

# THE STRUCTURE OF THE SIERRA MAESTRA NEAR SANTIAGO DE CUBA

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## ABSTRACT

The rocks of the Sierra Maestra near Santiago de Cuba are chiefly well-stratified, volcanic breccias and tuffs, with interbedded limestones and andesitic intrusives. The mountains are simple block mountains, uplifted along normal east-west faults and tilted toward the north. The uplift and tilting have accompanied the subsidence of the great Bartlett Trough that lies between Cuba and Jamaica.

The fault blocks are of different age. The oldest, and highest, forms the coastal ridge west of Santiago Bay. It possibly received part of its present elevation during the Pleistocene, but the uplift has continued intermittently down to the present time. The Sierra de Boniato, farther inland and northwest of Santiago, has been uplifted in post-Pleistocene time. Immediately in front of it on the south is a lower ridge, known as the Puerto Pelado, with scarp so fresh that its age must be measured in hundreds of years rather than tens of thousands. The region is unstable, and the displacements may be expected to continue at any time.

## INTRODUCTION

The Sierra Maestra extends along the south coast of Cuba from Cape Cruz to Cape Maysi, a distance of 235 km., and forms part of the northern rim of the Bartlett Trough. The structure and geological history of the Sierra Maestra are, necessarily, closely related to the structure and history of the great trough. In December, 1930, the writer made a geological reconnaissance of the Sierra Maestra in the vicinity of Santiago and was able to obtain additional data on the nature of recent crustal movements in this region.<sup>1</sup> Since our knowledge of the deep submarine troughs is very meager, any additional information is of value.

The paved highway (Carretera Central) from Havana to Santiago, recently completed through the mountains, together with the numerous construction roads along the line of the new Santiago aqueduct,

<sup>1</sup> Most of the data presented in this paper were obtained while making a geological examination along the line of the new Santiago aqueduct and at proposed reservoir sites on the Cauto, Cañas, and Guanánicum rivers for the Department of Public Works of the Republic of Cuba. The writer desires to acknowledge his indebtedness to Sr. Eduardo I. Montoulieu, of the Department of Public Works, who accompanied him on most of his trips. The thorough acquaintance of Sr. Montoulieu with the region and his very efficient assistance made it possible to accomplish much in the relatively short time that was available.

made the region immediately west of Santiago much more accessible than it has been in the past. Also, the extensive excavations along both highway and aqueduct, as well as at some of the proposed dam sites, furnished rock exposures that were unusually good for the tropics.

#### GEOGRAPHY

The major topographic features in the area studied are roughly sketched on the contour map (Fig. 1), which has been compiled from Chart 2611 of the Hydrographic Office, United States Navy, from surveys by the Department of Public Works and from barometer readings and observations by the writer.

The name Sierra Maestra is in general use for the entire range of mountain ridges found along the south coast of the Province of Oriente; but, locally, the name is also commonly applied to the most prominent ridge, and this, in some cases, has caused much confusion. In this article the name is used for the entire range and also for the well-defined divide that follows close to the straight east-west coast from Cabo Cruz to Santiago Bay. This ridge attains an altitude of 2,005 m. (6,560 feet) in Pico Turquino, the highest point in Cuba, 75 km. west of Santiago Bay. Near its eastern end the ridge bifurcates into two spurs separated by the Arroyo Hermitaño. The northern spur is locally known as the Sierra de Cobre, and some writers have extended this name to the main ridge.

Between Santiago and Guantánamo bays the principal ridges trend northwest-southeast, but east of Guantánamo Bay and as far as Cabo Maysi the main ridge of the Sierra Maestra again parallels the coast.

On the north, the Cobre spur of the Sierra Maestra is separated from another, overlapping, east-west ridge, with precipitous, south-facing scarp, by the broad valley of the Rio Cobre. The latter ridge has been called the Sierra de Boniato in several publications,<sup>1</sup> but it is locally known as the Sierra Maestra. In order to avoid confusion with the coastal ridge the former name will be used in this paper.

<sup>1</sup> C. W. Hayes, T. W. Vaughan, and A. C. Spencer, *Report on a Geological Reconnaissance of Cuba* (Washington, 1901); Waldemar Lindgren and Clyde P. Ross, "The Iron Deposits of Daiquiri, Cuba," *Trans. Amer. Inst. Min. Eng.*, Vol. LIII (1915), pp. 40-59.

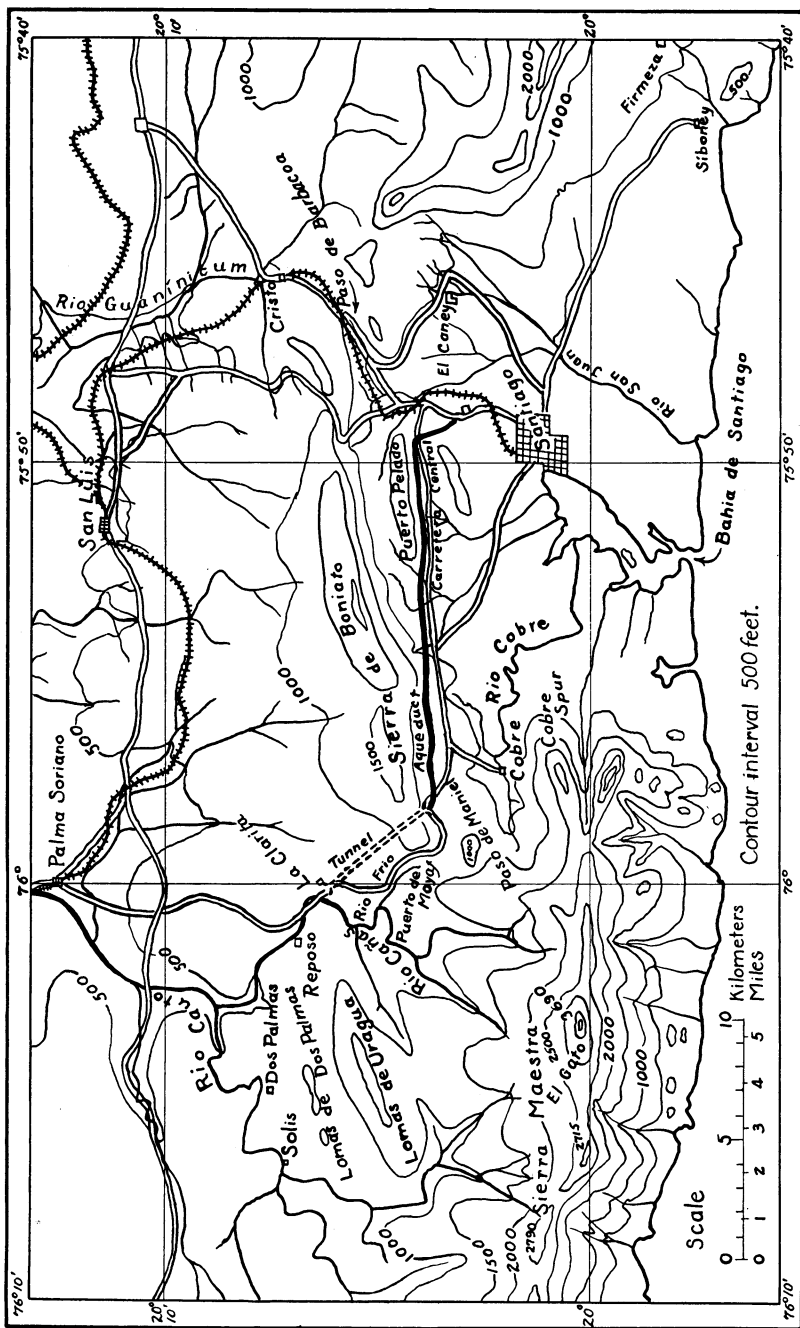


FIG. 1.—Sketch map showing major topographic features in the vicinity of Santiago de Cuba. Contour interval, 500 feet

The Sierra de Boniato (see Fig. 2) continues eastward, at an average elevation of about 1,500 feet, for 25 km., until it joins the mountain ridges west of the Santiago embayment at the Paso de la Barbacoa, through which passes the road from Santiago to Cristo. A low divide, known as the Paso del Maniel, or Puerto del Maniel, separates the head of the Cobre Valley from the drainage basin of the Rio Cañas.

Paralleling the eastern half of the Sierra de Boniato on the south is a lower ridge (see Fig. 3) known as the Puerto Pelado (literally, Barren Pass). The ridge is barren enough, but it is difficult to understand how the term *puerto* came to be applied to a ridge having such a precipitous scarp on the south that it is not crossed by a single trail. The Puerto Pelado is separated from the Sierra de Boniato by a through valley, called the Cerca de Piedra (inclosure of stone), with drainage both east and west.

Between the Puerto Pelado and Santiago Bay is an irregular range of hills, several hundred feet high. They extend in a general east-west direction and rise rather abruptly from the low ground north of the bay.



FIG. 2.—South-facing scarp of the Sierra de Boniato as seen from the Sierra Maestra. Valley of Rio Cobre in foreground. Town of Cobre on the extreme right.

North of the Sierra de Boniato is the broad featureless valley of the Guanínicum-Cauto system, which drains westward into the Gulf of Guacanayabo. The largest stream flowing south is the Rio San Juan, which has its headwaters in Barbacoa Pass, in Cerca de Piedra, and along the western slopes of Pico Escandel. It enters the ocean about 5 km. east of Santiago Bay.

The mountains of the Sierra Maestra are much more imposing than their relatively low elevations would lead one to expect, for their scarps are extremely precipitous and they rise abruptly from the ocean or from valleys that are close to sea level.

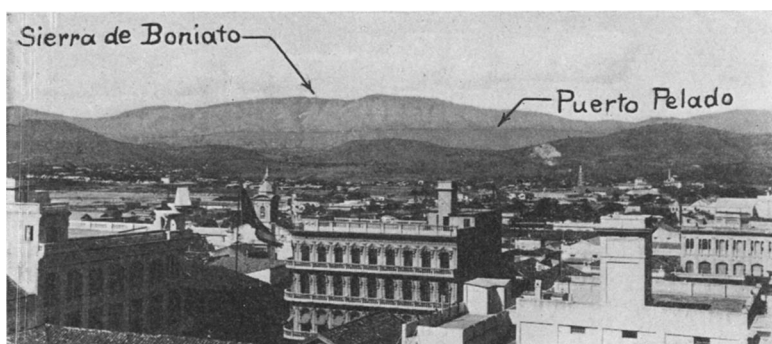


FIG. 3.—Sierra de Boniato and Puerto Pelado as seen from Santiago. Camera was facing N. 20° W.

The meager rainfall records available indicate an annual precipitation of about 95 inches in the basins of the Cañas, Cauto, and Guanínicum rivers, and about 36 inches at Santiago. There is a well-defined dry season at Santiago during the period from December to March.<sup>1</sup>

Vegetation is much more abundant on the northern slopes of the major divides, partly because of the greater rainfall and partly because the slopes are less steep. The increase in vegetation is also very abrupt in passing westward from the Cobre Valley across the low divide into the valley of the Cañas River.

<sup>1</sup> The rainfall estimates are based on incomplete records kept at the Colegio de Nuestra Señora de los Dolores in Santiago for the years 1920-30, and on observations by the staff of the Secretaria de Obras Publicas in the Cañas, Cauto, and Guanínicum valleys during the period September, 1929, to November, 1930.

## THE ROCKS

*The Cobre series.*—The Cobre series covers most of the area examined, except where igneous intrusives occur or where these older rocks are covered by the La Cruz marl of the Santiago embayment. The most abundant and most widely distributed rocks are volcanic breccias and tuffs.

The breccias are made up of angular to subangular fragments, chiefly andesitic in composition, and light green, reddish brown, or gray in color. The fragments vary in size up to blocks having diam-

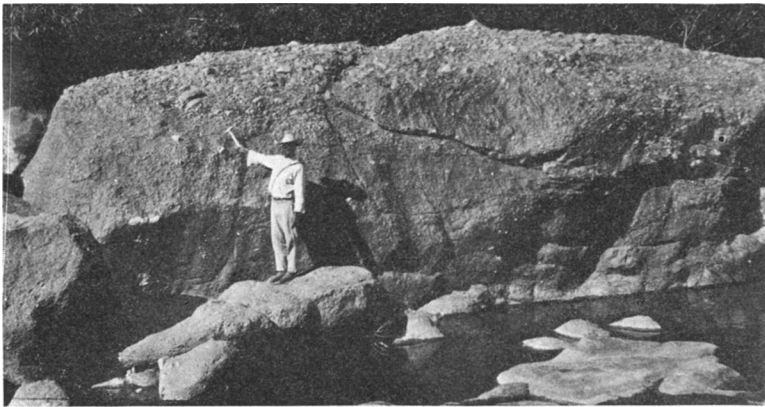


FIG. 4.—Volcanic breccia exposed in the bed of the Rio Cauto north of Solís. Passing upward from stream level, the breccia becomes coarser in texture.

eters of over a meter (see Fig. 4). At one place a block 2 m. in diameter was seen. No glassy material was identified. Fragments of white marble were found in two drill cores: one from the Rio Cauto northwest of Dos Palmas, the other from the Rio Cañas, 3 km. southwest of La Clarita. The rock is rather porous and, even where freshest, shows much alteration with the formation of calcite, chlorite, zeolites, epidote, and other secondary minerals.

The tuffs are mostly light to dark gray in color and in places show gradations into limestones and shales.

Except where coarsest, the volcanic clastics are well stratified; and, where they can be traced for long distances, as in the south-facing scarps of the Sierra de Boniato and the Puerto Pelado, the strike and dip are remarkably uniform for such materials. The

coarsest breccia was found chiefly in the western half of the area studied. The material forming the breccias and tuffs seems to have been deposited very largely, if not entirely, in water, for, in addition to being well stratified, these rocks are interbedded with limestones, and in places grade into them.

Interbedded lava flows are to be expected, and they have been reported by several geologists, but they certainly do not make up any considerable part of the volcanic series in the area immediately north and west of Santiago. In the Hayes-Vaughan-Spencer report it is stated that the higher portion of the Sierra Maestra is made up of volcanic flows and breccias, which extend across the valley of the Rio Cobre; and Section 6 on Plate I of the report indicates that the northern slope of the "Sierra de Cobre" (Sierra Maestra) is made up of volcanic flows.<sup>1</sup>

Moffet refers to a series of andesite and rhyolite flows interbedded with the breccias and tuffs at the copper mines of Cobre.<sup>2</sup> Spencer states:

The rocks exposed along the crest of the Sierra Maestra are coarse, well-stratified volcanic breccias, but upon the north slope these soon pass beneath strata showing an alternation of marine sediments and fine-grained volcanic tuffs, which are, in turn, covered by flows of basalt and still other fragmental volcanic deposits.<sup>3</sup>

The section described by Spencer is located back of Daiquiri<sup>4</sup> and was not examined by the present writer.

Some lava flows may be present in the localities visited by the writer, but it was impossible to identify them as such because of poor exposures. Since some of the dike rocks are amygdaloidal in structure it is difficult to distinguish between flows and intrusives except where the exposures are good.

<sup>1</sup> C. W. Hayes, T. W. Vaughan, and A. C. Spencer, *Informe Sobre un Reconocimiento Geológico de Cuba* (translated from the English by Pablo Ortega y Ros; 2d ed.; Havana, 1925), p. 29 and Plate I, opposite p. 64.

<sup>2</sup> F. H. Moffet, "The Copper Mines of Cobre, Santiago de Cuba" (abst.), *Amer. Geol.*, Vol. XXXII (1903), p. 64.

<sup>3</sup> A. C. Spencer, "Manganese Deposits of Santiago, Cuba," *U.S. Geol. Surv. Bull.* 213 (1902), p. 251.

<sup>4</sup> Personal communication from Dr. A. C. Spencer.

Interbedded limestones are quite common in the Cobre series and seem to consist of two somewhat different types. One type is a dense-textured rock occurring in thin beds (see Fig. 5) that are reddish brown or green in color. Plagioclase feldspars and other fine-grained tuffaceous material may be identified under the microscope; and in two specimens that were analyzed the volcanic material made up

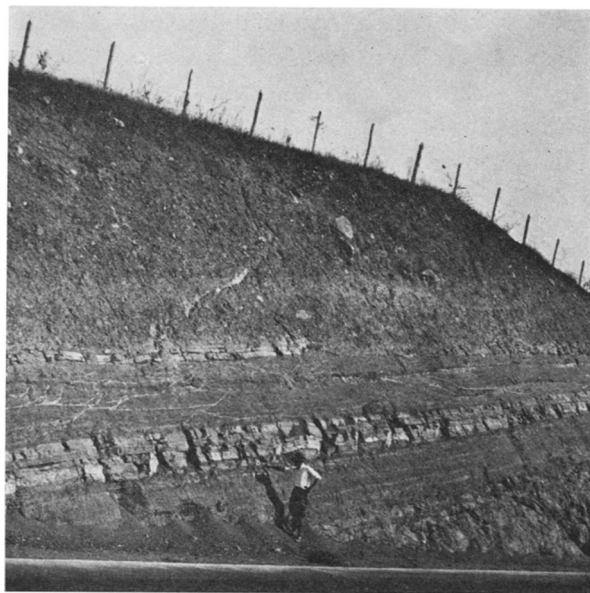


FIG. 5.—Bed of tuffaceous limestone in cut along Carretera Central 5 km. northwest of Santiago.

from 44 to 62 per cent of the rock. Foraminifera were also recognized under the microscope, but, because of poor preservation, they could not be identified. These rocks were found outcropping at several places along the Carretera Central, at Charco Mono on the Rio Cañas, and half way up the scarp of the Sierra de Boniato on the road (Caminacita del Isleño) that climbs the ridge a short distance west of the western end of the Puerto Pelado.

Similar limestones were found in the bed of the Rio Guanánicum, 6 km. southeast of Cristo. In this vicinity one of the limestone beds



consists largely of foraminifera which have been identified by Cushman as Eocene.<sup>1</sup>

The other type of limestone is a white or light-gray rock, nearly free from impurities, in which bedding is absent or poorly developed. It is sometimes slightly cavernous, and in places shows traces of fossils, usually coral, though they are so poorly preserved as to make identification difficult.

A few fossils were collected from an outcrop on the lower slope of the Sierra de Boniato, about 4 km. northeast of Cobre, where a small limestone quarry known as La Gloria was operated during the construction of the aqueduct. Dr. T. W. Vaughan, who kindly examined the coral, states:

Four, perhaps five, species are represented, and these seem to belong to four different genera. One of the genera is *Stephanocoenia*, and another seems to be *Cyathophora*. The presence of *Cyathophora* indicates a Mesozoic age, not younger than middle Cretaceous and perhaps somewhere in the Jurassic.

A crab claw in the collection was examined by Dr. Mary J. Rathbun, who reported as follows:

The crab claw from Cuba is new to me, but I believe it to belong to the genus *Lobonotus*. The only described species of the genus are *L. mexicanus mihi* from the upper Eocene of Lower California, and *L. sculptus* A. Milne Edwards from the Oligocene of Haiti.

Limestones of this second type occur at several localities in the region around Dos Palmas and form the crest of the ridge known as the Lomas de Uragua. At an outcrop 3 km. southwest of Reposo the limestone contains a few angular fragments of volcanic material ranging up to 7 cm., or more, in diameter. Limestone interbedded with breccia outcrops in the trail on the south side of the Arroyo Hermitaño at an elevation of 1,360 feet, and about 350 m. from the crest of the Sierra Maestra. Limestone is reported to outcrop along the crest of the Cobre spur near its junction with the Sierra Maestra.

On the northern slope of the Sierra de Boniato and in the Guanínicum valley southeast of Cristo the proportion of marine sediments to volcanic material increases markedly.

<sup>1</sup> J. A. Cushman, "Fossil Foraminifera from the West Indies" in "Contributions to the Geology and Paleontology of the West Indies," *Carnegie Inst. of Wash. Pub. No. 291* (1919), p. 29; E. F. Burchard, "Manganese-Ore Deposits in Cuba," *Trans. Amer. Inst. Min. Eng.*, Vol. LXIII (1920), pp. 55, 72.

The total thickness of the Cobre series is difficult to determine because of faulting and the absence of easily recognized and widely distributed key beds. A careful study of the limestones might supply the information. The maximum thickness is certainly great, possibly 15,000 feet or more.

The age of the different rocks within this series is somewhat uncertain. The beds at the base of the series are apparently Cretaceous or older, and near the top they are Upper Eocene. The rocks at the iron mines east of Santiago probably belong to the same series, and in a limestone at Daiquiri, 25 km. east of Santiago Bay, fossil coral and sponges were found, which were identified by Dr. Vaughan as Mesozoic and probably Cretaceous.<sup>1</sup>

*La Cruz marl.*—The La Cruz marl occupies a considerable area in the vicinity of Santiago Bay. It was laid down on tilted and eroded beds of the Cobre series within a baylike indentation of the land. The former extent of the marl is unknown, as it is abruptly cut off by faulting along the present coast. The formation was studied and named by Vaughan, who considers it Middle Miocene.<sup>2</sup> It was not examined in any detail by the writer.

*Seboruco.*—Along the coast, modern, coral limestone rests on the La Cruz marl and on the older igneous rocks east and west of the Santiago embayment. The coral rock, known locally as seboruco, has been lifted high above sea level and veneers many of the coastal terraces.

*Intrusive igneous rocks.*—Intrusive igneous rocks were found to be most plentiful in the area southwest of the Carretera Central and especially on the slopes of the Sierra Maestra. They vary in texture and composition, but have evidently been derived from a common magma. With the exception of the basalts, most of the rocks are porphyritic. Plagioclase feldspar, ranging in composition from labradorite to anorthite, is the dominant mineral, and in some cases little else is present. The feldspars frequently show zoning. Potash feld-

<sup>1</sup> J. T. Singewald, Jr., and B. L. Miller, "The Genesis and Relations of the Daiquiri and Firmeza Iron Ore Deposits, Cuba," *Trans. Amer. Inst. Min. Eng.*, Vol. LIII (1915), pp. 67-74.

<sup>2</sup> T. W. Vaughan, "Correlation of the Tertiary Geologic Formations of the Southeastern United States, Central America, and the West Indies," *Jour. Wash. Acad. Sci.*, Vol. VIII (1918), pp. 268-76.

spar and primary quartz are rare in most of the dike rocks. The ferromagnesian mineral is usually pyroxene but sometimes hornblende. Magnetite is usually present and is abundant in some localities.

Most of the rocks are here classed as andesite, although the feldspars are rather high in calcium. It is unusual to find feldspars of this type in rocks having such a small percentage of the ferromagnesian minerals. Some of the rocks are also coarser in texture than the typical andesites.

Cavities, now filled with amorphous silica, quartz, and chlorite, are abundant in some of the rocks, even where they have a relatively coarse porphyritic texture. Quartz may occupy the center and be surrounded by opal, or this arrangement may be reversed. Some cavities contain more than one layer of quartz. Chlorite, when present, usually forms an outer rim around the other minerals. The feldspars commonly show alteration to calcite.

Dikes are especially numerous in the vicinity of Solís; and as blasting had been done on several of them, it was possible to obtain fairly fresh specimens. The dikes here have a northerly strike, and dip at steep angles, mostly toward the west but in some cases toward the east.

The largest dike at Solís (see Fig. 6) is an andesite porphyry with numerous phenocrysts of anorthite, ranging up to 7 mm. or more in diameter, and a few slightly smaller crystals of augite. The ground-mass is chiefly anorthite with a few grains of magnetite and much chlorite.

The smaller dike a little to the west is similar in composition, but is somewhat finer grained and contains quartz-opal amygdules, some of which are over a centimeter in length. The dike 400 m. east of the large one is a fine-grained, light-gray, andesite porphyry, which, under the microscope, is seen to consist almost entirely of plagioclase, with only a small percentage of pyroxene and other minerals, chiefly calcite, chlorite, and magnetite.

The dike exposed in the river bed near the northern boundary of the map (Fig. 6) is a light-brown, felsite porphyry consisting chiefly of plagioclase with a little chlorite, magnetite, and quartz, some of which may be primary.

Three hundred meters farther east, in the bed of the Arroyo de la Sucursal, a tributary of the Cauto, a porphyry is exposed that has phenocrysts of plagioclase, near anorthite, 2–3 cm. in diameter. The groundmass is relatively fine grained, and consists of plagioclase, pyroxene, magnetite, and chlorite.

At several places in the Cauto drainage basin and also near the aqueduct 5 km. northeast of Cobre, there are outcrops of a dense-

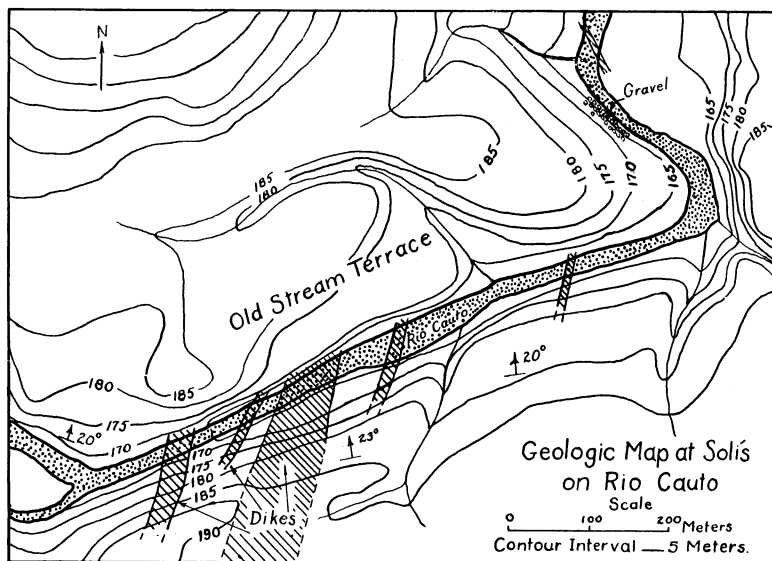


FIG. 6.—Map of Rio Cauto at Solís, showing old dissected stream terrace and dikes cutting beds of volcanic breccia.

textured andesite which has a light pink color. Aside from the plagioclase, which occurs partly in crystals large enough to be seen with the unaided eye, it seems to contain nothing but a little fine-grained magnetite, hematite, and, in some specimens, chlorite.

In a tunnel at Charco Mono on the Rio Cañas a porphyry was exposed which contains a few orthoclase phenocrysts showing Carlsbad twinning although most of the phenocrysts are plagioclase. The groundmass consists chiefly of plagioclase with much magnetite and a little chlorite and calcite.

As one climbs the north slope of the Sierra Maestra ridge west of Cobre, the andesitic intrusives increase in abundance and become

more plentiful than the breccias. The south slope consists almost entirely of intrusives, chiefly diorite and andesite; but at a point 4 km. from the coast, and at an elevation of only about 500 feet, an intrusive breccia was found in which the included fragments consisted of volcanic breccia.

Near the crest of the ridge on the south side an amygdaloidal andesite porphyry was found. The rock contains numerous phenocrysts of plagioclase and a few pyroxene crystals, the groundmass

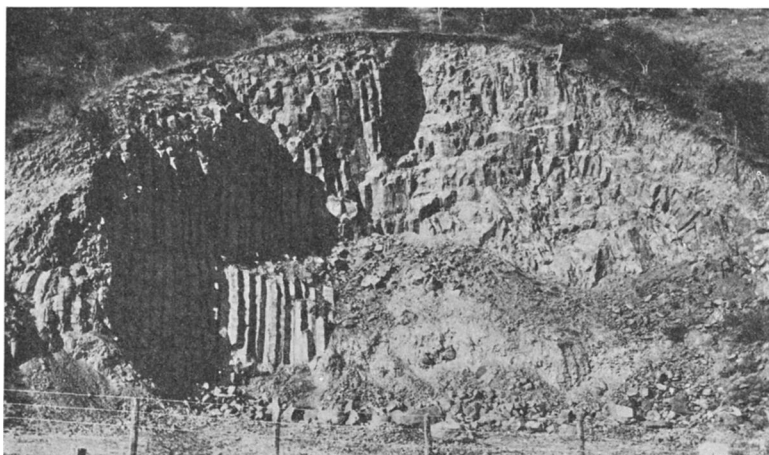


FIG. 7.—Small laccolith of columnar basalt in the Puerto de Moya

consisting chiefly of plagioclase with much magnetite and some pyrite. The cavities have been filled with opal, quartz, and chlorite.

At the coast the rock is a quartz diorite containing numerous dark-green hornblende phenocrysts, 2 cm. or more in length. The rock contains no pyroxene and little or no orthoclase. Magnetite is abundant, and some of the hornblendes show alteration to chlorite.

Columnar basalt, in the form of dikes and small sills or laccoliths (see Fig. 7), is found along the Carretera Central north of Santiago and at several places in the vicinity of the Puerto de Moya, where the highway crosses the western end of the Sierra de Boniato. The basalts are probably younger than the andesites, as they differ more from the breccias in composition than do any of the other igneous rocks of the area.

## TECTONICS

The Sierra Maestra has usually been attributed to folding; but folding has not been a factor in producing the present topography of the region studied, and it has probably been of little importance in the development of the structure, or of the earlier topography of Tertiary and Pleistocene times. The existing mountains are due to direct uplift accompanied by faulting and the tilting of large crustal blocks toward the north. They are simple block mountains in different stages of uplift and erosion.

The general strike of the strata is approximately east and west, varying a few degrees in different localities. The dips are almost invariably toward the north; and, while the angle of dip varies considerably, the beds are more steeply inclined on the average in the southern part of the area. Along the northern flank of the Sierra Maestra near Cobre the dips are around  $60^{\circ}$ – $70^{\circ}$ , while on the gentle slopes north of the Sierra de Boniato and in the region around Solís and Dos Palmas the dips average  $20^{\circ}$  or less.

For a short distance along the Carretera Central north of Santiago the beds are nearly vertical, possibly because of local faulting; and a similar high inclination was observed in a small area near the top of the Barbacoa Pass south of Cristo. Southerly dips were observed in only two places: on the Guanínium River southeast of Cristo, and on the Cañas River southeast of Reposo. At the latter place there are slickensides along the bedding planes of a tuffaceous limestone, and the writer suspects that the reversed dip here is due to monoclinial flexing.

A gentle syncline, a few hundred feet wide, with the axis pitching in a north or northeasterly direction, is exposed along the Carretera Central 2 km. southeast of Reposo.

A small fold thrust, exposed in the side of the Arroyo de la Mina about 240 m. southwest of its junction with the Guanínium River southeast of Cristo, is the only clear evidence of compressive forces observed. The anticline, with axis running north and south, is not more than 5 m. wide, and the fault displacement is only a few centimeters. This and all of the other departures from the normal northerly dip may be attributed to purely local forces that have resulted from the major earth movements. The tuffs and breccias, although

relatively very weak rocks, are entirely lacking in schistosity or other evidence of compression.

*Sierra Maestra fault block.*—The Sierra Maestra fault block is topographically older than the others in the district, as is shown by its much greater dissection. The south-facing scarp is deeply incised by the short streams that drain toward the ocean, although the rocks into which the valleys have been cut are the most resistant rocks of the area. The recently formed terraces along the coast and the occasional earthquakes accompanied by the sea waves give evidence that the uplift of the mountain front is continuing.

The back slope of the block is relatively gentle, though near the crest of the ridge it is much steeper than the northern slopes of the other ridges in the district. This difference between the Sierra Maestra and the other ridges is due to the greater uplift of the former and to the more resistant intrusive rocks near the crest, together with the erosion of the less resistant breccias that predominate on the lower slopes.

The Cañas and Cauto rivers have been rejuvenated by the uplift and tilting of the block, thus enabling them to intrench meanders that had developed when they flowed in broad valleys at a lower elevation (see Figs. 1 and 8). If all of the area had been mapped with equal accuracy, additional meanders would be shown on the map. The modern canyons of the Cañas and Cauto have been cut to a depth of 20–50 m. below the floors of the old valleys. Stream terraces at different elevations indicate that the uplift did not occur all at once (see Fig. 6). At present these streams are busily deepening their valleys, and therefore much rock is exposed in their beds.

If a general uplift had occurred instead of the northward tilting, the Rio Cauto would have been rejuvenated near its mouth rather than near the headwaters of its tributaries.

The relatively steep dips along the north flank of the Sierra Maestra are, in large part, due to earlier uplifts. The precise nature of these earlier tectonic movements may be difficult to determine, but no evidence was found that would indicate they were different from the recent tilting. There must have been some initial dip in the volcanic *ejectamenta*, especially where it is coarsest; but the direction is unknown.

The large amount of intrusive rock exposed along the flanks of the Sierra Maestra as compared with the areas farther north may, in part, be due to proximity to the loci of volcanic activity; but the much greater amount of erosion here, where the uplift has been greatest, is undoubtedly another factor. While the presence of very coarse material in the breccia is indicative of nearness to volcanic vents, it will be necessary to map a much larger area before these vents can be located even approximately.

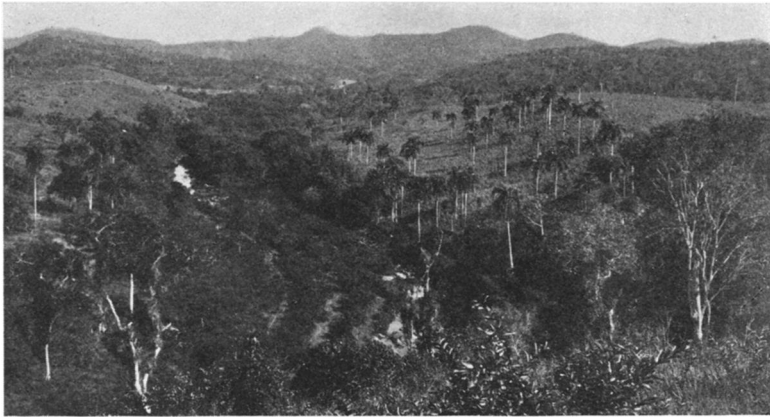


FIG. 8.—View up the Rio Cañas and the Valley of the Rio Frio. The Cañas, in making a hairpin bend, flows toward the left, back of the low ridge with the high palms, and, after joining the Rio Frio, flows toward the foreground.

In the area mapped, no trace was found of the older rocks on which the volcanic series must have been laid down. Near the Guantánamo naval station, however, schists occur that are probably Paleozoic or older.<sup>1</sup>

The structure of the Uragua hills and the Dos Palmas hills was not studied. They are possibly due to differential erosion.

*Sierra de Boniato fault block.*—The southern scarp of the Sierra de Boniato is furrowed by short dry gullies, the dissection being somewhat greater along the western half of the scarp (see Fig. 9). Because of insufficient erosion, triangular facets are poorly developed, with the exception of one good facet near the east end of the

<sup>1</sup> N. H. Darton, "Geology of the Guantánamo Basin, Cuba," *Jour. Wash. Acad. Sci.*, Vol. XVI (1926), pp. 324-26.



range, which may be seen over the crest of the Puerto Pelado from elevated points in Santiago. Alluvial fans and talus slopes are absent. In places along the base of the scarp a deep narrow ravine is



FIG. 9.—Sierra de Boniato fault scarp as seen from a point 10 km. northwest of Santiago.

found running parallel to the ridge, and some of the spurs separating the gullies show side hill ridges such as are indicative of recent displacements.

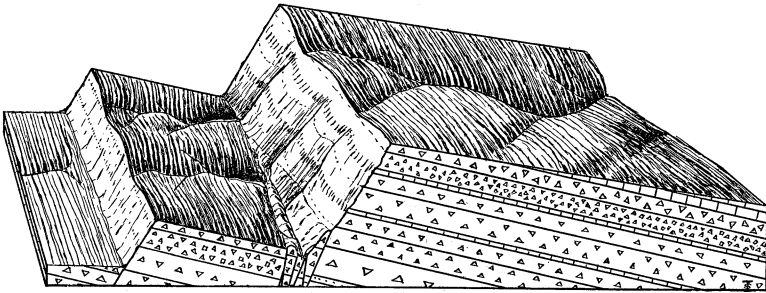


FIG. 10.—Block diagram of the Puerto Pelado and Sierra de Boniato fault blocks

The precipitous fault scarp on the south side of the Sierra de Boniato is in marked contrast to the gently inclined dip-slope on the north (see Fig. 10), where the broad shallow valleys of an old erosion surface reach to the crest of the divide. The northward slope of the ground is slightly less than the dip of the rock strata, a fact which indicates that the land had been given a gentle northerly tilt and subjected to erosion before the uplift of the present Sierra.

The Sierra de Boniato broadens out near the western end; and, when viewed from a distance (see Fig. 2), a distinct terrace, probably an old erosion surface, may be seen at the top of the scarp with higher points rising from it a little farther to the north.

The differential uplift at the west end of the mountain block seems to have been accomplished by distributed cross-faulting, rather than by flexing, for closely spaced, normal faults of small displacement are exposed in the road cuts of the Puerto de Moya at the west end

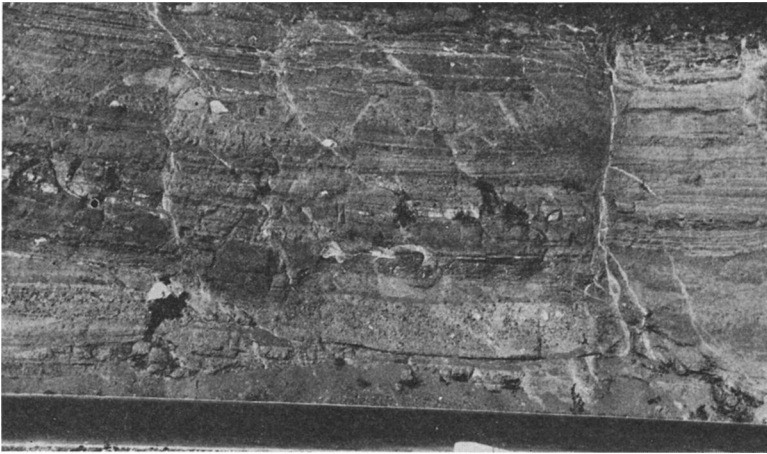


FIG. 11.—Small faults marked by white veinlets. Highway cut at the Puerto de Moya.

of the Sierra de Boniato, where the fault scarp gradually dies out. In fact, the rock strata are here much shattered by the movements. The fault fractures are commonly marked by thin white veins of calcite and other secondary minerals (see Fig. 11).

*Puerto Pelado fault block.*—The Puerto Pelado is the smallest of the tilted fault blocks. Its scarp is so fresh that it is not even furrowed by gullies; and, from a distance, the rock strata may be seen outcropping on the face of the scarp in horizontal lines which may be followed for several miles (see Figs. 12 and 13). The north slope is an old erosion surface with relatively mature valleys. The upper part of one of these valleys, which has been beheaded by the faulting so that it notches the crest of the ridge, is shown in Figure 14. Be-

cause the valleys collect the rainfall and concentrate the runoff, small youthful ravines have begun to extend upward into the valleys from the base of the slope.

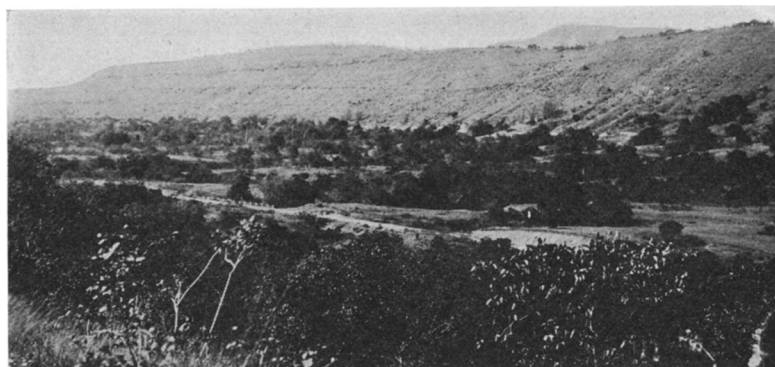


FIG. 12.—Puerto Pelado fault scarp near its eastern end. The Sierra de Boniato shows above the crest of the ridge. Carretera Central in middle foreground. Note the slight irregularities in the crest of the ridge due to valleys cut in the back slope; also the mature topography in the foreground.



FIG. 13.—Puerto Pelado fault scarp as seen from a point near the western end. The opposite side of the ridge at this point is shown in Figure 14.

The through valley (Cerca de Piedra) between the Puerto Pelado and the Sierra de Boniato has a low indistinct divide about midway its length. The valley floor is of rock or thin residual soil, there being

almost no transported rock waste. Low, narrow, discontinuous ridges, characteristic of fault-zone topography, are present, especially along the north side of the valley.

Slickensides and fault striae, indicating vertical or nearly vertical displacements, were exposed in excavations near the base of the Sierra de Boniato and Buerto Pelado scarps.

The topography north and east of Santiago cannot be attributed to folding, for the dip of the rock strata is almost invariably in one



FIG. 14.—Crest of the Puerto Pelado from the north. The notch in the sky line is due to the valley being beheaded at that point by the fault which forms the opposite side of the ridge (see Fig. 13).

direction. Neither can it be explained by differential erosion. The stratified rocks, other than the limestones, differ little in their resistance to erosion. The limestones are more resistant, but they are not sufficiently extensive in most places to have any effect on the topography. The southern slopes of the Sierra de Boniato and Puerto Pelado would be greatly dissected if the through valleys separating the parallel, east-west ridges had been cut by erosion. An enormous amount of material would have to be removed by the stream systems flowing into Santiago Bay, whereas there is only a moderate amount of alluvial material deposited around the Bay, and soundings near the entrance indicate the absence of a large submerged delta. In contrast the Rio Cauto, which, with its tributaries, drains the north side of the divide, has built a very large delta.

The rocks exposed in the face of the scarps are relatively fresh, considering the depth of residual decay in this region at places where the streams are not actively deepening their channels.

The persistent, rectilinear scarps of the Sierra de Boniato and Puerto Pelado cannot be explained otherwise than as fault scarps, and the topographic evidences of recent displacements are much clearer than those that may be observed along similar faults in California, although the rainfall near Santiago is greater.

Opportunity for study of the structure of the mountains east of Barbacoa Pass was very limited, but the evidence available indicates that the recent tectonic movements there have been similar to those that have tilted the other mountain blocks of the area. The Rio Guanínicum southeast of Cristo is a rejuvenated stream now

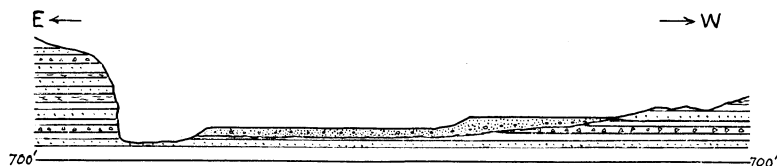


FIG. 15.—Profile across Rio Guanínicum Valley, showing two broad terraces. Scale 1:40,000.

flowing on bed rock. At a point 5 km. from Cristo two broad flat terraces are found on the southwest side of the river with a high cliff on the opposite side (see Figs. 15 and 16).

Because of lack of time, almost no field study could be given to the range of hills south of the Puerto Pelado or to the terraced area, consisting chiefly of Miocene marl, which surrounds Santiago Bay. The hills may be due to faulting, but, if so, they are topographically older than the fault blocks described above. The few facts available suggest that the Miocene area has shared, in part at least, in the uplift and northward tilting of the mountain block west of the bay. Along the coast east of the bay, cliffs over 200 feet high are veneered with Recent coral limestone. The Rio San Juan drains to the sea through a gorge 500 feet wide at La Laguna, while farther inland it flows on a valley fill, into which wells have been sunk to a depth of 170 feet without reaching the coral bed rock, except along the borders of the valley, where it is near the surface.<sup>1</sup>

<sup>1</sup> M. L. Fuller, "Notes on the Hydrology of Cuba," *U.S. Geol. Surv. Water-Supply and Irrigation Paper*, No. 1110 (1904), p. 192.

Santiago Bay and its narrow entrance are analogous to the valley and gorge of the Rio San Juan, but the streams now entering the bay are incompetent to have cut this drowned valley while the San Juan was excavating its gorge barely to present sea level. These features suggest that the uplift of the fault blocks north of the city has been accompanied, perhaps, by some stream diversion.

The contact between the La Cruz formation and the older rocks was examined at only one place, a cut on the Carretera Central north

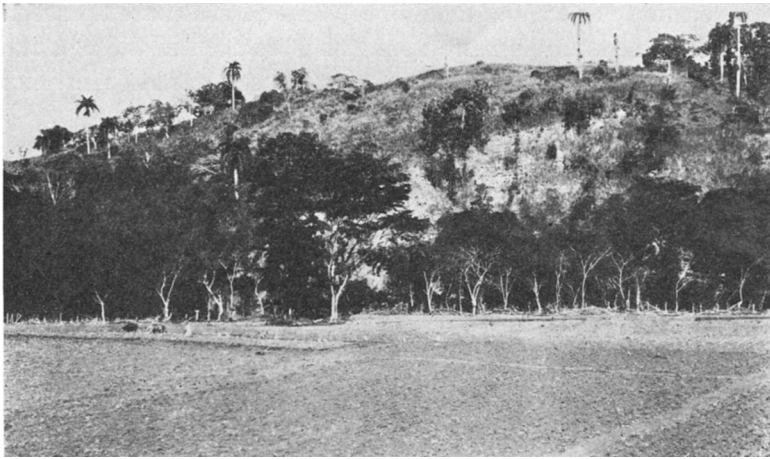


FIG. 16.—Lower terrace in Guanínicum Valley as seen from edge of upper terrace

of Santiago, and here the exposure, because of weathering and slumping, was not good. The contact appeared to be rather steeply inclined, perhaps  $30^{\circ}$ , and there were large angular fragments of white limestone near the contact, which graded into waterworn cobbles within a short distance.

No less than eight marine terraces have been distinguished by Hayes, Vaughan, and Spencer in the vicinity of Santiago, the most prominent being the Morro terrace, elevation 280 feet (85 m.), the Cathedral terrace, at 100 feet (30 m.), and the coastal terrace at 20 feet (6 m.). The highest terrace, having an elevation of about 400 feet (120 m.), is greatly dissected. In the northern part of the city there is a terrace with elevation of between 60 and 70 feet (18–21 m.), and along the shores of the bay are three benches between the 20-foot

terrace and water level.<sup>1</sup> Because of differential displacement and tilting of the crustal blocks near Santiago, it is difficult to correlate and trace the different terraces. This work would require careful studies with the aid of accurate topographic maps.

The geology of the mountains extending along the coast east of Santiago Bay has been studied in the vicinity of the iron mines by several geologists; and their descriptions indicate that it is essentially similar to that of the mountains west of the bay.<sup>2</sup> A series of igneous rocks, differentiates from a common magma, have been intruded into volcanic clastics and limestones, some of which are tuffaceous. Limestone seems to be more abundant here than in the mountain block west of Santiago Bay, and some of it occurs as large inclusions in the igneous rocks.

The main mountain block is separated from the coast by a range of low hills which have been described by Roesler. He states that on the south they consist of terraced cliffs, cut in coral limestone, rising to a height of 300 feet, with no beach except at Siboney. Back of the cliffs the land slopes gently down to a flat east-west valley covered with silt. In this valley the streams from the mountains are generally lost in lagoons and swamps, but some of the larger ones, such as the Rio Carpintero, find their way to the sea through comparatively narrow gorges cut through the cliffs. Roesler concludes that the silt-covered east-west valley is due to general subsidence; but his description suggests that it may have been formed by the northward tilting of a fault block.

It will take much detailed work to determine whether the fault-block structure, found in the vicinity of Santiago, is characteristic of the entire Sierra Maestra from Cabo Cruz to Cabo Maysi; but the meager data now available indicate that the structure of the region is dominated by block faulting with some local subsidiary folding.

<sup>1</sup> C. W. Hayes, T. W. Vaughan, and A. C. Spencer, *Informe Sobre un Reconocimiento Geológico de Cuba*.

<sup>2</sup> J. P. Kimball, "Geological Relations and Genesis of the Specular Iron-Ores of Santiago de Cuba," *Amer. Jour. Sci.*, 3d Ser., Vol. XXVIII (1884), pp. 416-29; *idem*, "The Iron-Ore Range of the Santiago District of Cuba," *Trans. Amer. Inst. Min. Eng.*, Vol. XIII (1885), pp. 613-34; J. F. Kemp, "The Geology of the Iron-Ore Deposits in and near Daiquiri, Cuba," *ibid.*, Vol. LIII (1915), pp. 3-38; Waldemar Lindgren and Clyde P. Ross, *op. cit.*, pp. 40-59; Max Roesler, "Geology of the Iron-Ore Deposits of the Firmeza District, Oriente Province, Cuba," *Trans. Amer. Inst. Min. Eng.*, Vol. LVI (1917), pp. 77-127.

The mountains between Guantánamo and Cabo Maysi, as viewed from the sea, have an appearance strongly suggestive of a fault block. The Guantánamo Basin, according to Darton,<sup>1</sup> is a broad syncline, opening toward the east, the strata ranging from Upper Eocene to Upper Oligocene or Lower Miocene. No evidence is given to indicate whether the syncline is due to compression or to the tilting of large fault blocks.

The absence of detritus at the base of such fresh scarps as those of the Puerto Pelado and Sierra de Bóniato makes it impossible to believe that they could have been transformed from overhanging scarps by down-slumping. While the principal faults in the Santiago area are normal faults, they are not directly due to gravity and cannot be explained as step faults that mask a great thrust fault. The uplift and tilting have been accomplished by forces acting vertically or nearly so. These mountain-forming movements have accompanied the down-faulting of the Bartlett Trough, and the two processes are probably related genetically.

#### AGE OF THE FAULT BLOCKS

Uplift of the mountain blocks has taken place so recently that the usual methods of determining the age of faults are of little value, and the relative amount of erosion is the only practical criterion. While the uplift of the Sierra Maestra block has continued during Recent time, the relatively great dissection of its scarp, composed of resistant rocks, indicates that it received much of its present elevation at an earlier date than the other blocks, possibly as early as the Pleistocene.

The Sierra de Boniato uplift has clearly occurred during Recent time; and the Puerto Pelado scarp, although composed of rocks offering little resistance to weathering and erosion, is so fresh that its age must be measured in hundreds of years rather than tens of thousands. The relative amount of erosion would indicate that the freshest fault scarps are younger than the higher and older coastal terraces.

It is not improbable that the earthquakes of 1678, 1679, 1766, and 1852, which were so disastrous in Santiago and which were unaccompanied by sea waves, such as occurred in 1755, may have been

<sup>1</sup> N. H. Darton, *op. cit.*, pp. 324-33.



caused by a continuation of the displacements along some of these local faults. The evidence from topography and from earthquakes indicates that the uplifts, instead of occurring uniformly, have been intermittent and have occurred now along one fault or part of a fault and now along another.

#### GEOLOGICAL HISTORY

The facts bearing on the geologic history of the Santiago area obtained in this investigation agree in the main with the history of the West Indies as outlined by Schuchert<sup>1</sup> and Vaughan,<sup>2</sup> but the last chapter in the geologic history of the area may now be written in a little greater detail.

During the Eocene and extending as far back as the Cretaceous and perhaps earlier, there were violent explosive eruptions which resulted in the formation of the great series of volcanic *ejectamenta* interbedded with coralline and more or less tuffaceous, foraminiferal limestones. Intrusion of porphyritic dike rocks occurred during the long period of explosive activity, but probably chiefly near its close.

At the close of the Eocene the land was uplifted with some tilting, but the differential displacement was unimportant north of the present coastal ridge. There is no evidence that this region shared in the folding which is said to have formed mountains in some of the Greater Antilles between late Eocene and middle Oligocene. During middle Miocene time the region around Santiago Bay was depressed to receive the La Cruz marl, but the rest of the region seems to have been subjected to continuous erosion, with occasional uplifts which affected chiefly the coastal area. The La Cruz marl is cut off at the coast by faulting, which Vaughan concludes took place in Pliocene time.<sup>3</sup>

During the Pleistocene there was emergence, probably in part due to withdrawal of water to form continental ice caps, but also due to uplift and northward tilting along the coast. Submergence, resulting from deglaciation, probably accounts for the modern coral

<sup>1</sup> Charles Schuchert, "Geological History of the Antillean Region," *Bull. Geol. Soc. Amer.*, Vol. XL (1929), pp. 337-60.

<sup>2</sup> T. W. Vaughan, "Geologic History of Central America and the West Indies during Cenozoic Time," *ibid.*, Vol. XXIX (1918), pp. 615-30.

<sup>3</sup> *Ibid.*, p. 626.

limestones resting on both the La Cruz marl and the older igneous rocks along the coast. These limestones now form coastal terraces, because the uplift and northward tilting has continued intermittently during Recent time. Also, during this last phase in the history of the area, block faulting has extended northward with the formation of additional ridges farther from the coast. This faulting is continuing, for the region is unstable.

#### GENERAL CONCLUSIONS

The Sierra Maestra near Santiago de Cuba contains some of the youngest and best-defined, fault-block mountains in the world. Fault scarps comparable in freshness are practically limited to desert regions, whereas the rainfall in these mountains is considerable. The lower slopes and intermontane valleys are free from the débris that masks the geology in many similar localities. The recent geological and seismological history of the region proves that it is unstable. Therefore, renewed faulting accompanied by severe earthquakes may occur at any time.

The beauty of precipitous mountain scenery is enhanced by tropical vegetation and glimpses of the ocean. A modern paved highway from Havana to Santiago has just been completed through the district, and it has been so located as to give the finest views of bay and mountains. The area in the Puerto de Moya where basaltic columns are exposed has been set aside as a National Park.<sup>1</sup> These natural features, together with the great historic interest of Santiago, will undoubtedly bring many visitors.

Considering the long history of Santiago and the fact that most of the mineral resources of Cuba have been found in the Sierra Maestra, it is remarkable that no accurate maps of the region have been made, and geological studies, except in the immediate vicinity of the mines, have been of a reconnaissance nature. The new aqueduct, unfortunately, has been built along two active faults, so that it is in great danger from faulting and from earthquakes. The future development of the Santiago region would be aided and mistakes avoided if it could be mapped both topographically and geologically.

<sup>1</sup> E. I. Montoulieu, "Apuntes sobre la ocurrencia de Basalto Columnar, en la Sierra Maestra, Puerto de Moya.—Provincia de Oriente," *Boletín de Obras Publicas*, Vol. VII, No. 2 (1930), pp. 3-8: "Un Hallazgo Geológico en Oriente," *ibid.*, pp. 31-32.