A COASTAL RECONNAISSANCE OF CENTRAL PANAMA*

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This paper represents an attempt to give an explanatory account of the coastal features of central Panama. It is based on field observations in the summer of 1959 and on the study of all pertinent literature available to the writer in Panama and in the libraries of the University of California and the University of New Mexico. Field work was facilitated by: (1) The availibility of topographic maps made by the Panama Canal Company and the Corps of Engineers of the U.S. Army (For certain coastal areas, these maps are drawn on a scale of 1:20,000 with a contour interval of twenty feet), and (2) the accessibility of the coasts. The Pacific coast can be reached by jeep for wide stretches from Panama City westward to David. The Atlantic coast is more difficult to approach from the land. In 1959 one could drive from María Chiquita to Salud, and to several fishing villages between these two points.

DESCRIPTION

Atlantic Coast; Canal Zone and East (Figures 1 and 2). The Atlantic side of the Canal Zone displays two major types of coast: broad bays fringed by swamp deposits known as muck, and silt islands that have accumulated on reefs of dead coral. The two largest bays, Limón and Manzanilla, are separated by a silt island on which Colón is built. Limón Bay has a smooth and rounded outline. The depth of its floor increases from five feet near the southern shore to 40 feet at the mouth. Strong and persistent trade winds used to produce heavy swells that did much damage to the wharves and shipping in the bay prior to the construction of breakers. The outline of the bay is at least partly the result of wave erosion, for Hill[1] described how the high swash of the waves constantly undermined the bay's muck-lined shore.

Muck or littoral swamp deposit is widely distributed along both the Atlantic and Pacific coasts of Panama[2]. On the Atlantic side it is exposed around the edges of Limón, Manzanilla and Las Minas bays, and in the lower Chagres valley. The thickness of the deposits varies greatly and this large variation suggests that the muck covers an uneven bedrock floor. For example, at Limón Bay the thickness of muck is 83 feet[3]; at the mouth of

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[1] R. T. Hill, "The Geological History of the Isthmus of Panama and Portions of Costa Rica," *Mus. Comp. Zoology,* Vol. 28, 1898, p. 174.

[2] *Ibid.,* pp. 173, 199; *Report of the Governor of Panama Canal, 1947,* Public Law 280, 79th Congress, 1st Session, Appendix 8: "Geology, Isthmian Canal Studies" (hereafter cited as *Report of Governor*), pp. 9-10.

[3] D. F. MacDonald, "The Sedimentary Formation of the Panama Canal Zone with Special Reference to the Stratigraphic Relations of the Fossiliferous Beds," *U. S. Nat. Mus., Bulletin 103,* 1919, p. 13.

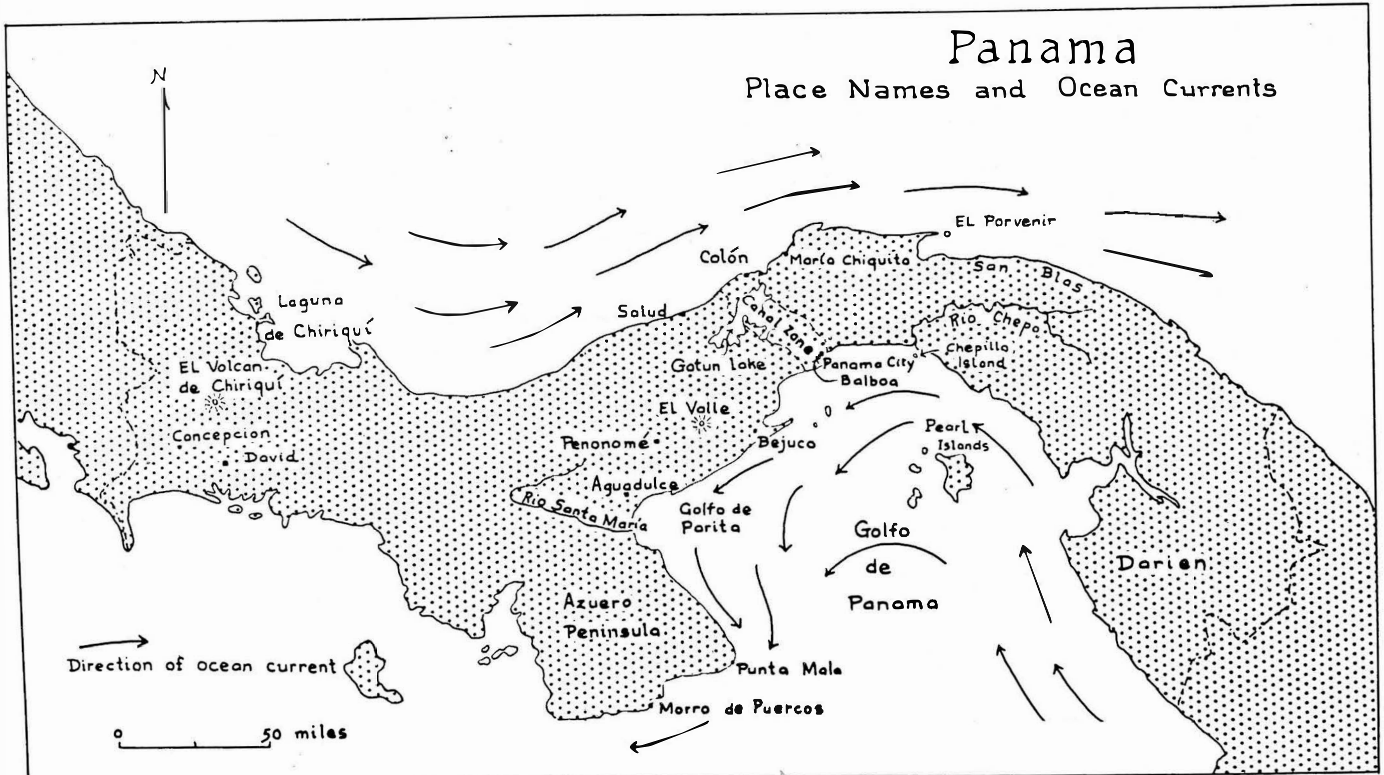

Fig. 1. Place names and ocean currents. Panama.

the Río Chagres it is 50 to 60 feet[4]; at Gatun Dam, 258, feet[5]; at Bohio, 150 feet[5], and at San Pablo, 90 feet[5].

Muck consists of soft, silt-sized sediments. Near the coast both marine and fluvial facies occur, and they intergrade laterally. Marine sediments include an abundance of mollusk shells, believed to be of Pleistocene to Recent age, in an organic black silt matrix.[6] Fluvial sediments include wood and other semi-decayed vegetable matter intermixed with silt. The shell-bearing muck now appears five to ten feet above sea level.

Colón is built on a small square piece of land, which orginally was a mangrove swamp, later filled from the work of the railway and canal. Northeast of Colón, Galeta and Largo Remo Islands are still mangrove

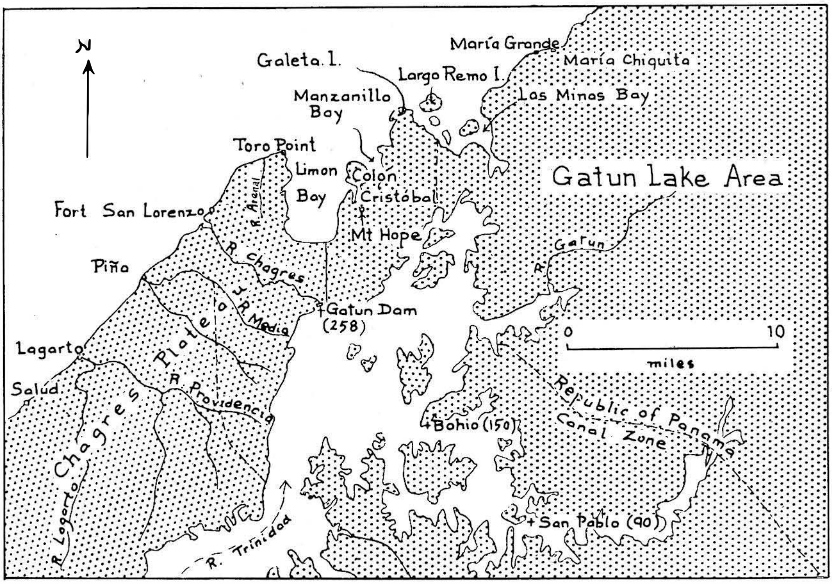

Fig. 2. Gatun Lake Area.

swamps behind their fringing reefs (Figure 3). The surface of the reef flat is convex seaward in outline and disappears where streams enter the sea. It lies one to two feet below sea level for a distance of 300 to 1,000 feet. Blocks of cemented coral, detached and thrown up by storm waves, litter its surface and project above water. The flat of dead corals continues seaward to a depth of about 12 feet where the edge then decends more steeply to 30 or 40 feet within a horizontal distance of 1,000 feet. East of Las Minas Bay the distance between fringing reef and mainland bedrock narrows so that about one mile east of María Grande, the fringing reef disapears and a smooth beach backed by a wave-cut clifflet two to five feet high faces the open sea.

[4] L. W. Bates, *The Panama Canal: System and Projects,* 1905, pp. 22-23.

[5] F. D. Willson, "The Climatology and Hydrology of the Panama Canal," Paper no. 9, in: *The Panama Canal,* Vol. 1, 1916, pp. 273-274.

[6] *Report of the Governor,* p. 22. W. P. Woodring, "Geology and Paleontology of Canal Zone and Adjoining Parts of Panama," U. S. Geol. Survey, *Professional Paper 306-A,* 1957, p. 50.

Between Limón and Las Minas Bays, the bedrock of sandstone, siltstone and tuff has been eroded into hills and clusters of hills surrounded by muck. These prominences reach 40 to 60 feet in elevation near the coast. R. T. Hill[7] noticed the accordance at 40 feet of the summits of Monkey Hills south of Mt. Hope. Inland, the rugged hilly topography does not clearly reveal any erosional surface. However, east of the Canal Zone,

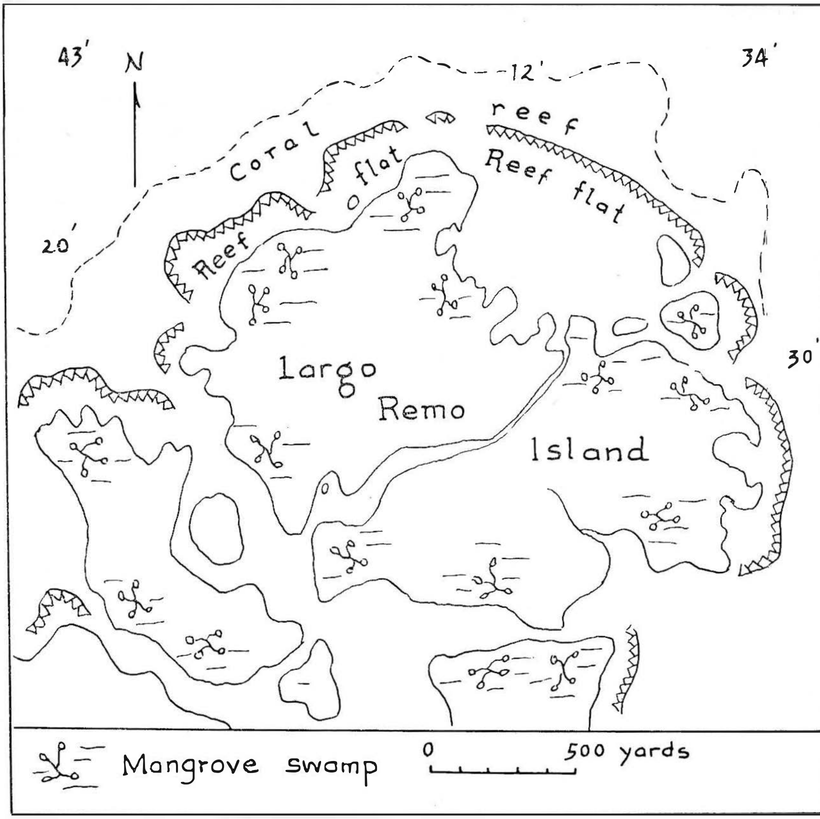

Fig. 3. Largo Remo Island. Mud and silt have collected on dead coral flats. (See Figure 2 for location).

Terry observed small terraces notched in igneous rocks. They are seldom more than a mile or two in width and are interrupted by fingers of the interior plateau extending to the sea[8].

Atlantic Coast; Canal Zone and West. A deeply dissected plateau lies to the west of Limón Bay. It is formed in a massive sandstone that dips seaward at angles of 5° to 15°.[9] Most of its surface lies below 350 feet though its summits may rise above 600 feet. Streams that originate at its

[7] Hill, *op. cit.*, p. 174.

[8] R. A. Terry, *A Geological Reconnaissance of Panama* (San Francisco: Calif. Academy of Sciences, 1956), pp. 16-17.

[9] MacDonald, *op. cit.*

southeastern edge, such as the Providencia, Media and Piña, occupy broad, alluviated valleys in their headwaters. Near the coast, however, they are deeply trenched. Río Chagres also reaches the sea through a deep valley cut into the plateau. But above Gatun Dam, Río Chagres and its tributaries used to move sluggishly across broad swamps before these were

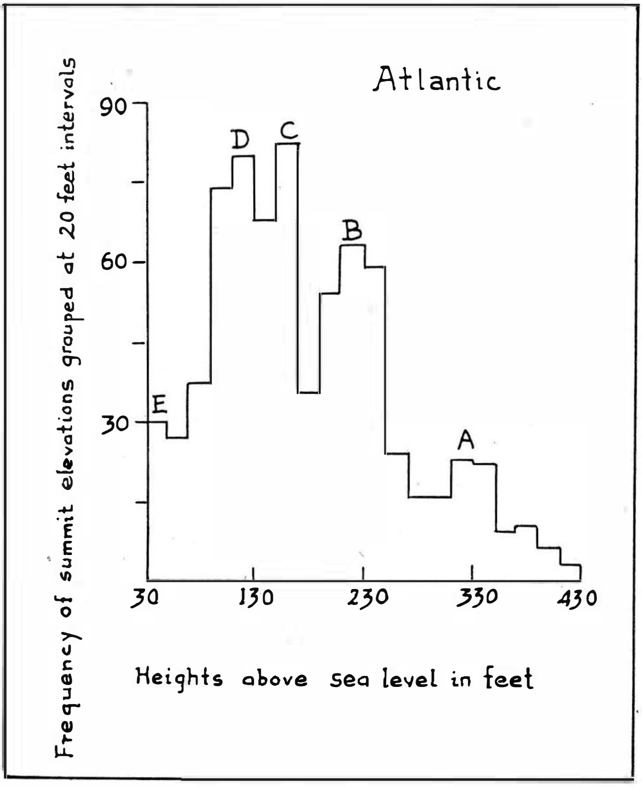

Fig. 4. Altimetric frequency graph for the Atlantic coast. The graph is drawn for an area of 15 square miles in the neighborhood of Pina, Chagres plateau. The area is divided into a rectangular grid and the summit elevation for each square of the grid is read from the topographic map made by the Panama Canal Company and the Corps of Engineers, U. S. Army. The scale of the map is 1:20,000 and the contour interval is at 20 feet. The frequency of each group of summit elevations (e.g., 30 to 50 feet) is plotted on the vertical scale against actual heights on the horizontal scale.

flooded into the artificial Gatun Lake (Figure 2). The drainage pattern and topography thus suggest that the sandstone plateau has been uplifted in relation to the basin now submerged in water. Geologically recent fault scarps, 50 to 150 feet high and draped by waterfalls, bound the southeastern landward edge of the sandstone plateau.[10] The rise of the plateau relative to the sea is marked by benches. The altimetric frequency graph suggests the existence of at least five of them (Figure 4): A, 310-350 feet; B, 210-230 feet; C, 150-170 feet; D, 100-120 feet; E, 40-50 feet.

[10] S. M. Jones, "Geology of Gatun Lake and Vicinity," *Bull., Geol. Soc. America*, Vol. 61, 1950, p. 906.

Although the lowest bench (E) is the least conspicuous on the graph, it can be discerned most readily in the field for it is in places cleared of vegetation.

For a distance of nearly four miles from Toro Point west of Limón Bay, a reef of dead coral fringes the steep coast. Farther west the reef disappears, and the coast, 25 to 30 feet high, is bordered locally by a

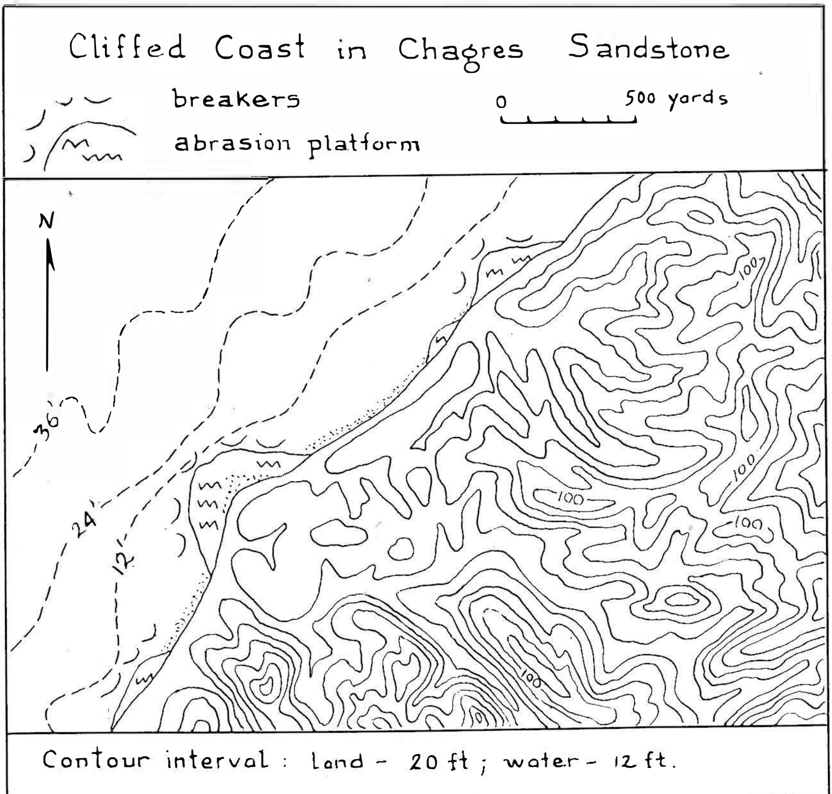

Fig. 5. Cliffed coast in Chagres sandstone, and showing stranded abrasion platforms. Topography after U. S. Corps of Engineers.

smooth platform cut by waves in the massive sandstone. The platform is awash and its edge is marked by breakers (Figure 5). This exposure is not limited to low tide for the tidal range is negligible, being less than one foot. Where it occurs, the platform fringes the seaward protrusions of the coast even where the protrusion is very slight. In contrast, each coastal indentation is lined with beach sand. In some places, a low, weathered bench, covered with vegetation, stands one to three feet above the modern beach. The inner edge of this bench rises to the higher one of 40 to 60 feet elevation (Figure 6).

Apart from the narrow strips of beach sand, most of which have been cliffed by wave erosion, depositional forms are uncommon along the coast from the Río Arenal westward to the mouth of the Río Lagarto. The mouth of the Río Chagres is narrowed by the extension northeastward of a spit. The outer flank of this spit, however, is retreating rapidly under wave attack. Smaller spits, variously oriented, occur in entrants between promontories.

Pacific Coast; Canal and East (Figure 7). Panama City and adjoining Balboa in the Canal Zone lie on top of a coastal bench eroded in

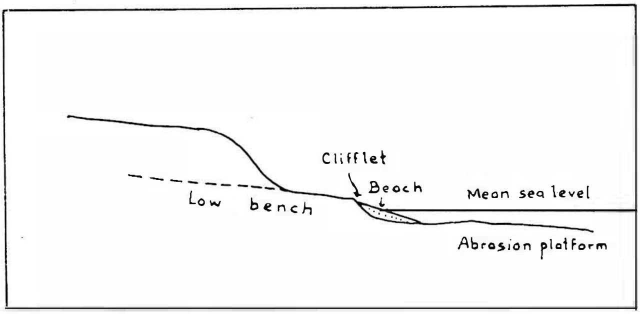

Fig. 6. Low, weathered bench.

tuff and agglomerate. The altimetric frequency graph for this area shows the prevalence of height readings between 10 and 50 feet (Figure 8). The 20-foot interval of the graph fails, however, to distinguish between the low coastal swamps, which lie below 15 feet, and the bedrock surface at 30 to 60 feet.

In sharp contrast to the graph for Chagres plateau, the graph for the Pacific bench shows only one prominent maximum—a frequency distribution that characterizes a simple coastal plain. Small benches may well

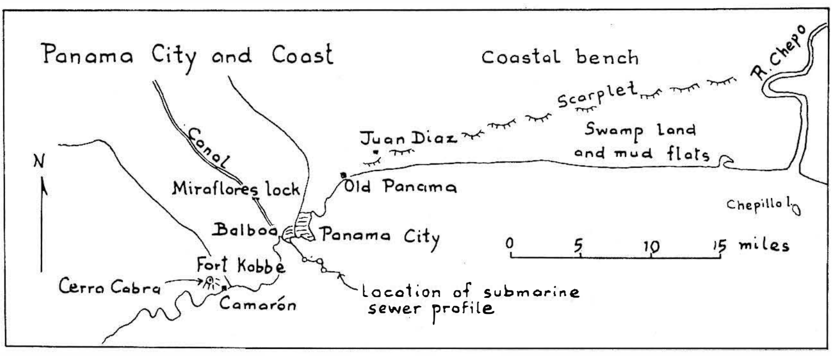

Fig. 7. Panama City and coast.

have been omitted by the crudity of the method, but the same method was applied to the Chagres plateau. This morphologic difference between the two sides of the isthmus is obvious in the field, and the graphs serve simply as a check on field observations.

The outer edge of the coastal bench is a scarplet that varies in height from five to 20 feet. Seaward it is fringed by broad expanses of mud and bedrock flats that are exposed at low tide. Muck similar to that described for the Atlantic coast occurs to depths of 40 feet or more from Miraflores

Lock to the Pacific entrance of the canal and beyond.[11] Marine fossils have not been reported in the muck at Miraflores Lock, where the original bottomland was over 10 feet above the present mean sea level. On the other hand, the lower swamps that formerly bordered Balboa and Panama City on the landward side do contain shells.[12]

East of the ruins of Old Panama, rocks of the bench change from volcanic tuffs and agglomerate to sandstone and siltstone. The flat parts

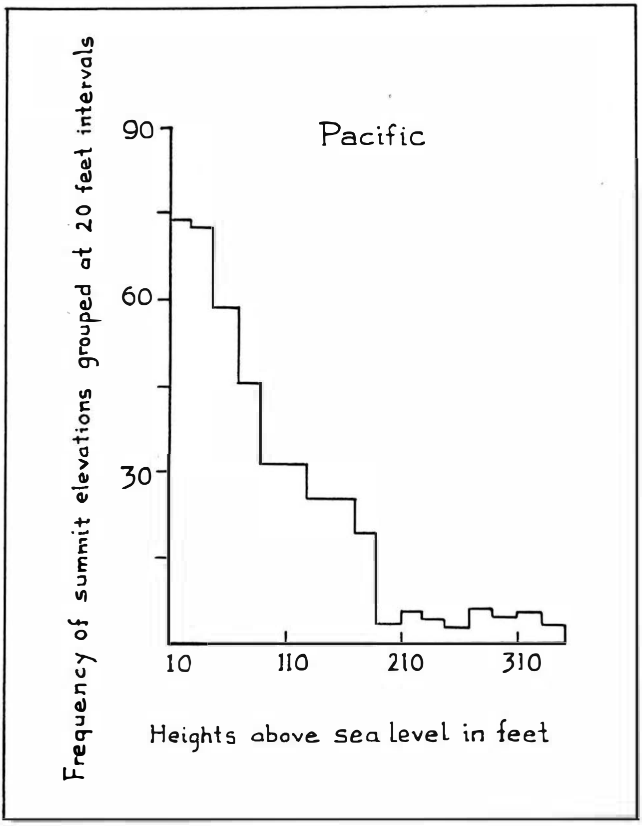

Fig. 8. Altimetric frequency graph for coastal bench north of Panama City. The graph is drawn for an area of 15 miles. (See Figure 4).

of the bench's gently rolling surface bear thin patches of alluvium and lie above the streams, many of which occupy valleys some 50 to 80 feet deep. Weathered bedrock occurs in shallow road cuts. The outer edge of the bench is a scarplet almost 15 feet high, fringed by a swampy grass land. Toward the sea, mangroves (e.g., *Avicennia* spp.) appear. Sand ridges rise above both the grass and mangrove swamps. At the longitude of Juan Diaz, the mangrove belt is narrow and bordered by eroded mud flats. Cakes of

[11] *Report of Governor*, p. 10.

[12] G. A. Maack, in: T. O. Selfridge, *Reports of Explorations and Surveys to Ascertain the Practicability of a Ship Canal between the Atlantic and Pacific Oceans by Way of the Isthmus of Darien* (Washington, D. C., 1874), p. 165.

old mud, still supporting dying mangrove, stand sharply above a younger mud flat that is exposed for one mile offshore during low tide. The entire zone of swamps, sand ridges, and mud flats increase in width eastward to Darien Province. West of old Panama, the trend of the coast line corresponds to the outer edge of the bedrock bench. East of there it corresponds to soft material of the coastal swamps.

Pacific Coast; Canal Zone and West. In Fort Kobbe west of the Panama Canal, a bench cut in volcanic rocks fringes steep-sided knolls (Figure 9). Near Howard Field, it borders an inlet of mangrove swamp drained

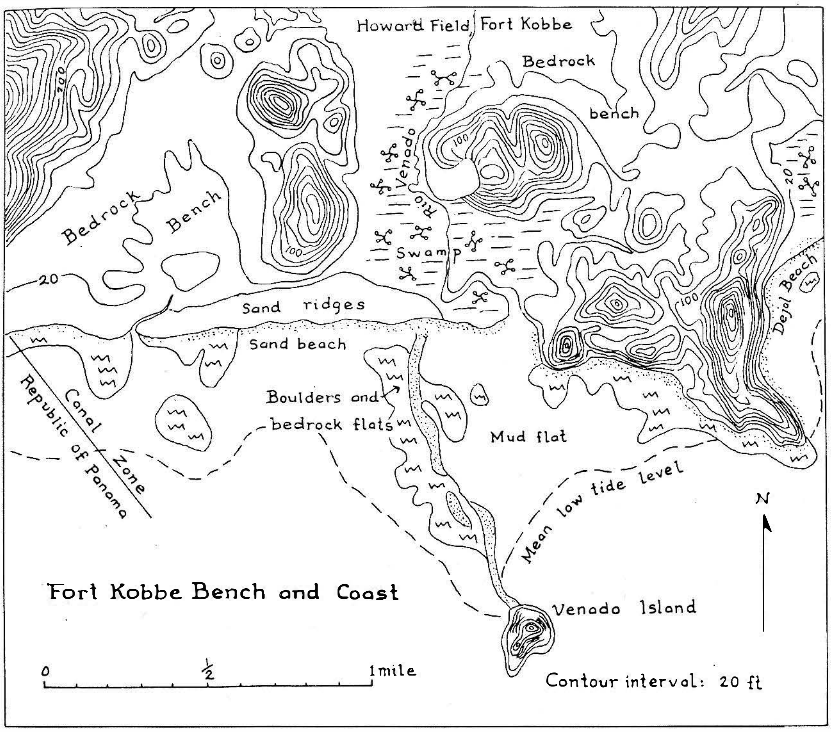

Fig. 9. Fort Kobbe, bench and coast.

by the Río Venando. The seaward edge of the swamp ends in a sand ridge, beyond which spread mud flat, patches of bedrock boulders and bedrock. At Dejal Beach, Fort Kobbe, the sand beach is fringed seaward by a clifflet cut in bedrock that marks the outer edge of a low weathered bench. The inner edge of this low bench rises to the higher one on which Fort Kobbe is located.

West of the Canal Zone boundary, the coastal plain at the foot of the Cerro Cabra (1,980 feet) is less than a quarter of a mile wide, and composed of volcanic bedrock thinly veiled by alluvium. It terminates in beach sand, beyond and below which lies bedrock of the marine abrasion platform. Stands of mangrove find a precarious foothold in the silt that accumulates in the hollows of the platform. During high and mean sea level, surf waves move across the platform and through the trees to the sand beach (Figure 11). The mangrove stands appear to be in process of destruction.

Between Bejuco and Penonomé are massive beds of water-sorted tuff, thin layers of fine alluvium and beds of mud-flow conglomerate with boulders that may be two or three feet in diameter. The formation, deposited around the El Valle crater, is believed to be of Middle Pleistocene age.[13] Streams radiate outward from the crater. They cut deep canyons and leave behind flattish interfluves. Although the drainage pattern is radial, the cliffed coast line from Pueblo Nuevo to Nuevo Gorgona is nearly

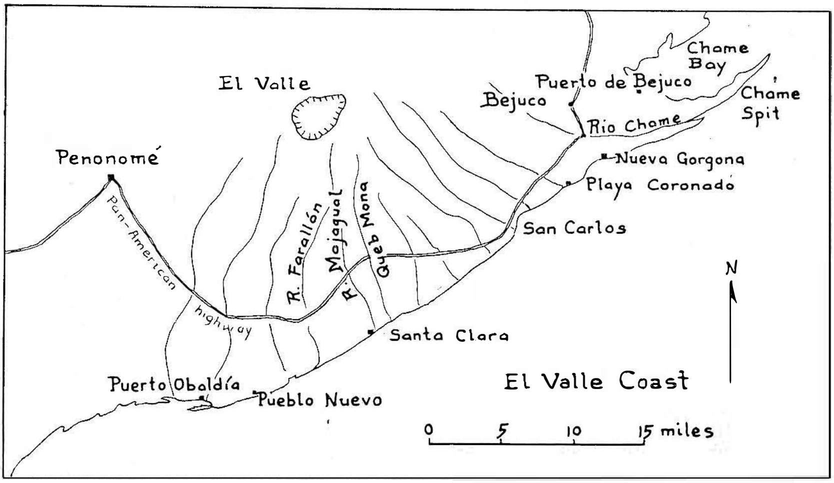

Fig. 10. El Valle coast.

straight (Figure 10). Waves appear to have straightened it and produced the cliffs. The eroded material is carried both northeastward and southwestward by longshore drift. This disposition of material is indicated by the deflection of the lower stream courses. In the northeastern part of the coast, Río Chame is deflected northeastward by a forested sand spit for a distance of six miles. Beyond the mouth of Río Chame is the Chame sand spit, which continues seaward for seven miles. The spit partially encloses a body of water, Chame Bay, over which mud flats have developed. In the southwestern part of this coast, the lower stream courses are deflected southwestward by sand spits. The lower course of Río Farallón is an example. Between these extremities of the tuffaceous coast, no distinct trend of longshore and beach drifting occurs. East of Santa Clara, for instance, the Río Majagual is deflected northeastward, whereas the Queb Mona to the northeast is deflected southeastward. The streams thus run into each other, and both hug the base of the tuffaceous cliff.

Present Processes

Effect of Currents. On the Atlantic side, the offshore current moves from west to east; in the northern part of the Golfo de Panama of the Pacific, it moves from east to west (Figure 1). Both currents are weak,

[13] O. H. Hershey, "Geology of Central Portion of Isthmus of Panama," *Univ. Calif. Bull., Dept. Geol.,* Vol. 2, 1901, p. 260; Terry, *op. cit.,* p. 15.

their average velocity being less than one knot.[14] Offshore currents can have no direct effect on coastal features but indirectly their load of suspended matter may contribute to the building of mud flats when it is carried in by flood tide. On the Pacific side, stray logs from the timber mills of Darien Province have been carried northwestward for over 70 miles, and dropped on the mud flat east of Río Chepo with the retreat of high spring tide.[15] East of the canal entrance a causeway was built to Naos Island to deflect the westward movement of currents carrying mud, and so reduce the cost of dredging the channel. The mud was estimated to amount to over one-half million cubic yards per year.[16]

Effects of Tides. Tides differ greatly along the two coasts.[17] At the Atlantic entrance to the Panama Canal the tide has an average rise and fall of 0.9 foot, with a maximum of two feet between sucessive high and low tides, and generally there is but one high and one low tide in a day. At the Pacific entrance to the canal there are two high and low waters during the day, the average rise and fall being 12.6 feet and at times over 20 feet.

Observers like Hantzschel,[18] Boucart and Francis-Boeuf,[19] and van Straaten,[20] based on experiences in Europe, evoke the tide as an agent in the building of mud flats. Evidence in Panama supports this view, for wide mud flats fringe only the Pacific coast of high tidal range. Mud from streams and offshore currents are carried in by flood tides and deposited near shore during the slack periods as the tide turns. The source of mud along the Pacific coast appears to be largely local, for both the Aguadulce and the Juan Diaz mud flats border low erosional plains drained by sluggish rivers, the Río Santa María in the former, and the larger Río Chepo in the latter. The mud continues for three or four miles beyond the main shore line. Opposite the mouth of Río Chepo, the depth or water four miles offshore (to Chepillo Island) is about 10 feet. Opposite the mouth of the smaller Río Santa María, shallow water with a mean depth of about 10 feet occurs three miles offshore. The water in both areas then deepens to 30 or 40 feet within a mile. This slope may correspond to the edge of mud supplied by the rivers.

Effect of Wave Action. The force exerted by waves on the coast depends on their size, which varies with the velocity of the winds, their fetch, and on the width and depth of the continental shelf. The length of the fetch is greater on the Atlantic than on the Pacific side, for the nearest island of the Caribbean Antilles, Jamaica, is almost 600 miles from the

[14] *Pilot Charts of the Central American Waters,* 2nd edition (Washington, D. C.: Hydrographic Office, 1955).

[15] R. A. Terry, personal communication.

[16] H. H. Rousseau, "Terminal Works, Dry Docks and Wharves of the Panama Canal," *The Panama Canal,* Vol. 2, 1916, Paper No. 23, p. 418.

[17] Willson, *op. cit.,* pp. 263-264. H. A. Marmer, "The Tides at the Entrance to Panama Canal," *Geog. Rev.,* Vol. 16, 1926, pp. 502-503.

[18] W. Hantzschel, "Tidal Flat Deposits," in: P. D. Trask, *Recent Marine Sediments: A Symposium* (London: Thos. Murby & Co., 1939), p. 202.

[19] L. Boucart and C. Francis-Boeuf, *La Vase* (Hermann & Co., 1942), p. 42.

[20] L. M. J. U. Van Straaten, "Texture and Genesis of Dutch Wadden Sediments," *Proc. Third Int. Congress of Sedimentation* (Groningen-Wageningen, Netherlands: 1951), pp. 239-240.

Atlantic coast, whereas the Golfo de Panama opens out to the west coast of Colombia and the two shores are about 250 miles apart. Moreover, Pearl Islands in the Golfo de Panama are only 25 miles from the Panamanian coast. The prevailing winds are onshore and from the northeast on the Atlantic side; they are offshore, from the north and northwest on the Pacific side.[21] In the dry season between January and April, the trade winds sweep across the entire isthmus. This is the season of strongest onshore winds along the Atlantic coast. The average velocity of 15 knots is frequently exceeded. Average wind velocity is also greater during this dry season along the Pacific coast but the winds are offshore. During the wet season, between May and December, the winds are weaker and more variable. Though prevailing winds are still from the north along both the Atlantic and the Pacific coasts for the wet season as a whole, in September and October they are from the southwest in the Golfo de Panama. The continental shelf is from five to 10 miles wide on the Atlantic side, and its shoulder occurs at a depth of 300 feet. On the Pacific side, the shelf underlies the Golfo de Panama and the 300-foot depth contour is 45 miles from the coast. From these considerations and from direct observation of size, waves appear to exert a greater force on the Atlantic than on the Pacific coast.

Beach drifting, the deflection of stream courses, and the building of spits result from wave action. The coast of El Valle illustrates this process. The conical curvature of El Valle is indicated by the radial pattern of its streams. However, wave erosion has straightened and cliffed the curved base of the cone. The cliffed coast is oriented approximately at right angles to the direction of maximum fetch from which the dominant winds and largest waves may be expected to come. Wave action is thus not related to the prevailing winds, which are offshore for the Pacific coast. The material eroded from the cliff and brought down by streams from the flank is carried in opposite directions through beach drifting, northeastward to Chame spit, and less conspicuously, southwestward to a spit opposite Puerto Obaldía. By far the greater portion of the material moves northeastward, and the dominance of this drift is probably related to the fact that the strongest winds, up to 38 miles per hour, are from the south and southwest in September and October.

Turbulent water generated by large waves hinders the deposition of mud. Along the Pacific shore, broad mud flats occur in the sheltered Golfo de Parita opposite the Aguadulce Plain and in Chame Bay behind Chame spit. East of Juan Diaz, a low, irregular scarplet is bordered seaward by swamps, sand ridges and mud flats; and this depositional coast line has an east-west trend, oriented at right angles to the direction of maximum fetch. The low erosional plain behind the scarplet indicates that even before the deposition of mud, the offshore zone was probably shallow, and over this shallow expanse of water, waves from the direction of maximum fetch have prograded the shore line.

Between the Atlantic and the Pacific coasts, the gradient of the immediate offshore zone differs appreciably, as the coastal profiles (Figure 11) and the following table show.

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[21] F. W. Pope, *A Study of Weather Conditions in Panama with Special Emphasis on the Belt of Doldrums* (Canal Zone: Albrook Air Base); *Pilot Chart of Central American Waters,* 1955.

Depths of Water One Mile from Mean Shore Line

Atlantic	1. Low coasts		30-45 feet
	2. Cliffed coasts		55-65 feet
Pacific (Golfo de Panama)	1. Mud-flat coasts	less than	10 feet
	2. Low coast		15 feet
	3. Cliffed coasts		25 feet

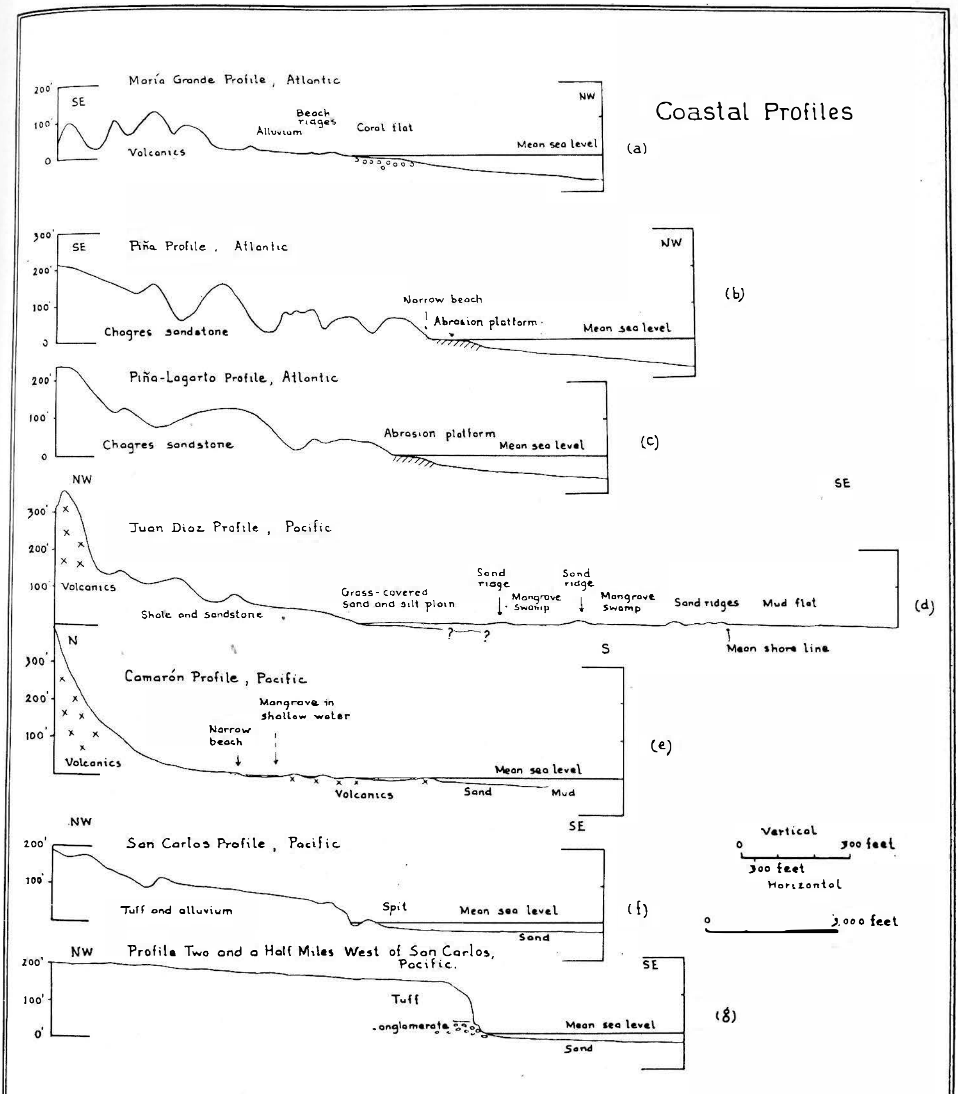

Fig. 11. Coastal profiles of central Panama.

Difference in the size of waves may be a factor in the contrast between Atlantic and Pacific depths within one mile offshore. On the Pacific side, low coasts bordered by swamps and mud flats have shallow, offshore water. On the Atlantic side, east of Límon Bay, low coasts bordered by swamps may descend to depths of 30 feet within 1,000 feet of horizonal distance. Explanation lies in the fact that the mud and silt of the low Atlantic coast have collected behind a fringing coral reef, and the steep slope offshore is the slope of the reef, not that of the mud. Where fringing reef does not occur, as on either side of Colón, waves propelled by strong onshore winds have enlarged bays. Though submergence may have initiated Limón Bay, its present size and shape is the work of waves. Fringing reef does not appear along the Pacific coast either, but here the evidence is of over-all progradation and an extension of the coast line seaward.

Cliffed coasts also show significant contrast in the depth of offshore water. Here again the greater depth of the Atlantic side may be due to its exposure to larger storm waves.

Effect of Sea-Surface Temperature. The surface temperature of sea water on the two sides of the isthmus differs significantly.[22] From January through April, it is 80 to 82°F on the Atlantic, and 72 to 74°F on the Pacific side. Strong upwelling occurs in the Golfo de Panama regularly each year during this season, for this is the time when northerly winds are blowing offshore and the warm water at the surface is replaced by colder water from below. From May to December, the difference in sea surface temperature between Balboa on the Pacific side and Cristobal on the Atlantic side is small; both stations record temperatures of 80 to 82°F, with the Atlantic station usually showing a higher register by 1°F.

Fringing reefs are common in the warm winters of the Atlantic coast, especially in the Golfo de San Blas, where reefs and islands of coral sand dominate the seascape. West of San Blas, an interrupted fringing reef borders both low and steep coasts. The cool Pacific waters in the months between January and April apparently suffice to prevent the development of coral reefs nearshore. The greater deposits of mud along the Pacific coast and the fresh water at the mouths of the larger rivers may be additional factors. However, even where the mud flat is absent, as along the coast of El Valle, reef corals do not grow.

Land and Eustatic Movements

To sketch the history of coastal land forms in Panama, one has to consider movements of both land and sea. Though topographic evidence for the occurrence of *relative* movements is usually clear, whether the dominant motion was by land or by sea can be inferred with much less certainly.

Evidence for Relative Movement. (1) Benches. On the Atlantic side, at least five benches occur on the Chagres Plateau. They also appear east of the canal Zone. On the Pacific side, only one, the present coastal plain, is clearly discernible. It continues westward to Bejuco but west of Chame it is hidden by an increasing thickness of tuffaceous alluvium and the bedrock is exposed only at the base of the sea cliff.

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[22] M. B. Schaefer, Y. M. M. Bishop, and G. V. Howard, "Some Aspects of Upwelling in the Gulf of Panama," *Inter-American Tropical Tuna Commission, Bull.,* Vol. 3, 1958, no. 2.

No marine deposits are known to exist on the benches. On the Atlantic side benches are deeply dissected and appear locally as the accordant summits of knolls, for example, Monkey Hills. Nevertheless waves probably cut the benches, excepting perhaps the highest one. This marine origin is suggested by the fact that they lie close together within a belt of only three miles from the coast. At present, the main rivers, being entrenched at their mouths, are not bordered by denudational surfaces whereas platforms of marine abrasion do fringe the sea cliffs. On the other hand, the highest plateau surface is probably of subaerial origin, for a gentle erosional tpography still exists at the southeastern edge, where headstreams of the Providencia, Media and Piña occupy alluviated valleys. The Pacific coastal bench bears weathered alluvium, from coarse gravel to silt, on the interfluves. In contrast to the Atlantic benches, it appears to be primarily the work of subaerial processes. This suggestion, though based on inconclusive evidence, is in line with the operation of present processes, which show stronger marine erosion on the Atlantic than on the Pacific side. However, the steep outer edge of the Pacific bench is cut by waves. It rises as sea cliffs or as scarplets bordered by sand ridges and brackish-water swamps.

(2) Buried topography. Relative submergence of the land is abundantly attested by erosional topography buried by muck, or by muck and water. The artificial Gatun Lake itself occupies former swamplands of muck, the thickness of which varies from 90 to over 250 feet. The floor of the Pacific entrance of the Panama Canal consists of weathered bedrock overlain by muck as the borings taken in connection with a proposed bridge indicate.

A Sample of the Log for Balboa Bridge

Depth in feet	Description of Material[23]
0-14	*Muck;* soft to medium soft, low placticity, low dry strength, high water content, variably sandy and silty, very carbonaceous, abundant calcareous shell debris; color, dark blue-gray to black.
14-30	*Weathered bedrock* (dacite); medium hard to hard, moderate strength, closely jointed with joints highly weathered, fine grained, porphyritic; color, medium brown mottled with white.
30-115	*Sound bedrock* (dacite); very hard, strong, closely jointed, fine grained, porphyritic, containing many phenochrysts of white feldspar; color, light grey mottled with white.

Two and a-half miles from the present coast line, opposite the Pacific entrance of the canal, a submarine profile taken in connection with a proposed sewer shows a weathered, uneven bedrock surface covered by 10 to 30 feet of muck and sand and 15 to 50 feet of water (Figure 12). Sea level was therefore lower by at least 80 feet.

[23] R. H. Stewart, *Geological Logs of Drill Holes for Construction of Balboa Bridge Substructure, Canal Zone,* Panama Canal Company, 1959.

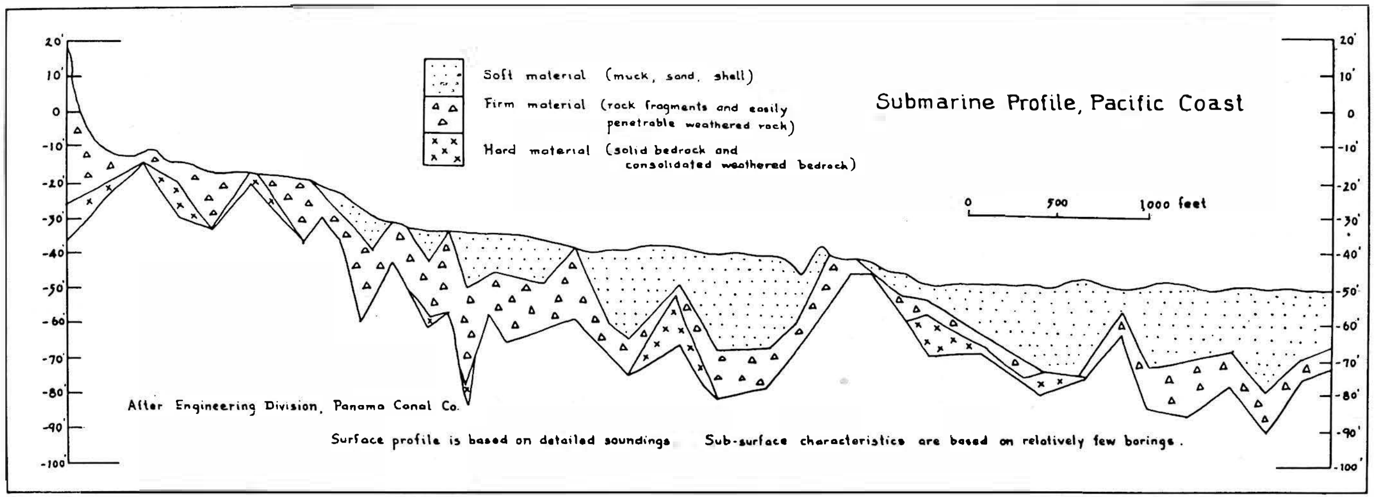

Fig. 12. Submarine profile, Pacific coast. (See Figure 7 for location.)

(3) Marine muck, dead coral flats, stranded platforms of marine abrasion, and low weathered benches. These features indicate a small negative movement of the sea. Exposed marine muck provides the clearest evidence for this movement. Dense clusters of dead corals flush with the sea surface also give strong support to the conclusion. Much less clear is the meaning of stranded platforms of marine abrasion, and of low, weathered benches.

A few stranded platforms, usually projecting beyond the tips of prominences along the coast, have been noted on the Atlantic side (Figure 5). Waves break at the outer edge of the platform and send a shallow swash over its surface to the base of the cliff. In the field, the sight of waves pounding on the outer edge of platforms has led me to believe that they well eventually eliminate it and produce a lower surface. Since the mean tidal range on the Atlantic side is less than one foot, it cannot alter significantly the level of concentrated wave attack and so nullify the pertinence of the observation. Along the Pacific coast the abrasion platform is continued seaward by a mud apron. In contrast, along the Atlantic coast the shallow water of less than 3 feet over the abrasion platform increases sharply to 20 feet beyond the platform's outer edge, where wave attack is taking place. The occurrence of stranded platforms supports the notion of a negative shift of sea level—a notion based on the independent evidence of marine muck and dead coral flats. By themselves, platforms are susceptible to another interpretation. Edwards, in his study of the coast of Victoria, Australia, suggests that the stranded platform is maintained by storm waves during high tide; only ordinary waves attack the platform's outer edge.[24] However, tidal range along the Atlantic coast of Panama seems too small to be an important factor, and it is difficult to see how storm waves could maintain rather than destroy the platform unless water level rises well above it.

In distinction to the marine platform, the low, weathered bench appears in sheltered embayments. The evidence of marine muck indicates a former sea level that would have covered the bench, but unlike the wave-cut platforms at the coastal protrusions the subsequent retreat of the sea has left the interior bench exposed to weathering. Not enough is known about the bench, its distribution and origin (whether it is cut by streams or by waves), for it to provide independent evidence of a small change in sea level, but its existence is a reasonable corollary of the hypothesis.

Evidence for Tectonic Movement. According to Jones, deformation appears to have been continuous in central Panama throughout Cenozoic time, for the older formation show progressively more disturbed conditions.[25] However, the youngest formation in the Gatun Lake area thus affected is the sandstone of Chagres plateau, which is probably late Miocene or early Pliocene in age.[26] Evidence for structural disturbance in the Quaternary period occurs in the form of fault scarps that Jones recognized at the southeastern edge of the Chagres plateau. These scarps rise at intervals as straight, undissected cliffs 50 to 150 feet above Gatun Lake.[27] At

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[24] A. B. Edwards, "Wave Action in Shore Platform Formation," *Geological Magazine,* Vol. 88, 1951, pp. 41-49.

[25] Jones, *op. cit.,* p. 906.

[26] Woodring, *op. cit.,* p. 50.

[27] Jones, *op. cit.,* p. 908.

Gatun Dam the thickness of alluvium and muck is 258 feet. The bedrock floor is therefore some 200 feet below present sea level. North of Gatun Dam, Río Chagres cuts across Chagres plateau to the sea through a valley 300 feet deep. Since the river must once have flowed on the plateau's surface, a differential movement of the order of 500 feet has taken place.

The Pleistocene eruption of El Valle attests to structual instability. Fault movements along its flanks have occurred in Recent time.[28]

Evidence for Eustatic Movement. Sea level has oscillated with the expansion and contraction of ice sheets in the northern hemisphere during the Pleistocene period. Topographic evidence for such movements, such as a bench, is reliable only if it can be traced over wide stretches of the coast. Benches of Panama are fragmentary, and the writer has been able to trace them for only short distances on either side of the Canal Zone.

From available evidence, two movements, primarily of sea level, appear to have taken place. One is the rise of sea surface that resulted in widespread drowning of erosional topography, evident especially on the Pacific side, and the other is the slight drop in more recent time. That the drowning of erosional topography is due to the rise of the sea rather than to depression of the land is suggested by the rapidity of the movement; so rapid that weathered rock and regolith have not been removed from the submerged surface. This rise of sea level may have taken place from 8,000 to 12,000 years ago with the last major deglaciation. The mollusks found in the Atlantic muck are known to be living in the Caribbean Sea,[29] but no radio-carbon dating on them or on the carbonized wood is yet available.[30] The more recent withdrawal of the sea, perhaps of the order of 10 feet, is suggested by the testimony of several types of evidence. The occurrence of marine muck only a few feet above high tide level on both sides of the isthmus, around Limón Bay and north of Panama City, suggests a withdrawal of the sea. On the Atlantic coast are flats composed of dense clusters of dead corals. The fact that these coral flats, from the base of the Chagres plateau to Golfo de San Blas, all appear at one or two feet below the mean sea level suggests eustatic rather than land movement, for with land movement one might expect greater difference in their relative elevations. Live corals now grow sporadically at depths of three to five feet. Dense clusters need slightly greater depth. The appearance of dense clusters of dead corals at the present sea level suggests a retreat of the sea by at least 10 feet. The stranded abrasion platforms and the low benches agree with this conclusion.

Historical Outline and Summary

From the survey of evidence for land and eustatic movements, the following sequence of events may have taken place in central Panama. The land rose relative to the sea. Benches, of which five are discernible on the

[28] Terry, *op. cit.*, p. 15.

[29] Woodring, *op. cit.*, p. 50.

[30] After the manuscript had gone to press, the author received the following C14 report from the United States Geological Survey through the courtesy of Dr. W. P. Woodring. The ages of three samples of muck, two from the Pacific side and one from the Caribbean side, are as follows:

Balboa Bridge core hole (BBR-53)—6,700 ± 300 years (Lab. No. W-958)
Balboa Bridge core hole (BBR-128)—7,680 ± 300 years (Lab. No. W-959)
Mindi Road Bridge core hole, Mindi 2—7,240 ± 300 years (Lab. No. W-960)

Charges plateau and at least one on the Pacific side, have been cut. Waves appear to have cut the lower Atlantic benches whereas the Pacific coastal bench is essentially a surface of subaerial denudation, though it may have been modified by the sea. The ancestral forms of the present coastal bench may be traced to the earlier part of the Pleistocene, for west of Bejuco the bench disappears under a tuffaceous formation considered as Pleistocene in age.

The 330-foot bench in Chagres plateau does not appear on the Pacific side, nor the deeply entrenched streams. Uplift was therefore greater on the Atlantic side. Tilting is further suggested by the difference in the depth of the shoulders of the continental shelves. The shoulder of the Atlantic shelf occurs at the depth of 42 fathoms, whereas on the Pacific side it lies at 72 fathoms below sea level.[31] However, the inclination of the Pacific coastal bench was affected by the movement. Streams are incised though much less deeply than those in Chagres plateau.

In spite of the greater uplift on the Atlantic side, the Pacific coastal bench, because of its gentler gradient, reached further out to sea The evidence of the submarine profile (Figure 12) indicates that sea level was lower by at least 80 feet, which means that the Pacific coast line opposite the canal entrance extended at least eight miles beyond its present position. Since the Pearl Islands are separated from the Pacific coast by a channel with minimum depths of 100 feet, it is possible that they were connected with the mainland prior to the last major rise of sea level. Pearl Islands are 25 miles offshore. On the Atlantic side, a drop in sea level by 80 feet would add a strip of land only one and a-half mile wide to the base of the Chagres plateau.

The last rise of sea level, perhaps during the last deglaciation, was rapid and covered the weathered surfaces of the coastal bench. At its maximum height the sea rose beyond the present shore line and reached into bays and inlets, where muck accumulated in brackish water. On the exposed coast, the sea was in contact with the steeper gradients of the upper parts of the denudational plain, where sea cliffs and scarplets that bound the outer edges of the present coastal bench were probably initiated. The subsequent retreat of the sea by about 10 feet produced features such as swamps of muck, dead coral platforms and stranded marine platforms.

The relative stability of the present sea level is suggested by the extent of coastal modification that the sea is able to achieve in its present position. Both regressional and progradational changes in coast lines have taken place since the sea reached its present level. Regression results in cliffed coasts, such as where the tuffacous flank of El Valle reaches the set, and on the Atlantic side, in the sandstone of Chagres plateau. The cutting of El Valle sea cliff takes place *pari passu* with the construction of spits in opposite directions on either side. Thus the lower course of the Río Farallón on the west and of the Río Chame on the east have been deflected by sand ridges that are densely forested, and rise 10 to 25 feet above the level of the mean tide. Recent beach sand, covered by water during high tide, has been added to these ridges. More extensive progradation appears east of Old Panama. Here the coastal bench ends in a grass-covered scarplet; beyond it spread tall-grass swamps between coconut-crowned sand ridges

[31] Terry, *op. cit.*, p. 16.

with comparable elevations above sea level (maximum: +25 feet), and the mangrove swamp at the edge of the sea. The width of this progradational plain increases eastward from a narrow edge just east of Old Panama to about seven or eight miles at Río Chepo. Progradation was probably punctuated by shorter phases of regression. Thus the present coast line bears evidence of erosion in the cakes of old mud flats at Juan Diaz and in the clifflets cut in sand ridges. However, beyond them are broad deposits of new mud, exposed only during low tide. Progradation, apart from the mud that collected on coral flats, has been much less extensive on the Atlantic side. Forested beach ridges occur, for instance, in the vicinity of María Chiquita but they are much smaller and narrower than the Chame and Farallón ridges.

Marine erosion is now the dominant process operating on both shores of the Panamanian isthmus. This is illustrated by beaches littered with drift wood especially on the Atlantic side, and by the ubiquitous beach scarps. More striking examples of beach erosion occur on both shores. Thus the mouth of the Río Chagres on the Atlantic side is partly blocked by a spit. A paved road that used to run along it is now crumbling into the sea. On the Pacific side, the mud cakes east of Juan Diaz, and the precarious stands of mangrove in heavy surf at Camarón west of the Canal Zone, are clear manifestation of erosion.