VI. A very good exposure of this limestone is along the Descalabrada River, at the crossing of the military road.

The section along the east fork of Jacaguas River measures 250 feet and probably represents the greatest thickness of this formation.

The Coama tuff limestone presents the most striking lithologic characters of any rock in the district. In typical specimens it is made up of angular fragments of white, grading to cream-colored limestone, mixed with igneous rock fragments, some of which measure two inches, but the greater number of much smaller size. The composition of these igneous fragments is chiefly andesitic, and their color when weathered is, as a rule, a chocolate hue, which, in contrast with the whitish limestone fragments, gives the mass a very unique appearance. In some specimens the limestone fragments are of a bluish gray color, resembling closely the typical San German formation. The beds exhibit little structure, being prevailingly massive in character. They grade into tuff below and shale above. In the section exposed in the Ponce District the beds stand nearly vertical and strike northwest-southeast; but on the Descalabrada River, just west of the area considered in this report, the formation has a gentle southward dip and is folded into a distinct monocline.

The formation of this unusual lithologic type necessitates the breaking up of previously formed limestone and igneous rocks and subsequent deposition of the resulting fragmental material. Such conditions can be accounted for by volcanic activity in the form of outbursts through previously formed rock, and the deposition of this broken material to give a new formation.

The presence of *Radiolites,* together with the stratigraphic position of the strata, places this formation in the Upper Cretaceous. The true relation of this rock to the San German limestone could not be determined

It is probable that it is in part equivalent to the San German, but was deposited under different conditions.

Guayabal Limestone.—The type locality for this formation is the vicinity of Guayabal Reservoir north of Juana Diaz, where the rock makes up the conspicuous white hills to the east and west of this point. Berkey tentatively placed this formation with the Coama tuff limestone, but the section exposed on the upper east fork of Jacaguas River shows the typical Coama tuff beds overlain by limy shale, upon which follows the Guayabal limestone. As stated in the discussion of the Coama tuff limestone, its stratigraphic position below shale identical with the Peñuelas shale and the presence of *Radiolites* in the limestone indicate a close relationship

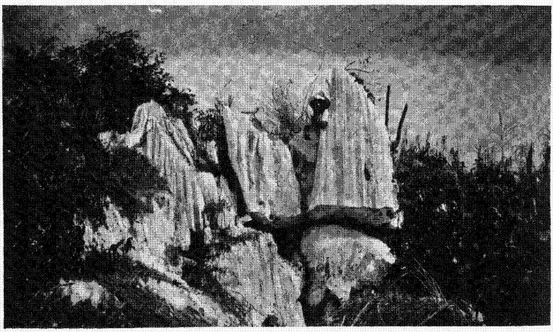


FIG. 3.—*Fluted Guayabal limestone north of Juana Diaz*

between the Coama tuff limestone and the San German formation, but necessitates different conditions of deposition. Since field relations show the Coama tuff limestone and the limestone at the Guayabal Reservoir not to be equivalent, it is proposed here to use the term Guayabal limestone for the white, massive rock developed in the vicinity of Guayabal Reservoir. This formation continues southeastward in prominent development into the adjoining district studied by Hodge (1920). To the west, beds of this character were traced northwestward for three to six miles, when they were found to pinch out. Whether or not they are developed in the district to the north cannot be said. It is possible that their development is local and they will not be found in the area north of the Ponce District.

The section on the upper east branch of Jacaguas River proved the best for determining the thickness, which measured 950 feet.

Hand specimens of this limestone are a mottled cream color, with dendritic manganese marking some of the rock. The material is massive and brittle, breaking easily under the hammer. In some exposures jointing is prominently developed, but this is not true of all the material. Bedding is rather obscure, but the true attitude of the formation can easily be determined from the structure of the underlying shale. A considerable quantity of fragmental organic remains are present, including *Radiolites* and foraminifera. The beds strike north 50° to 65° west and dip south 25° to 35° on the north limb of the syncline, and stand nearly vertical on the south side of the fold. It is in this rock that the manganese north of Juana Diaz is found.

Differential weathering has produced a characteristic fluting in portions of the outcrop. The narrow channels stand vertical and are sometimes two inches wide and over three feet in length. In figure 3 a good illustration of this fluting in the white limestone is shown. Diller (1897) describes fluted limestone from Baird, Shasta County, California, of which he says:

> This limestone is exposed in large masses, making a mountain ridge along the McCloud River. At many points its surface bears peculiar small ridges and intervening depressions. In the field it is evident that the little valleys are lines of drainage, and it may readily be concluded that they are a form of rain erosion due to the solvent action of the water running over the surface. An examination of many ridges and valleys discloses no difference in composition or structure to which the variation in surface form may be due. From the fact that the flutings are drainage lines, it appears that they may be referred to the rilling of the water on the surface of the limestone. Where the water flows the solvent action is most intense, and a minute valley is formed by solution. This form of differential weathering is common upon limestone exposures, but is rarely so well developed as in the example from which specimen 154 was collected.

The fluted character of the Guayabal limestone is a very striking feature where strongly developed and probably has the same origin as that described by Diller.

The noticeable absence of fragmental volcanic material would indicate a period of decreased vulcanicity. The presence of *Radiolites* places the limestone in the Upper Cretaceous. Its structural relation to the Coama tuff limestone, which is probably equivalent to part of the San German formation, would place the Guayabal limestone in a higher position in the Upper Cretaceous.

Tertiary Sediments

INTRODUCTORY STATEMENT

The Tertiary sediments along the south coast of Porto Rico extend from a short distance beyond the southeastern section of the Ponce District westward to Point Aguila, in the southwest corner of the island. They represent a former more extensive coastal plain series deposited upon and partially around an eroded central core of complex rocks. Whether or not these later sediments formerly extended across to the north coast cannot be determined, but the evidence is clear that they once had a greater extent northward. Their stratigraphic relation to the Cretaceous formations has been complicated by the fault which determines the northern limit of these rocks. However, other structural features are such as to show without doubt that the conditions were similar to those on the north coast, where the Tertiary rests with a marked unconformity upon the older formation.

In general, the Tertiary formation is made up at the base of fossiliferous, yellowish, marly material with occasional sandy layers. This basal portion grades into the yellowish and white, chalky limestone characterizing the upper portion. The highest strata contain fragmental masses of coral heads bedded in soft, chalky material. Some harder strata of pinkish semi-crystalline limestone, at times a foot or more in thickness, are found in the higher, chalky portions. From its typical development in the region around Ponce, it is proposed to use the name of that city to designate this formation.

PONCE FORMATION

The Ponce formation is confined to remnants of variable extent along the southern border of the district. The largest area is northwest and west of Ponce, where the chalky limestone is best developed. To the east of Ponce, and underlying the Ponce-Juana Diaz Valley, is found the best exposure of the lower marly and shaly portion. The upper part of these lower beds is found at the fault contact just east of Yauco and at other points along the military road from Yauco to Ponce; also in the face of the hills just south of Yauco.

The lowest beds are made up of yellowish, marly and shaly material in which sandy and more compact strata are developed. These harder layers are sometimes two feet or more thick and contain abundant foraminifera (*Orbitoides mantelli*), which fossil also characterizes the more shaly and softer portion of the rock. Other fossils identified in the collection from the lower beds include *Laganum* sp., *Pecten* sp., *Fasciolaria* sp., *Cythara* sp., *Turritella halensis, Turritella halensis* var. *alpha, Cardium* sp., *Astarte* sp., *Cypræa* sp., *Amphistegina lessoni* (abundant), *Ensis* sp., leaf fragments and fish teeth. Pieces of petrified wood are also present and coal is reported to occur in these beds, but none was found. Besides the sandy portions, there are thin layers of fine gravel in which shell fragments are plentiful. Some of the sandy layers are filled with broken shells and foraminifera, especially the forms *Amphistegina lessoni* and *Orbitoides mantelli.* The lower beds pass disconformably into the upper yellowish, chalky limestone so well exposed in the hills around Ponce. This material is characterized by its yellowish white color and chalky nature. It contains numerous casts of *Lucina* sp., *Arca* sp., *Bulla* sp., and other forms. In structure it is generally massive, but hard, thin, yellowish strata are prominent in some localities and are valuable in determining the structural habit. The chalky material continues to the top of the formation, which, if anything, becomes more chalky. The uppermost beds are well exposed along the coast from Culebrinas Point to Guanica Bay. At Culebrinas Point the rock contains abundant specimens of *Clypeaster rosaceus,* together with other forms of Oligocene age.

The basal portion of the Ponce formation was deposited in comparatively shallow water near shore, as shown by the sandy character of the strata, together with the abundance of broken fossil fragments and remains of plants. The distribution suggests a broad embayment whose eastern limit was located approximately a short distance east of Juana Diaz and whose western extent was in the vicinity of Yauco, though faulting has made it impossible to determine the exact extent of these lower beds. How far north this embayment reached is not certain, but, judging from the lithologic character of the rock and structural features, it was certainly more extensive than at present.

The present width of the island on a north-south line through Juana Diaz is approximately 34 miles. The distance between the Tertiary of the north and south coast along this line is about 18 miles and the elevation of the highest point nearly 3600 feet. Considering the fact that the central mountain mass was much lower at the beginning of the Tertiary period, as shown by the peneplane developed on the north side, it would appear that the lower beds of the Tertiary must have been laid down much to the north and south of their present boundaries, on the two sides of Porto Rico at about its central portion. The conditions influencing the deposition of these lower beds changed to those under which the chalky material was formed. In this later period more quiet and deeper water prevailed, with a continuance of these conditions through the Oligocene at least, as no record of further deposition is found until the San Juan formation (Pleistocene) is reached. The question as to how extensive the upper beds were is also unsolved. They surely reached farther north, but whether or not they covered the island cannot be determined from any evidence thus far secured. The fact that there is a difference in the Tertiary fauna of the north and south coast, as far as can be told from the fossils already identified, is a fact to be considered in this connection. Further detailed studies of the fauna from the north and south coasts may prove or disprove a former connection.

The lowest beds, as exposed along the Jacaguas River northwest of Juana Diaz, are characterized by abundant *Orbitoides mantelli.* They are forms which establish the Oligocene age of the Ponce formation, with the basal portion of Lower Oligocene (Vicksburg age) and the higher part representing Upper Oligocene (Chipola).

Quaternary Deposits

SAN JUAN FORMATION

The San Juan formation, first identified and named by Berkey (1915, p. 11), is found at Cape Rojo Lighthouse, in the southwest corner of the district. At this locality it caps the eminence upon which the lighthouse stands.

The rock at Cape Rojo has the same general characters as that of material in San Juan Point. Æolian cross-bedding is present and the rounded grains of carbonate of lime which make up the bulk of the formation are plainly visible in hand specimens. A conglomerate bed three feet thick, made up chiefly of pebbles of Cretaceous rocks, is found resting on the San Juan at the edge of the cliff south of the lighthouse. This is a feature not seen at San Juan. The relation of the San Juan to the Ponce formation is unconformable. Details of the petrographic character of this rock, which is one of the most interesting types found in the district, will be discussed under Petrology.

The unconformable relation of the San Juan to the underlying Tertiary limestone, as shown in the cliff at Cape Rojo, necessitates a period of erosion at the close of the Tertiary sufficient to bevel the underlying beds. Just how much erosion has taken place is not known, since the latest Tertiary record in the district is Upper Oligocene, and there is no evidence that Miocene or Pliocene strata were ever deposited.

The presence of æolian cross-bedding indicates a dune origin. The capping of conglomerate made up of well-rounded pebbles and the presence of *Conus* sp., which resembles *Conus portoricanus,* show that the San Juan was at one time below sea-level. The age of this formation has been placed as Pleistocene (Berkey, 1915, p. 12). The fossil content and situation of the beds at Cape Rojo support this conclusion.

ALLUVIUM

Alluvial material can be found along all streams and mantles the greater part of the broad lowlands near the coast. The low coastal regions known as playas are coated with deposits of this nature to a depth of 25 feet or more.

Deposits of this type are composed of material ranging from boulders two feet and over in diameter to the finest silt. An examination of the gravel shows representatives of the range of rocks in the Cretaceous formations, and in some deposits nodules of Tertiary limestone are present.

That some of this material was deposited when the land stood at a lower level is shown by the presence of interstratified, recent marine fossils in the surface layers of the playas and river floodplains and in elevated estuarine sediments. It may be noted that the alluvial material can be grouped under two general heads:

(1) Elevated estuarine gravels, mud and silt, occurring along the present river valleys.

(2) Deposits of the same character, covering the present river floodplains and playas and being augmented by each successive flooding. The first might better be correlated with the San Juan formation, while the latter would represent the more recent deposits.

Igneous Rocks

For purposes of mapping, the igneous rocks have been divided into diorite, andesite, diabase, and augite porphyrite. The occurrences of quartz diorite are too small to be shown areally on the geologic map. This is also true of the trachy-andesite. However, due to the petrographic interest of these rocks, they have been discussed in detail under Petrology, where will also be found a more extended discussion of the igneous rocks.

All of the igneous rocks in the area have an intrusive relation to the Cretaceous sediments and occur as dikes, sills and irregular masses. The largest intrusive is represented by peridotite altered to serpentine in the region north of Sabana Grande. The dikes and sills range from thin sheet-like bodies to masses 50 feet or more in thickness and are all confined to the Cretaceous formations. In no instance were intrusives found cutting the Tertiary rocks. The general elongation of the intrusive bodies along the strike of the pre-Tertiary beds is a noticeable feature.

Metamorphic Rocks

ANAMORPHICS

The anamorphics, including garnetiferous limestone, epidote rock, and garnet rock, are typical contact metamorphic effects produced by igneous intrusions in limestone. The extent of these rocks is limited to small zones. They are of particular interest in connection with the associated iron deposit on the upper Portugues River. Further details of these rocks will be found in the section on Petrology.

KATAMORPHIC ROCK

The original peridotite from which the serpentine has been derived was intruded into the tuff and shale of the pre-Tertiary series. This intrusive relation is clearly shown in the area north of Sabana Grande, where small beds of tuff are found inclosed in the serpentine. At other points, as, for example, southeast of Mayaguez, the serpentine cuts across and lies along the bedding in the ashy shale, thus placing the age of this rock as later than the deposition of the Upper Cretaceous and before the formation of the Tertiary, namely, in late Cretaceous time. In all probability the intrusion of the original peridotite was an accompaniment of the folding which deformed the pre-Tertiary beds.

STRUCTURE

Introductory Statement

On the basis of structure, the Ponce District is readily divided into two sections—a northern, more extensive area, made up of strongly folded Cretaceous rocks, and a southern border of Tertiary and later formations. The structural habits of these two sections are so strikingly different that one cannot help being impressed by the fact. The marked degree of folding which has affected the Cretaceous rocks, in places throwing them into closely folded, steeply dipping beds, is not to be found in the Tertiary formations.

In an attempt to unravel the structure of the different beds, seven main traverses were made across the area from north to south, along lines which gave promise of the best results. One shorter, north-south, section was studied in detail, and the formations between the main traverses were

traced east and west. In this way it was possible to locate all field units of any consequence, and work out in some detail the structural relations of the different beds. The making of such traverses in this region is no easy task. The rank growth of tropical vegetation and the ruggedness of the country, combined with excessive weathering of rock exposures, make geological work exceedingly arduous. One factor, however, which facilitated the work was the presence of numerous trails and roads along which it was possible to secure data which probably could not have been acquired otherwise. Many streams afforded sections which helped in determining structural relations. The data collected along the traverses, which in all cases were necessarily sinuous, have been projected to straight lines, as represented in the cross-sections.

Folding

LATE CRETACEOUS FOLDING

The strong folding of the Cretaceous formations is the most striking structural feature of the area occupied by these rocks. The dynamic forces involved have produced rather closely folded, steeply dipping, and

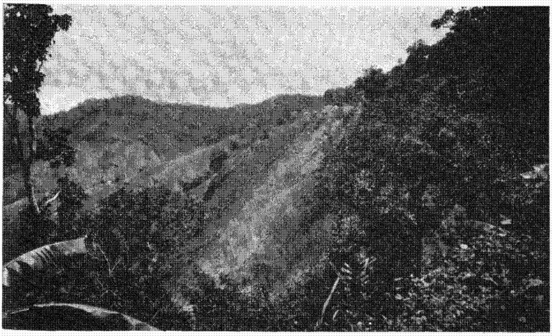


FIG. 4.—*Rio Yauco shale, as seen from point one mile north of kilometer 15.0, Yauco-Lares road*

in cases overturned strata, which in some instances are accompanied by thrust faulting. Dips of 90° were recorded, but the prevailing angles of inclination are usually between 45° and 75°. In the southern part of this northern area the beds are generally overturned to the northeast, but on reaching the summit of the main range, along the northern border of the district, the steeper slopes are more often on the southwest side. This would indicate thrusting from the southwest and northeast. The broader features of these foldings are shown on the cross-sections, Plates V and VI. The general strike of the beds is northwest-southeast in the northern half of the area, with a change to east-west along the southern border, as seen in the region around and west of Ensenada. Variations between these directions are due to local flexures or mark the ends of pitching folds, as is well shown by the shales along the Yauco-Lares road north of Yauco. The section exposed along this road affords the best illustration of folding in the Cretaceous rocks. Here is found an almost continuous section, involving shale, tuff, limestone and igneous intrusives whose structural habit is shown in figure 4. Other localities where the structure of the Cretaceous rocks is clearly shown are:

(1) On the road from San German to Lajas.

(2) Along the Ponce-Adjuntas road.

(3) Peñuelas-Ponce road, especially in the vicinity of kilometer 67.0.

(4) In the region around and west of Ensenada.

(5) South and west of Cabo Rojo.

(6) North of Peñuelas.

(7) North of kilometer 114.0, on the Ponce-Juana Diaz-San Juan military road.

(8) On the upper Bucana River, northeast of Ponce.

In addition to the larger foldings, there are innumerable smaller crumplings, which are not shown in the cross-sections. Examples of local distortion can best be seen in the shale along the Jayuya road, at kilometer 3.0 and vicinity; also at kilometer 22.7, on the Ponce-Adjuntas road.

The presence of such marked folding necessitates the action of mountain-building forces comparable in part to those which have affected regions like the Appalachian Mountains. While the forces which deformed the Cretaceous of Porto Rico have not been active over so long a period as is attributed to those which folded the Appalachians, still the two regions, from a structural standpoint, have features in common. It does not seem possible to attribute the folding of the Cretaceous formations of Porto Rico to igneous intrusions, although such an hypothesis has been advanced.

FOLDING OF TERTIARY

The Tertiary limestone and marl comprising the Ponce formation have been folded to the extent of producing low anticlinal deformation, which

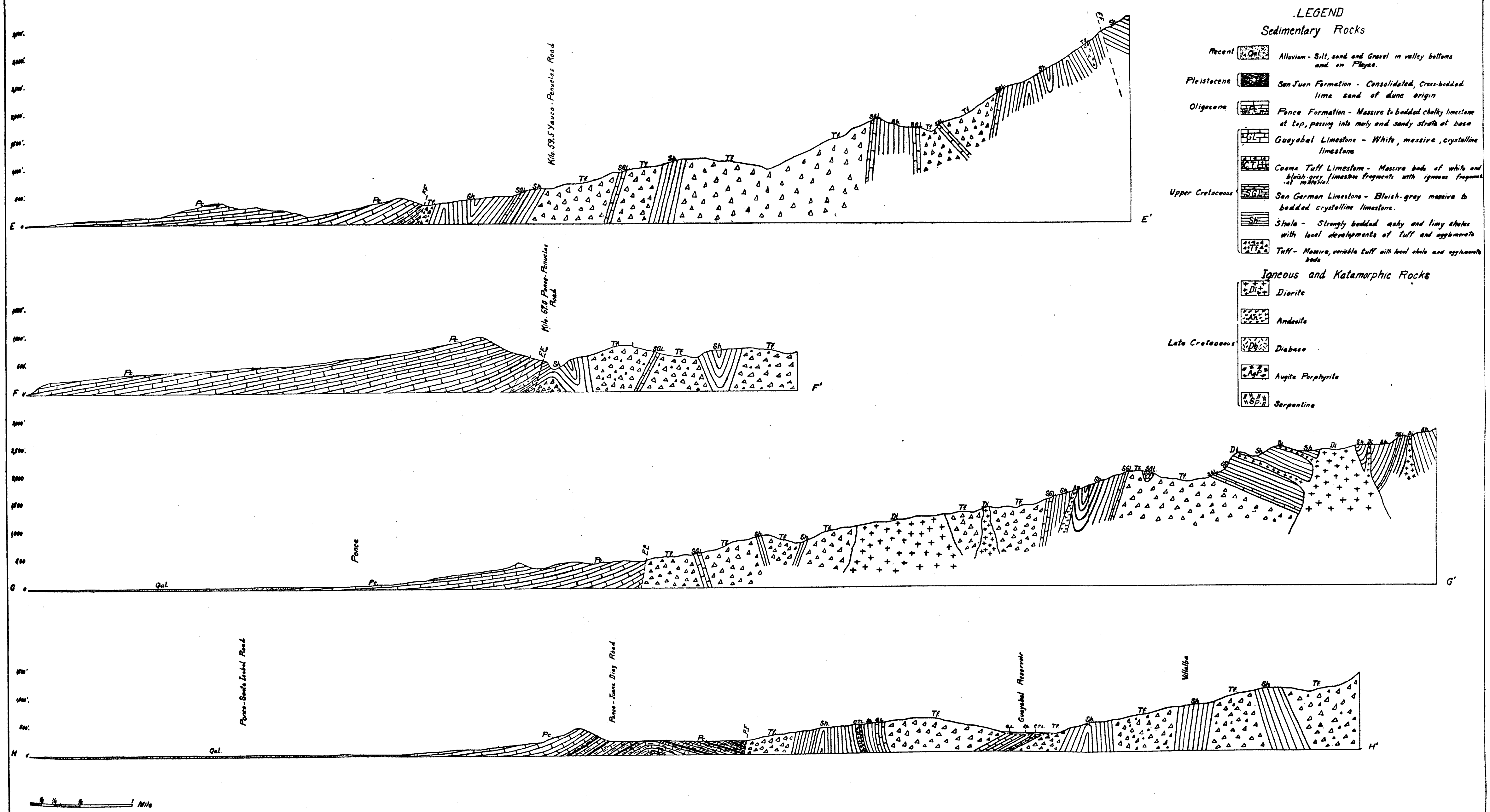


PLATE VI GENERALIZED GEOLOGICAL CROSS-SECTION OF PONCE DISTRICT

in places pitches with low angles to east and west. How extensive this folding has been cannot be determined, because the fault which marks the boundary between the Tertiary and Cretaceous rocks cuts out the lower part of the Tertiary beds, and thus conceals their structural habit. That folding has taken place is clearly shown in the section (H. H[1], Plate VI) along the Jacaguas River, north and south of the Ponce-Juana Diaz road crossing. At this point anticlinal structure of the formation is present, with the crest of the fold just north of the Jacaguas River bridge. The north limb of the fold dips with an angle of 15° to 10° into the fault bounded on the north by the tuff. On the south side of this anticline the beds are exposed in the prominent erosion cliff plainly visible to the southwest from the Jacaguas River crossing. Here the strata dip from 35° to 10° southward; the steeper dips are in the face of the cliff, and become more gentle north and south of this point. This is the only locality where such pronounced dips in the Tertiary rocks occur. In general, the inclination is from 10° to 20° southward, the steeper angles being read on strata near the fault zone, and are due in part to dragging up of the beds by faulting. Besides this folding, with axes trending approximately east and west, there are broad, shallow deformations which have nearly north-south axes. This latter folding was determined by tracing the marl and limestone beds from east to west.

The Tertiary formation shows none of the minor crumpling so characteristic of the pre-Tertiary. The absence of structural contortions comparable to those in the Cretaceous beds clearly indicates a period of diastrophic movement much inferior to that which affected the older rocks.

Faulting

IN CRETACEOUS ROCKS

By far the greater number of faults in the Cretaceous rocks are of the normal class, although, in some instances, as along the Jayuya road, at kilometer 3.0, the shales have been overturned, accompanied by thrust faulting. Other evidence of faulting in the form of crushed zones was seen in many localities (Fig. 5); for example, at kilometer 9.0, Yauco-Lares road, where limestone, tuff and igneous rocks are involved in the crushing, and on the Ponce-Adjuntas road, at kilometer 17.0 and 16.8+, where the limestone is extremely crushed and broken, due to faulting. Other localities are in the region north of Peñuelas; along the main drainage divide west of Adjuntas; northwest of Villalba; southwest of San German; north of Hormigueros, and at many other places too numerous to list here. In the majority of cases examined no great displacement had taken place, which would indicate that the intensity of such deformational forces was not so great as has been the case in other regions of mountain-making.

The most conspicuous faults in the Cretaceous formation are shown in the structure section (B. B¹ and C. C¹, Plate V). In the first instance the rupture has occurred in the serpentine and is marked by the intensely

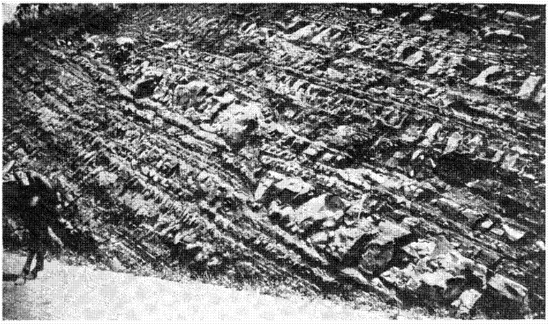


FIG. 5.—*Faulted shale at kilometer 14.3, Yauco-Lares road*

crushed and slickensided condition of the rock, as well as by physiographic features. In the section C. C¹, the break has taken place along the contact of serpentine and shale. The amount of movement in either case could not be determined. In both cases the physiographic expression supports structural evidence of faulting.

LATE TERTIARY FAULTING

The most pronounced fault in the district is the one marking the contact of the Tertiary limestone and marl on the south, with the Cretaceous formations on the north. Berkey (1915, p. 39) was the first to call attention to this structural feature, and he says:

> The most prominent fault, in its effect upon present features, is the one now marking the inner margin of the younger series of chalky limestones and shales constituting the coastal belt along the south side of the island from Juana Diaz past Ponce a short distance to the north, crossing the Ponce-Aricebo road at K-4.8, and thence westward, crossing the Ponce-Peñuelas road at K-10. This is the only large fault actually observed that is necessarily of

recent age, although a few others are inferred. It must be of very late Tertiary age, because the chalky Ponce beds are abruptly cut off by it. The older rocks of the pre-Tertiary are lifted with respect to the younger series, forming the present coastal margin wherever this fault has been seen. It has been traced by us from Juana Diaz to the vicinity of Peñuelas, a distance of about 12 miles. What becomes of it at either end is not yet determined, but it is believed to extend much farther in both directions.

Further evidence secured by the writer during field studies in this district substantiates the conclusion reached by Berkey and has also made possible the tracing of this structural feature to a greater distance east and west. The additional evidence relating to this question has been secured at a number of localities, extending from the vicinity of Juana Diaz to a point five miles east of Point Melones, on the west coast. The most eastern locality where faulting is clearly shown is on the Jacaguas River, northwest of Juana Diaz. The structural relations of the Tertiary marly limestone to the Cretaceous tuff are shown in cross-section H. H[1], Plate VI. It will be noted that the folded Tertiary beds have been dropped down against the upraised tuff. If these Tertiary beds were raised sufficiently to allow them to lap over the eroded surface of the Cretaceous formations, which they must have done before their displacement, then we would find that the movement down the steeply inclined dip slope of the fault plane was at least 900 feet. However, the base of the Tertiary is not exposed; so the exact amount of movement which has taken place cannot be measured. The contact between the marly beds and the tuff is represented by a crushed zone over 50 feet wide, in which tuff and marly material are mixed with surface wash. The evidence of faulting to the east of this point is concealed by the alluvial cover; but, judging from the position of the Tertiary and Cretaceous beds and the presence of crushed zones, the fault is believed to cross the Ponce-Juana Diaz-San Juan military road in the vicinity of kilometer 112.0 and continue southeastward beyond the limits of the district. Going westward from the Jacaguas River, the fault can be traced to the Ponce-Adjuntas road where it crossed at kilometer 4.8. Here the Tertiary chalky limestone is separated from the tuff by a crushed zone over 100 feet wide. The Tertiary beds are dragged up so that they dip 20° south near the fault and flatten out to 12° and 10° a short distance southward. Continuing westward to the west fork of Canas River, the same relations as seen on the Ponce-Adjuntas road are found.

The next locality to be considered is kilometer 67.0 (10.0 by old numbers), on the Ponce-Peñuelas road. The structural relations of the Cretaceous shales and Tertiary limestone are shown in cross-section F. F[1]. The folded shales have been raised so as to cut out the lower Tertiary beds and bring the chalky limestone in contact with the Cretaceous rocks. This contact is also marked by crushing, and the Tertiary beds are sharply turned up against the older rocks. From this point the fault passes south of the military road, and the next locality where the evidence is clear is just south of kilometer 48.0, on the Yauco-Peñuelas road, east of Yauco. At this locality the marly beds just below the chalky limestone are turned up against the Cretaceous rocks, with a narrow zone of crushed material lying between.

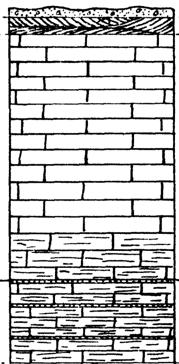
Passing farther west, the line of faulting runs north of the base of the Tertiary limestone and marly material forming the hills just south of Yauco. Here structural relations are concealed by the alluvium of the valley; but farther west, in the region of the San German limestone outcrop, at the east end of the railroad bridge over the Susua River, the faulted relations are again conclusive. At this point, which is three-fourths of a mile southeast of the railroad bridge, the white, chalky Tertiary formation is sharply dragged up against the San German beds. The crushed zone, which is approximately 20 feet wide, is filled with powdered Tertiary limestone and fragments of the San German. South of the contact, chalky Tertiary limestone assumes a normal dip of 10°, which is the average inclination maintained to the south coast. Three miles farther southwest the same relations can be seen. Here the San German limestone and the Tertiary chalky beds are again involved in the displacement. From this point the line passes southwest to Ensenada, where the Tertiary and Cretaceous are brought in contact. The relations here are best seen on the south side of the ridge of Cretaceous shales south of Ensenada. By following westward along the south face of the ridge, the chalky limestone is found to approach the older shales where the former is upturned against the steeply dipping Cretaceous. The dip of the Tertiary south of the contact is 8° to 12° south. The narrow crushed zone between the formations is filled with powdered, chalky limestone, fragments of shale, and surface wash.

In structural section B. B^1 the same relations as seen west of Ensenada are found to be present. The sharply upturned Tertiary limestone abuts against the Cretaceous shale, with a narrow zone of crushing between. Westward, beyond this point, the break has been traced to the playa of Cape Rojo, where it passes beneath the red sand deposit which covers that low coastal area.

In conclusion, the evidence as shown by the structure sections clearly indicates faulting between the Tertiary and Cretaceous rocks. The Jacaguas River section affords the only opportunity for measurements of the displacement; but, as already noted, the exact amount of movement

PLATE VII GENERALIZED COLUMNAR SECTION OF PONCE DISTRICT

Scale 1 inch ≈ 1800 ft.

System	Series	Formation	Symbol	Columnar Section	Thickness (Feet)	Provisional Correlation Table: Porto Rico (Berkey 1915)	Santo Domingo	Jamaica	Gulf Coast U.S.	Lithologic Character	Physiographic Expression
Quaternary	Recent	Alluvium	Qal	 Unconformity	0'-30'±	Alluvium				Silt, sand, gravel and boulders.	River flood plain and Playa deposits
	Pleistocene	San Juan Formation	S.J.	Unconformity	0'-20'	San Juan Formation				Cross-bedded sand chiefly calcium carbonate	Caps Tertiary at Cape Rojo
Tertiary	Miocene	Ponce Formation	Pc.	Disconformity	2350+	Arecibo Limestone	Zone G.H.I. (of Miss C.J. Maury)	Bowden marl	Chipola, Fl.	White massive to bedded chalky limestone passing into yellowish marly material at base.	Low rounded hills. Sink-holes in local areas.
	Oligocene	Juana Diaz Formation		Unconformity	750'	San Sebastian Shale		Montpelier white limestone	Vicksburg, Fl	Marly and shaly beds with thin sandy strata. Orbitoides mantelli abundant	Lowland i.e. Ponce - Juana Diaz Valley.
Mesozoic	Upper Cretaceous	Local designations i.e Rio Yauco Shale, Penuelas Shale, Ensenada Shale, San German Limestone, Coama Tuff Limestone and Guayabal Limestone.		Interbedded series of variable tuff with ashy and foraminiferal shale; massive to bedded, bluish-gray and white limestone and local developments of agglomerate and sandy strata. The limestones contain Radiolites sp. This form is more abundant in the San German Limestone which also contains Actaeonella sp. Ensenada Shale contains Hemiaster berkeyi. n.sp.	8250'±	Older Series	May be equivalent in part to Sierra Group (of Gabb)	Probably equivalent in part to Blue Mountain Series (of R.T. Hill)		Variable, massive tuff of prevailing Andesitic composition with local developments of shale and agglomerate, also small irregular masses of chert. Ashy and foraminiferal shale with local developments of tuff and sandy strata. Irregular masses of grayish chert. Massive to bedded bluish gray limestone, massive tuff limestone, massive white limestone. The above rocks make up an interbedded conformable series with tuff and ashy shale at the base and foraminiferal shale and limestone nearer the top. This series has been invaded by intrusive Diorite, Andesite, Trachy-Andesite, Diabase, Augite-porphyrite and peridotite.	Deep narrow valleys separated by sharp ridges in more youthfully dissected portions. Less relief and broader valleys in early maturely dissected areas. Prominent ridges formed by limestones. Broader valleys cut in tuff and shale.

cannot be determined and is probably much greater than the figure given. The age of this disturbance was at least late Tertiary, since the upper Oligocene beds are involved in the movement. The total displacement is the sum of a number of slippings at intervals throughout the later Tertiary. That the region may still be subject to further structural deformation is indicated by the rather strong earthquakes which were felt during the month of August. Besides the structural evidence already presented, the physiographic habit of the island, as pointed out by Berkey, supports the view of faulting with uplift of the island as a whole, along the southern side, and tilting of the block to the northeast. The presence of the fault along the southerly margin of the island has been questioned by Dr. A. K. Lobeck. After a study of the physiography of Porto Rico, he has concluded that the evidence of faulting can be attributed to sink-hole formation along or near the contact of the Tertiary and Cretaceous rocks. The abnormal dips of the beds near the fault he attributes to drag, produced by caving action accompanying the sink-hole formation. Such a "sink-hole hypothesis" seems incapable of explaining the structural features involved.

PETROLOGY

Introductory Statement

The purpose of this chapter is to summarize the petrographic details of a selected set of typical rocks from the area investigated. The material chosen includes sedimentary and igneous representatives, most of which are of sufficient field extent to be shown on the geologic map of the district. Some contact metamorphics are also described, but are not differentiated from formations of which they are only an altered portion.

Igneous Intrusive Rocks

QUARTZ DIORITE

Rocks of this type are well exposed at kilometer 23.4, on the Ponce-Adjuntas-Aricebo road, and where seen occur as an intrusive in the form of dikes or small bosses. Hand specimens of the quartz diorite are characterized by medium-grained texture and the presence of hornblende and feldspar, giving a greenish gray color on fresh fracture. Upon weathering, a whitish, sandy soil is produced, in which a few quartz grains can be identified.

The leading primary essential mineral in this rock is plagioclase, with hornblende next in prominence. The feldspar ranges from oligoclase to labradorite, andesine being the most abundant. The hornblende is of the pale-green pleochroic variety, occurring in rectangular plates and irregular broken crystals. Quartz is interstitial and contains many dust-like inclusions and gas bubbles. The texture is that of a medium-grained, crystalline rock. The primary accessory minerals, in the order of their abundance, are: titanite, orthoclase, magnetite, ilmenite and apatite. Alteration has taken place in the minerals to a considerable degree, the feldspars and hornblende having been most affected. The former have given rise to a sericitic aggregate which marks the central portions as well as the borders of the crystals. A saussuritic complex, in which epidote is the prominent constituent, occupies portions of the labradorite crystals. The change in hornblende has resulted in the formation of chlorite, which in some instances is penninite. Titanite has remained unchanged, while the ilmenite has in places passed to leucoxene. Magnetite has given rise to limonitic iron, which in places stains the sections yellowish. The effect on orthoclase has been similar to that on the more acid plagioclase. Quartz is practically unaffected and contains many stout little apatites in perfect condition.

DIORITE

Typical diorite is found at several points in the district, the best exposures being at kilometer 23.9, Ponce-Adjuntas-Arecibo road; four miles up the Portugues River from Ponce, and at kilometer 29.5, Ponce-Adjuntas-Arecibo road, just north of the Ponce District. The forms in which these rocks occur are the same as those of the quartz diorite. The diorites, however, are much more extensive and represent a type closely related to the rock just described. In the field, diorite is marked by a medium to coarse texture, in which feldspar and hornblende are the chief minerals. The greenish black hornblende is more strongly developed in some localities—for example, on the Portugues River—while at kilometer 23.9, Ponce-Arecibo road, feldspar with porphyritic habit is the prominent mineral.

In thin sections the rocks of this group prove to be normal diorites, consisting of plagioclase (andesine and labradorite) and hornblende as primary essential minerals, with a few crystals of oligoclase present. The accessory constituents are ilmenite, titanite, pyrite, pyroxene, magnetite, apatite and biotite. The texture ranges from medium to coarse and in places tends toward ophitic. In a specimen from kilometer 23.9, Ponce-Arecibo road, large crystals of hornblende not only act as "host" for the metallics, but inclose numerous large plagioclase crystals, producing a beautiful ophitic structure. In many instances the plagioclase shows zonal banding, with the successive zones becoming more acid from the center outward. Among the most prominent products of alteration are chlorite, sericite and leucoxene, the chlorite developing from the hornblende and pyroxene and the sericite from the feldspars. Leucoxene is seen filling zones of decomposition along the crystallographic directions of the ilmenite—a feature characteristic of these two mineral associations. Epidote is present as an alteration of hornblende, and pyrite has been changed along the crystal borders to limonite. A small amount of lime carbonate was noted as coming from the hornblende.

TRACHY-ANDESITE

A specimen collected from kilometer 22.2, Ponce-Adjuntas road, proved upon microscopic examination to be a trachy-andesite. Although the areal extent of this type will not permit its differentiation from andesite proper on the geologic map, it is thought best, for the sake of completeness of the petrographic series, to describe it. At the above locality this rock occurs as a small dike and is probably related to the larger dioritic mass which occurs in close proximity. In the field, this rock was classed as an andesite, for its true character is only seen in thin sections. What is true of the andesites as to field characteristics holds also for this rock.

The interesting feature of this specimen is the prominence of orthoclase in a rock which otherwise satisfies the requirements of a hornblende andesite. Oligoclase and andesine are both present, the former being the more abundant. Hornblende of both the light brown and the uralitic varieties is plentiful, the former appearing as basal sections in which the cleavage is well shown, and uralite in more rectangular plates, closely associated with secondary epidote. Orthoclase occurs interstitially as well as in the groundmass, while the plagioclases are arranged in such a manner as to simulate diabasic structure. Magnetite is the chief primary accessory mineral, with apatite and pyrite the only other representatives present. Alteration of hornblende has given rise to epidote and a few patches of lime carbonate closely associated with the epidote. An earthy substance having the appearance of kaolin occupies portions of the feldspars. Magnetite shows practically no alteration.

HORNBLENDE ANDESITE

A typical exposure of this rock is found at the north end of Guayabal reservoir, on the road to Villalba. At this locality the andesite is in the form of a small dike cutting the tuff. The megascopic characteristics of this rock are its greenish white color and the very fine-grained groundmass, in which are set a few feldspar and hornblende phenocrysts. In the field the material looked exceedingly fresh, but thin sections show that alteration of the minerals has progressed to a marked degree.

Although the rock is badly altered, there is still enough left of the primary minerals to determine its original character. Andesine and labradorite, together with hornblende phenocrysts, are set in a dense, fine-grained groundmass made up chiefly of small plagioclase crystals. As accessories, a few oligoclase, pyroxene, magnetite and apatite crystals are seen; the oligoclase and pyroxene being interstitial, while the magnetite occurs chiefly as inclusions in the hornblende. Some grains of magnetite, together with apatite, are distributed throughout the groundmass. The alteration of the feldspars has produced an aggregate of sericite which in places incloses carbonate. Hornblende has altered chiefly to chlorite and carbonate, with some epidote. Apatite is unaffected.

AUGITE ANDESITE

The following localities will serve as representatives of this rock type: Just north of the limestone quarry at Ensenada, "Guanica Central"; one mile west of "Guanica Central"; on the east line of the district, two miles north of the Ponce-Santa Isabel road; kilometer 64.2, Ponce-Peñuelas road; the southeast end of Guayabal reservoir; at kilometer 8.1, Mayaguez-Las Vegas road; and on the west branch of the Canas River, north of the Ponce-Mayaguez road. Augite andesite generally occurs as sills or sheets in the shales and tuffs. In some instances, as, for example, in the tuffs, it is hard to determine the relation, as bedding in this rock is not clearly shown and jointing is so perfect that it might easily be confused with bedding. As seen in the field, rocks of this class vary in color and in their tendency toward porphyritic texture. Specimens one mile west of Ensenada and at the east end of Guayabal reservoir are porphyritic and have a reddish hue, due to the presence of more iron oxide (readily seen in thin sections), while the specimen at the east end of the district, north of kilometer 17.0, Ponce-Santa Isabel road, is dark greenish and shows a stronger porphyritic habit. In all occurrences, pyroxene crystals are visible as phenocrysts, but feldspar cannot always be recognized.

The mineralogy of this rock is that of a normal pyroxene andesite, consisting of plagioclase (andesine, labradorite) and augite as primary essential minerals. The feldspars occur both as phenocrysts and in the groundmass and are marked in many cases by zonal structure. Intergrowths of one feldspar in another are also seen in parts of the thin sections. Augite is developed mainly as idiomorphic crystals with basal and longitudinal sections visible. The minor primary minerals are magnetite, ilmenite and hornblende, the latter being very sparingly represented. The texture varies in some localities, as, for example, just north of the limestone quarry at Ensenada, where there is not the porphyritic habit that is seen in the rock just west of Ensenada. In the former the feldspars have a stubby habit and the contrast between phenocrysts and groundmass is not at all pronounced, while in the latter case the typical porphyritic habit of the andesites is well shown, with feldspars and augite as phenocrysts. The common alteration products are chlorite and iron hydroxide. An example of the former is very well seen in a specimen procured at kilometer 64.2, Ponce-Peñuelas road, where the chlorite is developed from augite, which occurs both in the groundmass and in phenocrysts. Iron hydroxide is developed chiefly from magnetite. Sericite is present as a result of the decomposition of feldspar. Carbonate has been developed both in feldspar and augite. Some of the lime carbonate, however, clearly shows an introduction origin. A small amount of epidote is closely associated with chlorite developed from the pyroxene. Leucoxene is seen to come from ilmenite, which in some slides is rather generously distributed. Native copper, associated with amygdules in a pyroxene andesite, was found on the west branch of the Canas River, just north of the fault between the Tertiary and Cretaceous.

DIABASE

Good exposures of diabase are found at the following points: Kilometer 22.5, Ponce-Adjuntas-Arecibo road; kilometer 3.2, Yauco-Lares road; and kilometer 2.3, Mayaguez-Las Vegas road. Dikes and sills of diabase are not an uncommon feature in the tuff and shale of the Older Series. The above-mentioned localities are a few of the occurrences noted in the field. In size these intrusives vary from small stringers to masses 50 feet or more across, as, for example, the exposure at kilometer 3.2, Yauco-Lares road. The most prominent feature of the hand specimens of diabase is the texture, which ranges from rather coarse diabasic at kilometer 3.2, Yauco-Lares road, to very fine in the rock at kilometer 22.5, Ponce-Adjuntas road. The coarser varieties have a grayish green color, while the finer-grained ones are a dark greenish shade. Outcrops weather to a muddy yellow color, and the soil derived from such material is of a darker hue.

The essential primary minerals of this rock are plagioclase feldspar, of the labradorite and andesine varieties, and augite. The feldspars are arranged in characteristic diabasic fashion, with the augite filling the spaces between. This structure is well seen in the rock from kilometer 2.3, Mayaguez-Las Vegas road. In other instances the diabasic fabric, although present, is not so prominent a feature. Of the primary accessories, magnetite and ilmenite deserve first mention. The proportion of these minerals varies. In the sample from kilometer 2.3, Mayaguez-Las Vegas road, ilmenite is much in excess of magnetite, while in the other specimens magnetite appears in greater quantities. Apatite in needle-like crystals and stubby cross-sections is also present. Alteration has

FIG. 6.—*Augite porphyrite showing zoned augite crystal set in fine-grained groundmass* Taken in plain light, magnified about 30 times. K. 8.6, Mayaguez-Consumo-Maricao road.

resulted in the production of chlorite from the pyroxene, a feature well shown by the rock from kilometer 22.5, Ponce-Adjuntas road. Sericitization of the feldspar has advanced in some cases to such a degree as to completely replace the original crystal. Leucoxene developed from ilmenite and iron oxide from magnetite complete the list of alteration products. In the material from the Mayaguez-Las Vegas road, lime carbonate is present in veinlets cutting the other minerals, showing its introduction from outside sources.

AUGITE PORPHYRITE

Although porphyritic habit in rocks of the Ponce District is not uncommon, two instances of that type of texture are such striking examples of porphyrite that it is thought best to give them more prominent mention than they might otherwise deserve. The two occurrences are at kilometer 8.6, Mayaguez-Consumo road, and two miles north of kilometer 15.0, on the proposed extension of the Yauco-Lares road. In both localities the augite porphyrite occurs as dikes in the pre-Tertiary shale and tuff. On the Yauco-Lares road the intrusion is much larger than the one on the Mayaguez-Consumo caraterra, being over 75 feet across. This rock is readily identified in the field by the presence of the large, well-formed pyroxene crystals set in the dark greenish, fine-grained groundmass. The specimen from the Mayaguez-Consumo road is of a lighter greenish color and the augite crystals are not so conspicuous.

The most striking petrographic feature of this rock is the porphyritic habit of augite. These large pyroxenes, showing marked zoning, are set in a fine groundmass composed of feldspars and partially decomposed ferro-magnesians. Oligoclase and andesine are present, both in the groundmass and as phenocrysts, with the former more strongly developed in the groundmass. Some glassy matter is also present. Magnetite is prominent as inclusions in the pyroxene and feldspar and as small particles scattered through the finer portion of the thin section. Alteration has progressed farther than would be suspected by an examination of hand specimens. Chlorite is the chief result of this alteration, and has developed from feldspars and ferro-magnesians in the groundmass and from the phenocrysts of these minerals. Cavities which were originally filled with other mineral matter are now occupied by chlorite. Magnetite is partially changed to iron oxide, which has stained portions of the groundmass.

PYROCLASTICS

TUFFS

From many specimens of tuff a set has been selected for microscopic study, which covers the lithologic range of this class of rock. The distribution of the samples chosen is such as to permit comparison in different sections of the district. The thin sections include specimens from the following localities: Kilometer 3.9, Mayaguez-San German road; kilometer 19.8, Ponce-Adjuntas road; at the intersection of Ponce-Adjuntas and Jayuya roads; kilometer 13.7, Ponce-Adjuntas road; kilometer 14.9, Ponce-Adjuntas road; kilometer 12.8, Ponce-Adjuntas road; Guaniquilla

Point; one-quarter of a mile southwest of Lajas; on Jacaguas River where the road to Villaba makes first crossing; kilometer 31.1, Yauco-Mayaguez road; kilometer 11.3, Ponce-Adjuntas road; just west of Ensenada; north three-quarters of a mile from kilometer 72.3, Ponce-Peñuelas road; 2 miles northeast of Maricao; and on the divide ten miles east of Maricao. In all the above localities the tuff occurs as massive, faintly bedded material varying greatly in thickness and attitude. On the whole, the tuff shows evidence of fragmental habit, the included rock fragments being plainly visible. However, in some exposures the rock is thoroughly indurated and does not show evidence of its pyroclastic origin. The color varies from greenish to reddish tints, with shades of yellow and white. It is found on microscopic examination that the colors are due chiefly to the prominence of different secondary mineral products, the reddish varieties being richer in iron oxide, the green in epidote, and the whitish in decomposed feldspar.

The petrographic features of the tuff may be summarized as follows:

(1) The composition is predominantly andesitic, with trachytic, basaltic and glassy varieties present.

(2) Fragmental habit characterizes all the slides, although this feature is more strongly developed in some instances than in others. The fragments show wide range in size, varying from pieces plainly visible in hand specimens to those of microscopic dimensions. Jagged outlines of crystal and rock fragments are characteristic features.

(3) The matrix in which the fragments are set generally contains a quantity of ashy matter, which packs in around the fragments, forming a compact mass.

(4) Many of the individual crystals, as, for example, feldspars and ferro-magnesians, occur as broken fragments.

(5) Included fragments showing spherulitic habit are sometimes present.

(6) Secondary mineral products, including calcite, chlorite and epidote, are strongly developed; the calcite and epidote favoring the feldspars and the chlorite favoring the ferro-magnesians. Where calcite is strongly developed, epidote shows a decrease. All of these minerals also show introduction, especially the calcite and epidote.

(7) Magnetite is abundant in some slides and shows alteration to hematite and limonite.

(8) The geologic history of this group of rocks, as far as can be ascertained from the study of thin sections, suggests the following steps:

(*a*) Accumulations of volcanic ejectamenta on land surfaces, with marginal portions of these deposits reworked by water. This marginal reworking accounts for the rudely stratified portions in which the fragments show more or less rounding.

(*b*) Induration involving carbonitization, chloritization and epidotization, which binds some of the rock into a hard, resistive mass.

(*c*) Fracturing and introduction of carbonate, epidote and chlorite.

(*d*) Weathering, producing iron oxides and hydroxides.

Sedimentary Rocks

SHALE

Specimens from the following localities have been chosen as typical representatives of the range of rock included here under the general head of shale:

(1) Kilometer 5.6, Mayaguez-Consumo-Maricao road.
(2) Kilometer 3.7, Mayaguez-Consumo-Maricao road.
(3) Lapena Point, north side of Mayaguez Bay.
(4) Kilometer 6.+, Mayaguez-San German road.
(5) Kilometer 14.6, Yauco-Lares road.
(6) Kilometer 20.5, Ponce-Adjuntas road.
(7) Kilometer 22.7, Ponce-Adjuntas road.
(8) Kilometer 1.1, Jayuya road.
(9) Kilometer 1.1, Jayuya road.
(10) Kilometer 21.0, Ponce-Adjuntas road.
(11) Intersection of Ponce-Adjuntas and Jayuya road.
(12) Kilometer 16.6, Ponce-Adjuntas road.
(13) East bank Jacaguas River, two miles south of Villalba.
(14) One and three-fourths miles south of San German, on road to Lajas.
(15) One-fourth mile south of San German, on road to Lajas.
(16) Kilometer 7.2, Yauco-Lares road.
(17) Kilometer 111.9, Ponce-Juana Diaz-San Juan road.
(18) One mile north of kilometer 114.0, Ponce-Juana Diaz-San Juan road.
(19) One mile northeast of manganese deposit northeast of Juana Diaz.
(20) Kilometer 112.1, Ponce-Juana Diaz-San Juan road.
(21) One mile northeast of manganese deposit northeast of Juana Diaz.

The most evident field characters of the shale are the bedded and laminated structure and the color. The former is by far the more constant and has an important bearing on the solution of structural relations of the pre-Tertiary formations. The colors exhibited by this class of material have a wide range, including red, bluish gray, black, yellowish and green, with gradation between these colors. Although the color is the first feature which attracts one's attention in the field, especially in the case of the reddish varieties, it must be borne in mind that the colors are the result of alteration and, as will be shown in the petrographic discussion, are dependent upon the decomposition of certain minerals.

The petrography of the shales in the Ponce District may be summarized as follows:

(1) On the basis of composition a general division can be made into those high in carbonate of lime and those high in ashy matter. The lime content is present in the remains of foraminifera shells and as finely disseminated carbonate. When the ashy content is predominant, foraminifera are scarce or entirely absent, and the rock in thin section has the appearance of fine volcanic dust with angular crystals distributed through it. Numbers 1, 2, 3, 4, 6, 9, 10, 11, 12, 15, 17, 19, 20 and 21 are typical ashy shales. Numbers 5, 8, 13, 14 and 16 represent characteristic limy shale. There are gradations between these two extremes, as shown by numbers 7 and 18.

(2) When crystal fragments are large enough to be identified, they are found to be feldspar.

(3) Glass fragments are present in the more ashy shales.

(4) Pyrite, crystalline and massive, is plentiful in numbers 1, 2, 4, 5, 6, 9, 10, 11, 12, 13, 16, 17, 19 and 21.

(5) Magnetite occurs in some slides, but not so extensively as pyrite.

(6) In number 2 an inclusion of coarser-grained material shows lithic fragments of andesite.

(7) The foraminiferal content varies in amount, but is greatest in specimens of the dark bluish gray, strongly bedded rock. A list of the identifiable foraminifera in the different specimens of shale will be given in the paleontological section.

(8) Finely laminated structure is present in numbers 2, 8, 11, 12, 13, 14, 17 and 18. This feature is plainly visible in hand specimens.

(9) The chief alteration has been the oxidation of the iron-bearing minerals, chiefly pyrite. The color of the red and yellowish shale is due to finely distributed earthy hematite and limonite respectively. Leucoxene is present as finely disseminated specks.

(10) The greenish rock, well exposed at kilometers 19.6 and 15.8, Ponce-Adjuntas road, derives its color from the presence of abundant chlorite.

(11) Introduced veinlets of carbonates, chiefly calcite, are prominent in numbers 5 and 14. Many slides show micro faults and fractures.

(12) Cavities left by the removal of mineral matter characterize numbers 1, 3, 6 and 9. These specimens represent the more highly altered and porous rock.

CHERT

The two samples of chert chosen for thin sections are from Lepena Point, on the north side of Mayaguez Bay, and kilometer 6.+, Mayaguez-San German road. At both localities the chert occurs as small, irregular masses in shale and tuff. Hand specimens are grayish to red, with weathered surfaces colored whitish. Some dark red and green chert was found in the vicinity of Villalba. The rock is massive and is traversed by numerous veinlets of quartz.

In thin sections, the rock presents the exceedingly fine-grained quartzose make-up characteristic of that class of material. In some cases the quartz is large enough to be determined optically. Many veinlets of quartz traverse the sections. Pyrite is prominent and hematite in a few grains is identified. Oxidation has produced limonitic substances from the pyrite. This yellowish material is distributed through the rock. Crushing has developed weaknesses which have been filled with quartz veins. A search for radiolaria was made, but none was found in the sections.

SAN JUAN FORMATION

As seen in thin section, the rock is made up chiefly of lime carbonate in more or less rounded grains and irregular masses, through which are distributed angular quartz grains. Feldspar crystals are identified, but are not a prominent constituent of the rock. One crystal of tourmaline was noted. The angularity of the quartz and feldspar crystals is a noticeable feature and shows that the material has not been subject to much wearing action of stream or wind. The quartz and feldspar, together with the tourmaline, which were in all probability derived from the nearby Cretaceous rocks, have been subjected to very little wear before their incorporation in the lime sand. The carbonate of lime is of two types:

(1) Rounded grains.

(2) Crystalline and massive carbonate, filling in around the other minerals. This carbonate of the latter type is responsible for the binding together of the mass.

Metamorphic Rocks

CONTACT METAMORPHICS

Garnet Rock.—The garnet rock described here is located at the iron prospect of Sr. T. Blasini, about four miles north of Ponce, on the Portugues River. This rock occurs as a contact phase of limestone which has been cut by an intrusive dike. The structural relation of the rocks involved are discussed in another section, under Magnetite. The most noticeable feature of this rock in the field is the knot-like aggregate of reddish brown garnet set in a light greenish, fine-grained mass which is cut by calcite veinlets. Chalcopyrite and pyrite are present in appreciable amounts.

Pale yellowish brown garnet, determined to be grossularite, makes up approximately 90 per cent of the thin section. The garnet is cut by numerous fractures filled with introduced mineral matter and secondary alteration products. Among the other constituents, named in the order of their abundance, are lime carbonate, quartz, chlorite, epidote and sulphides. Carbonate, quartz, chlorite and sulphide have been introduced, while epidote is derived from garnet. The order in which the introduced minerals have come in overlaps. All have entered the rock at approximately the same time with the sulphides, slightly in advance of the others. Carbonate has continued as the last introduction product, with quartz and chlorite following in the order named. The time relations of these introduced minerals is clearly shown in the veinlets which cut the garnet. The sulphides, chalcopyrite and pyrite fill fractures and veinlets in the garnet and are also included in the carbonate.

The chief interest in this rock and the other two, about to be described under the contact metamorphics, is in their relation to the magnetite. A mineral group association which characterizes this rock and which might serve as one example of the result of contact metamorphism of limestone is the following: garnet, calcite, quartz, chlorite, chalcopyrite and pyrite.

Garnetiferous Limestone.—This rock is from the same locality as the garnet rock. The garnetiferous limestone is a contact metamorphic phase of the San German limestone, which at this locality occurs interbedded in the Cretaceous tuff and shale. Fresh material of this class is composed of closely packed calcite and dolomite crystals, with numerous reddish brown garnets dotting the mass. Pyrite cubes and massive chalcopyrite, which shows the iridescent tarnish, are present.

Calcite and dolomite crystals, packed together so closely that crystal outlines have merged one into the other, are the chief constituents of this rock. Calcite is much in excess of dolomite and has the crossed-twin lamellæ well developed. Pyrite cubes and massive chalcopyrite are included in the carbonate and also lie at the junction of several of the calcite and dolomite grains. The garnet is the pale yellowish brown variety, grossularite, in which are quartz and chlorite crystals. Minute dust-like inclusions are common in the carbonates. The rock is very fresh; the sulphides show but little alteration.

Epidote Rock.—The epidote rock is also from the Señor Blasini prospect, on the Portugues River. It occurs as a contact phase of limestone and an igneous intrusion. The nondescript appearance of this rock hardly suggests the beautiful development of epidote which is shown in the thin sections. Veinlets of epidote cutting the dark crystalline mass are the most noticeable feature in hand specimens. Dark brown garnet has a very slight development and a few sulphides can be identified.

In thin sections epidote and quartz are seen to be the chief minerals present. The time relation of these minerals is practically the same. Both act as "host" and "guest." Where "host," the minerals occupy large, irregular patches; and where "guest," they are present as small inclusions. Actinolite is identified as inclusions both in quartz and epidote. Patches of lime carbonate with chalcopyrite and pyrite inclusions are identified. The sulphides have been slightly attacked by weathering, but otherwise the rock is quite fresh. The mineral association is epidote, quartz, actinolite, calcite, chalcopyrite and pyrite.

KATAMORPHIC ROCK

Serpentine.—The distribution of serpentine rock can be seen on the Geologic Map. Its most extensive development is in the region north of Sabana Grande and southeast of Mayaguez. Specimens chosen for microscopic examination are from one-quarter of a mile south of the Reform School, southwest of Mayaguez; north of Sabana Grande five miles; from kilometer 41.7, Yauco-Mayaguez road. At the first and last locality mentioned this rock occurs in the form of dikes, but in the region north of Sabana Grande it takes the shape of a large, irregularly outlined intrusive mass in the Cretaceous formations. The exposures of serpentine are most frequently dark green to nearly black, with light shades of green characteristic of the more altered material. Some exposures are coated with a whitish alteration product, while in other instances iron stains the outcrop yellowish or reddish. The only minerals recognizable in hand specimens are pyroxenes and chrysotile, the latter forming small veinlets cutting the mass, and the former as phenocrysts, best seen on freshly broken surfaces. More thoroughly serpentinized exposures have a characteristic oily appearance and soapy feeling. In the specimens south of the Reform School, pyroxene crystals have weathered in relief, giving the surface a rough appearance. Much of the rock is strongly jointed and sheared and slumps where exposed in steep banks.

Microscopic examination shows the serpentine to be derived from peridotite. Enstatite and olivine are the most abundant primary minerals, the former occurring generally as large, lath-shaped crystals showing varying stages of alteration to serpentine, and the olivine is distributed as individuals among the pyroxene and as inclusions in the enstatite. Residual cores of olivine in serpentine are prominent in portions of the slides. Bronzite and diopside are present as scattered individuals. Olivine is more abundant in the rock north of Sabana Grande and south of the Reform School. Magnetite and chromite are plentiful, much of the magnetite being secondary after olivine. Alteration has produced antigorite and chrysotile from the olivine. Cores of olivine surrounded by serpentine characterize sections where this mineral is present. At times only the outline of the former olivine crystal remains, the center having been filled with a serpentinous product. Veinlets of chrysotile cut portions of the slides. The decomposition of olivine gives rise to magnetite, which in turn has furnished the iron oxide and hydroxide which appear as stainings. Enstatite has been changed to bastite, which replaces entire crystals of the former. In other instances the attack has progressed only so far as to produce a change on the border and along lines of weakness in the pyroxene. The lamellar structure of the enstatite is inherited by the bastite, giving a structure easily distinguished from the core-like pattern of the decomposed olivine.

PALEONTOLOGY

Introductory Statement

The paleontological material collected during the survey of the Ponce District lends itself to the following general classification:

(1) Post-Tertiary fossils found in elevated gravel, sand and silt of former embayments; shells on the elevated wave-cut terraces along the coast and in the surface layers of playas.

(2) Fossils from the Tertiary limestone and marl along the south coast.

(3) A few forms of upper Cretaceous age from the limestone and limy shale of the Older Series of Berkey.

In this report one new species and one variety are listed. The paleontological publications in the bibliography contain descriptions and illustrations of the other species here identified. The post-Tertiary fossils, all of living species, are found in perfect state of preservation. Details as to location and occurrence of these forms have been given under the discussion of terraces. The Tertiary formation has yielded a variety of forms with representatives from the lower and upper Oligocene. In the discussion of the lithology of these beds reference has been made to the distribution of the fossils and the lithologic character of the rock in which they are found. Upper Cretaceous *Radiolites* sp., *Actæonella* sp. and *Hemiaster berkeyi* n. sp. have been identified from the formations making up the older rocks in the district. The first two forms have been determined by Dr. T. W. Stanton, of the United States Geological Survey, and the *Hemiaster berkeyi* by Dr. R. T. Jackson. Details of the formations in which these forms occur have been discussed heretofore.

Post-Tertiary Fossils

Post-Tertiary fossils were found in the elevated terrace gravel, sand and silt and in the estuarine deposits on the floodplains of some of the rivers along the south and west coasts. The list of forms identified are:

Conus sp. like *Conus portoricanus,*
Strombus pugilis,
Lucina jamaicensis,
Lucina tigrina,
Arca tuberculosa,
Byssoarca ziebra,
Murex elongatus,
Arca rhombea,
Turritella imbricata,
Pecten nucleus,
Venus cancellata.
Ostrea sp.,
Strombus accipitrinua,
Fissurella nodosa,
Turbo pica,
Manicina sp.,
Cerrithium litteratum,
Pterna sp.

Tertiary Fossils

The Tertiary fossils from the Ponce formation have been identified as forms belonging to the Oligocene. The following is a list of those determined:

Clypeaster rosaceus, Lamark (Fig. 7),
Pecten sp.,

Phacoides sp.,
Strombus sp.,
Bulla sp.,
Teredo incrassata, Gabb,
Arca sp.,
Spondylus sp.,
Lucina sp.,
Leda sp.,
Corbula sp.,

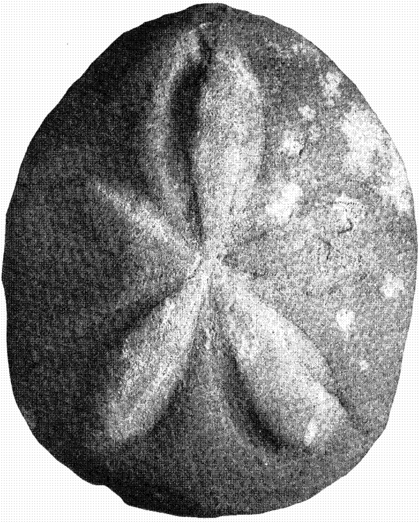


Fig. 7.—*Clypeaster rosaceus*, Lamark

Orbitolites complanata, Lamark,
Nummulites sp.,
Arca sp.,
Cardium sp.,
Pecten chipolanus, Dall,
Ensis sp.,
Pecten sp.,
Amphistigina lessoni, d'Orbigny,
Cyprœa sp.,

Natica sp.,
Amauropsis sp.,
Astarte sp.,
Cardium sp.,
Turritella halensis, Dall,
Turritella halensis alpha, new var.,
Cythara sp.,
Fasciolaria sp.,
Pecten sp.,
Laganum sp.,
Orbitoides mantelli, Morton,
Leaf fragments.

A new variety of *Turritella halensis* var. *alpha* has been found, associated with *T. halensis.* Its variation from *halensis* is given below in the description of the form.

Turritella halensis var. alpha

This form differs from *T. halensis* in having the secondary spirals less prominent and also by the lesser prominence of the primary spirals on the main surface of the whorl. Only the upper two spirals are strongly developed, the third one being very weak, thus giving a distinction to that portion of the whorl. The lower two spirals are pronounced and become confluent into a nearly uniform ridge on the later whorls. The beading is well marked on the upper two spirals, but obsolete on the others. There may be a slight change in the surface of the shell, due to solution; but the general characters could not have been affected to the extent shown.

Locality.—Jacaguas River, northeast of Ponce; occurs in the marly beds above the *Orbitoides mantelli.*

Cretaceous Fossils

The following fossils have been collected from the San German limestone *Radiolites* sp. (Upper Cretaceous) and *Actæonella* sp. (Upper Cretaceous). The *Radiolites* sp. is abundant in large and small fragments. It can be easily identified on weathered surfaces by the mesh-like structure produced by weathering of transverse sections. The *Actæonella* sp., together with the *Radiolites* sp., serves as an index of these limestones.

From the Cretaceous shale and limestone the following foraminifera have been identified:

(1) Shale just south of Melones Point. These beds are the westward extension of the shale at Ensenada, which carries *Hemiaster berkeyi.*

Textularia sp.,
Pulvinulina sp.,
Globigerina cretacea, d'Orbigny,
Orbulina universa, d'Orbigny,
Globigerina bulloides, d'Orbigny.

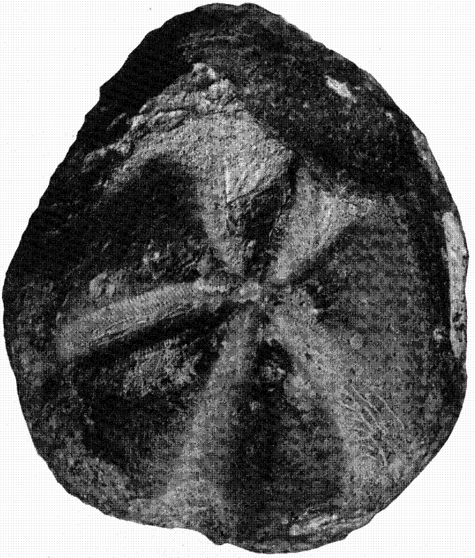


FIG. 8.—*Hemiaster berkeyi* n. sp., Jackson. × 3/2

(2) Guayabal limestone, one mile east of the manganese deposit north of Juana Diaz.

Globigerina sp.
Much fragmental foraminifera not identifiable.

(3) Ensenada shale.

A large amount of fragmental foraminifera.

The description of the new species of *Hemiaster* (Fig. 8) found in this shale has been furnished by Dr. R. T. Jackson, who states that its affinities are with the Cretaceous. His description follows:

Test large, cordiform, high, subconical, rounded below, from the highest point of the test dorsally sloping anteriorly, posteriorly and laterally to the ambitus. Ambulacra petaloid, wide, in deep broad furrows. The anterior ambulacrum III is narrower than the others and lies in a shallow furrow which reaches to the ambitus. Ambulacra II and IV, the anterior pair, are widely divergent at an angle of about 95° to each other and are in grooves which extend nearly to the ambitus. They measure 30 millimeters in length. The posterior ambulacra I and V lie in grooves and are narrower and much shorter than the anterior pair, measuring about 18 millimeters in length. The pores in the paired ambulacra are at the ends of narrow slit-like grooves. The interambulacra are narrow and elevated dorsally. The apical disc is very close to median in position, perhaps actually median, but from imperfections posteriorly exact measurement in the antero-posterior axis cannot be made. The apical disc is quite well preserved and shows the four genital plates with large perforations; the madreporite is of medium size, meeting but not separating the other genitals. Oculars I and V are in contact on account of the absence of genital V, as is characteristic of the genus. From imperfections the peristome and perisproct are not preserved. Small perforate tubules with subtubules are scattered over the test, somewhat distantly, and small granules thickly cover the spaces between the larger tubules. The specimen measures 40 millimeters in height, and this is a close approximation to the real height, though, if not worn ventrally, it would be slightly higher. It measures about 65 millimeters in length and 65 millimeters in width. The specimen is very much larger than any other fossil species found in the West Indies. It differs also in its shape from any known North American species.

At the request of the collector, Mr. Graham John Mitchell, this species is named in honor of Prof. Charles P. Berkey, of Columbia University.

GEOLOGIC HISTORY

Introductory Statement

In an historical summary of the geology of Porto Rico, Berkey (1915, p. 60) noted the following steps:

(1) A long geologic period of volcanic activity, accompanied by marginal attempts at assorting of fragmental and detrital material of organic accumulations, disturbed from time to time by renewed or extended igneous activity.

(2) A dying out of volcanic energy, greater stability of the mass with respect to elevation and subsidence, and erosional attack continued long enough to result in extended planation and partial baseleveling, with final extensive submergence.

(3) The development of an unconformable overlying series of shales, reef limestone and related deposits, chiefly of organic origin, brought to an end by final re-emergence.

(4) The development of present surface features under stream erosion and marine marginal attack, with modifications arising from oscillation of level.

These, with a few additions, are essentially the events in geological history of the Ponce District, a summary of which is given below.

Cretaceous Rock Deposition

The oldest geological record in the Ponce District is represented by a series of interbedded tuff, shale and limestone beds which comprise the Cretaceous formation. These rocks represent a period of volcanic activity in the form of explosive eruptions, with periods of lesser activity marked by the development of limestone and foraminiferal shales. The greater part of the tuff was deposited upon land with the sea encroaching upon the borders of this material and reworking areas to form shale. Heavy showers of volcanic dust contributed to the supply of material for the shales found interbedded in the tuff. That there were intervals during this volcanic period when organisms could exist in abundance is shown by the *Radiolites* sp., which formed reef-like masses, now represented by the interbedded San German and Guayabal limestone. Foraminiferal shales also accumulated in these less-disturbed intervals. In some instances previously formed rocks were broken up by the eruptions and redeposited to form such rock as the Coama tuff limestone. The Guayabal limestone represents a period of limestone formation higher than the San German and Coama tuff limestones, but in the same geological epoch, namely, Upper Cretaceous. The latest Cretaceous record, as shown by the rock in the district, is that of renewed volcanic activity with the formation of tuff.

Deformation and Intrusion

Toward the close of the Cretaceous the region was subjected to dynamic disturbances which resulted in a pronounced folding of the formations. Accompanying this folding came the igneous intrusions of diorite, andesite, diabase, peridotite, etc. It has not been possible, from the date secured, to work out the sequence of these intrusions. Their effect has been to produce baking, which is exhibited by the shale, and to form mineral deposits, as, for example, the magnetite on the Portugues River.

Erosion of Cretaceous

Toward the close of the Cretaceous there was uplift of the region, followed by a period of erosion long enough to wear down the exposed rocks to a partial plain, designated as the Eocene peneplain (Berkey, 1915, p

41). This old surface is probably represented in the Ponce District by the mesas southeast of Mayaguez.

Tertiary Sedimentation

The next event of which there is a record is found in the deposition of lower Oligocene shaly and marly limestones. The base of the Tertiary in the Ponce District has been obliterated by faulting, which has also destroyed the normal relations of the Tertiary and Cretaceous beds. However, as stated elsewhere in this report, the marked unconformity existing on the north side of the island between the formations of these two geologic epochs was also undoubtedly present on the south side.

The lowest Tertiary is represented by the rocks exposed along the Jacaguas River northwest of Juana Diaz. The sandy character of the marly and shaly limestone and the presence of many fragmental fossils and plant remains indicate shallow-water deposition. The change from this near-shore type of deposition to somewhat deeper water is indicated by the passage of these lower beds up into the chalky limestone of the upper Ponce formation. The waters in which these higher beds were laid down were much quieter and freer from sand and mud. Toward the top of the Oligocene (Upper Oligocene) the conditions became suitable for coral growth, as is indicated by the masses of coral heads imbedded in the chalky limestone. Whether or not Tertiary beds higher than the Upper Oligocene were deposited in the district cannot be determined, as the next record of deposition above the Oligocene is in the San Juan formation of Pleistocene age.

Deformation and Uplift of Tertiary

Toward the close of Tertiary deposition the region was again uplifted, accompanied by dynamic disturbances which produced gentle folds whose axes trend north-south and east-west. The fault between these rocks and the Cretaceous probably started its first movement at that time and reached its present amount of displacement before the close of the period of erosion which followed.

Erosion of Tertiary

The next event was the dissection of the Tertiary Coastal Plain and stripping of these deposits from much of the area formerly covered. The Complex Mountain Province thus uncovered or still exposed continued to undergo erosion and to contribute to the supply of waste which is now partially represented by the playa deposits. The larger valleys—for example, Guanajibo and Yauco-Boqueron—were cut during this period.

Submergence with Marine Terrace-cutting and Formation of San Juan Formation

The submergence which followed the main Tertiary erosion allowed the sea to extend up the river valleys, where it laid down gravel, sand and silt and formed the present elevated estuarine deposits. It was during this period that the highest marginal terraces were cut. The highest recorded terrace is approximately 200 feet, but the amount of submergence may have been somewhat greater than that. During this submergence the fossiliferous San Juan dune sand was consolidated and a conglomerate consisting chiefly of pebbles derived from the Cretaceous rocks was deposited upon it.

Emergence

From that time the movement appears to have been one of periodic uplift, finally reaching the present land-level. These uplifts resulted in the terracing both of the estuarine and inland floodplain deposits and in the cutting of the lower terrace levels on the formations along the south and west coasts.

ECONOMIC GEOLOGY

General Statement

The metallic mineral deposits in the Ponce District are confined to the Cretaceous rocks. The most extensive deposit is the limonitic iron, which is associated with serpentine rock. Manganese is the next in extent and is confined to the Guayabal limestone north of Juana Diaz. Magnetite is found along the upper Portugues River north of Ponce, where it has been formed along the contact between limestone and an igneous intrusive. No deposit of copper was found, although greenish stained andesite in which small particles of native copper are present outcrops north of kilometer 72.+, Ponce-Peñuelas road.

Among the material classed as non-metallics are salt, building stone, road-metal, cement material and petroleum. In the following pages all of the above resources are treated in as much detail as the individual cases seem to warrant.

Manganese

The only locality in the district where a deposit of manganese was found is north of Juana Diaz, where it occurs in the Guayabal limestone.

The property is owned by a company of which Deputy United States Marshal George Trautman, of Ponce, is the local representative. Several pits have been opened and a quantity of ore extracted. The method of working is as follows: The good ore is removed from the pits by means of pick and shovel. It is then sorted by hand, sacked and carried by pack-train to the military road, a distance of about three miles, where ox-carts transport it to the Ponce Playa for shipment.

The ore occurs as irregular-shaped masses along crushed and jointed zones in the Guayabal limestone. The size of the pits from which ore has been removed averages about 20 feet wide and 30 feet deep. The ore minerals are psilomelane and pyrolusite. The former is the more abundant and has the characteristic botryoidal form. It also occurs in layers with the pyrolusite, which shows short, indistinct crystals. Much of the manganese is massive black psilomelane, some of which is carried down the hillside by surface water, leaving a black trail behind. Calcite, crystalline and in banded form, is intermixed with the manganese.

The manganese owes its origin to secondary processes. The mode of occurrence of the oxides eliminates the possibility of a primary origin of these minerals in the limestone. The presence of the ore in pocket-like bodies of no great extent laterally or in depth and the location of such bodies in crushed and jointed zones indicate a concentration of the oxides by surface waters moving through these channels in the limestone. Such fracture zones would offer an easy course to manganese-bearing solutions. The original source of the manganese is not entirely evident. A microscopic study of the limestone country rock disclosed no primary manganese minerals or other minerals from which the oxides might be derived. A possible source of the manganese would be the jasper, which occurs as irregular masses in the limestone and which is found coated with manganese oxides. These jasper masses are not always found in direct association with the ore, but in most cases are only a short distance away. In one instance reddish jasper was found with manganese oxides coating the jasper and replacing it. From the field evidence, it appears that the jasper was the original source of the ore where the manganese minerals were probably present as rhodonite and rhodochrosite. Subsequent leaching, in the process of weathering concentrated the psilomelane and pyrolusite in the crushed zones in the limestone. Fragments of limestone are found imbedded in the manganese oxides which have partially replaced the country rock. In thin sections the oxides can be seen replacing the fragmental *Radiolites* and foraminiferal remains and cutting the wall rock in a network of veinlets.

Harder (1910) discusses the manganese ores in the Franciscan jasper of California and states that "the original source of the ore is the jasper itself." Further search for manganese in the Ponce District should be confined to the limestones, especially the Guayabal formation, and those portions closely associated with the jasper should receive first attention.

Magnetite

A prospect of magnetite along the Portugues River north of Ponce was visited in company with the owner, Señor T. Blasini, of Ponce. The property is known as Tibes and is about four miles north of Ponce. No development work had been done up to the time of the writer's visit, with the exception of a few shallow pits, which were not sufficient to determine the extent of mineralization.

From an examination of the few openings made, it can be seen that the ore owes its origin to contact metamorphic action of a felsitic dike cutting the San German limestone. The intrusive is so strongly modified that its original character cannot be determined. However, it has the appearance of an andesite.

The magnetite, with a little pyrite and chalcopyrite, is intimately associated with garnet (grossularite). The ore, as far as could be determined from the openings, occurs in irregular replacements along the limestone igneous contact. The limestone at this point dips with a steep angle and is cut by the felsite dike, which has a nearly horizontal attitude. The property is worthy of further prospecting to determine the full extent of the ore.

Limonite

The most important limonite deposit in the district, on the Mayaguez mesa, has been discussed in a very comprehensive paper by Fettke and Hubbard (1918). Since this paper may not reach all those interested in this iron deposit, it is proposed to summarize here the results of Fettke and Hubbard's study and to add additional localities for this type of ore. In regard to the distribution and mode of occurrence of the limonite, Fettke and Hubbard state:

> The limonite occurs as a mantle of brown to reddish brown soil overlying the top of the mesa and extending part way down its sides. Over most of the steep northern and southern flanks, however, it is absent, the underlying serpentine rock coming to the surface here. The material does not furnish a very fertile soil, so that vegetation on the mesa is scanty, as compared with the luxuriant growth of tropical plants covering the adjoining hills. Over most of the mesa the total thickness of the limonite is not exposed, and, as this cannot be determined without drilling, a few measurements only were obtained during the hasty reconnaissance made by the writers.

The gradation from weathered serpentine into limonite, wherever the contact is exposed, is a sharp one. As a rule, the serpentine just beneath the iron ore has been altered from the dark green, dense rock, already described, to a light yellowish green, soft, porous mass, abundantly stained by brown hydrated oxide of iron. The iron ore itself usually has a reddish brown color, but intervening between it and the altered serpentine there are, in most cases at least a few inches of brown material.

The character of the iron ore is summarized by them as follows:

Most of the limonite deposit consists of a loose, porous, earthy mass varying in color from light yellowish to a dark reddish brown. Usually the red portions occur nearest the surface, while the brown rest upon the serpentine. The relative percentage of iron in the ore cannot, however, be determined from the color, as frequently the brown varieties contain a higher percentage of ferric oxide than the darker red. The shade of color is undoubtedly due to the degree of dehydration of the ferric oxide. Toward the surface the limonite tends to lose its combined water and gradually passes into less hydrated forms of ferric oxide and finally to hematite.

In addition to the loose earthy material, numerous boulders and masses of hard ore occur scattered over the limonite area. These boulders retain the porous structure of the soft ore, but contain little veinlets running in all directions and filled with the botryoidal form of limonite with varnish-like luster. These boulders range in diameter from a few inches up to several feet; apparently they have been washed out of the upper layers of loose material.

A thin section from such a boulder, under the microscope, showed that the hydrated iron oxide is present in two forms, cryptocrystalline and amorphous. The former variety retains the structure of the serpentine, while the amorphous has been deposited afterward in little veinlets running in every direction throughout the former; these show a banded structure. Small grains of magnetite and chromite appear here and there, just as in the serpentine rock.

The conclusions of these authors upon the origin of the limonite is quoted below:

From the preceding description, it is seen that the limonite deposits of the Mayaguez mesa are almost exactly similar to those in northeastern Cuba, which have been studied by a number of geologists, all of whom have agreed that they are residual in origin, being derived from the underlying serpentine by the weathering of this rock.

It will, therefore, be sufficient to summarize briefly here the main lines of evidence that point to the residual origin of the limonite. These have already been ably discussed by the geologists who have described the Cuban deposits.

The close association of the limonite and the serpentine points strongly to such mode of origin; where other rocks lower in iron underlie the surface, the soils are relatively poorer in iron oxides. That the original structure and texture of the serpentine can still be detected in some of the hard ore furnishes almost indisputable evidence that the limonite has been derived from it in this manner. The irregular contact of the iron ore with the underlying serpentine is also characteristic of residual deposits derived from underlying rocks by the process of weathering. Likewise, the extremely porous structure of the limonite, where slumping has not occurred, shows that it has been formed by a leaching process in which the more soluble constituents have been dissolved by circulating waters, leaving the less soluble constituents behind. The relatively high percentage of chromite in the ore also indicates the same origin. Chromite is a relatively insoluble mineral, and therefore remains behind in the residual soils.

Finally, a comparison of the analyses of the serpentine and the limonite furnishes further evidence for supposing that the latter was derived from the former (Table 6).

TABLE 6.—*Comparative Composition of Serpentine and Limonite*

	Serpentine, per cent.	Limonite, per cent.
SiO_2	38.41	2.44
Al_2O_3	4.96	20.21
Fe_2O_3	6.32	57.69
FeO	1.27	0.85
MgO	33.32	0.61
CaO	0.04	trace
Na_2O	0.27	not det.
K_2O	0.10	not det.
H_2O at 110° C	0.83	1.09
H_2O + ignition	13.40	14.96
TiO_2	0.08	0.26
NiO	0.72	1.00
Cr_2O_3	0.42	1.57
	100.14	100.68

The only further information which might be added is to note other, less extensive occurrences of the same type of ore as that found in the Mayaguez mesa. The writer has gone over the area examined by Fettke and Hubbard, and has also studied the serpentine to the east of the mesa and at other points in the Ponce District. The limonitic iron was found at a number of localities in the mass of serpentine, the western end of which forms the Mayaguez mesa. The deposits are very irregularly distributed, much of the serpentine showing only iron stains. The other locality worthy of mention is at the Reform School southwest of Mayaguez, where shallow pits have been sunk. The limonitic soil at this point is filled with shiny nodules of brown iron ore.

COPPER

An unsuccessful attempt was made to locate a reported copper deposit north of San German. The rock in this region is chiefly serpentine, and, although places showing copper staining were found, no deposit was encountered. It is possible that ore may occur here similar to that found on the Pacific coast (Butler and Mitchell, 1916). Copper in the form of small particles was found in andesite north of kilometer 72.+, Ponce-Peñuelas road, near the fault contact. The mineral is very sparsely distributed in the andesite, being associated with the filling of amygdules. Weathering has produced greenish copper stains coating the surface of the rock.

Salt

Salt is derived by solar evaporation of sea water in artificial salt pans along the south and southwest coasts, at four different places. The largest of these is the Salinas de Cabo Rojo, in the extreme southwest corner of the district, near Cape Rojo. A memorandum of the Salinas de Cabo Rojo, furnished by Señor Arturo Bravo, of San Juan, is included here:

The so-called Salinas de Cabo Rojo are situated on the southwest point of this island, about where Morrillos Lighthouse is located.

The salt production is divided into three sections, viz: "Fraternidad" on the south, between Morrillos and Punta Aguila; "Candelaria" on the west, between Punta Aguila and Punta de Hicacos; and the "Corozo," between Punta de Hicacos and Punta de Penones.

The salt is obtained by solar evaporation.

There are two large ponds, one natural and the other artificial, which receive the sea water through ditches. From these ponds, by means of wooden canals, the water is pumped into the crystallizers, wind power with five mills being used. The salt is taken with wheelbarrows from the crystallizers and stored near by in pyramid piles, and when dried is carried to the shore in small open wagons, driven by oxen, through rails in some instances, and in others with common ox-carts, which unload into lighters at a small wharf, and the lighters take the salt to the vessels.

The number of crystallizers amounts to 41, and their capacity of salt varies from 25 to 100 tons each, averaging in all about 3500 tons. In ordinary weather conditions through the year, these crystallizers condense four times, showing a total production of 14,000 tons. There is room for building more crystallizers at a very small cost, to duplicate the production, and with some further improvements it might yet considerably increase.

Exceptional unfavorable weather is usually experienced every ten or twelve years, and we had to encounter with such contingency in 1913, when the yield amounted only to 2870 tons.

Wages are paid at the rate of 50 cents per day for any ordinary work, but the labor on shore for shipping is paid by the weight, at the rate of one cent per hundred pounds. The labor for gathering the salt in the crystallizers, carting it out and piling is paid at 4 cents fanega. Shipping by lighters is paid at $2.00 per hundred fanegas. Each fanega is equivalent to about 300 pounds or over, according to the weight of the salt.

Our salt is well known in different American markets and particularly so in Boston. During the years 1910, 1911 and 1912 eighteen cargoes were shipped to the United States in vessels from 550 to 1750 loading tons capacity, but said shipments have been stopped since the duty on foreign salt was taken off, according to the Underwood tariff.

The island's consumption is estimated at from 11,000 to 12,500 tons per year, of which we furnish about 5000, the other smaller salt places here about 5000, and the remainder is imported from Curacao. These importations from Curacao have been considerably increased since foreign salt is coming in free of duty, but we hardly think the competition with home production may be much longer maintained in spite of the exceedingly cheap production in the neighboring island, due to small wages and more reduced expenses prevailing there.

Our property consists of about 1853 cuerdas (each cuerda approximately one acre) of land, about one-third of which covers the extension required for the salt manipulation.

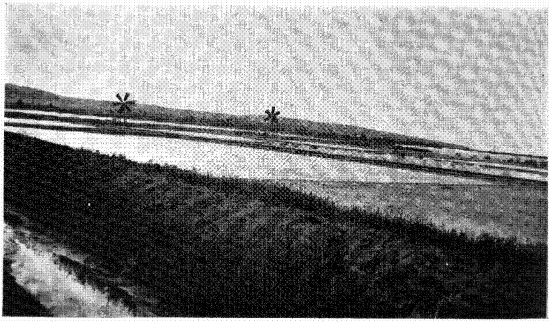


FIG. 9.—*"Montalva" Salina, west of Guanica, on south coast*

Other places producing salt are the so-called Boqueron, near the Salinas de Cabo Rojo, which yields nearly 1000 tons annually; Guanica, on the south coast, producing 3000 tons, and Montalva (Fig. 9), near Guanica, 1500 tons. The methods used in these smaller salinas is practically the same as that employed at the Salinas de Cabo Rojo.

BUILDING STONE

Only three formations in the district lend themselves to building purposes. These are the Coama tuff limestone, Guayabal limestone, and portions of the Ponce chalky limestone. All of these stones have been used, with the exception of the Guayabal limestone, which, though it appears to be suitable for interior marble-work, has not, to the writer's knowledge, been employed for such a purpose.

The Coama tuff limestone has been used in some buildings, notably in Ponce, where it has also been employed in curb construction. The striking lithologic character of the rock makes it a unique building stone. The Ponce chalky limestone has also been used in some of the older buildings in Ponce. It has served very well in the smaller structures. The Guayabal limestone north of Juana Diaz offers a considerable supply of material suitable for interior decorative purposes. The rock takes a good polish, presenting an attractive cream-colored surface. Joints are prominent in much of the material, but field examination shows that blocks of considerable size, free from joints, can be secured.

Road-metal

An abundance of first-class road-metal can be found in nearly all parts of the district. The rock used for the excellent macadam road depends in a large measure upon the local supply. Among the varieties in use are San German limestone, tuff of all varieties, shale, igneous rocks and the white Ponce chalky limestone. Of the above, the best materials are the San German limestone, highly indurated tuff, foraminiferal shale and igneous rocks.

Cement Material

An abundance of cement material is found in the shales and limestones which are so prominently developed in the area from Peñuelas westward. However, the lack of a local fuel supply on the island makes the possibility of developing such an industry a doubtful one.

Petroleum

The only locality where conditions appear favorable to the accumulation of oil is in the region west of Juana Diaz, in the sandy, shaly and marly beds of the lower part of the Ponce formation. An examination of these beds disclosed no indication of the presence of oil, although the structure is such that oil could accumulate. The sandy portions of the beds are capable of acting as a reservoir, with the more shaly material serving as capping strata. If further investigation of oil possibilities is made in Porto Rico, these beds should receive attention, though from the evidence secured during the present survey there is nothing to justify the belief that petroleum will be found in this district.

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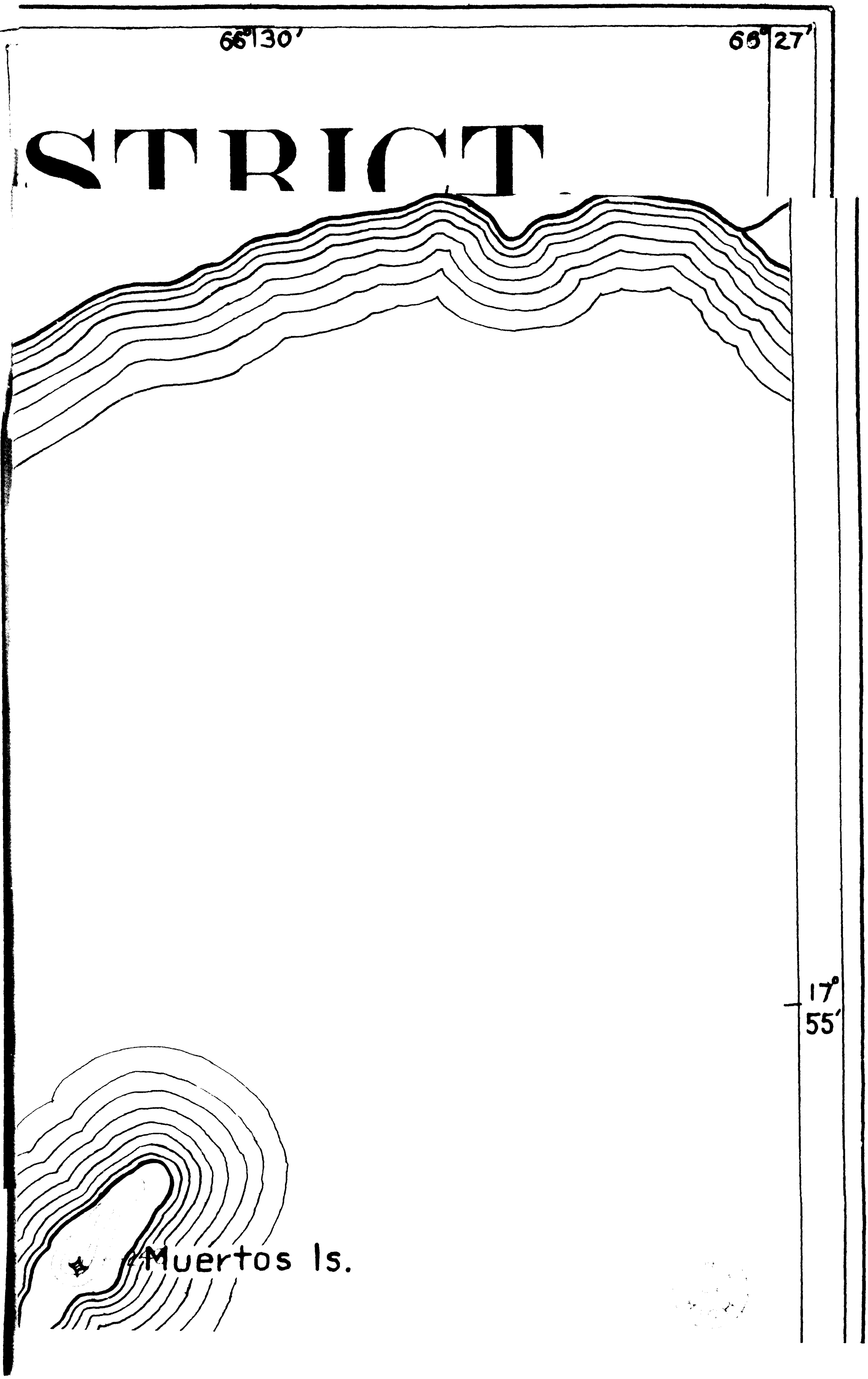
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