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Special Report 71

FEBRUARY, 1965

Background Study of Puerto Rico

Briefing Report for use in Aerial Sensing Studies of Tropical Areas

U.S. ARMY MATERIEL COMMAND
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
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by
Virginia L. Prentice

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PREFACE

The Photographic Interpretation Research Division, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H., is engaged in a program of multiband sensing research for engineering, military and scientific purposes. A portion of this broad study is concerned with the development and application of multiband sensing techniques in the tropical environment (TROPICAN) for obtaining information about (1) remote tropical surface features and (2) military activities against various tropical backgrounds.

The original proposal for TROPICAN was submitted by Office, Chief of Engineers, Military Sciences Division, to Office, Chief of Research and Development, Army Reseach Office, on 26 March 1962 and provided for a means of exploring aerial sensing techniques in tropical areas by coordinating efforts of USA CRREL with tropical soil studies being initiated under Army Mobility Research Center (Project No. 8570-05-001). Later developments within ARO through discussions with Advanced Research Projects Agency made it worthwhile to expand the efforts of TROPICAN to include exploring the potentialities of aerial sensing in problems of immediate concern in other tropical areas. Toward this end, the scope of TROPICAN was revised to permit initiation of field activities in Puerto Rico in early fall 1962.

Information contained in this report provided the basis for briefing field personnel about natural and cultural aspects of Puerto Rico prior to field work. The material was obtained through an extensive literature search and review. The Bibliography, while lengthy, is not exhaustive for Puerto Rico. In reviewing the literature primary emphasis was placed on soils, rocks, vegetation, physical makeup, and land use. Engineering aspects, that is, problems related to location, design, construction, etc., were not included in the literature survey. Secondary emphasis was given to historical and sociological aspects.

During October 1962 a short trip was made to Puerto Rico for purposes of advance planning. This was followed in November 1962 by the major field effort concerned with the operational phases of the combined study. A total of 46 persons from seven organizations participated during the November study. USA CRREL was represented by 14 persons (see Appendix B, Trip Report, R. E. Frost). A classified report has been published on the results of the November study.

Because of continuing interest in tropical areas and the value Puerto Rico offers as a field research laboratory, it was deemed worthwhile to publish this briefing report.

Special acknowledgements are due a number of persons who contributed to the collection of material for and the preparation of this report. Miss Dorothy J. Edwards aided with the literature search, review of the technical literature, and compilation of the Bibliography. Mr. Geoffrey Hamer provided invaluable assistance in translating the Spanish language literature. Editing and review of the manuscript in its various stages were performed by Mr. R. E. Frost, Chief, PIRD. Mr. Stephen B. McLaughlin gave

PREFACE (Cont'd)

assistance in planning the illustrations and prepared those not obtained directly from other sources as noted. Miss Eunice V. Salisbury, USA CRREL Librarian, patiently ordered non-routine maps and books, handled innumerable interlibrary loan requests, located obscure items and suggested additional sources of information.

Dr. Rafael Pico, Director, and Mr. Hector Berrios, Assistant to the Director, Government Development Bank of Puerto Rico, gave generously of their time in discussing the project with the author, provided books and pamphlets, and made available information in the Puerto Rico Land Use Survey files. Dr. C. F. Jones, Professor Emeritus, Northwestern University, graciously supplied an important list of basic references. Thanks are due also to members of the staff in the Reference and Map Divisions at Baker Library, Dartmouth College.

Manuscript received 11 December 1963

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Virginia L. Prentice

INTRODUCTION TO PUERTO RICO

Puerto Rico is the easternmost and smallest of the islands of the Greater Antilles. It is located between 17°55' and 18°31' N latitude, 65°39' and 67°15' W longitude. It is bounded by the Atlantic Ocean to the north and the Caribbean Sea to the south. The island is roughly rectangular, being approximately 100 miles long (east-west) by 35-40 miles wide (north-south). The total area is only 3435 square miles. The island is approximately the same length as Long Island and twice the width (Fig. 1).

The general physiographic makeup of Puerto Rico consists of a central core of mountains trending east-west, with a narrow coastal plain fringing the island. The crestline of the mountains is offset to the south from the centerline of the island. That is, the coastal plain on the north side is broader than that on the south. Spurs of the mountains extend to the sea in spots on both the east and west ends of the island. These spurs form steep sea cliffs at the shoreline. Foothills of varying ruggedness and extent flank the mountains on the north and south. These merge with the gently rolling to flat coastal plain areas. The mountains attain elevations of over 3000 ft. Cerro de Punta, the highest peak, is about 4400 ft in elevation.

Puerto Rican climate and vegetation reflect the tropical location in the Caribbean area. Temperatures, mild for a tropical area, average from 73 to 79F; the trade winds and topography cause alternating land and sea breezes; an average of only 5 days a year are entirely without sunshine; and rain is abundant but falls, for the most part, in brief showers. Vegetation is luxuriant except in the drier areas of the island. Flowering plants, both cultivated and natural, abound, providing a profusion of color during most seasons of the year.

The fauna of Puerto Rico is most notable for the lack of indigenous land mammals or reptiles. No squirrels, skunks, foxes, alligators, or similar animals inhabit the island. The most common mammal is the mongoose, which was introduced from Cuba. Rats and mice abound, and bats are numerous in the limestone caves. Aquatic animal life is abundant. There are many types of both fresh and salt-water crabs, shrimp, fish, etc. One species of fresh water snail, common to some Puerto Rican streams, is the intermediate host for a parasitic worm which causes schistosomiasis, a severe endemic disease. Lizards and frogs are numerous but snakes are rare and none of them are poisonous. Between 1400 and 1500 species of insects are known. Flies, mosquitoes, termites, and livestock parasites probably cause the most concern, but Puerto Rican efforts at improving health and sanitation have minimized the danger of insect-carried diseases such as malaria. Only two poisonous spider or spider-like animals exist - the scorpion and a local tarantula, the guaba. Birds are not as plentiful as might be expected. This is due to destruction of nests and young birds by hurricanes and to the high density of human population. The most common birds to be seen are the grackles and egrets feeding on grubs and ticks in the fields and pastures. The egrets were originally imported from Africa to help combat the problem of ticks.

Puerto Rico is a densely populated island with an area of some 3400 square miles and a population of 2,393,000. The density averages over 600 persons per square mile. In some of the rugged interior mountainous areas population density falls to less than 200 per square mile, but in the urban areas on the north coast it is over 800 per square mile. Even in the Luquillo Forest region, an area of relative wilderness, the population averages 120 persons per square mile.

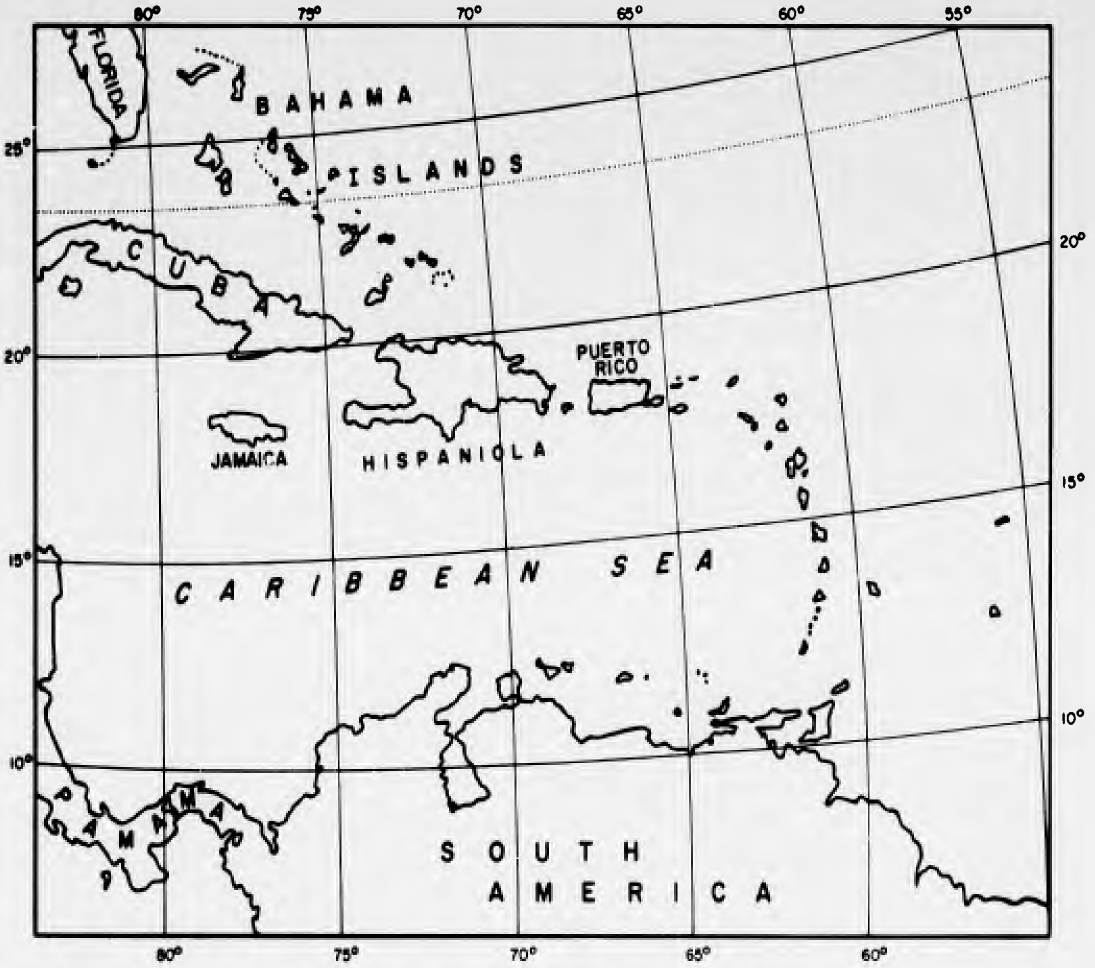

Figure 1. Location map of Puerto Rico.

The major cities of Puerto Rico in order of size are: San Juan, on the north coast; Ponce, on the south coast; Mayagüez, on the west coast; Caguas, an eastern interior valley city; and Arecibo, on the north coast. The sixth ranking city, Rio Piedras, is adjacent to San Juan, forming a part of the San Juan metropolitan area. With the exception of a few interior valley cities such as Cayey and Utuado, the larger Puerto Rican towns are located on the coast or the northern and southern foothill slopes just inland from the coast. The highway transportation net is very well developed (Fig. 12).

The economy of Puerto Rico has long been based on agriculture. In 1961 the income from industrial or manufactured products surpassed that of agriculture for the first time in history. In number of people employed, agriculture still outranks industry, and much of the industry is concerned with the processing of agricultural products. Furthermore, industrial activity is primarily of the light manufacturing type, and the plants are relatively small with a limited number of employees. All in all the island may still be considered primarily agricultural. Puerto Rico's major natural resource is soil, yet less than one-half the total area is considered arable, and increasingly large areas of agricultural land are being appropriated for urban expansion, highways, and industrial sites.

NATURAL FEATURES

For its small size Puerto Rico exhibits a wide diversity of natural features. Physiographically speaking, the major landscape units — mountains, hills, plains — are well expressed. Within each major landscape division are smaller geomorphic units of varying size, shape, position, and degree of dissection. Some of the lesser landforms such as the "pepino" hills dominate the landscape in geometric regularity and are almost classical in their form and character. The climate of Puerto Rico is equally diverse, ranging from desert conditions in the southwest to tropical on the mountain slopes in the east. Soils of the island are also diverse, and range from recent stream alluvium and beach deposits to thick deposits of lateritic-like soils on some of the metamorphic rocks in the higher areas. This general diversity of climate, soils, rocks, and landscape has contributed to a great diversity of vegetation, which is further complicated by the long cultural history of man in the area. Natural vegetation in Puerto Rico has suffered from the highly competitive efforts of man. Close association, however, exists between landforms, bedrock, soil mantle, and the effects of the near tropical climate.

Climate

The major climatic influences for Puerto Rico are its position in the westerly tradewind belt and its diversity of relief. The combination of tropical temperatures and maritime humidity is ameliorated by the constant cooling and drying effect of the westerly trade winds.

Temperature

Temperature ranges in Puerto Rico are small. Diurnal, annual and regional temperatures vary only a few degrees (Fig. 2). Typically tropical, the diurnal range is greater than the annual range (Smedley, 1962). In general, temperatures in Puerto Rico seldom exceed 90F and seldom fall below 60F. Extremes recorded in the Luquillo Mountains are 92F and 52F. The highest temperature ever recorded in Puerto Rico was 103F at San Lorenzo in 1911, and the coldest was 40F at Aibonito in the same year (U. S. Department of Commerce, 1962). Coastal stations average 75-80F; at elevations above 1000 ft the annual temperatures average 68-74F. In the Luquillo Mountains the summer temperatures are cooler than the coastal winter temperatures. The daily temperature range is usually 10-15F along the northern and eastern coasts, and increases inland and with elevation. The range is 15-20F in the southeast, over 20F in the west and southwest, and 26.6F at Utuado, in the west-central mountain area. To persons conditioned to the temperature extremes experienced in temperate and some arctic and subarctic environments, these small temperature ranges mav seem insignificant. The differences of 5-10F at various elevations in Puerto Rico, however, are of extreme ecologic and agricultural importance.

Rainfall

More important than temperature differences in Puerto Rico are the differences in rainfall. Westerly winds pick up moisture over the Atlantic and drop it as rainfall as they cross Puerto Rico, according to well-known orographic principles. Thus, the northeast coast and the mountains receive the greatest amount of rainfall (Luquillo Mountains - 200 in.) and increasingly less rain falls to the west and south until semiarid and arid conditions (25 in.) are reached in the south central and southwestern portions of the island (Fig. 3). The humid and subhumid areas of Puerto Rico have a wet season and a less wet season, the latter being from January to April. For the most part, these areas receive at least 2 in. of rainfall during each month of the year. In the wet and humid areas of Puerto Rico daily showers may be expected. These are of relatively short duration (less than 1 hour) and bright sunshine follows. There may be more than one shower per day (Howarth, 1934). According to one authority (Pico, 1950), Puerto Rico is well-watered except in three distinct regions: the southern coastal plain from Patillas to Boqueron; the northwest corner in the vicinity of Ramey Air Force Base; and the Cayey Valley, which is in the lee of the Cordillera. In addition to the general deficiency and unpredictability of rainfall, the porous nature of the limestone soils contributes to the aridity of the Ramey AFB area.

Statistics based on the annual average rainfall fail to give a true picture. Many areas receive sufficient rainfall for several years in a row, then suffer a long dry spell in one year. Occasional droughts are so severe as to dry all reservoir sources of water supply, even in the subhumid regions. The dry season usually occurs in the winter months, but even this may vary. It should be emphasized that in an area with such consistently high temperatures, rainfall efficiency is lower than in temperate climates. In Puerto Rico 30 in. of rainfall will equal in efficiency 15 in. in the midwestern United States.

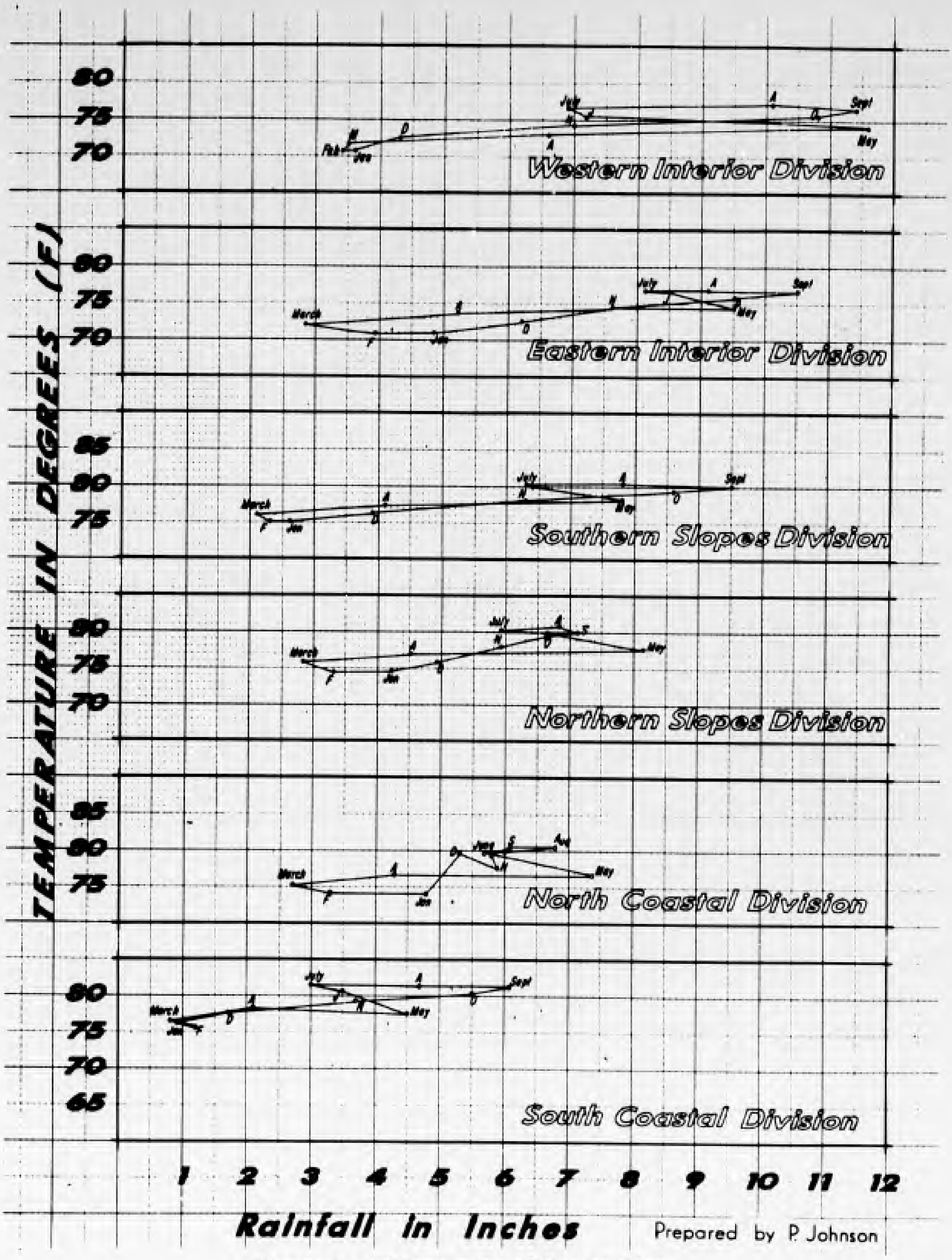

Figure 2. Climographs of Puerto Rico

The high humidity and orographic activity at higher elevations cause clouds which surround the mountain tops intermittently or for extended periods daily. Fog at lower elevations is rare.

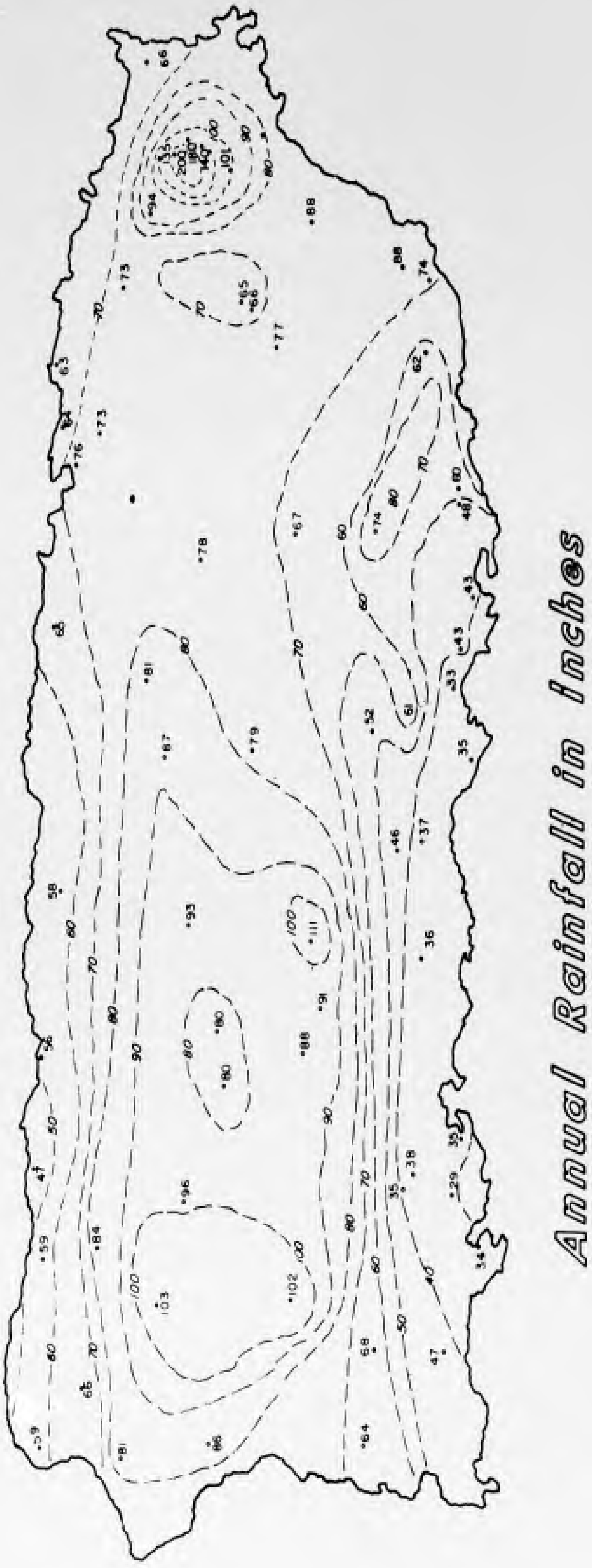

Figure 3. Rainfall map of Puerto Rico

Winds

Winds are generally constant and, although the humidity is high, breezes produce a cooling effect. Personal comfort is attainable when one is situated so as to take advantage of the breezes. However, the combination of humidity and high temperature without benefit of a breeze may be uncomfortable and extremely enervating. While hurricanes are infrequent (once in 30 years is the average), they are nonetheless feared and may be extremely destructive. The hurricane season is concentrated during August and September, but hurricanes may occur from 1 July to 1 November. The greatest danger of damage is to tree crops and forests (Thorp, 1941). In recent years the hurricane warning system has improved considerably. Warnings are now out so well in advance of the storm that loss of life and even of property may be prevented.

Physiography

Puerto Rico presents a variety of landscape types which have evolved from the interaction of geologic materials and processes in a tropical environment. Essentially, Puerto Rico is the eroded summit of a mountain mass rising above a submerged platform. The Brownson Deep (27,922 ft) lies about 90 miles offshore to the north. The highest point on the island is at Cerro de Punta with an elevation of 4390 ft. The classification and description of the physical landscape of Puerto Rico has been treated diversely by various authorities. Basically there are such major units as mountains, hills, and plains in well-defined form, but authors vary in their treatment of regional grouping and terminology. Roberts (1942) suggests three general physiographic regions: complex mountains, coastal plains, and playa plains. Lobeck (1922) divides Puerto Rico into five physiographic types: (1) the upper (St. John) peneplain; (2) the higher mountains; (3) the lower (Caguana) peneplain; (4) the limestone areas of the coastal plains and; (5) the flat playas or alluvial plains. Dr. Pico (1937, 1950) doubles the number of regions to ten (eleven counting the offshore islands), but his regions are essentially geographic and are based on a combination of physiographic, climatic and economic factors. Mitchell (1954) recognizes seven physiographic units. For the purpose of this report, these seven are presented and described (Fig. 4).

The mountainous uplands or monadnocks

This unit consists of the Cordillera Central and Sierra de Luquillo, the highest mountains which form the "backbone" of the island. The east-west trending row of peaks ranges from 2000 to 4400 ft in elevation. The peaks descend abruptly to the south. To the north a maze of north-south trending mountainous spurs is interrupted in places by rolling to level remnants of the St. John peneplain. The mountains in the western half of the Cordillera Central are higher than those in the eastern half. Cerro de Punta, the highest peak on the island, is located in the western portion. The Sierra de Luquillo, east of the Cordillera Central, contains a number of high peaks but none as high as Cerro de Punta. The western half of the Cordillera Central also contains fewer granitoid formations than the east, thus most valleys are narrow. The eastern portion of the Cordillera is characterized by a number of wide valleys eroded in the granitoid formations. Earlier investigators such as Lobeck considered these monadnocks or residuals to be more resistant materials which remained after erosion had reduced surrounding areas to peneplain level. Mitchell (1954, p. 12) explains the monadnocks as resulting from uparching and faulting. The axis of uplift did not coincide with the geographic axis of the island, hence an unequal tilt was given to the island and the watershed divide is offset to the south. Later faulting and downthrow of the southern blocks accentuated the asymmetry. The wider coastal plain to the north, the longer northward-flowing streams, and the steep south-facing fault scarp of the Sierra de Luquillo reflect this asymmetrical structure. Differential uplift during the Quaternary raised the island more on the west than on the east. This is evidenced by the higher mountain peaks and a more youthful stage of dissection in the western Cordillera.

The St. John peneplain

The mountainous peaks or monadnocks of the previous section rise above a general level of lower rugged topography. This lower level is particularly obvious north of the Cordillera crest and may be observed when looking from the north coast toward the mountains. There is a general level skyline with the monadnock peaks projecting above it. This dissected erosional surface is the St. John peneplain. The level of the peneplain ranges from 3000 ft in the vicinity of Adjuntas to as low as 1200 ft in the hills east of Mayagüez.

> "At the time of its formation, this peneplain was accordant with sea level, and sloped up gradually to the higher mountain divides of the interior. Over this land mass, composed of highly folded older rocks and low dipping younger Tertiaries, the streams attempted to establish themselves at grade and began lateral degradation with formation of floodplains. Renewed uplift cut short this cycle of erosion" (Mitchell, 1954, p. 16).

Stream erosion was rejuvenated and consequent dissection has been so extreme as to leave only scattered visible remnants of the peneplain surface. The streams now flow in deep gorges and canyons and the topography is rugged indeed.

The Caguana peneplain

Seaward from the St. John peneplain and occurring at a lower elevation is the Caguana peneplain, which represents an erosional surface postdating the St. John. On the north side of the island, the two peneplains are separated by a prominent scarp, 750-800 ft high. On the southern side of the island, the distinction of a peneplain surface is less definite. The Caguana peneplain extends from the vicinity of Lares eastward, broadening to encircle the Sierra de Luquillo (Fig. 4). A northward and eastward tilt to the erosion surface causes the northern edge to descend below sea level eastward from the island. The Caguana peneplain is typified by a topography of low rolling hills to relatively rugged hilliness. From Ciales to the Loiza River, for example, elevations are under 1000 ft; the hills are gentle and there are many level areas. Around the Luquillo range, elevations are higher, relief is greater, and terrain is more rugged. The hills in this area are the eroded spurs from the mountains. The Atalaya Hills, on the western end of the island, were indefinitively included by Mitchell (1954) in the St. John peneplain section. However, their physiographic expression as a series of low hills separated by steep, V-shaped valleys, somewhat removed from the rugged Cordillera Central, suggests their proper inclusion in the Caguana peneplain region. Further, as elevations seldom exceed 1000 ft and are predominantly lower, Meyerhoff (1954) and Pico (1950) suggest the eventual establishment of these hills as of the Caguana peneplain erosion cycle. Semmes (1919) and Lobeck (1919) suggested some marine erosion of this Caguana peneplain, but Mitchell (1954) states that ". . .in essence, this surface is the result of fluvial, not marine action."

Foothill zone

As previously mentioned, the peaks of the Cordillera Central descend abruptly to the south. The foothill zone is the area between this abrupt descent and the level lowlands of the southern coastal plain. Pico (1937, 1950) calls the foothills a piedmont zone. Low hills predominate in this region, but some areas are quite rugged, with relief varying from 400 to 1600 ft. The zone stretches in a 5 to 10 mile wide belt the length of the south coast, but is split in the west by the Lajas and Guanajibo Valleys. In some areas it occurs as a steep escarpment or precipitous cliff. The foothills have not been eroded to the degree found in the Caguana peneplain north of the mountain divide due to the shorter watershed and streams, and the more arid conditions. It has been postulated (Lobeck, 1922 and others) that this foothill zone is the southern equivalent of the Caguana peneplain which did not reach a similar stage of erosion. Lack of accordance in summit levels makes it difficult to verify the postulation.

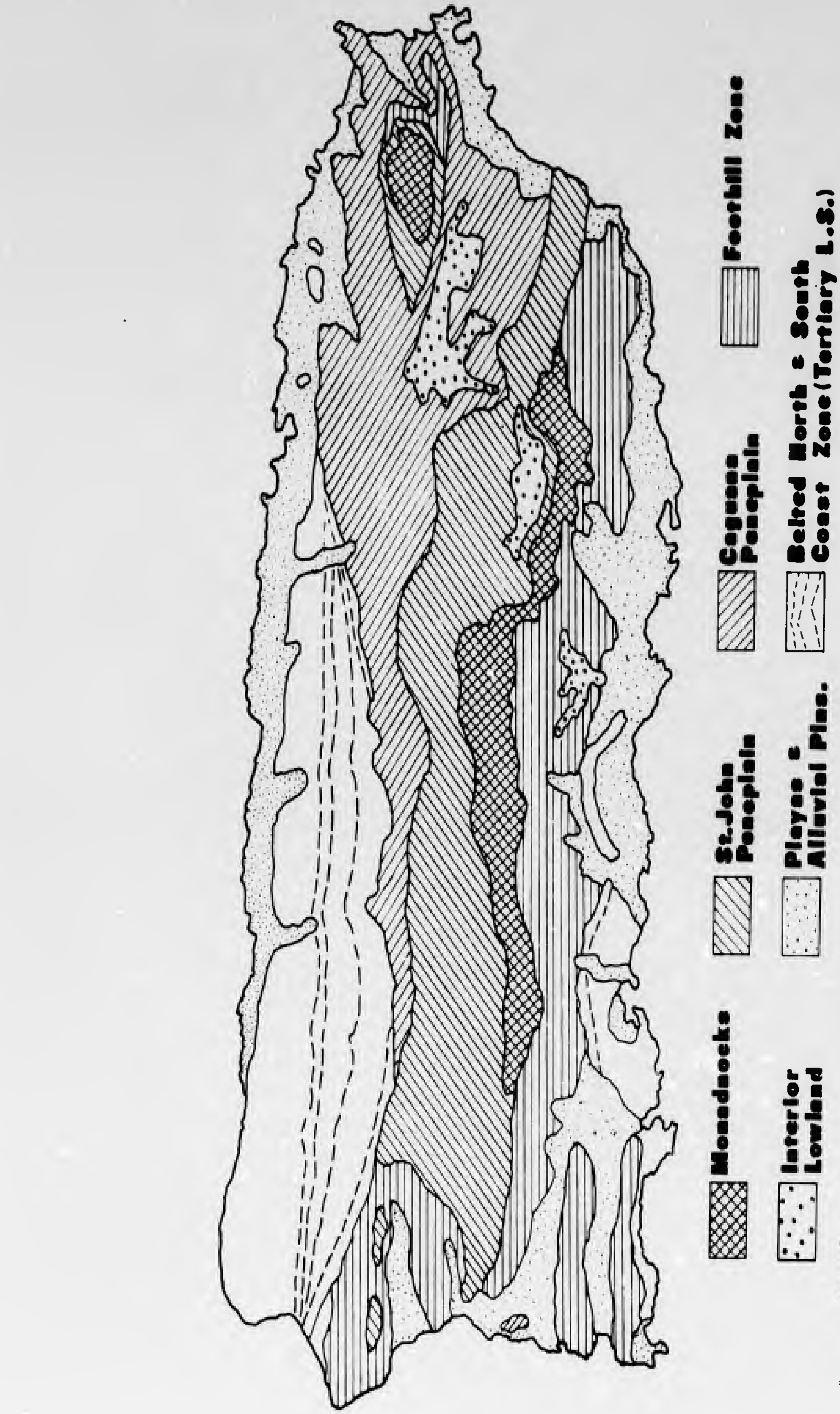

Figure 4. Physiographic regions of Puerto Rico.

Interior lowlands

Three relatively flat basins are found within the mountainous regions of Puerto Rico: The Caguas, Cayey and Coamo basins. The Caguas and Cayey basins are on the north side of the divide, the Coamo basin is south of the divide. The Caguas Valley is the largest (43 square miles) of these basins and is treated as a separate unit by Pico (1950). It is a broad, level lowland composed of alluvial flood plain and terrace materials. It has an average altitude of 350 ft, with the surrounding mountains rising 1200 ft above it. Meyerhoff (1931) concluded that the basin was initially an anticlinal valley, while Mitchell (1954) explains its formation as due to excessive deposition by rejuvenated streams. Following uplift of the Loiza and Gurabo Rivers, the streams were hindered by fault blocks from eroding equally the full length of the course, and deposited sediments upstream from the fault block. There is general agreement that the basin is the result, in part, of the lithologic structure. Remnants of diorites in the nearby hills and outcropping in the valley indicate the basin was formed in an area of easily eroded material.

The Cayey basin, an area of about 30 square miles, has an average elevation of 1200 ft. It has been formed in the upper reaches of the Rio de La Plata and is considered to be an interior expression of the Caguana peneplain. Rejuvenation of stream erosion, after uplift, in an area of easily eroded material has carved out this basin. No fault block is present as in the Caguas Valley. The basin is smaller in extent, higher in elevation, and generally more hilly than the Caguas basin.

The Coamo basin was formed by a combination of faulting and rejuvenated stream erosion following uplift. The basin has a general elevation of about 500 ft and is formed of relatively soft tuffs. The resistant adjacent limestones slowed down the streams, causing deposition. Faulting with downthrow to the north is believed to be partially responsible for formation of the lowland (Mitchell, 1954, p. 20).

Belted north-south coast

The Tertiary limestone area of the northern coast of Puerto Rico presents one of the most distinctive physiographic units on the island. Generally described, the karst topography is a combination of a variety of distinct hill or tower forms and intervening valleys or sinks. Local relief seldom exceeds 400 ft, yet the shape and arrangement of these forms give a rugged aspect to much of the terrain. Mogotes or "haystacks", which are small conical hills, alternate with valleys and sinks. The hills are sometimes, but not always, arranged in rows, and usually have sharp, steep western faces due to differential solution from the rains borne by the trade winds (Thorp, 1943). Pepinos are elongated, knobby, cucumber-shaped hills oriented in a northeast-southwest direction. As erosion proceeds, they may break up into mogotes. Sinkholes or solution valleys between the hills vary in size, depth, and extent. Some coalesce to form uvalas and some have filled with alluvium to form poljes (Monroe, 1960). Surface drainage disappears into the ground or the sinks and makes its way in underground solution drainage-ways. Streams which have maintained a course across the limestone belts have cut deep, V-shaped gorges. The area abounds with caves, caverns and solution galleries. Along the north coast five distinct limestone formations form a series of east-west trending belted landform zones paralleling the present coastline. The belted nature of the landscape is closely related to uplift and erosion of these various layers of Tertiary limestones.

Some Tertiary limestones outcrop on the south side of the island (Fig. 5). They are less extensive in area and form a narrower belt than the Tertiaries in the north. These limestones have not developed a typical karst topography and appear more as rounded conical hills. Lower rainfall, the impurity of the limestone, and a steeper dip to the formations, preventing horizontal movement of water along bedding planes, account for this lack. Geologists have not as yet fully agreed as to the exact correlation of the north and south coast Tertiary limestones. Mitchell (1954, p. 36) divides the southwest limestone into upper and lower members with the division between the third and fourth formations of the north coast.

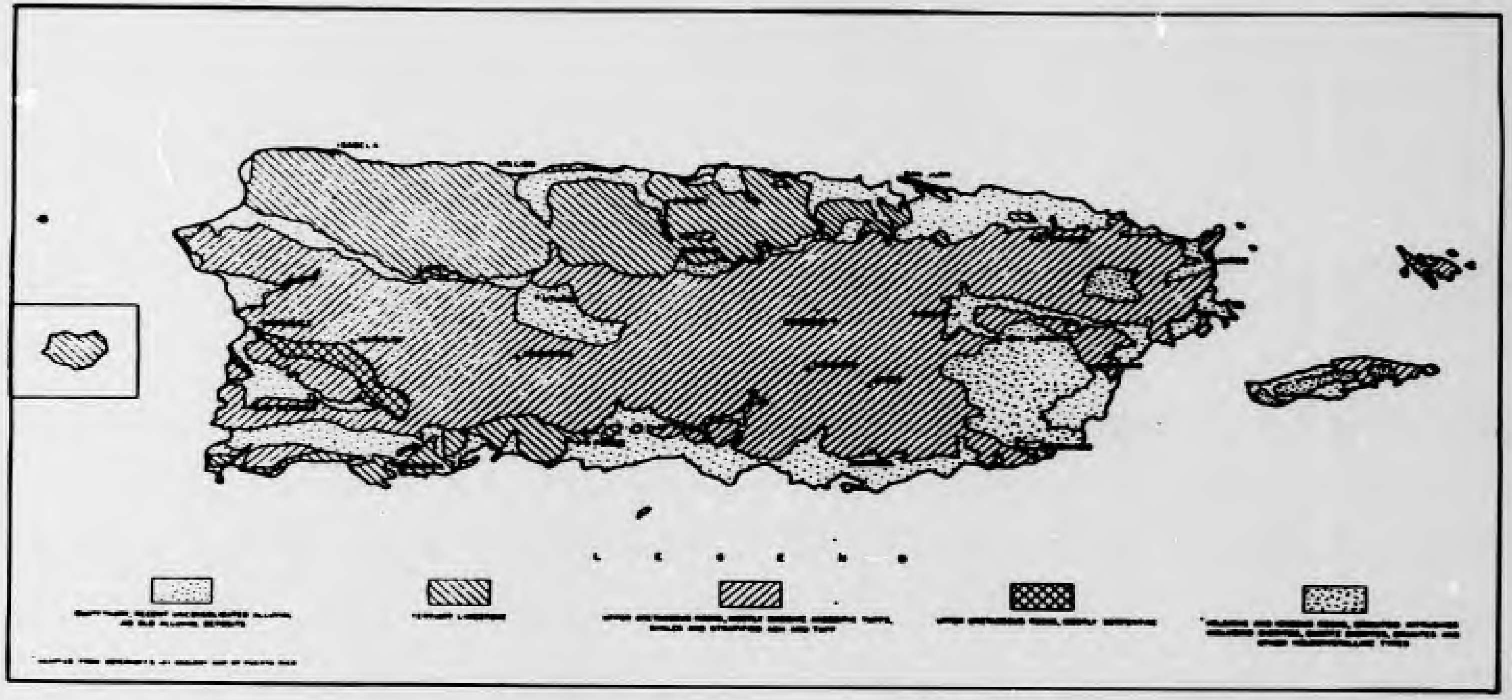

Figure 5. Simplified geologic map of Puerto Rico. The unconsolidated recent alluvial and old alluvial deposits largely comprise the playa plains. The areas occupied by Tertiary limestone comprise the northern and part of the southern coastal plains. The remainder of the island consists of complex mountain ranges and dissected plateaus of various rock types indicated in the legend. From U. S. Department of Agriculture, "Soil Survey of Puerto Rico" by R. C. Roberts.

Playas and alluvial plains

Playas and alluvial plains fringe most of the north and south coasts of Puerto Rico. Mitchell includes the major east and west coastal valleys in this province. "Playa," as used in Puerto Rico, refers to the flat alluvial plains occurring at the mouths of larger streams or rivers. They seldom rise more than a few feet above sea level and have been formed by a combination of deltaic and flood-plain deposition. On the north coast the alluvial plain broadens from west to east, but nowhere is it wider than 5 or 6 miles except for the inland extension of alluvial river valleys. Sand dunes have developed along the shore near some river mouths, at times blocking the stream valley and causing marshy or swampy conditions. Lagoons have also formed along the north coast. These Mitchell (1954) explains as due to ponding when the most recent deposit (the San Juan formation) was formed. Mangrove swamps have developed in the marshy areas caused by the sand dunes and lagoons.

Along the south coast the alluvial plain has the aspect of a series of coalescing alluvial fans, especially on the eastern end. The inland margin of the southern alluvial plains is higher than that on the north coast. The plains slope gradually to sea level and are fringed in many places by mangrove swamps. The climate and the shorter distance from mountain crest to seashore, thus a rapid change in stream gradient, have contributed to the alluvial fan development on the south coast. In the more arid western corner of the south coast, the alluvial deposits are more deltaic in character. Few streams reach the coast, and the geological structure has placed the mountain crest further inland.

The Lajas Valley in southwest Puerto Rico is the largest of the alluvial valleys. This valley is not drained by one large stream but by several small intermittent streams. Some drainage is internal— to the shallow lakes in the valley, which are also intermittent and the only fresh-water lakes on the island. The Guanajibo, Anasco and Mayagüez (Lower Culebrinas) Valleys on the west and the Fajardo and Yabucoa Valleys on the east represent the other alluvial plain sections of Puerto Rico. All are broad, flat alluvial valleys which broaden seaward and are drained by subsequent streams meandering across their floors. Formation of the valleys was aided by submergence of the coastline and drowning of the river mouths, filling with alluvial material, then uplift bringing them to their present level. It is believed that the mouths of some of the rivers on the west and south may have been re-flooded by a rise in sea level, thus forming harbors such as those at Guánica and Paguerra (Kaye, 1959b).

Geology

There is an orderly arrangement of the gross landscape features of Puerto Rico and a close association of those features with the lithology. In areas where the major rock types—igneous, sedimentary or metamorphic—occur in great areal extent and thickness, there is a remarkable coincidence between physiography, lithology, and stratigraphic sequence, even though the island has experienced vulcanism, orogenic movement, emergence, submergence and re-emergence and has been subjected to the stress of tropical weathering (Fig. 5). Locally, rock types and the attendant landforms may be complex, particularly where folding and faulting have been severe and in those areas where intrusive activity has resulted in intermixing of igneous and sedimentary types.

History and stratigraphy

Geologically, Puerto Rico can be simply described as an older central complex mountain mass flanked by younger sedimentaries and mantled in places with a relatively thin covering of recent alluvium. Structurally, the island is a geanticline, or broad arch whose axis is essentially the same as the geographical axis. The younger rocks crop out on both north and south coasts where they dip gently away from the outcrop of older rocks. The older rocks extend as a continuous belt from the west to the east coast and form the more rugged interior complex (Kaye, 1959a). The exact dating of the earliest geological formation in Puerto Rico has not been unanimously established. Schuchert (1935) claimed Precambrian evidences for the Caribbean region, but, generally, geologists agree that the Caribbean basin is a creation of Mesozoic times. The oldest rocks so far noted in Puerto Rico are the agglomerates of the Cabo Rojo area (Mitchell, 1954, p. 132). These are composed of both intrusive and extrusive rocks cemented by andesite porphyritic material, indicating earlier volcanic activity and plutonism. Lower Cretaceous limestones rest conformably on the agglomerates; therefore, Late Jurassic is presumed to be the formative period for the earlier rocks (Table I, Appendix A).

Early and Late Cretaceous were periods of vulcanism and magmatic activities. At the beginning of the Cretaceous the island area was probably a lowland. The igneous activity of the Cretaceous built up a complex core of pyroclastics and plutonics. Lower Cretaceous rocks consist chiefly of tuffs and shales. The shales grade into tuffs and limestones. Recrystallization of the limestones has produced extremely resistant rocks which form marked topographic features.

Upper Cretaceous rocks make up the bulk of the pre-Tertiaries on the island. They are chiefly pyroclastics with true sedimentaries occurring as minor depositions. The shales are next in prevalence to the tuffs. Very few are pure, but they are important as soil-forming material, and the calcareous shales, like the recrystallized limestones, are ridge-formers. The Upper Cretaceous limestones, though minor in occurrence, are important indicators of stratigraphic sequence. They are so distinct that there is little likelihood of their being confused with the Tertiary limestones.

The limestones and shales at various locations and levels attest to periods of quiet invasions of the sea during the general period of igneous activity. Differences in composition, texture, and position of the pyroclastics indicate two distinct periods of vulcanism, the Early and Late Cretaceous, spearated by a long period of relative volcanic inactivity. Evidence also indicates that orogenic activity disturbed and upfolded the Lower Cretaceous rocks. Igneous activity of the Early Cretaceous produced dykes, sills, and shallow intrusive sheets as well as large lava flows. Vulcanism of the Late Cretaceous produced the stocks, bosses, and batholiths of the island.

During the late Mesozoic and early Tertiary, world-wide orogenic activity, coinciding with the Laramide orogeny, took place. Meyerhoff (1954) refers to this period in the Caribbean as the Antillean revolution while Mitchell (1954) prefers to call it the Caribbean orogeny. By whatever name, this is the period when powerful disturbances deformed large areas and produced a truly mountainous region of Puerto Rico. Deformation and compression produced folding rather than faulting on the island, probably because of predominance of weak over strong rock.

The orogenic disturbance was initiated while the igneous activity of the Late Cretaceous was still in process. The combined activity produced the mountains. The steep slopes and chaotic masses of pyroclastics were easily attacked by erosive forces, and by middle Eocene the mountains were reduced to hills.

Toward the end of the middle Eocene another period of volcanic activity began. This continued into the Oligocene and was accompanied by mild deformation. By the end of the early Oligocene, igneous activity ceased, and further disturbances were in the form of downwarping, subsidence, or uplift.

The identification of specific Eocene deposits is still in some doubt, though Mitchell (1954) has established, to his own satisfaction, the presence of Eocene strata. The oldest of the young Tertiaries has been firmly established as of middle Oligocene origin. This series was deposited on a markedly irregular surface with relief as much as 1000 to 2000 ft. This fact, combined with the supposition that the middle Eocene landscape was one of mature erosion, and that toward the end of the age a period of vulcanism set in, would indicate that late Eocene or early Oligocene rocks should be encountered.

During the middle Oligocene, a major downwarp occurred in the middle section of the island from Quebradillas to Ponce. This downwarping persisted through the early Miocene. Tertiary limestones were deposited following the onset of the downwarp. The thickest beds of Tertiaries are found in this sector on both the north and the south coasts; limestones occur primarily within the downwarp area. Two questions regarding Tertiary beds remain unanswered: (1) Did the Tertiaries of the north and south coasts coalesce and form a more or less continuous cover over parts of the island? (2) Were even younger Tertiaries deposited and subsequently completely eroded away? Mitchell (1954) believes there is evidence in favor of a strong positive answer to the first question, but there is only the suggestion of late Miocene strata on the west coast to provide a possible positive reply to the second.

During the middle Miocene, uplift and tilt set in motion the erosion cycle which produced the St. John peneplain. At the beginning of the Pliocene, renewed uplift interrupted the St. John cycle and initiated the Caguana cycle of erosion. About the end of the Pliocene, this cycle was also terminated by fresh uplift accompanied by minor faulting and tilting to the northeast. It was probably at this time that Puerto Rico was separated from Hispaniola. Disturbances continued into the Quaternary, resulting in a slight uplift and tilting of the island to north and east. Deposition of alluvial fans, fluvial terraces, and flood terraces indicate the erosive activity during the Quaternary. Fluctuations in glacial and interglacial sea levels are evidenced in wave-cut platforms, off-shore bars and marine degradational terraces. At the close of the Wisconsin glaciation the Pleistocene waters withdrew for the last time. Whether the San Juan formation was formed previously or subsequently is another question still in doubt. Some geologists consider it Pliocene in origin. The San Juan formation is an aeolianite—a windblown sand cemented with calcium carbonate derived from the sea. Tilting of the island has occurred since its formation, as it now occurs 40 ft above sea level at Arecibo, at sea level at San Juan, and as much as 30 ft below sea level in the Cordillera Reefs to the east.

Recent geological history in Puerto Rico is characterized by erosion and alluvial deposition. Recent alluvium of various depths is found on the coastal plains and in the interior valleys. Continued disturbances in the form of earthquakes (few and not severe) and tremors indicate that the island is still a geologically unstable area.

Description of an important lithologic sequence

There are two major geological rock groups in Puerto Rico, the older series and the younger series. The older series predates the Tertiary and includes volcanics, meta-morphics, conglomerates, tuffs, some shales, and breccias. The younger series includes the deposits associated with Tertiary, Pleistocene, and Recent times and consists primarily of limestones, some shales and marls, cemented sand dunes and beach, and recent alluvial materials. The areal extent and dominance of the Tertiary limestone sequence on the north warrants detailed discussion. Erosion of these five limestone formations has resulted in a dominant belted landscape. In places the area is near classic in its karst topography. The Tertiaries, deposited unconformably on older Cretaceous material, dip at 1° to 6° angles to the north and tilt slightly to the east. The oldest, southernmost unit flanks the north slope of the Cordillera. Each successive unit coastward represents the next younger formation. The typical karst topographic forms are most pronounced in the western half of the island. The formations successively disappear to the east, the youngest formation having the largest eastern extent (Fig. 5).

San Sebastian formation. The oldest formation is the San Sebastian which rests on the older Cretaceous rocks. The formation consists of layers of sands, laminated sands and clays, with shales predominating near the top. It contains lenses of gravel and cobbles, and near the top is a "persistent layer of silty, finely glauconitic marl" (Monroe, 1960). Mitchell describes the physiographic form of the San Sebastian subsection as the inner low-land. The inner lowland is represented by the Culebrinas Valley on the west. There is no lowland between the Camuy and Morovis Rivers, but it may be observed between Morovis and Bayamón and is represented by low hilly country from Rio Piedras to Luquillo. According to Meyerhoff (1938) the San Sebastian formation is essentially insoluble, thus the absence of pepinos, sinkholes, and other phenomena typical of karst topography. The development of a lowland along the contact of the Tertiary/Cretaceous formations is ex-plained by Mitchell (1954) as due to the pronounced differences in resistance of the rocks.

Lares formation. The Lares formation, deposited over the San Sebastian, has a basal unit of coarse glauconite quartz sand and calcareous sandstone up to about 90 ft thick. This is overlain by massive to thin-bedded limestones 30 to 500 ft thick. The Lares lime-stone has eroded to very steep-sided towers, 200 to 500 ft high, separated by long, narrow valleys of connected sinkholes. Mitchell (1954) calls this physiographic subsection the Lares cuesta. He is evidently referring primarily to the contact zone between the Lares and San Sebastian formations where the karst topographic forms appear in rugged contrast to the inner lowland. The cuesta is a prominent feature from Lares to west of San Sebastian. Between Lares and Ciales, where there is no inner lowland, the Lares formation rests against the Cretaceous rocks, and the karst forms are less well developed, the hills are lower and the sinkholes are shallower.

Cibao formation. Resting on the Lares, the Cibao formation consists of 300 to 600 ft of marl, limestone, chalk, sand, and sandstone. This lenticular unit has eroded to form gently rolling hills in contrast to the steep-sided pepinos and mogotes to the north and south. Surface drainage has become well established, and sinkholes have developed only where limestone layers are over 60 ft thick. Mitchell refers to this subsection as the Cibao lowland. It is best developed between the Manati and Morovis Rivers and in the area north of San Sebastian east to Bayaney.

Aguada formation. The Aguada formation consists of limestone interbedded with chalk and marl. The topography here is typical mature karst topography with deep sinkholes separated by narrow ridges of limestone. The ridges and low hills are characterized by more rounded slopes and flatter tops than those of the Lares formation. The landscape resembles an "inverted" Lares topography with more and deeper sinks and fewer and lower hills. This subsection, called the Aguada cuesta by Mitchell, extends from the west coast east to Bayamón.

Aymamon formation. The Aymamon formation, the youngest of the Tertiaries, consists of over 600 ft of thinly bedded to massive limestone. This has eroded into steep-sided towers and ridges, parallel to the strike. The towers are relatively low, usually less than 160 ft. Sinks have developed only on the southern edge of the section where the Aguada is just below the surface. The topography also varies from east to west. In the west, where uplift has been greater and the rainfall is less, the pepino hills are higher and more rugged. Evidence of solution is more prominent. Rivers have eroded vertically more than horizontally and flow in gorges or canyons with steep walls. In the eastern portion of the section horizontal stream erosion and alluvial deposition have been more extensive. Many of the valleys or depressions between the hills have been filled or partly filled with alluvium, and the pepinos are more subdued. In some areas flat level land predominates, with scattered pepino remnants dotting the landscape. The border between the Aymamon lowland and the playas and alluvial plains is not everywhere distinct.

Special geologic features

Puerto Rico exhibits several physical features which are outstanding or unique and deserve special attention. Among these are thermal springs, Phosphorescent Bay, the frequently mentioned karst features, beach rock and pitting, cemented dunes, oölitic islands, and tidal terraces.

Thermal springs. There are many thermal springs in Puerto Rico but only three have received attention in the literature. The Banos de Coamo spring, located 3 miles southwest of Coamo, issues from a bed of conglomerate and tuff. Almost no deposits are formed by the spring. Origin of the thermal waters was a point of discussion for years, but according to Arnow and Crooks "...the spring water is derived directly from rainwater which percolates deep into the earth and then rises rapidly along a fault plane; changes in the rate of flow reflect pressure changes in the hydrostatic head" (USGS, 1961, p. A-47). The Virella Spring northwest of Arroyo issues from coastal Quaternary deposits, and the Quintana Spring, north of Ponce, is in an area of pyroclastics. Hodge (1920) made chemical analyses of these springs as well as the Banos de Coamo. The Virella Spring seems related to fissures in the older rock series underlying the Quaternary deposits and is probably similar to the Coamo Spring (Beishlag, 1953). References were found to thermal springs at Juana Diaz, Rincón, Sabana Grande, and Caguas (Ober, 1899) but specific locations were omitted, and no mention or description of these springs has been noted in the more recent literature. The Juana Diaz citation may have referred to the Quintana Spring. The Banos de Coamo, Virella and Quintana Springs were all developed as health resorts at one time. Now, even the world-famous Banos de Coamo guest facilities have ceased operation.

Phosphorescent Bay. In the Paguerra area on the southwest coast of the island is a bay whose waters emit a phosphorescent glow upon disturbance. This is caused by marine microorganisms.

Karst features. Puerto Rico is well endowed with advanced expressions of limestone weathering in the many karst features displayed. Sinkholes vary in size from a few feet to large basins several hundred feet across. Great "break-away" cliffs forming the steep sides of solution valleys occur at many locations along the streams crossing the belted limestone area. Pepinos and mogotes of a wide variety of sizes, shapes, and heights occur in abundance. Caves also occur throughout the limestone area. In discussing the development of karst topography in Puerto Rico, Meyerhoff (1938) has concluded that pepino and sinkhole development is related to the relative solubility of the various limestone formations. Thus, the highly soluble Lares and Aguada formations (Meyerhoff called this the Los Puertos formation) and the medium to high solubility of the Aymamon formation (Meyerhoff called this the Quebradillas formation) have produced the rugged areas of karst formations. He also observed a relationship between ground water level and the texture of the karst features. That is, the number of surface forms (haystacks, pepinos, etc.) increases in ratio as the vertical distance (of the ground water level) decreases. Monroe's studies indicate that "closely spaced, deep sinkholes form in rocks consisting of alternating hard and soft beds and that tower-karst develops on homogeneous medium to dense limestone" (1960).

Interesting shoreline features

Kaye (1959b) has described and explained a number of shoreline features which have been relatively neglected or superficially treated previously. These include the large lunate embayments on the north coast, beachrock, and cemented dunes with attendant pitting. Lunate shorelines, characteristic of the north shore, are caused by the arcuate action of the waves due to the effect of offshore obstacles. Progressive change of a straight shoreline to a lunate and back to a straight shoreline has been noted in areas where two or more lines of cemented dunes occur. Beachrock is a hard pavement, cambered seaward, which is composed of beach sand or gravel cemented by $CaCO_3$ or iron oxides. It is limited to the intertidal range and occurs mostly along the limestone coasts. Cemented dunes (eolianite) are found exclusively on the north coast and are well represented at San Juan. Curious geomorphic features result from erosion or wastage of these cemented dunes. The shoreline dunes are subject to erosion at the base by the surf, frontally by storm waves, and on the surface by chemical and organic processes. Pitting is one of the most notable effects of this erosive action. The pits vary in size, form and number depending on position in relation to the sea. The depth and diameter of the pits tend to vary inversely with the distance above the water level. Round-bottomed pits occur outside the spray zone and are thought to be mostly due to rainwater solution. These are similar to typical solution pits of limestone and in many instances closely resemble coral formations. Within the spray zone the larger pits are generally flat-floored with undercut sides. Cylindrical pits of the true pothole type occur on the flat terraces within or just above the tidal area. (These are the holes Hubbard (1920) called molds of palm tree trunks).

Tidal terraces. A conspicuous terrace with surfaces occurring between mean tide and high tide is a characteristic feature of eolianite shores exposed to wave action. Such terraces occur along the north coast of Puerto Rico and fringe the small islands off the north coast. Low, sinuous shelves rise to successively higher elevations, giving the terraces an appearance resembling travertine terraces formed around hot springs. Such terraces seldom form on the lagoonal side of eolianite ridges or along protected shores. Protected areas develop, instead, a nip or sea level notch, sometimes of surprising depth. These are probably caused by solution rather than mechanical action, and do occur in association with terraces on the unprotected side of cemented dunes or eolianite ridges.

Oölite islands. La Cordillera is a chain of small islands off the northeast coast of Puerto Rico. The islands are composed entirely of oölitic eolianite and provide the only example of oölite known in the Greater Antilles. The islands are aligned in a north-northwest chain about 18 miles long. The cemented dunes are aligned west-northwest and are cut by transverse N68°E grooves. The oölite is white when freshly exposed and turns gray with weathering. Friable when freshly exposed, it hardens on contact with air and has the texture of fine sandstone. Rock from Cayo Icacos is used in sugar refining on the main island. The quarries provide good exposures showing the dune structure of the material.

Economic geology and mineral resources

Puerto Rico is not a significant producer of mineral products and is self-sufficient in only a few non-metallic resources. In the past gold, iron, and manganese were the only minerals seriously considered by mining interests in Puerto Rico. Other metallics and non-metallics were known to occur, but the limited quantity, low quality, or relative inaccessibility deterred exploitation. More recent geological-geophysical investigations tend to verify the low mineral potential for the island. These investigations, however, have been far from exhaustive to date. Exploration for petroleum continues along the north and south coasts, and prospecting and exploration for copper, iron, gold, and molybdenum continue in the interior mountains. No metals or mineral fuels have been produced in recent years. The commercially important non-metallic products are cement, clays, lime, salt, sand, and gravel and stone (Knox et al., 1961).

Metallics.

Gold: The principal known gold deposits in Puerto Rico occur as alluvial placers along the major streams draining the Sierra de Luquillo and north-flowing streams draining the Cordillera Central. The bulk of the readily accessible gold was presumably extracted by the Spaniards in the first 45 years of their domination over Puerto Rico (Mitchell, 1954, p. 99). Modern methods of research and operation could well produce worthwhile amounts of gold through reworking and the discovery of more extensive deposits of auriferous alluvium. "Lode" deposits of gold have been noted, but, to date, none have been of an extent or quality to justify mining.

Iron: Magnetite and limonite deposits are known on the island. Magnetite has been extracted, but the limonite deposits have not yet been exploited. The largest magnetite deposit occurs in the Juncos area where the Keystone Mine operated open-pit mining activities in the 1950's. Six additional deposits occur in a belt from Juncos to Las Piedras and may be found to form a continuous deposit. Other magnetite deposits occur in the vicinity of Humacao, Arroyo, Ponce, and Adjuntas. Limonite occurs as a weathered residual soil derived from serpentine in the Las Mesas area east-southeast of Mayagüez. This deposit is unexploited as a mineral as yet, but many investigators consider it to be of more potential value as a mineral than as a soil (e.g., Mitchell, 1954; Pico, 1950; Roberts, 1942).

Manganese: Manganese was mined in the Juana Diaz area from 1915 to 1939. Mining operations ceased when the surface and shallow subsurface ore was exhausted. High-grade ore is believed to exist at greater depths, and surface deposits are known to extend over a much larger area than developed. Manganese deposits near Adjuntas, Lares, and Aguada are of extent and quality to merit further investigation. Shipping costs and refining problems subdued earlier enthusiasm over these deposits. A limited deposit in Corozal is considered uneconomical for exploitation and a low-grade deposit near Loiza is of academic interest only as being the only metalliferous deposit in the younger Tertiaries of the islands.

Copper: Copper occurs in various forms, qualities, and amounts in several areas in Puerto Rico. Now defunct copper mines operated at Barrio Pasto, south of Ciales-Morovis and near San Germán. The copper content of the latter deposits is low, but could possibly be extracted profitably in a gold-silver-copper combination. Numerous veins of rich ore are known in the manganese area south of Aguada but the quantity is thought to be limited. Other limited deposits are known in Corozal, Guánica, Humacao, and Lajas. All traces of a reported copper mining venture of the 1860's in the Luquillo National Forest area (north of Naguabo near the headwaters of the Rio Blanco) have disappeared and no substantial copper deposit is known in the area.

Lead and zinc: Lead and zinc are found in combination northwest of Guayama and near Ciales. Galena showing over 58% lead is known in the Naranjito area. The Guayama deposit is the only one which has been developed. It is currently inactive and its extent or potential is uncertain. The Ciales deposit, while rich, is small. Very little is known about the Naranjito deposit.

Other metals: Cassiterite, the chief ore of tin, has been noted in small veinlets near the Barrio Pasto copper deposits. Cinnabar, a source of mercury, is found associated with copper and manganese in the andesite flows south of Aguada. Native platinum has been found in the auriferous gravels of the rivers draining the Corozal district. Silver occurs in combination with gold, copper and galena in several areas previously mentioned, and probably other areas not "discovered" as yet.

Non-metallics.

Limestone: Various grades and types of limestone are found everywhere in Puerto Rico. The cement industry probably utilizes the greatest amount. Lime for fertilizers, sugar refining, chemical industries and sanitation is derived from limestone. Numerous lime consuming industries have imported commercial lime in recent years, indicating the profitable potential for expansion of the lime industry in Puerto Rico. Crushed limestone is used for concrete aggregate and limestone is used in mortar and plaster products and terazzo tile chips. Exploitation of limestone for building stone has been limited, although small amounts have been used for dimension stone for buildings and dock and harbor improvements.

Building and ornamental stone: There has been little demand for building and ornamental stone in Puerto Rico until recently. Extensive marble quarrying has been done only on the Rio Descalabrado between Coamo and Juana Diaz. Good marble and crystalline limestones occur near Trujillo Alto, Guaynabo, Caguas, and Pena Parada. White marble is located along the Icacos and Camuy Rivers, and there are quantities of excellent granite, basalt, diorite, and monzonite throughout the island. Two occurrences of high-grade alabaster are known. Veins of rose-colored alabaster occur north of Yauco and veins of verd antique are found in the serpentine area of western Puerto Rico.

Sands and gravel: Extensive deposits of glass sands occur along the north coast associated with the Tertiary and Quaternary strata. These silica sands are used for pottery, in foundries and cement plants, as an abrasive in commercial sand-blasting and marble polishing operations, and for glass. Sand and gravel is used in large quantities for concrete aggregate. Excess sands from the deposits worked are used primarily for building plaster, fills, asphalt paving and road base, grading access areas, and improving beaches and parks.

Clays: Most of the Puerto Rican clay production is used in the cement industry. Some, however, is used by the pottery and tile industries and for heavy clay products. Clays suitable for pottery tile and heavy clay products are found in the vicinity of Carolina, Bayamón, and Manati. Bentonite of the non-swelling type occurs south and east of Aguada, near San Germán and Corozal. Kaolin deposits of good quality are known around Yauco, Arroyo, Maricao, and Sabana Grande. Bauxitic clays have recently been located in sinkholes in the Lares limestone south of Florida (Hildebrand, 1960). This provides positive evidence for Mitchell's contention (1954, p. 114-117) that a search for bauxite should be worthwhile.

Salt: There are no known deposits of rock salt in Puerto Rico, but salt is produced by solar evaporation of sea water along the south coast of the island. Most of the salt is used for table or cattle salt. One operation, however, now uses the entire production for raw material in a caustic soda chlorine plant. Production of salt could be increased readily and profitably if more modern methods and techniques were employed.

Phosphate: Phosphate fertilizers have been obtained from caves in Puerto Rico and the west coast islands of Mona and Desecheo. The best deposits of this bat guano have been worked and commercial production has ceased. Smaller deposits are still available and probably undiscovered deposits will be located as more caves are explored.

Other non-metallics: A number of potential non-metallic mineral sources are worthy of mention. Potash and alumina may be available from the silica alunite outcrops in the vicinity of Aguas Buenas. Barite deposits occur near Lajas and Cabo Rojo. Gypsum of varying purity has been noted in limestones near Manati, Ponce and Yauco. The serpentines northwest of Yauco contain veins of magnetite useful in metallurgical and chemical industries. Lignite has been noted in the San Sebastian formation near Moca, San Sebastian, and Lares. This may be developed as a fuel by washing and compacting as done in other non-coal-producing areas of the world. Monroe (1962a) has suggested that peat moss from the Manati area may be useful in gardening and truck farming. Chalk of commercial quality has been found in some localities (Monroe, 1960). Petroleum has not been produced on the island as yet. Exploration is underway in the sedimentaries where structure and age of the rocks indicate oil potentialities. At least three exploration wells have been drilled on the south coast and one on the north coast (Knox *et al.*, 1961, p. 2), but no oil discoveries have been made.

Soils

The soils of Puerto Rico are characterized by number, variety, and complexity (Fig. 6 and 7). Roberts (1942, p. 171) states: "The factors responsible for soil development—climate, native vegetation, relief, age and parent material—are extremely varied within short distances in Puerto Rico, and therefore a large number of soil types may be expected." He recognizes 115 soil series (including 352 soil types and phases) which he expresses in 46 parent material—depth—color—texture groups. The reader is referred to his text, maps, and association charts for detailed description. Table II (Appendix A) presents a summary of the soils as named and as grouped in the 46 groups. Other authorities have grouped the soils differently. Bonnet (1944) uses 11 representative groups containing 24 series, while Pico (1954) prefers two major groups based on climate with further differentiation based upon parent material and landform. Pico (1954) also states that as a rule the soils of all humid and subhumid regions in Puerto Rico can be classed as pedalfers. Red and yellow lateritic, red and yellow and gray-brown podzolic, rendzinas, and laterites are the most abundant. In the dry south the pedocals predominate.

Soils and Man, the Yearbook of Agriculture for 1938 (U. S. Department of Agriculture, 1938), summarized the Puerto Rican soils by grouping major types into ten generalized categories. This grouping is used here in the interest of brevity.

Los Guineos - Catalina - Alonso soils

These soils are red and yellow podzols (lateritic) derived from tuffaceous rocks, shales, conglomerates, and andesites, all of which weather rapidly in the moist, hot climate. The soils are deep and have been leached of most of the bases. They occur primarily in the humid uplands of the interior associated with steep slopes and sharply rounded ridges. With rainfall variation of 76 to 160 in., the vegetation is mesophytic, rainforest, or mossy. All of the soils in the group are well-drained, fairly permeable, acid, and slightly granular clays or silty clays. Profiles vary little from the surface to bedrock, which may occur at a depth of 3 to 40 ft.

Sabana Seca - Lares soils

These red and yellow podzols (lateritic) are confined to the long and narrow terraces or terrace-like areas associated with coastal plain landforms. The Sabana soils are alluvial in nature. The Lares were formed from the tuffaceous material washed from adjacent hills. Internal drainage of the soils is generally poor; native vegetation has given way to crops. In general the soils contain a compact, stiff, mottled brown/gray/red subsoil from 10 in. to 6 ft in depth.

Coto-Bayamon soils

These yellowish-brown and reddish-brown lateritic soils include the extensive limestone belt of the northwestern flanks of the Cordillera. The entire area is characterized by streamless valleys and haystack hills. Rainfall varies from 50 to 78 in. Flat lands are under cultivation while steep-sided and sharply rounded haystack hills are mantled with mesophytic forests. Soils are residual and in places weathering of limestone has resulted in soils 30 to 40 ft deep. In this region soils of the Coto series are generally clay and range in thickness from 2 to 10 ft. The Bayamón soils are also clay, red and deeper, as they occur primarily in the valley bottoms. The Tanamá soils, also derived from limestone, are very shallow as they occur on the steep slopes.

Rosario-Nipe soils

The Rosario and Nipe soils are the laterites derived from serpentine. They exist in long, narrow belts in the uplands of southwestern Puerto Rico where the rainfall averages from 80 to 100 in. per year. The Nipe soils often extend to 20 ft; they are red-purple in color and are clays high in iron and aluminum hydroxide. The Rosario soils occupy the steep slopes and are very shallow, often only inches thick.

Poncena-Coamo soils

These are the soils of the southern coast and the long, narrow disconnected fertile plains lying between the arid uplands of southern Puerto Rico. The parent materials are shaley

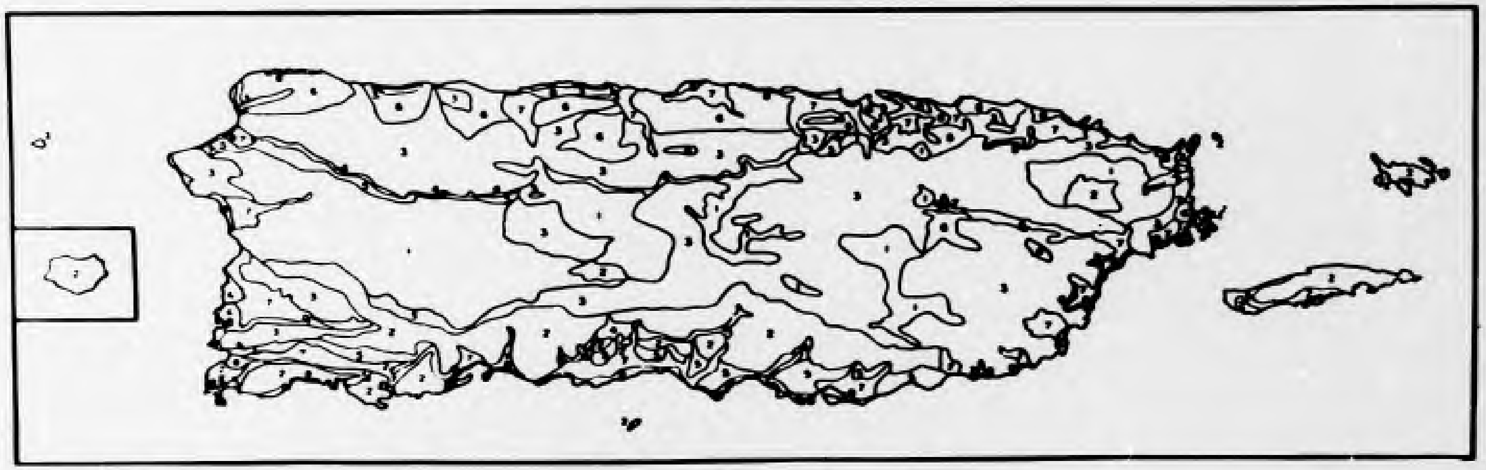

Figure 6. Diagrammatic map of Puerto Rico, showing the approximate soil groupings and physiographic divisions: 1, Deep soils of the uplands; 2, shallow soils of the uplands; 3, medium-deep and some shallow soils of the uplands; 4, soils of the inner plains; 5, soils of the terraces and alluvial fans; 6, soils of the smooth coastal plains and, in places, some shallow soils of the uplands; 7, soils of the river flood plains; and 8, soils of the coastal lowlands. From U. S. Department of Agriculture, "Soil Survey of Puerto Rico" by R. C. Roberts.

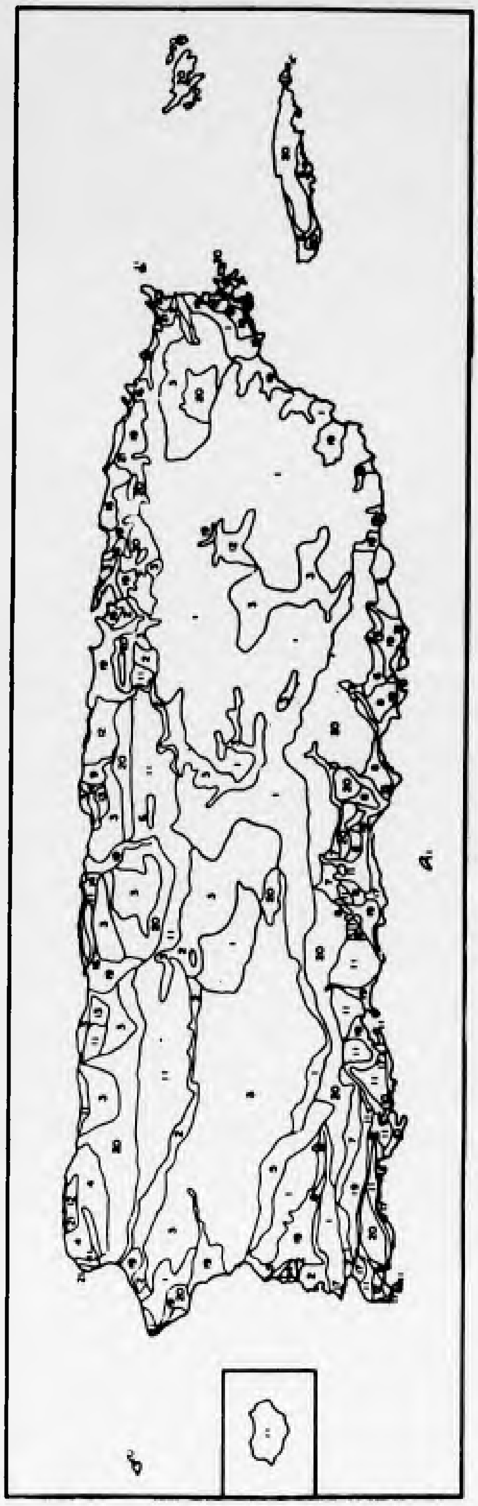

Figure 7. General distribution of the important soils in Puerto Rico: 1, Gray-brown podzolic; 2, red and yellow podzolic; 3, reddish-brown lateritic; 4, yellowish-brown lateritic; 5, laterite; 6, reddish prairie; 7, chernozem; 8, reddish-chestnut; 9, reddish brown; 10, red desert; 11, rendzina; 12, ground-water laterite and planosol; 13, ground-water podzol; 14, wiesenboden; 15, half-bog; 16, bog; 17, solonchak; 19, alluvial; 20, skeletal and lithosol; and 21, dry sands. From U. S. Department of Agriculture, "Soil Survey of Puerto Rico" by R. C. Roberts.

limestone, tuffaceous rock, and similar material washed from the adjacent hills. They are in the reddish Chestnut class. Surface soils are often black, granular, plastic clays which are high in organic content. Subsoils are heavy, yellowish-brown silty clay or clay. Claypans occur and soils approach Planosol in character. Some are 6 to 10 ft deep.

Santa Isabel-Paso Seco soils

The soils of this group include small, gently sloping alluvial fans of the southern coastal area. They are reddish Chestnut soils composed of material washed from the neutral and alkaline soils of the uplands. Some areas have a high water table and are affected by harmful salts.

Sollar-Aguilita soils

The parent materials for these soils are limestones and marl. They are associated with the long and fairly wide belts of undulating or hilly coastal plains of the northern and southern coasts. The soils are characterized by dark, heavy, calcareous granular clay surfaces high in organic matter resting on yellowish-brown subsoil which in turn rests on the limestone or marl at fairly shallow depths. These are in the rendzina group.

Descalabrado-Guayama soils

These soils exist under arid to subhumid conditions and are generally derived from tuffaceous rocks and shales. The Descalabrado soils have brown or dark-brown, granular, neutral or alkaline, clay or silty, dry loam surface soils underlain by shallow, light-brown clay or silty clay grading into the bedrock (tuffaceous). The Guayama soils are reddish-brown throughout and are derived from greenish-gray calcareous shale.

Mucara-Naranjito soils

Soils of this group occur on elevations from near sea level to 2000 ft. They receive 65 to 100 in. of rainfall and exist on hills and in V-shaped, rock-bottomed ravines. Parent materials are igneous and tuffaceous. Soil profiles are shallow and range from 8 to 18 in. with textures including clays and silty clay. These are in the lithosol group.

Alluvial soils

Examples of the alluvial soils are the Toa, Coloso and San Anton series. Origin of these alluvial soils is in the adjacent uplands. Textures range from sand to clay. They occur in a nearly continuous band around the island within 4 miles of the coast.

Natural Vegetation

Over 400 years of competition between physical conditions, environmental stresses, and man's desire to utilize the landscape have had a marked effect on survival of native stands of vegetation. Not only has man cleared the lands on slopes and soils suited to his needs, but he has undercut and underplanted in the forests so that the natural succession processes have been altered considerably. As Gleason and Cook (1920) point out:

> "A survey of the vegetation of Puerto Rico shows at once the presence of a large number of different plant associations in the natural vegetation. Some of these are of large extent and were originally, before their destruction by man, nearly continuous over wide areas. Others are very small in area and are represented by scattered and isolated examples. Some show clearly that their existence is precarious and their duration frequently short because of the rapid change in environment which they occupy. Others offer no evidence that they are subject to change, except as they have been or may be destroyed by man. Still others show clearly that they owe their existence to man, through his activities in cutting, clearing or burning."

With a high density of population and a high intensity of land utilization, there are few localities where virgin stands can still be observed. One of the more important of such areas is to be found in the Luquillo National Forest. In spite of its small size, Puerto Rico contains as many tree species as there are in the United States proper. This wide variety of species results from certain natural conditions. In response to the position of Puerto Rico in the Trade Wind Belt, its diversity of relief, and its rapidly changing soil types, the vegetation exhibits wide variation in type and character in its adjustment to prevailing conditions (Fig. 8 and 9). In a broad sense, vegetation varies from xerophytic plants in the southwestern desert to the rainforest types in the moist, humid mountains. Heaviest growth is in the humid regions and less heavy growth in the arid portion or on the windswept slopes of the high mountains. Edaphic variations produce vegetation variations within some climatic regions. For example, on droughty soils (coarse-grained, steep slopes, etc.) vegetation may be more related to the dry soil environment than to the moist atmospheric environment, while vegetation in wet soil environments (bogs, swamps, etc.) is characteristic of moist atmospheric environment.

Regarding vegetation of Puerto Rico, Gleason and Cook (1926, p. 27) provide the following summary:

> "... in Puerto Rico the great climatic features of rainfall, atmospheric humidity, wind, and temperature have a distinct relation to topography; that all of them exert an influence on the distribution of species and on the grouping of species into distinct types of vegetation, but that no one of them alone can offer an adequate explanation of the nature or distribution of the plant life of the island. How far each of these climatic factors contributes to the allocation of the vegetation can be determined only by the most careful experimentation."

The general vegetation groupings as developed by Gleason and Cook (1926) are primarily geographical in nature and are correlated with certain broad features of climate and soils. The groupings are: (1) Vegetation of the Northern Coastal Plain; (2) Vegetation of the Central Mountain Region, and; (3) Vegetation of the South Shore. The vegetation of the Northern Coastal Plain coincides quite accurately in its distribution with geological and physiographical conditions. The arid vegetation of the South Shore occupies not only the coast proper, but extends up the southern mountain slopes to a northern limit determined primarily by rainfall. Between the two lies the Central Mountain Region (Fig. 10).

For scientific and technical details of vegetation, the reader is referred to the works of Gleason and Cook (1926, 1928), Wadsworth (1949, 1951), Beard (1944, 1953, 1955), Murphy (1916), Holdridge (1940, 1942), and Britton and Wilson (1923, 1925).

Vegetation of the Northern Coastal Plain

The Northern Coastal Plain is a region of limestone and alluvial soils and is characterized by heavy rainfall. The elevations in this area vary from sea level to about 1300 ft. Vegetation probably reached its climax development as a mesophytic forest centuries ago. The approximate nature of the mesophytic forest can only be conjectured as it has been altered considerably through activities of man. Much of the original climax type vegetation has been displaced by agricultural crops. The fluctuation of the land level with respect to the sea level is an additional influencing factor believed to have seriously affected the selection and succession of species.

Inland from the coast the only stands of the mesophytic forest are to be found on the steep slopes and tops of the limestone pepino hills. The intervening areas are now given over almost entirely to agricultural pursuits. The original forest of large trees is represented by a few emergent species which occur on the pepino hills. The present vegetation mantle on the limestone hills consists of second-growth thickets of a large number of species. Height of the trees and shrubs is usually 10-15 ft. The pepino surfaces present an almost impenetrable tangled mass of shrubs, vines, aerial roots and brush.

Conditions along the shores, beaches, lagoons, estuaries and other near-shore features are in a constant state of flux due to submergence, emergence, tides, winds, and currents. The type of vegetation established is related to position, salinity, depth to water table, and protection. For example, the sand beaches and dunes support xerophytes which give way to mesophytes inland from the beach under more stable conditions. In protected areas on the dunes, the brush thickets are quite dense (3 ft high) but may be broken by wind scours. The shorelines of fresh-water lagoons, estuaries, and streams support hydrophytes and ponded areas support aquatics. The species associations are differentiated by depth of water table, soil type, and protection. The brackish water areas, lagoons, etc.,

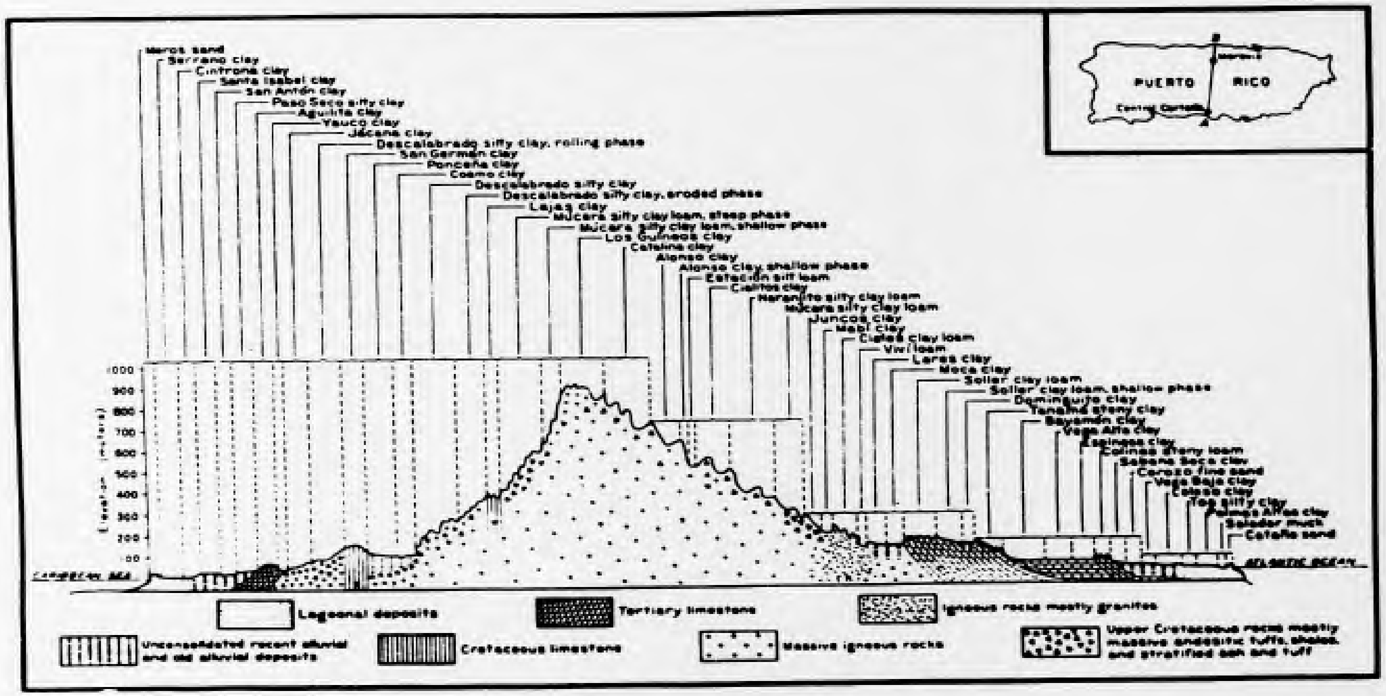

Figure 8. Cross section of Puerto Rico, indicating soil types in respect to elevation, relief, and parent rocks. The hypothetical line passes through Morovis and Central Cortada. From U. S. Department of Agriculture, "Soil Survey of Puerto Rico" by R. C. Roberts.

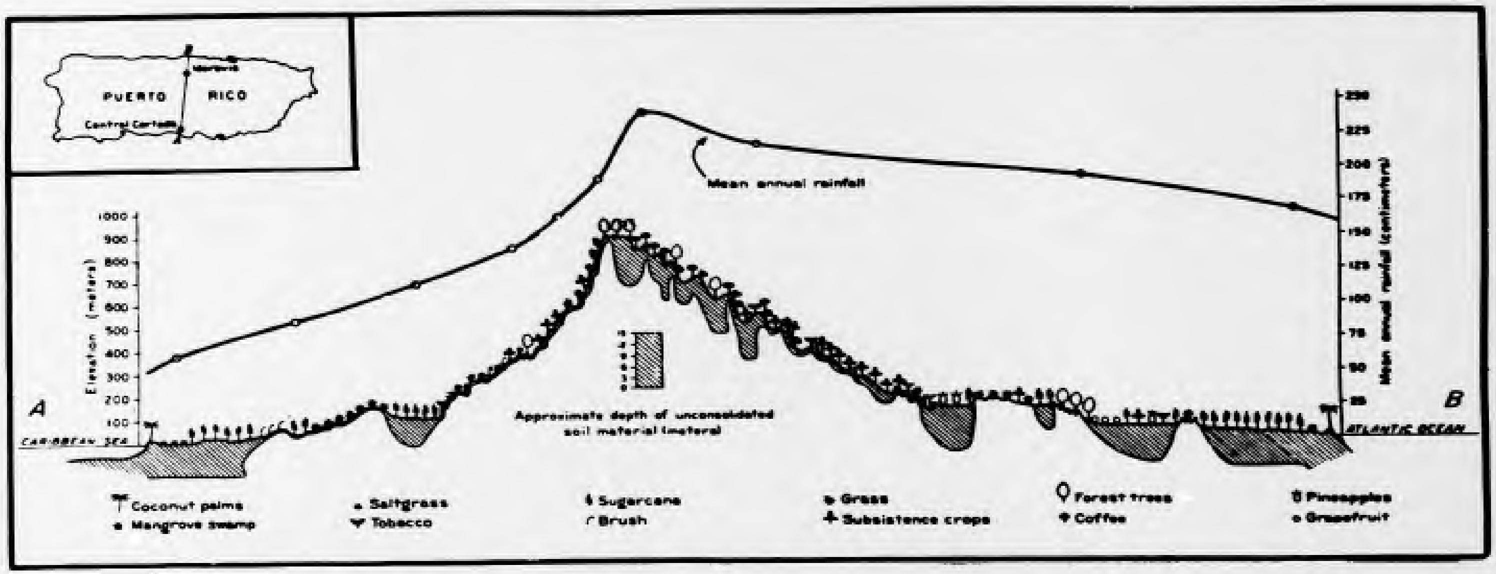

Figure 9. Cross section of Puerto Rico, indicating elevation, depth of soil and unconsolidated rock, mean annual rainfall, and vegetation. From U. S. Department of Agriculture, "Soil Survey of Puerto Rico" by R. C. Roberts.

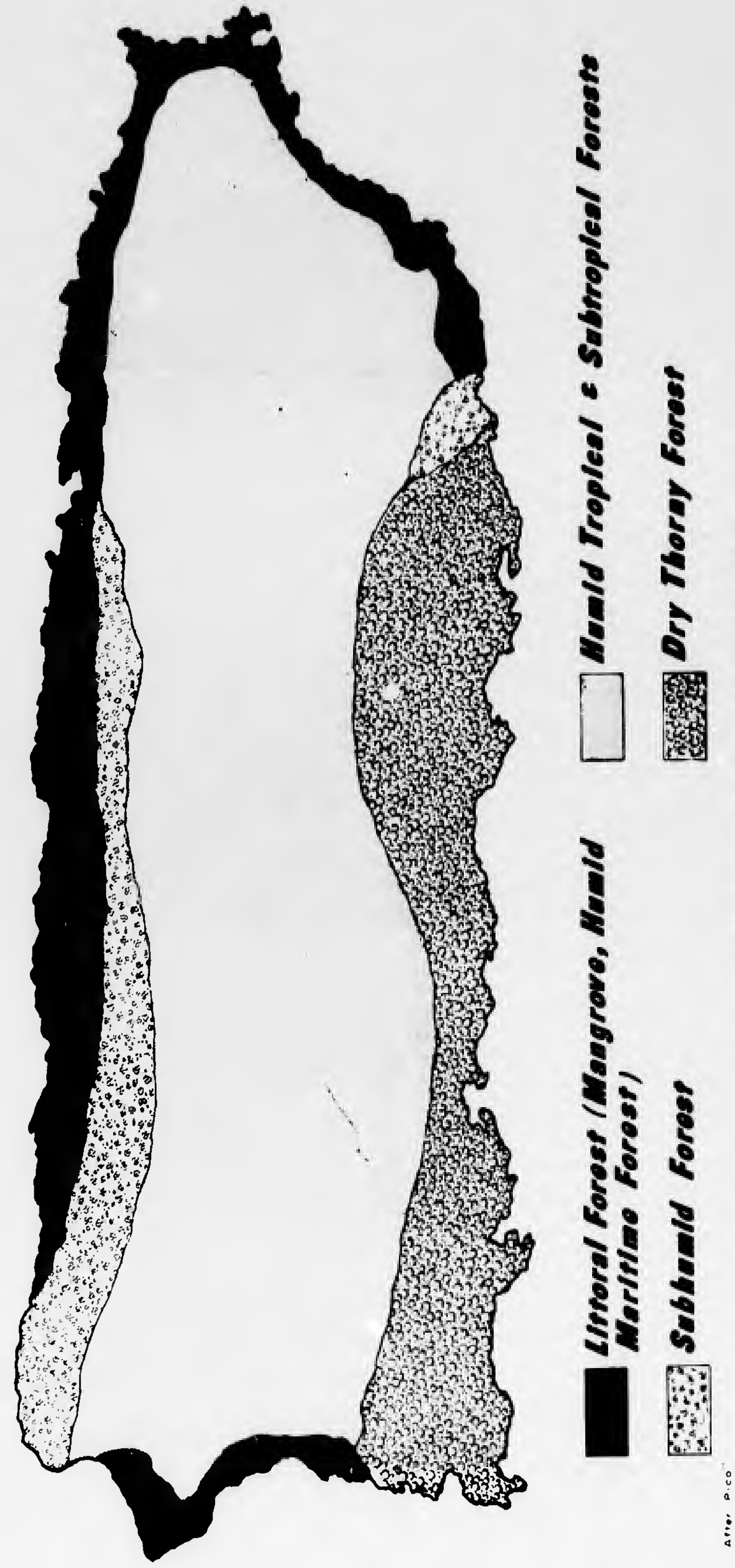

Figure 10. Vegetation map of Puerto Rico

support halophytes such as mangrove associations. The mangrove areas are thick, tangled and present an almost impenetrable mass.

Vegetation of the Central Mountain Region

This area does not include all of the ancient volcanic mountain region. On the north, it extends to the Tertiary limestone region; on the east and west it extends only to the limit of adequate rainfall. Roughly, this is represented by an elevation of about 1500 ft. The chief contributing environmental factors in this area relative to vegetation are abundant rainfall, high humidity, and soils derived from decomposition of volcanic rocks.

North of the region the rainfall is adequate for vegetation, but the rocks/soils are different. South of the region the soils/rocks are satisfactory but the rainfall is deficient. The northern boundary, which is set by geological conditions, is independent of altitude. In the northeast corner near Fajardo, the "mountain" vegetation extends to sea level but near Lares it ceases at about 1200 ft, the highest elevation of the Tertiary limestone.

On the north side of the island the transition is sharp and conspicuous and is marked by the occurrence of a fern which is restricted to "old soils" of the mountains. In passing from the younger limestones to the older rocks, the transition is well marked by the fern. The southern border is very well marked by sharp contrasts between xerophytes and mesophytes. The mesophytes descend down the ravines which are flanked by spurs of rock. The xerophytes mantle the rock spurs. Thus, the border is often marked with local variations in elevation and sharp contrasts in vegetation.

Within the mountain mass the common and more dominant species of trees and the structure of the general vegetation complex reflect no specific relationship to rock type. Even in the mountains man has altered the landscape. Steep hillsides have been cleared, the broad valleys are farmed extensively, and large areas have been opened to pasture or planted to coffee and its cover crops. Areas of natural forest are preserved in Luquillo Forest and near Maricao. The original forests which extended down to the sea on the east and west ends of the island have been almost completely destroyed by man. Study of the few scattered remaining wood lots indicates that at least five major associations existed. These are the low mountain forests, moist tropical forest, rain forest, the sierra palm forest, and the mossy forests.

The low mountain forests have almost entirely given way to agriculture except along fence rows, roadsides and rock areas too steep for cultivation. Natural stands are almost exclusively second growth consisting of weed trees. It is believed that the low mountain forest type originally extended to the seashore on the eastern and western ends of the island.

Above the lowland forests is a complex of four distinct forest types—the moist tropical forest, the rain forest, the sierra palm forest, and the mossy forest. Collectively these are all referred to as the "forests of higher altitudes." The original forest of the higher altitudes is believed to have contained a great number of species. Activities related to coffee utilization have altered conditions considerably in the western Cordillera. The elevation range for coffee is roughly coincident with that for the upper forests—roughly 500 to 2000 ft. When viewed from a distance, the mountains and belted hills appear to be mantled with dense forest. However, what is seen is actually "shade cover for the coffee." Within the mesophyte forest are two specific groups—the moist tropical forest and the tropical rain forest.

The tropical rain forest occurs up to elevations of 2000 ft. It is here where much of the original forest remains. Cutting has been severe but not enough to destroy the forest structure. The rain forest is characterized by an almost complete cover or canopy which blankets all but the sharpest relief features. Even sharp ridges appear to be softened by the screen of canopy. The forest cover is roughly 60 ft high but many emergent species rise to greater heights. Trees are close together with generally rounded and irregularly-spaced crowns. Leaves vary in size and shape. While few of the trees exceed 1 ft in diameter, some giants approach 5 ft. Beneath the upper canopy is a great development of vegetation. Variations include mosses, herbs, ground plants, tangled masses of vines, climbing grasses, epiphytes, and a wide variety of smaller trees. In some instances layering occurs.

The sierra palm forest starts abruptly at about the 2000 ft elevation at the edge of the rain forest. Within the sierra palm forest the dominant plant is sierra palm. This occurs extensively throughout Puerto Rico at elevations above 2000 ft. The upper limit of the palm forest is just below the summit of the peaks except on the slopes of Cerro de Punta. At this location the palms extend almost to the summit (4000 ft). The palms are about 6 in. in diameter, 30 to 50 ft high, with leaves 6 to 8 ft long. The associated species are weed trees, shrubs, climbing aroids, bamboo, ferns, and some epiphytes.

The mossy forest occupies the upper portions of the mountain masses— areas usually wrapped in fog or clouds. Soils are thin but usually saturated. The effect of the wind on the size and shape of the trees in this zone is quite severe. The contributing environmental conditions are lower temperature, high wind exposures, water-soaked soils, and high precipitation. Trees are short, stubby, gnarled, and exhibit flattened crowns. The floor is marked with a moss carpet which often extends up the tree trunks.

Vegetation of the Sourthern Coastal Plain and foothills

From an ecological standpoint, the vegetation of the south shore is simple. Over most of the region, with the exception of the immediate shoreline, dynamic changes have come to a standstill. Vegetation has long since reached climax or sub-climax conditions. The climax type is no longer in existence because of grazing and agriculture. The sub-climax vegetation occupies the arid coastal hills of shale, serpentine, and limestone, and is characterized by xerophytes. Throughout the region, water supply is the most important environmental influence. Three vegetation series—halarch, hydrarch and xerarch—are to be found. In places the transition between these series is quite marked.

The halarch series is characterized by at least four species of mangrove which occur in protected salt water lagoons. These are widespread on the south shore. The mangrove associations promote land building by trapping alluvial soils in suspension.

The hydrarch series is characterized by floating plants, marsh plants associated with fresh water lagoons, and backwater alluvial situations.

The xerach series is represented by shrubs, thorny bushes, and species of cactus on the shale and serpentine hills.

CULTURAL SETTING

The cultural setting of Puerto Rico is a reflection of both the diversity of natural features and the historical background of the island. Agricultural land use has developed in response to the natural environment—topography, soils, climate— and to the political and economic influences of the past 450 years. Settlement patterns and population distribution, in turn, reflect land-use patterns and the social traditions which have evolved. Puerto Rico was populated with Carib Indians at the time of discovery by Columbus. It was under Spanish rule of varying interest and intensity from the time of discovery until it came under the American Flag in 1898. Various attempts to capture the island were made by the British, French, and Dutch through the intervening years. Negro slaves were imported during the 16th century. These factors have influenced the population composition and the social, political, and cultural heritage of Puerto Rico.

Population

The most recent population figure for Puerto Rico is 2,393,000 (Commonwealth of Puerto Rico, 1962). This provides an average density of 672 persons per square mile. The distribution of population in any area is seldom simple, and Puerto Rico is no exception (Fig. 11). Density and distribution vary from one area to another over the island. There are few, if any, spots devoid of population or even with a relatively sparse population. Nowhere in Puerto Rico, except on the island of Culebra, is the rural population density below 100 per square mile. Only five municipalities on the island proper have a rural population density below 200 persons per square mile. Two of these, Coamo and Salinas, are in the semiarid southern foothills area and Salinas contains a military reservation from which resident rural population was resettled. Two of the municipalities, Las Marias and Maricao, are located in the western Cordillera Central. The fifth, Ceiba, is on the east end of the island incorporating a large military area essentially devoid of rural

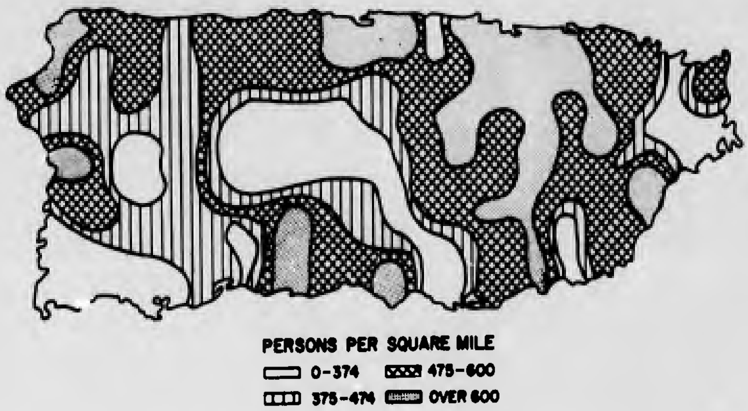

Figure 11. Density of population in Puerto Rico, 1960 census. From Hanson, E. P. (1962)

population. Nine municipalities have rural population densities exceeding 600 persons per square mile. Of these, two are adjacent to the San Juan metropolitan area. They may well be considered urban areas by the next census. The remaining seven are located in the coastal sugar cane areas or the interior valleys where sugar cane is the dominant crop.

Distribution patterns

The dense population is distributed throughout Puerto Rico in a variety of patterns. Rural population patterns reflect land use and agricultural practices. The urban patterns have evolved more directly from historical and economic factors.

Urban population is unequally distributed over the island. More than 50% of the urban population is concentrated in the northern coastal lowlands. Seventeen percent is distributed in the southern coastal lowland, fourteen percent in the western coastal valleys section, and the remainder is variously distributed over the island, particularly in the interior valleys.

San Juan, the largest city on the island, is one of the few located immediately on the shoreline (Fig. 12). West of San Juan on the northern coast, Arecibo is the only sizable town at the shoreline. Camuy and Hatillo, much smaller towns, are located on the beach at the mouth of the Camuy River. West of the Camuy River, Quebradillas and Isabela are removed from the immediate coastline and located atop the limestone sea cliff which makes the beach area too narrow for village or town development. Other cities along the north and east coasts are some distance inland. Original settlement inland was probably influenced by the need for protection against invasion from the sea and distance from deleterious pests of the coastal mangrove swamps. Most of these towns have an associated "playa" which serves as port or harbor for the town. On the west coast Mayagüez and Aguadilla, both located on embayments, are the only coastal towns which provide a semblance of shelter for a harbor. Both towns are also "backed up" by rugged terrain, precluding settlement at some distance from the immediate coast. Other west coast towns are located upstream along river valleys, or at higher altitudes in the hills to benefit from cool breezes and a generally more pleasant aspect. No cities and only a few towns, such as Paguerra, Ensenada, and Arroyo, are located at the waters edge along the south coast. Urban expansion between Ponce and its "playa" may soon form one urban unit, but Ponce was originally established well in from the coast line. Urban developments in the foothills and mountains are primarily established along rivers where water supply and level land are available. Two exceptions are Maricao and Las Marias which are high up on the divide in the west central mountains.

Rural population patterns in Puerto Rico have some distinct forms. Augelli (1950-1955) has described six rural settlement types particularly typical of interior Puerto Rico. These are found in some form in the coastal areas also.

1. The Hacienda grouping is typified by a large landowner's home and associated plantation buildings including a cluster of workers' huts. Formerly, the hacienda was the center of activity for this grouping, but now the paths lead away from the hacienda toward the highway stores and villages.

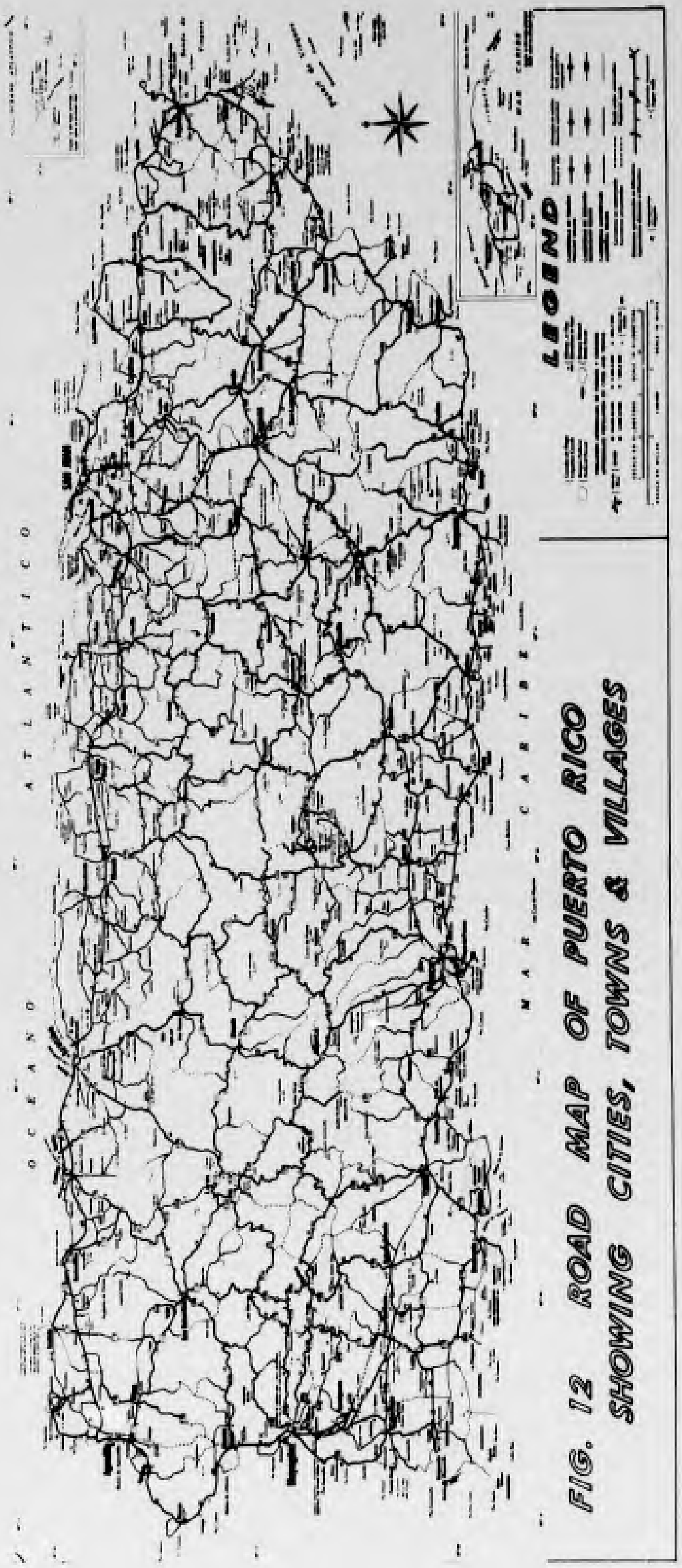

FIG. 12 ROAD MAP OF PUERTO RICO SHOWING CITIES, TOWNS & VILLAGES

2. The Isolated Farmstead* or dispersed pattern of settlement is typical of the interior mountainous areas, some of the foothills, and the limestone areas. Dwellings and outbuildings are usually located on the poorer, stoney land unsuited for crops. Settlement groupings or clusters are limited to "strings" which align the highways or stream valleys.

3. The Pueblo or small town is, almost without exception, built around a plaza with the church on the east side. The town serves as a trade center, administrative center, and occasionally will have some small industry. The structure of the Puerto Rican pueblos traditionally places the better homes near the center of town, close to the square. Middle-class housing quarters are above the commercial establishments facing the square. Lawns, yards, or gardens are a rarity, and have only recently become a part of the middle and upper-class residential areas. Lower-class housing, including slum type, usually fringes the town. Strings of houses, both poor and middle-class, frequently line the roads radiating from the town.

4. The Kilometer Hamlets occur where trails or secondary roads intersect major highways, at the ends of roads, or at intervals along the highways. They consist of at least two stores with residences for the proprietor's family and are designated by the kilometer stop of the highway on which they are located. These hamlets are generally about 5 kilometers apart, which is as far as a farmer would be willing to walk for his wants. They have frequently developed at sites of schools or churches to serve the pupils or patrons. With the increase in population and construction, these hamlets are becoming integrated into some of the strings or clusters of settlement which line the highways in the more populous urban fringes.

5. The Pueblito is an area of low-cost housing which serves as a dormitory to excess population moving from the country to town. Pueblitos, as distinguished from the slum areas of the pueblos, are recent developments and are somewhat removed from the town. Inhabitants generally view pueblito residence as a temporary step from country to town. Most tenants are of the laboring classes.

6. The Suburb, like the Pueblito, is a recent development in Puerto Rican settlement patterns. It functions as a high-class, high-cost residential area primarily for business and professional people. Suburbs are located on the outskirts of towns along roads radiating from town, but seldom include a mixture of lower-class housing, stores, and shops.

In addition to the six types described above, mention should be made of the Parcelas. These settlements were established by the Puerto Rican government as resettlement areas for persons displaced from military reservations or from sugar haciendas when such properties were purchased and redistributed in one form or another. Parcelas usually consist of small plots, on which houses have been constructed by or for the owner. The plots are $\frac{1}{4}$ to 3 cuerdas† in size, providing land enough for a few subsistence crops. By resettling in this manner, the government can better provide such services as water, sanitation, schools, and electricity. There are well over 150 such settlements in Puerto Rico.

Composition

Puerto Rican population is an amalgam of Spanish, African Negro, indigenous Indian, colonial French, and Anglo Saxon. Combinations of the features, stature, and colors of each of these people may be seen in variety everywhere. Generally speaking, Puerto Ricans are thought of as small, dark, and youthful. The small stature may be attributed to a number of causes, but is principally due to hundreds of years of a meager diet. Hancock (1960) points out that "...Puerto Ricans of the upper class, whose fathers and grandfathers have always had plenty to eat, are generally big people. Thus, size has as much to do with the caste system as color." Until quite recently, the indigenous Indian was considered to

*The density of population in Puerto Rico is such that few truly "isolated" farmsteads exist. "Dispersed" is probably a more meaningful term here.

† Cuerda—.97 acre.

have been completely wiped out soon after Spanish conquest of the island. Anthropologists today suggest strong traits of the stock and remnants of the Arawak culture may be found in some rural areas of the interior mountains (Augelli, 1950; Hancock, 1960, 1962).

The age group make-up of Puerto Rico is typical of any area with a high birth rate and a dropping death rate. Approximately two thirds of the population is under 35 years of age; about a quarter of the population is between 35 and 64 years, and only a small fraction (105,000 out of a total of 2.3 million) is 65 years or older. The life span of the Puerto Rican is increasing, but not enough time has elapsed to provide a significant residue of older people.

Agriculture

Crops and practices

The major agricultural crop in Puerto Rico is sugar cane. Puerto Rico's economy, in fact, was based primarily on sugar cane until the past few years. Almost every acre of land which could even marginally produce sugar cane was used for that crop. In more recent years some lands suitable for cane have been turned to use for pineapple production and dairying. Other important agricultural activities on the island include tobacco, coffee, minor crops (Frutos Menores), livestock, and tree crops such as coconuts and citrus fruits.

Distribution of the agricultural land use is mapped in a generalized manner in Figure 13. Sugar cane is predominant on the level lands of the coastal plains and interior valleys. Tobacco is grown predominantly on the steep hillsides of the eastern mountains. Coffee is concentrated in the western mountainous interior. Pineapple and citrus crops are produced in the flatter lands of the foothills and coastal plains in the area from Manati east to San Juan. Dairying as a major agricultural activity predominates in the hinterlands of urban areas. Minor crops are produced everywhere for home consumption, and the agricultural economy of some of the rugged mountain regions is based on minor crops. This is particularly true of the east central region bordering the tobacco region. The eastern foothills area of the north coast is the major truck-crop-producing area on the island. Coconuts are raised in groves on the sandy beaches fringing much of the entire coast. Many environmental and economic factors determine location, extent and importance of each crop or agricultural activity.

Sugar Cane. There are four types or qualities of sugar cane grown in Puerto Rico: Gran Cultura, Petit Cultura, Primavera and Ratoon*. All are cultivated and harvested in much the same manner. The types of cane differ in the required length of growing time to maturity and therefore in sucrose content. Other factors being equal, the longer the growth, the higher the sucrose content.

Gran Cultura takes from 18 to 20 months to produce the first sugar crop. It is planted in August and September and harvested in February, March, or April 2 years later.

Petit Cultura is a 14- to 16-month growth cane. It is planted during the period from October to December, and cut from January to June the second year.

Primavera will produce a sugar crop after a 12-month growth. It is planted anytime from January to July and harvested 12 months later.

Ratoon cane includes all sugar cane cuttings following the initial crop. The sucrose content is little affected by the original class of cane in ratoon crops, but is always lower than the original, and decreases each year.

The methods of planting and cultivating sugar cane vary according to soil type, site, and moisture conditions. Usually, the land is plowed, cross plowed, and harrowed after each plowing. Sugar cane "seed" consists of cane stalks 9 to 12 in. long. Gran Cultura seed is obtained from ratoon growth about 8 months old. Primavera "seed" is obtained from mature cane stalks cut at harvest time. The seed is planted in furrows or holes about 4 ft apart, and must be weeded several times until the cane is tall enough to discourage weed growth

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*A ratoon or volunteer crop is one which grows as shoots from perennial plants such as sugar cane, cotton and pineapple. Second, third, and fourth year crops from any one planting are all ratoon crops.

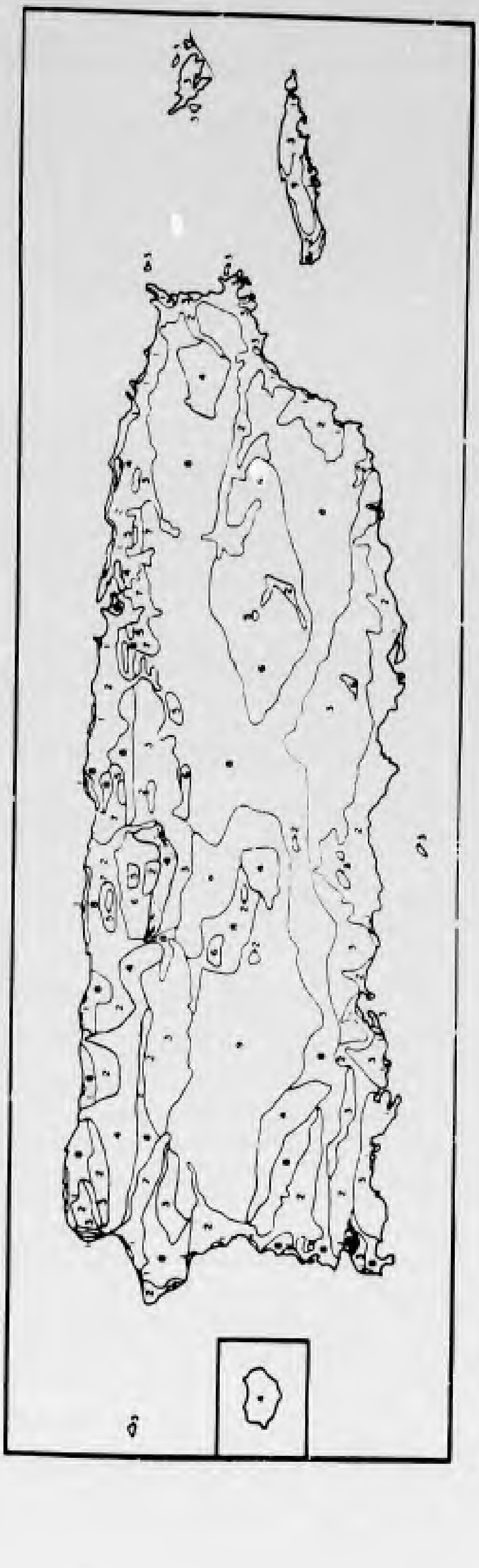

Figure 13. Map of Puerto Rico, showing the different types of farming: 1, Coconuts; 2, sugar cane; 3, pasture and some subsistence crops;4, trees and some subsistence crops; 5, pineapples; 6, tobacco; 7, grapefruit; 8, subsistence crops; and 9, coffee. From U. S. Department of Agriculture, "Soil Survey of Puerto Rico" by R. C. Roberts.

naturally. In areas where sugar cane is grown on poorly drained or waterlogged fields, the Grand Bank system of cultivation is used. A drainage ditch is dug on each side of every second to fifth row of cane with cross ditches at intervals as necessary. Most sugar cane fields are fertilized from 1 to 2 months after planting, with a second application 2 months later. The fertilizer is spread within a radius of 8 in. of the cane plants, then covered using a one-horse plow or hoe.

The sugar cane harvest, called "Zafra," extends from December or January to the end of July. Cane is cut by hand labor with a machete. The cane is loaded immediately onto carts or trucks for hauling to the loading derricks or directly to the sugar central. Sucrose content decreases rapidly after cutting, necessitating transport to the central within hours. The sugar centrals work day and night during the harvest season, usually stopping for 1 day each week to clean and repair machinery.

Within 2 weeks after harvest, the ratoon crops are plowed for the next season. Dead plants are replaced by new plants at this time.

Sugar cane can be grown successfully on a large variety of soil types, but yields vary from 15 tons per acre on poorer soils to over 100 tons per acre on the best soils. The best soils for sugar cane in Puerto Rico are those with a friable loam or silt loam surface soil, high in organic matter, neutral or alkaline in reaction, free from gravel or harmful salt, and granular, with a slightly heavier but friable alkaline subsoil at a depth of 10 to 12 in. extending to at least 5 ft before free water or gravel is reached. Maximum efficiency of sugar cane plants is based on a well-developed root system which, in turn, is determined by the physical and chemical condition of the soil.

Sugar cane rainfall and temperature requirements, like soil requirements, are somewhat flexible. The minimum tolerable temperature is 60F, and without irrigation at least 60 in. of rainfall is necessary. Sucrose content decreases with increase in moisture just prior to harvest, therefore the harvest is scheduled during the driest season of the year.

In the areas where sugar cane is irrigated, lateral irrigation ditches are laid out with the contours of the land. These convey water to the plants from large canals which in turn are fed from relatively large reservoirs. The source of water supply may be from mountain streams or from deep wells. Irrigation ditches or canals will be lined with concrete slabs in areas where they traverse porous soils or where a rock or gravelly substratum is near the surface. The number of irrigations varies with season, soil and plantings. The higher quality canes (Gran Cultura) require more water than the ratoon crops and permeable clay soils require more water than alluvial soils. In most irrigated areas, the cane is watered when planted and rewatered a week later if the weather is dry. The period between later irrigations averages 15 days, but will vary according to the rainfall.

Tobacco. Tobacco is a shallow-rooted crop and therefore can be grown on relatively shallow soils and steep slopes. It produces a high yield per acre and is a crop not readily adaptable to mechanized methods of planting and harvesting. Thus, small plots may be utilized profitably.

Tobacco seedling beds may be planted as early as May, but are usually planted in the fall from late August to early November. Seedling beds are covered with cheesecloth to protect the young plants from the intense sun, hard rains, and insect pests. When several weeks old, seedlings are transplanted (late October to early January) to fields which have been cultivated by hand or ox-drawn plow. The tobacco is fertilized a few days after transplanting and again about 30 days later. It is cultivated two or three times during the growing season. About 35 days after planting, the lower leaves of the tobacco plant are removed to improve air circulation, and terminal buds are pinched off from all except potential seed tobacco. Seventy to ninety days after transplanting, the tobacco is ready for harvesting. The most common practice in Puerto Rico tobacco regions is to pick three times. The lower tobacco leaves are picked first, middle leaves (highest quality tobacco) next, and the top leaves last. The leaves are strung on wire, strings, or poles and hung in a tobacco barn to dry for 20 to 40 days before the crop is ready for marketing. In some instances the entire tobacco plant may be picked and leaves sorted after the initial drying period.

Crop rotation is practiced in tobacco areas after the tobacco harvest. The second crop will depend on location and individual needs of the farmer. On the steep hillsides fields will be left either fallow or as pasture for 2 or 3 years. On level lands and some of the better grades of hill land, tobacco will be grown year after year.

Best yields of quality tobacco are obtained on friable, well-drained, well aerated soils that are neutral or alkaline in reaction, rich in plant nutrients, and situated at considerable distances from areas affected by the salt spray of the ocean. Shallow ditches are dug around every plot of about 900 square feet to enable water to drain off rapidly without serious loss of soil.

Coffee. Coffee is a perennial tree or bush crop. It is not productive until 4 to 8 years after planting, but will produce crops thereafter for 20 to 30 years. It grows best on deep clay soils of the uplands, with 68F average temperatures and 85 in. of rainfall annually. Rainfall during the ripening season is important and coffee is harvested during the rainy season in October, November and December. Well tended coffee is weeded annually just before harvesting and thinned after harvesting. Replanting of seedlings is done in August.

Most Puerto Rican coffee is shade-grown. Shade is commonly provided by bananas and plantain when seedlings are young and until the larger trees have grown enough to provide shade needed. The guama, guaba, moco and mountain orange are predominant shade trees used in the Puerto Rican coffee areas. The bananas, plantains and oranges yield subsistence foods for the farmer and his workers. Citrus crops are seldom harvested as a commercial crop as labor and transportation costs are not sufficiently offset by returns to be profitable.

Coffee is harvested or picked by hand. This may be done by either the wet or dry method. All beans are picked at one picking in the wet method. The dry method consists of picking only the beans of optimum ripeness, and involves more than one picking. After picking, beans are taken to the finca or plantation farmstead where they are partially dried, then husked, washed, and sun-dried. These operations are mechanized to various degrees, depending on size and capital investment of the plantation. The coffee may be hulled, roasted, and ground at the plantation, or taken to the marketing cooperative as dried beans. All Puerto Rican coffee is now marketed through the cooperatives, and is consumed on the island.

The most favorable combination of soils, temperature, and rainfall for coffee in Puerto Rico is found at elevations above 2000 ft. Experience in the past with hurricane damage, which is more severe at the higher elevations, has all but completely discouraged coffee production in the optimum areas. Most coffee is now produced below the 1500 ft elevation.

Pineapple. Pineapple production occupies a relatively small acreage of cropland in Puerto Rico but is one of the most important commercial crops of the island. With improved methods of freezing and canning it should become even more important.

Pineapple is a sensitive plant, but responds well to proper care and suitable soil conditions. It is a shallow-rooted plant and does not require large quantities of water. Soils best suited to pineapple are acid, well-drained, permeable, and contain considerable organic matter. Good air drainage is essential for pineapple production, thus site location is important.

Pineapple is planted during the rainy season— July to August— in fields which have been plowed and harrowed at least once. Either slips or suckers are planted. Slips are miniature plants produced at the base of mature fruit. Suckers resemble slips, but are larger and are produced in the leaf axils of the plant. Suckers may be planted at almost any depth, but slips must be set no deeper than 2 in. The plants are set out in beds at distances of $1\frac{1}{2}$ to 3 ft apart depending on soil type and slope. Pineapple fields must be cultivated to keep the surface soil loose. Weeds are cut only until the plant is large enough to shade the ground and thus prevent further weed growth. Fertilizer is usually applied in July, September, and January. The crop is harvested within 12 months after planting—that is, between March and July. Plants may be smoked to hasten ripening, but this precludes development of slips and suckers for the next crop. Harvesting consists of gathering the fruit in baskets which are loaded on trucks or carts to be taken to the packing shed or canneries.

Two ratoon crops are usually picked after the first crop. After the second ratoon crop the field is plowed and replanted either to a rotation crop or a new pineapple crop, or it may be left fallow for a year.

Coconuts. Palm trees, including coco palms, are found scattered in many places over the island of Puerto Rico. Commercially productive coconut palms, however, are confined to narrow strips of sandy beach. They tolerate a certain amount of alkali or salt in the surface soil, and even seem to need a small amount. For good nut production, coconut palms require a well drained, fairly fertile, loose sandy neutral or calcareous soil. They grow better and produce higher yields at elevations 300 ft above sea level or lower, where the water table is at least 30 in. below the surface. They will grow in soils with a water table as shallow as 18 in. below the surface, but when the water table depth is less than 18 in., the tree will usually be stunted or killed.

Trees are planted in checkrows approximately 34 ft apart, or 50 trees to the acre. They start producing when about 6 years old, and will continue to produce for many years. Nuts are harvested every 2 to 3 months and each tree will average 40 to 60 nuts per year. (Some trees may produce 200 or more.)

The coconut palms themselves need no cultivation. Frequently subsistence crops or pasture grasses are planted in the palm groves. Cultivation and fertilization of these crops will also benefit the coconuts.

Coconut water, a colorless fluid in green coconuts, is a popular drink in Puerto Rico. The white meat of the mature coconut is used for desserts, confectioneries, and extraction of oil. It is also used as hog feed, particularly when the commercial market price is low. Husks are used in the manufacture of brushes and coarse fabrics, and leaves are used for thatching. Copra, the dried meat of coconut, may be produced locally, but Puerto Rico exports none. Coconut trunks are often used in fences.

Citrus fruits. Grapefruit, oranges, limes, and lemons are grown to various extents in Puerto Rico. Grapefruit is the only citrus fruit to have been commercially important as an orchard and/or export crop. Oranges grow in abundance, but have never been seriously cultivated as an export crop. Limes are grown entirely for home consumption, and lemons are rarely used at all.

Large citrus orchards, primarily grapefruit, were developed at one time on the coastal plains between Arecibo and San Juan. These have, for the most part, been neglected, abandoned, or replaced by other crops. Competition for U. S. markets and destruction by hurricanes have discouraged the citrus industry in Puerto Rico.

Grapefruit will grow on many types of soils, but for high yields and long periods of production soils should be deep, well-drained, well aerated, neutral or acid, and sandy textured. Grapefruit trees need protection from high winds either by site location or by planting of windbreaks. They also need good soil drainage and air circulation. Slightly undulating sites are better than flat lands, and concave slopes are preferable to convex slopes or depressions. Commercial citrus groves are all situated at elevations below 500 ft above sea level. If rainfall is less than 65 in. a year, irrigation is needed to produce good crops. Rainfall in excess of 75 in. is optimum. Grapefruit trees are planted 40 to 70 per acre depending on soil type and the moisture available. Young trees must be kept well watered until the root system is firmly established. After trees are 4 or 5 years old, cultivation of the ground is no longer necessary. Grass and weeds should be cut occasionally, however, to allow the trees to utilize available soil nutrients and water. Fertilizer is applied about the first of December and again in February and June. Grapefruit trees will first bloom at 5 years, and will continue to produce fruit for 30 to 35 years. Maximum yields are produced when trees are 9 to 12 years old. It takes at least 7 months for the fruit to mature after blossoming. The major harvest season in Puerto Rico is February to July, but blossoms may appear or may be regulated so as to produce fruit almost all year.

Oranges grow in a semi-wild state in Puerto Rico, and have long been an accessory crop in the coffee-producing areas. Soils adapted to grapefruit are also excellent for oranges. Oranges will do well at high elevations having cool, damp climates. The major season for harvesting oranges is from November to May and during this time the fruit is sold from street corner and roadside stands at prices as low as a penny each.

Lime trees thrive mostly in the coffee areas associated with the oranges. They could be grown elsewhere, but to date little attention has been given to limes, and the entire production is sold on local markets. Lemons are of even less importance then limes in

Puerto Rico. The fruit is seldom seen in private homes, much less on the markets. The trees were formerly used for grafting purposes in grapefruit groves.

Minor crops (frutos menores). The "minor crops" in Puerto Rico are the subsistence crops which feed the local population. There are more than 30 such crops commonly grown but the more important ones are corn, beans, yams, sweet potatoes, yautia, plantains, and bananas. These crops are grown in small patches, usually intermixed. Large fields of single crops are rare, particularly in more rugged country of the interior. Many of the subsistence crops may be planted on almost any soil type at any time of the year in any part of the island without complete failure. Also, most of these crops have high nutrient value and cost little to plant and cultivate. The combination of minor crops will vary from area to area, determined to some extent by the climate and soils. Planting of minor crops is primarily a winter and spring activity, but planting dates are adjusted to produce a certain amount of harvest all year.

Bananas and plantains are similar in appearance and agricultural requirements, and are the most important food fruits on the island. As they require considerable water they grow most abundantly in the areas of high rainfall. For best yields the plants need deep, fertile, well drained soil and an average of 80 in. of rainfall evenly distributed over the year. However, both plantains and bananas will grow on nearly every soil type and are easily grown. Farmsteads over the entire island have at least one plant in the dooryard, if not several in the garden.

The tuberous or root crops most commonly grown in Puerto Rico are the sweet potatoes, yautia, yams, and yaucca (cassava). Although there are optimum conditions for best production of these plants, all may be easily grown under a variety of soil and climatic conditions, with a reasonable assurance of some crop return. The sweet potato is probably the most universally grown. It will grow where soil appears to be only a few grains collected on bare rock. It is often planted with corn following the tobacco harvest. The major advantage of yautia is that it will thrive in imperfectly or poorly drained soils, therefore will produce well where other crops will fail or give poor yields. It is grown more widely than any other root crop in the humid and subhumid areas of the island. Yams are less extensively grown primarily because they require more care in cultivation and planting, must be fertilized, and the vine type plant necessitates above-ground supports. The major advantage of the yam over the other tuberous crops is that it is practically free from insect pests and plant diseases. Further, one planting will give two diggings. A second supply of edible roots is produced about 4 months after the first crop is dug. Yaucca is grown for use fresh, for grinding into flour, or for tapioca. It will produce well on a wide variety of soils, being intolerant only of frost and waterlogged soils. It can be planted at any time of the year but most farmers prefer to plant just before the rainy season.

Corn is grown everywhere on the island. In the southwest part of the island large fields, not suited for sugar cane, are given over to corn. These fields are often interplanted with squash. In other parts of the island corn is grown in smaller patches, frequently being part of the tobacco rotation pattern, where it is interplanted with beans. Corn is raised primarily for livestock feed and corn meal. Sweet corn or table corn is rarely found.

Pigeon peas, cow peas, and beans are the major leguminous crops grown in Puerto Rico. Pigeon peas have the advantage of being a perennial, and they serve to renew the soil fertility when planted as a cover crop on "worn out" soils. Beans can be grown, though giving poor yields, on shallow soils which will not support other crops. They are also grown with corn or alone following tobacco harvest.

Mangos, avocados, papayas and breadfruit are tree crops popularly grown in dooryards or on farmsteads. The fruits are usually available in the markets, but the crops are not of major economic importance.

Truck crops are increasing in importance in some areas. The most successfully grown marketable vegetables are tomatoes, peppers, onions, green beans, pumpkins and squash, cabbage, eggplant, lettuce, okra and cucumbers. With the recent improvement in roads and expanding urban population, some areas previously devoted to subsistence type agriculture should find truck crop production quite profitable.

Dairying and livestock. Dairy, livestock and poultry farming are increasing in importance in Puerto Rico. In 1961 the value of dairy and meat products outranked sugar products in the Commonwealth for the first time in history.* Dairy farming is still more concentrated in the vicinity of urban areas than elsewhere, but is gradually assuming importance in more remote areas. Improved methods of farming and processing, improved feed, pasture grasses, and breeds of cattle, and better transportation are making it possible to obtain higher yields from smaller acreage (Aiken, 1952). Many "tired" fields, especially in the mountains, are being converted to permanent pasture.

Dairy farms range from 10 head of milking cows on 50 cuerdas of land to over 200 head on farms of more than 300 cuerdas. It takes 1 to 2 cuerdas of land to support each head of cattle. A high percentage of land on dairy farms is in pasture and forage crops. Small amounts will be in minor crops, and, in some areas, in secondary cash crops such as tobacco or sugar cane. Cattle are pastured year round, but are brought to the barn for milking and supplementary feeding twice each day. Cattle barns are long, open-sided structures, and only in the arid southwest are silos noted. The need to store fodder for use during the dry season in the southwest was responsible for introduction of the silo to that area. The type of pasture grass and fodder varies according to the area and environment. On the south coast, sugar cane tops are used as fodder. Fortunately the cane harvest coincides with the dry season, thus providing the extra fodder at a critical time (Doerr, 1951, 1955).

Beef cattle ranching is most important on the south coast. Prior to the irrigation, south coastal areas were almost exclusively devoted to cattle raising. Hides and leather products were important in earlier days. When irrigation made sugar cane production possible, cattle were needed for work animals. Some oxen and horses are still used in the cane industry, but mechanization has decreased the need. Cattle are now raised primarily for beef but dairying is becoming increasingly important on the south coast. Grazing lands are located in the foothills areas of the southeast and southwest coasts, and on unirrigated areas of the southwestern valleys and coastal plains.

Poultry is raised commercially, particularly in the La Plata area. Other livestock, however, is of minor importance economically. Very few sheep exist in Puerto Rico. The climate is not conducive to healthy breeding of the wool-producing breeds. Goats and hogs are usually kept by individual farmers. They either roam free to root for themselves or are tethered to a stake or tree in the dooryard.

Agricultural land use patterns

Land holdings in Puerto Rico are not based on survey systems and present no geometric or planned pattern. Original farm boundaries and fields were established centuries ago based on physical features such as streams and ridges. Thus, fields and farms are generally irregular in shape and size. Land-use patterns and settlement features are distinctive for each of the major agricultural land-use types in Puerto Rico. Combinations and distributions of individual buildings, field patterns and roads reflect different agricultural practices in different and unique patterns. These may vary in small details, but, for each crop, the pattern generally holds true over the entire island.

Sugar cane. Sugar cane fields are as large as natural and cultural features will permit. All land that is suitable for sugar cane is utilized for that crop in the major cane areas of Puerto Rico. Small plots of land, unsuitable for cane but cultivatable, are used for minor or subsistence crops. The utilization of all possible land for sugar cane is reflected in the distribution of houses in these areas. Buildings are clustered in groups on poorer land which may be steep, rocky, or poorly drained. These agglomerations vary in size from small groups of 4 to 10 dwellings to larger clusters of 50 or more on an area of 3 to 4 cuerdas. The sugar centrals form an even larger settlement including stores as well as dwellings, and may contain as many as 200 buildings. In areas of optimum sugar cane production, such as the irrigated areas of the south coast, agglomerations of dwellings will occur along roads and near water tanks. The farmstead complex associated with sugar cane is differentiated from the clusters of workers' dwellings in that they contain at least one large, single-storied machine shed or garage,

*Personal communication from Mr. Hector Berrios, Government Development Bank of Puerto Rico.

a well constructed house, and several small miscellaneous sheds as well as a few aggregado (workers) dwellings. The machine shed is for storage of the sugar cane carts which are unique to cane agricultural activity. Another feature unique to sugar cane culture is the cane loading derrick. This is a "giant-sized" tripod-type apparatus used to transfer cane from carts to trucks. The derrick usually serves as the focal point of several roads or lanes radiating into the cane fields, and is always located adjacent to an automotive road.

The road pattern within cane areas is much denser than in any other agricultural area. Cane loses its sucrose content rapidly after cutting, and therefore must be transported to the central for processing in a matter of hours. This necessitates a fine network of oxcart trails, automotive roads, and (formerly, at least) railroad lines to reach all parts of the cane fields in a short period of time. Railroad lines were narrow gage and frequently could be put down temporarily, then moved to another field. Few sugar-cane enterprises still use these railroads, but some of the cars and the permanent tracks remain a part of the sugar-cane settlement pattern, particularly on the south coast.

In irrigated cane areas, the ditches, water tanks, and aqueducts form features seldom found in other agricultural areas. The large water tanks are merely shallow depressions or basins with a 3- to 5-ft embankment surrounding them. Irrigation ditches are usually constructed of brick and mortar or concrete and form a trellis type pattern utilizing the slope of land for flowage. Some cane is grown on poorly drained land in the north central coastal area. Drainage ditches form a part of the pattern in these areas.

Pineapple. Pineapple growing produces land-use patterns similar to sugar cane in many respects. Fields are as large as conditions permit and all possible land is used for pineapple. Smaller plots are planted to subsistence crops or pasture and clusters of dwellings are concentrated on poorer land. Pineapple, like cane, must be processed rapidly after harvest, thus a good, relatively dense road net is typical. The farmsteads in pineapple areas are distinguished by the presence of at least one pineapple packing house in addition to a substantial dwelling and usually one or two garages to house the trucks needed for transport. The packing houses are unique to the pineapple areas. These are large, low structures, at least 50 ft wide and 100 ft long, and the most conspicuous feature of the farmstead. Farmsteads are always located on a good automotive road. Occasional groups of packing houses may be found in the pineapple areas, usually at the junction of major roads. These are not as common, however, as the packing houses associated with the farmstead.

Canneries are also significant features in the land-use pattern of pineapple areas. These large, single-storied buildings are associated with one or two packing houses, good roads, and are part of the rural rather than urban scene.

Tobacco. The tobacco areas are located primarily in the rugged central mountains. In contrast to sugar cane and pineapple, tobacco fields are small, scattered, located on hillsides or steep slopes, contain shallow soils, and occupy only a small portion of the total cultivated land. Tobacco is raised on small plots of less than 1 to 5 cuerdas in size. It occupies only about one-fifth of the total acreage. More than half the land is in rotation pasture and forest, and the remainder in minor crops. Dwellings and farmsteads are dispersed in a relatively uniform pattern. The small farms and field patterns emphasize this distribution. Only along major roads, particularly at intersections, are dwellings found in clusters. The farmsteads usually consist of the dwelling and a tobacco barn. The tobacco barn is the most conspicuous feature in the tobacco areas. Barns vary in size and shape, but typically are twice as long as they are wide—approximately 40 x 80 ft. They are built to provide a well ventilated but dry place for tobacco drying. Sides are often constructed of thatch (banana or plantain leaves) and the roof of sheet metal. Some are made entirely of wood. Tobacco barns are not always in immediate association with a dwelling, but may be placed apart, particularly if the dwelling site is not favorable for the tobacco barn. Preferable barn sites are on low ridges where good ventilation is available, yet some protection from hurricane winds is possible.

In addition to the tobacco barns on the farms, some large privately or cooperatively owned barns are found in tobacco areas. These are much larger than the farmstead barns and may be found isolated or in groups. The tobacco warehouse is another feature of these areas. Warehouses are large, one-storied buildings always located on a main road. The large cigar factories near Comerio, Cayey, and Caguas are located outside the tobacco farming area, thus do not form part of the agricultural settlement pattern.

Another conspicuous feature in the tobacco land-use pattern is seasonal. Tobacco is planted in seedling beds and the seedlings transplanted to the fields. The seedling beds are covered with a cheesecloth sheet 4 to 5 ft above the ground. This protective covering is conspicuous on the landscape during the fall months.

The road net in tobacco areas is the least well developed of all the agricultural type areas. Tobacco is cultivated on small plots in rugged country by hand labor and does not require rapid handling, thus a well developed road net has not evolved. Many farms are reached only by jeep trails or foot paths.

Coffee. Coffee, like tobacco, is cultivated in the rugged mountain country on land too steep for sugar cane or pineapple production. Further, it is grown on deep, acidic soils not suited for tobacco, while tobacco is grown on shallow, neutral soils not suited for coffee. Where coffee and tobacco are grown in the same geographical area, coffee is usually found at the lower elevation and in the basins, with tobacco on the upper slopes.

The field pattern produced by coffee cultivation is the least distinct of all the agricultural types. Coffee is a perennial, therefore fields need not be cultivated each year and have a tendency to be curvilinear rather than rectangular or angular in shape. Also, coffee is grown under the shade cover of other trees, producing a forest-like aspect. Coffee areas are characterized by large irregular fields, forest lands, and scattered small subsistence crop plots. Most land not used for coffee is left in forest or is pasture land. Two types of settlement pattern occur in coffee areas. Where large coffee haciendas predominate, the pattern is agglomerated. Each large hacienda will include an agglomeration of workers' dwellings; few scattered dwellings will be found. In areas where smaller coffee fincas are typical, the dispersed pattern of settlement predominates. Farms are smaller and workers' dwellings are scattered.

The coffee farmstead always consists of three major elements—the house, the coffee barn, and the coffee drying floor. Coffee drying racks on rollers may also be present, and miscellaneous sheds or barns are common. One of the farmstead buildings may be constructed well off the ground to accommodate the drying rack on rollers. The coffee barn is distinctive as it is constructed to house the machinery for husking and hulling the coffee beans and thus is at least the height of a two-story building. The coffee drying floor is a large concrete slab near the coffee barn, and may vary from 30 to 150 ft in length.

Road patterns in the coffee areas are the least well developed on the island. Coffee is a non-perishable crop, farms are large in size, and settlements either dispersed or clustered around the hacienda, so the need for well developed roads is relatively minor when compared to sugar cane and pineapple areas.

Minor crops. Minor crops (frutos menores) dominate the agricultural economy in a number of areas in Puerto Rico where conditions of slope and soils are too poor to support a commercial crop. Minor crops are frequently intertilled, which makes it difficult to distinguish one specific crop from another. The minor crop areas are confined to rugged or hilly terrain. Small farms with small and irregularly shaped fields predominate. About half the land area is minor crops, two-fifths pasture, and a small amount in some cash crop such as coffee or tobacco. The small farms favor a high density distribution of dwellings which are uniformly dispersed. The minor crops areas have the highest density of dwellings of the agricultural regions of Puerto Rico. Minor crop farmsteads are unique in that they consist of one small, often ramshackle dwelling. Occasionally a barn or shed may be in evidence, but minor crops need no special equipment or processing demanding structures on the farmstead. Road patterns in minor crops areas are similar to those in tobacco areas. Few farmsteads are located on main roads, most being served by trails and paths. Much of the farm produce is used locally, and that which is marketed is relatively non-perishable so a good road system is not an economic necessity. With the recent and current highway construction program in Puerto Rico, the transportation pattern in the various agricultural areas is undoubtedly changing. Soon all areas will be served by hard-surfaced, all-weather roads.

Dairying and poultry. Dairy farms are found in areas with the same physical and economic conditions favorable to cane and pineapple production. Dairy farms and the associated fields must be large to support cattle herds efficiently. The farms are seldom less than 50 cuerdas in size. Fields and pastures vary from 20 to over 100 cuerdas in size. Over half the farm is in permanent pasture. Small plots, 3-50 cuerdas in size, may be in forage crops and occasionally sugar cane. Density and distribution of dwellings and structures is also similar to that in cane and pineapple areas. Agglomerations of workers' dwellings are located on poorer lands or associated with the farmstead. The farmstead in the dairy area is differentiated from those in the cane and pineapple areas primarily by the distinctive dairy barn, a long, low, open-sided structure. Silos are evident only in southern Puerto Rico. The typical Puerto Rican dairy barn is large in order to house grinding machinery for fodder as well as the cattle. (Frequently a farmstead will have a second barn for young stock which will not necessarily be of the long, low, open-sided type.) Road systems are well developed in dairying regions as milk is a perishable product and must be shipped to market rapidly. Within the farm, cattle lanes are well established between fields, but the network of auto roads is not as intense as in the cane areas.

Poultry farming is rapidly increasing in Puerto Rico. The La Plata area, particularly, shows evidence of a new agricultural settlement pattern evolving. Groups of long, low, narrow poultry houses are the conspicuous and distinctive features in this pattern. The poultry farms lack the large forage and pasture field patterns of the dairy region.

Industry

Puerto Rico, long regarded as strictly agricultural, has concentrated on industrial development in recent years. Prior to 1940 most Puerto Rican manufacturing was based on agricultural products. In 1939-40, for example, sugar products accounted for 35% of the manufacturing income. In 1961-62 sugar products, while increasing in total value, accounted for less than 8% of the manufacturing income (Commonwealth of Puerto Rico Report, 1962).

The economics and politics of Puerto Rican industry, manufacturing, and trade is somewhat involved and not specifically pertinent here. Suffice it to say that by such means as offering a 10-year tax-free period to new industries in addition to advice and aid on problems of location, labor, language, etc., the Puerto Ricans have induced American capital and industry to locate in Puerto Rico. Since 1940, when the industrialization program was initiated, over 700 new or expanded industries have taken advantage of the 10-year tax-free offer. Currently, new industries are opening at the rate of 70 per year (Hancock, 1960). Being relatively poor in native raw materials, industrial growth in Puerto Rico depends on use of imported materials or agricultural products produced on the island. Much of the new industry consists of assembling small, easily shipped components into finished products which, again, are easily and economically shipped, or of processing of bulk materials for products usable on the island.

Puerto Rican industry can be divided into four general types: (1) processing of agricultural or food products, (2) small industry, (3) heavy industry and (4) construction and power development.

Agricultural and food products

The sugar centrals, producing molasses and sugar, are such an integral part of the sugar-cane farming process as to be considered more agricultural than industrial. Rum distilleries are located at Ponce, Mayagüez, and Catano (just outside of San Juan).

Cigars and chewing tobacco are the major products derived from Puerto Rican tobacco. Chewing tobacco is largely a cottage-type industry providing cash for a few individuals. Cigar manufacturing has grown in recent years. Previously it was a scattered small-shop type industry. There are now three large cigar factories operated by the Consolidated Cigar Company. These are located at Caguas, Comerio, and Cayey and produce such brand name cigars as Dutch Masters.

Stokely-Van Camp operates a pineapple cannery near Manati. Practically no citrus fruits are processed for export. Some juices such as papaya, coconut, and orange are canned and bottled for local consumption.

All Puerto Rican coffee is locally consumed. Most is processed and packaged by the coffee cooperatives.

Two large tuna fish canneries operate at Ponce (Chicken-of-the-Sea) and Mayagüez (Star Kist) and a third is under construction at Mayagüez. The tuna is brought from African waters as Puerto Rican waters are considered too deep for profitable commercial fishing.

Two large rice mills process bulk rice imported to the island. A flour and feed mill processes bulk wheat and grains for cattle feed as well as flour.

Meat and poultry packing plants, small canneries, and breweries process local products to produce food and beer for island consumption.

Small industries

The small industries are those manufacturing plants which process component parts, semi-finished products, or use economically imported raw materials. For example, nearly all American-made electric shavers are assembled in Puerto Rico, and about one fourth of all brassieres* sold in the U. S. are finished in Puerto Rico. Some of the well-known American companies operating plants in Puerto Rico are General Electric, Sunbeam, Western Electric, Sprague Electric, Sperry Rand, American Can, Carborundum Corporation, and Phelps Dodge.

Puerto Rico has long been known for its hand needlework (one of the few native handicrafts). Drawing on this capability are the clothing and leather goods industries. Van Raalte, BVD, W. R. Grace, and Beatrice Needlecraft represent some of these small industries.

Heavy industries

The heavy industries in Puerto Rico include the processing of petroleum, chemicals, steel, and cement. All of these except cement are based on imported raw materials.

There are two large oil refineries in Puerto Rico. The Commonwealth Oil Refining Company is located at Guayanilla on the south coast within the sphere of the Ponce urban area. The Caribbean Refining Company is located at Catano, the major industrial suburb of San Juan.

The manufacturing of chemicals has evolved from the petroleum industry. Large chemical plants have been constructed in the vicinity of the refineries and use by-products of the refineries. On the south side of the island, the Wyandotte Chemicals Corporation has established a chlorine and caustic soda plant in the Penuelas area, and Caribe Nitrogen, Inc. operates at Guanica Bay. In the San Juan-Catano area, Union Carbide and Alkaloid, Inc. have established plants using by-products of the refinery. Union Carbide manufactures polyethylene plastic from raw ethylene.

Steel is manufactured from domestic and imported scrap iron. Currently, there are two steel plants in Puerto Rico, both in the San Juan area. Siderurgica is at Catano and Danrich at Bayamón.

The Ponce Cement Corporation of Ponce and the Puerto Rico Cement Corporation at San Juan are the two large cement plants on the island. Raw materials for cement are produced on the island and most of the cement produced is used on the island.

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*One report quotes "86% of American brassieres are now made there" (Rand, 1958). The figure is so high it is assumed to be a misprint and probably should be 26%.

Construction and power

Industrialization in Puerto Rico has necessarily meant a corresponding increase in power production and construction. As of June 1961 there were 16 hydroelectric plants and 4 steam plants operating in Puerto Rico. In addition, two steam plants, one nuclear plant, and one gas turbine plant were under construction (Federal Power Commission, 1962). At least one of the steam plants (Palo Seco) has been completed since then.

The construction industry is booming in Puerto Rico now, and has been for at least 10 years. Housing, roads, industry, commercial establishments and schools to serve the housing areas, etc., are continuously under construction. This in turn keeps the sand and gravel companies operating at capacity and stimulates the glass, tile, and brick fabricating industries.

From the foregoing it is noted that heavy industry is concentrated in the Ponce and San Juan areas. Much of the small industry is also located in these areas in spite of attempts on the part of the Puerto Rican government to spread the smaller industries over the island. Problems of housing, education, language, and availability of such amenities as shopping and entertainment have influenced continental industrial firms to locate close to the metropolitan areas.

Recreation and tourist industry

The tourist industry has increased perhaps more than any other on the island. This industry is based on the inexhaustible natural resources of sun and sea. The government has subsidized the construction of a number of large resort hotels. These are concentrated primarily in the San Juan area, but increasing numbers are being constructed in other parts of the island, capitalizing on mountain and forest scenery and deep-sea fishing as well as the sun-drenched beaches.

Recreational attractions for the tourist include a number of other activities such as horse racing and horseback riding, cock-fights, golf, touring historic buildings and sites, and the gambling casinos.

Transportation and Communication

Transportation

The major mode of transportation on the island of Puerto Rico is by road. The highway network is good and is being improved. All-weather roads reach most villages and towns of the island, although many individual farms are still accessible only by rough trails or footpaths (Fig. 12).

The public railroad line, which at one time circled the island along the coast, is no longer operative. The small rail trackage currently in operation is privately owned by sugar centrals. These lines are narrow gage and many may be moved from field to field during the cane harvesting season. Even the sugar interests, however, are turning more and more to trucking. Commercial hauling by rail, other than sugar cane, is nil.

San Juan is the major seaport and airport on the island. Small civil airports are maintained at Ponce, Mayagüez, and several other coastal towns. Ramey Air Force Base at the northwest end of the island and Roosevelt Roads Naval Base on the east end represent the large military airfields. There is a limited capacity field at the San Juan Naval Base, and landing strips are maintained at several small military areas. In addition to San Juan, Ponce and Mayagüez operate port facilities for freight and passenger cargo. A limited amount of "tramp steamer" shipping is carried on in several other coastal towns such as Arecibo. Docking facilities for oil tankers are available near the Guayanilla refineries. Small fishing craft also operate out of coastal harbors such as Paguerra and Fajardo.

Communications

Telephone and telegraph lines serve all communities in Puerto Rico. The telephone network is such that service is physically available to any home. It is, however, still economically unattainable by many. Technical imporvements in the system and expansion are needed. Service is frequently disrupted by minor deficiencies and the present lines cannot efficiently handle the load.

Electric transmission lines serve all cities, towns and most villages. Electricity is available even in some of the more remote areas of the island.

Political and Sociological Factors

Political aspects

Politically, Puerto Rico is a commonwealth within the United States. This status is unique, and can be described in general terms as being the status of a state with the following major exceptions: (1) Puerto Rico has no congressional vote; (2) Puerto Ricans cannot vote for the U. S. President and (3) They pay no Federal taxes. Puerto Ricans are United States citizens, and they operate the Commonwealth in much the same manner as the several states. Political parties differ somewhat, as the traditional Republican and Democratic parties do not exist as such in Puerto Rico. Three parties exert the most influence in the island. These are distinguished primarily by their views on the political status of Puerto Rico. One party advocates independence, one statehood, and the third prefers to maintain the commonwealth status. The head of the state is a governor, elected by popular vote of the people.

Education

The public school system has improved immensely in Puerto Rico in recent years, but education remains one of the most pressing problems. Free schooling is provided through high school, but compulsory schooling to age 15 or 16 is not enforced. Most schools are so crowded as to necessitate two half-day sessions. Free school lunches are provided, with the morning students eating at the end of the school day and the afternoon students starting the school day with lunch. Parochial schools, both Catholic and Protestant, are numerous. These are sanctioned and encouraged in every way possible by the government as the need for schools is so acute. In the public school system, English is taught as a compulsory subject, but all other subjects are taught in Spanish. The University of Puerto Rico at Rio Piedras and the Agricultural College at Mayagüez are public universities, constantly improving in quality of education provided. The Inter-American University at San Germán and the Catholic University of Puerto Rico at Ponce are private institutions of higher education on the island. The Puerto Rican government provides and is continuously improving an effective adult education program.

Religion

Puerto Rico, reflecting the Spanish heritage, is about 80% Catholic. At the time the United States took possession of Puerto Rico in 1898, the American Board of Missions divided the island into sectors, with each of the major Protestant faiths being assigned to operate within a specified geographic area. Thus, the Protestant composition is predominantly Baptist in one area, Methodist in another, Episcopalian in another, etc. The Evangelistic faiths, not members of the Mission Board, operate over the island with various degrees of success, but with some followers almost everywhere.

Remnants of witchcraft and voodoo are noted among the lower classes. This seems to be confined to beliefs in the possible power of evil spirit, evil eyes, etc. over everyday events and personal health rather than in actively invoking witchcraft or voodoo to attain desired results.

Social classes - income - family life

Prior to industrialization, Puerto Rican society was typical of a primitive agricultural society with two classes—the peasantry and the landowners. With the coming of industrialization and advancement of economic and sociologic status, a middle class is evolving rapidly. Classes are primarily economic. Racial discrimination is no problem in Puerto Rico. Indeed there are many claims that it does not exist. However, Rand (1958) points out that dark Negroes are rare in governmental positions, on the faculty at the University of Puerto Rico, and in the professions.

Puerto Rican average income and standard of living have been rising continuously since 1940, but average income is still lower than the lowest of the states. Slums still exist and will probably always spring up in new spots as old ones are torn down.

Small houses still predominate, particularly in the country. The old wooden homes with thatched roofs and the gasoline-can huts, however, are fast giving way to low-cost concrete houses. Electric lines lead to most rural areas now, and even the small huts high on hillsides with only footpaths leading to them have bottled gas tanks conspicuously placed in the dooryard, and television aerials are evident. Most rural communities are furnished with a safe water supply. Public pumps are located within reasonable carrying distance of most homes, and for a small additional fee village or community residents may have water piped to the house.

As the economic and sociologic picture changes in Puerto Rico, so family traditions and old customs change. The family was traditionally a close-knit unit. The father was head of the household and made major decisions. The mother stayed in the home and was the dominant influence in disciplining the children. Children learned relatively rigid rules of expected behavior within the family and the community. The types of industry springing up in Puerto Rico frequently utilize female labor; the women are becoming wage earners and are absent from the home. The automobile, television and radio are taking new ways to the country, and the traditional family life is being generally disrupted in many localities.

The cultural-social-economic complex of Puerto Rico is intricately interwoven and involved. It has evolved in response to many environmental, historical and human factors. That it is treated so briefly and superficially here is regretfully due to the expediencies of time and space in view of overall project needs.

REFERENCES

Akin, W. E. (1952) The dairy industry of the San Juan region of Puerto Rico, Department of Geography, Northwestern University, Ph.D. Dissertation.

Arnow, T. and Crooks, J. W. (1960) Public water supplies in Puerto Rico, Puerto Rico Water Resources Bulletin 2, 34p.

Augelli, J. P. (1950) Geography of agriculture and settlement in interior Puerto Rico: Problems of the upper Loiza basin, Harvard University, Ph.D. Dissertation, 238p.

__________ (1955) "Rural settlement types of interior Puerto Rico—Sample studies from the upper Loiza basin" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. XIII, p. 325-336.

Back, K. W. (1962) Slums, projects, and people: Social psychological problems of relocation in Puerto Rico. Durham, North Carolina: Duke University Press. 120 p.

Barbour, W. R. (1942) Forest types of tropical America, Caribbean Forester, vol. III, no. 4, p. 137-150.

Batchelder, R. B. (1951) The subhumid plain of northwestern Puerto Rico: A study in rural land utilization, Department of Geography, Northwestern University, Ph.D. Dissertation, 255p.

__________ (1955) "Land use problems in the minor commercial agricultural region of the hinterland of Isabela" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. VI, p. 129-153.

Beard, J. S. (1944) Climax vegetation in tropical America, Ecology, vol. 25, no. 2, p. 127-158.

__________ (1953) The savanna vegetation of northern tropical America, Ecological Monographs, vol. 23, no. 2, p. 149-215.

__________ (1955) The classification of tropical American vegetation types, Ecology, vol. 36, p. 89-100.

REFERENCES (Cont'd)

Beishlag, G. (1953) Trends in land use in southeast Puerto Rico, University of Maryland, Ph.D. Dissertation, 333p.

Bonnet, J. A. (1944) "Series importantes de suelos de Puerto Rico" in El almanaque agricola de Puerto Rico, Puerto Rico Department of Commerce and Agriculture, p. 83-90.

Britton, N. L. and Wilson, P. (1923-1930) "Botany of Porto Rico and the Virgin Islands - descriptive flora - Spermatophyta" in Scientific survey of Porto Rico and the Virgin Islands, New York Academy of Sciences, vol. V, p. 1-620; vol. VI, pt. 1-3, p. 1-370; pt. 4, p. 523-582.

Brockmann, V. W. (1951) Physical land types and land utilization in the Caguas-San Lorenzo region of Puerto Rico, Department of Geography, Northwestern University, Ph.D. Dissertation.

Brunnschweiler, D. (1955) "Problems of land use in the municipios of Ciales, Morovis, and Orocovis," in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. XVI, p. 403-439.

Burchfiel, W. W. (1952) Geography of the pineapple industry of Puerto Rico, University of Maryland, Ph.D. Dissertation, 267p.

Commonwealth of Puerto Rico Government Development Bank for Puerto Rico (1962) A special report on the Commonwealth of Puerto Rico, 24p.

Cook, M. T. and Gleason, H. A. (1928) Ecological survey of the flora of Porto Rico, Journal of the Department of Agriculture of Porto Rico, vol. 12, no. 1-2, 139p.

Doerr, A. H. (1951) The relationship of human activities in southwestern Puerto Rico to the semiarid climate, Department of Geography, Northwestern University, Ph.D. Dissertation, 161p.

__________ (1955) "Environment and economic activities in southwestern Puerto Rico," in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. VIII, p. 185-211.

Dyer, D. R. (1950) The development of geographic survey techniques for the rural land classification program of Puerto Rico, Department of Geography, Northwestern University, Ph.D. Dissertation, 203p.

Garcia-Molinari, O. (1952) Grasslands and grasses of Puerto Rico, University of Puerto Rico, Agricultural Experiment Station, Bulletin no. 102, 167p.

Gleason, H. A. and Cook, M. T. (1926) "Plant ecology of Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N.Y. Acad. Sci., vol. VII, pt. 1 and 2, 173p.

Gruber, R. (1960) Puerto Rico: island of promise. New York: Hill and Wang, 216p.

Guillou, R. B. and Glass, J. J. (1957) A reconnaissance study of the beach sands of Puerto Rico, U. S. Geological Survey Bulletin 1042-I, p. 273-303.

Gulick, L. H., Jr. (1955) "Occupance summary of rural Utuado and Jayuya" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. XV, p. 369-401.

Hancock, R. (1960) Puerto Rico: a success story. Princeton, New Jersey: D. Van Nostrand Company, Inc., 182p.

__________ (1962) Puerto Rico: a travelers guide. Princeton, New Jersey: D. Van Nostrand Company, Inc.

Hanson, E. P. (1960) Puerto Rico, land of wonders. New York: Alfred A. Knopf, 320p.

REFERENCES (Cont'd)

Hanson, E. P. (1962) Puerto Rico: ally for progress. Princeton, New Jersey: D.Van Nostrand Company, Inc., 133p.

Hildebrand, F. A. (1960) Occurrences of bauxitic clay in the karst area of north central Puerto Rico, Geological Survey Research 1960, USGS Professional Paper 400-B, p. 368-371.

Hodge, E. T. (1920) "The geology of the Coamo-Guayama district, Porto Rico" in Scientific survey of Porto Rico, N. Y. Acad. Sci., vol.I, pt. 2, p. 111-228.

Holdridge, L. R. (1940) Some notes on the mangrove swamps of Puerto Rico, Caribbean Forester, vol. 1, no. 4, p. 19-29.

________ (1942) Trees of Puerto Rico, U. S. Department of Agriculture, Forest Service, Tropical Forest Experiment Station, Occasional Paper no. 1, vol. 1.

Howarth, M. (1934) Climatic studies in Puerto Rico, Clark University, Masters Thesis, 147p.

Hubbard, B. (1920) The Tertiary formations of Porto Rico, Science, New Series, vol. 51, p. 395-396.

Huebener, T. (1960) Puerto Rico today. New York: Henry Holt and Company.

Imus, H. R. (1951) The Mayagüez area of Puerto Rico: A study in farm economy analysis, Department of Geography, Northwestern University, Ph.D. Dissertation.

________ (1955) "The sugar economy of the Mayagüez area," in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. VII, p. 155-183.

Kaye, C. A. (1959a) Geology of the San Juan metropolitan area, Puerto Rico, USGS Professional Paper 317-A, 48p.

________ (1959b) Shoreline features and Quaternary shoreline changes - Puerto Rico, USGS Professional Paper 317-B, 138p.

Kinoer, J. B. and Reed, W. W. (1941) Supplementary notes on the West Indian Islands - Puerto Rico, U. S. Department of Agriculture, Yearbook of Agriculture, p. 1228.

Knox, C., Vazquez, L. and Ashizawa, R. Y. (1961) Mineral industry of Puerto Rico, Panama Canal Zone, Virgin Islands and Pacific island possessions, U. S. Department of the Interior, Bureau of Mines, Reprint from "Minerals Yearbook, 1960," vol. 3, p. 1-7.

Lobeck, A. K. (1919) Five land features of Porto Rico: A story of cause and effect, Natural History Magazine, vol. XIX, no. 6, p. 522-540.

________ (1922) "Physiography of Porto Rico," in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. I, pt. 4, p. 301-379.

Lounsbury, J. F. (1951) Rural settlement features and their association to agricultural economics in Aguas Buenas, Comerio, Corozal, and Naranjito, Puerto Rico, Department of Geography, Northwestern University, Ph.D. Dissertation, 208p.

________ (1952) "Types and patterns of rural settlement in Puerto Rico" in The rural land classification program of Puerto Rico, Northwestern University Studies in Geography no. 1, p. 219-261.

MacPhail, D. D. (1953) The cattle industry of the south coast of Puerto Rico, University of Michigan, Ph.D. Dissertation.

Meinzer, O. E. (1923) Outline of the ground-water hydrology, USGS Water-Supply Paper 494, 71p.

Meyerhoff, H. A. (1926) "Geology of the Virgin Islands, Culebra and Vieques: Physiography" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. IV, pt. 1, p. 71-141; pt. 2, p. 145-219.

REFERENCES (Cont'd)

Meyerhoff, H. A. (1931) "The geology of the Fajardo district, Porto Rico" in Scientific survey of Porto Rico and theVirgin Islands, N. Y. Acad. Sci., vol. II, pt. 3, p. 201-360

________ (1938) Texture of karst topography in Cuba and Puerto Rico, Journal of Geomorphology, vol. 1, no. 4, p. 279-295.

________ (1954) Geomorphological history of the Antillean arc, N. Y. Acad. Sci. Transactions, ser. 2, vol. 16, no. 3, p. 149-155.

Mitchell, R. C. (1954) A survey of the geology of Puerto Rico, University of Puerto Rico, Agricultural Experiment Station, Technical Paper 13, 167p.

Monroe, W. H. (1960) Sinkholes and towers in the karst area of north-central Puerto Rico, Geological Survey Research 1960, Short Papers in the Geological Sciences, USGS Professional Paper 400-B, p. B356-360.

Murphy, L. S. (1916) Forests of Puerto Rico, past, present and future, U. S. Department of Agriculture, Bulletin 354, 99p.

Naley, D. F. (1955) "Land use in Guanica, Yauco, Guayanilla and Penuelas" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch.X, p. 245-267.

Ober, F. A. (1899) Puerto Rico and its resources. New York: D. Appleton and Company, 282p.

Perloff, H. S. (1950) Puerto Rico's economic future. Chicago: University of Chicago Press, 422p.

Pico, R. (1937) Studies in the economic geography of Puerto Rico, University of Puerto Rico Bulletin, Series VIII, no. 1, 84p.

________ (1939) Land tenure in the leading types of farming of Puerto Rico, Economic Geography, vol. 15, no. 2, p. 135-145.

________ (1950) The geographic regions of Puerto Rico. Rio Piedras: University of Puerto Rico Press, 256p.

________(with the collaboration of A. F. Chaves and Z. B. de Santiago) (1954) Geografia de Puerto Rico - Parte I, Geografia fisica. (Geography of Puerto Rico - Part I, Physical geograpy). Rio Piedras: Editorial Universitaria, 230p.

Rand, C. (1958) The Puerto Ricans. New York: Oxford University Press, 178p.

Roberts, R. C. (1942) Soil survey - Puerto Rico, U. S. Department of Agriculture, Bureau of Plant Industry, in cooperation with the University of Puerto Rico Agricultural Experiment Station, Series 1936, no. 8, 503p.

Schuchert, C. (1935) Historical geology of Antillean Caribbean region or the land bordering the Gulf of Mexico and Caribbean. New York: John Wiley and Sons, Inc., 811p.

Semmes, D. R. (1919) "The geology of the San Juan district, Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. I, pt. 1, p. 33-110.

Smedley, D. (1961) Climates of the states; Puerto Rico and the U. S. Virgin Islands, U. S. Department of Commerce, Weather Bureau, Climatography of the United States, no. 60-52, 20p.

Steward, J. H. et al. (1956) The people of Puerto Rico: A study in social anthropology. Urbana, Illinois: University of Illinois Press, 540p.

Stone, R. G. (1942) "Meteorology of the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XIX, pt. 1, p. 1-138.

Thorp, J. (1941) "Climate and settlement in Puerto Rico and the Hawaiian Islands" in Climate and man, U. S. Department of Agriculture, Yearbook of Agriculture, p. 217-226.

REFERENCES (Cont'd)

Thorp, J. (1943) Asymmetry of pepino hills of Puerto Rico in relation to trade winds, Journal of Geology, vol. XLII, no. 5, p.537.

U. S. Department of Agriculture, Soil Survey Division, Bureau of Chemistry and Soils (1938) "Soils of Puerto Rico and the Virgin Islands" in Soils and man, Yearbook of Agriculture, p. 1137-1147.

U. S. Department of Commerce (1961) U. S. census of agriculture: 1959, vol. 1, Municipalities, pt. 53, Puerto Rico, 121p.

U. S. Department of Commerce, Weather Bureau (1962) Decennial census of United States climate, Puerto Rico and the Virgin Islands, no. 45, 1p.

U. S. Geological Survey (1961) Synopsis of geologic and hydrologic results, Geological Survey Research 1961, USGS Professional Paper 424-A, p. A8, 47, 61 and 90.

Wadsworth, F. H. (1949) Development of the forest land resources of the Luquillo Mountains, Puerto Rico, University of Michigan, Ph.D. Dissertation.

__________ (1950) Notes on the climax forests of Puerto Rico and their destruction and conservation prior to 1900, Caribbean Forester, vol. 11, p. 38-47.

__________ (1951-1952) Forest management in the Luquillo Mountains. I. The setting; II. Planning for multiple land use, Caribbean Forester, vol. 12, no. 3, p. 93-114; vol. 13, no. 2, p. 49-61.

Wills, B. L. (1953) Land utilization in the north-central area of Puerto Rico—Mayamon to Vega Baja, Department of Geography, Northwestern University, Ph.D. Dissertation.

__________ (1955) "The limestone belt of the north central area of Puerto Rico," in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. IV, p. 71-95.

Young, R. N. (1954) A geographic classification of the landforms of Puerto Rico, University of Wisconsin, Ph.D. Dissertation, 158p.

Maps

Federal Power Commission, Bureau of Power (1962) Principal electric facilities, Alaska, Hawaii and Puerto Rico.

Monroe, W. H. (1962) Geology of the Manatí quadrangle, Puerto Rico, USGS Miscellaneous Geologic Investigations Map I-334 (text on map sheet).

Monroe, W. H. and Pease, M. H., Jr. (1962) Preliminary geologic map of the Bayamón quadrangle, Puerto Rico. USGS Miscellaneous Geologic Investigations Map I-347 (text on map sheet).

BIBLIOGRAPHY

Akin, W. E. (1955) "The dairy industry of the San Juan area" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. III, p. 47-70.

Alberts, H. W. and Garcia-Molinari, O. (1943) Pastures of Puerto Rico and their relation to soil conservation, U. S. Department of Agriculture, Miscellaneous Publication 513, 46p.

Allee, W. C. (1962) Measurement of environmental factors in the tropical rain forests of Panama, Ecology, vol. 7, p. 273-302.

Allen, P. H. (1956) The rain forests of Golfo Dulce. Gainesville, Florida: University of Florida Press, 417p.

BIBLIOGRAPHY (Cont'd)

Anthony, H. E. (1925) "Mammals of Porto Rico, living and extinct - Chiroptera and Insectivora" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. IX, pt. 1, p. 3-96.

__________ (1926) "Mammals of Porto Rico, living and extinct - Rodentia and Edentata" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. IX, pt. 2, p. 97-241.

Arnow, T. (1961) Water-bearing properties of the rocks in the Arecibo-Barceloneta area, Puerto Rico, Geological Survey Reseach 1961, U. S. Geological Survey Professional Paper 424-C, p. 201-202.

________ and Bogart, D. B. (1960) Water problems of Puerto Rico and a program of water resources investigation, Transactions of the Caribbean Geological Conference, 2nd, Puerto Rico 1959, p. 120-129.

Banks, A. L. (Editor) (1954) The development of tropical and sub-tropical countries, London: Edward Arnold, Ltd., 217p.

Barber, H. G. (1939) "Insects of Porto Rico and the Virgin Islands - Hemiptera-Heteroptera(excepting the Miridae and Corixidae)" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol XIV, pt. 3, p. 263-441.

Barnes, H. H., Jr. and Bogart, D. B. (1961) Floods of September 6, 1960, in eastern Puerto Rico, USGS Circular 451, 13p.

Bartel, F. O. ( ) Drainage of mangrove swamps and other marshy lands in the coastal region of Puerto Rico, U. S. Soil Conservation Service and Department of Commerce and Agriculture of Puerto Rico, Agriculture and Livestock Research Bulletin no. 3.

Beard, J. S. (1948) Natural vegetation of the Windward and Leeward Islands, Oxford Forestry Memoir 21.

Beckmann, J. P. (1956) "Antilles (sauf Cuba et Antilles Vénézuéliennes)" in Amérique Latine, lexique stratigraphique internationale, International Geological Congress, Stratigraphic Commission, Centre National de Recherche Scientifique (Paris), vol. 5, fasc. 2b.

Beishlag, G. (1955) "Trends in land use in southeastern Puerto Rico" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. XI, p. 269-296.

Berkey, C. P. (1919) "Introduction to the geology of Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. 1, pt. 1, p. 11-29.

Berryhill, H. L., Jr. (1961) Ash-flow deposits, Ciales quadrangle Puerto Rico, and their significance, Geological Survey Research 1961, USGS Professional Paper 424-B, p. 224-226.

____________, Briggs, R. P., and Glover, Lynn, III (1960) Stratigraphy, sedimentation and structure of Late Cretaceous rocks in eastern Puerto Rico, preliminary report, American Association of Petroleum Geologists Bulletin, vol. 44, no. 2, p. 137-155.

Briggs, R. P. (1960) Laterization in east-central Puerto Rico, Transactions of the Caribbean Geological Conference, 2nd, Puerto Rico 1959, p. 103-119.

__________ (1961) Recent shoreline changes and sedimentation at Puerto Arecibo and vicinity Puerto Rico, Shore and Beach, vol. 29, no. 1, p. 27-37.

__________, and Pease, M. H., Jr. (1960) Compressional graben and horst structures in east-central Puerto Rico, Geological Survey Research 1960, USGS Professional Paper 400-B, p. 365-366.

BIBLIOGRAPHY (Cont'd)

Brockman, V. C. (1955) "Land types and land utilization in the Caguas-San Lorenzo region" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. XII, p. 297-323.

Burchfiel, W. W. (1955) "The pineapple industry" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. V, p. 97-128.

Butterlin, J. (1949) Greater Antilles: geologic structure, Société Haitienne d'Histoire et de Géographie Revue, vol. 20, no. 74, p. 75-87.

__________ (1956) La constitution géologique et la structure des Antilles. Paris: Centre National Recherche Scientifique, 453p.

Cable, R. M. (1956) "Marine Cercariae of Puerto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVI, pt. 4, p. 441-577.

__________, Conner, R. S. and Balling, J. W. (1960) "Digenetic trematodes of Puerto Rican shore birds" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVII, pt. 2, p. 187-255.

Caribbean Commission (1950) Soil science in the Caribbean, Report of Soils Conference held in Puerto Rico, March 30-April 8, 1950.

Carpenter, J. C. (1948) Stabilize muck in Puerto Rico, Engineering News-Record, vol. 141, no. 4, p. 52-54.

Clark, H. L. (1933) "A handbook of the littoral echinoderms of Porto Rico and the other West Indian Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVI, pt. 1, p. 1-147.

Comstock, W. P. (1944) "Insects of Porto Rico and the Virgin Islands— Lepidoptera (suborder) Rhopalocera (superfamily) Papilionoidea (true butterflies)(superfamily) Hesperioidea (skippers)" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XII, pt. 4, p. 421-622.

Cook, O. F. and Collins, G. N. (1903) Economic plants of Porto Rico, Contribution of U. S. National Herbarium, vol. 8, pt. 2, 269p.

Corbet, A. S. (1935) Biological processes in tropical soils with special reference to Malaysia. Cambridge, England: W. Heffer and Sons, Ltd., 156p.

Corwin, E. H. (Editor) (1949) Ecology of health. New York: Commonwealth Fund, 196p.

Coryell, H. N. and Ohlsen, V. (1929) "Fossil corals of Porto Rico, with descriptions also of a few recent species" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. III, pt. III, p. 167-236.

Crum, H. A. and Steere, W. C. (1957) "The mosses of Porto Rico and the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. VII, pt. 4, p. 399-599.

Curran, C. H. (1928) "Insects of Porto Rico and the Virgin Islands - Diptera or two-winged flies" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XI, pt. 1, p. 1-118.

Dachnowski-Stokes, A. P. and Roberts, R. C. (1934) Saline peat profiles of Puerto Rico, Journal of the Washington Academy of Science, vol. 24, p. 175-182.

Forbes, W. T. M. (1931) "Insects of Porto Rico and the Virgin Islands: supplementary report on the Heterocera or moths of Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XIII, (supplementary part). Also Journal of the Department of Agriculture of Porto Rico, vol. XV, no. 4, p. 339-393.

BIBLIOGRAPHY (Cont'd)

Fox, A. J., Jr. (1951) Building water works in Puerto Rico, Engineering News-Record, vol. 146, no. 17, p. 32-35.

Freile, A. J. (1956) Peneplains and terraces in Greater Antilles, International geographical union, Commission for Study and Correlation of Erosion Surfaces Around the Atlantic, 8th Report, pt. 4, p. 48-49.

Galloway, J. J. and Heminway, C. E. (1941) "The Tertiary Foraminifera of Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol, III, pt. 4, p. 275-491.

Gardner, N. L. (1942) "Botany of Porto Rico and the Virgin Islands: The Myxophyceae of Porto Rico and the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. VIII, pt. 2, p. 249-311.

Gill, T. H. (1931) Tropical forests of the Caribbean. Baltimore, Maryland: Tropical Plant Research Foundation, Read-Taylor Co., 317p.

Glover, Lynn, III (1957) Occurrence of free oil in limestone concretions in Puerto Rico, American Association of Petroleum Geologists Bulletin, vol. 41, no. 3, p. 365-366.

________ and Mattson, P. H. (1960) Successive thrust and transcurrent faulting during the early Tertiary in south-central Puerto Rico, Geological Survey Research 1960, USGS Professional Paper 400-B, p. 363-365.

Golley, F., Odum, H. T. and Wilson, R. F. (1962) The structure and metabolism of a Puerto Rican red mangrove forest in May, Ecology, vol. 43, p. 9-19.

Gomez-Moreno, E. (1847) Memoria sobre las aguas minerales y la composicion y demas especialidades de la de los Banos de Coamo y San Lorenzo, Imp. del Boletin, 15p.

Gourou, P. (1961) Tropical world. New York: John Wiley and Sons, Inc., 3rd ed., 159p.

Gregory, L. E. (1946) An ecological survey of the Polytechnic Institute Arboretum, Caribbean Forester, vol. 7, pt. 1, p. 1-25.

Grossman, I. G. (1961) Ground water conditions in the lower Tallaboa Valley, Puerto Rico, Geological Survey Research 1961, USGS Professional Paper 424-C, p. 202-203.

Haas, W. H. (1940) The American empire. Chicago: University of Chicago Press, 408p.

Hagelstein, R. (1932) "Botany of Porto Rico and the Virgin Islands—Revision of the Myxomycetes" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. VIII, pt. 2, p. 241-248.

________ (1938) "Botany of Porto Rico and the Virgin Islands—Diatomaceae" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. VIII, pt. 3, p. 313-444.

Haig, I. T., Huberman, M. A. and U Aung Din (1957-1958) Tropical silviculture, Food and Agriculture Organization of the United Nations, Forestry and Forest Produce Studies, no. 13, vol. 1, 190p.; vol. II, 414p.

Hanson, E. P. (1933) Are the tropics unhealthy? Harper's Magazine, vol. 167, p. 556-568.

________ (1955) Transformation: The story of modern Puerto Rico. New York: Simon and Schuster.

Hildebrand, F. A. (1961a) Andalusite-topaz greisen near Caguas, east central Puerto Rico, Geological Survey Research 1961, USGS Professional Paper 424-B, p. 222-224.

________ (1961b) Hydrothermally altered rocks in eastern Puerto Rico, Geological Survey Research 1961, USGS Professional Paper 424-B, p. 219-221.

BIBLIOGRAPHY (Cont'd)

Hill, R. T. (1899) Porto Rico, National Geographic, vol. 10, p. 93-112.

Hitchcock, A. S. (1936) Manual of the grasses of the West Indies, U. S. Department of Agriculture, Miscellaneous Publication 243, 439p.

Holdridge, L. R. (1954) "A brief sketch of the Puerto Rican flora" in Plants and plant science in Latin America, Chronica Botanica, vol. 16, p. 81-83.

________ (1956) "Middle America" in A world geography of forest resources (S. Haden-Guest, J. K. Wright and E. M. Teclaff, Editors), American Geographical Society, Special Publication 33, p. 183-200.

Hollick, A. (1928) "Paleobotany of Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. VII, pt. 3, p. 177-389.

Horn, C. L. (1945) "Plant resources of Puerto Rico" in Plants and plant science in Latin America, Chronica Botanica, vol. 16, p. 83-85.

Hubbard, B. (1920) "Tertiary Mollusca from the Lares district, Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. III, pt. II, p. 79-164.

________ (1923) "Geology of the Lares district, Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. II, Pt. 1, p. 1-115.

Jones, C. F. (Editor) (1952) Rural land classification program in Puerto Rico, Northwestern University, Studies in Geography, no. 1, 261p.

________ and Pico, R. (Editors) (1955) Symposium on the geography of Puerto Rico. Rio Piedras: University of Puerto Rico Press, 503p.

Joseph, R. (1951) U. S. playground, Puerto Rico, Esquire, vol. 35, no. 2, p. 76, 77, and 100.

Kaye, C. A. (1951) Some paleosols of Puerto Rico, Soil Science, vol. 71, no. 5, p. 329-336.

________ (1956) Lower Tertiary of Puerto Rico, American Association of Petroleum Geologists Bulletin, vol. 40, p. 108-121.

________ (1957) Notes on the structural geology of Puerto Rico, Bulletin of the Geological Society of America, vol. 68, no. 1, p. 103-117.

Kemp, J. F. (1926) "Introduction and review of the literature-geology of the Virgin Islands, Culebra and Vieques" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. IV, pt. I, p. 1-69.

Klots, E. B. (1932) "Insects of Porto Rico and the Virgin Islands: Odonata or Dragon Flies" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XIV, pt. 1, p. 3-107.

Lehmann, H. (1954) "Der Tropische Kegelparst auf den Grossen Antillen" in Das Karstphanomen in den Verschiedenen Klimazonen, Erdkunde, Band VIII, Heft 2, p. 130-139 (text in German).

Linehan, D. (1940) Earthquakes in West Indies region, Transactions, American Geophysical Union, 21st Annual Meeting, pt. II, p. 229-232.

McGuinness, C. L. (1946) Records of wells in Puerto Rico, Puerto Rico Aqueduct and Sewer Service, in cooperation with U. S. Geological Survey, 267p.

________ (1947) Geology and ground-water resources of Puerto Rico, Economic Geology and Bulletin of Economic Geologists, vol. 42, no. 6, p. 563-571.

________ (1948) Ground-water resources of Puerto Rico, Puerto Rico Aqueduct and Sewer Service, 613p.

BIBLIOGRAPHY (Cont'd)

McDowell, D. C. (1950) Weather variation in the Caribbean, Institute of Tropical Meteorology, University of Puerto Rico, Report 30.

McLean, R. A. (1951) "The Pelecypoda or bivalve mollusks of Porto Rico and the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVII, pt. 1, p. 1-183.

MacPhail, D. D. (1955) "The cattle farms of southern Puerto Rico" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. IX, p. 213-244.

Marvel, E. (1961) Guide to Puerto Rico and the Virgin Islands.

Mason, J. A. (1941) "A large archaeological site at Capa, Utuado, with note on other Porto Rican sites visited in 1914-1915." Appendix by Rouse, Irving, "An analysis of the artifacts of the 1914-1915 Porto Rican survey" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVIII, pt. 2, p. 209-303.

Mattson, P. H. (1960) Geology of the Mayagüez area, Puerto Rico, Bulletin of the Geological Society of America, vol. 71, no. 3, p. 319-362.

__________ and Glover, Lynn, III (1960) Stratigraphic distribution of detrital quartz in Pre-Oligocene rocks in south-central Puerto Rico, Geological Survey Research 1960, USGS Professional Paper 400-B, p. 367-368.

Maury, C. J. (1920) "Tertiary Mollusca from Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. III, pt. 1, p. 1-77.

Maxon, W. R. (1926) "Descriptive flora - Pteridophyta" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XI, pt. 3, p. 373-521.

Merrin, S. (1958) Beachrock (Puerto Rico) (Abstract), Caribbean Geological Conference Report, 1st Meeting, Antigua, British West Indies, p. 37.

Miller, R. G. (1960) The interpretation of tropical vegetation and crops on aerial photographs, Photogrammetria, vol. 16, no. 3, p. 232-240.

Mitchell, G. J. (1922) "Geology of the Ponce district, Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. I, pt. 3, p. 229-300.

Mitchell, R. C. (1954a) "Age and structural relations of the peridotic and dioritic rocks of the West Indies" (abstract) in Questions diverses de géologie générale, Pt. 3: Paléontologie stratigraphique, Quaternaire et pétrographie, 19th International Geological Congress, Algiers, Comptes rendus, sec. 13, fasc. 15.

__________ (1954b) Submarine landslides, Nature, vol. 173, no. 4394, p. 119-121.

__________ (1954c) Tectonic errors from exagerrated vertical profiles, West Indies, Cahiers Géol. de Thoiry, no. 23, p. 201-205.

__________ (1955) Resena geológica de Puerto Rico, Estudios Geológicos, no. 26, p. 203-216.

__________ (1957) "Die Geologische Bedeutung von Schwereuntersuchungen auf Puerto Rico" in Neues Jahrbuch fur Geologie und Paläontologie, (Monatshefte), Heft 5, p. 206-215 (text in German).

Moneymaker, B. C. (1947a) Geology of Dos Bocos Dam, Puerto Rico (Abstract), Bulletin of the Geological Society of America, vol. 58, no. 12 (pt. 2), p. 1210.

__________ (1947b) Geology of Garzas Dam, Puerto Rico" (Abstract), Bulletin of the Geological Society of America, vol. 58, no. 12 (pt. 2), p. 1210-1211.

__________ (1947c) Geology of the Garzas power tunnel, Puerto Rico (Abstract), Bulletin of the Geological Society of America, vol. 58, no. 12 (pt. 2), p. 1211.

BIBLIOGRAPHY (Cont'd)

Netzer, D. L. (1953) Climate and agricultural land utilization in Puerto Rico, University of Illinois, Ph.D. Dissertation.

Nichols, J. T. (1929-1930) "The fishes of Porto Rico and the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. X, pt. 2 and 3, p. 161-399.

Noll, J. (1953) Silting in the Caonillas Reservoir, Puerto Rico, U. S. Soil Conservation Service, Technical Paper 199, 22p.

Northrop, J. (1954) Bathymetry, Puerto Rican Trench, Transactions, American Geophysical Union, vol. 35, no. 2, p. 221-225.

Nyyssonen, A. (1962) Aerial photographs of tropical forests, Unasylva, vol. 16, pt. 1, p. 2-12.

Osborn, H. (1935) "Insects of Porto Rico and the Virgin Islands: Homoptera (excepting the Sternorphynchi)" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XIV, pt. 2, p. 111-260.

Osburn R. C. (1940) "Bryozoa of Porto Rico with resume of the West Indian Bryozoan fauna" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVI, pt. 4, p. 321-486.

Parry, J. H. and Sherlock, P. M. (1956) A short history of the West Indies. New York: St. Martins Press, 316p.

Pease, M. H., Jr. (1960) Structural control of hydrothermal alteration in some volcanic rocks in Puerto Rico, Geological Survey Research 1960, USGS Professional Paper 400-B, p. 360-363.

Pedreira, A. S. (1932) Bibliografia Puertorriquena 1493-1930, Monograflas de la Universidad de Puerto Rico, Serie A, Estudios Hispanicos num. 1, Madrid, Imprenta de la Libreria y Casa Editorial Hernando (s.a.), 707p.

Poole, B. L. (1951) The Caribbean Commission: background of cooperation in the West Indies. Columbia, South Carolina: University of South Carolina Press, 303p.

Price, A. G. (1939) White settlers in the tropics, American Geographical Society, Special Publication 23, 311p.

Puerto Rico Department of Agriculture and Commerce (1948) Insular forest atlas, Puerto Rico Forest Service (2 vol.).

Puerto Rico Reconstruction Administration (1940) Puerto Rico: A guide to the island of Boriquen. New York: The University Society, Inc. (American Guide Series), 409p.

Rainey, F. G. (1940) "Porto Rican archaeology" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVIII, pt. 1, p. 1-206.

Rathburn, M. J. (1933) "Brachyuran crabs of Porto Rico and the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XV, pt. 1, p. 1-121.

Reck, D. (1939) Puerto Rico and the Virgin Islands. New York: Farrar and Rinehart, 241p.

Record, S. J. and Hess, R. W. (1943) Timbers of the New World. New Haven: Yale University Press, 640p.

Richards, P. W. (1952) The tropical rain forest: An ecological study. Cambridge, England: Cambridge University Press, 450p.

__________ (1955) The secondary succession in the tropical rain forest, Science Progress, vol. 43, p. 45-57.

BIBLIOGRAPHY (Cont'd)

Richards, P. W., Tansley, A. G. and Watt, A. S. (1940) The recording of structure, life form, and flora of tropical forest communities as a basis for their classification, Journal of Ecology, vol. 28, p. 224-239.

Riehl, H. (1954) Tropical meteorology. New York: McGraw-Hill Book Company, 392p.

Rouse, I. (1952a) "Puerto Rican prehistory: Introduction: Excavations in the west and north" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVIII, pt. 3, p. 307-460.

_______ (1952b) "Puerto Rican prehistory: Excavation in the interior, south and east; chronological implications" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVIII, pt. 4, p. 463-578.

Russell, R. J. (1963) Recent recession of tropical cliffy coasts, Science, vol. 139, no. 3549, p. 9-15.

Schaus, W. (1940a) "Insects of Porto Rico and the Virgin Islands—Moths of the family Noctuidae" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XII, pt. 2, p. 177-290.

_______ (1940b) "Insects of Porto Rico and the Virgin Islands—Moths of the families Geometridae and Pyralididae" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XII, pt. 3, p. 291-417.

Schmidt, K. P. (1928) "Amphibians and land reptiles of Porto Rico, with a list of those reported from the Virgin Islands," in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. X, pt. 1, p. 1-166.

Schmitt, W. L. (1935) "Crustacea Macrura and Anomura of Porto Rico and the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XV, pt. 2, p. 125-227.

Seaver, F. J., Chardon, C. E. et al. (1926) "Botany of Porto Rico and the Virgin Islands - Mycology" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. VIII, pt. 1, p. 1-208.

_______, Toro, R. A. and Kern, F. D. (1932) "Botany of Porto Rico and the Virgin Islands—Supplement to mycology" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. VIII, pt. 2, p. 209-240.

Shoemaker, C. R. (1935) "The amphipods of Porto Rico and the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XV, pt. 2, p. 229-253.

Shurbet, G. L. (1956) Gravity reconnaissance survey of Puerto Rico, Bulletin of the Geological Society of America, vol. 67, no. 4, p. 511-534.

_______ (1957) Puerto Rican Trench, gravity anomalies and structure, part 3, Bulletin of the Geological Society of America, vol. 68, no. 2, p. 263-266.

Siddiqi, A. A. and Cable, R. M. (1960) "Digenetic trematodes of marine fishes of Puerto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVII, pt. 3, p. 257-369.

Slodowski, T. R. (1958) Geology of the Yauco area, Puerto Rico (Abstract), Dissertation Abstracts, vol. 18, no. 1, p. 200-201.

Smith, R. M. and Chandler, J. V. (1951) Tropical kudzu moves into Puerto Rico, Crops and Soils, vol. III.

Smith, R. V. (1957) Characteristics and locational problems of Puerto Rican industrialization, Department of Geography, Northwestern University, Ph.D. Dissertation.

Stehle, H. (1945-1946) Forest types of the Caribbean islands, Caribbean Forester, vol. 6, p. 273-408; vol. 7, p. 337-709.

BIBLIOGRAPHY (Cont'd)

Swinnerton, A. C. (1942) "Hydrology of limestone terraces" in Physics of the earth, pt. 9, Hydrology (Meinzer, O. E., Editor), p. 656-677.

Swisher, C. L. (1958) Agricultural development regions and sub-regions of Puerto Rico, Department of Geography, Northwestern University, Ph.D. Dissertation.

Thorp, J. (1932) Some important soil profiles of southern Puerto Rico, Soil Science, vol. 34, p. 241-257.

________ and Smith, L. R. (1933) Concerning the origin of the white quartz sands of northern Puerto Rico, Journal of the Department of Agriculture, Puerto Rico, vol. 17, p. 157-170.

Tobiaski, R. A., Bassett, J. R. and Rush, E. S. (1960) Trafficability predictions in tropical soils; Puerto Rico study, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Miscellaneous Paper no. 4-355, Report 2, 76p.

Tosi, J. A., Jr. (1959) Forest land utilization in western Puerto Rico, Clark University, Ph.D. Dissertation, 479p.

Treadwell, A. L. (1939) "Polychaetous annelids of Porto Rico and vicinity" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. XVI, pt. 2, p. 151-313.

Turner, M. D. (1956) Beaches and beach erosion, Shore and Beach, vol. 24, no. 2, p.4-8.

__________ (1958) Geology of the San Sebastian area, Puerto Rico (Abstract), Caribbean Geological Conference Report, 1st Meeting, Antigua, British West Indies, December, 1955, p. 25.

U. S. Department of Agriculture, Forest Service (1940) Caribbean National Forests of Puerto Rico.

U. S. Department of the Army, Corps of Engineers, Beach Erosion Board (1948) Punta las Marios, San Juan, Puerto Rico, beach erosion control study, U. S. 80th Congress, House Document 769, 16p.

U. S. Department of Commerce, Weather Bureau (1961) Generalized estimate of probable maximum precipitation and rainfall frequency data for Puerto Rico and the Virgin Islands for areas to 400 square miles, duration to 24 hours and return periods from 1 to 100 years, Cooperative Studies Section, Hydrologic Service Division, Weather Bureau, for Engineering Division, Soil Conservation Service, Department of Agriculture.

U. S. Department of Labor (1950) The cement industry in Puerto Rico, Wage and Hour and Public Contracts Division.

U. S. Department of Labor (1950) Lumber and wood products industry in Puerto Rico, Wage and Hour and Public Contracts Division.

U. S. Naval Photographic Interpretation Center (1952) Aerial photo interpretation of trafficability characteristics of pocket beaches, Vieques Island, Puerto Rico, PIC 114-51, 39p.

University of Puerto Rico, Agricultural Experiment Station (1941) Soils of Puerto Rico - classified by geological formation, series, types, phases with productivity rating of each based on inherent quality of land, area, and percent of total area, Mimeo Report 19.

Upson, A. T. (1946) "Forest and land tenure in Puerto Rico" in Caribbean land tenure symposium, Caribbean Commission, Committee on Agriculture, Nutrition, Fisheries and Forestry of the Caribbean Research Council, p. 233-237.

Usera-Alarcon, J. (1868) Aguas minero-medicinales de Coamo, Imp. Militar de Gonzalez, Puerto Rico, 15p.

BIBLIOGRAPHY (Cont'd)

Vandercook, J. W. (1939) Discover Puerto Rico. New York: Harper and Brothers, 44p.

Van Deusen, R. J. and E. K. (1931) Porto Rico: A Caribbean isle. New York: Henry Holt and Company, 342p.

Van Name, W. G. (1930) "The ascidians of Porto Rico and the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. X, pt. 4, p. 403-512.

Vazquez, L. (1958) Silica sands of Puerto Rico (Abstract), Caribbean Geological Conference Report, 1st Meeting, Antigua, British West Indies, December, 1955, p. 42.

Velarde, J. (1946) "The land authority of Puerto Rico" in Caribbean land tenure symposium, Caribbean Commission, Committee on Agriculture, Nutrition, Fisheries and Forestry of the Caribbean Research Council, p. 203-222.

Velez, I. (1950) Plantas indeseables en los cultivos tropicales. Rio Piedras: University of Puerto Rico Press, 497p.

_______ (1957) Herbaceous angiosperms of the Lesser Antilles, Biology Department, Inter-American University, 121p.

Wadsworth, F. H. (1944) Development of a Maria plantation on a poor site, Caribbean Forester, vol. 5, p. 207-211.

_______ (1957) Tropical rain forest, Food and Agricultural Organization, Forestry and Forest Products Studies, Tropical Silviculture, vol. II, no. 13, p. 13-23.

_______, and Bonnet, J. A. (1951) Soil as a factor in the occurrence of two types of montane forest in Puerto Rico, Caribbean Forester, vol. 12, p. 67-69.

_______, and Englerth, G. H. (1959) Effects of the 1956 hurricane on forests in Puerto Rico, Caribbean Forester, vol. 20, no. 1 and 2, p. 38-51.

Weaver, J. D. (1958) Utuado pluton, Puerto Rico, Bulletin of the Geological Society of America, vol. 69, no. 9, p. 1125-1141.

Wetmore, A. (1927) "The birds of Porto Rico and the Virgin Islands" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. IX, pt. 3 and 4, p. 248-569.

Whitebeck, F. (1926) Geographic influences in the development of Porto Rico, Journal of Geography, vol. XXV, no. 1, p. 8-20.

_______ (1930) "The sugar industry of Puerto Rico", Journal of Geography, vol. XXIX, p. 363-371.

White, D. G. (1948) Bamboo culture and utilization in Puerto Rico, Puerto Rico Experiment Station in Mayagüez of the U. S. Department of Agriculture, Circular 29, 34p.

Wilgus, A. C. (Editor) (1959) The Caribbean: natural resources. Gainesville: University of Florida Press, 315p.

Wilson, H. M. (1900) Puerto Rico - its topography and aspects, Bulletin, American Geographical Society, vol. XXXII, no. 3, p. 220-238.

Wolcott, G. N. (1936) Insectae Borenquenses, Agriculture Experiment Station, Journal of Agriculture of the University of Puerto Rico, vol. XX, no. 1, 627p.

Worzel, J. L. and Ewing, M. (1954) Gravity anomalies and structure of the West Indies, Bulletin of the Geological Society of America, vol. 65, no. 2, p. 195-200.

Young, R. N. (1952) A karst topography of Puerto Rico (Abstract), Indiana Academy of Sciences Proceedings, vol. 62, p. 225.

BIBLIOGRAPHY (Cont'd)

Young, R. N. (1955) "A geographic classification of the landforms of Puerto Rico" in Symposium on the geography of Puerto Rico, (C. F. Jones and R. Pico, Editors). Rio Piedras: University of Puerto Rico Press, ch. II, p. 27-46.

Davidson, M. J. (1956) Aeromagnetic survey, Continental Shelf, West Indies (Abstract), Transactions, American Geophysical Union, vol. 37, no. 31, p. 341.

Diffie, B. W. and Diffie, J. W. (1931) Porto Rico: a broken pledge. New York: Vanguard Press, 252p.

Dinwiddie, W. (1889) "Our new possessions - Puerto Rico", Harper's Weekly, vol. 43.

Doerr, A. H. and Hoy, D. R. (1957) Karst landscape of Cuba, Puerto Rico and Jamaica, Scientific Monthly, vol. 85, no. 4, p. 178-187.

Durland, W. (1929) Forest regeneration of Puerto Rico, Economic Geography, vol. 5, no. 4, p. 369-381.

Edel, M. O. (1962-1963) Land reform in Puerto Rico, Caribbean Studies, vol. 2, no. 3, p. 26-60; vol. 2, no. 4, p. 28-50.

Ewing, J. I., Officer, C. B., Johnson, H. R. and Edwards, R. S. (1957) Geophysical investigations in eastern Caribbean: Trinidad Shelf, Tobago Trough, Barbados Ridge, Atlantic Ocean, Bulletin of the Geological Society of America, vol. 68, no. 7, p. 897-912.

Ewing, M. and Worzel, J. L. (1954) Gravity anomalies and structure of the West Indies, Bulletin of the Geological Society of America, vol. 65, no. 2, pt. I, p. 166-174.

Fettke, C. R. (1924) "The geology of the Humacao district, Porto Rico" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. II, p. 117-197.

__________ and Hubbard, B. (1919) Limonite deposits of Mayagüez Mesa, Porto Rico, Transactions of the American Institute of Mining Engineering, vol. 61, p. 97-112.

Forbes, W. T. M. (1930) "Insects of Porto Rico and the Virgin Islands—Heterocera or moths (excepting the Noctuidae, Geometridae, and Pyralididae)" in Scientific survey of Porto Rico and the Virgin Islands, N. Y. Acad. Sci., vol. VI, pt. 3, p. 373-521.

Maps

Berryhill, H. L. and Glover, Lynn, III (1961) Geology of the Cayey quadrangle, Puerto Rico, Miscellaneous Geologic Investigations Map I-319, U. S. Geological Survey (text on map sheet).

Glover, Lynn, III (1961a) Preliminary geologic map of the Salinas quadrangle, Puerto Rico, Miscellaneous Geologic Investigations Map I-337, USGS (text on map sheet).

__________ (1961b) Preliminary report on the geology of the Coamo quadrangle, Puerto Rico, Miscellaneous Geologic Investigations Map I-335, USGS (text on map sheet).

Pease, M. H., Jr. and Briggs, R. P. (1961) 1960 geology of the Comerio quadrangle, Miscellaneous Geologic Investigations Map I-320, USGS (test on map sheet).

Zapp, A. D., Bergquist, H. R. and Thomas, R. R. (1948) Tertiary geology of the coastal plains of Puerto Rico, Oil and Gas Investigations Preliminary Map 85, USGS.

APPENDIX A

Table I. Geologic history and stratigraphy.

TIME				ACTIVITY	AREA †	FORMATION / SERIES *
CENOZOIC	QUATERNARY	RECENT		OSCILLATIONS IN SEA LEVEL EARTH QUAKE SHOCKS-ETC EROSION		ALLUVIUM & REEFS
CENOZOIC	QUATERNARY	PLEISTOCENE		QUATERNARY ALLUVIAL DEPOSITION (Gentle uplift - tilting to north and east) FLUCTUATION OF SEA		SAN--JUAN-FORMATION (Aeolian)
CENOZOIC	TERTIARY	PLIOCENE		NEW UPLIFT-NEW EROSION CYCLE-MIN FLT CAGUANA PENEPLAIN UPLIFT-NEW EROSION CYCLE INITIATED		
CENOZOIC	TERTIARY	MIOCENE	U	EROSION TO ST JOHN PENEPLAIN		GUANAJIBO FORMATION (W Coast)
CENOZOIC	TERTIARY	MIOCENE	M	DIASTROPHISM & TILT-UPLIFT YOUNGER TERTIARIES ? ? ?		TERTIARY LIMESTONES NORTH COAST: AYMAMON, AGUADA, CIBAO, LARES, SAN SEBASTIAN SOUTH COAST: PONCE (UPPER MEMBER, LOWER MEMBER), JUANA DIAZ
CENOZOIC	TERTIARY	MIOCENE	L	DEPOSITION OF TERTIARY LIMESTONE		
CENOZOIC	TERTIARY	OLIGOCENE	U			
CENOZOIC	TERTIARY	OLIGOCENE	M	MAJOR DOWNWARP		
CENOZOIC	TERTIARY	OLIGOCENE	L	DEFORMATION (MILD) END OF IGNEOUS ACTIVITY		CAÑAS FORMATION
CENOZOIC	TERTIARY	EOCENE	U	VULCANISM		COAMO SPRINGS
CENOZOIC	TERTIARY	EOCENE	M	EROSION-OF-MOUNTAINS-TO-HILLS		RIO JUEYES
CENOZOIC	TERTIARY	EOCENE	L	CARIBBEAN OROGENY		
MESOZOIC	CRETACEOUS		UPPER	RENEWED VOLCANIC AND PLUTONIC ACTIVITY	LARES	RIO YAUCO SERIES RIO BLANCO SERIES RIO CULEBRINAS
MESOZOIC	CRETACEOUS		UPPER		PONCE	ENSENADA SHALE GUAYABAL LST COAMO TUFF LST PENUELAS SHALES SAN GERMAN LST RIO YAUCO SHALE
MESOZOIC	CRETACEOUS		UPPER		SAN JUAN	TUFFS, SHALES } COROZAL LST, LA MUDA LST, AGUAS BUENAS LST & CHERT BEDS CONGLOMERATE
MESOZOIC	CRETACEOUS		UPPER		FAJARDO	SAN DIEGO FORMATION FAJARDO SHALE FIGUERA FORMATION TRUJILLO ALTO LST LUQUILLO FORMATION RIO CONGLOMERATE LA MUDA LST GUAYNABO FORMATION HATO PUERCO TUFFS GUZMAN FORMATION
MESOZOIC	CRETACEOUS		UPPER		HUMACAO	COLLORES LST TUFFS & SHALES
MESOZOIC	CRETACEOUS		UPPER		COAMO-GUAYAMA	GUAYAMA SERIES SIERRA DE CAYEY SERIES
MESOZOIC	CRETACEOUS		LOWER	(OROGENIC ACTIVITY ?) VOLCANIC ACTIVITY	COAMO-GUAYAMA	BARRANQUITAS-CAYEY SERIES RIO DE LA PLATA SERIES
				CONFORMITY		? ? ?
MESOZOIC	JURASSIC		UPPER	VOLCANIC ACTIVITY & PLUTONISM EVIDENCED BY AGGLOMERATES OF INTRUSIVE & EXTRUSIVE MATERIALS CEMENTED WITH ANDESITE PORPHYRITICS		AGGLOMERATE

† Cretaceous Formations Listed in Stratigraphic Sequence Within Geographic Area

* After Mitchell

APPENDIX A

Table II. Physiographic/climatic grouping of soils.)
(After Roberts, "Soil Survey of Puerto Rico")
(Described by depth, color, texture, type; Parent material - Crop or cover supported.)

HILLS and MOUNTAINS - HUMID

Group 1 — Deep, red to purple, friable, lateritic; Tuffaceous rocks - Coffee
- Alonso (silty clay loam, clay)
- Catalina (clay, stony clay)
- Cialitos (clay)
- Los Guineos (clay)
- Malaya (clay)

Group 2 — Deep, red, friable, lateritic; Granite - Coffee
- Jayuya (silty clay loam)

Group 3 — Deep, red, friable, laterites; Serpentine - Trees
- Nipe (clay)

Group 4 — Medium depth, black, friable to plastic rendzinas; Limestone - Subsistence crops and cane
- Colinas (fine sandy loam, stony loam, clay loam)
- Soller (clay)

Group 5 — Medium depth, red, friable, lateritic; Limestone - Subsistence c rops
- Tanamá (stony clay)

Group 6 — Medium depth, brown, friable or plastic; Tuffaceous rocks - Subsistence crops and tobacco
- Daguao (clay)
- Naranjito (silty clay loam)
- Juncos (clay)
- Múcara (silt loam, silty clay loam)
- Plata (clay)
- Rio Piedras (silty clay loam, clay)
- Sabana (silty clay loam)

Group 7 — Medium depth, gray, friable; Granite - Subsistence crops and tobacco
- Cayaguá (sandy clay loam)
- Ciales (loam, clay loam)
- Pandura (loam, sandy clay loam)
- Teja (loam)
- Utuado (loam)

Group 8 — Shallow, black, friable or plastic, rendzinas; Limestone - Pasture
- Colinas (stony clay loam, clay loam - steep phase)
- Soller (clay loam)

Group 9 — Shallow, brown, friable or plastic; Tuffaceous rocks - Pasture and brush
- Múcara (silty clay loam, silt loam)
- Mariana (clay loam)
- Naranjito (silty clay loam)
- Picacho (stony clay loam)
- Yunes (silt loam, clay)

Group 10 Shallow, red, friable; Limestone - Brush
Lajas (clay)
Tanamá (stony clay)

Group 11 Shallow, brown, lithosols; Hard rocks - Trees
Rough stony land

HILLS and MOUNTAINS - HUMID/SUBHUMID

Group 12 Shallow, red or brown, friable; Serpentine - Brush
Rosario (silty clay)

HILLS and MOUNTAINS - ARID

Group 13 Medium depth, grayish-brown, friable; Granite - Subsistence crops
Vieques (loam)

Group 14 Shallow, red, friable; Limestone - Brush
Ensenada (clay)

Group 15 Shallow, brown, friable; Granite - Grass
Vieques (loam - steep phase)

Group 16 Shallow, reddish-brown, friable or plastic - Tuffaceous rocks or sandstone; Pasture
Descalabrado (silty clay)
Guayama (clay)
Jacana (clay
Juana Diaz (clay loam, silty clay)

Group 17 Shallow, dark grayish-brown, friable, rendzinas; Limestone - Pasture
Agulita (stony clay, clay)
San Germán (clay)

INNER PLAINS - HUMID

Group 18 Medium depth, brown, friable or plastic; Granite - Cane
Las Piedras (loam, clay loam)

Group 19 Medium depth, grayish-brown, plastic; Tuffaceous rocks- Cane
Cabo Rojo (clay)
Dominguito (clay)
Mabi (clay)
Moca (loam, silty clay loam, clay)
Rio Arriba (clay)

Group 20 Medium depth, black, plastic; Limestone - Cane
Camagüey (clay loam, silty clay)
Santa Clara (clay loam, clay)

INNER PLAINS - ARID

Group 21 Medium depth, black or dark brown, plastic; Limestone and Tuffaceous rocks - Cane
Barrancas (silty clay loam, clay)
Poncena (clay)
Portugués (clay)
Pozo Blanco (clay loam, clay)
Mercedita (clay)
Yauco (clay)

Group 22 Medium depth, brown, plastic; Tuffaceous rocks - Cane
Amelia (clay)
Rio Canas (clay)

APPENDIX A

TERRACES - HUMID

Group 23 Medium depth, brown, friable; Tuffaceous materials - Cane
- Fajardo (clay)
- Lares (sandy loam, silty clay loam, clay loam, clay)
- Torres (silty clay loam, clay)
- Via (clay, silty clay)

Group 24 Medium depth, gray, friable; Granite - Cane
- Humacao (sandy loam, loam, clay loam, clay)
- Mayo (loam, clay loam)

Group 25 Medium depth, gray, compact; Granite - Cane
- Candelero (sandy loam, sandy clay loam, loam, clay)

TERRACES - ARID

Group 26 Medium depth, brown, friable; Granite - Cane
- Arcadia (loam)
- Resolución (clay loam)
- Llave (sandy loam, loam)

TERRACES and ALLUVIAL FANS - SEMIARID

Group 27 Medium depth, dark grayish-brown, friable; Tuffaceous materials - Cane
- Coamo (silty clay loam, clay)
- Marchete (loam, clay loam, clay)
- Paso Seco (loam, silt loam, silty clay loam, silty clay, clay)
- Vives (sandy loam, loam, clay loam)

ALLUVIAL FANS - ARID

Group 28 Medium depth, brown, compact; Tuffaceous materials - Cane
- Fé (clay)
- Fraternidad (clay loam, clay)
- Santa Isabel (loam, silty clay loam, clay)
- Teresa (loam, silty clay loam, clay)

FLOOD PLAINS - HUMID

Group 29 Well drained, brown, friable; Tuffaceous materials - Cane
- Estación (sandy loam, loam, silt loam, clay loam, silty clay)
- Toa (fine sandy loam, loam, silt loam, silty clay loam, silty clay)

Group 30 Well drained, gray, friable; Granitic materials - Cane
- Vivi (loamy sand, sandy loam, loam, silt loam, silty clay loam, clay loam, clay)
- Riverwash

Group 31 Poorly drained, brown, plastic; Tuffaceous materials - Cane
- Coloso (loam, silt loam, clay loam, silty clay loam, silty clay, clay)
- Fortuna (clay loam, silty clay loam, clay)

Group 32 Poorly drained, gray, plastic; Granitic materials - Cane
- Irurena (loam, clay loam)
- Josefa (clay loam, clay)
- Talante (fine gravel, sandy loam, loam clay, clay loam, silty clay loam, clay)
- Maunabo (loam, clay loam, silty clay loam, clay)
- Yabucoa (loam, clay loam, clay)

FLOOD PLAINS - ARID

Group 33 Well drained, brown, friable; Tuffaceous materials - Cane
- Altura (loam, silt loam, silty clay, clay)
- San Antón (fine sandy loam, loam, silt loam, clay loam, silty clay loam, silty clay, clay)

FLOOD PLAINS and COASTAL PLAINS - HUMID

Group 34 Poorly drained, brown, plastic; Tuffaceous materials - Cane
- Martin Pena (sandy clay loam, clay)
- Vega Baja (silty clay, clay)

FLOOD PLAINS and COASTAL PLAINS - ARID

Group 35 Poorly drained, brown, plastic; Tuffaceous materials - Cane
- Aguirre (silt loam, clay)
- Vayas (loam, silt loam, silty clay loam, clay)
- Guánica (clay)

COASTAL PLAINS - HUMID

Group 36 Medium depth or deep, red or yellow, friable; Limestone - Cane and subsistence crops
- Bayamón (sandy clay loam, sandy clay, clay)
- Coto (sandy clay, clay)
- Espinosa (sandy clay, clay)
- Matanzas (sandy clay, clay)
- Vega Alta (sandy clay loam, clay loam)

Group 37 Medium depth or deep, red or yellow, very friable; Limestone - Grapefruit
- Bayamón (loamy fine sand, fine sandy loam)
- Coto (loamy sand)
- Espinosa (loamy sand, sandy loam)
- Islote (sand, loamy sand)
- Maleza (loamy sand, fine sandy loam)
- Rio Lajas (sand, sand-hardpan phase)
- Vega Alta (loamy fine sand, fine sandy loam)

Group 38 Medium depth, red or yellow, compact; Limestone - Cane
- Almirante (fine sandy loam, sandy clay, clay)
- Vega Alta (heavy subsoil phase of sandy clay loam, clay loam, clay)
- Islote (clay loam, sandy loam)

Group 39 Medium depth, gray, compact; Mixed materials - Cane
- Caguas (sandy clay loam, clay)
- Sabana Seca (sandy clay loam, clay)

Group 40 Medium depth, light colored, loose; Mixed materials - Pasture or idle
- Algarrobo (fine sand)
- Corozo (fine sand)
- Guayabo (fine sand)
- St. Lucie (fine sand)

COASTAL LOWLANDS - HUMID

Group 41 Well drained, loose - Coconuts
- Aguadilla (sand, loamy sand, sandy loam)
- Catano (sand, loamy sand)
- Palm Beach (sand)
- Coastal Beach
- Dune Sand

Group 42 Poorly drained, gray, friable - Cane and coconuts
Aguadilla (poorly drained phase of loamy sand and sandy loam)
Catano (poorly drained phase of sand and loamy sand)
Córcega (sandy loam, sandy clay)

Group 43 Poorly drained, black, plastic - Cane
Palmas Altas (loam, sandy clay loam, silty clay loam, silty clay, clay)
Pinones (sandy clay loam, silty clay, clay)

COASTAL LOWLANDS - ARID

Group 44 Well drained, gray, loose - Coconuts
Jaucas (sand)
Meros (sand)

Group 45 Poorly drained, gray, plastic or friable - Cane (salt)
Cintrona (loam, silty clay loam, clay)
Serrano (sandy loam, loam, sandy clay loam, clay)
Ursula (clay)

COASTAL SWAMPS

Group 46 Poorly drained, black; Mostly organic materials - Mangroves
Saladar (muck)
Tiburones (muck)
Peat
Pinones (clay-peaty subsoil phase)
Reparada (clay)

Table III. Classification of Puerto Rican soils according to the great soil groups.
(After Roberts, "Soil Survey of Puerto Rico")

ZONAL SOILS

1. Gray-Brown Podzolic	2. Red and Yellow Podzolic	3. Reddish-Brown Lateritic	4. Yellowish-Brown Lateritic	5. Laterite soils	6. Reddish Prairie	7. Chernozem	8. Reddish Chestnut	9. Reddish Brown	10. Red Desert
Cayaguá(21) Ciales Humacao Juncos Las Piedras Marlana(21) Naranjito(21) Plata(21) Sabana(21) Teja Utuado(21) Vía	Cabo Rojo Fajardo Jayuya(21) Lares Los Guineos(2)(21) Moca Río Arriba Vega Alta	Alonso(21) Bayamón(5) Catalina(5)(21) Cialitos(21) Islote(2) Malaya(5)(21) Matanzas(5) Maleza(2) Río Lajas Río Piedras(2) Torres(2)	Almirante Coto Espinosa	Nipe	Amelia Arcadia Barrancas Daguao(21) Dominguito(2) Llave Mabí(1) Machete Paso Seco Resolución Vives	Camagüey Coamo(8) Ponceña Río Cañas(8) Santa Clara(11)	Fé (17)(18) Fraternidad Juana Díaz Mercedita (17)(18)	Jácana(7) (8)(21)	Ensenada(21) Pozo Blanco (9)

INTRAZONAL SOILS

11. Rendzina	12. Planosol	13. Ground-Water Podzol	14. Ground-Water Laterite or Planosol	15. Wiesenboden	16. Half-Bog	17. Bog	18. Solonchak	19. Solonetz
Aguilita(9)(21) Colinas(1)(21) Portugués(7) San Germán(9)(21) Soller(3)(21) Yauco(7)	Candelero(2) Guayabo(2) Sabana Seca(2) Santa Isabel(8)	Algarrobo(2) Corozo(2)	Caguas(12)(2) Sabana Seca(2)	Guánica(8) Maunabo(1) Palmas Altas(1) Piñones(1)	Peat, shallow phase(1) Reparada(8) Saladar muck, shallow phase(1) Ursula(8)	Peat(1)(9) Saladar muck (1)(9) Tiburones muck(1)	Cintrona(9) (8)(15) Serrano(8)(9) (15)	Teresa(8)(9)

AZONAL SOILS

20. Alluvial	21. Lithosols and shallow soils	22. Sands (Dry)
Aguirre(8) Altura(7) Coloso(1) Córcega(1) Estación(1) Fortuna(1) Irurena(1) Josefa(1) Martín Peña(1)(2) Mayo(1) San Antón(8) Talante(1) Toa(1) Vayas(8) Vega Baja(1)(2) Viví(1) Tabucoa(1)(14)(16)(17)	Descalabrado(6)(7)(8)(9) Guayama(7)(8) Lajas(3) Múcara(1)(6) Pandura(1) Picacho(1) Rosario(5) Rough stony land(1) Tanamá(3) Vieques(6) Yunes(1)	Aguadilla(1) Cataño(1) Coastal beach(1) Dune sand(1) Jaucas(9) Meros(9) Palm Beach(1) Riverwash St. Lucie(2)

NOTE: Numbers in parenthesis refer to transitional or associated soil groups.

APPENDIX B: FIELD TRIP REPORT, TROPICAN

by

R. E. Frost
Chief
Photo Interpretation
Research Division

1. The following is a consolidated trip report covering the period of field activity connected with Operation TROPICAN conducted in Puerto Rico during the period 1 November to 7 December 1962.

2. The study was done under the following project numbers:

a. 8S70-05-001 Trafficability and Mobility Research

b. 8S70-09-001 Military Evaluation of Geographic Areas

c. ARPA Order 351, Amendment 1, Program Code 2860.

3. The Tropical Research Program (TROPICAN) consists of coordinated ground sampling and aerial sensing (photography, infrared and radar) of tropical surfaces for engineering, military, and scientific purposes. The Puerto Rico study has two objectives:

a. Obtain multiple images of selected transects across Puerto Rico for purposes of photoanalysis of soils, rocks, vegetation, land use, and landforms representative of tropical surfaces.

b. Special heat target sensing against and beneath the dense canopy of the rain forest (at specific request of ARPA).

4. Initial ground work was accomplished during a 10-day field trip to Puerto Rico by Messrs. Hansen, Rinker, Morgan and Frost in October for purposes of determining logistical support, selecting special target study areas, meeting with government and commonwealth personnel and location of potential pattern transects across the island. (See Trip Report "R. E. Frost and Party to San Juan, Puerto Rico, 1-10 October 1962 - Support for Tropical Research.") Equipment logistical support included the following. Airborne equipment included: photography and thermal scanners mounted in an R-4D aircraft operated by the University of Michigan under CRREL contract (AN/AAR-9 and AN/AAD-2); photography, thermal scanner and radar mounted in USAF JC-131 aircraft operated by Wright Air Development Center; and photography and thermal scanner mounted in USAF C-47 operated by Rome Air Development Center. Headquarters for the field activity was the office of G-4, Antilles Command, at Fort Brooke. The Antilles Command provided logistical support for the operation (vehicles, quarters, POL, etc.). Roosevelt Roads Naval Air Station provided parking space and minor maintenance for the R-4D and quarters for some of the personnel of Michigan and CRREL. The JC-131 aircraft and crew operated out of San Juan International Airport, Isla Verde. The C-47 aircraft and crew operated out of the National Guard facilities at San Juan International and Isla Grande (San Juan Naval Base and Coast Guard Air Strip). The Army Air Section stationed at Isla Grande furnished L-20 and H-19 aircraft for purposes of low altitude reconnaissance (hand-held photography).

5. Other government agencies either participated or sent observers. A list of participating agencies and personnel is attached. Mr. Donald Orr, assisted by SP/5 Young, placed a mine field at Salinas Training Area for purposes of "Detection in Tropical Background." Dr. George Zissis, Institute of Defense Research Corporation, spent several days in the forest

with Dr. Rinker as observers. Mr. William A. Fischer, U. S. Geological Survey, spent several days with Mr. Frost for purposes of geophysical correlations.

TRIP REPORT AND SUMMARY OF RESULTS

6. In order to accomplish the objectives set forth in each study it was necessary to conduct essentially two separate operations with some of the personnel contributing to each. The ARPA study covered the period 9 to 29 November and was under general supervision of Dr. Jack N. Rinker. He was assisted by Dr. Philip L. Johnson and Mr. Theodore C. Vogel (vegetation portion). Technical assistance and labor was provided by Pfc. Roger B. Arend and Pfc. Geoffrey H. Hamer. The Background Survey of Puerto Rico was divided as follows: Mr. Robert D. Leighty, assisted by SP/5 Jorge H. Montero, SP/5 David A Gaskin and SP/5 James P. Swing - engineering soils pattern analysis; Miss Virginia L. Prentice, assisted by Pvt. Gilbert Font-Jimenez - cultural pattern analysis; Dr. Philip L. Johnson and Mr. Theodore C. Vogel - vegetation pattern analysis; and Mr. Robert E. Frost and Mr. William A. Fischer - general landforms and rock pattern analysis. Each group attempted to obtain field information in representative pattern areas crossed by each of the aerial transect lines.

Engineering Soil Patterns
(R. D. Leighty, Civil Engineer)

7. The purpose of this portion of TROPICAN was to conduct a reconnaissance of selected Puerto Rican soils to gather information and data for correlation with visual, infrared, and radar imagery. The period 1-29 November 1962 was devoted to reconnaissance of the island. Most of the reconnaissance was accomplished by using centrally located large cities or military installations for lodging and for work in the area. From these locations a general reconnaissance was made of the area (driving roads to observe and photograph soil and rock conditions) and representative seismic and resistivity data obtained at selected sites. One 4-hour H-19 flight was utilized to obtain low oblique photographs of the southwest portion of the island. Two days were devoted to coordinated air-ground activities with USAF (RADC) IR scanner C-47 for work in mature and immature sugar cane areas. Some time was spent with Mr. Robert Benn, Waterways Experiment Station, in study of some of the trafficability prediction sites.

8. Tentative results of the soils study include: An overall appreciation for tropical soils and weathering of rocks in the tropics was obtained from the reconnaissance portion of the trip. It is estimated that 3000 miles of Puerto Rican primary and secondary roads were traveled while obtaining ground photographs and soil rock samples and checking the existing soils and geologic literature. Seismic and resistivity data were obtained at four locations on the island as a part of the overall program in the Division to correlate pattern features on aerial images with geophysical data obtained by ground means. Illustration photography (650 aerial obliques) was obtained of the southwest portion of the island from Fort Allen to Mayagüez. The coordinated air-ground effort with USAF (RADC) was successful inasmuch as the intended flight lines were covered and airborne equipment was operating (for the most part) while ground data were collected. Much of the aerial imagery is excellent.

Vegetation Patterns
Dr. P. L. Johnson (Ecologist) and
Mr. T. C. Vogel (Forester)

9. The purpose of this portion of TROPICAN was to conduct a reconnaissance of selected vegetation types of Puerto Rico for correlation with visual infrared and radar imagery. Nine days were devoted to an ecological survey of selected vegetation types in Puerto Rico. Sites were selected and briefly studied along 11 different flight lines. At each site representative ground photography was taken to characterize the vegetation and the area examined for the relationship between the community structure and its controlling environmental factors, including disturbance by man. The remainder of the time was spent in the Luquillo National Forest in connection with the vegetation portion of the ARPA study with Dr. Rinker.

10. Tentative results include: It was not possible to collect quantitative data in most sites because of insufficient time and/or equipment. Much of the field time was devoted to the ARPA project. The aerial photographs and vertical gradient tower were delayed in arriving. It will be possible to interpret the aerial imagery at these 11 sites from the observations obtained; however, it is probable that much more valuable information can be gained by revisiting the island after studying the imagery. Even though the study was handicapped by a shortage of time, many sites were visited and hurriedly studied, providing a good insight into the plant ecology of Puerto Rico. Some of these sites and types are listed below:

a. Luquillo north coastal plains—palm grove and mangrove swamp.

b. Vega Alta and Marchiquita north coastal plain—young and burned sugar cane with bamboo borders, sand dunes and San Juan formation along coast; pineapple fields.

c. Rio Abajo and Guajataca Insular Forests northern foothills, pepino hills and dissected karst plateau, Peace Corps camp—teak plantations; shade, coffee and citrus trees.

d. Mayagüez—west coastal plain, Federal Agricultural Station arboretum—mangrove swamp at Playa de Boquerón, irrigated crops in Lajas Valley, dry woodland at Guánica.

e. Cerro de Punta - cordillera central —mountain agriculture, dwarf cloud forest, mountain palm and tree fern forest.

f. El Verde - Luquillo mountains —large tabonuco stand. Playa de Humacao, south coastal plain—drained sugar cane. Fajardo east coastal plain and hills—grassy bluffs above sea. This included a trip with Dr. I. Veley to San Germán.

g. Maricao Insular Forest - cordillera central, serpentine mountains, high moist forest containing Podocarpus, Guanajibo Valley—dry overgrazed hills; La Parguera and Isla Maguey south coast—cactus and thorn desert, mangrove swamp.

h. Inter-American University, San Germán—mahogany stand. Ponce Playa, south coast—beach ridges alternating with halophytic swales. Salinas Training Area, southern foothills—disclimax savanna maintained by grazing.

Cultural Patterns
Miss Virginia L. Prentice (Geographer)

11. The major purpose of geographic participation in the Puerto Rico field exercise was to investigate representative cultural practices in relation to the natural environment with particular emphasis to be given to the potential representation of these practices on aerial imagery. To accomplish the stated mission a major portion of the available time was

devoted to reconnaissance trips to representative natural and agricultural regions of the island and to conferences with various government officials.

12. Tentative results include: During the field reconnaissance of representative agricultural regions observations were made on methods of cultivation, planting and harvest, ground appearance of crop as of date observed, settlement and transportation patterns in relation to agricultural practices, recent changes in crop emphases and, where pertinent, associated industrial enterprises. Agricultural activities thus observed included the following: sugar cane (drained, irrigated, undrained, and unirrigated); tobacco; coffee (shade grown, open grown); pineapple; frutos menores (subsistence farming, truck farming type); animal industry (cattle, chickens, hogs, goats, horses); and tree crops (coconuts, citrus, bananas, plantain, papayas, breadfruits and various spices).

Urban area studies included a reconnaissance, map and photo study of the structure of the urban complex of the San Juan area, observations on the patterns of settlement and growth of other urban areas, industrial development in selected areas (Carolina, Ponce, Mayagüez and Guanica). To supplement and substantiate the reconnaissance studies, visits were made to the following institutions or organizations:

a. Tropical Forest Research Center—to confer regarding wood products industries in Puerto Rico as well as general forest vegetation information.

b. Government Development Bank of Puerto Rico—conferred with Dr. Rafael Pico and Mr. H. Berrios regarding representative agricultural, industrial and cultural cross sections of the island. Mr. Berrios accompanied Geographer on one all-day field trip through tobacco and frutos menores regions.

c. Puerto Rico Department of Public Works, Public Relations Division—to obtain information on the master plan for transportation development on the island. (Information to be sent, as the man in charge was not available at time of visit.)

d. Department of Economic Development—to ascertain plans, procedures and progress for developing industry on the island.

e. Puerto Rico Planning Commission—to inquire as to the overall plans for the island (building, industry, agriculture, transportation, etc.), progress and alteration of previous plans, etc.

Rocks and Landform Patterns
Robert E. Frost (Civil Engineer) and
William Fischer (Geologist, U. S. Geological Survey)

13. The purpose of this portion was to obtain some ground data at selected locations along some of the transect flight lines, particularly to depict major landforms and rock types for pattern analysis. One reason Puerto Rico was selected for the overall TROPICAN study was that the island presents, in a small compact unit, dominant well-developed landform features of sedimentary, igneous and metamorphic rocks and unconsolidated recent deposits in a tropical environment.

14. Tentative results include: Because of the pressure required in connection with overall supervision of TROPICAN, field reconnaissance was limited to two L-20 reconnaissance flights, a series of short one-day trips to the western part of the island, and one three-day reconnaissance trip in company with William A. Fischer, USGS, on a circuit across and around the island. Two flights were made with the JC-131 as observer (Tri Sensor Display) and navigator (location of flight lines). Sufficient photos and ground data were obtained to illustrate and describe major landform and rock patterns on the images presenting the best landform-

rock pattern representation (may be limited to analogous extension).

ARPA Study - Heat Sensing
Dr. Jack N. Rinker (Research Physical Scientist)
and Joseph O. Morgan (Physicist)

15. The purpose of this project was to study methods of detection of small charcoal fires through a dense forest canopy.

16. The results of this mission are classified and will be released in a forthcoming report. The results were made available to ARPA in a briefing held at USA CRREL on 8 January 1963.

SUMMARY

17. Regarding the purpose of each part of the study—TROPICAL BACKGROUND SENSING and SPECIAL HEAT SENSING—the island of Puerto Rico was a wise choice for field work. The island presents a wide diversity of climate types (30 in. rain in southwest desert up to about 200 in. in the Luquillo rain forest). Major contrasts in landform reflecting susceptibility to tropical weathering of major rock types are to be found in many excellent exposures and surfaces. Airphoto patterns of landforms and associated rock types are outstanding and certainly dominate the tropical landscape. Some mistaken concepts concerning tropical soils/ rock weathering and laterization were corrected (personal concepts), thereby contributing much to better understanding of the complex interrelated environmental stresses contributing to soil formation in the tropics. Good correlation exists between cultural patterns on photos and social-economic implications and actual ground conditions. Also, the study served to further emphasize the important role of use of airphotos in planning and development of an area such as this. (Economic-social growth often phenomenal in the pattern expression on comparative photos.) The multiple images will yield much valuable information from pattern analysis standpoint. All major patterns are easily accessible by car and trail where necessary to gain ground access for correlation purposes. Luquillo National Forest, containing the island's only rain forest, proved to be an excellent setting for the special heat sensing part of the study. Puerto Rico provided an excellent location to study the impact of man on ecological groupings in a tropical environment. The ARPA program requires additional study in the field. For this the combined efforts of CRREL, University of Michigan, and Rome Air Development Center (personnel and aerial equipment of each) are urgently needed to develop certain concepts, operation techniques, define limitations and establish reliability factors of each system used (singly and in conjunction). Decisions concerning future requirements for the overall background study must await detailed analysis of data and imagery obtained. Due to malfunction of the Tri Sensor equipment on some of the lines it is essential that this portion be repeated.

ACKNOWLEDGEMENT

18. As USA CRREL representative in charge of this study I would like to acknowledge with thanks the efforts of the many personnel and agencies who helped make the study successful. To mention each one specifically would lengthen this considerably, therefore, I wish to call attention to agencies having people and/or groups of individuals actively participating.

a. The University of Michigan effort under Joseph O. Morgan. It is my opinion that this unit undoubtedly is the best in this field in the Country. Mr. Morgan and his group worked day and night and appeared to be completely dedicated to making the infrared part a success.

b. Officers and Personnel of the Antilles Command - particularly Col. Donald H. Greely, Lt. Col. C. K. Harris and Sgt. Hawkins. Personnel of Ft. Brooke and Ft. Buchannan gave much of their time in support of the operation. All were eager to help and personal relations between the Military and all research personnel were excellent - a condition which is very necessary in an operation of this type.

c. Officers and Personnel of Roosevelt Roads Naval Air Station - particularly Commander Krebs, Operations Officer. Project TROPICAN was supported out of Roosevelt Roads during a time of national emergency which caused a great load on the Navy Station (Cuban Shipping Inspection Program) and caused an increase in all Navy activities.

d. US Forest Service in Puerto Rico - Dr. Frank Wadsworth and Mr. Joseph Sposta were very helpful in providing technical assistance in identifying many of the tropical plants and in gaining access to the National Forest.

e. Personnel of Waterways Experiment Station in Puerto Rico - Mr. Robert Benn and his group for information on soils and trafficability conditions of Puerto Rico.

f. Personnel of the Various US Government and Commonwealth Government Agencies. Mr. Orlando Gonzalez, Department of Public Works, made available the aerial negatives of the latest photo coverage of Puerto Rico. Dr. Rafael Pico and his assistant Mr. Berrios gave freely of their time in discussing the economic conditions in Puerto Rico. Mr. Watson Monroe, US Geological Survey, proved to be an excellent source of geologic information.

g. To the Enlisted Men of CRREL who accompanied the technical personnel to Puerto Rico. I wish to personally call attention to many fine comments and compliments paid to these men by supervisory personnel. The men worked hard, often long hours (all night on occasion) and in good spirit.

LIST OF PARTICIPANTS

USA CRREL - Robert E. Frost, in charge
Robert D. Leighty, Civil Engineer
Dr. Jack N. Rinker, Research Physical Scientist
Dr. Philip L. Johnson, Ecologist
Virginia L. Prentice, Geographer
Theodore C. Vogel, Forester
John Y. Beck, Photographer
SP/5 David Gaskin, Geologist
SP/4 James P. Swing, Civil Engineer
SP/5 Jorge Montero, Electrical Engineer
Pfc. Roger B. Arend, Civil Engineer
Pfc. Gilbert Font-Jimenez, Civil Engineer
Pfc. Geoffrey Hamer, Geologist

UNIVERSITY OF MICHIGAN - Joseph O. Morgan, in charge
Dale S. Fisher, Research Assistant
Carl D. Miller, Research Associate
Richard E. Lane, Technician
Raymond F. Send, Technician
George England, Technician
Max R. Smith, Technician
Walter J. Schwarzhoff, Pilot
Harvey H. Doss, Co-Pilot
Joseph C. Stuky, Flight Engineer

ROME AIR DEVELOPMENT CENTFR - Alfred Stringham, in charge
- Arnold H. Lanckton, Physical Scientist
- Angelo S. Zieno, Photo Technologist
- Capt. Martin A. Poslick, Flight Test Pilot
- Capt. Myron M. Butch, Flight Test Co-Pilot
- A/1C Norman E. Maxon, Flight Test Crew Chief
- A/2C William E. Evans, Flight Test Crew
- Capt. John Gamble, Project Engineer
- S/Sgt. Sheldon Bray, Photo Processing Specialist
- Capt. John Kessinger, Photo Lab

WRIGHT AIR DEVELOPMENT CENTER - Virgil K. Yenner, in charge
- Capt. Donald E. Westbrook, Pilot
- Capt. Leonard H. Latham, Co-Pilot
- M/Sgt. Charles T. Jardina, Crew Engineer
- M/Sgt. Joseph A. McFadden, Crew Engineer
- M/Sgt. William Behnen, Equipment Operator
- T/Sgt. Thomas R. Ritter, Equipment Operator
- Hubert S. Summers, Texas Instruments Corp. Field Engineer

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