# AN EXPLANATORY DESCRIPTION OF THE SAND ISLANDS OF KURE, MIDWAY, AND PEARL AND HERMES ATOLLS: HAWAIIAN ISLANDS

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Master of Arts

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by

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TABLE OF CONTENTS

# LIST OF FIGURES

FIGURE PAGE

## ABSTRACT

The previously unnoted similarity of surficial form, shape, and distribution of land found on the Hawaiian atolls is shown to be related to the unique subtropical situation. Winter cyclonic storms have restricted the distribution of land on Kure, Midway, and Pearl and Hermes Atolls while giving the islands a characteristic form. Rapid changes of a small sand point on Kure Atoll similar to points found on other islands in these atolls are shown to be extremely sensitive to changes in wind direction and intensity. This thesis demonstrates that movements of these points and sand bars in the lagoon exhibit the sequential processes by which the permanent islands have been formed.

# CHAPTER I

# INTRODUCTION

Coral atolls have been described in various ways by many authors but are best typified by the singular characteristic of a reef encircling a somewhat shallow lagoon. Islands usually appear along the margins of lagoons, either on the reef or just inside it. The distribution of land that supports vegetation and is thereby considered permanent does not fall within any predictable pattern on most atolls. However, studies of several atoll groups have indicated that the arrangement of islets within a reef is not random.

A review of the literature has shown that, to this date, the distribution of land on atolls has never been considered a useful characteristic unifying geographic groups of atolls. However, on the atolls of the Hawaiian group visited by the author, a particular pattern of land distribution is both clearly defined and common to all the atolls. It is this predictability of land in the southern half of the reef ring that is the unifying characteristic of these atolls and sets them apart from all other atolls. Furthermore, this precise distribution of land in specific sectors of the lagoon margin results from the effects of winter cyclones directly associated with the unique latitudinal position of the Hawaiian atolls.

## I. THE PRESENT STUDY

The atolls examined in this study are part of the Hawaiian Chain which extends northwestward nearly two thousand miles from the large island of Hawaii on the east to Kure Island. Kure and her two neighbors, Midway, and Pearl and Hermes (one atoll), are the only atolls in the Hawaiian Archipelago (Figure 1). Their distinctiveness does not end here. Of more than four hundred known coral atolls in warm waters of the world, Kure, Midway, and Pearl and Hermes are the farthest north.[1] Indeed, in the Northern Hemisphere they are the only atolls poleward of the Tropic.[2] Coconut palms are absent, winters are cold, and typhoons have never been recorded.

Another important feature of the Hawaiian atolls is their pronounced similarity in appearance. Land is restricted almost entirely to the southern half of the lagoons. Most of the islands are long and narrow with the long axes trending northeast-southwest. Sand dunes are an important landform on the lagoon shore of several of the islands. The unique subtropical situation of the Hawaiian atolls and their proximity to one another suggests that some, if not all, of the similarities noted above have a common origin.

Statement of purpose. The purpose of this paper is to demonstrate that winter cyclones affecting the Hawaiian atolls have produced unique similarities in surficial form, distribution, and shape of islands within the coral rings. All the Hawaiian atolls are outside the tropics and far from other atolls, but they are quite close to one another. The atolls of Kure, Midway, and Pearl and Hermes

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[1]Edwin H. Bryan Jr., "Check List of Atolls," Atoll Research Bulletin, No 19, Sept. 30, 1953.

[2]There are two atolls in the Southern Hemisphere south of the Tropic--Oeno and Ducie, both near Pitcairn Island.

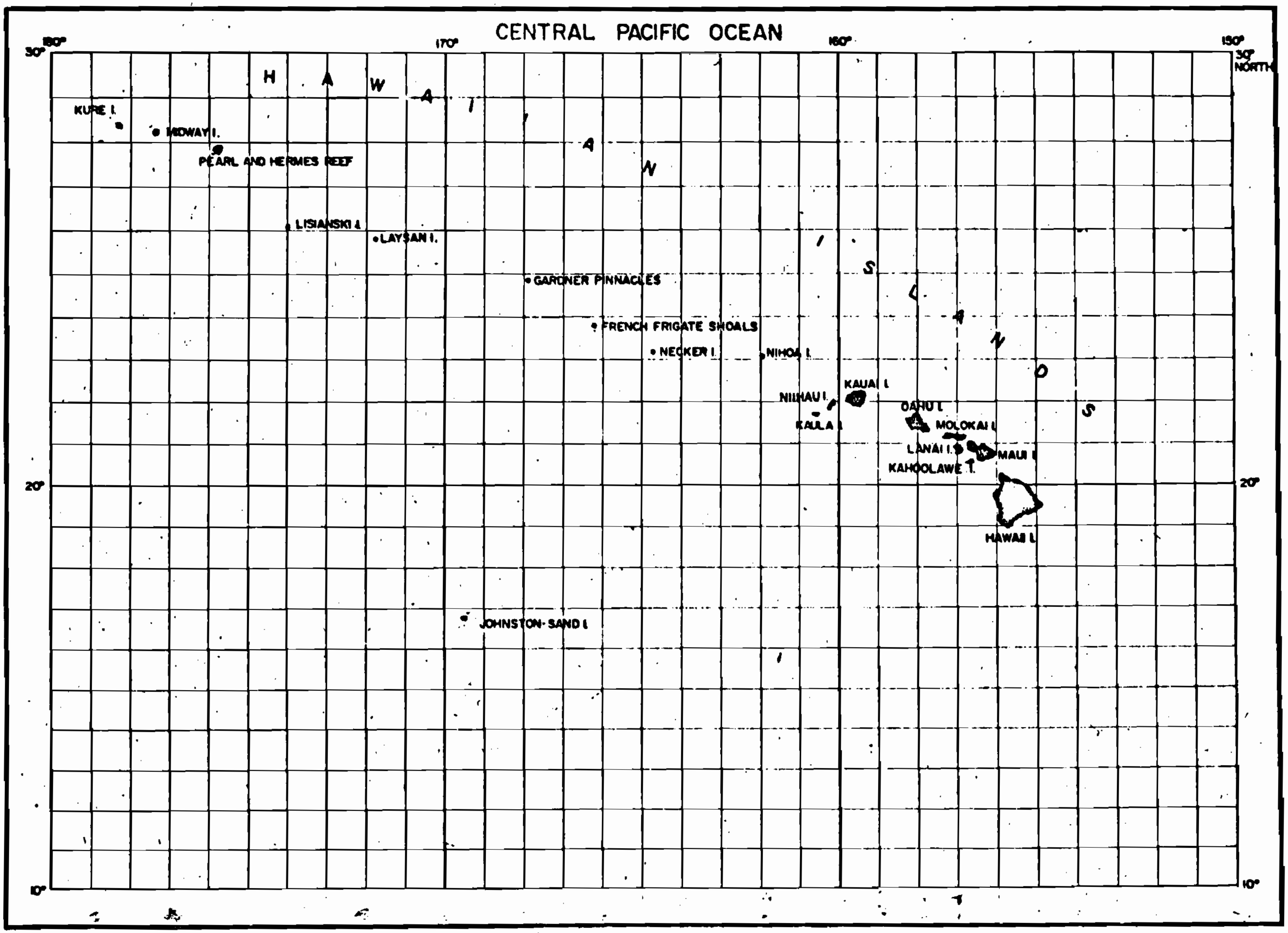
CENTRAL PACIFIC OCEAN
180°
170°
160°
150°
30°
30° NORTH
20°
10°
H A W A I I A N
I S L A N D S
KURE I.
MIDWAY I.
PEARL AND HERMES REEF
LISIANSKI I.
LAYSAN I.
GARDNER PINNACLES
FRENCH FRIGATE SHOALS
NECKER I.
NIHOA I.
KAUAI I.
NIIHAU I.
KAULA I.
OAHU I.
MOLOKAI I.
LANAI I.
MAUI I.
KAHOOLAWE I.
HAWAII I.
JOHNSTON-SAND I.

FIGURE 1

are all included in a small area that ranges only 39 nautical miles north to south and 143 nautical miles east to west. The atolls within this geographical range from a compact unit suitable for field study, the climate is essentially the same, and all the atolls are subjected to winter mid-latitude cyclones. No other atolls in the world fall within this cyclonic influence.

Field work. The present study is the result of observations made during field work supported by the Smithsonian Institution, Department of Vertebrate Zoology-Division of Birds, Pacific Ocean Biological Survey Program.[3] The writer spent nine weeks on Kure Atoll and four days on Midway during January, February, March, and April 1965. The peculiar orientation and distribution of sand islands on Kure, Midway, and Pearl and Hermes were noted at that time. The arrangement of islands on these atolls seems unrelated to the trade winds, reef structure, or ocean currents about them, yet the similarity of distribution of land within the three atolls is undeniable.

In addition, alterations in the shape of Green Island, Kure Atoll were observed. A study area on the west point of Green Island was staked out, and observed changes in the shape of this point were recorded for more than a month. During March 1965 an unusually late storm noticeably altered the shape and size of the point. This storm, like most others, was cyclonic, the winds coming from the

[3] Hereafter called (POBSP)

northwest in excess of twenty knots. These winter disturbances occur nearly every year on Kure, Midway, and presumably the uninhabited Pearl and Hermes Reef, only twenty-seven nautical miles farther south. Winter storms are peculiar to the Hawaiian atolls. They are in no way associated with tropical typhoons common on most atolls previously studied by other authors.

## II. PREVIOUS STUDIES

The classic circular or oval reef is not typical of all atolls. It is this characteristic of atolls, however, that has attracted the attention of most writers. Such famous naturalists as Darwin, Agassiz, Dana, and Wallace are associated with early attempts to determine the origin of these ring islands. Today subsidence is usually considered to have played a major part in their formation.

Though many geologic studies have sought to tie the similarities of all atolls to a common origin, very little investigation of the shape and distribution of permanent land on atolls has been done. The most comprehensive work of this kind is that of Wiens who studied the proportion of atoll circumferences occupied by land. Conclusions, though broad and not correlated with geographic groups of atolls, are of some interest to this study. He found that on "about 72 percent of all Pacific atolls less than one half the reef circumference is occupied by land."[4]

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[4]Harold J. Wiens, Atoll Environment and Ecology, (New Haven and London: Yale University Press, 1962), p. 41.

Wiens also studied the location of land on atolls and observed that vegetated land areas (reef islets above high tide) occur with greatest frequency in either the eastern or the western sectors of reefs with only a slightly higher frequency in the former. His conclusions on atoll land location are of great importance to this study because they indicated only tendencies for the land to be situated on certain parts of the atoll rim. This is demonstrated graphically in Figure 2 which shows atoll land distribution along various reef sectors for several groups of Pacific atolls as summarized by Wiens.[5] Note there is no easily discernible pattern on any of these frequency diagrams. In contrast to this, the diagram for Kure, Midway, and Pearl and Hermes (Figure 3) shows a clearly defined pattern, characteristic of the Hawaiian atolls, indicating the presence of land only in the southern half of the reef ring.

Wiens also noted that the frequency of reef passages was higher to the windward than the leeward on most atolls. This relation seems to hold both north and south of the equator.

Verstappen studied climate and its influence on the formation of coral islands.[6] His research is important here because he studied the shape of sand bars and the distribution of coral ramparts relative to the rest of the island. Although his study of islands in Djakarta Bay did not involve atolls, his work was an attempt to

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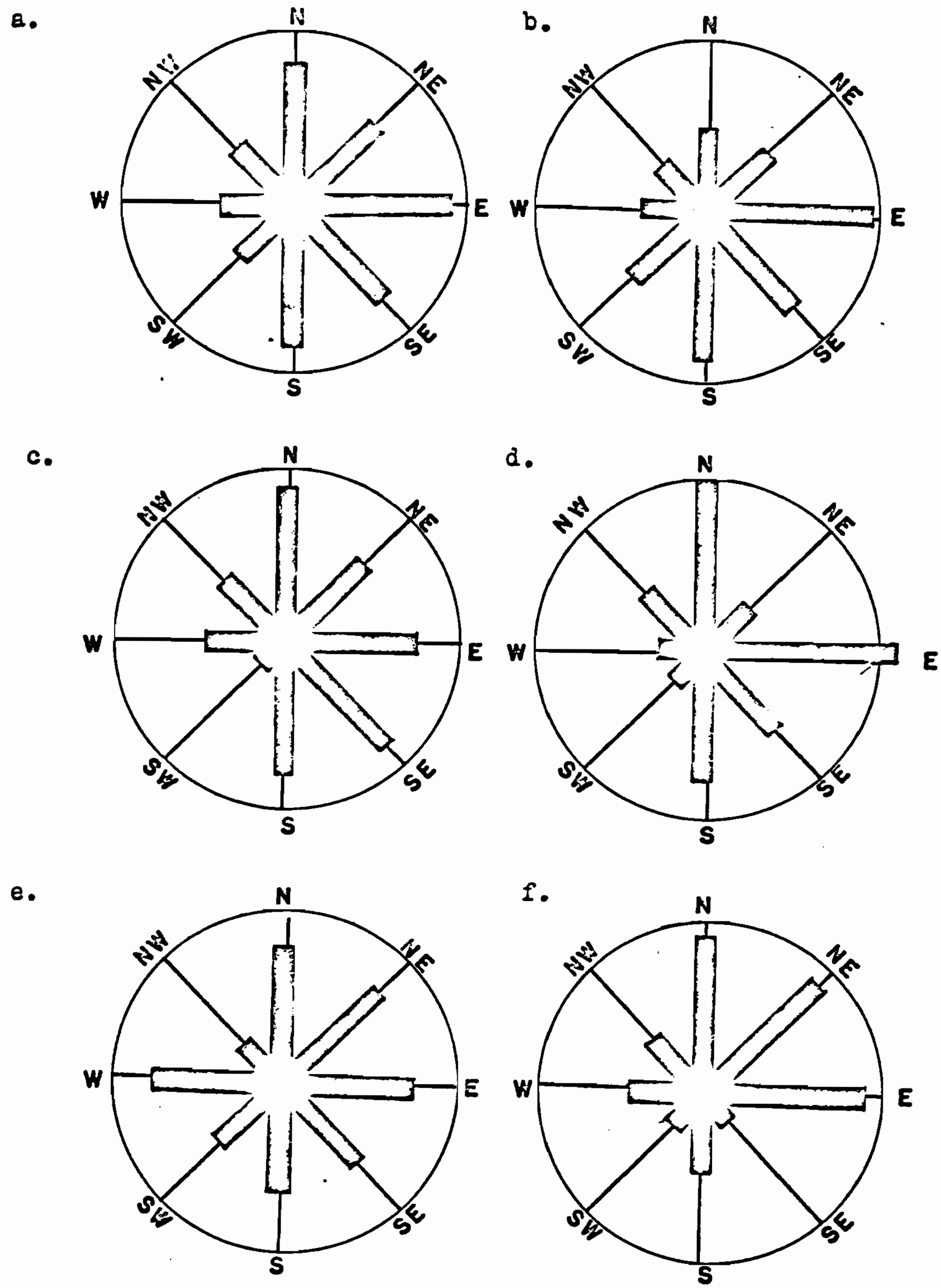
[5] Ibid., p. 43.

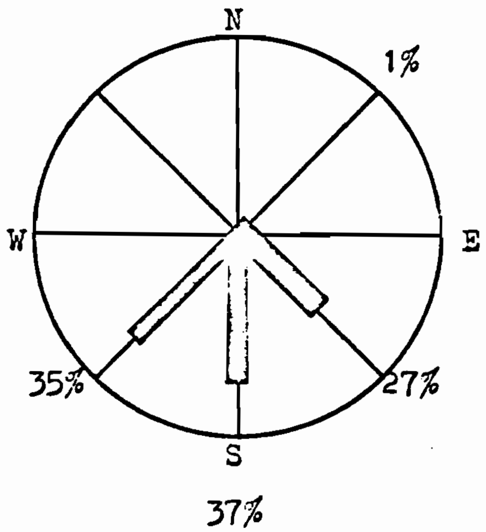
[6] Herman Th. Verstappen, "The Influence of Climatic Changes on the Formation of Coral Islands," American Journal of Science, 252: 428-435, July 1954.

FIGURE 2




The location of land on atoll reef sectors of 125 atolls in the north and south Pacific (a); Marshall Islands (b); Caroline Islands (c); Gilbert Islands (d); central Pacific (e); and Tuamotu Islands (f). Bars indicate percent of total land area in particular reef sectors and the radius of the circle represents twenty percent.
(after Wiens, op. cit., p. 44.)

FIGURE 3




Land location on atoll reef sectors in the Hawaiian atolls of Kure, Midway, and Pearl and Hermes. The bars indicate the percentage of total land area in particular reef sectors and the radius of the circle represents 20 percent. Here 99 percent of all the land is in the southern half of the atolls.

designate a common cause for the shapes of a compact geographical group of islands.

Verstappen's method was based on an earlier one by Umbgrove, whose approach to the problem utilized frequency and velocity of wind to determine what he called the "wind effect."[7] Umbgrove found that the material content and orientation of beaches on the sand islands in Batavia (Djakarta) Bay were caused directly by wind action. He was unable, however, to establish the length of time necessary for these changes to take place. Verstappen was able to show by the use of historical maps that the shapes of islands in Djakarta Bay resulted from a climatic change. He suggested the need for similar studies in the trade wind belt.

Schou studied the influence of wind on shoreline orientation and dunes in Denmark. He developed a method, somewhat similar to Umbgrove's, for determining the "Direction-Resultant Wind Work (DRW)."[8] He used the directional frequency of wind in percent and multiplied it by the Beaufort value. He then summed similar wind directions, and the results were shown in a vector diagram. He disregarded winds with force less than 4 Beaufort since he considered these velocities to be incapable of moving sand. He concluded the "terminant direction of the shore was at right angles to the DRW

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[7]J. H. F. Umbgrove, De koraalriffen in de baai van Batavia, (Dienst. v. d. Mijnbouw in Ned. Indie, Wetensch. Meded, 7), 1928.

[8]A. Schou, "Direction Determining Influence of the Wind on Shoreline Simplification and Coastal Dune Forms," Seventeenth International Geographical Congress, Pub. 6, 1952, (abstracts) pp. 81-82.

and dunes parallel to it." (sic)[9]

Problems. As seen above, some work has been completed on the causes of shapes of sand and coral islands, but these studies have never yielded enough information to divide atoll land configurations into distinct geographical types. Indeed, most studies have indicated that no such distinction exists. Wiens noted that "Atoll shapes cannot be correlated with particular factors that allow for generalization. . . ."[10] This may be attributed partially to the extended spatial distribution of most of the island groups studied and partially to the dearth of detailed investigations.

Wiens, for example, used the atolls of the Marshalls, Carolines, Gilberts, central Pacific, and Taumotus as separate and distinct geographical units. Although each group appears as a distinct unit on the globe, the north-south range within any one group is no less than 500 miles. In the oceanic realm within such distances the inherent variability of wind, ocean currents and associated climate is well known. The tropical rain forest of Palmyra Island in the central Pacific group of the Line Islands is just three hundred miles north of the near-desert on Christmas Island. Other geographical units such as the Gilberts and Marshalls experience both northeast and southeast trades during a normal year.[11]

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[9]Ibid.

[10]Wiens, op. cit., p. 19.

[11]Otis W. Freeman, Geography of the Pacific, (New York; John Wiley and Sons, 1951) pp. 9-10.

Most atolls in the world have a tropical warm climate. Many are frequented by tropical cyclones called typhoons. Trade winds are most often gentle, and although they may help account for the distribution of small features, like shingle and sand beaches on many atolls or lagoon passages on others, their influence has never been considered strong enough to produce predictable geomorphic features. In contrast, a tropical disturbance may modify the shape of an atoll island and establish more semi-permanent land forms in one day than the trade winds and associated ocean currents can do in many years. Blumenstock noted that in some cases on Jaluit Atoll in the Marshalls more than 75 percent of the coral rubble forming the new ocean-side bar off Jaluit Islet was deposited by typhoon "Ophelia."[12]

Typhoons really add little to atoll islands; most of their effects are seen in some form of degradation. Furthermore, with typhoon winds there is no protected side of an atoll. Virtually every part of an atoll is affected, first from one direction and then the opposite one as the storm passes. As a result there is no apparent tendency toward a particular distribution of islands on atolls frequented by typhoons. Blumenstock, however, has stated that more study is needed on atolls in typhoon and nontyphoon areas.[13]

Perhaps the problem in discovering distinct geographic types of atolls lies in the large spatial range of the groups studied. My observations made on the atolls of the Leeward Hawaiian Islands seem

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[12] David I. Blumenstock, "A Report on Typhoon Effects Upon Jaluit," <u>Atoll Research Bulletin</u>, No. 75, April 1961.

[13] <u>Ibid.</u>

to suggest this is the case.

## III. ORGANIZATION OF THESIS

In order to demonstrate that the unique situation of the Hawaiian atolls has played an important role in forming a morphologically homogeneous group of islands, the following approach is employed.

First, for purposes of comparison, several distinct levels of similarity are described. Configurations of sand islands on the three atolls of Midway, Kure, and Pearl and Hermes are shown and similarities are noted. Shapes and surficial forms of the islands are discussed. Next, the larger islands of Kure, Midway, and Pearl and Hermes are described briefly.

With a clear picture of the islands in mind, two possible causes for the similarities described are explored. These include submarine structure and certain climatic elements. It is then shown that structure alone does not dictate the site of land on the three atolls. Next, a detailed discussion of the climate emphasizes the importance of winter storms.

Moreover, based on the orientation of islands, the movements of sand spits, and the site of islands with respect to special wind conditions, the overwhelming importance of storms is demonstrated. Furthermore, the strength of these winter storms is studied to reveal their quantitative sand transport qualities and total effect on the islands.

In conclusion a theoretical sequence of events for island evolution in the Hawaiian atolls is discussed in order that their pertinent morphological features be explained. The transition period between winter and summer is shown to be very important in the formation of certain island features. Finally winter storms are shown to be the most important physical element contributing to the morphological similarities observed in the Hawaiian atolls.

## CHAPTER II

## THE HAWAIIAN ATOLLS

The Leeward Hawaiian Islands are considered to be the oldest part of the Hawaiian Archipelago. They comprise a clear sequence from east to northwest, from the maturely dissected volcanic cones, such as Kaula Rock, to the barely emergent volcanic necks of Gardner Pinnacles and La Parouse Rock, and finally to the three small atolls of Pearl and Hermes Reef, Midway, and Kure at the northwest end of the chain. On Kure and Midway atolls the reefs measure about 15 nautical miles in circumference, while on Pearl and Hermes this distance is 43 miles.

### I. UNIQUE SITE AND CLIMATIC RAMIFICATIONS

The Hawaiian atolls are uniquely situated in the Pacific realm (Figure 4). As previously stated, they represent the three northernmost atolls in the world as listed in Bryan's "Check List of Atolls."[14] Pearl and Hermes is the southern-most of the group at 27°45' North Latitude. The atolls range from 176° West Longitude at Pearl and Hermes to 178°30' west at Kure. The nearest atoll to the Hawaiian group is Wake Island, about a thousand miles to the southwest.

Because of their unique site the Hawaiian atolls might be expected to differ climatically from other atolls. Indeed a

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[14] Bryan, loc. cit.

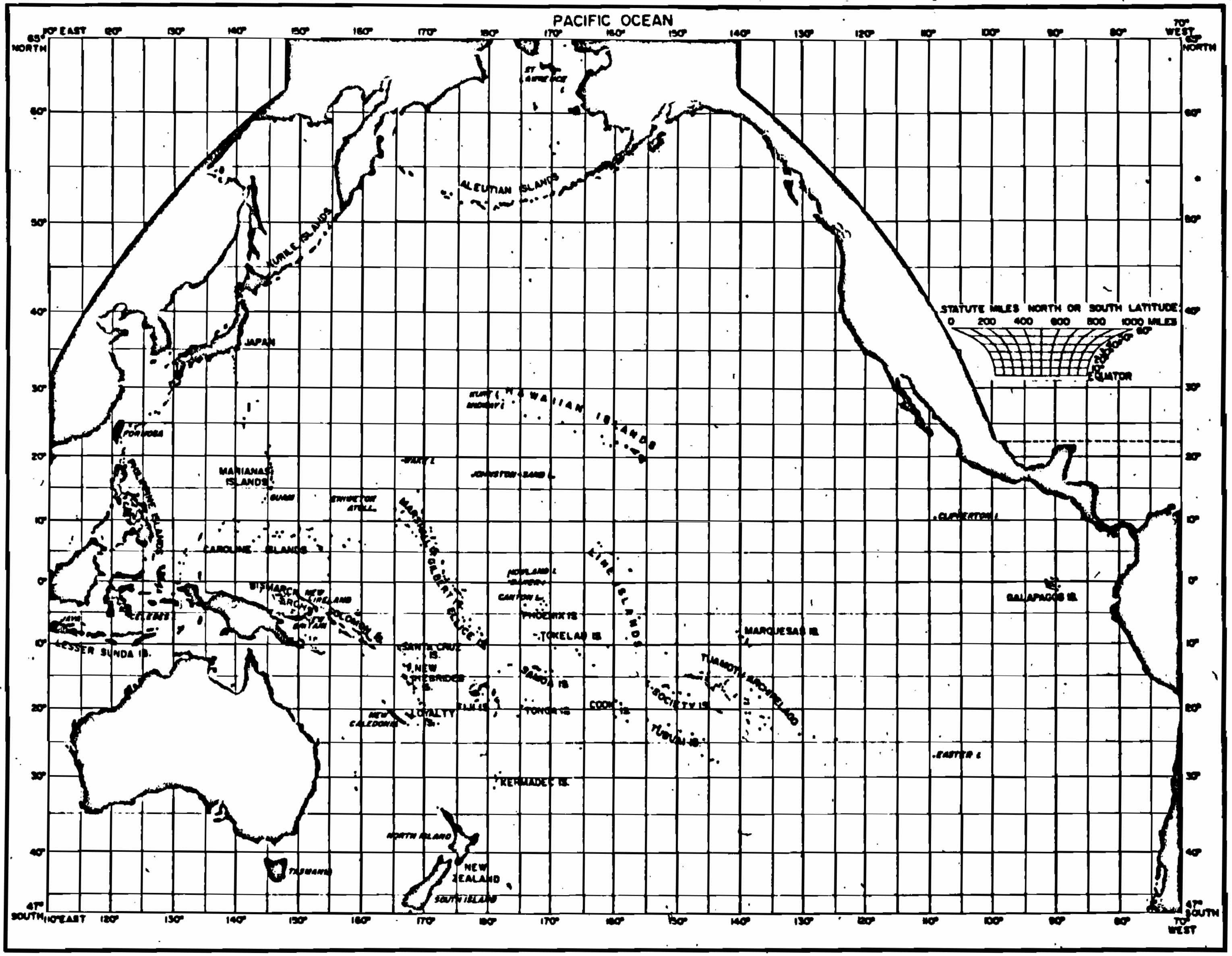
PACIFIC OCEAN
ALEUTIAN ISLANDS
KURILE ISLANDS
JAPAN
FORMOSA
MARIANAS ISLANDS
GUAM
CAROLINE ISLANDS
HAWAIIAN ISLANDS
JOHNSTON
MARSHALL
GILBERT
ELLICE IS.
HOWLAND I.
CANTON I.
PHOENIX IS.
TOKELAU IS.
MARQUESAS IS.
SANTA CRUZ IS.
NEW HEBRIDES IS.
LOYALTY IS.
NEW CALEDONIA
FIJI IS.
SAMOA IS.
TONGA IS.
COOK IS.
SOCIETY IS.
TUAMOTU ARCHIPELAGO
TUBUAI IS.
KERMADEC IS.
NEW ZEALAND
NORTH ISLAND
SOUTH ISLAND
TASMANIA
LESSER SUNDA IS.
CLIPPERTON I.
GALAPAGOS IS.
EASTER I.
EQUATOR
STATUTE MILES NORTH OR SOUTH LATITUDE
0 200 400 600 800 1000 MILES

FIGURE 4

preliminary survey indicates this is the case and the distinctive character of the climate of the Hawaiian atolls is discussed here. A detailed examination of individual climatic elements considered to be causal with respect to island evolution follows in a later chapter.

A study of the climate of the Hawaiian atolls is essential to a meaningful interpretation of the physical landscape. The only weather record for the area is that of the United States Weather Station Midway, which extends back to 1949.[15] A permanent record has been maintained there just 50 miles from Kure and 90 miles from Pearl and Hermes and can be considered typical for the three atolls.

Comparative atoll climates. The purpose of studying the climate of the Hawaiian atolls is to demonstrate the actual consequences of a subtropical position, which distinguishes them from all other atolls. Wiens has described the general character of tropical oceanic weather and climate. "The climate of the Pacific atoll realm is marine and tropical. . . . the range of temperature about 2°F annually." Temperatures on atolls as reviewed by Wiens range from 100°F to 65°F with the greatest absolute range for any one atoll being 34°F on Maldon Island.[16]

Winds on atolls seldom rise above a fresh breeze (20 knots) and rarely reach gale strength (24 knots). Although typhoon frequency in the Pacific is high, each storm is localized and individual atolls

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[15]Chief of Naval Operations, Aerology Branch, Summary of Monthly Weather Records, Midway Island 1949-62, Washington D.C., 1962.

[16]Wiens, op. cit. pp. 137-186.

"may experience heavy storm damage only at long intervals." Rainfall is extremely variable and the data for the Pacific far too spotty to reveal any pattern.[17]

<u>Hawaiian atoll temperatures</u>. In the entire Pacific, only the Hawaiian atolls have an average January temperature less than 70°F.[18] The annual range of temperature on Midway is 18°F. The average temperature of the warmest month is 71.8°F in September. The record high is 89°F. February is the coolest month with a 65.7°F average. The record low is 52°F, making an extreme range of 37°F; more than that of any other atoll in the world. The relatively cold winters have precluded the growth of tropical vegetation usually found on most atolls.

The annual march of temperature shows rather even winter and summer conditions with most of the heating and cooling taking place in the spring and fall. (Figure 5). The total change in the average monthly temperature from January to April is only 1.5°F. From April to May it is 3.5°F, and May to June 5°F. Through July, August, and September there is only 1°F variation of monthly average temperature. With the onset of fall the monthly mean drops 3°F each month from September through December.

<u>Hawaiian atoll rainfall</u>. Rainfall averages about 40 inches annually. It rains on an average of 12 days each month.[19] March is

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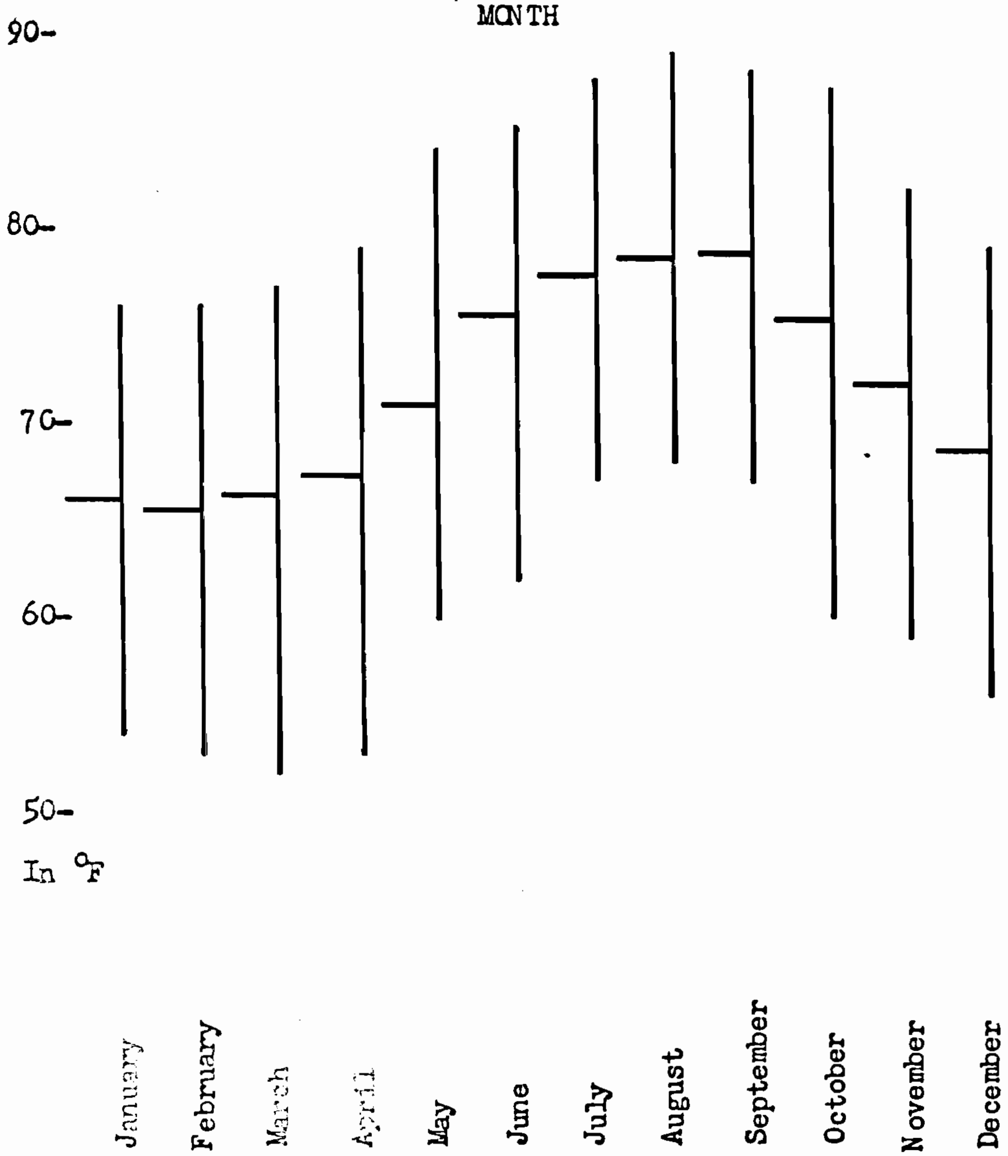
[17]Wiens, <u>op. cit.</u>, pp. 137-186.

[18]Severre Petterssen, <u>Introduction to Meteorology</u>, (New York: McGraw-Hill, 1958), p. 254.

[19]Chief of Naval Operations, <u>loc. cit.</u>

FIGURE 5

ANNUAL VARIATION IN TEMPERATURE ON MIDWAY ATOLL SHOWING ABSOLUTE RANGE AND AVERAGE BY MONTH



the driest month with 2.15 inches. There are two peaks of rainfall, January with 5.08 inches and October with 4.16. A monthly rainfall curve is not smooth but rather shows alternation between a wet month followed by a drier one. (Figure 6). However when a two-month running mean is applied to the monthly rainfall data, a smooth, bimodal curve is revealed. It shows that March-April and April-May are the driest months with the sum of the rainfall for each of these two-month periods less than 5 inches. It also shows that December, January, and February are the wettest months, their bimonthly totals all more than 8 inches. (Figure 7).

Heavy rainfall is most common, rain occurring on only six percent of all hourly observations. Light rain and drizzles are almost unknown. High winds are not always associated with rain. Winds in excess of 13 knots are about five times as frequent as rainfall itself. Days with .02 to .05 inches of rain are most common, but rainfall days with .06 to .10 inches are the next most common followed by days with .11 to .20 inches. Thunderstorms are relatively uncommon averaging six a year and always accompanied by rain. They only account for about four percent of the times when rainfall is recorded.

Hawaiian atoll winds. The Hawaiian atolls, lying just 28°north of the equator, are strongly influenced by the northeast trades. The predominant atmospheric circulation in the leeward islands is clockwise about the Pacific subtropical anticyclone. On the southern edge of this high-pressure system most of the year, the Leeward Hawaiian Islands are in the path of the northeast trades. In winter the northwesternmost leeward islands are on the northern edge of this

FIGURE 6

AVERAGE MONTHLY RAINFALL IN INCHES FOR MIDWAY

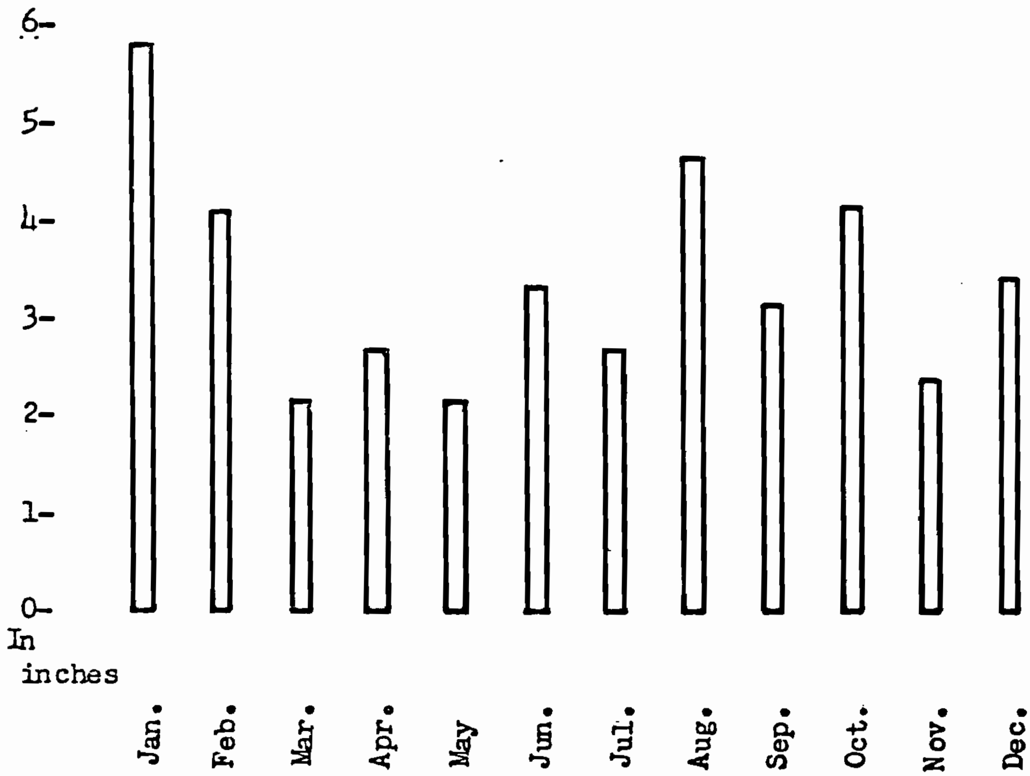
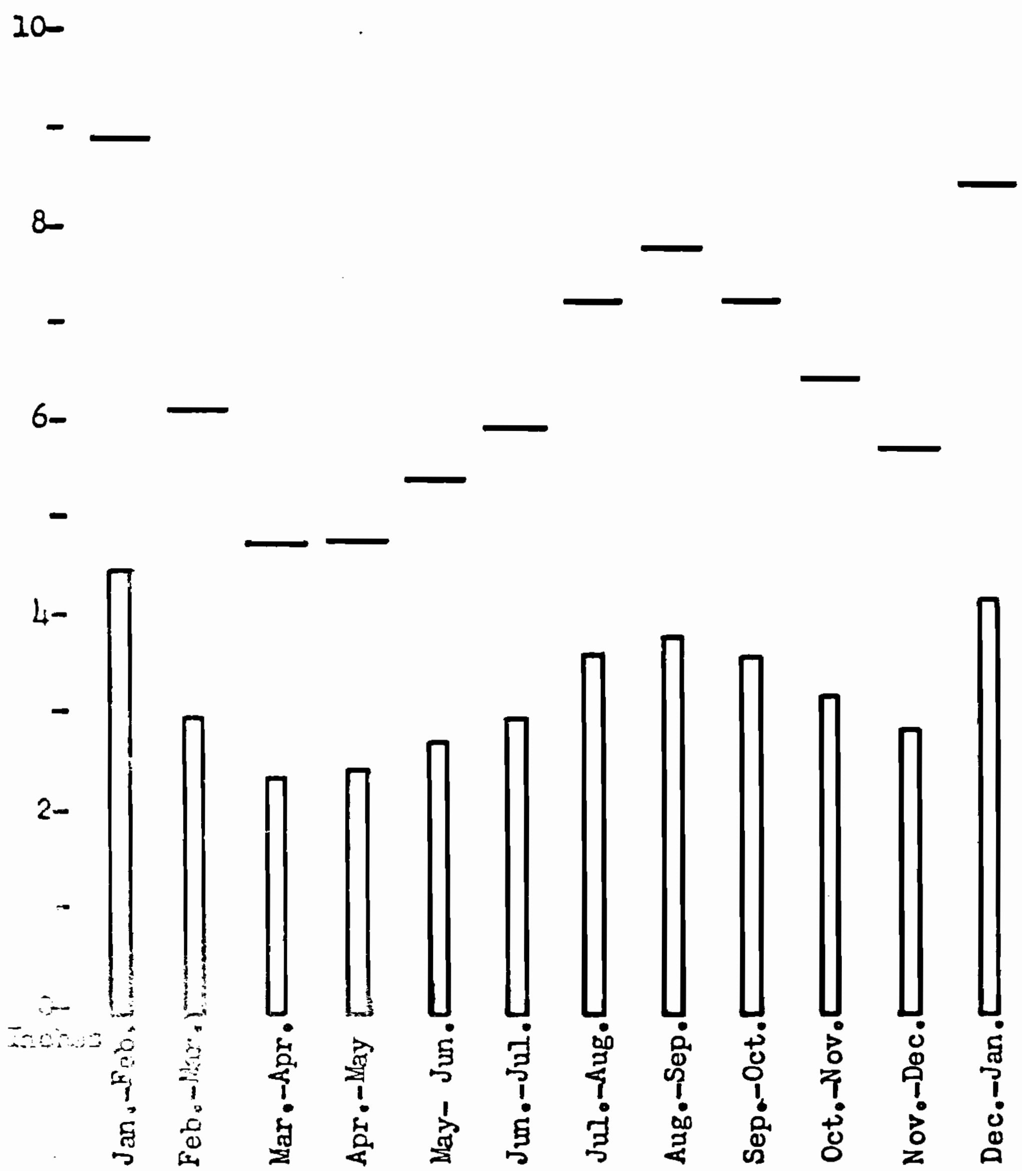


FIGURE 7

BI-MONTHLY RAINFALL TOTALS AND MEANS FOR

MIDWAY ISLAND



high-pressure system with winds from the west. At the same time they are on the southern edge of the variable Aleutian low.[20] Thus a shift occurs from the northeast trades in summer to winds with a strong westerly and northwesterly component in winter. This is shown in Figure 8. The shift in wind direction is especially evident in January when the Aleutian low is best developed and the winds from the northwest strongest. Figure 8 also shows the small seasonal variation in prevailing wind direction for the rest of the Pacific atoll realm. The latitudes of greatest atoll concentration are from 20° N to 20° S. For the most part there is little change in prevailing wind direction during the year in this region. The north equatorial westerlies are of little consequence because of their low velocity.

The varying seasonal character of the wind patterns about the Hawaiian atolls may be summarized as follows. Seventy-five percent of all winds have an easterly component. The wind blows most of the time; the lowest average monthly wind speed is 8 knots, and calms only account for six percent of all observations.

Ten months of the year the prevailing wind direction is east. May through August the trades are the controlling factor. They reach a peak in July when thirty-two percent of all winds are from the east. During the summer months the winds are lighter, and June and September have the most calms and winds below 7 knots.

In July the average wind speed is 9.7 knots. Only eleven percent

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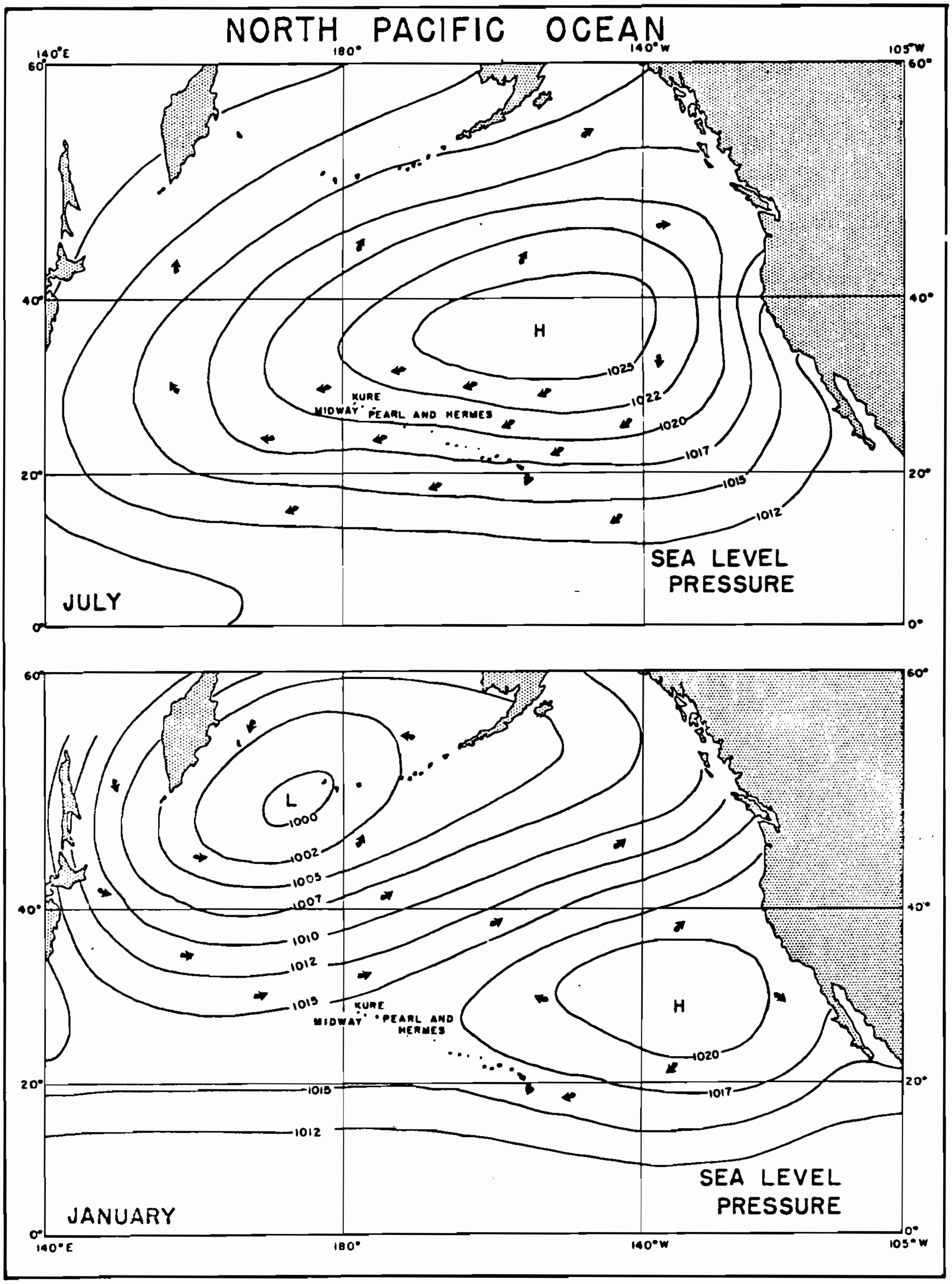
[20] Ibid., p. 254.

FIGURE 8




From U.S. <u>Navy Marine Climatic Atlas of the World- Vol. II-</u>
<u>North Pacific Ocean</u>, 1956.

of all wind readings for July exceed 12 knots. This is typical for the period May through September. During the same period less than one percent of the winds are stronger than 20 knots. (Figure 9).

The trades begin to shift south in the fall until by late December, winds from the east are no longer the most frequent. During January and February winds are quite variable, but the greatest percentage come from the northwest. Winds from the northwest have only a slightly higher frequency than other winds, but those with a westerly vector, as a group, represent sixty-three percent of all winds (not including north and south winds or calms).

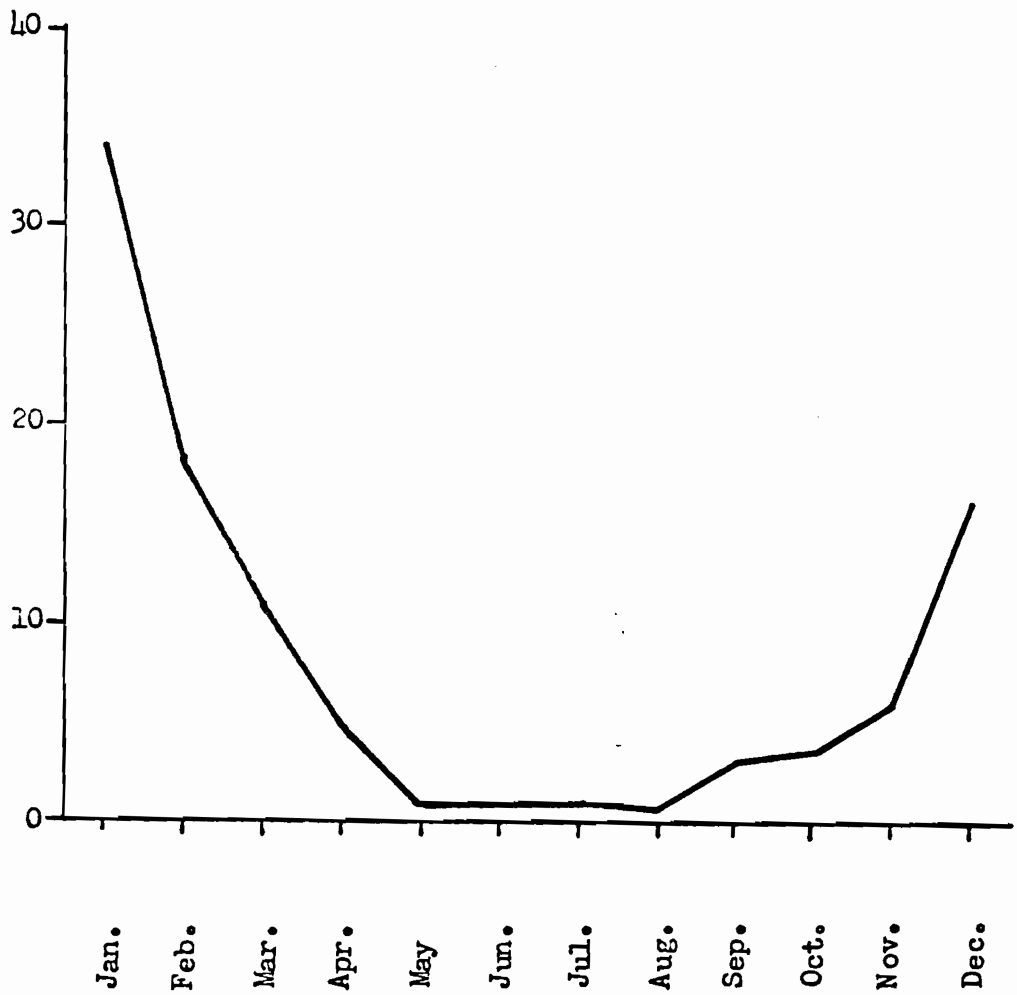
Wind speed also increases in late December and remains strong through February. During this period more than forty percent of the wind readings are above 13 knots. Sixty-seven percent of all wind velocities above 21 knots for each year are recorded in these three months. Gales occur on average of three days a month in winter. These higher wind speeds are from a westerly direction as the records for maximum winds clearly show. Of the six highest hourly wind speeds each month for January and February, five are from the west, five from the WNW and two from the SSW. The highest peak velocity ever recorded on Midway was a wind of hurricane force (77 knots) from the WNW. Seven peak gusts of hurricane force have been recorded on Midway, one in December and six in January. The time of year alone indicates that these are probably not tropical storms, but rather mid-latitude cyclones.

## III. CONCLUSION

Means and extremes of temperature on Kure, Midway, and Pearl and

FIGURE 9

PERCENTAGE FREQUENCY OF ALL WINDS ABOVE TWENTY KNOTS BY MONTH FOR MIDWAY ATOLL



Hermes atolls differ markedly from those of other atolls. Minimum winter temperatures are too cold for coconut palms, a tree noticeably absent from these atolls. Rainfall is irregular with heavy showers the most common form. Rain is seldom accompanied by wind.

The winds of the Hawaiian atolls may be characterized as follows. During all months except January and February winds from the east and especially the northeast prevail. The most frequent velocity of these winds is between 8 and 12 knots. Winds above 20 knots are rare. A ninety degree shift of wind direction occurs in winter, so that during January and February winds from the west and northwest are most frequent. Wind velocities from 13 to 20 knots are most common, and it is during this time that more than two thirds of the wind velocities over 21 knots are recorded. Thus there is both a shift in wind direction and a significant increase in wind speed during a normal year on the Hawaiian atolls. This is in striking contrast to other atolls in the world.

## II. HAWAIIAN ATOLL SIMILARITIES

Hawaiian atoll shape similarities. For ease of comparison of various reef sectors, one specific characteristic of the atolls themselves is helpful, namely, that the atoll reefs are roughly circular. A circular atoll may be divided into four quadrants by north-south and east-west lines meeting at the approximate center of the lagoon.[21] With the atoll thus divided, the general direction of

[21]Wiens, op. cit., p. 25.

the reef for a particular quadrant should be the same in the corresponding quadrant of another circular atoll. But all atolls are not similar and, as Davis said, "Most atolls depart rather freely from the ideal oval or circular outline in which they have been figured."[22]

Inasmuch as the three Hawaiian atolls are circular, the various reef sectors of one are easily comparable with the corresponding sectors of the other two. It should be noted, however, that any skewness of one atoll ring modifies the degree of comparability with corresponding sectors of the remaining atolls. The significance of skewness with regard to the distribution of land on the atoll will be shown later.

Hawaiian atoll reef characteristics. Another important feature of the Hawaiian atolls is a persistent reef on the east and north continuing into the northwest quadrant on all three atolls. Reynolds first noted the similarity in 1868 when he wrote, "Pearl and Hermes Reef, like Ocean (Kure) and Brooks (Midway) Islands has a coral wall above water at its N.W. extreme."[23] The reef continues east and then south without a break well into the southeast quadrant. Likewise the discontinuous reef on the extreme west of all the Hawaiian atolls is noteworthy.

These features are consistent with the ideas of those who contend that reef growth is best where wave action is most active.[24] In

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[22]William M. Davis, The Coral Reef Problem, (New York: American Geographical Society Publication No. 9., 1928), p. 512.

[23]William Reynolds, "Lackawanna," Nautical Magazine 37: 272, 1868.

[24]Wiens, op. cit., p. 39.

this case the trades produce the most persistent wave activity in the northeast sector of the reef while the western side is in the lee of this activity.

Land distribution on the Hawaiian atolls. The most obvious similarity in the Hawaiian atolls is the scarcity of land within the reef rims. (Figure 10). Small sand islands, only three more than a mile long, are scattered unevenly about the margins of the lagoons, protected from the open sea by the reef. At first glance one gets the impression that the land of the Hawaiian atolls is nothing but a group of shifting sand spits. With all the land in this precarious state it is a wonder there is any at all.

For comparison the atolls have been divided into four quadrants in Figure 10 as described above. Certain similarities are evident. There is an absence of land in the northwest quadrant. Midway and Kure have no land in the northeast quadrant. On circular atolls a northeast to southwest direction of the reef is found only in the northwest and southeast quadrants. In the Hawaiian atolls there is usually land on the northwest side of the northeast to southwest trending reef but only if the northwest side of the reef is inside the lagoon. Because the Hawaiian atolls are circular, these conditions are most often met in the southeast quadrant, and here most of the land is found. On Pearl and Hermes Reef, two islands are situated in the northeast quadrant. Here the reef is skewed somewhat and assumes a northeast to southwest trend in the northeast quadrant. The occasional incidence of land in the southwest quadrant of all three atolls is again accompanied by a slight turn of the reef to the southwest.

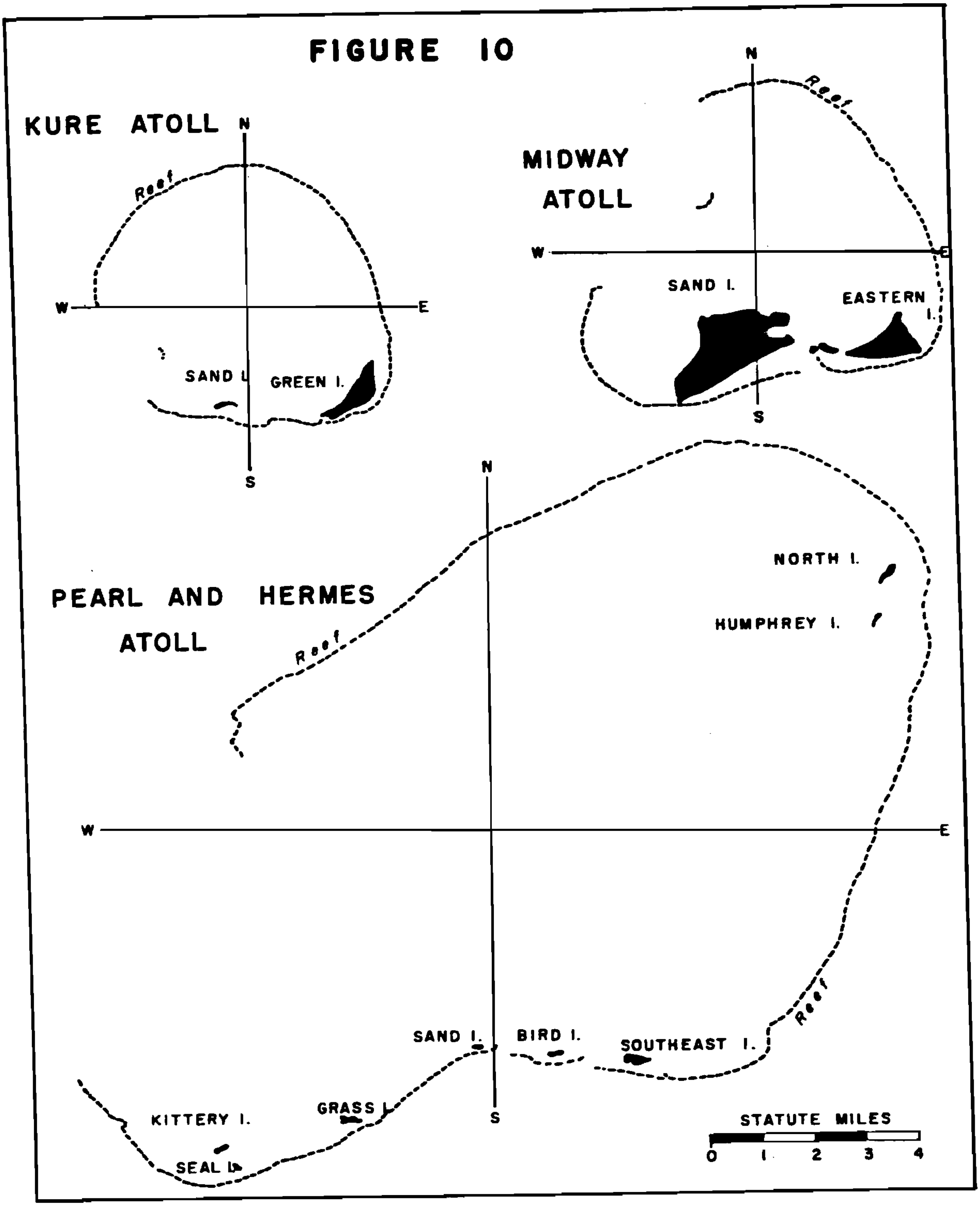
KURE ATOLL
Reef
SAND I.
GREEN I.
N
S
W
E
MIDWAY
ATOLL
Reef
SAND I.
EASTERN
I.
PEARL AND HERMES
ATOLL
Reef
NORTH I.
HUMPHREY I.
SAND I.
BIRD I.
SOUTHEAST I.
GRASS I.
KITTERY I.
SEAL I.
STATUTE MILES
0 1 2 3 4

FIGURE 10

The unique site of the Hawaiian atolls has been described and the homogeneity of land distribution within the three atolls demonstrated. This similarity of land distribution would be predictable for any atoll in these latitudes if one were familiar with conditions on one island in that area. Even the smallest morphological features of those atolls, as sand bars and sand spits, are quickly modified by storms. Similarity between the general outline of most of the sand bars and sand spits with that of the main islands of these atolls is readily apparent. Thus one might conclude that the main islands are also the result of storms, although their changes are slower and less apparent.

## III. ISLAND DESCRIPTIONS

The description of a typical sand island is helpful to familiarize the reader with its important morphological features. Kure Atoll and Midway Atoll render themselves suitable for this purpose. All of the islands of Pearl and Hermes are small and according to Elschner, "the sand islets in the lagoon seem constantly to be shifting in number, structure and location, the highest having an elevation of but twelve feet."[25] Even changes on these small sand spits, however, are related to similar but less catastrophic changes on the three larger islands.

Green Island, Kure Atoll. Green Island is about one and one-half miles long and one-half mile wide at its broadest point. It is

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[25]Carl Elschner, "The Leeward Islands of the Hawaiian Group," (Honolulu 1915), cited by Edwin H. Bryan, American Polynesia and the Hawaiian Chain, (Honolulu: Tongg Publishing Co., 1942), p. 197.

perched just inside the southeast rim of the encircling atoll reef, and its 214 acres represent the only permanent land mass in all of Kure Atoll. Concave to the lagoon, the crescent shape of the island follows the trend of the reef with its axis running northeast-southwest. The eastern half of the island averages about 200 yards wider than the narrow western half, and both ends of the island terminate in seasonally changing sand spits.

The small island is highest about its periphery where winds have formed transverse sand dunes behind the flat lagoon beach and strong waves have formed a steep continuous beach ridge on the seaward side. These high points and most of the interior are covered with Scaevola sericea, a stout bush three to nine feet tall with large, thick, shiny leaves.

The dunes occur about fifty yards from the lagoon beach and exceed 26 feet in height in some places. The high tides of winter sometimes reach the base of the dunes carving sheer 2-3 foot faces in the compacted sands and buried vegetative matter. Scaevola on the lagoon slope and atop these dunes having all their leaves blasted away by blowing sand (Figure 11) may barely survive winter storms. To the lee of the dunes Scaevola are actively buried in the slip face of the slowly advancing dune. Blow-outs between dunes are several yards wide and may be barren for some 50 feet back before any vegetation appears.

The dunes give way toward the interior, and the surface settles gently into a low, relatively flat depression. The elevation here is from 6-10 feet. A particular part of this region is called the central plain and is distinctive for its lack of Scaevola. This area,

FIGURE 11

SAND DUNES along the lagoon beach on Green Island, Kure Atoll. Photograph taken in March 1965 shows Scaevola that has been blasted away by the blowing sands of severe storm in December 1964. Lower portions of some of the dunes have been cut off by wave action during the storm. The lagoon is about 50 yards to the left from the foot of the dunes.

some have speculated, was probably once a shallow lagoon, now dried and filled. Both plants and soil seem to support this idea. The soil of the central plain is the best found anywhere on Green Island. On most of the island the soil is only composed of compacted sand. But on the central plain the sand is held together with smaller silt and has probably resulted from the slow filling of a lagoon. Scaevola is conspicuously absent and Eragrostis variabilis, an annual grass about a foot high, covers most of the area. Perhaps the normal sequence of plant succession has not had time to proceed to a climax in the central plain.

It is also possible that the soil found here is contrary to the edaphic requirements of Scaevola. The central plain is now and undoubtedly has been the nesting place for many of the sea birds since the lagoon disappeared. During the period between the disappearance of the lagoon and the establishment of Scaevola, the changes brought about in the soil by the addition of bird droppings may have altered its characteristics so that other plants were able to compete with Scaevola. In any case the former existence of a lagoon is necessary to account for the present features described in the central plain.

Dunes are absent from the seaward side of the island and elevations here do not exceed fifteen feet. The highest places along this side of the island occur as a combination of continuous beach ridge with additional wind-blown sand accumulated around the Scaevola. The vegetation ends abruptly as the steep beach drops off to the surf. The reef is but a few hundred feet off shore on this side of the island and its position probably accounts for the steep beach.

Other islets have been reported at Kure Atoll, all of them to the west of Green Island. These are known collectively as Sand Island. They appear and disappear with the changing winds and currents, do not exceed ten feet in elevation, never remain for an entire year and only allow the periodic growth of a few grasses. Although of variable size and shape, they are usually long and narrow with the axes running northeast to southwest.

An outstanding summary of the atoll's history is found in a Smithsonian report and need not be recounted here.[26] Some recent events are, however, important.

Green Island was altered considerably by the installation of a Coast Guard Loran Station in 1962. A four-thousand foot runway of crushed coral over asphalt was constructed along with a 625 foot Loran tower. The guy wire system of the tower covers most of the larger eastern half of the island. There are also facilities to house twenty-five men to maintain the station on a permanent basis. Despite these additions the general outline of the island remains unchanged.

Green Island actually represents a typical island in this area except for the vegetation which is more luxuriant here than elsewhere. The important features of islands of this type may be summarized as follows: They are sand islands in the southeast quadrant of the atoll lagoon, crescent shaped, with the long axes running northeast-southwest. Both ends of the longitudinal islands terminate in variable sand spits. On several islands, sand dunes have formed

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[26]William O. Wirtz II., Biological Survey of Kure Atoll, (Washington: unpublished paper 1965) To be published at a later date.

and built the highest points of the islands behind the lagoon beaches and appear to be moving to the southeast. Finally there are large depressions in the east central portions of some of the islets which appear, from all evidence, to be former lagoons.

## IV. MIDWAY ATOLL

On Midway the situation is quite different from Green Island with regard to alteration by man. On this atoll, originally used as a fueling depot for trans-Pacific steamers, a channel was blasted into the lagoon between Sand and Eastern Islands and a harbor constructed. This altered considerably the shape of Sand Island. Another section was flattened by the addition of two large runways during World War II. On Eastern Island much of the terrain was also leveled for an emergency runway and later the addition of several large communications antennae. Because of these changes, old maps and records provide the best observations on the original state of the larger islets and will serve as a basis for most of the description which follows.

Sand Island. Sand Island, Midway, is the largest islet of any of the Hawaiian atolls, measuring nearly two miles long and almost a mile wide. It has been so changed by man that only a few salient points will be considered here.

It was first described as "a sand heap of irregular shape," and that probably remains as the best description of its original state.[27]

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[27]Wm. Reynolds, op. cit., p. 270

The island, situated in the middle of the southern edge of the lagoon, has its long axis running northeast to southwest. It is rounded at the ends except at the northwest point which terminates in a sand spit. Sand dunes are found in an irregular line along the northwest-facing lagoon beach and form the highest point on the island at 43 feet. The dunes have progressed the width of the island moving from the northwest to the southeast. The island was described once as "a barren waste of ground coral," and grass was imported from the California coast to stabilize the blowing sands.[28] The introduction of Ironwood trees (Casuarina equisetifolia) and the addition of an estimated 9,000 tons of soil have altered conditions considerably. Sand Island today is a green oasis in the Leeward Hawaiian Islands.[29]

Eastern Island. In the first description of the island in 1868, Captain Reynolds noted that Middle Brooks (Eastern) Island is similar in appearance from the sea to Green Island, Kure, except that on the latter the shrubbery is higher.[30] Eastern Island is a mile long and a half mile wide, the long axis running northeast to southwest. From the two ends the island gradually slopes to the south "where there is a slight depression, embracing about five acres, extending from NNE to SSW." This area has "a superficial stratum of vegetable mould from eighteen inches to two feet in depth."[31]

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[28] Alfred M. Bailey, The Birds of Midway and Laysan Islands, (Museum Pictorial No. 12-Denver Museum of Natural History, 1956), pp. 12, 28.

[29] Edwin H. Bryan Jr., op. cit., p. 202.

[30] Wm. Reynolds, op. cit., p. 272.

[31] U.S. Hydrographic Department, "Island of the North Pacific Ocean," The Mercantile Marine Magazine, 15: 112, 1868.

Sand dunes stabilized by vegetation account for the highest point on the islet at only 15 feet. Here again the dunes appear to be moving to the southeast. The ends of the island are swept by winds and currents into wandering sand spits.

One or two small island are shown on most maps just to the west of Eastern Island. They are not connected to the sand spit that extends in that direction from Eastern Island but are separate islets which appear and vary in size and shape. They are important because such small islets in their variable state and form characterize the atolls of Kure, Midway, and Pearl and Hermes.

## V. PEARL AND HERMES REEF

The islets of Pearl and Hermes Reef are so variable that no two reports about them are alike even with regard to their number. Thus a description of the same order as those already presented is not possible. Instead, the temporary status of the islets, recorded at different times by several authors, must suffice.

None of the islands on Pearl and Hermes Reef is larger than the variable sand bars that appear periodically between Sand and Eastern Island, Midway and west of Green Island, Kure Atoll. There are about a dozen of these small islets, four of which have permanent vegetation and have been named. They are Seal, Grass, Southeast, and North Islands. The Smithsonian POBSP (see footnote page 4) added the names Kittery and Humphrey to the list of permanent islands. They were first reported in 1936 and 1937 respectively and were still present in 1965. The remaining islets appear irregularly in the reports of different observers.[32]

Every map of this area differs from previous ones, and it is impossible to tell without the names which are the permanent islets and which are temporary ones having the same size and shape. All are long and narrow sand bars. The orientation of the islands varies from east-west to NNE-SSW. A shallow lagoon is shown on a photograph of Southeast Island taken by Bailey in 1949.[33] A barren strip near one end shows that strong waves occasionally break clear across the island. There are no sand dunes on any of the islets, the highest elevation being only twelve feet. In 1923 it was reported that "there was a slight depression in the eastern part of Southeast Island in which fresh water collected after rains."[34]

Unpublished reports of the Smithsonian POBSP emphasize the changeable character of the islands of Pearl and Hermes.[35] The following excerpts of Wirtz's descriptions are paraphrased. He found there were nine islands in 1965. Humphrey Island, first reported in 1937 as a sand bar awash at high tide, presently has a limited flora and fauna. Named by the POBSP field team for its director, Dr. Philip S. Humphrey, the island has a long, low sand spit at its southern end, which appears to be extending itself southward with a curve to the west. Three small disconnected sand bars, presently

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[32]William O. Wirtz II, "Biological Survey of Pearl and Hermes Reef," (unpublished report of the Pacific Ocean Biological Survey Program, Smithsonian Institution Washington D.C., 1965).

[33]Bailey, op. cit., p. 31.

[34]Edwin H. Bryan, op. cit., p. 198.

[35]Wirtz, "Pearl and Hermes" op. cit., pp. 13-20.

just above high tide level, extend the length of the island another 500 feet. Kittery Island is subject to occasional inundation and supports no vegetation despite its size and relative permanency.

Wirtz's descriptions of other islands are very complete and of special interest here. Southeast Island, the largest (2600 feet long east-west with a maximum width of 1100 feet), has three tide-pools in the eastern half of the island. North Island is polywog-shaped; the tail extends southward from the body for 1000 feet, is about 100 feet wide throughout its length, and its distal portion is a low shifting sand spit. Grass Island is 1800 feet long east to west and only 400 feet wide. The report also mentions three islands which, though relatively constant in position, are continually changing sand spits located along the inner margin of the southern reef between Southeast and Grass Islands.

## VI. CONCLUSION

A final review of the descriptions, the similarities which undoubtedly tie all the islands to a common origin should be emphasized. The orientation of the islands is nearly the same on all three atolls. They usually trend northeast-southwest. Second, the islands are alike in form, being low, long, narrow, and terminating in sand spits. They are composed entirely of coral sand, and the higher ones have sand dunes. The sand dunes appear to be formed by winds from the northwest. Several islands have low flat depressions which appear, from the vegetation and finer materials found there, to be former lagoons. Small, reappearing sand bars are common on all three atolls, and their gross morphology is similar to that of the permanent islands. Finally, the small size of the islands within the larger reef rings would suggest that some outside force, acting in the same manner on all three atolls, has severely restricted the development of large islets on the Hawaiian atolls. Possible explanations for the land distribution will be examined in the following chapter.

# CHAPTER III

## EXPLANATION OF LAND DISTRIBUTION ON THE HAWAIIAN ATOLLS

The occurrence of a very small amount of land within the perimeter of any one of the Hawaiian atolls need not be surprising. However, it has already been shown that the pattern of land occurrence and distribution is repeated on all three of the Hawaiian atolls. Thus it is likely that some causal element common to all three atolls has produced these similarities.

First, submarine structure is considered as the sole determinant of land location and eliminated. Then the relatively infrequent winter storms, because of their catastrophic effects on the islands, are analyzed and shown to be the primary determinant of land occurrence and distribution in the Hawaiian atolls. Each permanent island occupies the site and assumes the shape best suited to survive in this harsh environment. Because the same storms affect all the Hawaiian atolls land similarities are to be expected, and an unequivocal description of the distribution of land on the Hawaiian atolls is justified. Islets are situated just inside the reef on the lee side of the atolls with respect to the northwesterly storm winds.

The bases of this explanatory description are established in the remainder of this thesis.

### I. SUBMARINE STRUCTURE

The simplest explanation for the peculiar distribution of land on the Hawaiian atolls of Kure, Midway, and Pearl and Hermes is that the site of each island is controlled by the submarine structure of the coral base. The forces necessary to bring about the formation of three separate atolls, so structurally alike as to dictate the site of land within the coral ring, will be discussed in this section.

Geology. The Hawaiian Chain appears to have formed from the activities of a series of volcanic eruptions beginning at the northwest end of the chain. Island building progressed along a submarine rift zone in a southeasterly direction. Today the only active vulcanism is found on the island of Hawaii. This island is farthest from the three atolls in question at the west or northwest end of the chain. Between the two extremes are volcanic remnants decreasing in size and elevation from cones progressively dissected by subaerial erosion to reef-enclosed lagoons with only the barest remains of the volcanic rock still visible.

Atoll origins. If Darwin and others were right regarding the origin of atolls, Kure, Midway, and Pearl and Hermes are in the final stage of up-growing coral on a subsiding volcanic base.[36] In 1851 when subsidence was first suggested as the primary cause of atolls, the idea was not accepted because sinking of large bodies of land was yet unknown. Since then, however, such movements have been demonstrated on a continental scale as well as locally, as in the case of many Pacific islands. Although still not accepted as the only process by which atolls are formed, subsidence is now considered

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[36] Charles Darwin, The Structure and Distribution of Coral Reefs, (Berkeley and Los Angeles: University of California Press, 1962), pp. 142-148.

an integral part of any hypothesis that tries to explain them.

Tilting. Each Hawaiian atoll is part of the same larger chain of islands. The islands and atolls of this 2000 mile archipelago are merely the emergent summits of the highest peaks along a submarine ridge. It is possible that some degree of tilting of the volcanic cones has occurred coincidentally with subsidence. Because all the atolls rest on the same base any tilting of this base would affect all three of them. The plane of all three atolls would dip in the same direction. Undoubtedly the tilting would occur very slowly. As a requisite for atoll formation the rate of upward coral reef growth must keep pace with the rate of subsidence. Consequently tilting of the reef might drown some sections while at the same time forming an emergent reef on the opposite side.

Implications of tilting. Tilting, as described above, would manifest itself in an atoll as an incomplete reef rim. The reef would be rather continuous for part of its circumference of the lagoon and equally discontinuous for the other. Depending on the time of tilting, the drowned reef might be visible below the surface or not be evident at all.

Tilting may now be brought to bear on the problem at hand. Kure, Midway, and Pearl and Hermes atolls all show a continuous reef on one side and an extensive broken (drowned?) reef on the opposite side. Furthermore, the same side of all the atolls is discontinuous. But this is not enough to be conclusive. If tilting has occurred on all three atolls it is probably the result of a common cause, especially if the tilting is all in the same plane. For example, if the sea floor were weaker to the north of the islands, the dip would be in that direction.

But on Kure, Midway and Pearl and Hermes it is the west side that is drowned. Because the islands themselves are in an east to west line, separate tilting of all three atolls to the west would be needed to produce the present situation. This is very unlikely. Also unlikely is one large dip of the planes of all three atolls to the west. This would drown the outer two leaving only one incomplete island ring, not the case in reality.

Profiles. Moreover, any tilting at all would be evident on atoll profiles. Several profiles were drawn for Kure, Midway and Pearl and Hermes, and they do not show any tilting of reef rims or lagoon floors. They actually show that several other places are more suited structurally for small sand islands than the places where the islands are now. (Figure 12, 13, 14).

Conclusion. It now seems safe to assume that no tilting on a large scale has taken place on these atolls. The reason suggested in Chapter II for the discontinuous reef rims on all three atolls is probably the better answer. That is, northeast trades, supplying a rich source of foods to the coral on the windward side of the atolls, favor the fastest and strongest reef growth, and the discontinuous lee side of the atolls is farthest from this source.

## II. THE STORM ELEMENT

Structure has been shown not to be responsible for the present distribution of land or the similar orientation of islets of the Hawaiian atolls. The purpose of this section is to show that winter storms common to the Hawaiian atolls have been the paramount factor

FIGURE 12

LAGOON PROFILES FOR

KURE ATOLL

Upper straight line in each profile is mean low tide level and bottom line represents depth of one hundred feet.

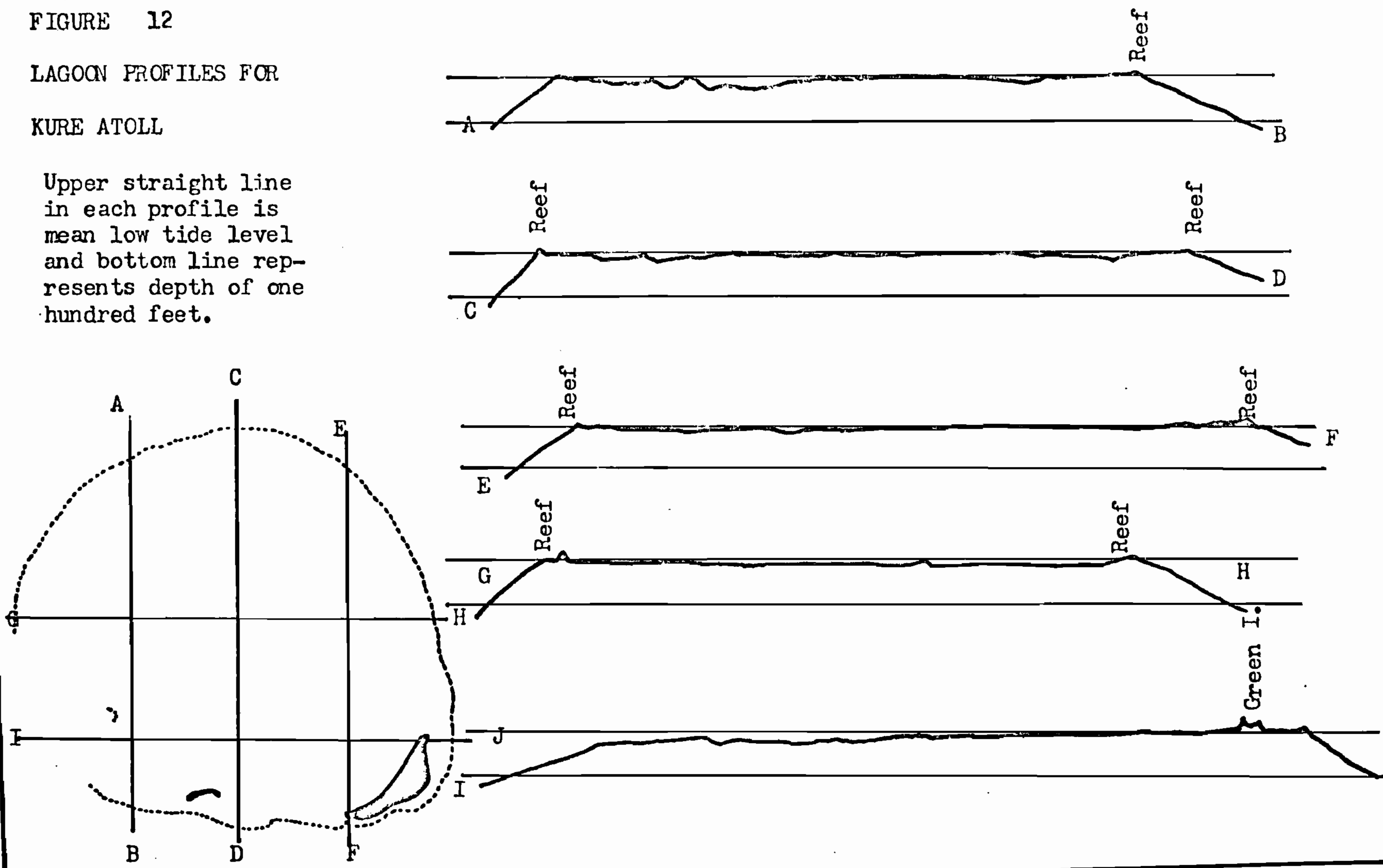
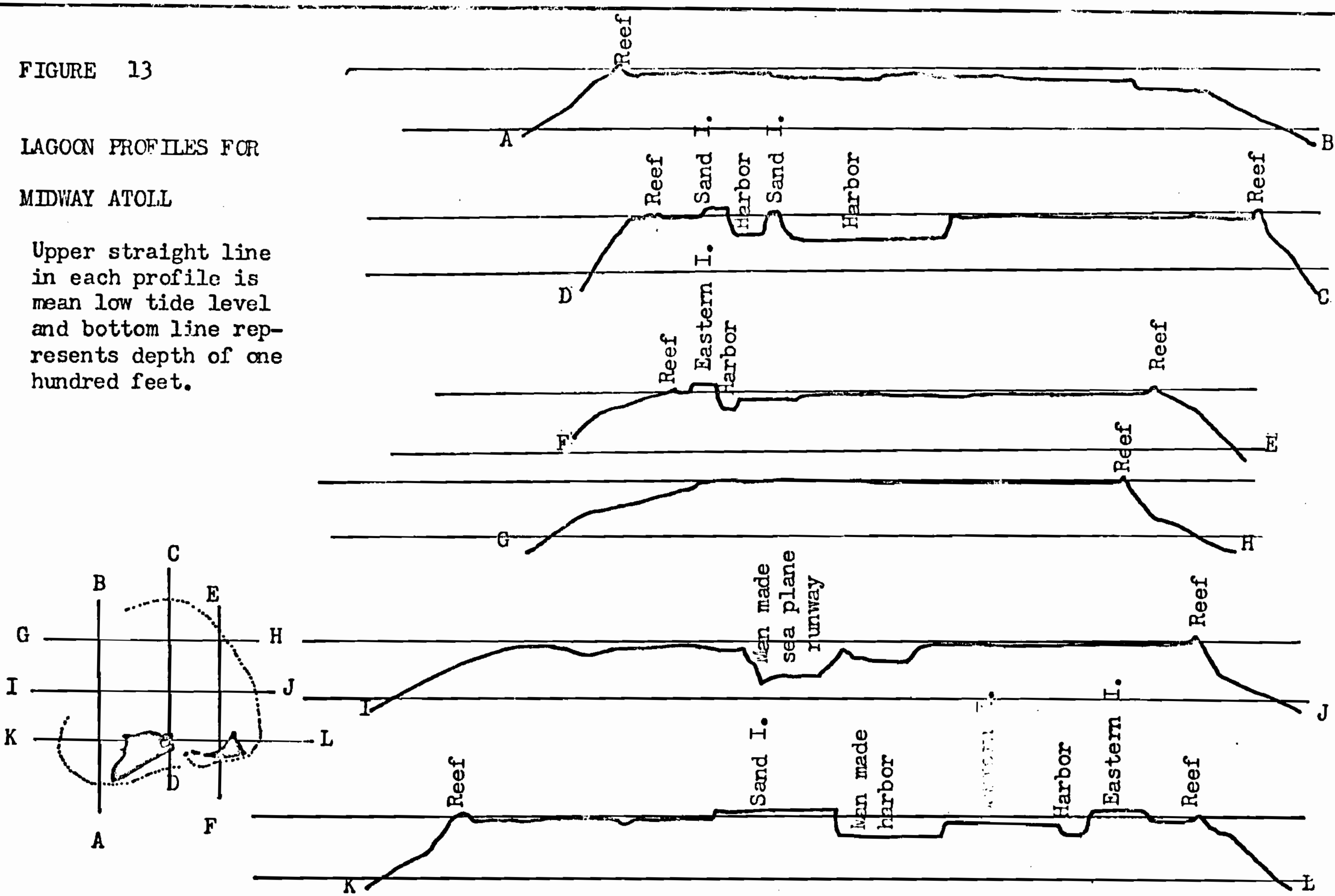


FIGURE 13

LAGOON PROFILES FOR

MIDWAY ATOLL

Upper straight line in each profile is mean low tide level and bottom line represents depth of one hundred feet.



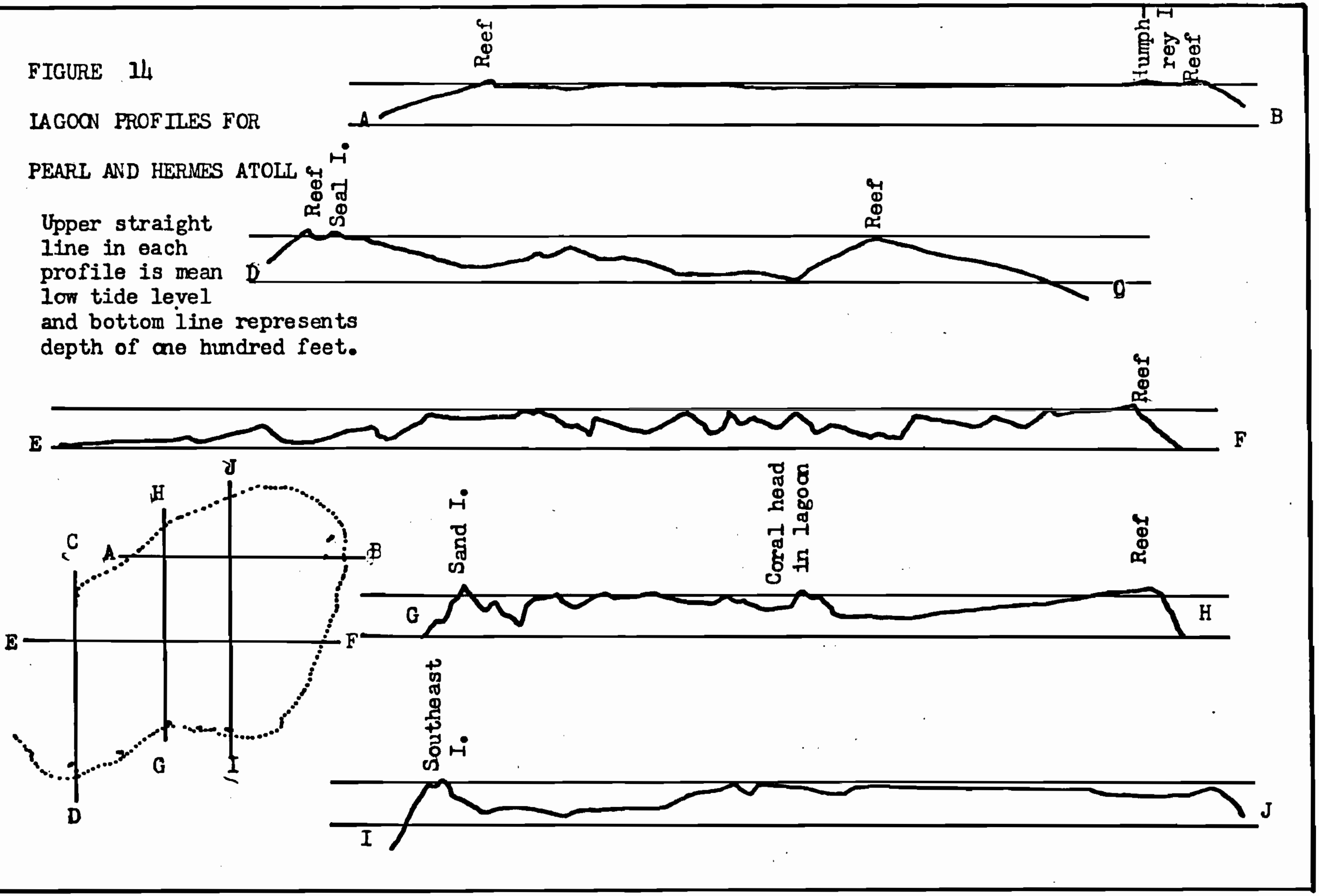



FIGURE 14

LAGOON PROFILES FOR

PEARL AND HERMES ATOLL

Upper straight line in each profile is mean low tide level and bottom line represents depth of one hundred feet.

in determining the distribution and orientation of the small sand islets of Kure, Midway, and Pearl and Hermes.

Yet to be established is the manner in which these storms actually determine the distribution and orientation of these islands. This can happen in two ways. Initially permanent islands may be so situated as to be least affected by storms. This suggests that winter storms have controlled the distribution and shape of sand islets by removing all the islets except those most protected from the forces of the storm. Those not washed away are shaped by the storms. The second idea is that the islands today are the result of storms. That is to say, the islands have developed in certain places during storms because these particular positions are focal points of deposition within the atoll. It is to be remembered that these two ideas are not mutually exclusive and indeed both may operate simultaneously.

Storm Evidence. Unfortunately most weather records fail to convey a realistic picture of conditions that exist during a storm. For this reason several descriptions of the destructive effects of winter storms will be given. It is absolutely essential to understand that these storms are a very significant and unique part of the climate of the Hawaiian atolls.

Edwin H. Bryan Jr. once wrote concerning the climate of Midway: "it is subject especially in winter to sudden and severe storms. This together with heavy winds, which drive loose sand into every nook and corner, rule out this island as a winter resort."[37]

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[37] Bryan, "American Polynesia," op. cit., p. 202.

The variable sand spits on these sand islands undergo sudden changes during storms and are especially sensitive to slight wind shifts. In 1868 Captain Reynolds noted this phenomenon on Midway, and these spits still remain a constant danger to navigation.

His report reads: "Captain Burdett has seen 250 yards of it (Eastern or Sand Islands?) washed away, and again reform during the few weeks he was ashore. The sand spit up by the northwest rocks, which was quite conspicuous on the 16th (of September), had almost disappeared by the 27th, and from the quantity of sand thereabouts a permanent island appears to be forming."[38] The rocks mentioned are on the western edge of the lagoon and in the lee of summer trades. During mild weather sand may be deposited in that area, but to the present day no permanent islands are found there.

Strong evidence of past storms is found on Pearl and Hermes Reef. These small islands lend themselves to rapid changes which are quite noticeable. Wirtz's POBSP report contains the following comments. "A Coast and Geodetic Survey marker placed at the northwest corner of Southeast Island in 1937 has been toppled into the water (1965) by erosion of the island from the west. Toward the middle of the same island are found rusting 55-gallon drums, and on the shore of the lagoon end of the eastern portion is a large steel tank, apparently washed up on the island by severe storms. On Green Island, Pearl and Hermes, the western end is presently (1965) being eroded by the sea so that there is a vertical drop of five feet to the water. Troughs eroded in the sand of the interior of

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[38]Reynolds, loc. cit.

Kittery Island suggest that it is periodically inundated during severe weather."[39]

During storms on Kure Atoll several conditions exist which usually bring about noticeable changes in islets there. The first change has been well documented but in a very strange way. During the POBSP study weekly counts were made of the number of Hawaiian Monk Seals (Monanchus schauinslandi) present on the beaches of Green Island. These seals are residents on Kure and several other islands in the Leeward Hawaiian Islands. Beach counts on Green Island show that there are considerably more seals in winter than in summer. This is related in part to morphological land changes which in turn are related to storms. Sand Island, one of the seasonal islets there, is washed away by waves just prior to the arrival of storms. When this occurs the seals on the islet make their way to Green Island. Records show a very good correlation between the number of seals on Green Island and the disappearance of Sand Island in December of 1964 and March of 1965.[40]

In another instance on Kure, a small buoy marking a shallow place in the lagoon was moved some distance. Originally located just off shore from the middle of the lagoon beach, it was found on the lee side of the north point after the storm of March 1965. The buoy was made from a plastic "purex" bottle anchored to a ten-pound concrete block. The block was still attached when the buoy was found

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[39]Wirtz, "Pearl and Hermes," loc. cit.

[40]Wirtz, "Kure," op. cit., pp. 28-30.

buried at North Point.

## III. WAVE ACTION

Further effects of storms are evident from the writer's studies of sand points made on Green Island, Kure Atoll in February 1965. During that period changes in the west point, which at times may be 500 yards long, were observed.[41] A severe cyclonic storm in December of 1964 had truncated the point leaving a five foot cliff at the end of the runway. Between then and April 1965, the point had begun to rebuild and lengthen, but variable weather thwarted substantial growth.

Point study. Casual observation indicated the shape of the sand point was very sensitive to changes in wind direction. A careful study of the adjustment of west point to the changes in winds was begun on February 7th, 1965, (Figure 15). Three 8-foot bamboo poles were pounded into the sandy point to a depth of about 6 feet. The position of each pole was set down on paper as a base and the varying shape of the point sketched in as changes became evident. Two more poles were eventually added as the point lengthened. During the study, which lasted through 7 March, more than 200 feet of new sand were added to west point. On the night of 6 March more than 250 feet were washed away, including all the reference points used in the study.

Method of analysis. Ten sketches were made of the point during the study and corresponding wind reading obtained from the U.S. Coast

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[41] Wirts, "Kure," op. cit., p. 18.

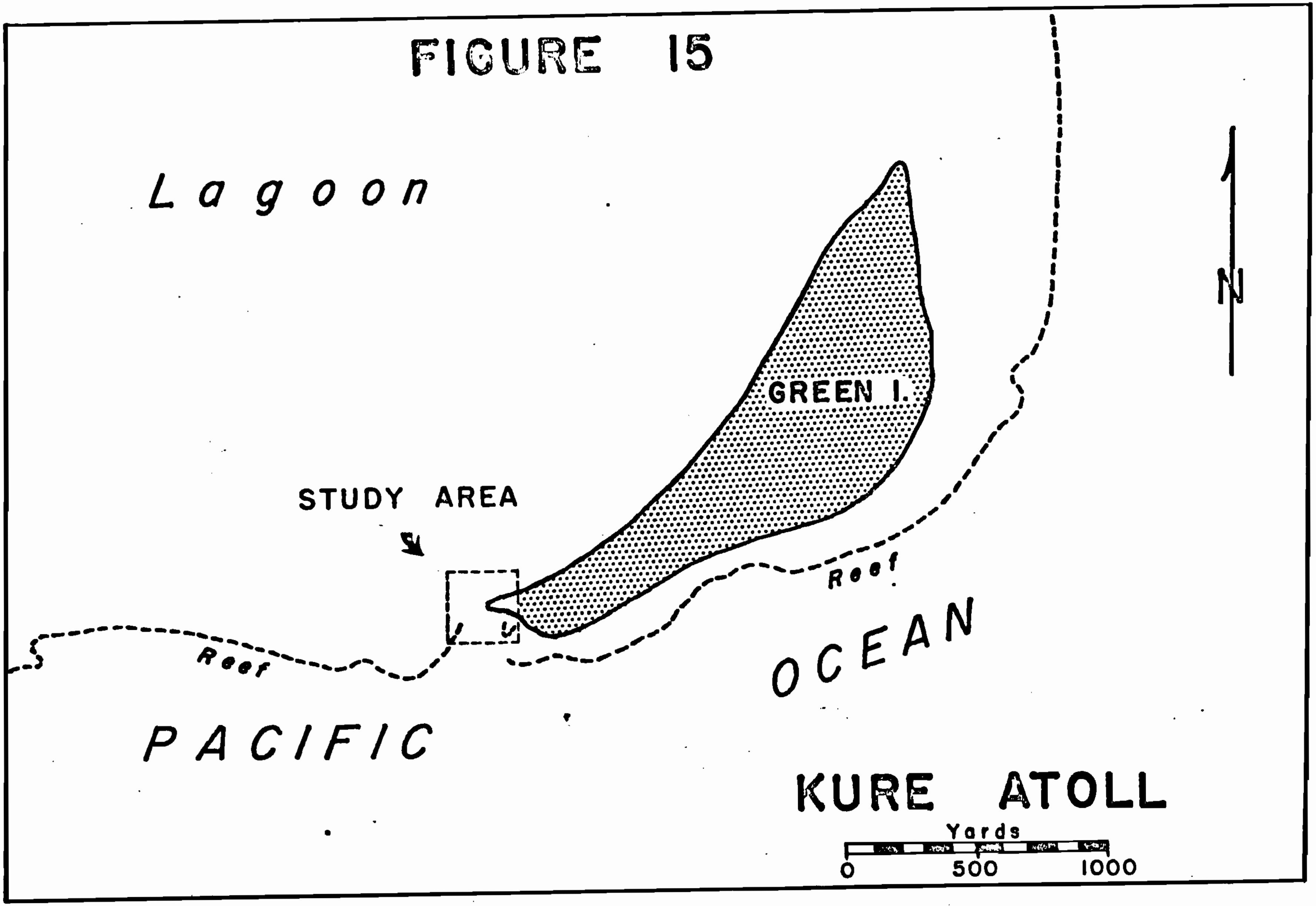
Lagoon
STUDY AREA
GREEN I.
Reef
Reef
OCEAN
PACIFIC
KURE ATOLL
Yards
0
500
1000
N

FIGURE 15

Guard Loran Station, Kure. They show relationships between wind direction and point shape which deserve further mention here.

The "direction-resultant wind work" (DRW) was determined for the study period as previously outlined by Schou, except that winds with a force less than Beaufort 3 were not used.[42] A DRW vector diagram as well as a wind rose were also constructed for each period between observations (sketches). In these cases, frequency, rather than percentage frequency, was used since the interval between observations was not always the same.

Observations. The point grew very rapidly at the beginning of the study. In the two days from 9-11 February the first two sketches show the point lengthened about 100 feet. (Figure 16-17). During this interval the wind was northerly 7-10 knots swinging to the east and decreasing in velocity. The vector diagram (Figure 17) is remarkably unimpressive for this two-day period of rapid growth.

The main body of the island curves away to the northeast from the west point providing a source of material to be moved by north and northeasterly winds. While winds of low velocity do not generate waves strong enough to stir up material from the lagoon bottom, they do produce waves capable of transporting sand along the beaches where the current is strongest. Deposition of sand occurs as the current passes the end of the island and its carrying capacity is dissipated in many eddies. The interval in question (February 9-11) was also marked by steady winds from but one quadrant, thus allowing rapid

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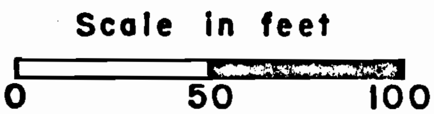
[42]Wind with a force less than Beaufort 3 was not considered strong enough to initiate wave action and thus move sand.

Figure 16

Outline of west point of Green Island, Kure Atoll on 9 February at beginning of study. Succeeding outlines on the following pages are all oriented in the same direction. The scale on all the point outlines is the same as used on this page.



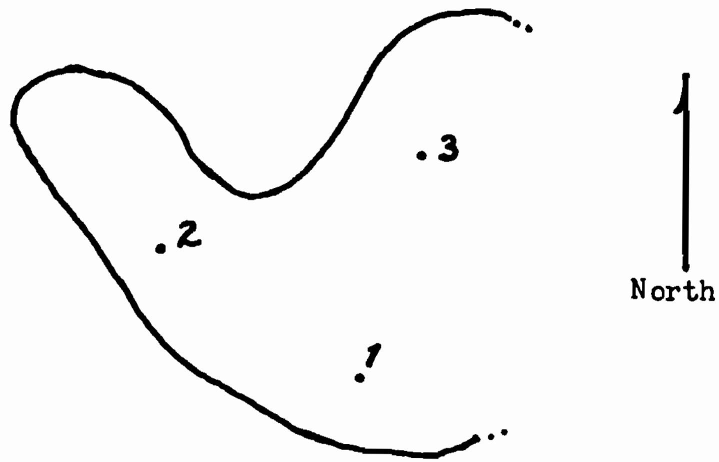
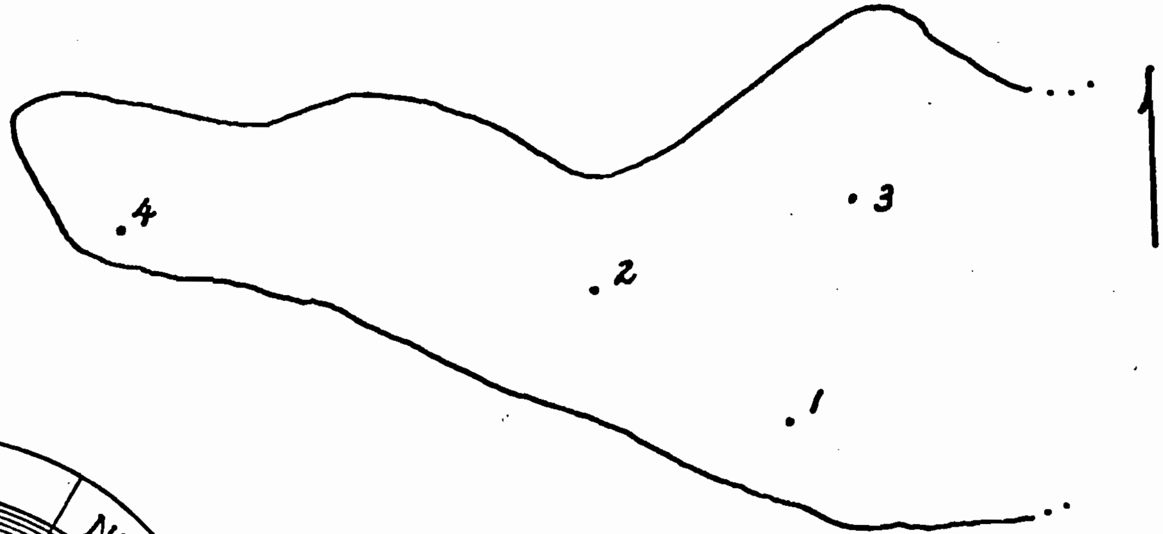
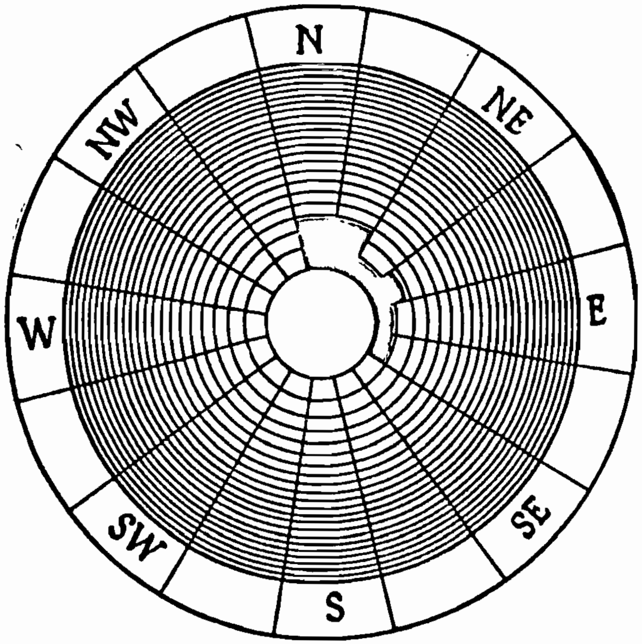



FIGURE 17

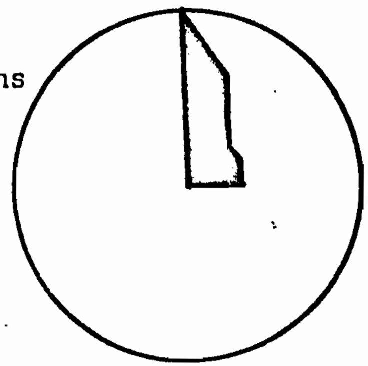



Point shape on 11 February 1965




Wind frequency by direction

Wind diagrams indicated conditions since the last point outline was drawn on this and succeeding pages.



Direction-resultant wind work
(see text for explanation)

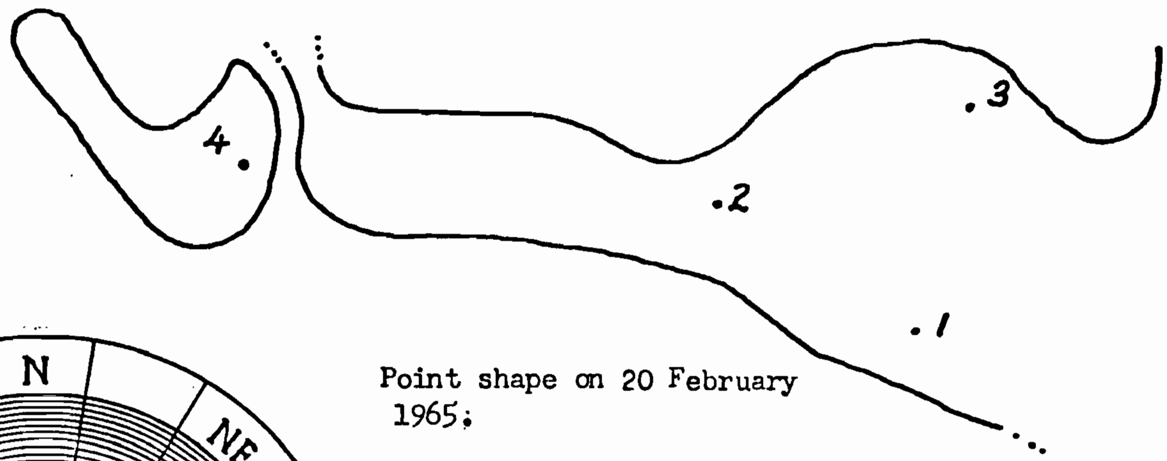
growth of west point to proceed undeterred.

Nine days elapsed before any significant change became evident at which time the third sketch of the point was made. (Figure 18). The point was about 25 feet longer and somewhat narrower than on 11 February. Wave surge across the point had eroded away a narrow section, and the last 50 feet were now separated from the main body of the island at high water. Weather during the nine days had been variable. A small storm lasting about twelve hours bore northerly winds on the third day. Calm weather followed as winds became easterly, increasing in velocity as they became more southerly. Winds above 20 knots were in their third day as the point sketch was made. Instability of weather is reflected in the point shape. The south or reef side of the point being a poor source of sand, little growth could occur during the southerly winds.

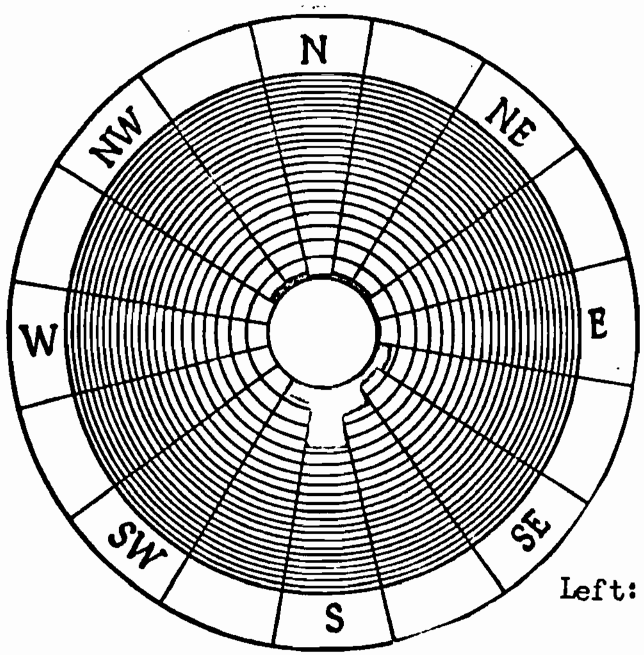
The winds died down as they became westerly, northerly and finally northeasterly two days later on 22 February. (Figure 19). The vector diagram is quite similar to that of 9-11 February. (Figure 17). The large source of sediment along the beach to the northeast contributed to the reestablishment of a substantial point.

Northeast winds increasing during the following night and through the next day (23 February) continued to provide a good source of sand, but little lengthening of the point occurred because currents were too strong beyond the tip. (Figure 20). Also the reef is poorly developed at west point, and the bottom drops off quickly toward the sea. The tip of the point was not eroding, however, owing to the large quantity of sand continually being redeposited there from the mile of beach upwind. Instead, strong

FIGURE 18




Point shape on 20 February 1965;




Left: wind frequency by direction.

Below:
Direction- resultant wind work

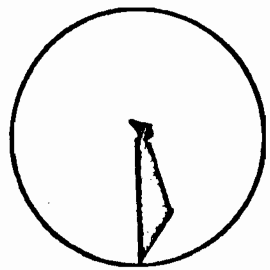
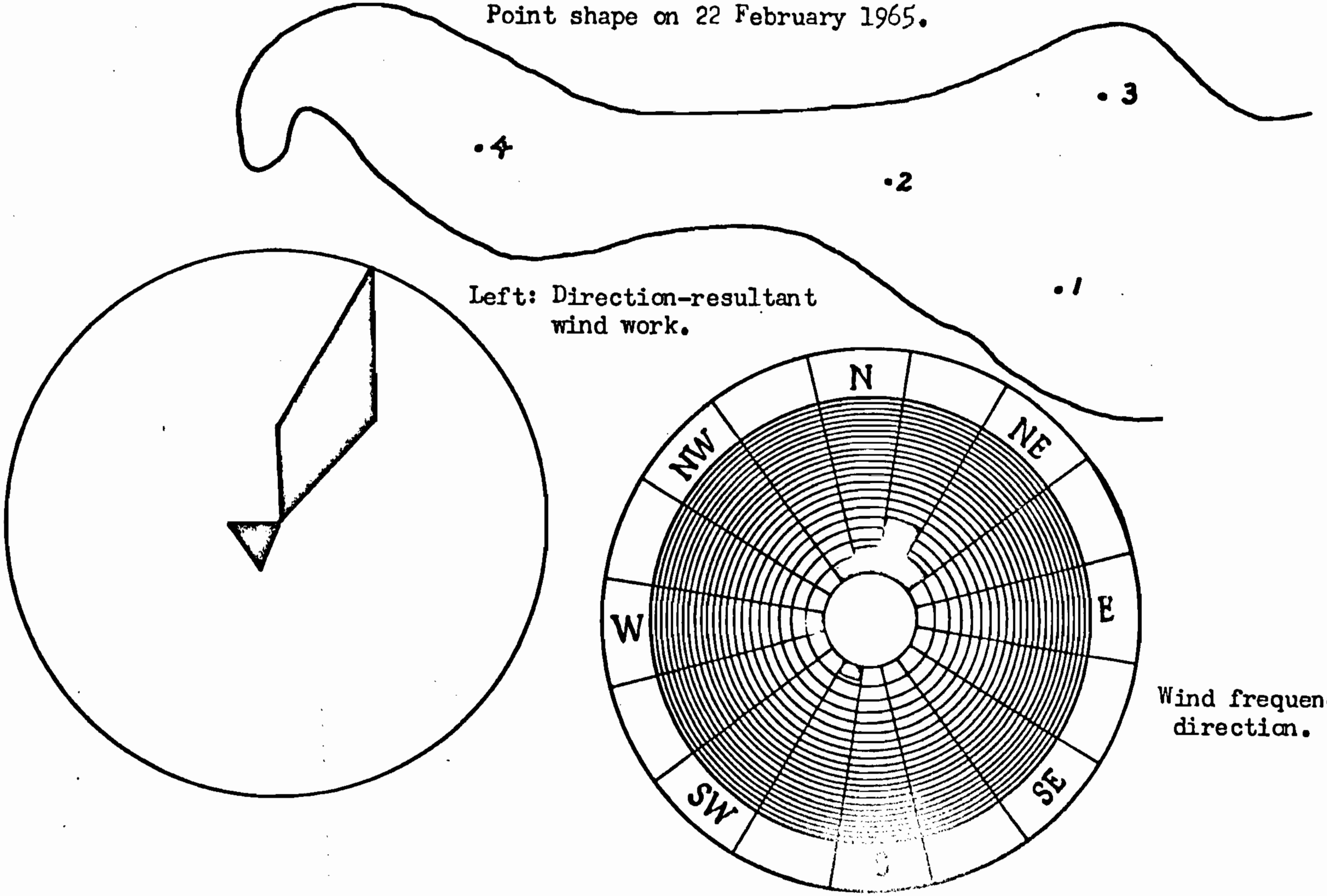


FIGURE 19



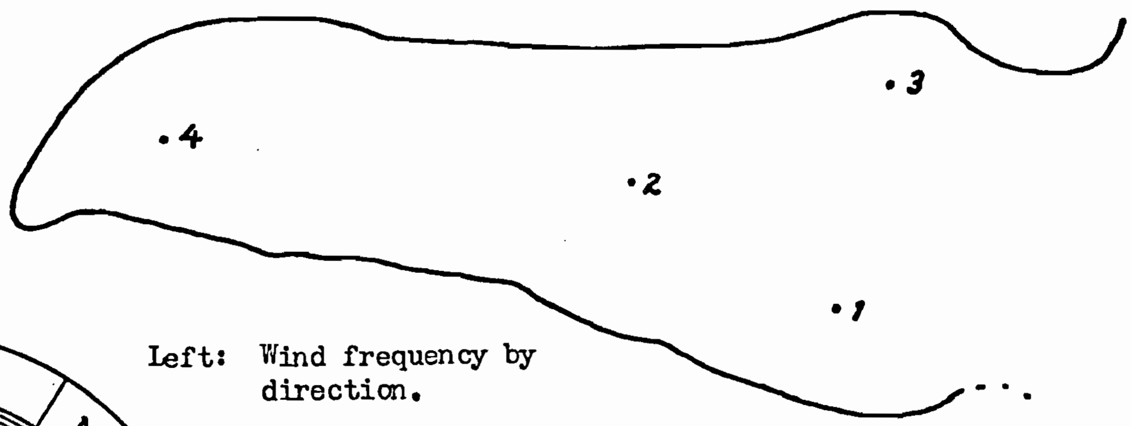

Point shape on 22 February 1965.

Left: Direction-resultant wind work.

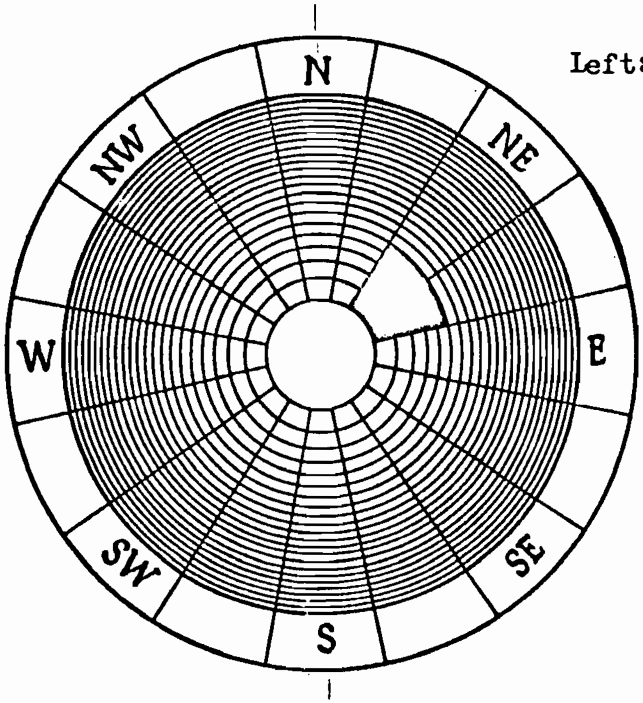
Wind frequency by direction.

FIGURE 20

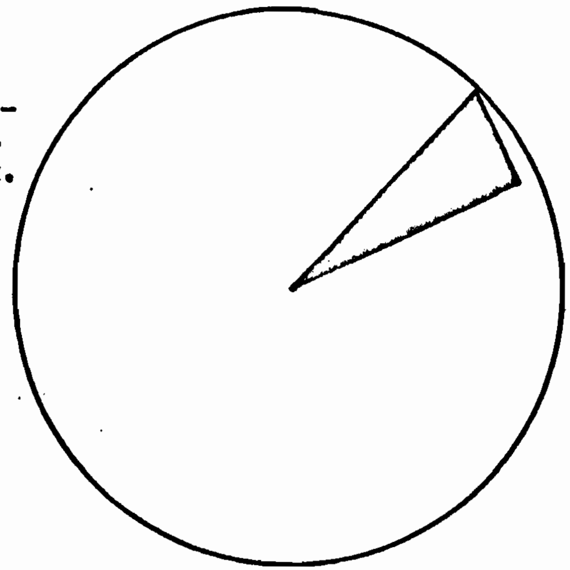
Point shape 23 February 1965.




Left: Wind frequency by direction.




Right: Direction-resultant wind work.



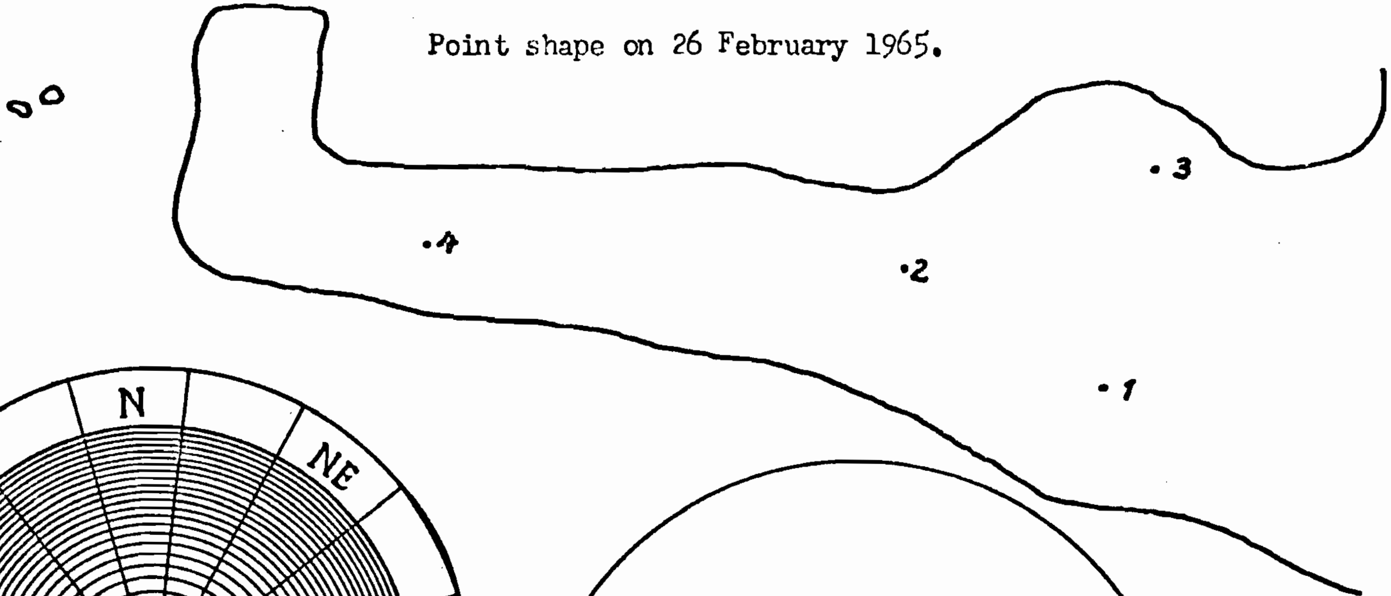
winds were able to generate waves in the lagoon powerful enough to pick up sand from the bottom and pile it onto the already existing point. Thus insignificant portions near its tip were washed away while the main body reached almost three feet above sea level.

The next observation period lasted three days, and the shape of the point was sketched again on 26 February. (Figure 21). Easterly winds prevailed until the night of the 25th when they became southerly and increased slightly. A condition now existed that had not been present before during the study. The material deposited in the deep water to the southwest of the point during previous northeast winds now provided some sediment for transport by southerly winds. This sand was now redeposited to the lee of the point during south winds, forming a hook protruding north into the shallow lagoon.

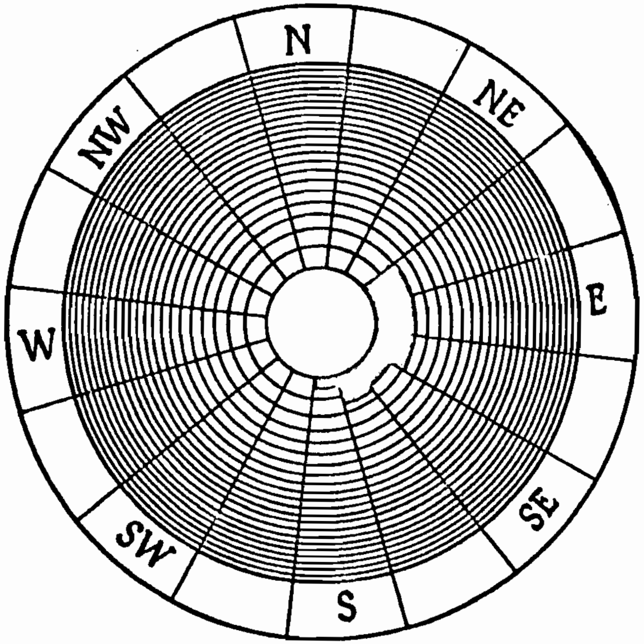
Little change was noted on the 27th when the point was sketched again. (Figure 22). Winds decreased as they shifted around and became westerly, and the only noticeable effect on the point was a smoothing of some of the sharper angles of the previous day.

Another seven days elapsed, and on March 6th the point was drawn again. (Figure 23). It was now about 100 feet longer than on 27 February and 200 feet longer than on 9 February when the study began. The hook, which formerly protruded north into the lagoon, had now straightened to the west and had lengthened slightly. Winds during the previous week had been light and variable until late on the 3rd of March when they became westerly at more than 20 knots. On the morning of the 5th, winds were strong from the south and stake No. 1 was washed away, and the material there redeposited at the end of the point. Late on the 6th of March cyclonic winds

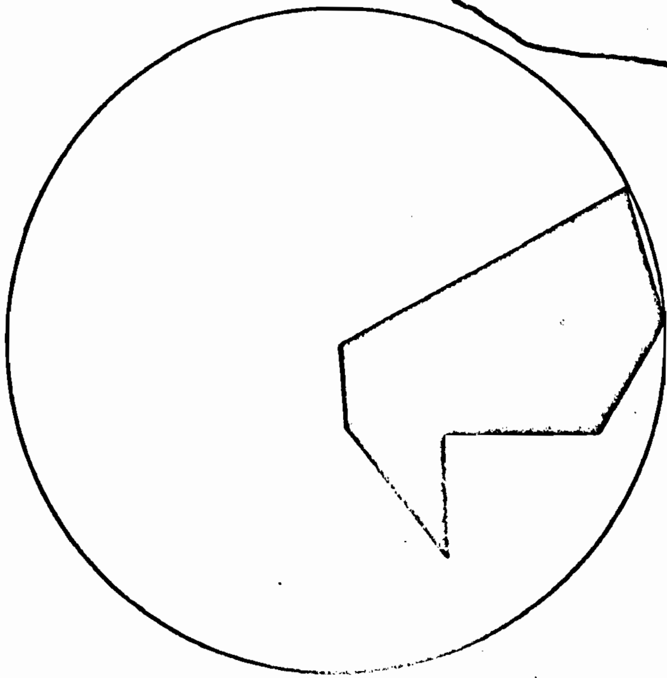
FIGURE 21




Point shape on 26 February 1965.

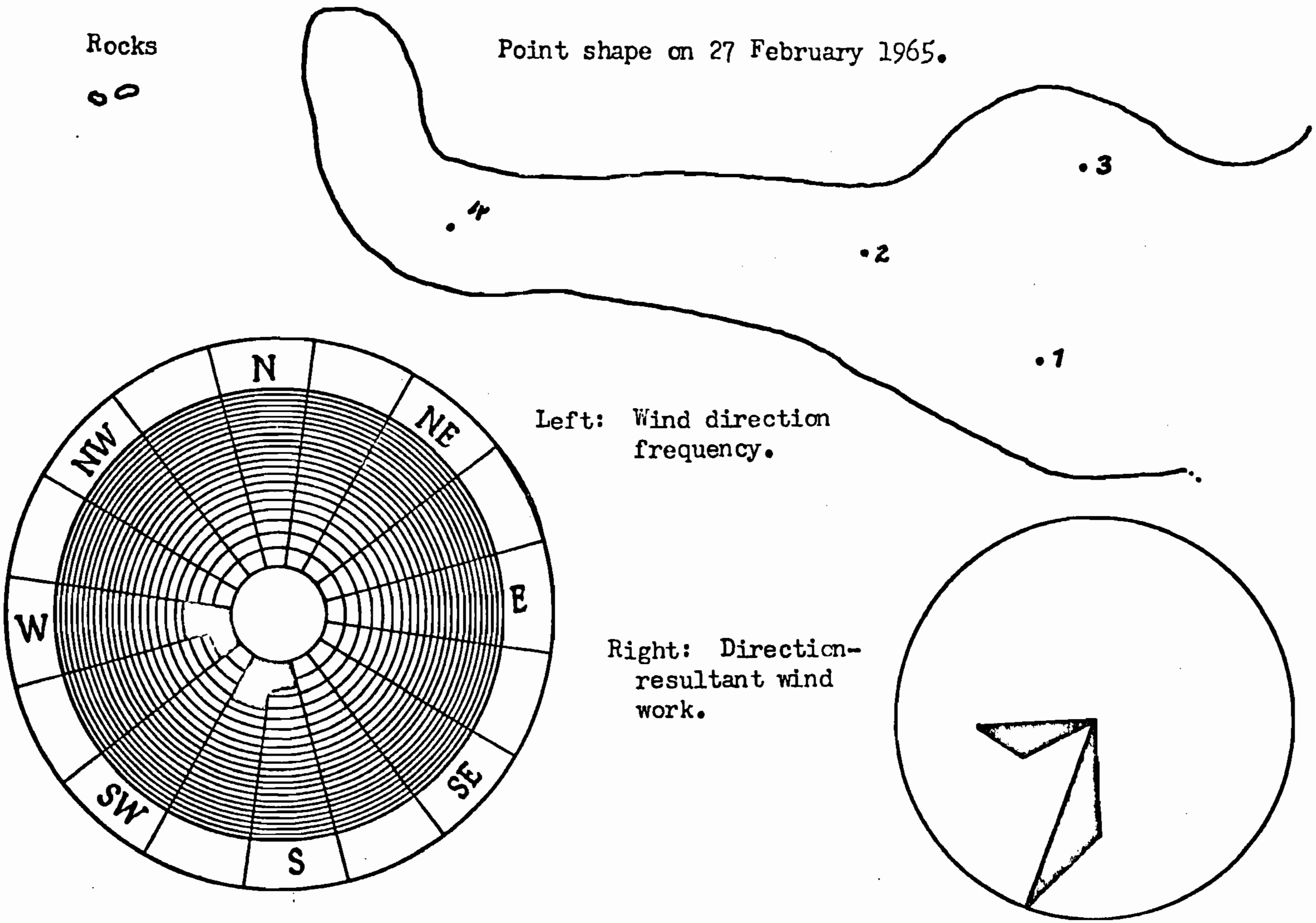



Above: Wind frequency by direction.



Direction-resultant wind work.

FIGURE 22

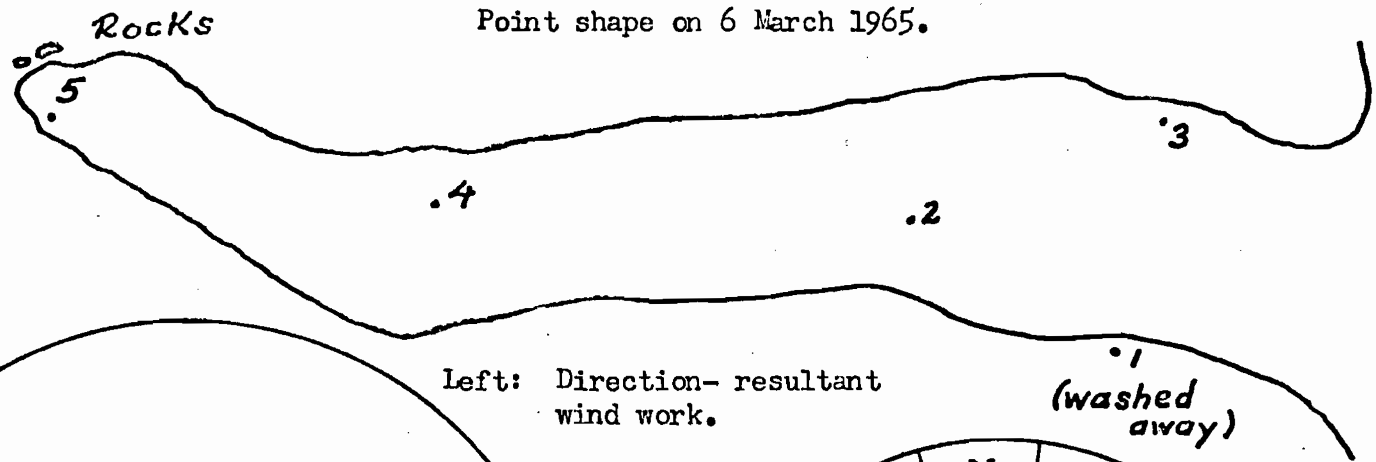


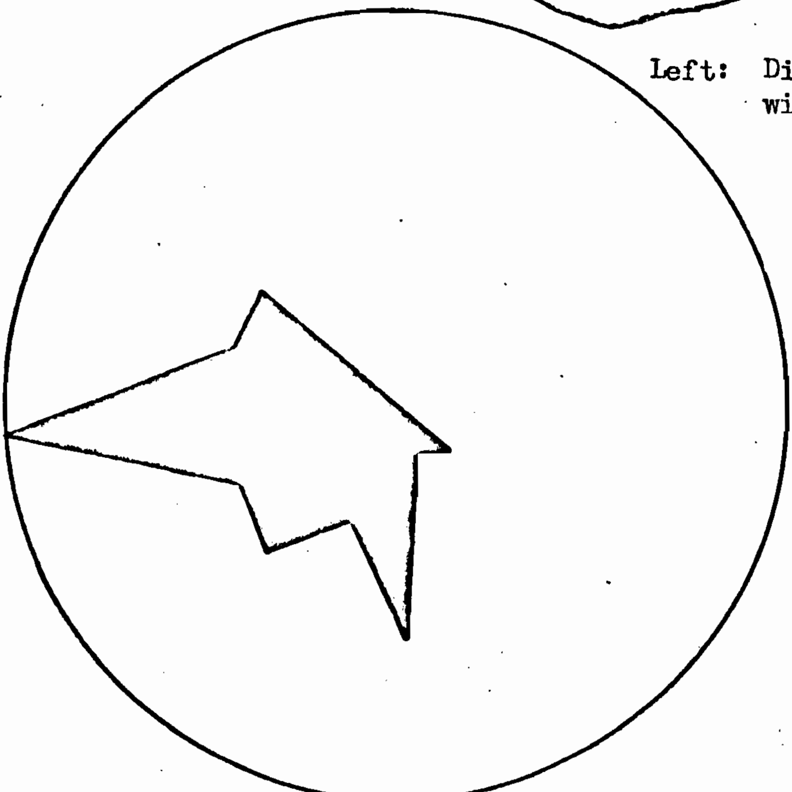

Left: Wind direction frequency.

Right: Direction-resultant wind work.

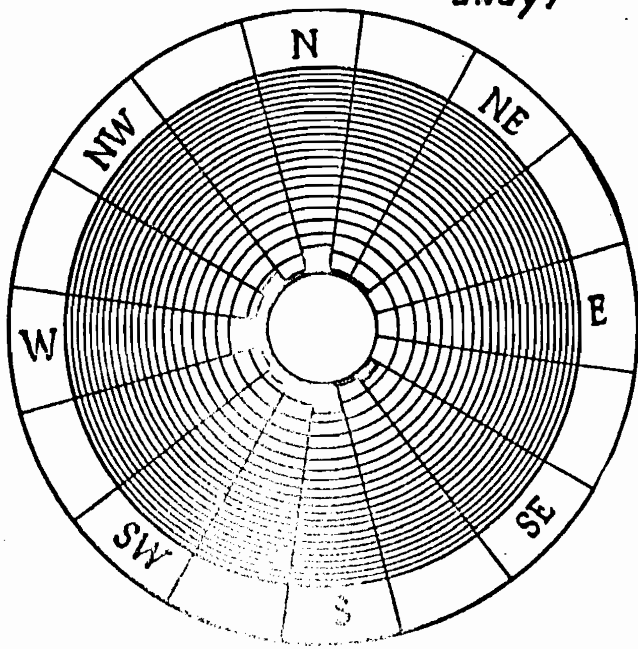
Figure 23

Point shape on 6 March 1965.



Left: Direction- resultant wind work.




Wind frequency by direction.

increased in velocity from the west, and by 0730 hours on the morning of the 7th the entire point had been eroded away. (Figure 24).

Conclusions. Several conclusions may now be drawn from the study of the point. First, wind direction and the wave action associated with it are key factors in determining island shape, especially regarding availability of material upwind to be transported. With the main body of land to the upwind side, waves are provided with a large source of sand. Stronger winds may also initiate wave action that picks up and carries sediments from the lagoon bottom. Waves from a direction with no source of material for transport become erosive agents to small islands at a rate increasing with their velocity and size.

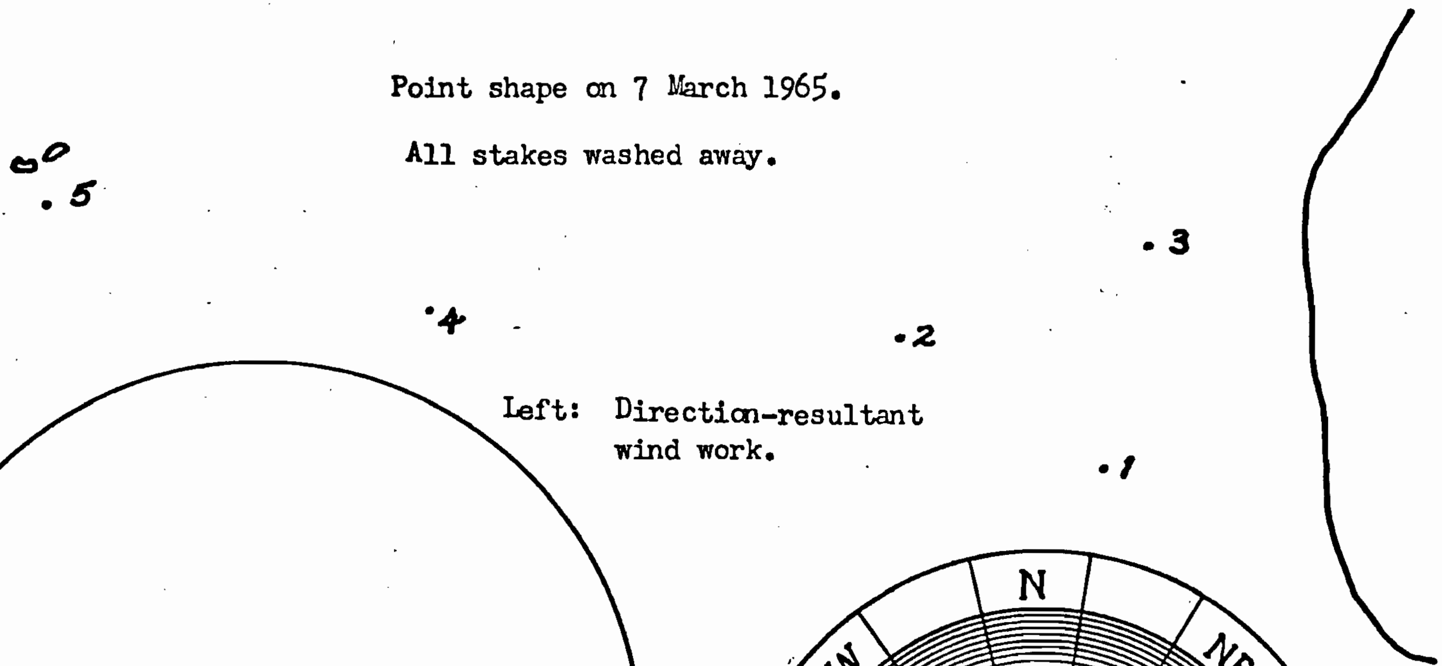
Wind speed determines where and how sand will be deposited by water currents. Waves and currents driven by winds less than Beaufort 4 deposit sand parallel to the wind in shallow areas to the lee of already existing islands or on sand bars. Waves and currents driven by winds above Beaufort 4 deposit sand perpendicular to the wind or parallel to the wave fronts. Thus the main axis of the island is perpendicular to the strongest waves, i.e. northwest where lagoon wave fetch is greatest. Vertical growth of the island through wave action occurs when the beach runs at right angles to the wind and thus the wave fronts, and when the winds are strong enough to generate waves which cast sand high on the beaches (farther back) without breaking entirely over the island.

Any new sequence of wind directions may temporarily cause a difference in amount of transported material owing to new sand recently deposited upwind. The usual sequence of winds is clockwise

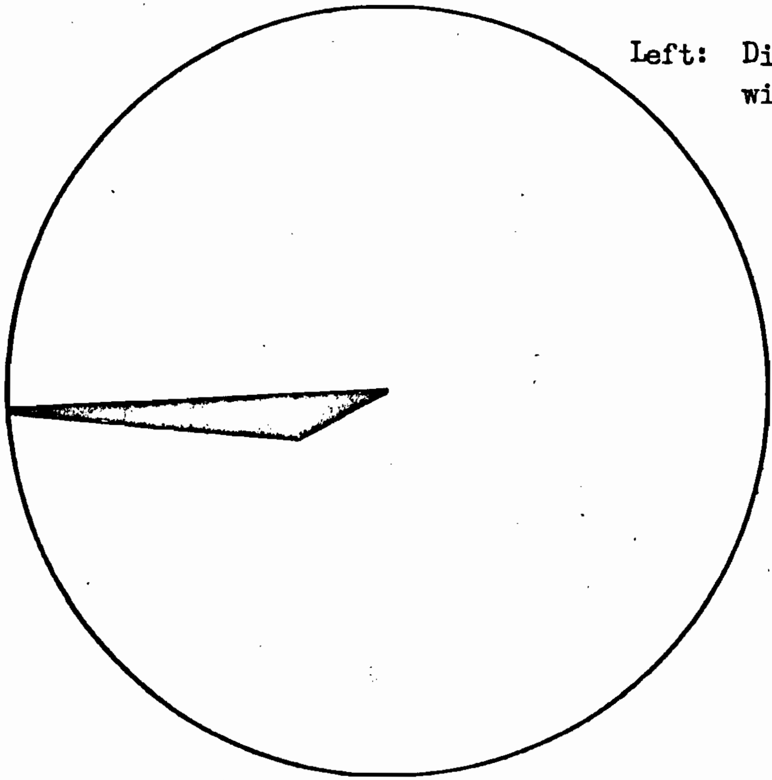
FIGURE 24

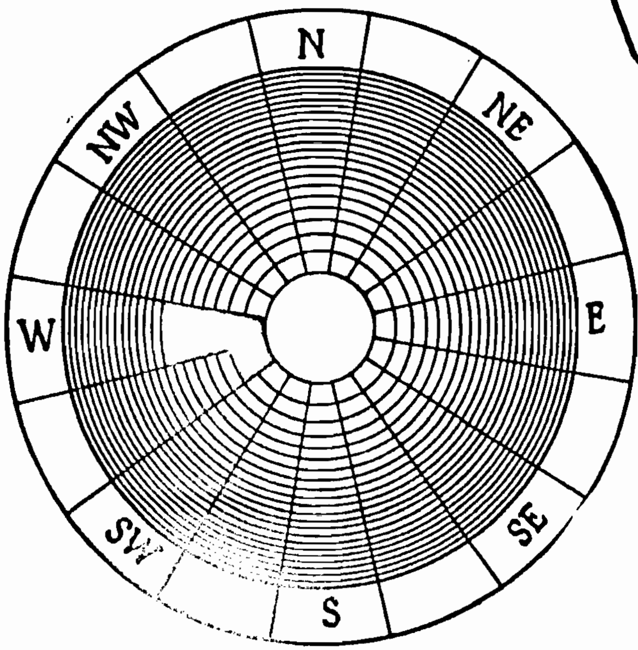
Point shape on 7 March 1965.

All stakes washed away.




Left: Direction-resultant wind work.






Wind frequency by direction.

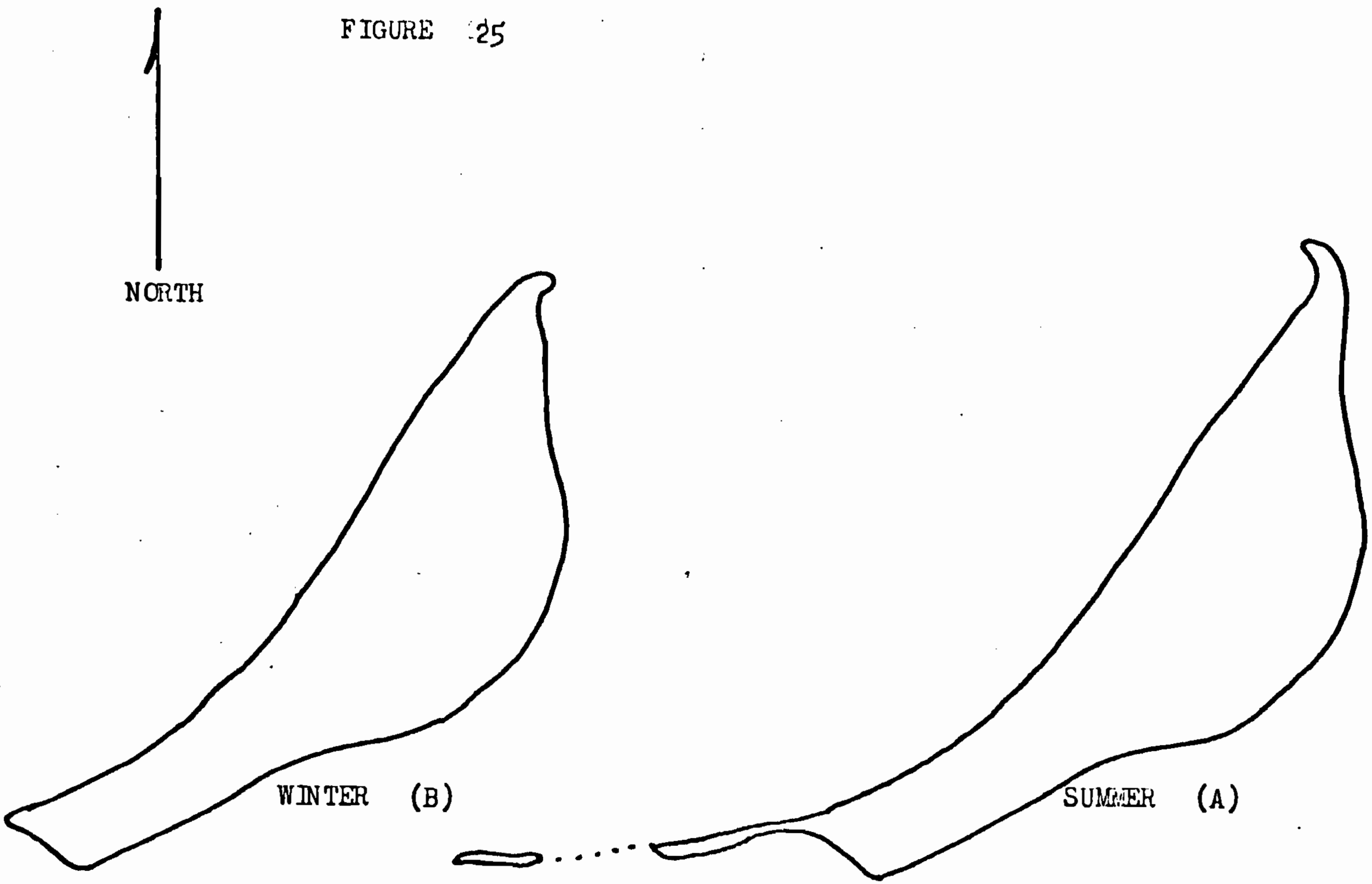
with the passage of lows, but occasional reversals do occur.

Application of Point Study to Observed Similarities on all the Hawaiian atolls. As a consequence of the conditions examined above, many peculiarities of the changing shape of Green Island, Kure Atoll, may now be explained. Moreover the movements of sand spits in the lagoon can be better understood. Allowing for special conditions regarding each island relative to its exact position with respect to the reef these conclusions can be applied to all the islands of the Hawaiian atolls.

Island shapes. Figure 25(A) shows the outline of Green Island, Kure Atoll, as it is usually given on maps. West point is well developed to the west, and north point is hooked slightly to the northwest. These features reflect summer trade wind conditions. Points at this time have no vertical development, but are instead long, low, and flat. Consequently the points might easily be washed away by a change in wind direction or a small storm. However, storms rarely, if ever, occur during the calm summer months. The shape described above is most common on maps because the atoll is visited most frequently during the summer when storms are uncommon and boat landings easier.

A typical winter outline of Green Island is shown in Figure 25(B). During the winter west point is almost non-existant. Winter cyclonic storms and their associated northwesterly winds quickly erode west point. There is never any hook to the south or southeast (lee of storm winds) because the reef is poorly developed there, and the bottom drops off quickly. At north point the situation is not the same. This point is several hundred yards from the emergent

FIGURE 25




Green Island, Kure Atoll showing typical winter and summer island shape.

reef, and the water between is quite shallow. Figure 25(B) shows that here the point is able to curve to the lee of northwesterly storm winds. Green Island is characterized in winter by little or no sand spit at west point and a spit hooking east at north point.

Sand bars. The movements of small sand bars and islets are similar to those of sand points except that the supply of sediments for the former is less apparent. In the case of island points the island itself may be a source of material for point development when the main body of the island is up-wind. Sand bars and non-permanent islands do not always have this constant source. Instead they depend on calm unchanging weather for their whole existence. They are built up slowly during calm weather by currents strong enough to collect sediments in shallow places in the lagoon, but not so strong as to wash over the bars that develop.

Most of the bars develop under easterly winds to the lee of permanent islands. The eddies that develop to the lee of these islands are soon dispersed, and waves redevelop as the fetch again increases. More sand begins to move again only to be redeposited in shallow water down-wind. This process may be repeated again and again forming several sand bars down wind. The numerous sand bars are summer phenomena but are not unknown in winter. They are present in conjunction with long spits on the permanent islands. Now a small, long, narrow sand bar (Figure 25(A)) can be added to the west of the typical summer island outline.

## IV. THE WORK OF WIND ON SAND

I have now discussed changes of beaches, points, and sand bars as a result of storms. So far all of these changes have been brought about by waves driven by wind. But some of the storm winds have velocities strong enough to move considerable quantities of sand on the islands themselves.

Blowing sands have added much to the vertical growth of the sand islands of the Hawaiian atolls in the form of dunes. The orientation of these transverse dunes is of course related to the winds that form them. Dunes are found on three islands, Green Island, Kure Atoll, and Sand and Eastern Islands, Midway Atoll and appear to have their windward slopes facing in a west or north-westerly direction. The tops of these dunes form a discontinuous ridge parallel to the lagoon beach. This orientation suggests that the sand dunes may have been influential in determining the orientation of the lagoon beach as well as the main axes of the islands where they are found.

The exact orientation of the sand dunes is obscured by two things. First the base of the windward slopes has been sheared off by heavy wave activity in winter. Second, the determination of the direction of travel of the slip faces is confused by their concave form and the tangle of vegetation in their path. A study of the direction of winds of the velocity necessary to move coral sands should help to establish the precise direction of travel of the sand dunes. Once the exact orientation of the dunes is determined it can be compared with the orientation of the islands. In this way it is possible to establish whether sand dunes have been a controlling factor determining the orientation of the main axes of islands.

Previous studies. The transport of sand by wind has been studied in different ways by many authors and for numerous reasons. R. A. Bagnold's work is still a primary source in this area. Much of his work was based on wind tunnel studies under controlled and measured (i.e. measureable) conditions. No such measurements are practical in the field, and many of his techniques cannot be used here. His work did bring forth an important fact regarding the quantitative transport of sand by wind. He found that the quantity of sand moved (i.e. carrying capacity) varies as the cube of the wind velocity above the threshold velocity.[43]

The threshold velocity is the speed necessary to initiate the movement of sand particles. This value may vary with individual grain size, the variety of grain sizes, and the water content. As grain size increases, the speed of the wind must increase to carry it. The mixture of different grain sizes also affects the threshold velocity. A wide range of grain sizes raises the threshold velocity considerably because the smaller grains are protected from the wind by the larger ones.

In studies on desert dunes with quartz sand grains of uniform size (average 0.2mm grain diameter), wind machines have been shown to initiate sand movement at speeds of about 11 knots.[44] In these experiments wind speed was recorded less than one foot from the ground, and the sand was dry.

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[43]Reginold Bagnold, The Physics of Wind Blown Sand and Desert Dunes, (London: Methuen and Co., 1941), pp. 69.

[44]U.S. Army Natick Laboratories, "A Study of Windborne Sand and Dust in Desert Areas," (Natick, Mass.: 1963), Technical Report ES-8, p. 37.

<u>The Physical Characteristics of Atoll Sands</u>. Before previous studies can be applied to the Pacific atolls the physical characteristics of atoll sands must be understood. Atoll sands are derived exclusively from calcarious materials, primarily the broken and cemented skeletons of foraminifers, various mollusks, and corals. Coral sand, as it is called, is noted for its dazzling whiteness and the striking contrast it makes with the blue ocean water which surrounds the islands where it is found. Studies of these sands in both the Pacific Ocean and Caribbean Sea indicate that the range of grain sizes is essentially the same and may be considered as such on all coral islands.[45]

<u>Grain size</u>. The sand found on the islands of Kure, Midway, and Pearl and Hermes Atolls is composed of broken coral and sea shells like sands of other atolls. Coral beach sands show a grain size distribution as follows:

| BEACH SANDS- | Grain diameter in mm. | percent |
|---|---|---|
| | 16.0-8.0 | 2 |
| | 8.0-4.0 | 2 |
| | 4.0-2.0 | 8 |
| | 2.0-1.0 | 21 |
| | 1.0-0.5 | 48 |
| | 0.5-0.25 | 17 |
| | less than 0.25 | 2 |

This table shows the wide range of particle size usually found in coral beach sands.

[45] D. R. Stoddart, "Carbonate Sediments of Half Moon Cay British Honduras," <u>Atoll Research Bulletin</u>, No. 104 Sept. 30, 1964.

The analysis of coral sands from sand dunes displays a strikingly different distribution from beach sands. Seventy percent of all the dune sands have an average grain diameter of slightly less than 0.25 millemeters. This difference has led Fosberg and Carroll to suggest that, "The low percentage of fine material in beach sands and concentration of fines in dunes suggest dune material comes from beaches."[46] Thus we can see that the wind must select out from among the large sand grains the smaller ones to be transported to the dunes.

This wide range of grain sizes (2.0mm-0.2mm) found in coral sands will raise the pick-up velocity. Some works indicate that a wind of 11 knots which moved sand of uniform 0.2 millimeter grain diameter had to be increased to 16 knots to move the same size particles when mixed with particles approaching 2.0 millimeters in diameter.[47]

Moisture content. Another important physical characteristic of coral sand is its moisture content. Because most of the sand is on the beaches, or at least subjected to the high humidity of its environment, sand usually has a high moisture content. Moreover the sand is porous and holds water longer than quartz sand and does not dry out rapidly. This high water content will, of course, raise the threshold velocity. It has already been shown, however, that

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[46]F. Raymond Fosberg and Dorothy Carroll, "Terrestrial Sediments and Soils of the Northern Marshalls," Atoll Research Bulletin, No. 113, December 1965.

[47]Natick, op. cit. p. 42.

high winds are far more frequent and of longer duration than rainfall. Thus the sand above the swash line is not always wet.

Furthermore a study of soil moisture conducted by the author on Kure showed that the upper layers of coral sand actually lost water during the storm of March 1965. It would be almost impossible to calculate how much the threshold velocity would be raised over that of dry sand because the moisture content is so variable.

An attempt to reach any absolute conclusions about wind velocities necessary to move coral sand is out of the question and beyond the scope of this paper. Suffice it to say that while sand of uniform 0.2 millimeter grain diameter will be moved by winds as low as 11 knots, a high moisture content and wide range of grain sizes will raise this value considerably. Based on these studies and observations on Kure Atoll, it does not seem unreasonable to take 20 knots as the threshold velocity used in this study. Although the selection of this value is arbitrary, it is considered to be higher than the minimum pick-up velocity.

Interpretation of wind data. In addition to the two physical factors of coral sand which give it a higher threshold velocity than quartz sand, a third may be added; the manner in which wind speeds are recorded. Although the manner in which wind speed is recorded does not change the threshold velocity of coral sand, it does alter the interpretation of the wind data itself.

The wind data used in this study came from the U. S. Navy Weather Station on Midway.[48] The wind gauge on the island is

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[48]Chief of Naval Operations Aerology Branch, op. cit., p. 1.

8.7 meters above the ground. Because wind speed varies considerably with height, these records should be reduced to ground level. This is theoretically possible if the air flow is considered to be non-turbulent. But since we are dealing with winds capable of moving coral sand (20 knots), turbulence is an important factor. Turbulence will cause mixing of different levels of air thus reducing the effects of surface friction. The total effect is that surface wind speeds begin to approach those at higher levels.

Theoretically, wind speeds increase with increasing height, but at varying rates. However, because of the turbulence factor the exact nature of this increase has not been established. For the purposes of this study an air speed of 30 knots at tower level is considered sufficient to reach the threshold velocity of 20 knots at ground level. Based on field observations on Green Island, Kure Atoll, a wind speed above 30 knots at the tower is sufficient to move coral sand on the ground. It is most unlikely that the requisite tower wind speed is much lower. Wind speeds well above 30 knots have been recorded at tower level, and these higher velocities consistently have a western vector.

Quantitative sand transport. The next step in the analysis of winds is to sum all wind frequencies above 30 knots by direction. The wind classes used are 31-40 knots and above 40 knots. Each class is given an average velocity above the threshold. These are 5, and 15 knots respectively. The averages above the threshold velocity are multiplied by wind frequency by direction. In this manner the higher wind velocities are weighted. After the wind speed classes are weighted they are cubed separately, because their carrying capacities vary as the cube of the wind speed above the threshold velocity.[49] Thus, if the frequency of winds in the 31-40 speed class from the north was 10, this would be multiplied by 5 (the average speed of the 31-40 wind speed class above the threshold velocity as recorded on Midway) and the result cubed. The two wind speed classes from the same direction are then added together.

The final numbers are shown in Table I and indicate the relative magnitude of sand transport by wind direction. These are based on wind records for Midway Atoll for the period 1949-62. Of the total of 113,724 wind observations recorded, only 145 (0.1 percent) were above 30 knots and therefore used in the study. It must be remembered, however, that these are hourly averages and do not include peak gusts.

Table I shows that eighty-seven percent of all sand transport results from winds with a westerly component. The significance of this statement is enhanced by the fact that seventy-five percent of all winds recorded each year have an easterly component. Thus, while most of the wind comes from the east, more sand is transported by winds from the west. Furthermore since sixty-four percent of all the winds over 30 knots come in the winter months of December, January, and February, most of the sand transport must be attributed to winter storms.

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[49]Bagnold, loc. cit.

TABLE I

WIND DIRECTION AND QUANTITATIVE SAND TRANSPORT CAPACITY

| | |
|---|---|
| W | 4,495,500 |
| SW | 1,157,625 |
| ESE | 857,375 |
| WNW | 614,125 |
| WSW | 343,000 |
| SSW | 91,125 |
| SE | 64,000 |
| E | 15,625 |
| NNW | 8,000 |
| NW | 3,735 |
| N | 3,735 |
| ENE | 3,735 |
| SSE | 3,735 |
| S | 125 |
| NE | 125 |
| NNE | 0 |

The numbers on the right represent levels of magnitude with no units involved.

Further analysis of winds shows that peak gusts with a westerly component average 7 knots faster than those with an easterly component (Figure 26). Within the group of winds with a westerly component, ninety-five percent bear from southwest to WNW. Moreover, as wind speeds increase, direction shifts about 25 degrees north. The six highest peak gusts ever recorded on Midway, which range from WSW to north, show this change also. Thus, the greatest amount of sand is transported by winds ranging from southwest to WNW. At higher wind speeds sand movement may be attributed almost entirely to winds from the northwest quadrant.

## V. CONCLUSION

On the three islands where sand dunes have developed, Green Island, Kure Atoll, and Sand and Eastern Islands, Midway Atoll, the dunes appear to have been formed by winds from the west or northwest. Their formation is somewhat confused by the shearing-off of part of the dunes by storm waves as mentioned earlier. The above calculations indicate that west winds contribute most heavily to sand transport and thus dune growth. If this is the case, then the dune summits are parallel to the northeast to southwest lagoon beaches, not because they are formed by northwest winds, but because the dunes have been sheared-off by waves a constant distance from the beach. The dunes are moving at an angle to the beach rather than directly away from it. Also because of this, the orientation of each dune is not related to the orientation of the main axes of the islands. Moreover, because the dunes are superimposed on the predetermined wave-formed outline of the islands, they must be

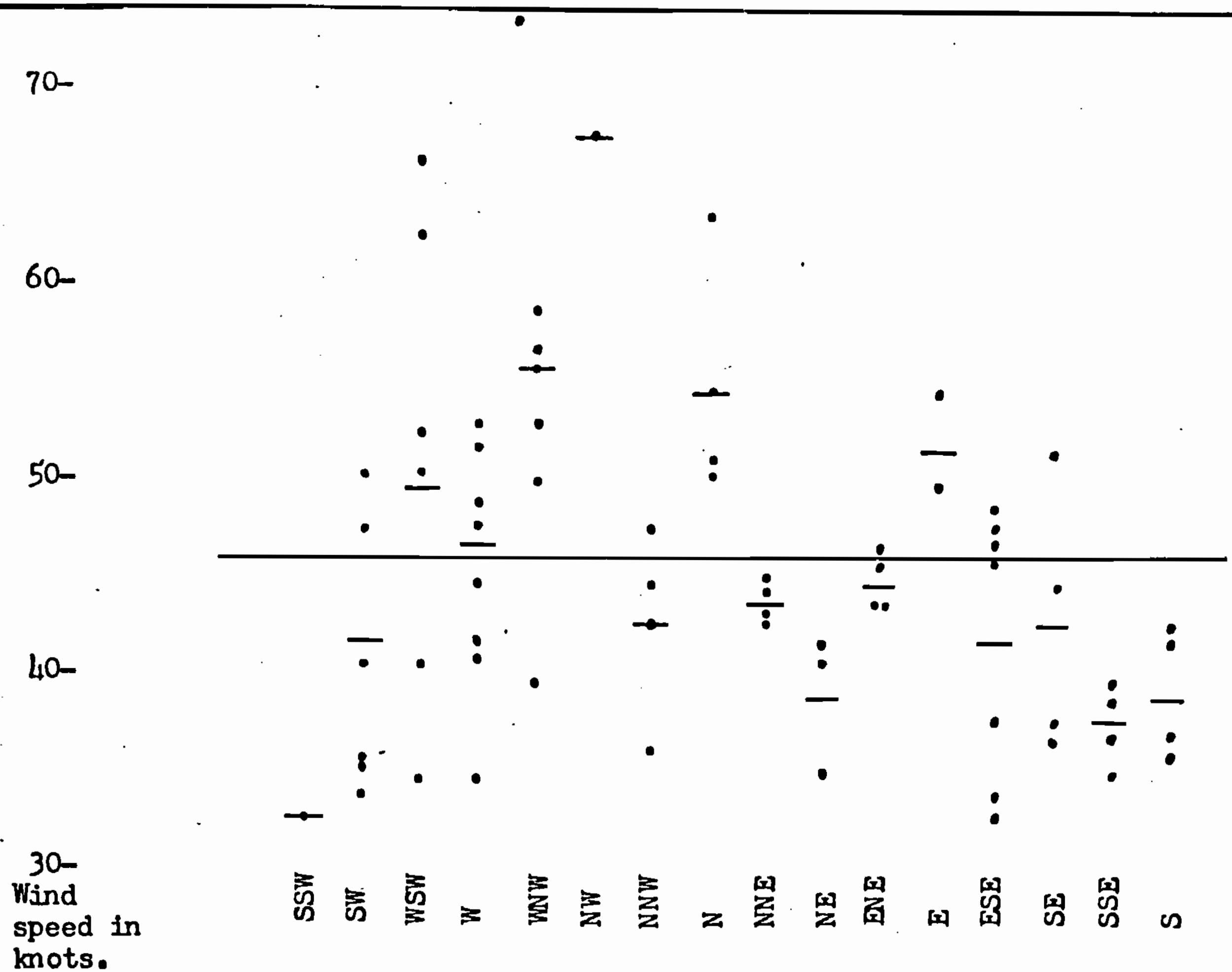


Figure 26. Frequency distribution of the six highest peak gust winds ever recorded on Midway Atoll for each month. Average peak gust wind velocity is indicated by short line for each wind direction. Horizontal line divides observations in half.

secondary in the formation of an island.

## CHAPTER IV

## ISLAND EVOLUTION

In the introduction to this study it was suggested that a satisfactory explanation for the similarity in shape, orientation, surficial form, and distribution of land on the Hawaiian atolls would lead to an understanding of how these islands evolved.

The land within the atolls of Kure, Midway, and Pearl and Hermes has been shown to be situated mainly in the southeast quadrant except in the case of North Island, Pearl and Hermes. Here a deviation from the usual circular outline found on the other atolls is responsible for the island's position. The reef supplies the sediments to be deposited in the lagoon. Thus the supply of sediments is about the same anywhere within the lagoon except where there is a break in the reef. These sediments, after being deposited in the lagoon, are then redistributed in the lagoon in response to wave action and currents. This study has shown that the strongest winds and thus waves come from the northwest quadrant. These waves transport sand to the south and southeast atoll rim. The distance between the island and the southeast reef is maintained by wave action from that side of the atoll. This distance increases from south to east because wave activity from the east is most frequent. Waves from the east, however, are not as strong as waves from the northwest where winds are strongest and lagoon wave fetch greatest.

The shapes of the permanent islands are mere magnifications of smaller sand bars. Changes in sandy points on the larger islands are similar to the changes on many of the small sand bars also found in the lagoon. Larger sections of land added to islands as sand spits during years with mild winters may become covered with vegetation and thus become part of the permanent island. More often sand spits and sand bars are washed away before plants become established.

Wind blown sand probably played an important role in the early stage of island development. Survival of a new sand bar would depend on the building of small ridges by wave or wind high enough to prevent waves from breaking across them. If an islet lasts through the following summer plants might become established and thus help to trap blowing sand the following winter.

The size of the three atolls is critical with respect to lagoon waves. Kure and Midway, which are very nearly the same size, show no evidence of waves breaking over the islands. Pearl and Hermes is nearly twice as wide as the other two atolls (Figure 10, pg. 29), and yet no large islands have ever developed. Two of the islands there show evidence of being washed over by waves. It is likely that much larger waves are possible on Pearl and Hermes because of the larger lagoon and its greater fetch. Some parts of the lagoon on Pearl and Hermes are 50 feet deeper than on Kure and Midway, another factor contributing to larger waves in the lagoon. This evidence indicates that large waves breaking entirely over the small islets of Pearl and Hermes have hindered the growth of islands of substantial size.

In addition there are small depressions on Green Island, Kure, Eastern Island, Midway, and Southeast Island, Pearl and Hermes.

These depressions, conceivably dried lagoons, all appear to have held water at some time. Their frequency, one on each of the three atolls, warrants further explanation.

On two of the islands the depression is decidedly in the eastern half of the island, and on the other it is more centrally located. As mentioned previously considerable room for sand deposits exists to the lee of northeast points under storm conditions. Thus the northeast points on most islands are able to build to the southeast. Instead of being sheared off by winter winds, a large point curves around to the lee of the island in winter (Figure 27). If a large enough hook had been formed in the winter, Figure 28, a small lagoon might be enclosed as winds moved from northwest to northeast in spring.

A map drawn by Elschner in 1915 of an island on Pearl and Hermes Reef contains the most striking bit of evidence for this idea.[50] His plan of Sand Island, Northeast on Pearl and Hermes (probably refering to North Island) shows a long narrow island with three successive lagoons present on the island at one time and a fourth one being formed (Figure 29). This lends support to the idea of seasonally induced island growth and lagoon development.

The island could grow in this manner until its proximity to the reef was such that wave action from the direction of the reef limited farther advance. At this final stage a steep beach would be formed, its slope changing in response to wave activity, a

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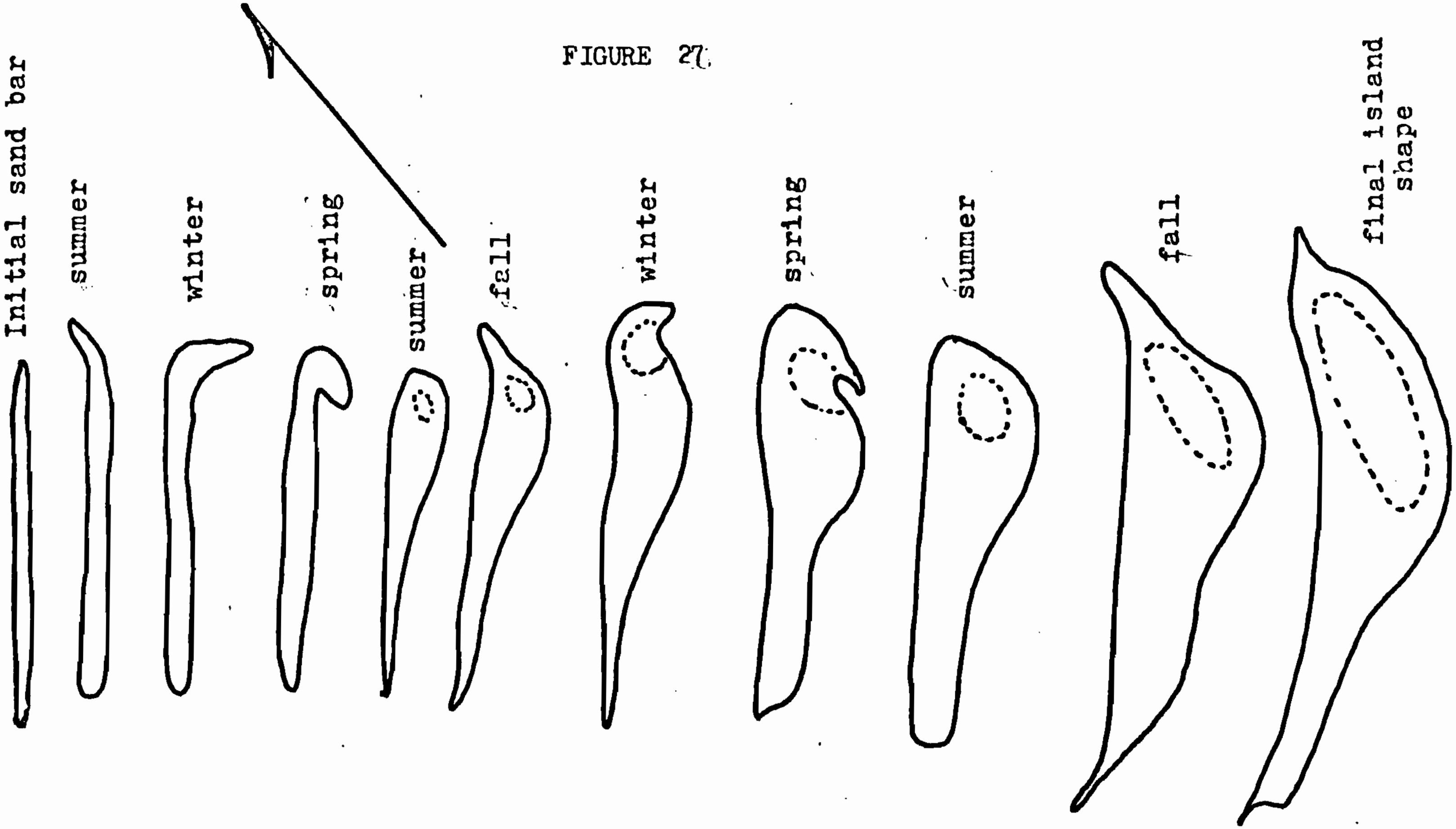
[50]Elschner, op. cit., pp. 58-59.

FIGURE 27.




Theoretical sequence of the evolution of Green Island, Kure Atoll, showing the development of low depression called the central plain.

FIGURE 28

NORTH POINT on Green Island, Kure Atoll looking east showing winter shape of the point hooking ESE.

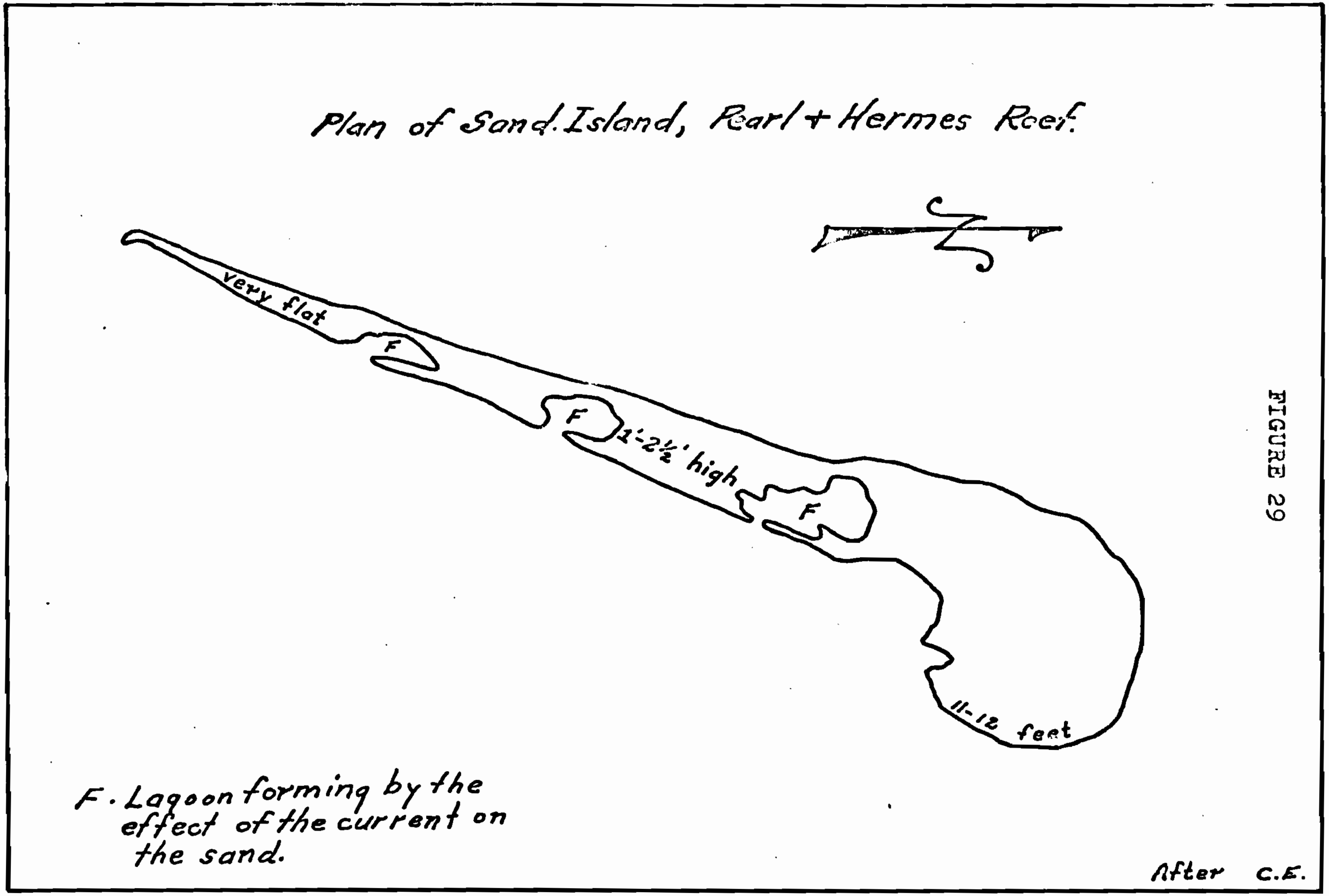

Plan of Sand Island, Pearl + Hermes Reef.
very flat
F
F
1'-2½' high
F
11-12 feet
F. Lagoon forming by the effect of the current on the sand.
After C.E.

FIGURE 29

function of distance to the reef. All deposits on the southeast beaches are the result of wave action and no dunes ever developed here. Occasionally large waves might rise over the beach ridge inundating the interior depression, but never washing completely across the island. Eventually the beach ridge would reach some terminant height.

For a while the enclosed lagoon would be tidal, as on Southeast Island, Pearl and Hermes today, but eventually it would fill with debris and dry. These interior protected areas are the favorite breeding grounds for sea birds. Bird droppings and accumulated nesting material probably altered the soil and thus its vegetative character from the rest of the island.

The dunes found on several of the islands are not as important to the establishment of the characteristic island shape found on the sand islands of Kure, Midway, and Pearl and Hermes Atolls as was first believed by the writer. Because dunes appear at first glance to be aligned with the main axis of the islands, they were thought to have played an important role in determining the shape and orientation of the islands. This study has shown that the trend of most lagoon beaches is northeast to southwest, perpendicular to the largest lagoon waves. These come from the northwest, because strong winds are common from that direction and the wave fetch from that direction is greatest. Sand Dunes, on the other hand, are perpendicular only to strong winds capable of blowing sand. Such winds come most often from the west and dune movement is therefore to the east. Movement of the dunes is thus shown to be unrelated to the axis of the islands.

# CHAPTER V

## SUMMARY AND CONCLUSION

<u>Summary</u>. An explanatory description of the sand islands of Kure, Midway, and Pearl and Hermes atolls has been presented. These atolls, part of the Hawaiian Islands, were shown to be uniquely situated in the atoll realm. Unlike most other atolls, they do not experience typhoons, but they do experience mid-latitude cyclones. Under the influence of the northeast trades during most of the year, the islands in December, January, and February are affected by cyclonic storms which regularly bring west and northwest winds of considerable strength.

The three Hawaiian atolls constitute a compact geographical unit measuring thirty-nine nautical miles north to south by one hundred and forty-three nautical miles east to west. These same atolls exhibit a marked similarity in area, distribution, shape, orientation, and surficial form of the sand islands found within the reef rim. The scarcity of land and its precarious state on the atolls has been described. Of more than a dozen islets in the Hawaiian atolls, only three are more than a mile in length, the longest being two miles. In contrast at least six seasonal sand bars are almost a half mile in length.

Aside from the small amount of land present on each atoll, the most striking similarity is land distribution. On all these atolls the reef rings have nearly the same shape (i.e. oval), and the land is concentrated in the southern half. There is no causal relationship between the site of these islands within the reef ring and the normal northeast trade winds. Furthermore, atoll profiles do not indicate that the coral base is tilted or the sand islands are situated in unique lagoon shallows. On the contrary, lagoon shallows are common on these atolls, but only a few of them are occupied by land.

The adjustments of the west point of Green Island, Kure Atoll, to changing winds and currents were studied in February and March 1965. These changes in shape, similar to changes in sand bars, indicate that the islands are very sensitive to changes in wind direction. Storms appear to remove all islands but those to the lee (i.e., southeast) of storm winds.

The small islands also have characteristic winter and summer shapes. During the summer the ends of the islands curve to the lee of the east or northeast trades. In winter the western ends of the islands are truncated, while the northern points may hook to the lee of winter winds (southeast).

Sand dunes are found on three of the islands. A study of winds capable of moving coral sands indicated that the dunes are formed by winds from the west and are advancing eastward. In addition, these winds represent only 0.1 percent of all observations, and their contribution to island similarities may go unnoticed by the casual observer. Thus while adding significantly to the vertical growth of several islands, sand dunes have been shown to be unrelated to the orientation of these islands.

An explanation for the depressions found on several of the islands was suggested. It seems possible, considering the rapid changes in the sand points of Green Island, Kure Atoll, that a point of an island may at times recurve back upon itself thus forming a small enclosed lagoon which eventually dries.

<u>Conclusion</u>. The site of Kure, Midway, and Pearl and Hermes atolls on the northern limit of the Pacific atoll realm accounts for the unique atoll climate found there. The summer climate is similar to that of most atolls while winters are distinctly mid-latitude in character. Winter storms with high winds consistently from the northwest have shaped all the islands within the reef rim and severely limited the distribution of land on the atolls.

Because of this direct causal relationship it is now possible to state that the Hawaiian atolls are indeed a geographically and morphologically distinct group. The land on these atolls may be characterized as being composed of a few long narrow sand islands, restricted primarily to the southeast quadrant of the atoll rings, in the lee of the northwest winter storm winds peculiar to these atolls, with the main axis of the islands perpendicular to these winds. Most important, while high winds characteristic of these storms only represent a small percentage of all recorded winds, they determine the distinctive morphological character of the sand islands of the Hawaiian atolls.

As is so often the case in nature prevailing physical conditions, though giving character to place, do not account for critical characteristics of that place. Environmental extremes, brief in time but intensive in effect, are the true determinants of such physical landscapes.

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