No. 75 April 15, 1961

ATOLL RESEARCH BULLETIN

75. A Report on Typhoon Effects upon Jaluit Atoll

edited by David I. Blumenstock

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THE PACIFIC SCIENCE BOARD

National Academy of Sciences—National Research Council

Washington, D.C., U.S.A.

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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past fourteen years.

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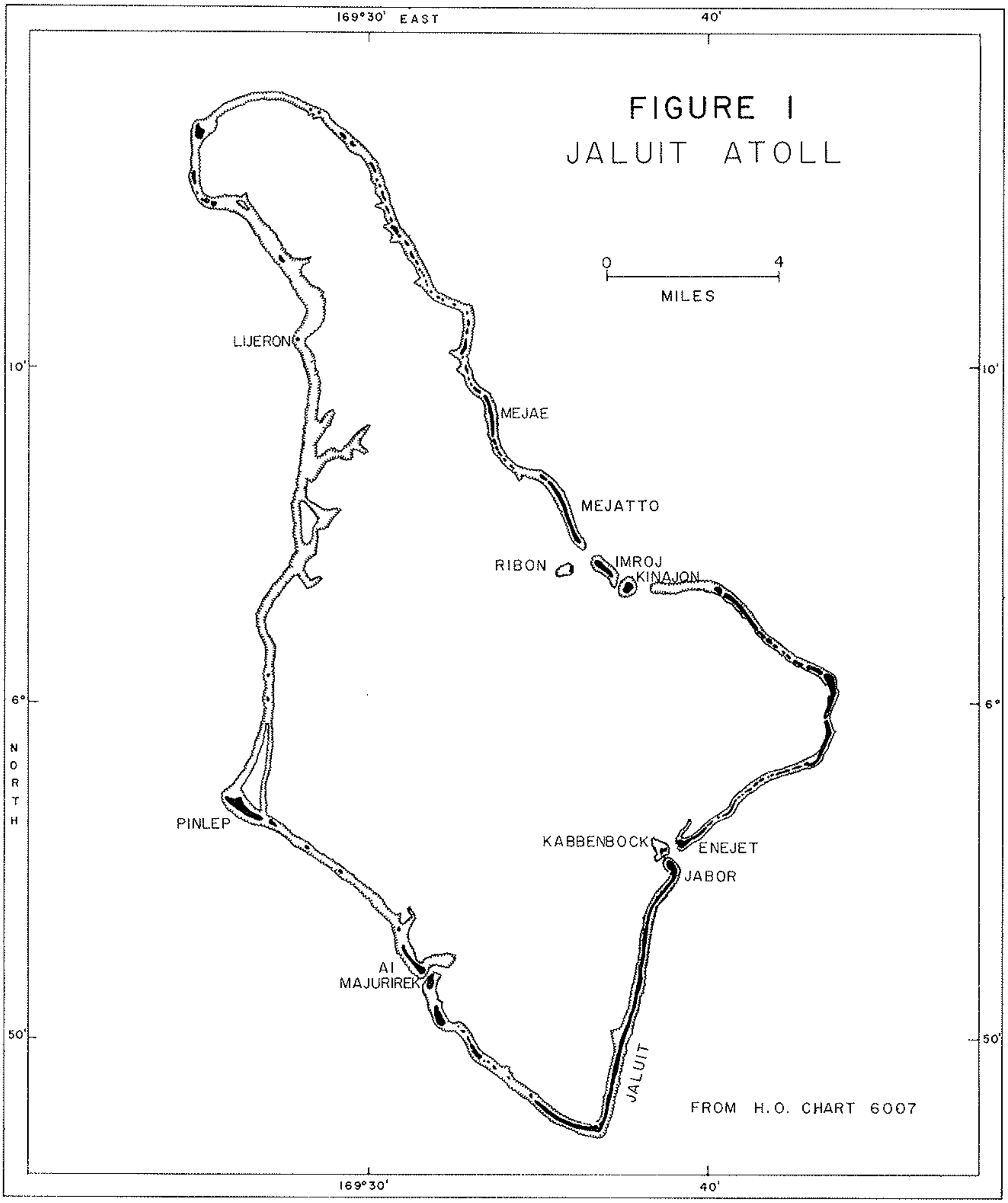

169°30' EAST
40'
FIGURE I
JALUIT ATOLL
0
4
MILES
LIJERON
10'
MEJAE
MEJATTO
RIBON
IMROJ
KINAJON
6°
NORTH
PINLEP
KABBENBOCK
ENEJET
JABOR
AI
MAJURIREK
50'
JALUIT
FROM H.O. CHART 6007
169°30'

A report on typhoon effects upon Jaluit Atoll

I. INTRODUCTION

David I. Blumenstock

On January 7, 1958, a typhoon passed directly over Jaluit Atoll in the Marshall Islands (5°51' N., 169°38' E.). First reports indicated that the effects of the storm had been severe. The storm destroyed several villages and killed fourteen Marshallese (two more died of exhaustion shortly afterwards). The storm also radically altered the morphology of several islets, destroyed many hundreds of trees, and scoured out soils or buried them beneath a rubble mantle.

These reports of widespread damage and alterations were verified by my visit to the Atoll two weeks after the storm. Though my visit lasted but a few hours I was able to view all the islets from the air and to talk with Mr. J. B. Mackenzie, then resident agriculturist on Jaluit for the Trust Territory of the Pacific Islands. The storm effects had been unusually severe. Thus a unique opportunity existed to study in the field the kinds of effects produced upon an atoll that had been subjected to a direct hit from an intense typhoon.

Accordingly, the Pacific Science Board of the National Academy of Sciences--National Research Council, jointly with the Office of Naval Research and the Trust Territory of the Pacific Islands, sponsored the formation of a party of seven scientists to conduct a brief, but intensive, field study of Jaluit. The U. S. Navy provided air transportation to Kwajalein and facilities there, as well as airlift to Jaluit. In addition to myself, the field party included Dr. A. H. Banner, director of the Marine Biological Laboratory, University of Hawaii; Dr. F. R. Fosberg, Pacific Vegetation Project, U. S. Geological Survey; Dr. J. Linsley Gressitt, chairman, Entomology Department, Bishop Museum; Dr. Edwin D. McKee, geologist, U. S. Geological Survey; Dr. Herold J. Wiens, professor of geography, Yale University; and Mr. J. B. Mackenzie, of the Trust Territory. This group studied conditions on several islets of Jaluit during the period April 24 to May 2, 1958.

The members of the survey group are indebted not only to the organizations listed above but to the U. S. Naval Air Station, Kwajalein for providing logistic support and transportation to and from Jaluit, and to the staff of the District Administration, Marshall Islands District, Trust Territory of the Pacific Islands, especially District Administrator Maynard Neas and Milton Sideris, agriculturist, for local arrangements, transportation, and help in the field. The staff of the Bernice P. Bishop Museum, Honolulu, was especially helpful in organizing the expedition to Jaluit and in preparing two parts of this report. Dr. Yoshio Kondo of the Bishop Museum kindly identified the Mollusca collected by Dr. Gressitt; and Mr. E. H. Bryan, Jr., of the Museum contributed most of the information presented in Table I of the Introduction.

[Note:--Jaluit was revisited by a second party, under the same sponsorship, Oct. 20-29, 1960, to study recovery from the typhoon damage, and a report of this restudy is anticipated--Ed.]

The findings of the field party are presented here, in the series of papers that comprise the principal sections of this report. Each paper was prepared by a single member of the field party, but views and information were exchanged freely among the party members and each benefited through discussions with the others.

As the editor of this entire report, I have taken the liberty of standardizing the usage of place names and of terminology. I have also inserted footnotes to refer the reader to relevant information in whatever paper it appears and to point up differences in interpretation among various members of the party. Footnotes for which I am responsible are followed by my initials (D.I.B.). Otherwise, except for occasional minor changes that it seemed to me would clarify the presentation, I have made no changes in the texts of the individual authors.

The reader may wish to refer to two papers already published on the Jaluit field study. One is my very general paper (Blumenstock 1958). This paper presents very briefly a few of the principal findings of the members of the field party. It is far less detailed than are the papers presented here and it adds nothing to them. It may, however, serve as a general introduction to these papers. The other is a paper by Edwin D. McKee (1959), which supplements and elaborates upon some of the results that he presents here. Those especially interested in the geologic effects of the storm should consult this paper.

Gross Geographic Features of Jaluit Atoll. Jaluit is a large atoll in the southern Marshall Islands. Its gross form is evident from the map of the atoll, Fig. 1. The features of chief interest are the large lagoon (approximately 15 X 30 miles), the presence of islets on all sides of the lagoon, the existence of three major passes (Southwest, Southeast, Northeast), and the presence of long, narrow islets on the eastern reef. Compared with other atolls, Jaluit is classed as having a deep lagoon. Most of the lagoon away from the reef is at least 15 fathoms deep and much of it is 20 fathoms or more. The greatest sounded depth within the lagoon is 29 fathoms.* There are a few scattered patches forming barely submerged or barely emergent reefs. Most of these are in the southern half of the lagoon. The maximum elevation is less than 20 feet above mean high tide and probably does not exceed 15 feet. Further, most of the islets lie below 12 feet above mean high tide.** Many of these general features are evident from Fig. 1.

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* U. S. Navy Hydrographic Office, Chart 6007, 1st Ed. May, 1944, revised 8/17/59. Soundings are available chiefly in the Pass areas and in the SE part of the Lagoon. It is likely that there are some depths in excess of 29 fathoms in the unsounded areas.

** Elevation estimates are based on the U. S. Army Map Service series (1:25,000), which do not, however, carry contours below 20 feet; and upon my general impression from having been on several of the islets and having viewed all of them from the air. Possibly the highest elevations above mean high tide are 12-15 feet on the northern side of Majurirek and the north to northwest side of Pinlep.

Jaluit is a rainy atoll, and had dense lush vegetation and well developed soils in many areas. The annual rainfall averages between 170 and 190 inches. The rainiest period is from May through November, when rainfall of 18 or more inches in a single month is common. During this period showers are frequent and the winds are often light and variable. The drier season extends from December through April. In the center of this period, from January through March, the tradewinds are especially strong and constant. Concurrently, monthly rainfall totals are often below 8 inches.

In a standard shelter at a 5 to $5\frac{1}{2}$ foot height, the temperature range at Jaluit is estimated as being from an absolute minimum of 68 or 69°F to an absolute maximum of 93 or 94°F. More commonly, the daily range is from the middle seventies to the high eighties. Temperatures tend to run 3 to 5° less during the dry tradewind season than during the rainy season. In the tradewind season maximum daily temperatures may be as low as 82 or 83°F and minimum temperatures, typically during nocturnal showers, may be as low as 70°F or even slightly lower.

Though moderate tropical storms pass near Jaluit every few years, the close passage of full-fledged typhoons is a rare event. Following the technical definition of a typhoon (or hurricane), which requires that it contain winds with sustained speeds of over 73 m.p.h. (63.4 knots), the passage of a typhoon center within a distance of 50 miles of any part of Jaluit Atoll probably does not occur more often than once in 20 years on the average. Further, these are typically small intense storms, with winds of typhoon speed extending outward no more than 25 or 30 miles from the center. The passage of a typhoon directly over Jaluit or within a very few miles of it is correspondingly an even more rare event. Such a very close passage probably occurs not more often than an average of once in 50 years.

The typhoon that hit Jaluit on January 7, 1958, was named OPHELIA. Prior thereto, in November 1957, two storms passed sufficiently close to Jaluit to produce some minor damage, chiefly on Jabor. These were the storms that later grew to typhoon intensity and became typhoons LOLA and MAMIE (Fleet Weather Central 1957). Thus the 1957-58 season appears to have been one that favored a high frequency of intense storms in the Marshall Islands, a fact associated with a major dislocation in the usual atmospheric circulation system throughout the entire tropical North Pacific (Blumenstock 1957). Prior to OPHELIA the last storm of typhoon intensity to pass very close to Jaluit was that of 1905 (Jeschke 1905-06). The older Marshallese on Jaluit recall this storm and state that its effects were much like those of OPHELIA

General History, Typhoon OPHELIA. OPHELIA was first detected as a disturbance near Palmyra (5° 23' N., 162° 5' W.), where it produced winds of 30 m.p.h. and heavy rainfall. It approached Jaluit from a general easterly direction, evidently moved directly across Jaluit, and then moved WNW through the Marshall and Caroline Islands and into the Philippine Sea, where it died out (Fleet Weather Central 1958). Among the other islands seriously affected by OPHELIA were Ponape, Truk, and the Hall Islands, all in the Carolines.

The typhoon intensity of OPHELIA was not known until it struck Jaluit and the word was relayed to Majuro by radio. Thus the storm appears to have deepened (intensified) rapidly between Palmyra and Jaluit.

Orthography. The names of the islets of Jaluit are spelled in many different ways. The spellings used in this report are shown in Table I, together with other spellings commonly used. Attention is called especially to the point that Jabor is used for the northern end of Jaluit Islet, as shown in Figure 1.

Organization of this report. The organization of this report is given in the Table of Contents. Attention is especially invited to the two Appendices, and to the Glossary, which defines certain terms used here about which there may be some difference of opinion. No concluding summary section is presented because it is felt that such can best be prepared after a re-survey of the Atoll to determine what the long-lasting effects of the typhoon have been.

TABLE I.

Place name spellings for some of the islets of Jaluit

Spellings used here[1]	Spellings on H. O. charts	Transliterated Japanese spellings
Ae	Ai	Ai
Enejet	Enybor	Eniboru
Imroj	Imrodj	Imuroji
Jabor[2]	Jabor	Jaboru
Jaluit[2]	Jaluit	Yaruto
Kinajon	Kinadyeng	Kinazen
Lijeron[3]	Lijeron	Rijieron
Majurirek	Elizabeth	Mejiruriku
Mejae	Medyai	Mejai
Mejatto	Medyado	Mejaddo
Pinlep	Pinglap	Pingurupu
Ribon	Ribon	

[1]Except where otherwise noted these follow the Marshallese and are based on the manuscript list compiled by E. H. Bryan, Jr.

[2]Used instead of Bryan's spellings because frequent, current usage makes it desirable to deviate here.

[3]This is Naen, according to Bryan's list; but according to J. B. Mackenzie and to local Marshallese informants, Naen is the adjacent islet and Lijeron is the correct name.

II. WIND, WAVE, AND STORM CONDITIONS AT JALUIT

JANUARY 7-8, 1958

David I. Blumenstock

The central physical events that led to the remarkable geomorphic, vegetative, and other changes on the islets and submerged reefs of Jaluit Atoll were the extreme wind and wave conditions that accompanied the storm. For this reason as well as from the viewpoint of intrinsic interest it is pertinent to reconstruct as accurately as possible the sequence of wind and wave conditions on January 7-8. In so doing, it is necessary to evolve a reconstruction that yields a coherent physical description of the storm itself: of its shape, size, intensity, and movement.

There are four major lines of evidence as to wind and wave conditions during the storm. These are the general (basic) tide conditions as given by standard tide tables, the accounts of natives, the vegetative evidence (especially direction of tree fall), and the geomorphic evidence. There are other, lesser, lines of evidence, as, for example, the destruction of a steel tower and the movement of a large storage tank. Each of these lines of evidence will be considered in turn, with a factual presentation of the observations together with my own comments as to their significance and accuracy. Thereafter I will present a summary of what I consider to be the significant, concordant evidence, at the same time making clear why certain evidence has been discarded or adjusted. Finally, I will estimate what the succession of wave and wind events were as related to the nature and movement of the storm that was the generating agent.

Basic tide conditions

Figure 2 shows the mean tidal height at Jaluit Atoll from 0500 to 2400, 180th meridian time, January 7, 1958.* The significant feature of this curve is the range of 6 feet, which is a very large range compared with the average, for this was a spring tide day. The upper portion of Fig. 2, which refers to wave conditions upon different islets, is discussed below.

---

* Time and height of the two pairs of high and low tide points are taken from U. S. Coast and Geodetic Survey 1957. Intermediate (hourly) values have been obtained through applying the short form for interpolation given in this reference.

Accounts of natives

Accounts of the sequence of events during the storm were given to me by the Head Chief of Majurirek Village, by Mr. Katje, a Marshallese employee of the Trust Territory, and by Mr. Morris, the Head Chief of Imroj Village and the Head of the Chiefs' Council for the Atoll of Jaluit. The account by the chief of Majurirek Village, was given through an interpreter. In contrast, Katje and Morris gave their accounts in quite good English, though two or three times Morris switched to Marshallese, which was then translated by Katje. In each instance the informant was asked to describe in his own words what took place and in what order, especially with reference to wind, wave, rain, and falling trees. Only after he had completed his narrative was the speaker questioned regarding specific points. The accounts of each of these three are given below, with a distinction being made between information that was volunteered and that which was given in answer to questions, since there might be a tendency for any one of them to answer a question in such a manner as to attempt to please the person asking it. All the accounts have to do with conditions on January 7th or in the early morning on the 8th. The accounts are from my abbreviated notes and are not intended to give the exact words or an exact translation of the words of the speaker. All times are local (approximately 180th meridian).

Account of Head Chief of Majurirek Islet,
with reference to conditions on Majurirek

Information volunteered: Around 8 in the morning the wind was from the north, not too strong. About 10 o'clock the wind started to blow "full", still from the north. Around 2 o'clock in the afternoon the wind went to northwest and at the same time there was a little wave that came in from the east and onto the islet (on the lagoon side). By late afternoon, around 4 o'clock, there were big waves from the east, and these went up the shore quite a way. Then for about four hours the wind was very full and it went from northwest to west to southwest and then to south. After this (about 10 p.m.) the wind died down.

Question: How far up the shore did the big wave come (from the lagoon in early afternoon)? Answer: About 10 to 15 feet up the shore. Question: When did the trees start falling down? Answer: From the time when the wind was full from the north through the time it was very full from the northwest and west. Question: Were there waves from the ocean? Answer: Yes, but only small ones. Question: Did it rain? Answer: Yes, there were heavy rains from around the middle afternoon until past midnight.

Account by Mr. Katje
with reference to conditions on North end of Jaluit Islet (Jabor)

Information volunteered: At about 9 o'clock the first big wave came from the east, and it went over the southern part of Jabor (the narrow part). The wind then was from the north. The second big wave came across from the east around noon. Still the wind was from the north. About 3 p.m.

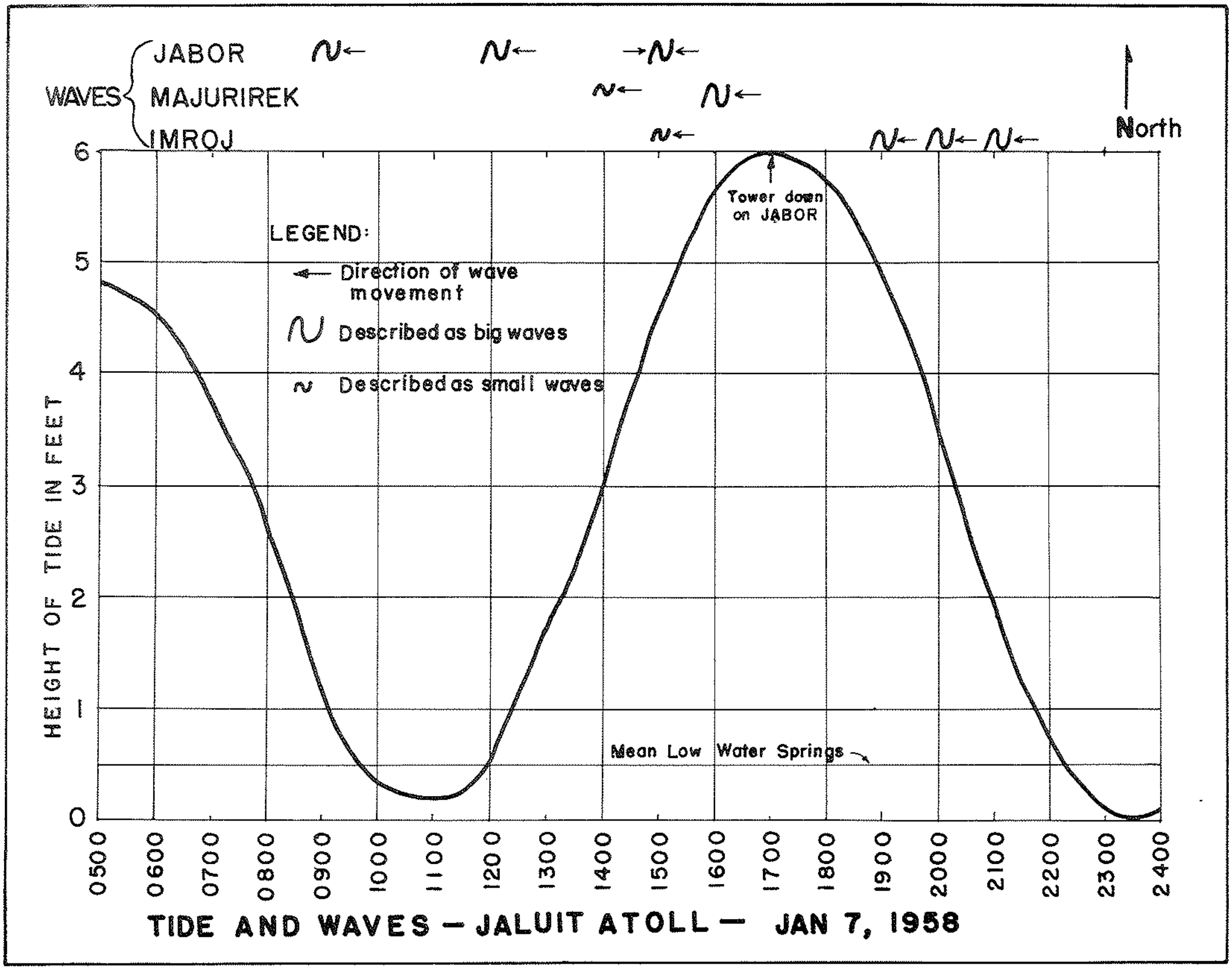
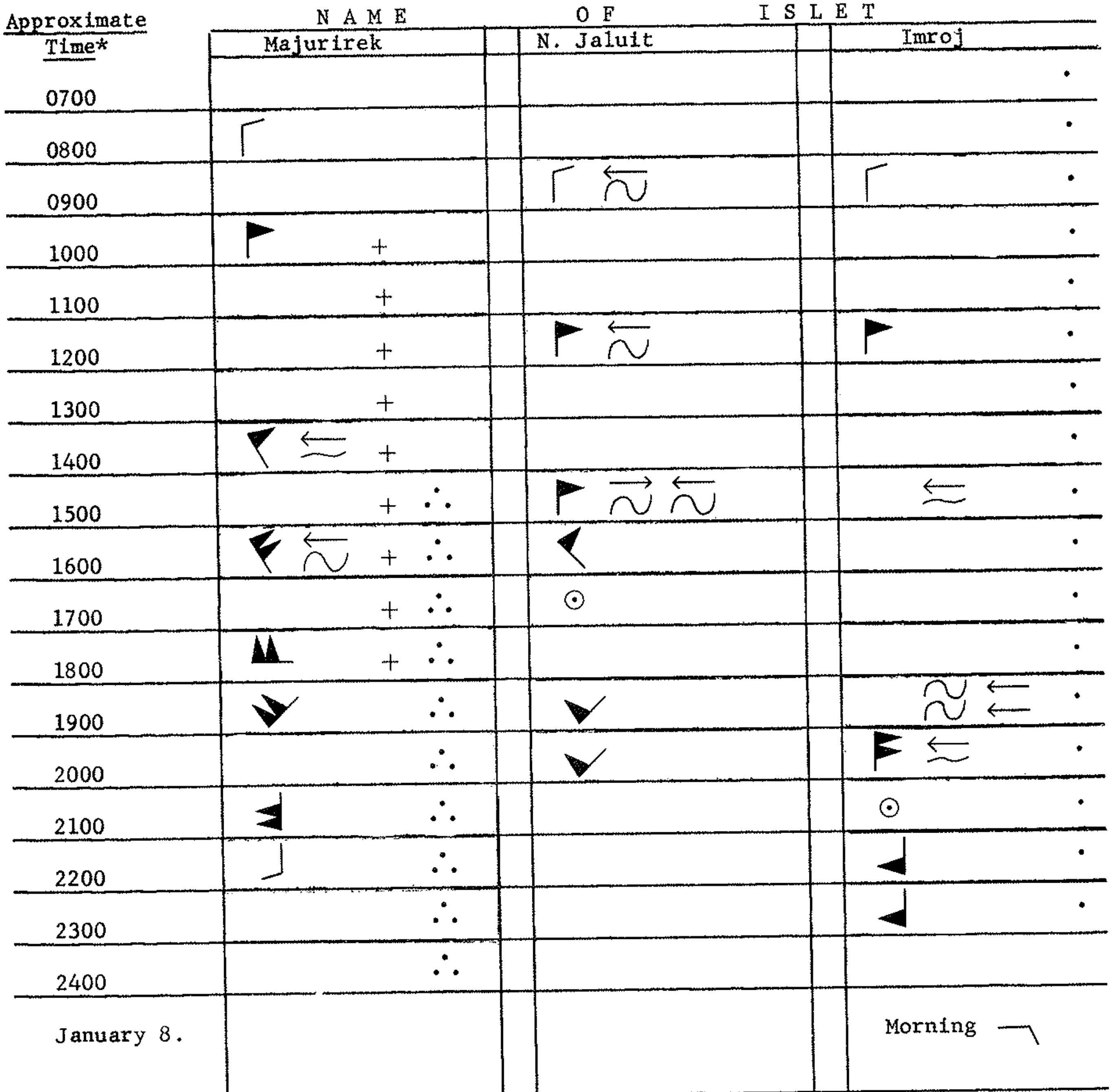

WAVES
JABOR
MAJURIREK
IMROJ
North
LEGEND:
Direction of wave movement
Described as big waves
Described as small waves
Tower down on JABOR
Mean Low Water Springs
HEIGHT OF TIDE IN FEET
0
1
2
3
4
5
6
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
TIDE AND WAVES — JALUIT ATOLL — JAN 7, 1958

FIGURE 2

TABLE II.

SUMMARY OF EVIDENCE BY INFORMANTS



*180th meridian time

NOTE: Light to moderate wind. Very strong or full wind. Strongest wind
Arrows fly with the wind. North considered to be at top of page.
E.g. =S. wind
Small waves. Large waves. Arrows above wave symbols show direction from which the wave came.
Light rain. Heavy rain. Trees falling or being snapped.
Calm or very light wind.

big waves came both from the east (ocean) and the west (lagoon) and they came together and made a big jumble of water. The wind was still from the north. Then after a while it was all finished.

Question: When were the winds the strongest? Answer: From noon on. Question: What happened to the wind direction from middle afternoon on, did it change? Answer: In later afternoon it went from north to northwest, then to west. At nighttime it was southwest. By the next morning it was east. Question: Did the wind stop blowing at all? Answer: Yes, it stopped for a little while just before nighttime.

Account by Mr. Morris
with reference to conditions on Imroj

Information volunteered: Rain began around 7 in the morning. Wind began around 9 in the morning. Full wind started blowing around noon. There were some waves from the east around 3 p.m. The first really big wave came around 7 p.m. The second big one about 20 minutes later. There were six big waves all together, all from the ocean. After the waves there was one more very strong wind at about 8 p.m. About 9 o'clock the wind died down.

Question: The big waves -- the six big waves -- from the ocean, about how much time was there between them? Answer: Always about 20 minutes between them. Question: The wind that began in the morning and then became full about noon, what direction was it from? Answer: North. Question: The last big strong wind, around 8 to 9 o'clock at night, what direction was it from? Answer: North. Question: What happened to the wind after it died down? Answer: There was no wind from about 9 to 9:30, then the wind started from the south and it blew from the south until very late. Question: About how late would you say? Answer: At least 11 o'clock; but by morning the wind was from the east. Question: Were there any waves from the lagoon? Answer: Just small waves. Question: When, would you say? Answer: After nighttime, after the big ocean waves. Question: Was there any rain during the storm? Answer: Yes, light rain all the time. Question: Could this have been ocean spray? Answer: Yes, or ocean spray. Question: Did anyone think a storm was coming before the waves came? Answer: Yes, the old men thought so. Question: I know you were on Imroj, not Mejatto, but could you tell whether water came across Mejatto? Answer: The water did not come across Mejatto.

In Table II, I have summarized the information provided by the three accounts given above. I have summarized it as given, even though I am aware that it is not necessarily to be taken literally. For example, the time references can scarcely be accurate even within a half hour, for these men were busy saving themselves and their families and even those that wore watches certainly did not bother to look at them at least while the storm was at its worst. Note, also, for example, the inconsistency in Morris' account: He says there were six waves at 20-minute intervals, all between 7 and 8 p.m. I will refer to Table II later on and will then attempt to justify correcting it to accord with other evidence.

Vegetational evidence

Some evidence as to the direction of first very strong winds is given by the direction of dominant treefall and breakage on the different islets. This information is summarized in schematic map form in Fig. 3. In this figure two directions are shown where treefall and breakage was commonly observed throughout a direction range of 30-60°. With the exception of two of the islets for which arrows are shown, there was good concordance of dominant direction of fall (within the range of the wind arrows). The exceptions were northernmost Jaluit (Jabor) where Fosberg observed treefall from all directions, even though falls from the east to northeast seemed most common (wind E to NE). Similarly, on Kinajon Fosberg reported a wide variety of directions, though again with some dominance (north to northwest winds). Fosberg and Wiens are agreed on the overwhelming dominance of north to south fall (north wind) on Lijeron and they and I are all agreed on the dominance of west to east fall (west wind) in central Jaluit Islet (beginning about 300 yards south of the southernmost Japanese block house at the southern edge of Jabor). As for the dominant direction on north central Mejatto (about 1000 yards from the northern tip), I made a methodical count of trees snapped off and, judging from the scars, found that 45 had snapped towards the southwest (NE wind), 2 toward the south (N wind), 2 toward the east (W wind), and one toward the northwest (SE wind).

From the uprooting and snapping off of trees, what conclusions can be reached regarding windspeeds? From discussions with Fosberg and judging from my own observations on Guam after that island was sideswiped by typhoon LOLA*, I believe the following estimates are warranted:

(1) On Mejatto, where palms and many other kinds of trees were snapped off, sustained windspeeds certainly exceeded 125 knots (from NE among other possible directions);

---

* LOLA passed south of Guam in November, 1957. Two or three weeks later I stopped on Guam and spent seven days in the field studying what the effects of the storm had been upon the land and upon the vegetation. Recorded windspeeds on Guam reached a maximum of 83 knots sustained speed and 103 knots for the peak gust, both on top of Mt. Alutom. Speeds in less exposed locations, as along the southern and eastern coasts, were around 50 to 70 knots sustained (over 60 at the Naval Air Station). It is reasonable to suppose that very locally, because of funneling effects and the like, speeds elsewhere reached 70 to 80 knots, sustained. Where breadfruit or pandanus stood in exposed locations, they were often down or snapped off a few feet below the crown. Yet I saw no palms either snapped off or down except in the coastal region from Inarajan to Merizo -- a region that had been inundated. *Casuarina*, like the palms, also stood well against the wind. Thus on the open beaches on the east coast of Guam, a few miles south of Ylig Bay, there were open stands of *Casuarina*, that had been well exposed to the winds, and among these many hundred trees I found only one that was down, and it stood east (oceanward) of the strand line where washing out of roots must have occurred just as it was observed to have occurred among neighboring trees that were still standing.

Figure 3

Dominant Directions of Tree Fall or Snapping

Directions are shown by wind arrows with reference to winds that would produce observed fall (assuming trees fall toward downwind direction). Wind arrows fly with the wind. Directions shown to eight points only. Where two arrows are shown dominant fall was from two directions as shown.

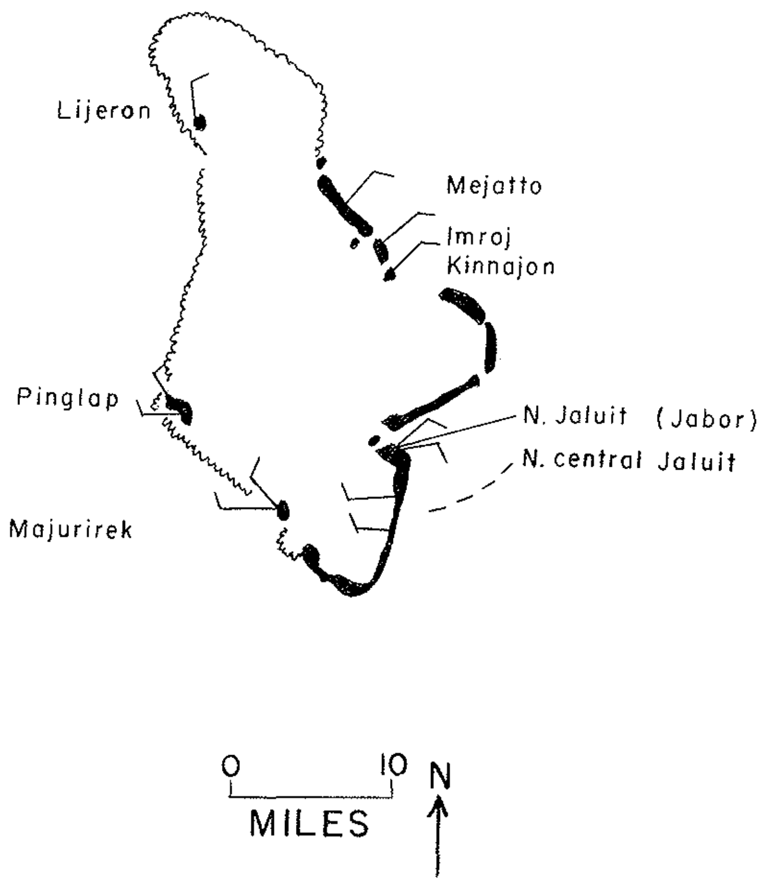


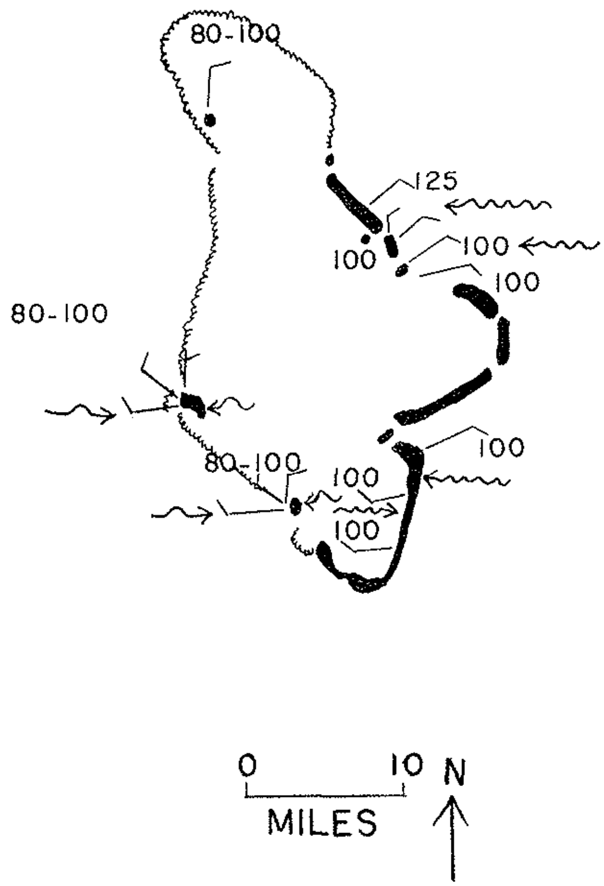
Figure 4

Minimum Speeds of First Strong Winds and Dominant Directions

Of Water Movement Across

Islets

(Deduced from vegetative and geomorphic evidence. Wind directions are to 8 points; windspeeds, in knots. Wind arrows fly with wind. Wavy arrows show direction of dominant water movement, with longer arrows representing major inundations and shorter arrows representing lesser inundations.)



(2) On Imroj and Kinajon the maximum windspeeds were perhaps slightly less (certainly, however, in excess of 100 knots). Here, as on the islets of Majurirek, Pinlep, and Lijeron, allowance must be made for the extent of tree stands -- the massing of trees on relatively wide islets. The same massing occurred at the northern and southern tips of Mejatto, where relatively few trees were snapped off or blown down compared to the 90% or more that were snapped or down throughout the central 2-2½ miles of Mejatto.

(3) The vegetative evidence shows that windspeeds on Jaluit Islet were also in excess of 100 knots (snapping from west to east south of Jabor, direction confused but generally east to west in northern Jabor). However, as Fosberg noted, beyond South Point there were far fewer trees snapped or uprooted than to the north of South Point.

(4) The evidence on Majurirek and Pinlep shows maximum sustained winds (from between north and west at time of fall or snapping) of at least 80 knots and probably at least 100.

(5) On Lijeron the maximum sustained winds were from the north at speeds comparable to those on Majurirek and Pinlep.

In general, no estimate of windspeed is warranted where trees were blown over during inundation. The above estimates are made on the basis of trees observed to be blown down where no inundation occurred or on the basis of trees snapped off.

Vegetational evidence also provides clues as to the dominant direction of water movement across various islets. On the lagoon side of Mejatto at several different points, some palms and other trees had been washed westward (or southwestward) and at the time of the survey were standing in water several fathoms deep. Clearly marked strand lines indicated inundation from east to west (or northeast to southwest) across the ocean beaches and almost to the center of Imroj. These same inundation directions held on Majurirek and Pinlep, but with the strand lines at lower levels, 4-7 feet above mean high tide (the spring tide would account for about 1 foot of this amount). On the other hand, strand lines indicated much lesser inundations from the ocean eastward (southeastward) onto Majurirek and Pinlep.

Finally, there was another curious line of evidence that is not conclusive but is suggestive. On central Mejatto, as Fosberg pointed out, the palm roots exposed by the erosion accompanying the inundation were, with two exceptions, combed in an east to west direction. This would appear to indicate that the water drained from east to west off this part of the islet. In contrast, in the gentle topographic trough just back (west) of the steep ocean beach on Mejatto, there were two roots (the only ones visible) that were combed south-to-north. This same trough contained large quantities of vegetable strand material, yet there was no source for such material on the beach to eastward. Two roots and some strand debris are not much evidence on which to hang an hypothesis, but I am inclined to guess that while the main body of water drained from east to west, some remained in the topographic trough and that thereafter this water was blown northward by a strong south wind, thus accounting for the perverse combing of the roots. As for the strand material, it may well have been brought in from the ocean during periods of strong tradewinds after the storm, having been derived initially during the storm not from Mejatto at all but from islets to the southeast -- to the east and south of Northeast Pass.

My interpretations of the vegetational evidence, discussed above, are summarized in schematic map form in Fig. 4.

Geomorphic evidence

On the several islets that were visited by the members of the field party, there is ample and usually quite consistent geomorphic evidence as to the direction of movement of water onto or across the land. To what extent the water came upon or across the land simply as huge, wind-driven waves and to what extent as a true surge -- a term that requires a local rise in sea level due to the friction of wind upon the water -- is another matter, and one on which the geomorphic evidence is not conclusive. Almost certainly both these factors were involved, at least on such eastern islets as Jaluit and Mejatto, which were under water to depths of at least one or two feet, as the following discussion makes clear.

The geomorphic evidence consists of depositional and erosional forms of the following kinds:

Depositional

Subaerial at least at low tide

1. Bars and ridges, emergent at least at low tide
   a. Upon reef flat, but separated from the land at mid-tide.
   b. Upon the reef flat, but tied to the land at mid-tide.
   c. New or augmented beach ridges upon the islets above high tide.
2. Patches or sheets of rubble
   a. Upon the reef flat, below water at mid- to high tide.
   b. Upon islets and emergent at high tide.
3. Irregular debris mounds upon islets, above high tide.
4. Pronounced strand lines upon islets, above high tide.

Submarine

1. Sediments, chiefly fine, deposited on floor of lagoon to west of several of the eastern islets.

2. Submerged portions of bar and ridge forms in lagoon to west of northern Jaluit Islet.

Erosional

Subaerial at least at low tide

1. Scour channels cut across islets (or for distances of many tens of yards across much of islet)

2. Scour pits and plunge holes, upon islets, roughly round to oval and without such channel features as marked elongation with undercutting for distances of at least tens of yards along sides to form distinct lateral boundaries

3. Breaks in older boulder ridges or in ridged beach rock

4. Beach scarp, cut in unconsolidated materials

5. Evidence of removal of fines in irregularly-shaped areas upon islets

Submarine

No evidence was seen directly of marked erosion below low water height, although at least one scour channel on Mejatto extended as a submarine feature for a distance of a few tens of yards into the lagoon. Presumably there was erosion of the reef front on the ocean side of the eastern islets, with rock fragments being torn from the reef or plucked from crevices on the reef front where they may have lodged after breaking off some time prior to the storm. However, the reef front on the ocean side was not examined.

These geomorphic features are described in future chapters. Here all that will be done is to mention these features, islet by islet, as they constitute evidence of water movement.

MEJATTO: Evidence: Gravel sheets thickest and most extensive on eastern (ocean) side of islet, thinning out and usually disappearing on western (lagoon) side; pot holes and scour pits excavated east to west as evidenced, for example, by their lying to the west of such obstructions as massive tree roots; fine sediments deposited chiefly along western side of islet and onto adjacent reef-flat and submarine slopes on lagoon side; most prominent scour channels begin on eastern side at break in old boulder ridge and extend westward. (Non-geomorphic evidence: Dead trees in lagoon with tendency to cluster near western end of scour channels.)

Conclusion: Dominant water movement was from east to west (ocean to lagoon) and water moved entirely across the islet except in the extreme north and south.

IMROJ: Evidence: Of the same kind as for Mejatto, but without the striking fine-sediment features on the west side and except that islet was not completely inundated.

Conclusion: Dominant water movement east to west.

NORTHERNMOST JALUIT

Evidence: Gravel ridge upon reef flat, ocean side, comprised largely of corals typical of reef front*; gravel sheet thinning out from east to west (toward lagoon); boulder about 4 X 4 X 6 feet lying 15 yards to west of ridged beach rock from which it was torn (and into which it could have been fitted); fine sediment deposits on western (lagoon) side; rubble from paved road carried east to west, into lagoon.

Conclusion: Dominant water movement east to west.

CENTRAL JALUIT (southern Jabor and southward extending a distance of about 1 mile south of old Sydneytown at the water tank).

Evidence: Gravel ridge upon reef flat on ocean side lower than farther north (0.5-4 yards high as contrasted with 3-8 yards farther north, except for one mound-like feature which was about 6 yards high, about 30 yards in diameter) and giving way to rubble patches in some places. Emergent ridge in lagoon, evidently composed of a high percentage of fine sediments as judged by view from shore; this ridge paralleled the shore at a distance of about 200 yards, and was barely emergent at high tide. Piece of glass found among debris that formed ridge on reef flat on ocean side. Rubble sheet more patchy than farther north and consists of only scattered coral-rock fragments in series of shallow channels that extend from near the ocean side (a few yards or tens of yards away) westward into the lagoon. Large water tank displaced from west to east a distance of about 200 yards (see p. 21).

Conclusion: Dominant water movement from west to east across islet.

PINLEP: Evidence: Small wave-cut scarp on western side of islet. Remnants of pronounced strand-line at about 5 feet above mean sea level on northern and eastern sides.

Conclusion: Dominant water movement probably alternately from east and from west.

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* See Banner's description, p. 76.

MAJURIREK: Evidence: Pronounced but small scarp, 3-4 feet above mean sea level, seemingly wave-cut, on western and southwestern side of islet. This scarp under-cuts some palms.

Conclusion: Dominant water movement, west to east. If there was water movement from east to west it was probably slight.

The conclusions stated above concerning dominant water movement onto or across the various islets are summarized in schematic map form in Fig. 4.

Other evidence regarding wind, wave, and storm conditions

Miscellaneous evidence is as follows:

(1) Mejatto-- All houses and other buildings were demolished, leaving not a trace that I could find. These were chiefly thatched native huts, though some were made from pieces of wood or lumber.

(2) Imroj-- Thatched huts were destroyed. Those made of boards were at least severely damaged, while some were totally demolished and others were partially demolished (roofs off, walls blown or washed in, etc.).*

(3) Central to northern Jabor-- Radio tower (steel tower) went down about 5:10 p.m., when radio went off the air (J. B. Mackenzie states this time is correct within a few minutes; he was on Majuro, where the broadcast was being received). All buildings demolished except for Japanese-built blockhouses, which were sunk 5-8 feet in the coral rock. Most buildings were completely swept away, leaving no trace, including the plywood buildings constructed only 12-18 months before by Holmes & Narver, American contractors. Some metal and wood remnants of buildings were found strewn about in an area to the east of the blockhouse building that was used as the headquarters for the Trust Territory government officials. One of the two water tanks was moved about 200 yards eastward from its concrete platform. An almost perfectly straight trench was scoured out to a depth of 3-4 feet, and this appears from old aerial photographs to have been a narrow water trench in Japanese times. (The trench runs almost due east from the lagoon to the ocean.) Scouring to a depth of 6-8 feet occurred at the NW corner of the southernmost blockhouse, leaving an irregularly shaped pit about 12 yards in diameter.

(4) Pinlep and Majurirek-- We were told that virtually all buildings had been blown down: that thatched huts were flattened by wind and that wooden shacks "flew apart". We observed some wood debris here and there but all buildings that I saw had been put together again, so this was not a direct observation.

---

* For a different estimate of degree of damage, see Wiens, p. 29.

(5) Path of storm-- According to J. B. Mackenzie, who surveyed the damage at Mili Atoll, OPHELIA caused the most wave and water damage on the north side of that atoll. Mili is at 6°10'N, 171°55'E. According to Fleet Weather Central (1958) OPHELIA was heading WNW when located to the west and slightly north of Jaluit, after passing over Jaluit.

Reconstruction of events as related to field evidence

It is impossible for me even to imagine a series of storm events that would follow in logical order according to what is known about typhoon structure and movement and that would satisfy all the evidence cited above. Virtually all the evidence would be satisfied by supposing that a small, intense typhoon with multiple centers passed over Jaluit on January 7-8, but this relatively easy solution of the problem does not seem warranted since I have found no known instance of multiple eyes in a typhoon a mere 50 to 70 miles across, which must have been the diameter (diameter of winds over 63 knots) of this one to satisfy even the preponderance of the evidence. What is most common is an eye, evidently often irregular in shape, and which changes its size and shape almost constantly. My reconstruction follows, placed side-by-side with the evidence both pro and con. The reconstruction is represented by the series of schematic maps in Fig. 5.

RECONSTRUCTION

1. On January 7, 1958 at 9 a.m. (180th meridian time) a small intense typhoon was approaching Jaluit, moving in a direction from 80° towards 260° at a speed of 5 to 7 knots. The storm was following a sinuous path and was later to curve first due westward, then west-northwestward as it crossed Jaluit. At the time the circulation about the storm was well defined with winds of 50 knots or more extending outward to a distance of 25-30 miles in the southwest quadrant, 30-40 miles in the NE quadrant, and 40-50 miles in the northwest quadrant. The northwest quadrant held the strongest winds, which were over 100 knots near the storm center, and the winds in this quadrant and around slightly into the west were strengthened well in advance of the storm by greatly intensified tradewinds that under the influence of the storm circulation had previously backed (shifted

EVIDENCE AND REMARKS

1. a. Supporting evidence: Winds were northerly at North Jaluit and Imroj at this time (Table II). There was light rain at Imroj, which is consistent, and that Katje failed to report rain at N. Jaluit is immaterial since he failed to report rain at any time -- and no rain at any time is a virtual impossibility. Katje stated large waves from the east were pounding the Jaluit reef. I accept this and point out that it was almost low-low tide so that this would help loosen debris along the reef front. Quite likely some of this coral debris was being already thrown up on the reef to form the debris bar that later was so evident on the ocean side of N. Jaluit. There is no evidence that winds were yet strong enough to topple trees or snap them. The winds were still probably moderate as reported by Morris and Katje, and I accept this as partial evidence, consistent with later evidence, that the center of the storm was still far distant, about 45 nautical miles away. The estimated speed of 5-7 knots brings the storm center in at about 4-5 p.m., and this later

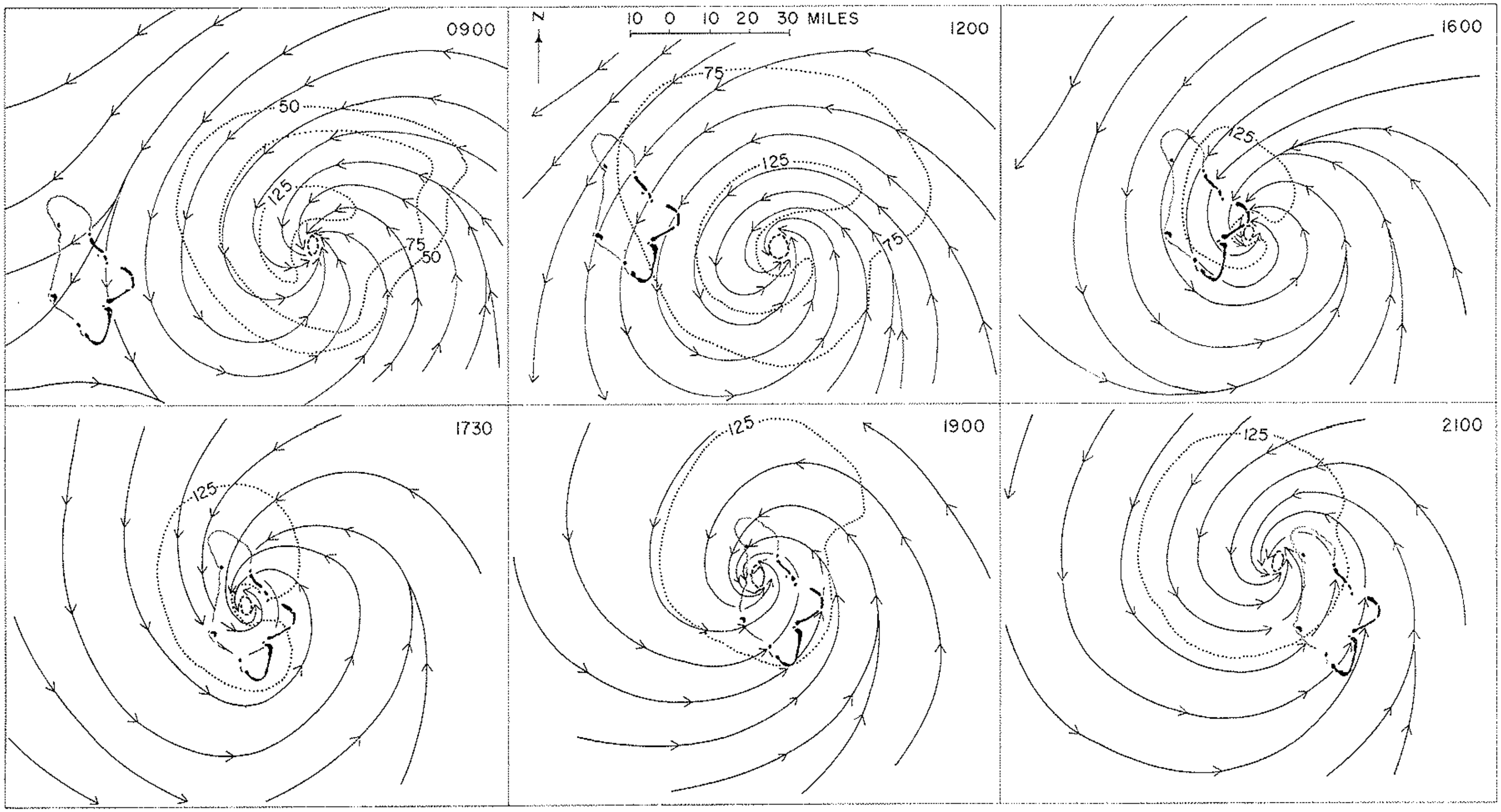


FIGURE 5 Schematic Streamline Charts Typhoon OPHELIA

JALUIT AREA JAN. 7, 1958 — Legend: Windflow Isotach (knots) Center winds <10 knots

RECONSTRUCTION (CTD.)

counterclockwise) to around 10-20°. The storm center was ill-defined, but generally elongated and was oriented with the major axis normal to the direction of storm movement. The storm center was about 7 hours -- roughly 45 nautical miles -- away from the eastern islets of Jaluit. As the storm approached it was itensifying (see Fig. 5).

EVIDENCE AND REMARKS (CTD.)

seems borne out (discussed below). The approach of the storm from about 80° is supported by the fact that it had passed north of Mili Atoll.

b. Negative evidence: Morris failed to comment on strong waves until about 3 p.m.). I discount his statement (a matter of what one calls strong waves) and point out further that it was raining (affecting visibility) and that waves coming dominantly from somewhat to the north of east may have piled more heavily onto North Jaluit than onto Imroj due to piling of water along ocean side of islets to the NE and "guiding" of waves of unusual size onto North Jaluit. Note also that Katje was on a very narrow islet as compared with Morris, so that Katje could readily see heavy surf with some waves topping onto land whereas Morris could not. The Majurirek chief reported strong north winds only an hour later (10 a.m.) with some trees down, but I must discount this and believe that the winds were merely fresh NNE with a few branches falling and that the extreme winds did not arrive on Majurirek until several hours later (between 3 and 4 p.m., when the chief began to report extremely high winds with heavy rain).

c. Remarks: For elongate centers perpendicular to storm path, note that this was characteristic of hurricane DOT in the vicinity of Kauai, Hawaii, in 1959 (as shown by aircraft reports and radar plots on file, mss. U. S. Weather Bureau, Honolulu); and for speed of movement, while 5-7 knots is somewhat slow it is certainly not unknown in this area (see data for LOLA, Fleet Weather Central 1957). As for small size and irregular shape of these storms (with ill-defined centers), as well as for their suddenness of appearance, see e.g., the information on the Hong Kong Typhoon of 1906 (Gibbs 1908).

RECONSTRUCTION (CTD.)

2. January 7. 12 (noon). The storm center was now about 30 nautical miles east of Southeast Pass and the storm was now approaching from about 100° (moving towards 280°) along the path shown in Fig. 5 and with winds as also shown in that figure. Waves were very strong from the east and against the reef on the ocean side of the islets from Northern Jaluit northward. It was just past low-low tide and debris had now been heaped high upon the ocean reef front in Northern Jaluit. There were N to NE winds at speeds in excess of 80 knots from Northern Jaluit northward (on eastern islets) and there was some toppling of trees that were poorly rooted or were awash near the eastern edges of the islets. There was snapping of branches on a wide scale, but no snapping of trunks of any but the very weakest trees. At Majurirek and Pinlep the winds were very fresh and northerly. With the ill-defined center, elongated now N-S, the windspeeds slacked off rapidly from N. Jaluit southward (Fig. 5). Occasional waves threw water across northernmost Jaluit, from east to west, but on Imroj (which is a higher islet) the waves only moved well up onto the eastern side. Nor had waves begun to sweep across Mejatto as yet, although there was heavy pounding of the boulder ridge along the eastern side of that islet. No waves of any magnitude were yet upon the western islets, though the very fresh northerly winds were piling some water into the southern part of the lagoon and producing some water up the beaches with superimposed small waves generated in the limited fetch area within

EVIDENCE AND REMARKS (CTD.)

2. a. Supporting evidence: The wind situation generally fits that given by the three informants, although winds were not directly from the north as reported. The wave (water) across North Jaluit was as reported by Katje. Dominant tree-fall and tree breakage directions support the view that not many trees were down or were snapped this early in the sequence. Before this happened the storm must tighten, change direction slightly, and come in so as to provide very high windspeeds from the northeast quadrant from N. Jaluit northward on the eastern islets.

b. Negative evidence: The Chief on Majurirek said trees were falling at this time. I believe he must have been off on his time or else that he was referring only to a very few trees (poorly rooted) going down or to breakage of branches, which would require only a wind of 50 knots or so. In this I am consistent in that field evidence shows the preponderance of trees going down before a wind from NW to W (falling SE to E) rather than from N or NE (Fig. 3).

c. Remarks: The elongate center with windspeeds decreasing very abruptly within a distance of a few hundred yards on N. Jaluit is necessary to account for the amazingly sharp transition from trees down from the NE to E (northernmost Jaluit) and from west to east (just south of northernmost Jaluit). This point is elaborated upon in the sequence that follows and in the corresponding evidence and remarks.

RECONSTRUCTION (CTD.)

the lagoon. Water was also running in through the eastern passes and the lagoon was perhaps 1-2 feet above normal level in the southern end; but still it was just above low-low tide so this did not represent an abnormal condition with reference to mean sea level.

3. January 7. 4 p.m. The storm center had become smaller and better defined and was now a few miles to the east of northernmost Jaluit (see Fig. 5 for location and for winds). The tide had been rising and was almost high-high. Water was crossing central and northern Jaluit from east to west, and was also crossing all but the extreme ends of Mejatto. Maximum winds were being or had been experienced during the past few hours from northernmost Jaluit northward (on eastern islets). Speeds exceeded 100 knots and trees were toppled. With extreme gust speeds exceeding 150 knots trees were snapped in this area, but there was a very sharp wind gradient and north central Jaluit had not yet received winds of these speeds. On Majurirek and Pinlep winds were from N to NW at speeds of close to 100 knots and trees began to fall where they were poorly rooted and much exposed (not shielded by massing) as along the upper beach on the north to northwest sides of these islets. The storm was now moving from about 70° and towards 250°.

4. January 7. 5 p.m. The chief significance of this time is that now the storm center had just passed into the lagoon and now also it was high-high tide. Within the past hour the waves crossing Mejatto and Jaluit had entered the lagoon and set up further waves that in combination with the basic tidal condition had

EVIDENCE AND REMARKS (CTD.)

3. a. Supporting evidence: Tree fall evidence fits this reconstruction with a single exception of E to W orientation of many of the fallen trees in northernmost Jaluit (see below). The general sequence of events as described by informants bears out the reconstruction here, but I have had to move up Morris' statements re Imroj (that is make them earlier by 3-5 hours than what he stated) and have had to move back (make later by 2 hours) the statements of the Majurirek chief.

b. Negative evidence: Some of this is covered immediately above, where a time adjustment is explained. The other principal negative item is that the sequence as given in this reconstruction does not explain the east-to-west orientation of many of the fallen trees on northernmost Jaluit (Jabor). Some may have been swung around by water moving W-E; but the broad northernmost part was not thoroughly inundated. A temporary second eye centered over northern Jaluit Islet would take care of things, but since I am rightly or wrongly eschewing multiple centers I did not draw my map to cover this (Fig.5).

4. a. Supporting evidence: The time adjustments referred to above still apply; otherwise the evidence from informants as well as the vegetational and geomorphic evidence support this phase of the reconstruction of storm events.

RECONSTRUCTION (CTD.)

caused flooding up-beach upon Majurirek, Pinlep, and other western islets. Trees fringing the beach had had their roots washed out and many had blown down before winds that were now backing to west at over 100 knots. By 5:30 p.m. or shortly after there were very strong NW to W winds across the southern part of the lagoon and this produced waves that now moved west to east from the lagoon onto Jaluit Islet. By 5:30 the strongest winds were past on the eastern islets north of northernmost Jaluit, but these strong westerly winds began to affect central Jaluit which was already wetted down; and between the flow of water (west to east) and the west winds, tree breakage and tree toppling now set in here. The radio tower had already gone down in northernmost Jaluit and about now (5:30) the water tank was floated eastward from its former location.

5. January 7. 7 p.m. (See Fig. 5). The storm was still intensifying and had accelerated slightly, to perhaps 5 knots. Furthermore, it had grown somewhat in size and the center was now better defined. It was centered over the northwest part of the lagoon. Winds were westerly on Majurirek and Pinlep, with speeds over 100 knots. Winds were southerly on the eastern islets, with speeds around 80-100 knots. The water had largely drained from Mejatto and from the very highest parts of Jaluit. It was raining very hard on the western islets, but there was only moderate rain on the eastern islets. Winds were now maximum and northerly on Lijeron, and trees were going down there. Some were snapping.

EVIDENCE AND REMARKS (CTD.)

5. a. Supporting evidence: With time adjustment already noted, this fits the evidence.

6. January 7. 8 p.m. About now the storm center cleared Jaluit Atoll, moving slightly north of west with the center passing a few miles to the south of Lijeron. This was an elongate center, oriented N-S (Fig. 5). Winds continued strong southerly over the northeast islets, were out of the SW and strong on the southeast islets, were very strong and out of the SW on the southwest islets, and were going to very strong northerly at Lijeron.

6. a. Supporting evidence: The evidence is all supporting (informants, vegetation, geomorphic) except that again a time adjustment is needed for Morris' account re Imroj. The south wind over Mejatto helps explain the orientation of combed roots, as suggested above (pp. 9-10). The Lijeron and Pinlep tree-fall evidence supports the view that the center must have moved westward out to sea between these islets, with a very elongate center to account for the lack of many east-west treefalls on Lijeron. Note that Lijeron and Pinlep were largely not under water, so water could not swing many fallen trees around here as it might have done on Jaluit or Mejatto.

7. January 7. 9-10 p.m. As the storm continued WNW away from the atoll the west to east wave within the lagoon carried some water against and slightly onto such northeast islets as Imroj and Mejatto.

8. January 7. 11 p.m.-midnight. Winds had slackened and now were generally southerly to southwesterly across the atoll. Unusual wave activity had ceased save for swells that arrived on the western islets from the WNW and that appeared as unusual surf on the west to northwest sides of Majurirek, Pinlep, and other western islets but that had little geomorphic effect because it was now at or very close to low-low tide.

9. January 8. Midnight-7 a.m. Winds lightened continuously during this period and winds continued to back with fresh trades reestablished by morning. These trades washed ashore onto Mejatto and other islets vegetable debris that was carried out to sea on the eastern side of the atoll, chiefly material blown northeast to north from more southerly islets such as Kinajon.

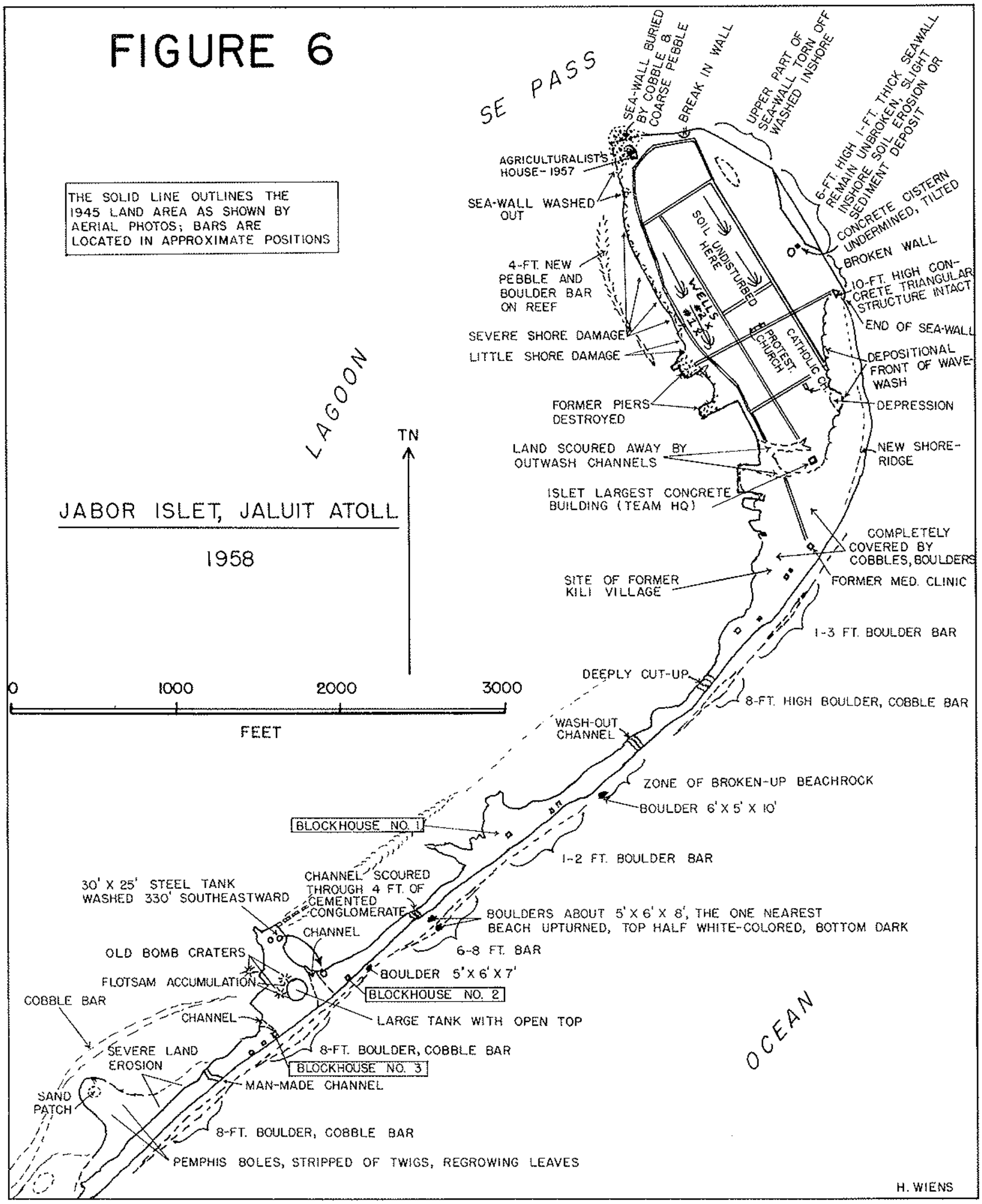
7-9. Remarks: These sequences are consistent with the evidence as shown in Table II, in Figures 2, 3, and 4, and in the text on geomorphic evidence (pp. 10-13). The sequences also fit the fact that the storm was located to the west and slightly to the north of Jaluit on January 8 (see Fleet Weather Central 1958).

RECONSTRUCTION (CTD.)

EVIDENCE AND REMARKS (CTD.)

The near high-high tide during this period promoted this wash-in of debris and helped form the pronounced debris line later observed. There was also some wash-up of debris onto the west to northwest side of the western islets during this same period because of the arrival of swell from the storm whose center was now (7 a.m.) 55-60 nautical miles away to the WNW.

FIGURE 6


THE SOLID LINE OUTLINES THE 1945 LAND AREA AS SHOWN BY AERIAL PHOTOS; BARS ARE LOCATED IN APPROXIMATE POSITIONS
JABOR ISLET, JALUIT ATOLL
1958
TN
0
1000
2000
3000
FEET
SE PASS
LAGOON
OCEAN
SEA-WALL BURIED BY COBBLE & COARSE PEBBLE
BREAK IN WALL
UPPER PART OF SEA-WALL TORN OFF WASHED INSHORE
6-FT. HIGH 1-FT. THICK SEAWALL REMAIN UNBROKEN, SLIGHT INSHORE SOIL EROSION OR SEDIMENT DEPOSIT
CONCRETE CISTERN UNDERMINED, TILTED
BROKEN WALL
10-FT. HIGH CONCRETE TRIANGULAR STRUCTURE INTACT
END OF SEA-WALL
DEPOSITIONAL FRONT OF WAVE-WASH
DEPRESSION
NEW SHORE-RIDGE
AGRICULTURALIST'S HOUSE-1957
SEA-WALL WASHED OUT
4-FT. NEW PEBBLE AND BOULDER BAR ON REEF
SEVERE SHORE DAMAGE
LITTLE SHORE DAMAGE
FORMER PIERS DESTROYED
SOIL UNDISTURBED HERE
WELLS
PROTEST. CHURCH
CATHOLIC CH.
LAND SCOURED AWAY BY OUTWASH CHANNELS
ISLET LARGEST CONCRETE BUILDING (TEAM HQ)
COMPLETELY COVERED BY COBBLES, BOULDERS
FORMER MED. CLINIC
SITE OF FORMER KILI VILLAGE
1-3 FT. BOULDER BAR
DEEPLY CUT-UP
8-FT. HIGH BOULDER, COBBLE BAR
WASH-OUT CHANNEL
ZONE OF BROKEN-UP BEACHROCK
BOULDER 6' X 5' X 10'
BLOCKHOUSE NO. 1
1-2 FT. BOULDER BAR
30' X 25' STEEL TANK WASHED 330' SOUTHEASTWARD
CHANNEL SCOURED THROUGH 4 FT. OF CEMENTED CONGLOMERATE
BOULDERS ABOUT 5' X 6' X 8', THE ONE NEAREST BEACH UPTURNED, TOP HALF WHITE-COLORED, BOTTOM DARK
CHANNEL
6-8 FT. BAR
OLD BOMB CRATERS
BOULDER 5' X 6' X 7'
FLOTSAM ACCUMULATION
BLOCKHOUSE NO. 2
COBBLE BAR
CHANNEL
LARGE TANK WITH OPEN TOP
SEVERE LAND EROSION
8-FT. BOULDER, COBBLE BAR
BLOCKHOUSE NO. 3
SAND PATCH
MAN-MADE CHANNEL
8-FT. BOULDER, COBBLE BAR
PEMPHIS BOLES, STRIPPED OF TWIGS, REGROWING LEAVES
H. WIENS

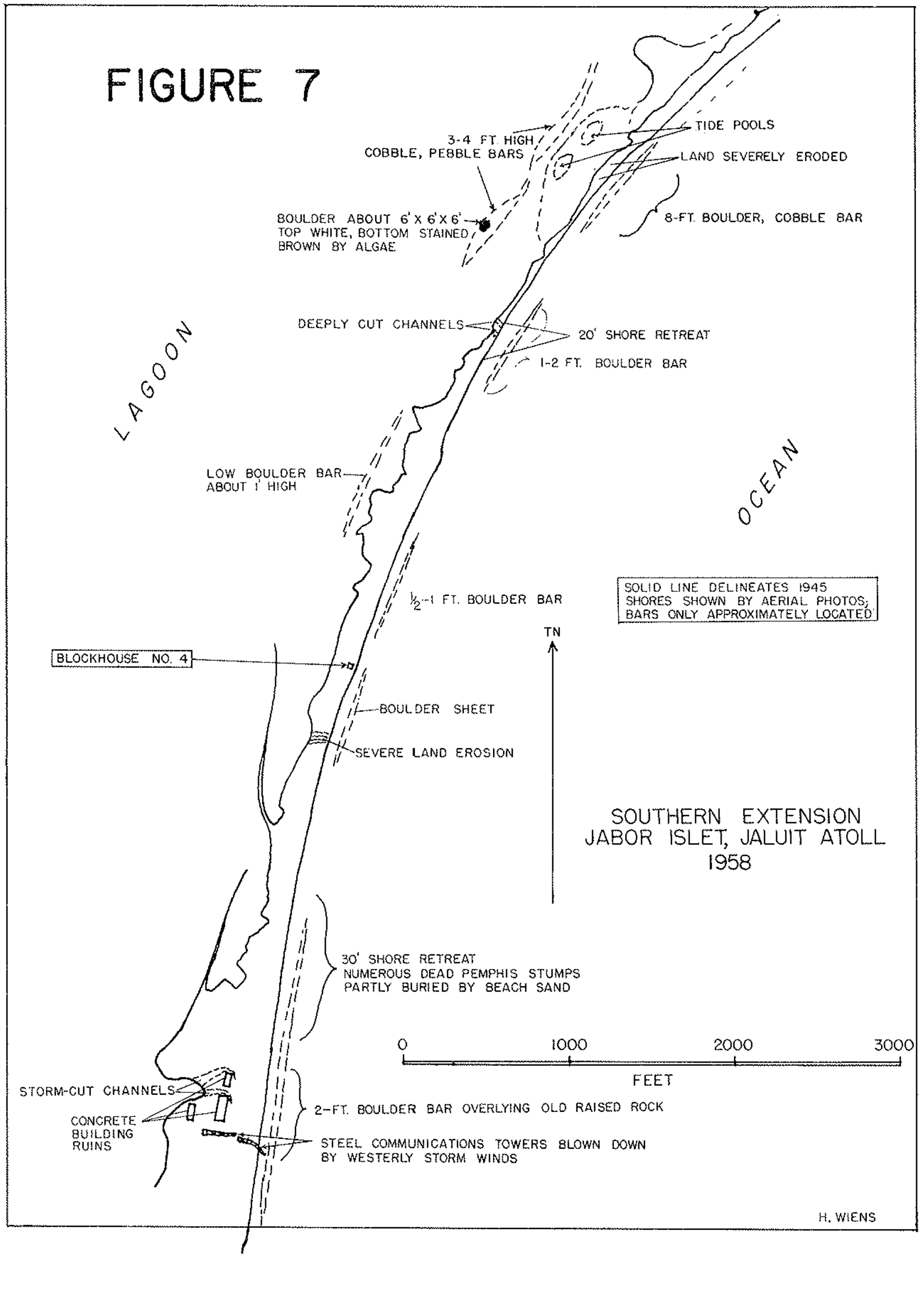
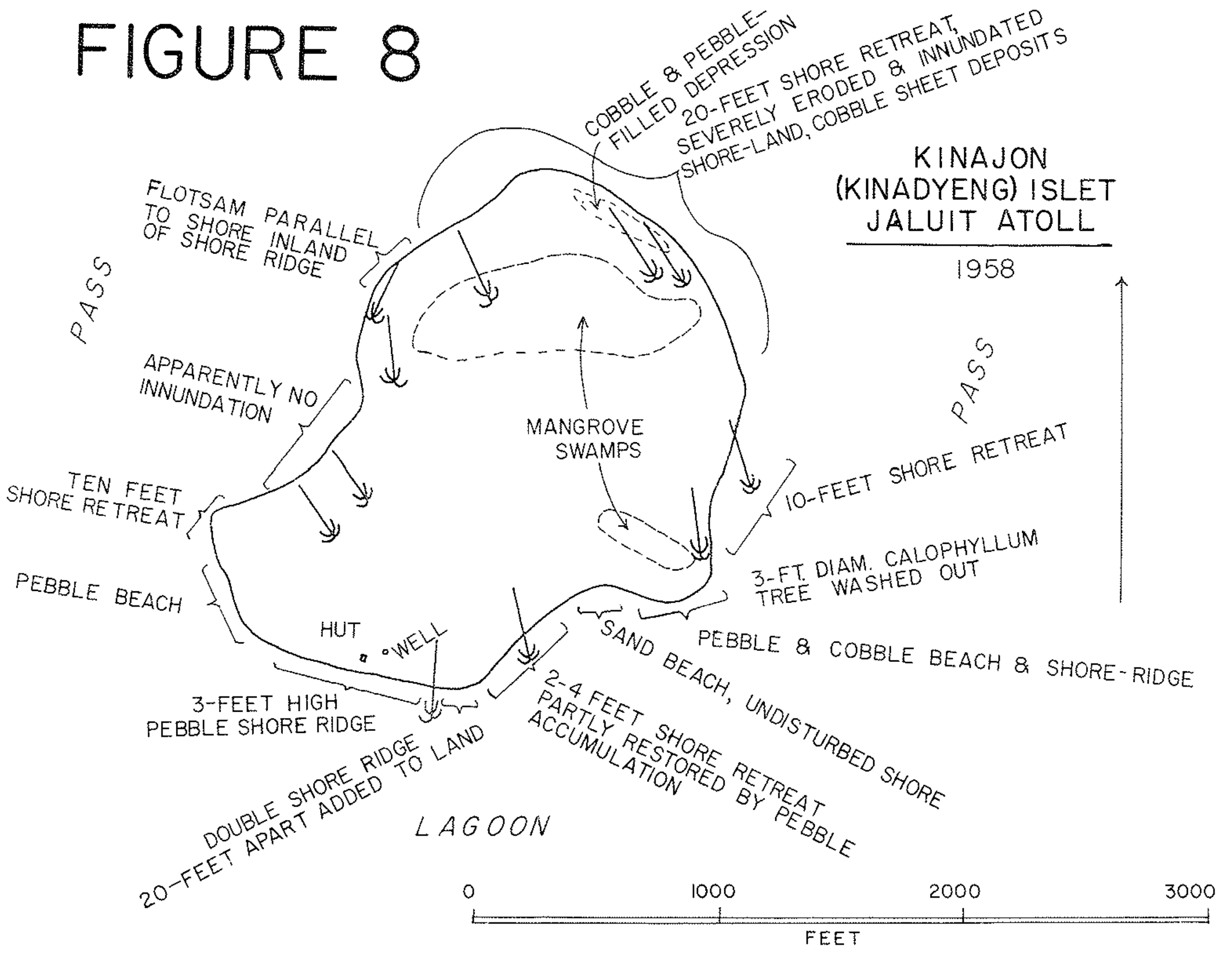


FIGURE 7
3-4 FT. HIGH
COBBLE, PEBBLE BARS
TIDE POOLS
LAND SEVERELY ERODED
BOULDER ABOUT 6' X 6' X 6'
TOP WHITE, BOTTOM STAINED
BROWN BY ALGAE
8-FT. BOULDER, COBBLE BAR
DEEPLY CUT CHANNELS
20' SHORE RETREAT
1-2 FT. BOULDER BAR
LAGOON
OCEAN
LOW BOULDER BAR
ABOUT 1' HIGH
½-1 FT. BOULDER BAR
SOLID LINE DELINEATES 1945
SHORES SHOWN BY AERIAL PHOTOS;
BARS ONLY APPROXIMATELY LOCATED
TN
BLOCKHOUSE NO. 4
BOULDER SHEET
SEVERE LAND EROSION
SOUTHERN EXTENSION
JABOR ISLET, JALUIT ATOLL
1958
30' SHORE RETREAT
NUMEROUS DEAD PEMPHIS STUMPS
PARTLY BURIED BY BEACH SAND
0
1000
2000
3000
FEET
STORM-CUT CHANNELS
CONCRETE
BUILDING
RUINS
2-FT. BOULDER BAR OVERLYING OLD RAISED ROCK
STEEL COMMUNICATIONS TOWERS BLOWN DOWN
BY WESTERLY STORM WINDS
H. WIENS

FIGURE 8


KINAJON
(KINADYENG) ISLET
JALUIT ATOLL
1958
COBBLE & PEBBLE-
FILLED DEPRESSION
20-FEET SHORE RETREAT,
SEVERELY ERODED & INNUNDATED
SHORE-LAND, COBBLE SHEET DEPOSITS
FLOTSAM PARALLEL
TO SHORE INLAND
OF SHORE RIDGE
PASS
APPARENTLY NO
INNUNDATION
MANGROVE
SWAMPS
PASS
TEN FEET
SHORE RETREAT
10-FEET SHORE RETREAT
3-FT. DIAM. CALOPHYLLUM
TREE WASHED OUT
PEBBLE BEACH
HUT
WELL
PEBBLE & COBBLE BEACH & SHORE-RIDGE
SAND BEACH, UNDISTURBED SHORE
3-FEET HIGH
PEBBLE SHORE RIDGE
2-4 FEET SHORE RETREAT
PARTLY RESTORED BY PEBBLE
ACCUMULATION
DOUBLE SHORE RIDGE
20-FEET APART ADDED TO LAND
LAGOON
0
1000
2000
3000
FEET

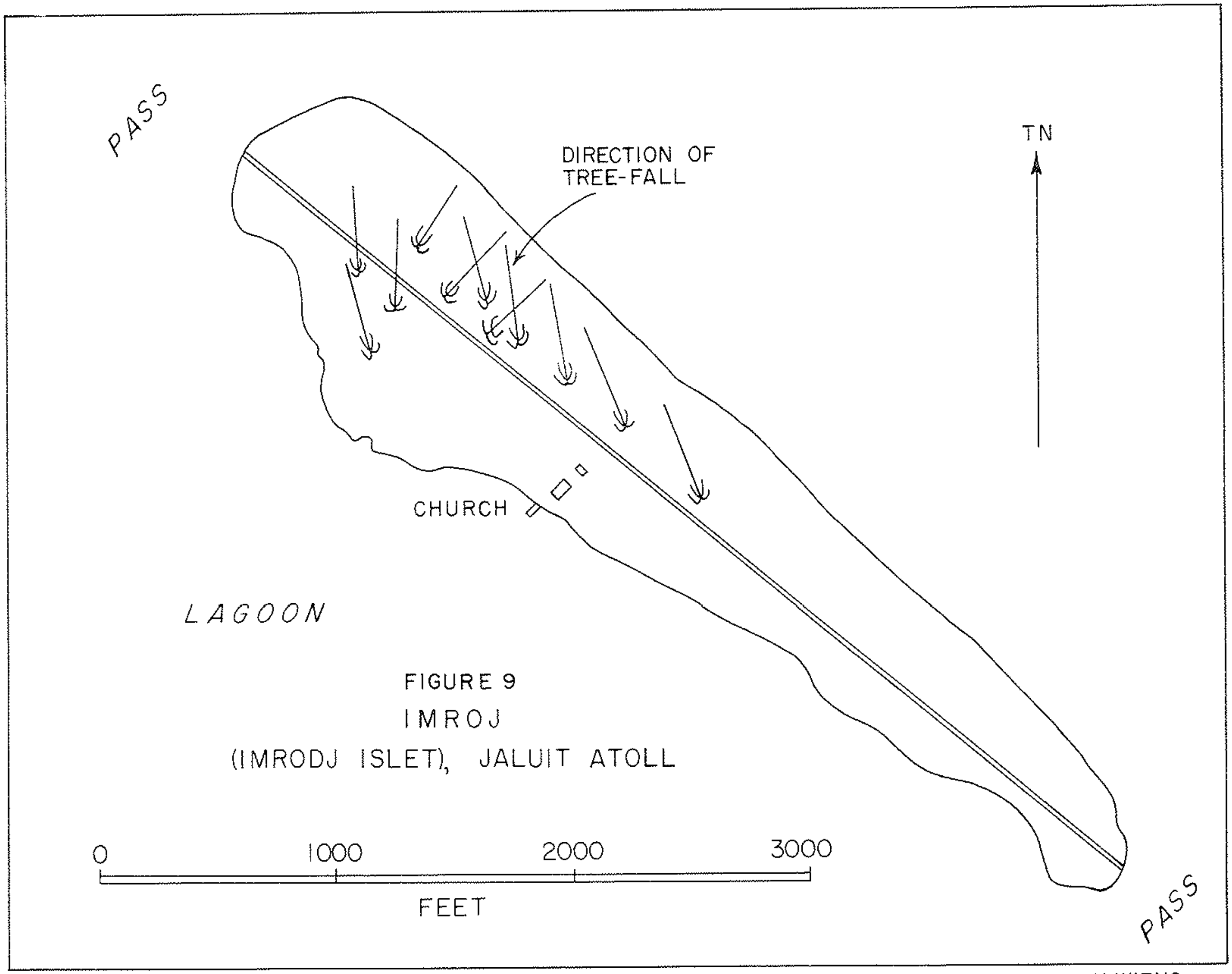


FIGURE 9
IMROJ
(IMRODJ ISLET), JALUIT ATOLL

H. WIENS

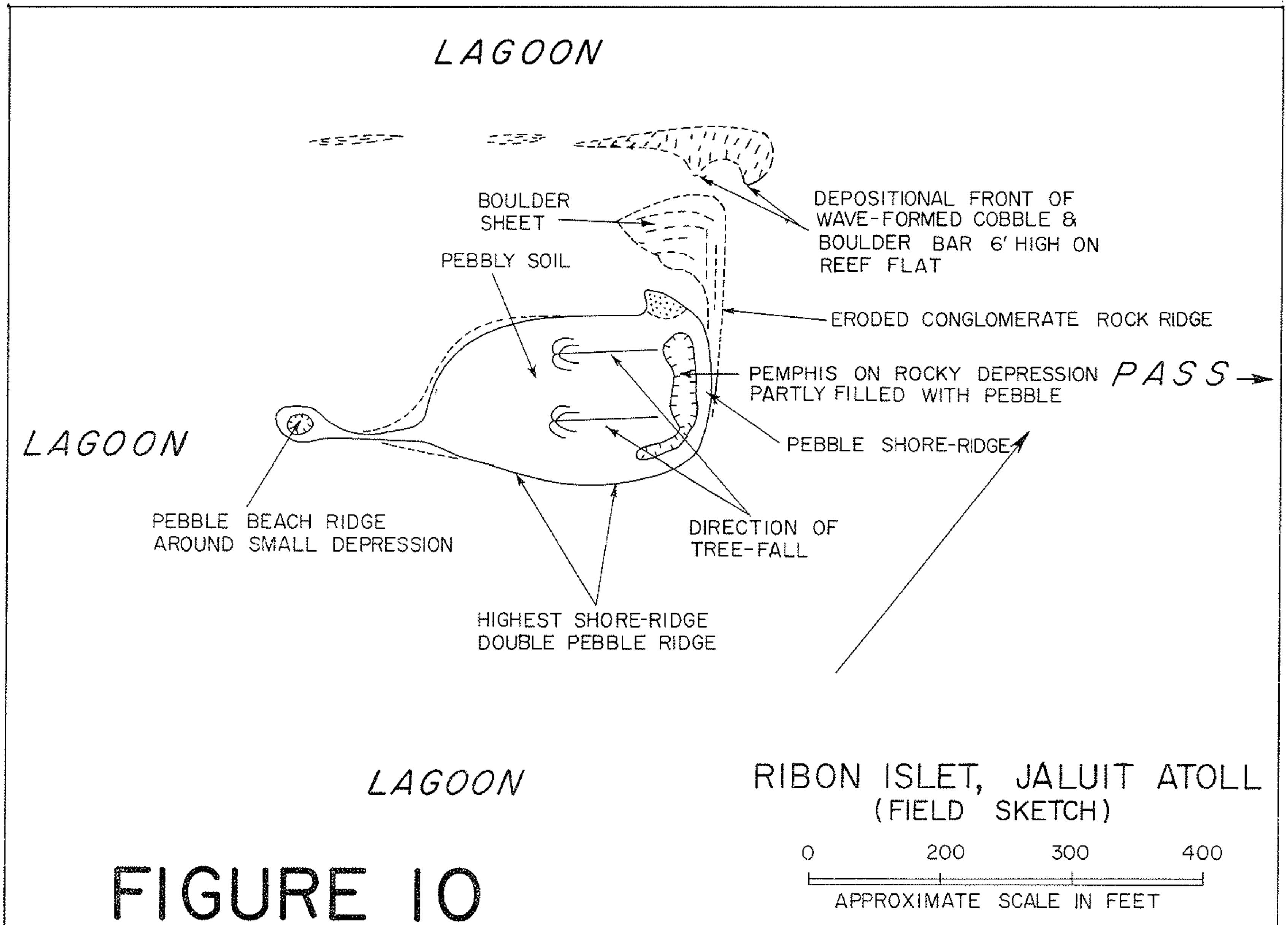
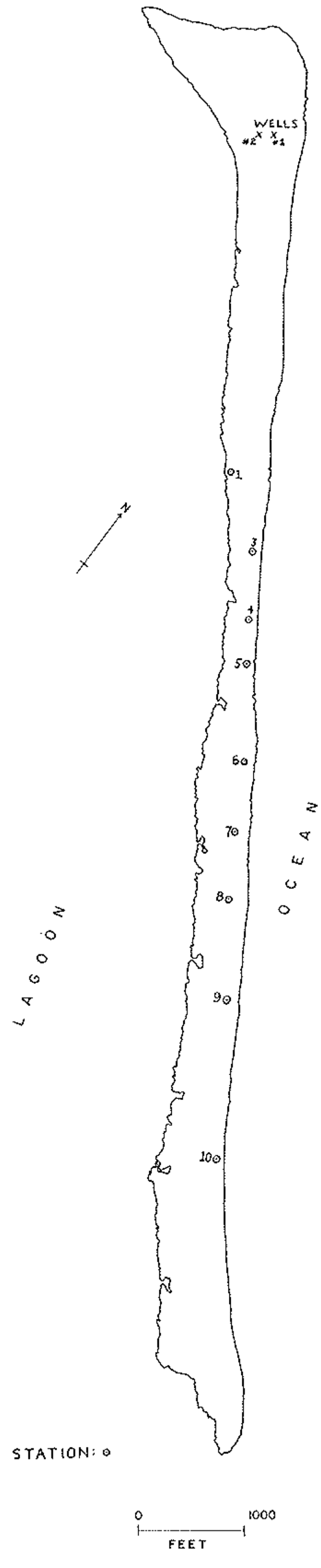

LAGOON
BOULDER SHEET
DEPOSITIONAL FRONT OF WAVE-FORMED COBBLE & BOULDER BAR 6' HIGH ON REEF FLAT
PEBBLY SOIL
ERODED CONGLOMERATE ROCK RIDGE
PEMPHIS ON ROCKY DEPRESSION PARTLY FILLED WITH PEBBLE
PASS
LAGOON
PEBBLE SHORE-RIDGE
PEBBLE BEACH RIDGE AROUND SMALL DEPRESSION
DIRECTION OF TREE-FALL
HIGHEST SHORE-RIDGE DOUBLE PEBBLE RIDGE
LAGOON
RIBON ISLET, JALUIT ATOLL
(FIELD SKETCH)
0
200
300
400
APPROXIMATE SCALE IN FEET

FIGURE 10



MEJATTO ISLET
FIGURE II

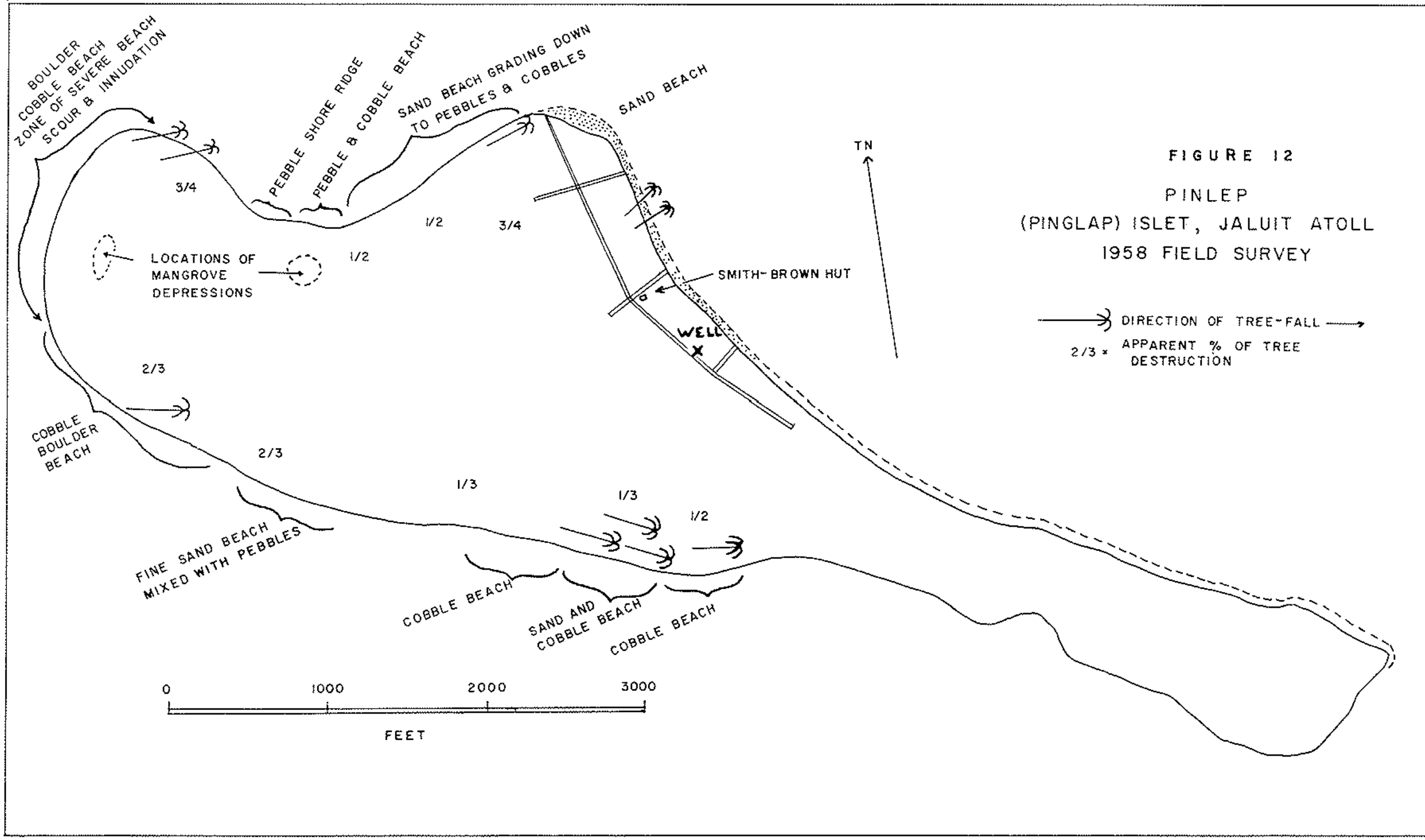
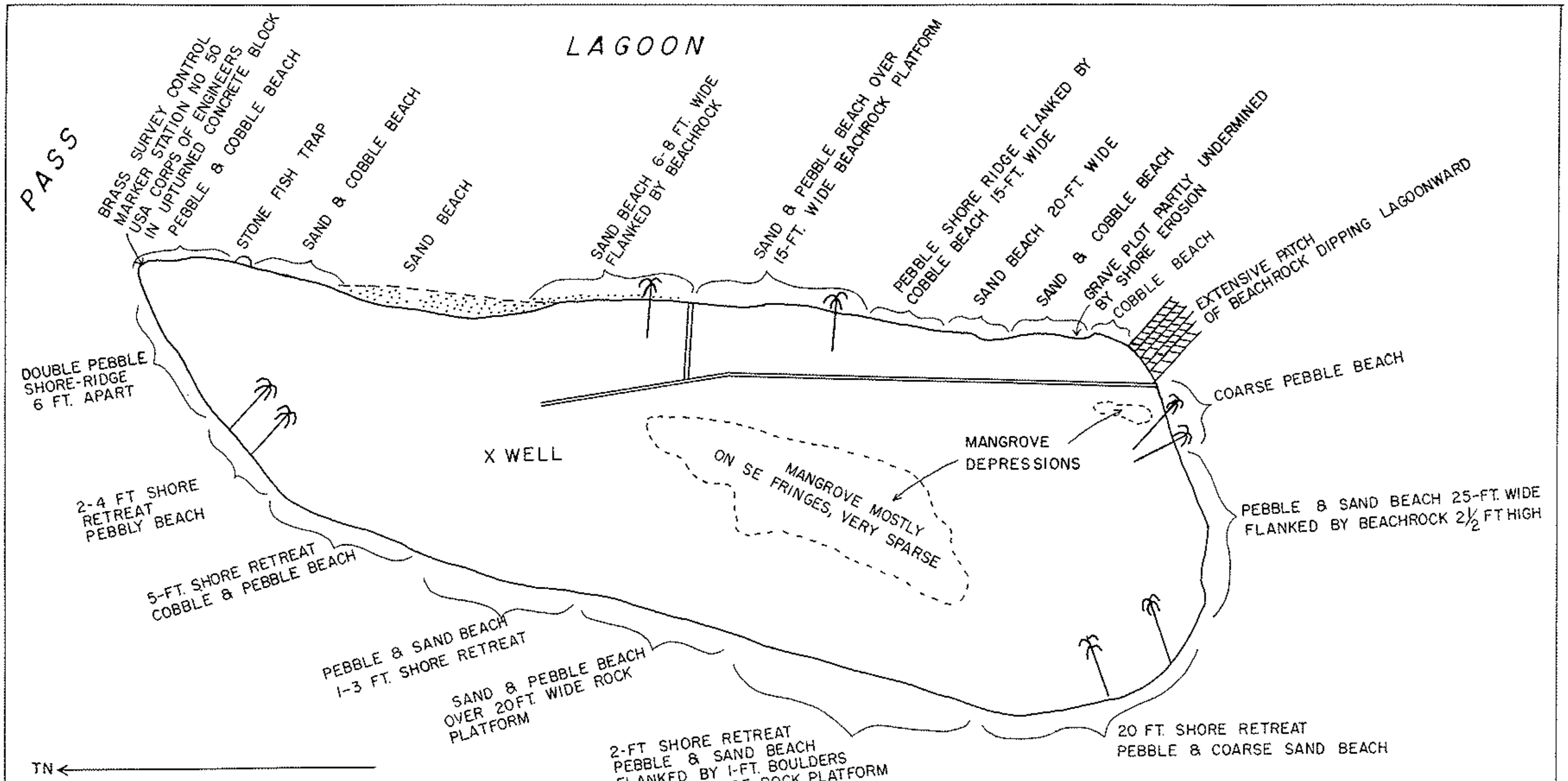


FIGURE 12

PINLEP
(PINGLAP) ISLET, JALUIT ATOLL
1958 FIELD SURVEY



MAJURIREK (ELIZABETH) ISLET JALUIT ATOLL

FIGURE 13

III. GENERAL DESCRIPTION OF STORM EFFECTS*

Herold J. Wiens

Direction of wind

Direction of wind from which damage was most extensive to vegetation varies from the northeast to the southwest sectors of the atoll. Roughly, in the northeastern two-thirds of the atoll the direction of tree-fall was towards the south or slightly east of south. In the southwestern third, largely towards the east. While wave and water wash did extensive damage in undermining or washing out tree roots, the overthrowing of the trees and certain structures such as towers and houses also resulted from the wind. Thus, the tree-fall direction may be taken as an indication of the direction of the most powerful or damaging winds.**

The islets of Jabor, Kinajon, Imroj, Ribon, Mejatto, Lijeron, Pinlep, and Majurirek (Elizabeth) were examined by making traverses along the beach and inland from the beach at intervals, and the directions of tree-fall were plotted on large scale maps (Figs. 6-13). On the western reef, Lijeron in the north suffered tree-fall from winds from the due north. At Pinlep, 15 miles to the south, however, the damage in tree-fall was mostly from west winds or winds from slightly north of west. On Majurirek, eight miles southeast of Pinlep, the most damaging winds were from slightly south of west. These same winds moved eastward across the lagoon to blow down two steel towers 150 feet high on the northern part of Jaluit. However, a mile northward toward Jabor on this SE reef the winds were most strong from slightly north of west, pushing lagoon water and carrying from its foundation a steel petroleum tank, 30 feet in diameter (as measured by pacing) and 25 feet high, and setting it on the land 330 feet away in a direction slightly south of east (see Pl. I-c).

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* Note: In this section, Wiens describes the effects of OPHELIA upon Jaluit Atoll. He first presents his general observations and conclusions with reference to wind directions and major changes throughout the atoll. Thereafter, he presents his observations islet by islet. Many of his observations are entered upon the islet maps that he prepared and that comprise the figures referred to in this section. It is intended that these maps be used in conjunction with the text since the maps often contain specific information not included in the text. --D.I.B.

** Blumenstock stresses the first powerful winds rather than the most powerful, and lays more stress on the effects of washing out of roots, see pp. 8-9. Fosberg considers that in addition the energy exerted by the coral-debris-filled waves played an appreciable part in uprooting of trees (personal discussion with Fosberg). --D.I.B.

Northward of here scarcely a mile away the strongest winds were blowing from a north or slightly west of north direction, or directly down the length of the wide part of Jabor Islet from the channel. Similar winds caused the extensive damage observed at Imroj, Kinajon and Mejatto.*

Degree of damage

The heaviest damage to vegetation and soils occurred in the northeast and southeast reef sectors where salt water swept across the reef and land most extensively. Of the islets observed, the most extensive damage probably occurred on Mejatto and Imroj where from 70 - 90 percent of economic trees were blown over (Pl. X-a , Pl. II-c). Jabor and Enejet suffered similar wind and wave force but neither had many coconut or breadfruit trees, and the land here is mostly government reserves. On the other hand, islets mostly affected by the westerly winds were less damaged, largely because of lack of salt water inundation very far inland from the beach. Wind damage also appears to have been less extensive.

In general, the interior of the larger islets and of the wider sections of long islets have less disturbed or undisturbed soil conditions although damage to trees may be just as severe in the middle as along parts of the periphery, depending upon local situations and at times apparently upon the whimsicalities of wind gusts. In the following discussion, islets will be taken up individually.

Jabor

The islet of Jabor is connected to the islet of Jaluit by a continuous strip of narrow land with only small breaks resulting from typhoon OPHELIA. It is difficult to tell, therefore, where Jabor ends and Jaluit begins. The whole section examined and shown in two large scale charts (Figs. 6, 7) will be considered part of Jabor Islet. The section examined by the writer on foot is about 12,300 feet in length from the north end of Jabor southward to the two steel towers where the islet widens. Here are the walls of 3 former concrete buildings, one of large size (150' by 50'). About 4000 feet south of the old hospital tower on Jabor is the remains of a Japanese petroleum storage depot where so-called Sydney Pier was situated. At the base of this pier is a large circular open-top tank surrounded by piled up coral rubble rising about 20 feet. Before the typhoon, two steel tanks 30 feet in diameter rested on circular concrete bases adjacent to the pier base and lagoonward of the large tank.

Between this locality and the wide part of Jabor and between this and the steel towers only the more or less intact remains of former Japanese blockhouses or gun emplacements serve as suitable points of reference. I have numbered these for reference on the maps (Figs. 6, 7) as Blockhouses 1 and 2 north of the tanks and 3 and 4 south of the tanks.

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* See discussions by Blumenstock, pp. 8-9, and by Fosberg, p. 53 for somewhat different views. --D.I.B.

Bar formation off Jabor

Coral rubble bars on the reef flat have developed as a result of the typhoon for almost the entire length of the seaward side of the reef from where Jabor widens opposite the old hospital southward to just past the steel towers (Pl. I-a, b). The highest rubble bars rise to about 4 feet above high tide at a number of places northward of a point about 2000 feet south of the large open tank. This height is indicated by the lack of algal staining in the upper part as contrasted with the brown stain in the tidal lower half. Southward of this point to the steel towers, the rubble accumulations generally are from half a foot to 3 or 4 feet above the reef flat. In the vicinity of the towers, they apparently rest on old beach rock. In the southern sector they form discontinuous strips 20-100 feet wide. Most of the bars are separated from the shoreside beachrock by 50 - 100 feet of the original reef flat. There are 3 stretches of these offshore bars south of the large tank rising to about 4 feet above high tide. North of the large tank there are two other such bars. In each case, the points of highest accumulation adjoin or are opposite storm-scoured breaks across the land from or to the lagoon. The land on the lagoon-side opposite these bars generally appears to have suffered severe erosion of the sediments of which it is constituted.

Since broken glass and other material deriving both from the land and from the lagoon have been found in the seaward reef bars, some of the material in these bars obviously came from the land and lagoon. However, much of the material appears to be derived from the outer reef margin and parts of the reef flat. Slabs of coral rock 2-3 inches thick form imbricated beds on the seaward slopes of the bars, and the landward fronts of the bars have the abrupt terminations of delta talus. Local inhabitants also stated that the bars smelled of rotting reef organisms after the storm, so that fresh materials from the live reef must have formed a large part of the bar. We may conclude, therefore, that the reef margin also suffered severe mechanical erosion from the waves, although much of the debris may have come from the bases and lower parts of the surge channels, as indicated by Banner (pp. 76-77).

So far as the writer observed, few large blocks of rock were torn off from the reef margin and tossed up onto the reef, unless some were buried under the higher accumulations of cobble-size and smaller boulder-size debris in the seaward reef bars. However, on the new bar on the lagoon side about half way between Blockhouses nos. 3 and 4 there is a block of coral about 6 feet in diameter which appears freshly broken off, because the top half standing out of the tides is white and lacks algal staining, while the lower half is only stained light brown where algae have grown between tide levels (Pl. I-d).

Bars are also found on the lagoon reef (see charts, figs. 6, 7), freshly formed as shown by their white coloring. Lack of time did not permit close examination of these. The most prominent bars run in an arc from the large coral block mentioned in the foregoing paragraph to the Sydney Pier base opposite the large tank. A fresh gravel bar also runs roughly parallel to the land strip northeastward from the broken remnants of Sydney Pier.

Just northward of Blockhouse no. 4 a fresh looking bar has formed on the lagoonside somewhat northward of low cobble bars on the seaward side. A new bar was added also to the lagoon reef in the northernmost parts of Jabor between the main pass and the old pier where the rusting hulk of a ship sits on the beach. This runs for about 800 feet in a narrow strip 200 - 300 feet offshore. The materials on it appear to have been derived from parts of the shore near the northern tip of the islet of Jabor and from sediments in the channel fringe.

Of the sections observed, the materials forming the bars were mostly pebbles, cobbles, and small boulders. Very few sand-size particles were apparent in most of the bars. This seems to indicate that most of the finer sediments may have been washed into deeper lagoon or ocean waters and that there was little disturbance of the lagoon bottom where most of the sand and finer material normally accumulate. This accords with the limited bottom inspections near shore by Banner (p. 78), who found the corals under 3-4 feet of water in the lagoon apparently generally unaffected by the storm. However, when the writer examined the same areas on foot in 1956, he found virtually no sand beaches along this entire stretch of land either on the lagoon or seaward side. During the present examination the writer found only one small section of the beach several hundred feet long and about 20 feet wide where fine sand was mixed with coarse pebbles and cobbles. This was on the seaward side not more than 200 - 300 feet northward of the fallen steel towers.

Land erosion and land-build-up on Jabor

In general, although in a few places debris accumulation has widened the land area and has added to the land surface above tide level, the net result appears to have been a significant reduction in the land area suitable for economic plantations. For the most part the old algae-blackened beach rock on the seaward side has remained intact, although here and there the violence of the storm has broken off slabs several feet in diameter, undermined sections of the rock on the landward side or scoured a breach between lagoon and seaward reefs. Undoubtedly the greater consolidation of this generally intertidal rock has served to protect the land in the manner of a low seawall.

Scouring of the less consolidated rock and sediments directly landward of the top of the beach rock in most cases has left a trough between the line of beach rock and the new shore ridge that now runs 10 - 20 feet from the old beach ridge that once adjoined the beach rock (Pl. II-a). At high tide this trough is partly filled with water. This general aspect is observable the entire length of the seaward side from the steel towers northward to where the island widens.

Scouring of this narrow part of the islet, which occupies all but about 3000 feet of the entire 12,000-foot section examined, is more severe on the lagoon side. In some instances this has resulted in channels cut almost or entirely through from lagoon to seaward reef, probably by headward erosion by water pouring over the land from the seaward side.*

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* Blumenstock believes there was primary water movement from seaward but secondary movement from lagoon to sea, see pp.17-18.--D.I.B. [But see also p. 12.--Ed.]

The addition of debris to the land has largely been in a layer from the newly formed shore ridge toward the lagoon (Pl. III-b). This type of debris addition is usually found only where the land widens to 200 - 300 feet or more. In the narrower parts no additional layer occurs on top of the old land surface. On the contrary, a layer of partly consolidated or loose material may most often be observed to have been stripped from narrow and sometimes from wider land surfaces, occasionally with small remnants of the original layers left in the form of platforms.

Especially noted erosional features in this section include a beach stretch 200 feet north of the steel towers where the new seaward shore ridge is now 30 feet inland from the seaward beach rock. Stumps of now dead Pemphis trees stand out of the sand and gravel all the way out to the edge of the beach rock, showing that the vegetated land reached this far prior to typhoon OPHELIA (Pl. III-a).

Lagoonward of the concrete buildings next to the steel towers wave action had washed out a channel from the reef that bifurcates to form two channels cutting inland around the northern sides of the two buildings nearest the seaward reef. The channels each end in a kind of swirl on the seaward sides of the buildings and do not cut all the way across this wide part of the land. The position of the buildings may have tended to funnel the ocean water into a stronger stream causing headward erosion of the land at these places.

Other especially noteworthy washouts of land occurred about 800 feet south of Blockhouse no. 4; at other areas half-way between Blockhouses 3 and 4; 500 feet south of Blockhouse 3, to the north and south of the high mound surrounding the large storage tank, and in most of the areas northward of Blockhouses 2 and 1 in the narrow part of the islet.

The widest channel cut across the land occurs at the north base of the high mound around the large tank (Pl. I-c). Here, at high tide, water runs across into the lagoon in a large stream. A smaller channel cuts through a 4 foot depth of conglomerate about 550 feet north of Blockhouse 2 (Pl. II-b), while still another channel has been cut through as far as the seaward beach rock about 900 feet north of Blockhouse no. 1.

On Jabor proper (the northern 3000 feet or wide part of the islet) the most damaging winds blew southeasterly roughly parallel to the islet as indicated by the direction of tree-fall*. Shore damage was severe all around the island. Inundation apparently occurred over most of the islet, although the soil surface was not much disturbed in the higher middle parts 400 - 500 feet inland from the north end and 300 - 400 feet from the remaining 6-foot high concrete seawall on the northeast side. The seawall was broken in its southern 200 - 300 feet as far as the triangular concrete structure which dates back to German times. The deposition of gravel and rocks was much reduced by the protection of the seawall along

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* For different estimates see Blumenstock, p. 8.
-- D.I.B.

the northeast side. Beginning with the triangular structure, however, gravel sheet deposition with a front depth of up to three feet advanced inland 200 - 300 feet from the seaward shore ridge as far south as the building occupied by the expedition and by the agriculturist. From this building southward the entire land surface has been strongly disturbed either by scouring or by deposition. The surface is covered with pebbles, cobbles and small boulders up to 6 inches thick and 1 - 2 feet in other dimensions. Except for the toppled trees and still standing trunks of Pandanus the scene looks like the bed of a rocky river. Only a few strips and patches of the original soil surface are identified by occasional growths of grasses such as Lepturus.

On the lagoon shore, the two stone and concrete piers on which the government generator equipment and a warehouse stood now are merely piles of coral rubble that protrude into the lagoon. The former 4-foot high seawall of cemented coral blocks along the lagoon shore has been stripped down to remnants 1-2 feet high, and at the north end some 200 feet of it has been torn off and upturned altogether. Rubble from the lagoon reef flat and shore has been scattered inland 30-50 feet in the northern half of the islet. The greatest piling up of coral rubble has occurred on the shore facing the channel, for the most damaging winds blew directly inshore across the channel from the north and hit this coast area squarely*.

Near the bend in the seawall on the eastern part of the channel shore a 50 foot break in the wall allowed the storm waves to scour out a semi-circular hollow backed by a curved shore ridge of pebbles, with additional debris spreading inland from it. At the northern point of the islet the seawall is buried by a gravel and rubble shore ridge that rises to the highest peak of any seen on the various islets, about 10 feet above low tide. This ridge slopes channel-ward in a gravel beach out about a hundred feet and drops off into deep channel water. Since, prior to the typhoon, the bottom at the base of the seawall dropped off quickly into the depths of the channel, the amount of debris filling in the channel fringe here is considerable. The shoaling of water in this area and westward across one of the branch channels has made it hazardous for ships to enter by the most direct channel to the Jabor anchorage, and forces ships such as the Roque to use the more northerly channel running northward past Enejet.

Inland, rubble has been deposited in a two-foot depth around the concrete walls of the agriculturist's former home completed just two years before the typhoon and situated 100 feet from the seawall. Farther inland, however, the ground surface is little disturbed, and ornamental croton hedges continue to flourish, although most of the trees are blown over.

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* For differing views, see Blumenstock, p. 8.
-- D.I.B.

Soil and vegetational damage on Jabor Islet

In general, 95% of the trees on this islet were toppled or snapped off at varying heights above the ground. From the concrete house in which the expedition stayed southward, virtually none of the original ground surface and ground vegetational cover remain except at small high spots such as the slope up to the large storage tank. In this area coconut trees still may be found growing at widely separated intervals. Almost all Pandanus appear to be killed, although the prop roots and part of the lower trunk may remain. No trees of large size grew in this area except near the Expedition Headquarters. These are mostly Calophyllum, and they have been toppled, with their great shallow root systems standing high in the air. Some of them have re-sprouted leaves on a few limbs, since the trees often retain a few roots still buried in their growing positions. On a number of the wider rocky platforms of the islet, however, the hardy Pemphis, stripped of smaller branches and twigs and left with vertical trunks 1 - 2 inches in diameter, has begun sprouting leaves on these remnants (Pl. VIII-c) and will no doubt soon be essentially recovered.

On the wide northern part of Jabor a few large Calophyllum trees near the base of the northern pier have not been uprooted and are sprouting leaves from trunks and large limb remnants. All the Casuarina trees which were up to 6 - 8 inches in trunk diameter were uprooted by wave wash and wind* and most of the other large trees and the coconut and Pandanus trees were uprooted or killed by trunk snapping. However, shrubs, weeds and grasses over most of the interior in an area 500 feet wide by some 1000 - 1500 feet long appear relatively undisturbed and similar in aspect to what they were in 1956.

Damage to structures

In general, all wooden buildings were demolished and thatched houses smashed flat by the wind. Some roofs were pulled back into position and are temporarily used. All houses require rebuilding, however. Concrete structures stood up well although the lower stories were inundated and doors and windows washed out. Cisterns mostly remained intact, but were contaminated.

Kinajon Islet

This islet stands between two of the channels of the Northeast Pass and across the channel southeast of Imroj Islet (Fig. 1). It is an oblong islet about 2500 feet in length by about 1500 feet in width at the widest part (Fig. 8). Much of the northern third of the islet appears to be occupied by a depression partly overgrown by mangroves. A smaller mangrove depression also is found in the eastern bulge of the islet. The southwestern third formerly (during World War II) contained some Japanese vegetable gardens covering about an acre in the middle. This area has fewer trees and a more open aspect.

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* But see Fosberg, p. 54.-- F.R.F.

The north end of the islet with the large mangrove swamp faces the seaward reef. Coral debris up to small-boulder size was carried inland by storm waves as much as 50 - 100 feet along the northern third of the shore-line, filling the seaward parts of the large mangrove swamp with gravel. The front of this deposit is 2-3 feet high. This deposition did not occur at the channel sides of the islet in the wide western indentation or along the eastern and southern shores. The latter two sectors were in the lee of the waves. The western channel escaped such inshore deposition possibly because of lack of reef shoaling from the deep channel and perhaps because the waves may have run more parallel with the coast than across it.

The beach sediments deposited by the storm in the western indentation are mostly sand and silt with small amounts of pebbles. The only other beach with similar sandy character is a small section 150 - 200 feet long directly southwest of the eastern bulge of the islet. The beach in the northern third of the islet is composed of coarse pebbles, cobbles and small boulders. In the rest of the shoreline small to medium size pebbles form the beach and shore ridges.

Erosion of the original shore appears most severe in the northeast sector where a 20-foot wide strip inland from the old beach rock has been scoured away and the new shore ridge moved this distance inward. At the southwest end erosion has eaten away about 10 feet of the original land along the shore, and about the same amount of erosion occurred as a result of the storm in the northeast sector just north of the eastern bulge of the islet. In the southern leeward and lagoonward sectors, however, an initial scouring of the shore washed out the roots of strand trees. Subsequent to this, pebble and cobble deposition has added a 10 - 20-foot wide strip of loose sediments to the shore. In the southeast lagoonside bend of the islet there are two shore ridges or storm ramparts 20 feet apart, and the strand trees blown over by the storm are partly buried by sediments.

The tree-fall direction in most parts of the islet was slightly east of south.* The largest percentage of tree destruction appears to be in the northern peripheral areas where an estimated 90% of the trees were uprooted. The largest percentage of trees left standing and growing appear to be around the small mangrove depression in the eastern bulge of the islet. Here about one-half of the coconut trees remain standing with growing fronds.

In most of the rest of the islet between 60 - 75% of the trees were felled. The taller mangrove trees had their foliage stripped off the top half, and some are dead, but most of them are forming new leaves. The smaller lower mangroves appear little damaged and relatively flourishing.

Except for the parts of the periphery of the islet damaged by gravel deposition, by storm wave scouring, or by uprooting of trees, the ground cover of low plants such as grass, weeds and shrubs appear to have been affected by the storm.

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* No one dominant direction according to Fosberg, notes. --D.I.B.

Imroj Islet

Imroj lies across the pass northwest from Kinajon and is about 4,200 feet long by 1000 feet wide 1000 feet from the northwest end, and about half this width in the southeast half (Fig. 9). It was and is the principal inhabited islet presently having about half of the atoll's population. Prior to the storm it had a very luxuriant aspect, with dense plantings of coconut, pandanus and many breadfruit trees.

Marked shore-line changes have occurred all around the islet. The old pier was not very well built and consisted mainly of uncemented coral blocks piled up in a regular line covered by coral sand and silt. This is now merely a mass of coral blocks protruding lagoonward into water of 4 - 6 foot depths.

The greatest shore and land damage has been on the seaward or northeast side. The islet extends roughly northwest to southeast, and the most damaging winds came from the northwest at a diagonal across the islet, as indicated by the direction of tree-fall.* Violent beach and shore scouring occurred on the seaward side, and pebbles, cobbles and small boulders were carried inland and deposited 50 - 150 feet from the old shore ridge. The mangrove depression at the northwest end is partly filled with gravel.

Water from the ocean scoured several shallow depressions across the lagoonward half, in the southeastern two-thirds of the islet. The closeness of the coconut and Pandanus plantings and the depth of root penetration made the soil disturbance unusually great. Each overturned tree resulted in the pulling out of a great mass of soil and gravel by the densely massed roots and the excavation of large holes 2 - 3 feet deep and 6 - 8 feet in diameter. The result is an extraordinarily rough surface which presents a very difficult problem in the replanting of the islet.

Vegetation damage

An estimated 90 to 95% of the economic trees were uprooted by the storm and a large part of the ground cover was killed on the seaward half of the islet.

House damage

All houses on the islet were demolished. Some reconstruction has been done through the use of scrap material from the old structures, but many of the people still must live in the most make-shift shelters. The materials for thatch-making are available only in very small quantities since most of the Pandanus and coconut leaves were destroyed by the storm, and few are growing.

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* North to northeast according to Fosberg (notes) and Blumenstock --D.I.B.

Ribon Islet

Ribon is a tiny islet about 450 feet long by about 250 feet wide oriented northeast to southwest (Fig. 10). A strip of beach rock runs roughly at right angles to this direction from the middle of the northeast beach northwestward for about 500 feet. Small boulders and gravel form a sheet up to a foot in depth near the northwest end of the beach rock strip and about 100 feet in diameter. A few yards farther northwestward a pebble and cobble bar about 60 feet wide rises to about 6 feet above the reef flat and runs at lower heights and narrower widths in three discontinuous strips in a southwesterly direction. This bar appears to have been freshly built by the typhoon waves.

The northeast end of the islet faces the pass opening to the ocean, and a 20-foot wide strip of the former land appears to have been scoured away between the old beach rock and former shoreline and the present shore ridge. Pebbles and cobbles have been washed inland and partly fill a rocky depression about 100 feet wide and 300 feet long running parallel to the northeast shore. A thriving stand of shrubby Pemphis grows on the rock of the depression.

At the southwest end of the islet a cobble and gravel spit has been built lagoonward for a distance of about 220 feet in a strip 5 - 6 feet wide and up to about high tide level or slightly above. At the landward end the current eddy of the storm waves apparently swirled to form an oblong to circular rampart or beach ridge around a depression 1 - 2 feet below the ridge level and filled with flotsam.

The islet has a high shore ridge all around it formed of pebbles and cobbles. In the southern half of the islet there is a double shore ridge which rises to the highest level on this side of the islet. While the strongest storm waves appear to have come from the north and piled up the 6-foot bar on the reef flat in this direction, the direction of tree-fall was to the southwest, indicating a wind of maximum violence from the direction of the open pass or northeast. The position of Mejatto Islet and of the pass may have influenced somewhat the apparently differing direction of the tree fall both on Imroj and Mejatto from that on Ribon. The protection afforded by Mejatto situated to the windward (with reference to the storm) of Ribon, also may have resulted in the decreased tree damage. Some 6 - 10 coconut trees were downed, 14 were left standing and growing. Most of the Pisonia trees still have their trunks and chief limbs intact and are regrowing leaves. Guettarda and Scaevola growing among the rotting old coconut stumps and Asplenium nidus continue to flourish in the interior of the islet. So little disturbance on such a small islet can only be attributed to its geographic position relative to Mejatto Islet and the open pass.

Mejatto Islet

Mejatto Islet is about 12,500 feet long and from 450 - 600 feet wide, although near the northern end it widens to over 2,200 feet (Fig. 1). Its long axis is roughly north northwest to south southeast. It lies north of the pass NW of Imroj (Fig. 1).

This islet suffered even more from wind and wave destruction than Imroj. With the exception of about the northern 2000 feet and 500 - 600 feet on the southern end, the entire islet appears to have been swept by ocean water and severely eroded and cut up. Gravel sheets were laid over large parts of it from the seaward side half to three-quarters of the way across the islet. Many channels were cut across the islet.

Coconut, Pandanus and other trees not only were blown over and washed out but a large number were washed into the lagoon where many stumps are visible on the lagoon reef and many trunks stand in the deeper water of the lagoon slope. From 1 to 4 feet of the original soil were washed from much of the islet although in other areas 1 - 3 feet of gravel cover the original surface (Pl. II-d, Pl. X-b).

A map for plotting data directly was not made before going to this islet. Instead a traverse line by plane table was made by Blumenstock and the writer down the length of the islet southward from a point 3000 feet from the north end, and notes were taken along the route of the traverse which was measured by pacing (Fig. 11). Most of the traverse route was near the seaward shore-ridge. The return trip to the point of origin w s made separately by Blumenstock and by the writer, who paced the last leg of the traverse (2475 feet) alone and returned along the lagoon side of the islet pacing only the first 500 feet from the south end. The features noted on the map of Mejatto (Fig. 11) thus are less exactly located and less correctly oriented than on the other maps made by the writer.*

At the starting point a very large Calophyllum tree standing at the lagoon shore has survived the storm. Its branches were broken back to the few remaining main limbs, but leaves are sprouting again from them.

Immediately to the south of this tree ocean water had poured across and scoured out a large channel across the islet. Coral debris from this area forms a convex bar on the lagoon side reef enclosing a shallow pool. Many similar bars and pools occur along the length of the islet opposite other channels cut across the islet so that the bars give a scalloped appearance to the lagoon side.

At station 3 (700 feet south of station 1) the land is badly eroded and many coconut tree trunks still standing have lost their crowns. A channel is almost cut through to the seaward reef by headward erosion and is about 150 feet wide.

At station 4 (560 feet south of 3) the erosion channel makes a 90-foot break in the ledge rock at the seaward side and a hole filled with water at low tide is scoured out landward of the beach. Two to three feet of the original surface are stripped from the seaward half of the islet, leaving high mounds of gravel where Pandanus or coconut roots remain in place.

A characteristic feature on this islet is the scour-pit formed on the down-stream side of the tree stumps opposite the accumulation of gravel and flotsam on the upstream side (see McKee, p. 40).

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* Traverse distances given are, I believe, correct within 10% --D.I.B.

While the lagoon sides of islets most often have sand beaches, Mejatto's sand beaches (if there were any) appear to have been washed away into the lagoon leaving only pebble and cobble beaches. Washed out tree stumps are numerous on the shallow lagoon reef and slope between stations 4 and 5.

The distance between stations 4 and 5 is 365 feet and between 5 and 6 it is 825 feet. About 200 feet south of station 5 is a barren wash or channel cut through, with no vegetation left. In this area a blown over Barringtonia tree 2 feet in diameter is sprouting a few leaves from the trunk. Some 550 feet south of station 5 a channel working headward from the lagoon side has left a V-shaped indentation. On the seaward side is a low spread-out cobble and boulder bar. The land between sea and lagoon, here about 275 feet wide from shore ridge to the channel head, is badly eroded and pitted and extremely hummocky. Some 3-7 feet of the soil and gravel have been removed.

In the vicinity of station 6 three trees with wide buttresses, which are probably breadfruit, are still standing upright but have had branches, bark and leaves stripped and appear dead. Many coconut tree stumps lie on the lagoon reef.

At station 6 there is another lagoon outwash channel-indentation, and at the mouth of it lies a dead breadfruit tree trunk with roots and some limbs. Near the lagoon close to a standing breadfruit tree trunk and two lagoon shore Calophyllum trees a patch of the original soil, black humus mixed with sand, remains. Lepturus grass growing in a thick mat on this soil apparently survived the typhoon inundation.

Stations 6 and 7 are separated by 550 feet. Two discontinuous patches of bouldery rubble lie off the seaward beach here but are not heaped up sufficiently to constitute bars. Stations 7 and 8 are 550 feet, and 8 and 9 are 825 feet apart. In the vicinity of station 9 there appears to have been a large breadfruit grove prior to the typhoon; 10 - 12 large trees with buttressed trunks and limb sections still standing indicate the remains of this grove. Much flotsam has been accumulated around their bases.

Station 10 lies 1310 feet south of station 9 and from station 10 to the southeast end of the islet is 2475 feet. North and south of station 9 on the seaward reef from 5 - 150 feet offshore are patches of scattered coral cobbles and small boulders.

Between stations 9 and 10 there is an extensive scoured-out backridge trough inshore from the new pebble shore ridge. The central part of the islet rises to about the ridge height or more and is covered by a sheet of gravel. Most of the coconut and Pandanus trunks and stumps have been uprooted and washed lagoonward. Few remain standing.

This general aspect is found southward over most of the area between station 10 and the end of the islet, except for the last 500 feet. Around the curve of the shore lagoonward of the pass between Mejatto and Imroj two pebble and cobble ridges flank the shore, the inner one about 20 feet inland. The lagoon half of this part of the islet has retained much of its original vegetation. Part of the area is occupied by a mangrove depression separated from the lagoon only by a pebble shore ridge.

There are two or three separate depressions in which mangroves are growing in this part of the islet. The one nearest the end of the islet is partly filled with pebbles and cobbles washed in from the seaward side (Pl. III-c). Many of the small mangrove trees appear to have been broken off but some stalks are still alive and have re-sprouted. Many low young coconut trees also have survived in this area. Northward of the southern mangrove depression and its surrounding trees there has been considerable erosion of the land back of the lagoon shore. A pool 3 feet deep and 20 by 50 feet in horizontal dimensions has been scoured out and many coconut palms overturned but not washed from the site of growth.

In this vicinity and adjacent to an outwash channel-indentation stands a concrete cistern with brackish water. It was sunk 2 feet into the ground with the walls rising 2.5 feet above the old ground level. Here the surface of the ground is not greatly disturbed. Northward of this the soils are badly eroded and cut up. Approximately opposite station 7 but on the lagoon side of the islet is another mangrove depression elongated parallel to the axis of the islet. Pebbles and cobbles have filled in about three-fourths of the depression from the seaward wash to a depth of about three feet (Pl. III-d).

The extreme northwest end of Mejatto was not visited by the writer, but a view from the schooner in the lagoon showed many more coconut and other trees to be standing here. Obviously, less wind and water damage had occurred in this widest part of the islet.

Lijeron Islet

This small islet on the northwest reef measures an estimated 300 by 600 feet but was not paced off.

On the east end a sand beach 50 feet wide borders the islet. The north and south sides are concave indentations protected from the normal waves from the east and have developed beach rock. At the west end there is a narrow neck of rock extending to a rock platform less than half the size of the eastern part of the islet and supporting a pure dense stand of Pemphis. This contrasts with the almost pure stand of Pisonia on the eastern end larger and higher part of the islet. A few Cordia and Tournefortia trees and perhaps half a dozen coconut trees also are on the eastern section. There appears to be little significant topographic change resulting from the storm save possibly the development of a long sand hook southward from the eastern sand beach. Some sand was spread in a sheet half-way across the islet from the north.

The vegetation on this small islet also survived well. A few Pisonia and Cordia and 2 - 3 coconut trees were toppled, the direction of fall being due south.

This isolated uninhabited islet is the nesting place for hundreds of white-capped noddy terns which are relatively tame. Most of the nests contained a young chick or an egg at the time of our visit. Overhead circled many terns and frigate birds.

About a dozen terns and one young frigate bird were caught by the Jaluit islanders from our schooner to take home for eating. Some eggs also were collected apparently for the same purpose.

Pinlep Islet

Pinlep Islet is situated on the west reef of Jaluit (Fig. 1). Between the islet and the lagoon proper is a faroe or secondary lagoon of relatively shallow depths resulting from the upbuilding of a reef enclosing a triangular body of water. The northwest shore faces a wide reef flat, but the oceanward reef to the south is narrow. The islet is about 8,500 feet long. The eastern half runs between 500 and 800 feet in width. The central portion of the western half is widest, about 2,200 feet. The main inhabited parts appear to have been along the lagoon-facing sectors of this wide portion (Fig. 12).

Our small boat made a landing near the middle of the islet after crossing the secondary lagoon. The schooner had to stand some distance off the reef of the secondary lagoon so as not to drift onto the reef, since the wind blew toward this reef from the east.

In an interview with the oldest inhabitant, named Brown-Smith, we were informed that the first severe storm wind of the typhoon blew from the north starting at about 6 p.m. By about 10 p.m. the wind had shifted to blow from the south with great violence. Our informant stated that it was this wind that blew down most of the trees. However, almost all the trees downed had fallen in an easterly direction, so that the most violent blow must have come from the west. If the first violent winds were from the north followed by violent west winds, as the tree-fall appears to indicate, the cyclonic whirl must have moved westward and then northwestward.

The most severe damage inflicted on the trees appears to have been near the western end of the islet where an estimated two-thirds to three-quarters of the coconut, Pandanus, breadfruit and other trees were killed. The central part of the south and seaward sides of the islet appear to have had the smallest proportion of the trees toppled, between one-third and one-half. The writer did not traverse the eastern half of the islet and cannot describe the extent of damage in this portion.

Along the beach north of the Brown-Smith hut, coconut trees were bent over northeastward, but were not completely overturned. Many breadfruit trees were toppled over along the village road parallel to the lagoon beach. Others remain standing but have most of the limbs broken off. These and others with some large roots still in the ground are sending out new leaves. Near the northwest beach a mangrove stand in a mucky depression has most of its trees stripped of leaves and twigs, and the trees appear dead. The northwest facing shore here is badly eroded and has retreated 10-15 feet. The character of the beach sediments along the shores observed are shown in Fig. 12.

Inundation was most severe and penetrated farthest inland at the west end of the islet, where the shoreline appears to have been scoured back 10-15 feet, while water-borne sediments and flotsam were carried in forty feet or more from the shore ridge. On the southerly section of this western end many Guettarda, Scaevola and Tournefortia, toppled over but only partly washed out, are sending out profuse leaf sprouts. About 1500 feet from the west end a breadfruit tree trunk still standing 80-90 feet high is sprouting leaves from parts of the large limbs remaining, although all smaller branches are gone. Along this south shore there appears to have been little salt water penetration inshore.

Majurirek Islet

Majurirek Islet is roughly 3000 feet in length (Fig. 13). Its long axis is aligned almost due north and south. Its greatest width, about 1100 feet, is near the south end, and it narrows gradually northward until at about 500 feet from its northern tip it has a width of some 600 feet. A mangrove depression about 1000 feet long by 250 feet wide occupies the south central interior of the islet. However, only sparse patches of mangrove are found, largely near the southeast fringes. Most of the depression is an open pool of salty or brackish water. A much smaller mangrove depression occurs near the southeast shore of the islet just west of the village path.

The character of the shore and beach areas at the time of the visit by the writer is shown in Fig. 13. In general, the severest storm winds of Typhoon OPHELIA came from the west, as indicated by the plotted direction of tree-fall in the chart. This accords with the observations made on Pinlep, also on the west reef, as well as with the observations made in the southern extension of Jabor Islet where the steel towers were also blown down in an eastward direction. Locally, the directions of tree-fall were not always toward the east. In a few instances where strand trees were undermined by wave wash the directions of fall were toward the beach. On the ocean side in the extreme north shore area the dominant direction of tree-fall appears to have been toward the southeast. In the southwest shore area the direction of tree-fall seems mainly somewhat north of east. At the southeast end the tree-fall was toward the southeast. Along the lagoon shore the direction was dominantly lagoonward or eastward.

Of the islets examined, this one appears the least changed morphologically along the shores. Inundation by ocean or lagoon water appears to have been restricted to a narrow zone of a few yards from the shore and only occurred locally. No significant amount of sediment was washed inshore, and the shores were only slightly scoured. Beach character probably was changed, but, without information on the nature of the beaches before the storm, the writer cannot evaluate this change. Shore retreat owing to wave-scouring occurred on the lagoonward side of the southeast bend of the islet about 100 feet north of the beach rock formation. Here an old family grave-plot was partly eroded away. The maximum retreat appears to have occurred just at and just south of the northwest bend of the seaward shore, where from 3 to 5 feet may have been scoured away from the shore. In the southern half of the seaward area, shore retreat appears to have been less than two feet. This is the only islet aside from the small Lijeron islet ("Bird Islet") where a considerable sand beach development was observed or retained. Characteristically, this sand is on the lagoon beaches, some of it overlying beach rock.

In the interior the only morphological change resulted from the excavation of holes or pits when falling trees brought out with their root clumps large amounts of gravel and soil held by the roots. Since many trees were toppled, the topography is very uneven where this occurred. Pandanus trees were mostly snapped off below their crowns, with roots and main trunks still standing although dead. Where they were killed, coconut trees tended to be uprooted rather than snapped off below the crowns. Many of the breadfruit trees likewise had all major limbs broken off, but the trunk with remnants of limbs remains standing, with roots still in situ. Where this occurred, the tree trunks and remnant limbs are re-sprouting leaves. Even those breadfruit trees that were overturned but which retained some large roots underground are re-growing leaves.

In terms of the most important tree types, the Pandanus suffered most destruction, up to an estimated 90% of these trees being killed on most of the islet except along the lagoon shore where low young trees suffered less damage. The coconut trees at the south end of the islet between the large mangrove depression and the shore suffered up to two-thirds loss. North of the large mangrove depression about half of the coconut trees were toppled. A large grove of large Pandanus occupied the area west of the northern third of the large mangrove depression. Almost all had their crowns and limbs snapped off. Further damage had been inflicted in this area by uncontrolled burning of the fallen fronds and trees. This burning also affected coconut trees still living and some young coconut sprouts.

The mangrove and Pemphis trees fringing the southern end of the mangrove depression appear little damaged by the violent wind. Bananas blown over and killed in the northeast quarter of the islet have re-sprouted young plants from their roots.

Salt water from the oceanside during high tide probably infiltrated the mangrove depression, because the land area west of the depression is made up of boulders up to 8-10 inches in diameter and probably allows relatively free water movement through it.

Where the small-boat from our schooner landed, about 350 feet from the southeast bend of the islet, two large Calophyllum trees and one large Hernandia sonora tree remain growing on the strand, having re-sprouted leaves from the branches and trunks.

In conclusion, it appears that of all those islets examined by the writer, Majurirek escaped with the least damage to its soil and economic plants.

IV. ISLAND STRUCTURES AND THEIR MODIFICATION

Edwin D. McKee

Development of islet strata

The peripheral reef of Jaluit Atoll, like that of other atolls, is composed of rigid, wave-resistant skeletons of corals and coralline algae, with clastic particles or unbroken shells and skeletons of benthonic organisms partly or entirely filling cracks and interstices. In contrast, rocks that rest upon these reefs and that normally form the islets rising above them are very different structurally and texturally. Such rocks consist entirely of accumulations of detrital materials, ranging from sand to boulder size, which are cemented to varying degree. These rocks may or may not exhibit well-developed stratification. Bedding is poorly defined and inconspicuous where coarse material has been laid down in broad sheets or as mounds; it is prominent and in the form of cross-stratification where the normal sorting processes of a beach have been responsible for its development.

The forming of islands upon the peripheral reefs of atolls generally is attributed to the accumulation of detrital debris, at a particular stand of sea level, following initial development of a surface irregularity or nucleus for concentration. Should sea level rise suddenly and appreciably, a probable result would be rapid upward growth of reef-forming organisms so that even the former island area might be covered with the new reef rock; should sea level go down the island doubtless would be destroyed by subaerial processes of erosion. With a relatively constant position of sea level, however, an island may be expected to develop, within certain limits, as a result of geological processes operating under two types of conditions: (1) the normal, day by day processes of deposition and erosion resulting from waves, tides, longshore currents and other regular controls; (2) the occasional great storms which act violently and abruptly modify the environment.

To interpret correctly the history of any particular islet on an atoll, the processes operating under each of the two conditions cited above must be understood and appraised and criteria must be established for recognizing the deposits formed in each instance. Clearly, most islets are formed of deposits representing both normal and storm conditions, but the proportions attributed to each on any particular islet vary widely.

In general, the deposits of normal sediments on an islet consist of sand and small gravel with good sorting and well-developed cross-stratification. Constant reworking by waves and tides tends to remove the very fine materials (below sand size) and to separate fine gravel and sand into distinct layers. Because permanent accumulation of sediments is largely in the lee of the islands, such sediments continuously contribute to a leeward extension of beach deposits and therefore islets normally build in that direction.

Islet deposits developed during major storms, in contrast to those formed in normal times, consist dominantly of gravel, including much of boulder dimensions, that appears to be the product of mass or collective movement. They form ridges along the windward shores and sheet or blanket deposits across large parts of islet interiors. They may also form temporary ridges out on the reef flat. In general, these deposits are characterized by relatively poor sorting and rude stratification, but commonly by fair to good imbrication among flat gravels. Removal of sand-size and smaller particles through winnowing action is normal.

The past history of certain islets on Jaluit Atoll can be deduced in part through examination of sections both in natural exposures and in man-made wells and trenches. On the islet of Jaluit, at Jabor, for instance, exposures in a section (Figs. 14, 15B) across the northeastern part, immediately southwest of the inhabited area, show consolidated, cross-stratified lime sandstone and lime gravel, with laminae dipping lagoonward, only 350 feet from the present seaward margin of the islet as well as near the present lagoon margin. These once-buried remnants indicate the extent to which beach sands have migrated across the reef in this area during early history of the islet.

Also on Jabor, but in a narrow section about a mile farther southwest, a trench dug across the land almost to low tide level illustrates that here, on the other hand, little or no beach sand development is represented (Fig. 15A). This section shows that above typical reef rock in the bottom is a 3-foot layer of brown, well cemented conglomerate, apparently formed under storm conditions during an early stage in the development of this islet. White, poorly consolidated but otherwise similar gravel above apparently had a similar origin at some later date. Thus, in this part of the islet there is no evidence of rocks having been formed by the normal beach accumulation of fine sediments.

Studies on Mejatto Islet illustrate variations during early stages of development in relative contributions of the two types of deposits (normal and storm) similar to those described from Jabor (Figs. 14, 15C-D). The transport of materials towards and into the lagoon is evident from a comparison (cf. Fig. 16) of aerial photographs made prior to OPHELIA (in 1944) and afterwards (in 1958).

Modifications of islet strata resulting from typhoon

A principal objective of the present study has been to determine and record the effects of Typhoon OPHELIA on the geomorphic and structural features of islets on Jaluit Atoll. This has been accomplished by examining in detail, measuring, and plotting in cross-section available data for two islets -- Jabor and Mejatto -- known to have been especially hard hit and awash during the storm. Effects of the typhoon on these islets include both accretion and removal of material and an attempt is made to indicate the distribution and extent of these changes.

Sedimentary deposits, adding to the bulk of Jabor and Mejatto Islets and attributed to Typhoon OPHELIA (possibly also, in part, to the storms of 1957) consist of very slightly weathered or unweathered gravels ranging from pebble to boulder size with very little interstitial sand or other fine particles. They consist in part of material torn loose from the reef front.* Such fresh gravels are readily recognized by color, being uniformly white, in contrast to older gravels that are gray or brown either as a result of algal covering or of weathering in a soil zone. Imbrication is commonly developed among flat gravels, with surfaces dipping in the direction from which the storm waters advanced.

Based upon their geomorphic position, gravel accretions of the typhoon may be divided into three classes. These are (1) gravel tracts that locally form bars on the seaward parts of the reef, (2) shore ridges, referred to as ramparts by many geologists, and (3) gravel sheets or blanket deposits.

Gravel tracts were especially well developed on the reef flat seaward of Jabor Islet (Fig. 15A-B, Pl.I-a,-b), where for most of its length they formed a ridge 8 feet high and 45 to 60 feet wide; they were less well developed seaward of Mejatto Islet. In both places they contained abundant blocks and boulders from one to five feet in diameter, many of which were recently derived from the reef front as shown by their fresh, uneroded surfaces and by the types of coral represented. They had been transported landward as shown by sections across the ridge near Jabor where conspicuous imbrication of large slabs dipping seaward, constitutes the principal structure. At the time of examination, three months after Typhoon OPHELIA, gravel in these tracts had already migrated toward the islet a considerable distance, according to observations of Mackenzie and others who have been on the ground during that interval, and there seems little reason to doubt that normal wave processes will eventually carry them further back and add them to the seaward deposits of the islet.

Shore ridges, as exhibited on the seaward sides of Jabor and Mejatto Islets, are in all essential respects, except location, like the gravel ridges on the reef. They represent an ultimate in accumulation and piling up of coarse debris. They rise higher and contain larger boulders than other geomorphic forms on the islets and indicate the maximum storm concentration along the islet front. Structurally also they appear similar to the gravel ridges or the reef and probably are enlarged by material from these when landward migration has continued sufficiently.

The most significant additions, quantitatively, to the islets during Typhoon OPHELIA, are the blanket deposits of gravel, here termed gravel sheets. These extend as thin layers of white, little-weathered gravel across large parts of those islets that were inundated by storm waters and they appear to have been spread out and deposited in the manner of river flood or glacial outwash plains. Examples on Mejatto Islet (Fig. 16, 17) begin on the seaward side immediately lagoonward of the shore ridge or of scour channels and plunge holes as layers of loose gravel a few inches thick and in places they extend two-thirds or three-fourths of the distance across the islet. They end abruptly, forming a ledge or nearly vertical drop of two or three feet along a sinuous front.

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* This also is Banner's conclusion, see p. 76.

Texturally they are distinctive because of the absence of sand or other fine sediment as matrix. Structurally they form a single bed or layer, but commonly show imbrication of flat slabs within.

Gravel sheets spread over the islets contain particles that vary considerably in size from place to place as shown on Mejatto and Jabor but, in general, the particles in these sheets are considerably finer than gravels of the shore ridges and beach tracts. The gravel sheet appears to have been derived from at least three sources: (1) The outer reef area; (2) earlier shore ridges; and (3) reworking and redistribution of gravel of older sheets, with a winnowing away of soils and fine materials. It was not possible during the present study to determine the relative contributions from each of these sources. A significant observation, however, is that enough gravel was introduced from outside the islet in most parts of the sheet to raise appreciably the general island level in those places and to leave a new stratum of gravel as a record.

Although a considerable amount of sediment, nearly all coarse, was deposited on islets by the floodwaters developed during Typhoon OPHELIA, notable erosion also resulted from these waters. Evidence of such erosion is especially conspicuous in areas on the islets that apparently were occupied by relatively weak sediment adjacent to resistant surfaces. On both Jabor and Mejatto Islets, scour trenches several feet deep were cut into unconsolidated sand deposits landward from and parallel to beds of resistant beach rock that dip toward the sea (Fig. 17). On Mejatto many plunge holes were developed, one of them six feet deep, in weak deposits of sand to the lee of areas tightly bound by the root systems of trees (Fig. 17A-B). Thus, with the advance of water from seaward, a selective scouring developed in unprotected areas southwest of obstructions on the seaward sides of the islets.

Erosion also was considerable in areas bordering the lagoon shores of islets, especially between the margins of newly formed gravel sheets and resistant beach rock of the lagoon edge. In such areas water apparently concentrated in channels to scour out large plunge holes that have subsequently formed tidal pools (Fig. 15D).

A very large amount of fine sediment, especially of sand size, must have been removed from the islets of Jabor and Mejatto by flood waters of Typhoon OPHELIA. These fine sediments were winnowed out of the sandy gravel of the island and were largely stripped from former sand areas. At present the only significant sand areas exposed on these islets are in the bottoms and sides of deep scour channels and undercut areas around trees and beach rock. Some of the large amount of sand that apparently was once present, judging from remnants, now forms bars that extend out into the lagoon at various places; some of it constitutes submarine offshore bars (Fig. 14) formed by waves. The great bulk, however, presumably has been carried into the lagoon whose floor is now considered to have been raised appreciably.

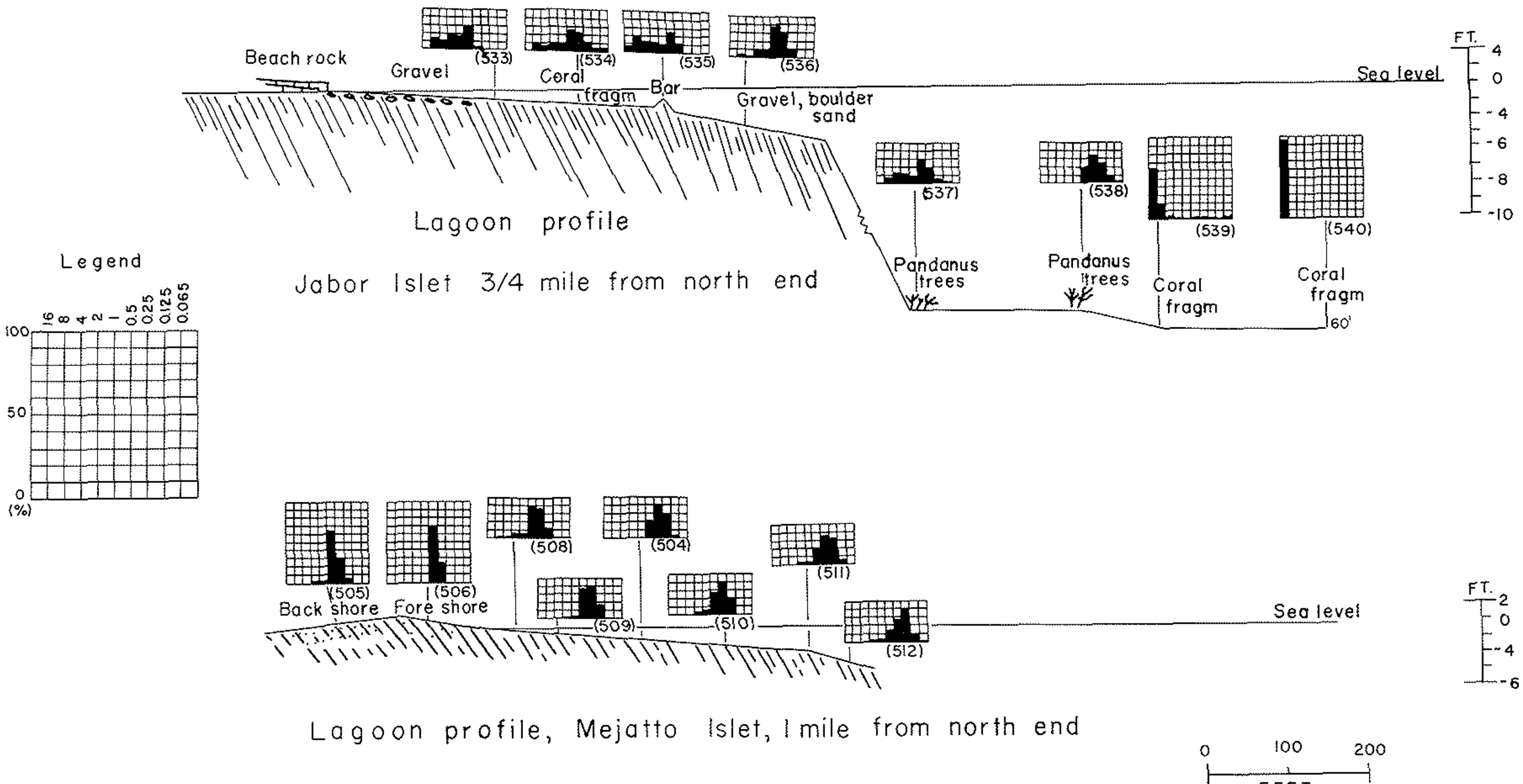
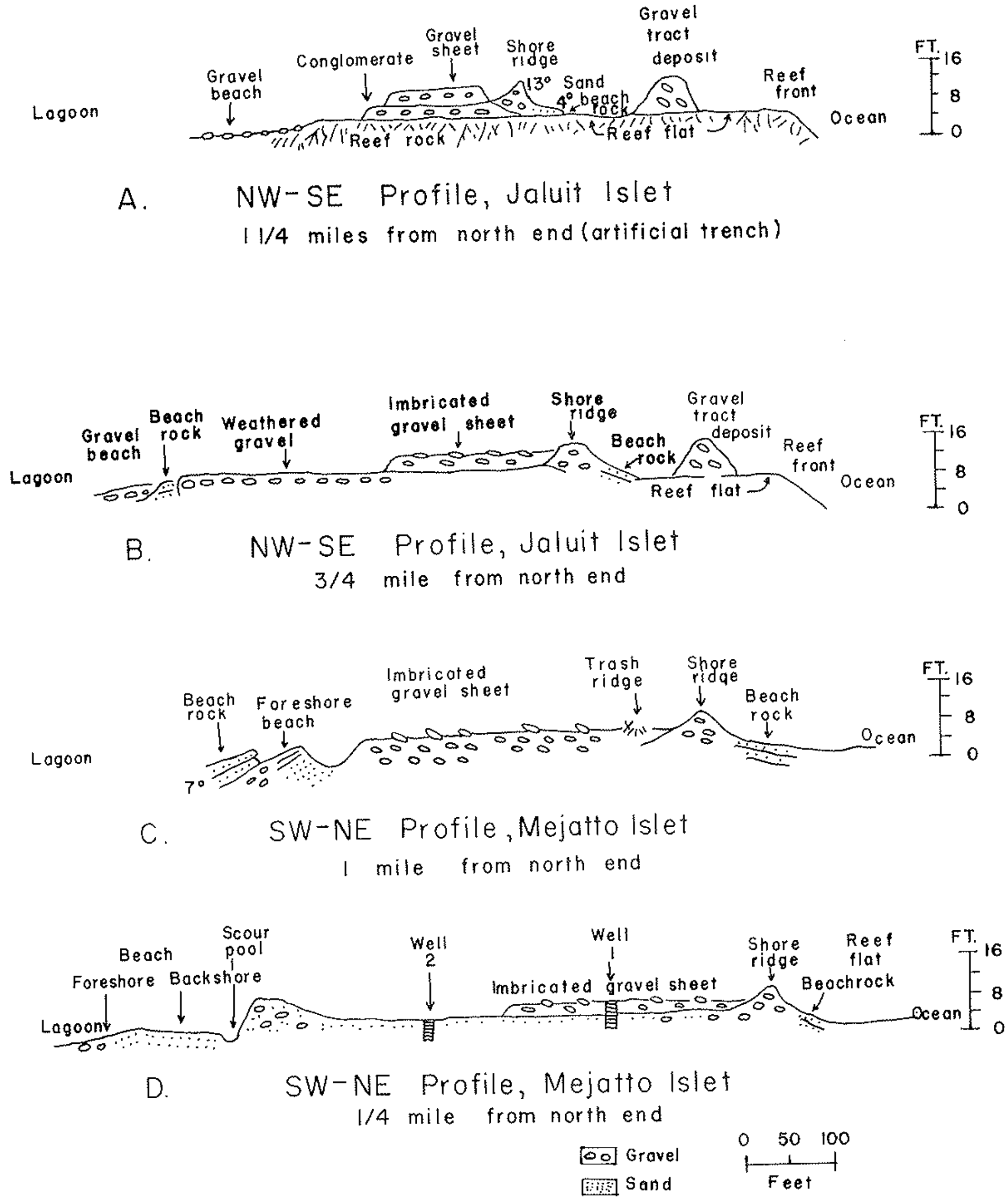
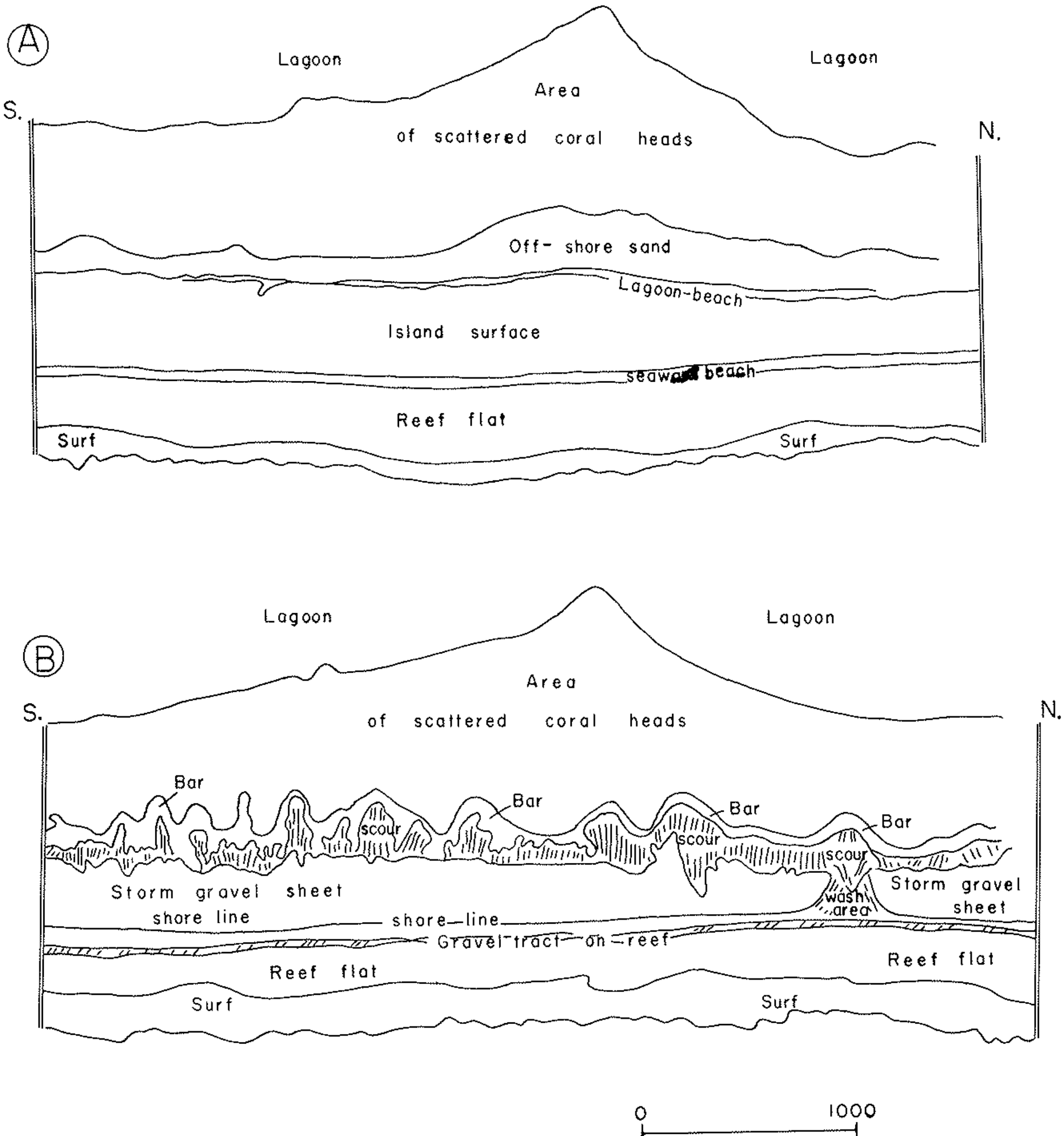

Beach rock
Gravel
Coral
fragm
Bar
Gravel, boulder
sand
(533)
(534)
(535)
(536)
(537)
(538)
(539)
(540)
Sea level
FT.
4
0
-4
-6
-8
-10
Pandanus
trees
Pandanus
trees
Coral
fragm
Coral
fragm
60'
Lagoon profile
Jabor Islet 3/4 mile from north end
Legend
16
8
4
2
1
0.5
0.25
0.125
0.065
100
50
0
(%)
(505)
(506)
(508)
(504)
(509)
(510)
(511)
(512)
Back shore
Fore shore
Sea level
FT.
2
0
-4
-6
Lagoon profile, Mejatto Islet, I mile from north end
0
100
200
FEET

FIGURE 14



SECTIONS ACROSS JALUIT AND MEJATTO ISLETS

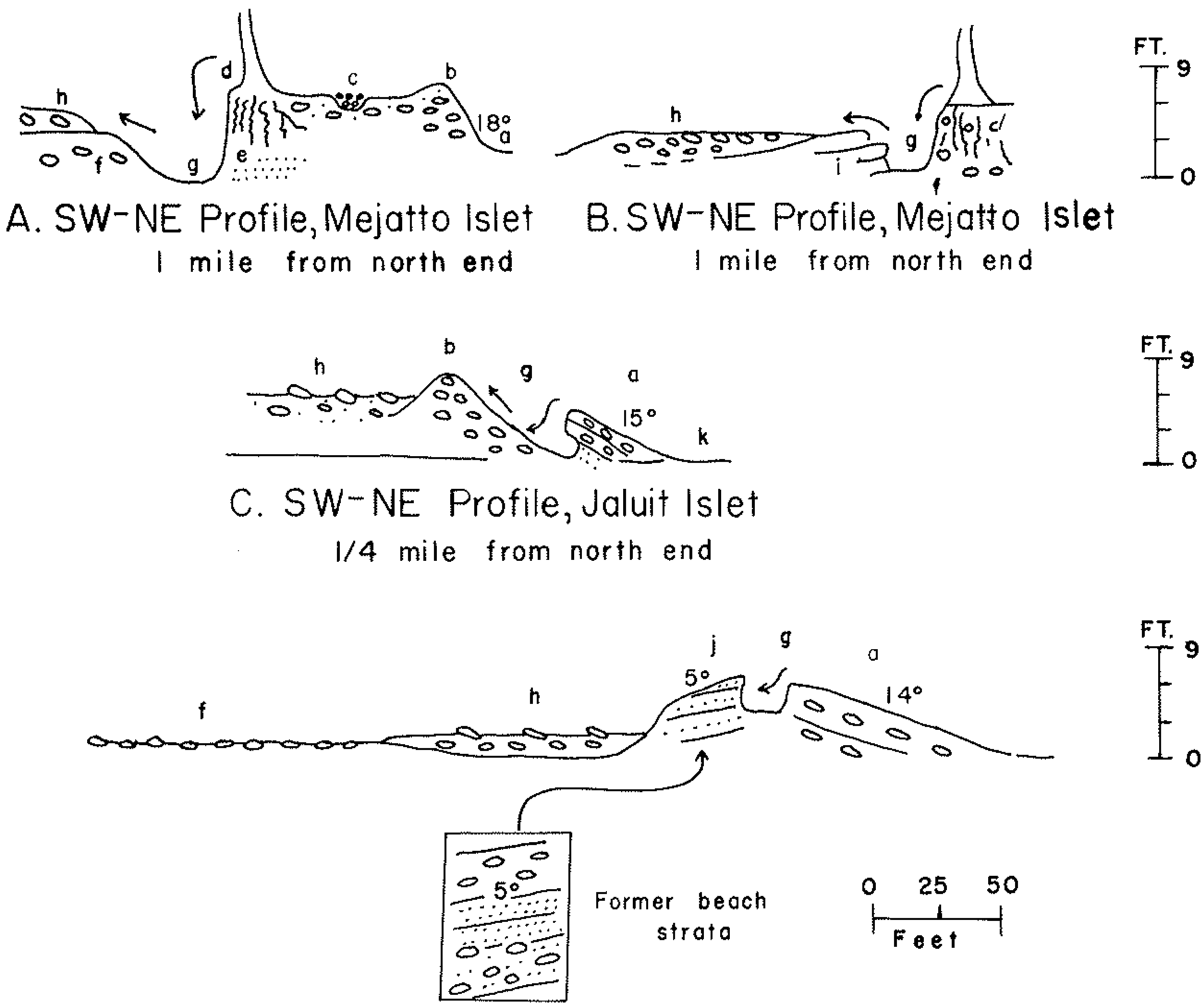
FIGURE 15



Section of Southern Mejatto A: 1944 B: 1958

FIGURE 16

FIGURE 17



D. SW-NE Profile, Mejatto Islet
1 1/2 miles from north end

SCOUR CHANNELS AND GRAVEL DEPOSITS FORMED BY TYPHOON OPHELIA ON JALUIT AND MEJATTO ISLETS

a. Beach rock
b. Gravel shore ridge
c. Debris, mostly logs, from typhoon
d. Roots of coconut tree
e. Unconsolidated sand
f. Weathered gravel, unconsolidated
g. Scour pit or scour trench from typhoon
h. Gravel sheet from typhoon
i Beds of conglomerate
j Sandstone, former beach
k Reef flat
↘ Direction of water movement

V. REMOVAL OF FINE SEDIMENTS FROM ISLETS

Edwin D. McKee

Sand and soil are nearly absent on Jabor and Mejatto Islets, both of which were awash during Typhoon OPHELIA. That such sediments formerly constituted significant parts of the surfaces of these islets is indicated by the prevalence of sand and soil on other islets, e.g. Pinlep and Majurirek, which were not flooded, and on the unflooded northern end of Mejatto Islet. Not only has sand that presumably once formed beaches along these islets largely been removed, but also sand and soil appear to be thoroughly winnowed out from among the cobbles and pebbles that now form a gravel sheet across much of these islets.

The destination of fine materials removed from the islets by storm waves has been determined by investigations of two types. First, a study has been made of sediments from the lagoon shore outward to determine the present position of various size-grades of material. Second, a comparison has been made of offshore geomorphic features of 1944 with those of 1958 through a comparison of aerial photographs.

The lagoon area off Jabor Islet was selected for examination of bottom sediments because it represents a place in which storm intensity and islet flooding had reached a maximum. Analyses of samples at 100- to 200-foot intervals from the shore outward and from depths down to 60 feet were made (Fig. 14). These show only coral gravel from the shore line outward 180 feet, poorly sorted lime-sand between 180 and 1000 feet, and an accumulation of leaf-like and branch-like coral fragments (*Montipora* sp. and *Acropora* sp.) beyond 1000 feet. This distribution is attributed to Typhoon OPHELIA. The lagoon beach with its lack of sand is in contrast with lagoon beaches developed by normal wave and tidal action. Poor sorting of the offshore sands and a lack of progressive decrease in median size with depths and distance outward suggest rapid deposition with consequent mixing. In those respects they differ considerably from offshore sediments reported from Kapingamarangi Atoll formed under conditions of normal sedimentation(McKee, Chronic, and Leopold, 1959, figures 5, 7, 8, and 9).

Additional features of the lagoon floor off Jabor Islet attributed to Typhoon OPHELIA are an offshore sand bar or ridge, parallel to the shore at 400 feet out, and a large accumulation of *Pandanus* trees from the land that rest on the sand floor at the 50-foot level, immediately beyond a steep drop-off 600 feet from shore (Fig. 14).* Thus the storm has left a record offshore consisting of poorly sorted fine sediments and land-derived materials which, if buried and preserved, will appear very different from the normal offshore deposits.

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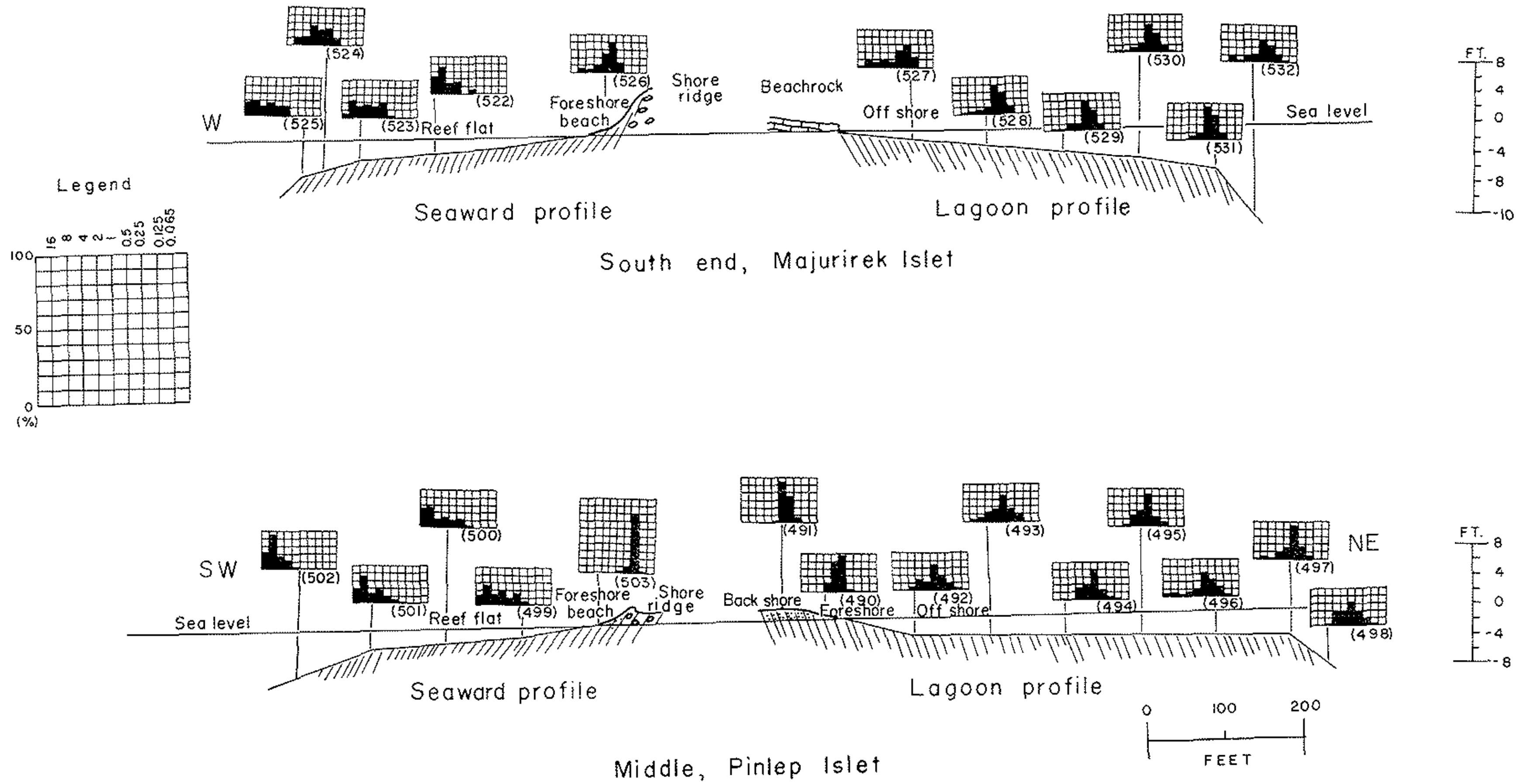
* See Banner's remarks, pp. 77-78.

Pinlep and Majurirek Islets, where the typhoon effects were great but where flooding of the land did not develop as on Jabor, were also studied from the standpoint of lagoon sediments. Relatively little fine sediment was removed from these islets. Nevertheless, the offshore sands are poorly sorted (figure 18) as on Jabor, and seem to indicate a considerable amount of mixing as far out as samples were taken, 600 to 700 feet, and at depths as great as 15 to 25 feet. In contrast, lagoon beaches on these islets were formed of sand, analyses of which show good to fair sorting similar to that of beaches developed under normal conditions of reworking by waves and tides.

Constituents of offshore sand in the Jaluit Lagoon are shown by sample counts to consist largely of broken and worn pieces of coral, although mollusk shell fragments are also very common in all size grades. The tests of foraminifers, relatively uniform in size, make up more than 50 percent of the particles in the coarse-grain size, but are scarce in other size grades. Other contributions, including sea urchin spines and sections of Halimeda, are quantitatively unimportant. Comparison of these sediments with those accumulated at Kapingamarangi Atoll in similar locations but under normal conditions of waves and currents, suggest that the proportionately smaller amount of foraminifera in the very near-shore waters and their correspondingly greater numbers far out from shore at Jaluit are direct results of redistribution by the typhoon (McKee, Chronic, and Leopold, 1959). The relatively larger amount of coral debris may also be a result.

Studies of bottom sediments on seaward sides of islets on Jaluit Atoll were attempted for comparative purposes. On Jabor and Mejatto Islets sand was absent, probably having been removed by the storm waters that swept from these reef flats entirely across the islets. On Pinlep and Majurirek Islets, where storm effects were less intense, fine sediment of the reef flat was poorly sorted and relatively coarse, median diameters being greater than sand size (figure 18). The sediment was composed largely of coral fragments, contained some broken mollusk shells and Halimeda segments, but no foraminifers. Apparently most of the fine sand, if formerly present, had been removed.

Sand beaches are at present non-existent along much of the lagoon side of Jabor and Mejatto Islets. Aerial photographs taken since Typhoon OPHELIA reveal that a considerable area formerly occupied by beaches on these islets is now scoured to reef rock surface and sand deposits currently form loops, or bars in the offshore waters, each bar appearing as a half circle, convex outward. This pattern is especially well developed and forms a conspicuous feature along the middle part of Mejatto Islet (Fig. 16). Gentle lagoonward slopes and steeper shoreward sides on these bars, as seen in the photographs, are believed to result from gradual reworking of the sand masses by incoming waves off the lagoon.



W
(524)
(525)
(523)
Reef flat
(522)
(526)
Foreshore beach
Shore ridge
Beachrock
(527)
Off shore
(528)
(529)
(530)
(531)
(532)
Sea level
Seaward profile
Lagoon profile
South end, Majurirek Islet
FT.
8
4
0
-4
-8
-10
Legend
16
8
4
2
1
0.5
0.25
0.125
0.065
100
50
0
(%)
SW
(502)
(501)
(500)
Reef flat
(499)
(503)
Foreshore beach
Shore ridge
Sea level
(491)
Back shore
(490)
Foreshore
(492)
Off shore
(493)
(494)
(495)
(496)
(497)
NE
(498)
Seaward profile
Lagoon profile
FT.
8
4
0
-4
-8
0
100
200
FEET
Middle, Pinlep Islet

FIGURE 18

VI. GROUND WATER

Edwin D. McKee

Although no studies of ground water had been made on the islets of Jaluit Atoll prior to the coming of Typhoon OPHELIA, dug wells have for many years furnished potable water, so fresh water lenses may be assumed to have existed on all but the very small islets. The quality of this water probably was similar, in general, to that reported from fresh water lenses on other Pacific limestone islands. Storm waves of the typhoon, however, submerged many of the islets, so their supply of ground water was locally contaminated and its composition greatly altered by mixing with sea water.

Samples of ground water were collected for analysis in May, 1958, about four months after the storm. These samples were obtained from four wells in existence prior to the typhoon, three wells dug at the time of sampling, one scour pool cut by the typhoon, and one mangrove pond (for location of wells, see Figs. 6, 8, 11, 12, 13). The three test wells and one of the original wells were on islets known to have been covered by a sheet of water during the typhoon (Jabor and Mejatto); the other three old wells were on islets not inundated (Pinlep, Majurirek, Kinajon) and their waters apparently were relatively little changed as a result of the storm.

Temperature and pH readings were taken at each of the wells examined (Table III). Temperatures ranged from 82° F. to 87° F. These were read near the middle of the day and probably are relatively high because all of the wells were in the open, unprotected from the sun, as a result of typhoon destruction of surrounding trees. Well waters ranged from about pH 6.0 to pH 7.0, all of the higher figures representing wells on islets known to have been inundated by typhoon-driven sea water.

TABLE III.--Readings of pH and temperature for well water

Well description	pH	Temperature*
Majurirek	6.0	86
Pinlep	6.5	83
Mejatto well #1	7.0	85
Mejatto well #2	7.0	87
Jabor well #2	7.0	82

* degrees Fahrenheit

Hardness of water (Table IV) in the three samples from islets not inundated by storm waves is less than 500 parts per million; in all others it is greater than 1200 ppm, apparently the result of contamination by sea water. Thus, low calcium and low magnesium in well waters of Pinlep, Majurirek and Kinajon islets probably represent amounts normal for fresh water on these islets; water of similar composition is reported from fresh water lenses in the northern Marshall Islands (Arnow, 1954, p.7) and on Kapingamarangi Atoll (McKee, 1958, p. 267). The amount of calcium and magnesium in such waters, higher than in average fresh water streams and lakes, results from solution of limestone and lime sand of the islets.

Well water from Jabor and Mejatto Islets (Table IV) which were covered by sea water during the typhoon are much higher in both calcium (over 200 ppm) and magnesium (over 170 ppm) than water from the islets cited above that were not inundated. Furthermore, the amount of magnesium in the Jabor-Mejatto samples is essentially equal to or greater than the amount of calcium, a result of contamination, since normal sea water has proportionately more magnesium than calcium, whereas most fresh waters are the reverse.

The extent of contamination by sea water is illustrated by analyses of sulfate (SO_4) and chloride (Cl) for well water from Jabor and Mejatto Islets (Table IV). Both of these islets were covered by ocean water during the typhoon, but apparently the lens on Mejatto with a combined sulfate and chloride content ranging from 10,000 to 15,000 ppm was contaminated more than that on Jabor where it ranges from 4,000 to 5,000 ppm. It is instructive to compare these figures with the 250 ppm sulfate and 250 ppm chloride recommended by the U. S. Public Health Service as the upper limit for water used in normal domestic consumption.

A summary of available data on the ground water resources of Jaluit Atoll after Typhoon OPHELIA is as follows. The fresh water lenses on those islets not covered by storm waters appear to be normal for Pacific atolls and probably were little or not affected by the typhoon. The fresh water lens on Jabor and that on Mejatto, judged by samples from two wells on each, show a sulfate-chloride content far too high for drinking purposes and will require a considerable period of dilution by rainwater to again become potable. How long a period of "freshening" will be needed with present annual precipitation of about 200 inches, is not known, but samples from the four wells in question, collected and analyzed periodically during the coming year should give significant information.

TABLE IV.—Analyses of water samples from original dug wells and test wells and comparative data for a mangrove pool and for normal sea water. (Analyses by U. S. Geological Survey)

LOCATION OF WELL	Chemical Components (ppm)						Physical characteristics		
	Ca	Mg	Na	K	SO_4	Cl	Hardness (ppm)	% Sodium	Sp.Gr.
Majurirek, 190 feet from lagoon beach crest W. end of island center.	102	17	138	11	45	238	324	47	1.000
Pinlep, 190' from lagoon beach crest.	53	8.8	62	5.8	26	62	168	43	1.000
Kinajon, 130' from low water, 99' from ridge on SW islet.	142	27	316	27	102	570	466	58	1.000
Mejatto, well #1, 174' from seaward gravel ridge.	285	529	4900	214	1370	8700	2890	73	1.011
Mejatto, well #2, 301' from lagoon beach crest.	362	888	7550	252	1910	13000	4550	77	1.017
Jabor, well #1, 130' from lagoon beach crest.	223	242	1990	84	535	3390	1550	72	1.004
Jabor, well #2, 265' from lagoon beach crest.	207	174	1500	84	473	2890	1230	71	1.003
Mejatto, water from scour pool on lagoon side of islet behind beach crest.	159	415	3570	147	1010	5950	2100	77	1.008
Majurirek, water from mangrove pond.	376	1090	8700	376	2300	14900	5420	76	1.020
Normal seawater.	400	1270	10560	380	2650	18980	6215	79	

VII. SOILS

F. R. Fosberg

Following Stone (1951, 1953) and Fosberg (1954), the principal soils on Jaluit Atoll fall into five categories: (1) Shioya Series, (2) Arno Atoll Series, (3) Jemo Series, (4) mangrove peat, and (5) stony and very stony complex.

The Shioya soils are gray-brown slightly altered lime-sands with varying amounts of gravel, the A-horizon, colored slightly by humus, varying in thickness, depending on the time elapsed since the last disturbance and type of vegetation. The B-horizon is lacking and the C-horizon is lime sand, not much altered, scarcely distinguishable from beach materials. This soil tends to be peripheral on the islets but may also be found in the interiors.

The Arno Atoll soils have a black or very dark gray A-horizon from 1 to several dm. in thickness. The organic content is high. The B-horizon, again, is lacking, and the C-horizon is similar to that of the Shioya with a gradual transition from the A. This series is found generally in the interiors of islets but may extend almost or quite to the lagoon beach. This soil is unquestionably much older than the Shioya.

The Jemo series (Fosberg 1954) has an A-horizon of pure humus varying in thickness up to a dm. or rarely more. Usually it has a consolidated B-horizon of highly phosphatic material of varying thickness. This lies on a C-horizon similar to that of the two foregoing series. Three areas of this series were found during the present survey, none of them typical. On Lijeron Islet under the Pisonia trees the A-horizon is well developed but somewhat mixed with lime-sand. The B-horizon is only slightly and very locally developed. On Imroj Islet the A-horizon is lacking and the B is eroded and cracked into a boulder-field (Pl. VIII-d). It is on the extreme northwest end of the islet, just south of a small mangrove depression. On Kinajon Islet the A-horizon is lacking in parts, present but rather thin elsewhere. Here the Jemo series occupies slightly high ground inside a roughly crescent-shaped group of mangrove depressions near the outer part of the islet. These soils are of great importance because of their phosphatic B-horizons.

The mangrove peats are soft to firm, red to black, purely organic accumulations found especially around mangrove depressions.

The stony and very stony complex is the undifferentiated gravel of varied sizes found especially in peripheral ridges (often termed boulder ridges or boulder ramparts), sometimes in wider areas. It may be very loose and porous, or may contain fine material, often highly organic, between the stones.

Time was not available for mapping these types, nor for mapping the areas of them that were either buried or stripped away by the typhoon. This damage was not very significant on those islets or parts of islets which were not swept over by waves, especially the islets on the south and west reefs, and presumably in the extreme north of the atoll. On the east reef islets, judging from work on the ground on four islets and aerial inspection of the rest, considerable areas of stony and very stony complex were stripped off, usually exposing either more of the same or beds of poorly consolidated conglomerate (Pls. II-a, V-b). Stripping was rather general along the seaward sides of most of the islets. This rocky material, probably including some freshly thrown up from outside the reef, was mostly spread inland, covering an estimated third or fourth of the total land area of these islets with a gravel sheet that will have to be classified with the stony and very stony complex (Pls. III, VII-b, IX-d, X-b). The buried soils here, at least where examined, were largely Arno Atoll, some Shioya. Lagoonward from the usually abrupt edges of this gravel sheet (Pl. III-a,-b) the Arno Atoll and Shioya soils are in places covered by a few cm. of lime-sand. On these same islets small areas, totaling a considerable amount, were scoured by the waves, removing the A- and often part of the C-horizon.

It is hard to estimate the agricultural significance of this destruction of soils. Unquestionably, where the surface soils have been removed there is a great decrease in fertility. To replace the humus lost from both the Arno Atoll and stony and very stony areas would require fallowing under vegetation for a long time. Even to bring about the slight humus accumulation characteristic of the Shioya soils will require a considerable fallow period. Analyses of similar soils from other atolls show that a large part of the mineral nutrients is concentrated in the more highly organic layers. Cessation of the common Marshallese practice of burning trash and brush would greatly hasten the needed humus accumulation.

The areas stripped down to consolidated material will certainly not be of any immediate agricultural use. Any vegetation that can be encouraged to grow on these areas will be of benefit, both in helping to disintegrate the rock and in accumulating wind-blown material and humus.

The areas covered by fresh gravel sheets would not seem to be very promising for any sort of agriculture. However, if the practice of planting coconuts in 3' x 3' x 3' pits is followed it is probable that in many places these pits may extend down through the gravel layer into the buried Arno Atoll or Shioya soils. The overlying material would then be of no consequence except to make digging more laborious.

The mangrove peat was not noticeably influenced by the typhoon except that in several places small areas were covered by deposits of wave-carried gravel (Pl. III-c,-d). Usually great quantities of vegetable trash were dumped into the mangrove depressions by the waves (Pl. V-c). This will, of course, eventually add to the peat.

An interesting feature was the buried A-horizon, at somewhat less than 1 m. depth, encountered in a well dug under Dr. McKee's direction near the center of the northwest end of Mejatto Islet. This apparently indicates the burial, at some earlier time, of an Arno Atoll soil, perhaps by a typhoon. The overlying material is a gravel similar to that of the gravel sheets laid down by the waves of Typhoon OPHELIA.

Another item of interest is the abundance of pumice fragments scattered inland wherever the land was inundated. Some of these were undoubtedly washed out of preexisting gravel ridges and soil layers, but much of the pumice probably came from the beaches, where much has accumulated, floated from across the sea, especially after the eruption in 1952 of San Benedicto Volcano, off the Mexican Coast (Richards 1958). That this pumice contributes to the fertility of the soil is indicated by the proliferation of roots tightly surrounding particles of pumice buried in atoll soils, observed both on this survey and in the northern Marshalls. Pounded pumice is used to fertilize gardens and taro pits in various atoll groups.

The Germans and Japanese had brought large quantities of volcanic soil from Ponape and spread it over certain areas on Jabor. One of these patches has now settled so that it is covered by salt water at the highest tides. Although all of the imported soil was inundated by sea water during the typhoon, it seems mostly still there and is now supporting a rank growth of weeds.

The overall consequences of the typhoon are unquestionably a loss in productive soils. However, this may be mitigated to some extent if the trash (Pl. VI-d) strewn over the islets by the typhoon and that accumulated under normal circumstances are allowed to rot, rather than being burned as has already started in several places.

VIII. FLORA AND VEGETATION

F. R. Fosberg

The indigenous flora of Jaluit Atoll is an enriched strand flora, typical of that of wetter atolls in the west central Pacific. In addition to most of the ordinary widely distributed strictly strand species that are to be expected in tropical maritime situations, wet sheltered forest sites have permitted the establishment of certain more mesophytic species not ordinarily found on strands. Peperomia ponapensis, Procris pedunculata, and Vittaria elongata are examples of these. The Marshallese made their contribution to the flora by bringing in such economic plants as the breadfruit, the taros, at least some kinds of pandanus, the coconut and others as well as a few weeds. Since the arrival of the first Europeans many weeds, some new food plants, and an array of ornamentals have been introduced, either deliberately or accidentally. The only peculiarity of the Jaluit flora is the presence of an unusually large number of these exotics resulting from the fact that the atoll was the site of the German and Japanese administrations and of a short-lived agricultural experiment station started by the present administration. A list of the known flora is to be published in another number of the Atoll Research Bulletin (see also Appendix I).

The islets of Jaluit Atoll, before the typhoon, had mostly been planted to coconuts and breadfruit. Except for the plantations only a few important vegetation types were present, and these in small areas. They were Pemphis forest or thicket, Pisonia forest, mangrove depressions, taro pits, and fringes of dense scrub along the windward sides of some islets, outside the plantations. A few open grassy areas represented abandoned gardens, as on Kinajon Islet and possibly Pinlep Islet.

The plantations (Pl. V-a,-b,-c) were either coconut, coconut and breadfruit, or rarely just breadfruit. The trees were from 15 to 25, rarely 30 m. tall, closely spaced, usually less than 6 m. apart. A scattered understory of Pandanus (Pl. V-c) up to 5 to 8 m. tall occurred in most parts, most of the trees being of varieties yielding edible fruits. Other small trees and shrubs, especially Morinda and Allophylus, were present but irregularly distributed, depending on the local productivity of the land and on the diligence of the plantation owners in clearing out the undergrowth. A ground cover of grasses, sedges, Wedelia, ferns, and other herbs was general. Epiphytic mosses and ferns were common, especially in denser parts of the plantations.

Around the edges of the plantations, especially on the gravel ridges on the windward sides of the islets, was usually a narrow zone of scrub composed of Scaevola sericea, Tournefortia argentea, Guettarda speciosa, Terminalia samoensis, and other woody species. In some very rocky areas, both in the scrub and in the coconut groves, Fleurya ruderalis, Boerhavia tetrandra, and Euphorbia chamissonis were common, forming a scattered ground layer. In a few spots in the coconut plantations near the windward side were groups of large trees of Barringtonia asiatica. Intsia bijuga and Ochrosia oppositifolia were also present in small groups.

Around villages, isolated dwellings, and grave yards were a few species of ornamentals, planted as scattered trees or bushes, hedges or borders, or in small gardens. Most of them produced flowers used for leis or garlands. Especially common were Pseuderanthemum, Plumeria, Crinum, Acalypha, Zephyranthes, Polyscias, Mirabilis, Catharanthus, Asclepias, Gomphrena, and Ocimum. Such food plants as Pandanus (Pl. V-a), bananas, papayas, and squashes, also were very common in the vicinity of dwellings.

On Jabor, the northern extremity of Jaluit Islet, where both the Germans and the Japanese had their headquarters, a great many cultivated exotic species were planted. Volcanic soil was brought from Ponape and spread in certain spots, making possible gardens with many species not commonly found cultivated on atolls. Certain weeds also became established in Jabor. Several years ago the U. S. Administration started an agricultural experiment station on Jabor, and more plants were brought in. Over a hundred species of cultivated plants and several weeds not normally found on atolls in this part of the world have been reported from Jaluit by German, Japanese, and later writers. Many of these have not persisted, but up to the time of Typhoon OPHELIA a substantial number were reported by Boyd Mackenzie to be growing on Jabor and some had been carried to other islets of the atoll.

In certain places, either interior depressions or marginal places where gravel ridges have cut off areas of reef flat, the water table reaches the surface of the ground. Here coconuts do not thrive well and other vegetation is found. On Pinlep two such interior depressions have been converted to taro pits where the giant taro, Cyrtosperma, is the principal vegetation, along with several weeds characteristic of such habitats. These are, especially, Echinochloa crus-galli, Cyperus odoratus, and Eleocharis geniculata. There may have been others before the typhoon. Other such depressions have mangrove vegetation of one sort or another. Most of the depressions studied have essentially a pure stand of Bruguiera gymnorhiza or Bruguiera with some Pemphis acidula. One had Lumnitzera littorea. Another had Bruguiera with a dense understory of Hibiscus tiliaceus. Still another had Hibiscus only.

Along both seaward and lagoon shores are areas of rock flats of limestone conglomerate with little or no soil. Some such areas were bare or almost so. Others were covered by thickets or scrub forests of Pemphis acidula. One area of rock flat on the lagoon shore near Sydneytown had, in 1946, a sparse stand of a mangrove, Sonneratia alba, almost the easternmost known occurrence of this species.

On several tiny islets coconuts have never been planted in large numbers. Two of these, Ribon and Lijeron, have been examined briefly. The vegetation was largely Pisonia grandis, with Tournefortia, Guettarda, Intsia, and Terminalia samoensis around the shore ridges and Pemphis on rock flats In the interior of Ribon is an open area dominated by Asplenium nidus. Lijeron is the home of large numbers of sea birds, some of which nest in the trees.

The very small islets, though less disturbed, had a very restricted flora, as has been observed elsewhere on atolls (cf. Kapingamarangi, acc.

Niering, 1956). Of the larger islets the broad ones tend to have a larger flora than the narrow ones.

The effects of Typhoon OPHELIA, even on the same vegetation type, or on the same plant, were by no means identical in all localities and parts of the atoll. In general, the islets on the east side of the atoll suffered much more damage to their vegetation than those on north, south, and west. Also, as might have been anticipated, narrow islets or parts of islets were far more affected than broad parts. This was well illustrated on Jaluit Islet, where the narrow parts south of Jabor were in places completely stripped of vegetation (Pl. V-b). Also on Jaluit Islet the difference in damage depending on orientation of the islet is well shown. At the southeast corner of this islet (see Fig. 1) the part running north suffered very severe loss of coconut trees, this continuing southward to the point. On the leg of the islet running westward from the southeast point the damage was conspicuously less, the difference at the time of examination being between a barren expanse of coral with scattered trees and a solidly green islet. The islets along the south and west sides and around the north loop of the reef were generally green, while along the east side only the wider islets were green. This seems well correlated with the exposure of the eastern side of the atoll to a combination of strong winds and great waves which swept over the narrower islets and parts of islets. Some of the broader islets here were only partly inundated, while on the other sides of the atoll most islets escaped serious flooding by the salt water.

This combined action of wind and large waves had several effects on vegetation. Many trees were uprooted, either completely so (Pl. VI-a) and sometimes swept away, or partly so (Pl. VI-b) and remaining in place and frequently still alive. Some were snapped off (Pl. V-d). Branches were broken or torn off of most of those that remained standing (Pl.VI-c). Some exotic plants were killed or their above ground parts killed by salt. In places large scale burial of plants by gravel occurred (Pl.III-a, VII-b). Elsewhere the soil with its vegetation was scoured away (Pl.V-b). Many tree trunks were seen in the lagoon on the shallower slopes along the east side. Masses of vegetable debris were strewn at random on areas that were inundated (Pl.VI-d). Some of this seemed to have washed around and become very worn and battered before it was finally stranded. Enormous amounts of such debris were washed into some of the mangrove depressions (Pl.V-c). It was impressive that not only trees but even shrubs and coconut seedlings were knocked down or dismembered in these areas. However, no particular evidence of abrasion of bark by wind- or water-driven sand and gravel was seen. Defoliation, according to reports, was at least in places complete. Root systems were extensively exposed (Pl.II-c, -d, VII-a).

On parts of the wider islets of the east reef and on the islets on the other sides most or all of the damage to vegetation was by wind. Here the ground vegetation was little hurt. The trees and larger shrubs, however, were seriously damaged, locally almost all trees being uprooted or broken, usually a substantial proportion even in the less affected areas. In some places, as on Majurirek (Elizabeth) and Imroj, trees had fallen in at least three main directions (Pl.VII-c). More usually they were predominantly pointing in one direction. The direction of fall of the trees, and its significance in terms of the storm, have been discussed above by Blumenstock and Wiens. Particular mention may be made of mangrove swamps and Pemphis thickets. Although the trees in these were in places uprooted, more often they were still standing but with their upper parts or branches dead (Pl.IV-d, VIII-c). A significant fact emerging from the observations on these islets that were not covered by salt water is that very serious damage to vegetation may result from wind alone (Pl.VII-d, VIII-a,-b).

Impressions gained of the comparative resistance to wind of different tree species are not very clear, as conditions varied so much locally. No kind completely escaped uprooting and breaking, but Pemphis, Cordia, Calophyllum, and Casuarina* perhaps stood up best, except for Bruguiera, which occurred in dense stands in low spots, where there was some protection. Pandanus (Pl.VII-d, X-c), breadfruit, and Terminalia catappa perhaps fared worst. Very few breadfruit trees with trunks 30 cm. or more in diameter remain standing, and the smaller ones which do remain have most of their branches torn off (Pl.VI-a, VIII-a,-b). Where inundated by salt water, breadfruit trees were killed or almost so. Of the larger shrubs Terminalia samoensis fared by far the best, suffering little damage. Small Pemphis bushes in some places escaped completely; others were snapped off (Pl.IX-a). The reactions of individual species are discussed in detail later on.

Smaller plants suffered perhaps less than others on the islets that were not inundated, but were enormously reduced in numbers on the ones swept by waves.

Recovery was well under way at the time of the survey, little over $3\frac{1}{2}$ months after the typhoon. Most of the dismembered and defoliated trees were putting out an abundance of leafy sprouts (Pl.VIII-b,-c). This was not true of Pandanus, which was scarcely sprouting at all (Pl.VII-d). In the badly hit areas of the east reef most of the breadfruit trees were either dead or very slow in showing signs of recovery, possibly because of the salt water. Elsewhere they were sprouting actively. Many of the trees of all kinds that were completely down but had some roots still in the ground were still growing, some even flowering. Abundant seedlings were seen of Tournefortia, Scaevola, Guettarda, Morinda, and, very locally, Barringtonia, and Pandanus. Many of the herbaceous plants had come up from seed after the typhoon in great profusion in favorable habitats, some of them doubtless greatly increasing their numbers as a result of the thinning of the forest and the consequent lessened shade.

Recovery of individual species is discussed below. In general, native atoll plants and those long cultivated on atolls show active recuperative powers. Some of the planted species came back well enough. Others were doubtless lost. It is difficult to say what, if any, species were completely eliminated, as only a part of the atoll was examined. In addition to such planted things as several palms, two native mangroves, Sonneratia alba and Lumnitzera littorea, may have disappeared. They were

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* But see Wiens, p. 27.--F.R.F.

known on Jaluit Islet only, from one small colony each, and these places were examined without finding a trace of the plants. Of course they may still exist on other islets which have not been explored botanically.

Native agriculture and subsistence plants were badly hit, especially Pandanus (Pl. VII-d), breadfruit (Pl. VI-a, VIII-a, -b), and coconut (Pl. IX-c, -d), but no other food plants of consequence were more than temporarily damaged. Banana shoots and papaya seedlings were coming up in abundance. Squash were growing well. The taro pits were not seriously hurt (Pl. IX-b). These matters will be considered more in detail in the chapter on economic consequences.

IX. TYPHOON EFFECTS ON INDIVIDUAL SPECIES OF PLANTS

F. R. Fosberg

Observations were made on the effects of the typhoon on many individual species and their recovery. These are indicated in the following systematic list of species. The list includes all plants which were known or thought to be present on the atoll in 1946 or thereafter. Various species reported earlier but of which there are no recent records are omitted. Information has been supplied by Prof. Harold St. John and by Boyd Mackenzie, as well as taken from records gathered by the writer on a visit in 1946 and in the present survey. Names have been adjusted to correspond with those considered correct at the present time.

Asplenium nidus--Very frequent locally, terrestrial and epiphytic. Reduced in numbers as trees on which it was growing were swept away or as ground was covered by gravel, but still very common except where islets were seriously swept by waves.

Nephrolepis acutifolia--Common locally, epiphytic, especially in and around mangrove depressions. Reduced in numbers where trees on which it was growing were swept away and individual clumps killed or seriously injured by salt or wind, but generally recovering, still common in protected places.

Nephrolepis hirsutula--Common locally. No injury noted but doubtless reduced or eliminated where islets were seriously swept by salt water.

Polypodium scolopendria--Generally very common, terrestrial and on bases and trunks of trees; still so except where islets were swept by waves. Buried by gravel in places, but otherwise no injury noted; doubtless reduced in numbers where host trees were swept away.

Pteris tripartita--Occasional and very local in protected places; terrestrial. No injury noted but doubtless reduced in numbers by destruction of habitats.

Vittaria elongata--Rare, epiphytic. No injury noted except that some clumps may have suffered from exposure to sun or salt.

Cycas circinalis--Planted in Jabor only, rare. Leaves seriously battered, one plant, at least, uprooted.

Pandanus tectorius--One of the commonest trees generally, forming part of the vegetation on the seaward margins of plantations and the principal component of the understory. Trees generally very seriously battered, some uprooted, many more broken off between stilt roots and first branches, or with most of the branches broken off. Branches either broken in leafless part or torn from trunk. Sometimes a few tufts of frayed green leaves left on trees, especially on those in more sheltered places. Even the trees otherwise in fair condition in least affected areas had leaves broken. No sprouting seen where breaks occurred below the leafy portions of branches or in trunks. The few sprouts noted were from the soft leafy parts of branches. Apparently the lower parts of branches, trunks, or roots have no capacity for sprouting. Young plants below 1.5 m. tall on the areas not swept by waves not particularly injured.

Thalassia hemprichii--In elongate patches on lagoon bottom in about 1 m. of water. No effects noted.

Cenchrus echinatus--Common locally. Absent from many places swept bare by salt water in situation where it would be expected to be abundant.

Cynodon dactylon--Scarcely seen, not known if it was common or not before typhoon; no obvious effects seen.

Digitaria pruriens var. microbachne--Widely distributed but local, not abundant. No effects noted, but some habitats undoubtedly rendered less favorable by removal of soil and flooding by salt water.

Echinochloa crus-galli--This species seen only in taro pits, where it forms large masses. No effect noted.

Eleusine indica--Very common. No obvious effects; but doubtless some habitats made less favorable and others more favorable, resulting in elimination where soil was removed or buried and greater abundance where trees were thinned and soil only moderately disturbed.

Eragrostis amabilis--Very common. No effects noted that might not have resulted from mere dry weather.

Lepturus repens--Very general, locally abundant. In places undoubtedly buried by gravel sheets; in many places removed by wave erosion; otherwise no effects noted. New open habitats will doubtless result in increase of this species in the near future.

Paspalum conjugatum--Only seen on Pinlep Islet, where it was very common. No effects noted, but thinning out of coconuts may well encourage this species, which was luxuriant in areas on Pinlep where many trees were knocked down.

Paspalum distichum--Found in brackish depressions. No effects noted, but scour pits may become habitats for this species.

Sorghum bicolor--Very rare, on Jabor only. No effects noted, plant very rarely persisting.

Thuarea involuta--Abundant, generally distributed. Undoubtedly buried in large areas covered by gravel sheet and removed in seriously eroded areas. Otherwise no effects noted except some browning of leaves, possibly by salt water.

Cyperus compressus--Local, in Jabor only. Inundated; no effects noted. These plants possibly grew from seeds since the typhoon.

Cyperus javanicus--Local, in low or wet places. No effects noted, but possibly some habitats buried by gravel or eroded away. Scour pits and channels may eventually become new habitats for this species.

Cyperus kyllingia--Occasional, only seen on Jabor. No effects noted except some browning of leaves and dwarfing of plants in areas flooded by salt water.

Cyperus odoratus--Seen only in taro pits. No effects noted.

Cyperus rotundus--Local, in Jabor village only. No effects noted except that only young shoots were seen. The tubers undoubtedly survived the inundation by salt water.

Eleocharis geniculata--Seen only on mud in taro pits. No effects noted.

Fimbristylis cymosa--Very general, especially in open places, locally abundant. Some stands of this species doubtless buried by gravel sheets, others eroded away by waves; gravel sheets doubtless will afford extensive new habitats. No effects noted in areas not affected by waves.

Cocos nucifera--Planted over entire atoll (Pl. IV-a,-b,-c). These trees showed the most conspicuous damage of all, because of their size and abundance. Thousands of trees were either uprooted or snapped off part way up the trunk (Pls.II-c,-d,V-d,VI-a,-b,-c,VII, VIII-a,IX-c,-d,X-a). On the islets along the east reef of the atoll the majority of coconut trees are down; on some islets almost all. On the south reef, west reef, and at the northern end many are down, but there are still a majority standing in most places. The nuts, of course, are stripped from most of those left standing. However, on the less damaged islets there are occasional trees with nuts in drinking condition and some trees are flowering. A surprising thing was the extent to which young palms, with scarcely any trunk, were flattened out, especially where hit by waves; here more were down than standing. Ripe nuts lying on ground are germinating in great abundance wherever they have not been picked up.

Elais guineensis--Planted on Jabor. The only tree was destroyed, apparently by waves.

Pritchardia pacifica--Planted on Jabor. The only tree was destroyed, apparently by waves.

Alocasia macrorrhiza--This was common generally on larger islets; seems not to have been much affected, even where inundated.

Colocasia esculenta--Very rarely noted; seems not to have been much planted by the Marshallese. No effects noted; not inundated.

Cyrtosperma chamissonis--Abundant in taro pits on Pinlep Islet (Pl. IX-b). The leaves were apparently destroyed by the storm but were sprouting up again. Leaves at time of survey up to 4-5 dm. high; not inundated.

Epipremnum pinnatum--Was common in experiment station grounds. Occasional plants survived inundation and are growing again.

Scindapsus aureus--Was common in experiment station grounds. Many plants survived inundation and are growing again.

Xanthosoma sagittifolia--Was occasionally planted around villages. Some plants, at least, survived inundation.

Rhoeo spathacea--Common on Jabor. Inundated but no effects noted.

Agave sisalana--Seen only in one place on Jabor, young plants only. Large ones may have been swept away, if there were any.

Cordyline terminalis--Planted on Jabor; battered by storm and inundation but recovering.

Sansevieria roxburghiana?--Planted on Jabor; no effects noted.

Crinum asiaticum?--Common around villages and home sites; survived inundation; large plants apparently mostly destroyed, smaller ones not flowering but appear healthy.

Hippeastrum puniceum--Rarely planted about dwellings; no effects noted.

Zephyranthes rosea--Commonly planted; no effects noted; survived complete inundation by salt water.

Tacca leontopetaloides--Generally distributed; doubtless some plants too deeply buried for recovery and others removed by erosion, but those in most situations apparently unaffected, even where inundated by salt water.

Dioscorea sp.--Seen by St. John in 1946 on Imroj but not found in 1958.

Musa nana--Not seen with certainty on this survey.

Musa sapientum--Generally planted; shoots destroyed by storm but rhizomes apparently unaffected, even by inundation by salt water, as healthy shoots, up to half mature size, were very common at time of survey.

Canna indica?--Occasionally planted; shoots apparently destroyed but tubers unaffected and new shoots appearing.

Peperomia pellucida--Weed on Jabor; plants seen were probably ones that had grown from seed after typhoon.

Peperomia ponapensis--After typhoon seen only on Majurirek in protected area on western end where there was no inundation; no effects noted, but seen on Imroj in 1946 and not after typhoon.

Casuarina equisetifolia--Planted on Jabor, trees reaching 10 m. height, a few trees uprooted, most of those standing had lost most of their branches and had been pretty well stripped of photosynthetic branchlets, but were vigorously sprouting new branchlets from trunk and remaining limbs, apparently unaffected by inundation.

Artocarpus altilis--(Impractical to distinguish A. mariannensis in dead condition but many of living trees were this.) Breadfruit was a common and important tree on all inhabited islets (Pl.IV-b). It was very badly damaged by the storm (Pls.VI-a,VIII-a,-b). On the eastern islets that were inundated most trees were uprooted and some that were still standing were dead probably from the effect of salt water on the roots. Most of the branches were torn off the trees left standing in all areas examined. In very few places were trees of over 3 dm. diameter at breast height left standing and these were mostly dead. On the non-inundated islets the trunks and few remaining branches were sprouting leafy branchlets. On Majurirek and Pinlep several partly uprooted trees were observed which had many partly grown fruits in good condition. It is probable that most of the standing trees on the south and west islets will make a rather prompt recovery. Seedlings were noted on many areas which had not been inundated and a few on lightly inundated areas. Breadfruit trunks were generally not broken. Either the entire tree was uprooted or branches were split off, mostly at their bases, and small branches torn off of larger branches that remained.

Ficus elastica--Several large trees were growing in Jabor. They survived the inundation and remain standing, but with most of the branches torn off and most of leaves damaged.

Ficus tinctoria--One tree seen on Jabor, uprooted but sprouting from trunk.

Fleurya ruderalis--Common generally in rocky or open places. Doubtless mostly destroyed by typhoon in all places where there was flooding by salt water or exposure to strong wind; but plants have since come up from seeds in most appropriate habitats.

Pilea microphylla--Naturalized from cultivation. Doubtless destroyed by typhoon, but on Jabor and Pinlep has come up abundantly from seed.

Pipturus argenteus--Common in some areas, especially somewhat protected places. Doubtless many plants destroyed by typhoon but some sprouting from battered plants and much seedling reproduction.

Procris pedunculata--Known only from one restricted area on west end of Majurirek Islet where there was no inundation by salt water. Common there but not flowering. No effects observed which could easily be ascribed to typhoon.

Boerhavia tetrandra--Known only from restricted area on east end of Majurirek Islet. No effects observed.

Bougainvillea sp.--Planted around villages and in experiment station, but apparently destroyed by storm except on Kinajon, where two somewhat defoliated plants remain.

Mirabilis jalapa--Planted around villages. No effects noted, but probably present plants have grown from seed since typhoon.

Pisonia grandis--Common, but only small plants seen in most places. On Mejatto one small tree still standing. On Ribon and Lijeron this is the most prominent species. Here some large trees have been uprooted, others are still standing but with many branches blown off and much defoliation (Pl.X-d). Almost all fallen trees and all standing ones sprouting vigorously.

Amaranthus viridis--Common weed, seen only on Jabor and Kinajon, where it is abundant locally, probably grown from seed since the typhoon.

Celosia argentea--Seen on Imroj in 1946, not found on present survey.

Gomphrena globosa--Planted commonly around dwellings even in inundated areas probably grown from seed since the typhoon.

Portulaca oleracea--Generally common. In areas inundated by salt water probably growing from seed since typhoon.

Cassytha filiformis--Common locally, parasitic on other plants. No effects noted.

Hernandia sonora--Occasional fair sized trees, mostly uprooted but continuing to grow, leaves on these trees in inundated areas reduced in size.

Nasturtium sarmentosum--Rare weed on Jabor; no effects noted, but may have come up from seed after inundation.

Kalanchoe pinnata--Local on Imroj and Kinajon, no effects noted but doubtless reduced in numbers on Imroj by burying and erosion.

Albizia lebbek--Planted on Jabor but did not survive inundation by salt water.

Canavalia microcarpa--Common on less disturbed islets, seedlings seen on some eroded areas and deposition areas; no effects noted.

Caesalpinia pulcherrima--Seen planted on Imroj in 1946 but not found during present survey.

Cassia occidentalis--Very local on Jabor, destroyed by storm but seedlings growing in some places.

Crotalaria incana--Dominant plant on many open areas on Jabor, plants grown from seed since inundation are flowering and fruiting abundantly. Deliberately introduced and spread long before typhoon.

Delonix regia--Several large trees planted on Jabor; uprooted by typhoon but still alive, flowering.

Erythrina variegata var. orientalis--One or two large trees planted on Jabor; inundated, uprooted by typhoon but still alive.

Inocarpus fagiferus--Several trees planted on Jabor; inundated, badly battered and defoliated by typhoon but still alive, sprouting from trunk.

Intsia bijuga--Seen on several islands but always blown down by typhoon and sprouting, even in inundated areas.

Leucaena glauca--Abundant on Jabor; survived inundation by salt water, defoliated and upper parts killed by typhoon, now sprouting abundantly from roots and lower parts.

Sophora tomentosa--Seen on Mejatto in 1946, not found on this survey.

Vigna marina--Common on all islets; large numbers undoubtedly buried by gravel and removed by erosion, but in less disturbed places very abundant, probably greatly increased by opening up of shady plantations by fall of trees. Seedlings common on newly deposited gravel.

Citrus aurantifolia--Occasionally planted; in areas inundated by salt water the trees look half-dead but sprouting from trunk, in other areas merely somewhat defoliated.

Citrus maxima--Planted on Jabor but did not survive typhoon.

Citrus sinensis--Planted on Jabor, some plants said to have survived typhoon, not seen.

Citrus reticulata--Planted on Jabor but did not survive typhoon.

Acalypha wilkesiana--Planted on Jabor and Pinlep; no effects noted.

Codiaeum variegatum--Planted on Majurirek Islet; no effects noted.

Euphorbia chamissonis--Common on lagoon ridges on Majurirek and Pinlep Islets; no effects noted.

Euphorbia glomerifera--Common weed on Jabor; no effects noted.

Euphorbia hirta--Very common in waste places on some inhabited islets; no effects noted but plants seen could have grown from seed after typhoon.

Euphorbia prostrata--Local around dwellings; no effects noted.

Euphorbia pulcherrima--Planted on Jabor but did not survive typhoon.

Phyllanthus amarus--Abundant weed on Jabor, Kinajon and Pinlep; no effects noted, but on Jabor could have grown from seed since inundation by salt water.

Ricinus communis--Planted on Jabor but did not survive typhoon.

Allophylus timorensis--Common on Kinajon, Majurirek and Pinlep; seen also on Imroj, Jabor and Mejatto in 1946, not in 1958. Larger trees on Kinajon uprooted but sprouting; others badly battered but growing and flowering; not definitely known to have survived inundation.

Triumfetta procumbens--Common generally, especially in open places, but not seen on Jabor; no effects noted but doubtless many plants buried and eroded away; seedlings common.

Hibiscus esculentus--Planted in garden of imported volcanic soil on Jabor; still growing and fruiting, in spite of inundation by typhoon and periodic inundation of this garden by highest tides.

Hibiscus mutabilis--Planted in Jabor but apparently did not survive typhoon.

Hibiscus tiliaceus--Occasional on inhabited islets. One or two trees knocked over but sprouting; seen on Imroj in 1946 but not in 1958. Abundant in some mangrove depressions but tops usually dead; apparently survived some inundation on Pinlep.

Sida fallax--Seen planted on Mejatto in 1946 but not found in 1958.

Thespesia populnea--Planted on Jabor but apparently did not survive the typhoon.

Ceiba pentandra--One tree planted on Jabor, uprooted and still alive, but doubtful if it will survive; seen on Imroj in 1946 but not in 1958.

Calophyllum inophyllum--Large and conspicuous tree on most islets, especially on lagoon ridges, badly battered by typhoon, more trees uprooted or partly so than not; some blown completely into lagoon. Generally sprouting if some roots still in ground even where inundated. Not seen on two smaller islets except for one seedling on Lijeron.

Passiflora laurifolia--Said to have been planted on Jabor but not found.

Carica papaya--On most islets, but large trees all eliminated by typhoon. Seedlings and partly grown, not very healthy, trees are occasional to common.

Citrullus vulgaris--Planted on Jabor but not seen after typhoon.

Cucumis sativus--Planted on Jabor but not seen after typhoon.

Cucurbita maxima--Commonly planted around habitations, no effects noted but small plants only and very scarce on areas inundated by salt water.

Cucurbita pepo--Planted on Jabor but not seen after typhoon.

Pemphis acidula--Common, especially on most exposed areas, on bare rocks; usually badly beaten and completely defoliated by typhoon (Pl.III-a), but seldom uprooted. Often broken off a few dm. above ground, small branches usually killed (Pl.IX-a). Sprouting abundantly from root crowns and trunks (Pl.VIII-c).

Sonneratia alba--Seen near Sydney Pier in 1946, not found in 1958.

Bruguiera gymnorhiza--Dominant tree in most mangrove depressions; larger trees often dead or with tops dead (Pls.IV-d,V-c), smaller ones, especially seedlings 1 m. tall or less, not much affected by typhoon.

Terminalia catappa--Planted around villages, especially on Jabor, mostly uprooted by typhoon but still alive and sprouting.

Terminalia samoensis--Common, especially on shore ridges and in brushy areas; generally not much injured by typhoon, but some larger plants uprooted though still sprouting.

Barringtonia asiatica--Small groves of several large and many small trees on Mejatto and Imroj islets; most of trees uprooted or large ones with branches torn off; sprouting abundantly from roots, stumps, trunks and large branches, as well as abundant seedlings. These groves were so situated that they got the full force of both wind and waves.

Miconia sp.?--Something identified as this genus was planted on Jabor but not found after the typhoon.

Brassaia actinophylla--Large tree planted on Jabor, badly battered by storm but sprouting from trunk and larger branches.

Polyscias fruticosa--Planted on Jabor but apparently did not survive typhoon.

Polyscias guilfoylei--Seen on Jabor in 1946 but not found in 1958.

Polyscias scutellaria--A few plants in village on Majurirek; no effects noted.

Centella asiatica--Common on several islets, mostly in places not inundated by salt water; no effects noted but plant probably was more common before typhoon, especially on inundated islets.

Jasminum sambac--Planted on Majurirek; no effects noted.

Catharanthus roseus--Planted on Pinlep; no effects noted, but was probably found on other islets before typhoon.

Cerbera manghas--Planted on Jabor; larger trees uprooted but sprouting, saplings locally very common.

Nerium spp.--N. indicum and N. oleander both known from atoll in 1946; plants seen on Majurirek Islet in 1958 not flowering and hence unidentified; no effects noted except lack of flowering.

Ochrosia oppositifolia--Seen only on the seaward side of the west end of Imroj Islet, where there were several fair sized trees. Most of these had been knocked down and the places where they were growing covered by a thick gravel deposit. Two, almost at the extreme end of the seaward side, were still standing, badly battered but with some green leaves.

Plumeria rubra--A few shrubs or small trees planted around dwellings and graves. Those on Mejatto, Majurirek and Pinlep showed no signs of damage, but one on Kinajon was partly uprooted. That on Mejatto was on a small section that was not touched by waves. That on Kinajon was not inundated either, except possibly by lagoon waves.

Ipomoea batatas--Seen planted on Imroj in 1946 but not found in 1958.

Ipomoea littoralis--Occasional locally on Jabor and Pinlep; seen on Imroj in 1946 but not in 1958; no effects noted but on Jabor probably much reduced by inundation and on Imroj probably eliminated.

Ipomoea pes-caprae ssp. brasiliensis--Seen only on Jabor, except for a single seedling on Ribon. In 1946 this was one of the most abundant plants on the narrow strip south of Jabor and around Sydney Pier. Now there is little of it to be seen, as might be expected, since this was where inundation and stripping of loose material were most severe.

Ipomoea tuba--Seen only on Kinajon and around large banked oil tank at Sydney Pier. No effects noted, but it would have been expected to be more abundant.

Cordia subcordata--Common generally, especially around periphery of most islets; few trees actually uprooted but several somewhat tipped over, some dead or at least leafless above, but with vigorous lower branches flowering even where there was severe inundation; seedlings common on deposited material.

Tournefortia argentea--Seen on all islets visited, on most of them common around periphery; variously battered by typhoon, uprooted or branches broken off, usually sprouting vigorously; seedlings abundant on newly deposited or disturbed ground.

Clerodendrum inerme--Occasional, locally common; defoliated but not badly hurt by typhoon, recovering even where inundated by salt water.

Lantana camara--Said to have been planted on Jabor but apparently did not survive typhoon.

Premna obtusifolia--Nowhere common; most plants severely battered, those seen on Mejatto were only stumps with sprouts, but perhaps cut before typhoon; plants on Majurirek less damaged than others.

Stachytarpheta urticifolia--Common weed on Jabor, probably all plants seen grew from seeds after typhoon.

Ocimum sanctum--Planted on Pinlep; seen on Imroj in 1946, not in 1958; no effects noted but probably eliminated from Imroj.

Nicotiana tabacum--Growing on Jabor in 1946, not seen in 1958.

Physalis angulata--Abundant weed on most larger islets; probably grew from seed since typhoon.

Solanum nigrum--Common weed on Jabor and Pinlep, probably grown from seed since typhoon.

Jacaranda filicifolia--Planted on Jabor but apparently did not survive typhoon.

Beloperone guttata--Planted on Jabor but not found after typhoon.

Blechum brownei--Abundant weed locally on Jabor, probably grown from seed since typhoon.

Hemigraphis reptans--Rare, only seen on lagoon side of Pinlep; no effects noted.

Pseuderanthemum carruthersii--and its variety atropurpureum. Planted very generally around habitations; suffered rather little damage even from inundation, except where bent down and partly buried by gravel sheets, even here flowering freely.

Dentella repens--Locally common on Jabor; said to have appeared rather recently in field of bananas brought from Kusaie and Ponape; no effects noted, plants probably from seed after typhoon.

Guettarda speciosa--Common on most islets; most trees either badly broken or uprooted, some of them sprouting, seedlings common.

Hedyotis biflora--Occasional on Imroj, Mejatto and Jabor in protected places; no effects noted, but probably much less common than before typhoon.

Ixora casei--On Imroj before the typhoon, not seen after, apparently did not survive typhoon.

Ixora fraseri--Planted on Jabor but did not survive typhoon.

Morinda citrifolia--Common on most islets, plants mostly bent down or broken off by typhoon but sprouting vigorously, several very large plants uprooted; seedlings occasional.

Hippobroma longiflora--Weed in Jabor, one plant seen, in flower, during survey.

Scaevola sericea--One of most common plants on most islets; doubtless greatly reduced in numbers by erosion of seaward ridges, many plants battered but sending out leaves; seedlings common.

Adenostemma lavenia--Seen on Imroj in 1946, not found in 1958 except one plant seen on Kinajon Islet.

Ageratum conyzoides--Known on Jaluit and reported by Germans and Japanese, but not found in 1946 or subsequently, until one small plant was collected just above lagoon beach on Jabor.

Cichorium endivium--Said to have been planted in garden on Jabor, not found.

Spilanthes iabadicensis--Said to have been a weed on Jabor, not found.

Synedrella nodiflora--Weed, common to occasional on Jabor, Kinajon, and Pinlep; no effects noted, probably grown from seed after typhoon.

Tagetes sp.--A few plants seen in garden on Majurirek, no effects noted but may have been planted after typhoon.

Vernonia cinerea--Common weed on most inhabited islets; no effects noted, but plants could have come from seed after typhoon; not seen on Imroj where it was found in 1946.

Wedelia biflora--Common on all islets visited except Lijeron. Abundant on parts of wider ones; no effects noted, but doubtless greatly reduced in places eroded by waves and where much gravel was deposited; probably much more abundant than formerly in places where coconuts were knocked down but which were not inundated by salt water (Pl.VIII-b).

X. TERRESTRIAL FAUNA

J. L. Gressitt

The effect on the terrestrial fauna by Typhoon OPHELIA was much less than expected in terms of the general damage to the atoll. On an atoll the size of Jaluit, it seems apparent that even with very severe damage to parts of the atoll, in most groups of land animals the percentage of survival of species is fairly high, at least in one part or another of the atoll. Thus, as those parts of the atoll that lost much of their vegetation and soil regain a normal vegetational situation, presumably the faunal picture will regain its previous status within a reasonable period. The length of this time period will be largely controlled by distances and wind directions, in relation to less affected portions, and by the habits and habitats of the animals and their vagility (natural ability for dispersal), as well as by rate of revegetation and by human travel.

It is felt that the natural populating of oceanic islands by insects is effected primarily by passive transport in air currents. In the case of mid-Pacific atolls the potential sources of additional species of insects are distant and therefore strongly limited. Also, the number of species of insects, and other animals, that an atoll can support is strongly limited by the lack of many types of environments present on high islands, and by the limitations of flora, soil, and fresh water. If some species were exterminated from the atoll as a whole, repopulation by those species not associated with man might be very slow.

Mammals: These on Jaluit were limited to rats, except for man and his domestic dogs, cats, and pigs. Possibly three kinds of rats* were present, or at least intermittently present, but precise data are lacking. Rats suffered considerably from the typhoon -- perhaps more than most groups of animals. Apparently rather few survived. None were seen during the survey, and only slight evidence of one was noted on Jabor.** Those presumably present earlier were *Rattus rattus*, *R. norwegicus* and *R. exulans*. One opinion expressed was that the rats were largely exterminated, at least on Jabor, but that repopulation had taken place from ships which had come in since the storm. Pigs and pets were only in small part lost during the typhoon. Only sixteen of the 1,300 people on the atoll were killed (two of these died of exhaustion immediately following the storm).

Birds: Birds were not greatly affected by the typhoon. Local residents stated that although some dead birds were noticed after the storm, in general the number of birds present afterwards did not appear to be

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* Mice, Polynesian rats and common black or brown rats were previously reported from Jaluit by Schnee (1904) and Kuroda (1934), Norway rat (as *Mus decumanus*) by Finsch (1893, p. 122) --F.R.F.

** Coconuts, gnawed open by rats, were seen on Majurirek I.--F.R.F.

materially decreased. During the week's observations, two land birds with rather few Marshall Is. records (New Zealand cuckoo and Micronesian pigeon) were observed. During a visit to "Bird I." (Lijeron), large numbers of birds were seen, particularly White-capped Noddies, Brown Boobies and Frigate Birds, the former with abundant nests (of Pisonia leaves on twigs), eggs, and young birds. One White Tern egg was seen. Birds seen were as follows (in addition to those listed below, 13 other species are recorded from Jaluit and 25 from the Marshalls as a whole by earlier authors):

Species not previously recorded at Jaluit Atoll are starred (*).
Letters refer to the places of observations as follows:

E -- Majurirek (Elizabeth)	L -- Lijeron
I -- Imroj	M -- Mejatto
J -- Jabor	P -- Pinlep
K -- Kinajon	R -- Ribon

*Puffinus pacificus cuneatus (Salvin) -- Wedge-tailed Shearwater . . . . J

*Phaeton lepturus dorotheae (Mathews) -- White-tailed Tropic Bird. . . . P

*Sula leucogaster plotus (Forster) -- Brown Booby. L

*Frigata minor minor (Gmelin) -- Pacific Man-O'-War (Frigate Bird) . . . I

Demigretta sacra sacra (Gmelin) -- Reef Heron . . . . .MRJE

*Pluvialis dominica fulva (Gmelin) -- Pacific Golden Plover. . . . . .IRJP

Numenius phaeopus variegatus (Scopoli) -- Whimbrel. . . .. J

Heteroscelus incanus (Gmelin) -- American Wandering Tattler. . . . . .KJPE

Arenaria interpres interpres (Linn.) -- Turnstone . . . . JPL

Thalasseus bergii pelecanoides (King) -- Crested Tern L

Anous stolidus pileatus (Scopoli) -- Common Noddy . . . . MRKEPL

Anous tenuirostris marcusi (Bryan) -- White-capped Noddy. . . . . MRJKEL

Gygis alba candida (Gmelin) -- White Tern . . . . MRJEPL

Ducula oceanica oceanica (Lesson and Garnot)-- Micronesian Pigeon . . . K

Eudynamis taitensis (Sparrman) -- Long-tailed New Zealand Cuckoo. . . .JL

Reptiles: Terrestrial reptiles in the Marshalls include only lizards. These do not seem to have been seriously affected by the typhoon. Large populations of the small striped skink were seen on most islets, and also fair numbers of geckos and the green, black and slender blackish brown skinks. The lizards are the most important predators of insects in the Marshalls, where perching birds are absent. Thus with any diminution of the lizard population, serious consequences might result with an abundance of insects resulting. The lizards observed are as follows:

Lepidodactylus lugubris -- Small House Gecko . . . . J

Gehyra oceanica -- Big Tree Gecko . . . . J

Dasia smaragdina smaragdina -- Green Skink. . . . . EJ

Emoia cyanura cyanura -- Striped Skink. . . . . MRIJEPL

Emoia arnoensis -- Black Skink. . . . . JPK

Emoia boettgeri (?) -- Slender Skink. . . . . P

Amphibians: There are no native amphibians, and the giant toad (Bufo marinus) has apparently not been introduced to Jaluit.

Fresh water fish: There are no native fresh water fish in the Marshalls. Gambusia minnows have been introduced to Jaluit for mosquito control. These survived in at least one cistern (elevated about 1 m.) in the middle of the wide portion of Jabor. Those in non-elevated water tanks apparently were killed by salt water inundation.

Insects: In general, insects seem to have been very successful in surviving the typhoon. About 225 species of insects and about 23 species of other terrestrial arthropods were collected during the survey. The number of species surviving is undoubtedly very much larger. Insect collections may be incomplete for the atoll as a whole because we worked mainly on islets more heavily hit by the typhoon. Various traps (light trap, fly traps, and AEC fallout sheets) were operated on Jabor, but strong winds, rain and a bright moon interfered with their functioning. It is estimated that the normal insect fauna of Jaluit should number about 500 or more species. Probably very few, if any, of these were eliminated by the storm. But one week, with much time spent in reaching the different islets, was insufficient for an adequate survey. The insect population appeared to be reviving and increasing rapidly. With short life-cycles for many groups of insects in this latitude, some species had undoubtedly already multiplied their populations many fold in the $3\frac{1}{2}$ months since the typhoon.

In abundance of individual species, there was great variation, partly related to normal trends, but partly accentuated by the typhoon. Soil insects, normally weakly represented on atolls, were particularly scarce, especially on islets that were inundated.

In some limited spots on less affected islets, and on broader parts of more disturbed islets, litter (rotting vegetation) was found which contained spring-tails, phorid flies and maggots of other flies. Some of this material consisted of rotting Pandanus leaves (even of lost roofing), rotting leaves of downed coconut palms, or old rotting logs. As mentioned elsewhere, much soil, humus, and dead vegetation was washed into the lagoon, besides many living trees. With the superabundance of newly killed trees, the populations of many of these scavenging insects, reduced by the typhoon, will undoubtedly undergo further great increase. On the other hand, the burning frequently practised by the Jaluit people (noticed particularly in the case of Majurirek) will considerably restrict these insects, as well as humus production, which are related. Insects that live under dead bark survived reasonably well, and were found to be breeding up very large populations because of the great abundance of killed and fallen trees, particularly breadfruit trees.

In the many old Japanese water cisterns, or oil tanks, as on Jabor, considerable breeding of some insects was observed, even in tanks which had been overrun by salt water. Most of these tanks now contain rotting plant debris, and many of them support numerous mosquito larvae (Culex quinquefasciatus), as well as larvae of a pale tendipedid (chironomid) fly, a dark ephydrid fly, a damsel fly and two species of dragonflies. The day-biting mosquito (Aedes marshallensis) was much rarer than the night-biting Culex, and was seen breeding in a hole in the side of a downed coconut palm.

House flies were quite abundant, together with other filth-flies, particularly sarcophagids, and to a much lesser extent calliphorids. The breeding places were not too well determined, other than latrines. In some villages, flies were being trapped in large numbers in screen fly traps baited with dead fish.

The insects which were encountered in perhaps greatest numbers were a species of pale broad leafhopper (Exitianus fusconervosus) on grasses, herbs and some trees; a dark-striped lygaeid bug (Nysius pulchellus) on Physalis, Cyperus, Phyllanthus, Sorghum, grasses, Morinda, and other plants; a slender predaceous bug (nabid) often on these same hosts and on Crotalaria; certain small species of flies, mainly seen resting on leaves or flowers of Terminalia, Hernandia, Tournefortia; certain species of small ants on various plants; and several species of moths. The moths included several abundant microlepidopterans and pyrales on Terminalia, Hibiscus, etc. and some noctuids, some of which often heavily defoliated Wedelia, and also some on Pemphis, etc. The ubiquitous day-flying moth, Utetheisa pulchelloides, was seen on Tournefortia on all islets. The single butterfly species (with several color forms), Hypolimnas bolina, was very abundant on the wide part of Jabor, and on the less affected islets. An abundant beetle, besides those found under bark of dead breadfruit trees, was a small anthicid, probably a predator, on Sorghum, Cyperus, etc.

One group of insects which was noticeably scarce was the locusts. Only one specimen was found, whereas one or more species are generally very abundant on most atolls in grassy areas. The long-horned grasshopper, Physis, was also quite rare, and seen mostly in the nymphal stage, indicating population build-up from a low level.

Spiders: About four species were moderately abundant, a few others rare. Two species of centipedes were taken, and one scorpion. No millipedes were taken except for a minute questionable form.

Terrestrial Mollusks: Terrestrial mollusks are scarce in species in the Marshalls and mostly quite small. Because of their protective devices, they did not suffer much from the typhoon. Only in a few cases were any found to be abundant. On Kinajon Islet a small species of snail was very abundant on leaflets of young coconut palms, as well as on Canavalia vines entangling the young palms. A more elongate land snail was found in several spots (see Appendix II).

Fresh water or brackish water snails of about three species were found in the mangrove pools on Majurirek, Pinlep and Imroj Islets.

Other terrestrial invertebrates: Few other strictly terrestrial forms were encountered. No earthworms were seen. Isopods and amphipods were scarce, aside from shore-living or mangrove-pond species. A few small shrimps were found in mangrove swamps:

Ceridena sp. (Ateidae) -- in mangrove pond, Imroj

Leander sp. (Palaemonidae) -- in mangrove pond, Majurirek

Metabetaeus minutus (Alphaeidae) -- in mangrove pond, Jabor, Mejatto, Imroj

Land crabs included Sesarma, Grapsus grapus tenuicrustatus, and Metasesarma rousseauxi.

XI. SUBMARINE EFFECTS OF THE TYPHOON

A. H. Banner

With only minor variations, the coral reefs of Jaluit Atoll are generally similar to those of other atolls. On the ocean side of the windward islets the seaward margin of the reef flat is serrate with surge channels; however, the algal ridge, so often prominent on windward reefs, was not seen in any of the sectors examined. Behind the outer front of the reef, the gradually sloping reef flat, exposed at low tides, is smooth; its surface is composed to a large extent of encrusting coralline algae. Landward the flat gives way to the eroded beach rock formation that reaches to near high tide level.

On the lagoon side of the windward islets the beach is composed of beach rock, coral shingle, or sand, depending upon exposure to prevailing winds, waves, and currents. At the low tide level there is a sandy terrace, either a reef flat covered by sand or a deeper sand deposit or apron, bearing scattered living corals; this terrace may slope off gradually to water ten or more feet deep, or it may abruptly change from a shallow shelf to a steep slope into deeper water. This lagoon slope is also of either sand or coral gravel, but has a greater abundance of growing coral, often in massive groupings of many species.

On the lagoon side of the leeward islets the conditions are somewhat similar to those of the lagoon side of the windward islets, but with more extensive sand flats. On the ocean side of the lee islets the reef is markedly different from that of the windward side, being broader, with the surface of the reef flat less smooth, and with the outer edge sloping more gradually into deep water without any definite development of surge channels.

All of these areas were examined except the front and foreslope of the windward reef. In all areas examined very few changes due to the storm were noted.

There was evidence, however, that the area not examined suffered rather extensive damage from the storm. Because of the high waves during the visit of the group it was dangerous to venture to the outer edge of the windward reef and impossible to explore the surge channels. Presumably that portion of the reef was originally similar to the windward reefs on other atolls: from the outer reef flat the surge channels would be separated by buttresses; in the actual surf region there would be almost nothing but encrusting coralline algae; from the depth of about five feet and down there would be an ever-increasing covering of living and dead corals including Pocillopora meandrina and shelf-like species of Acropora (for example A. spicifera) both on the buttresses and in places on the walls of the surge channels. Both the buttresses and the surge channels would level off at a shelf about fifteen or twenty feet deep; the shelf would be in the neighborhood of one hundred or more feet wide, sloping to about 40 feet deep; there the bottom would drop abruptly away to the greater depths. Scattered on the shelf would be many heads of living corals, again predominantly species of Acropora; among the bases of these heads and massive coral growths would lie a thick layer of dead coral fragments broken from the growing reef front during normal storms.

Lacking direct observation of this section of the reef, the damage to it must be deduced from the bars of boulders and gravel lying on the reef flat. This bar has been described in detail earlier (See p. 39); here it will suffice to state that it is a new feature along the windward beaches examined. In a typical section near Jabor it was about 60 feet wide, up to 8 feet high, and about 100 feet from the reef edge and 30 feet from the beach rock.

The composition of the bar varied from place to place, but the bulk of its components appeared to come from the reef front and foreslope. Evidence of this origin includes the following:

1. The presence of many fresh pieces of coral with the calices uneroded, and in some instances with the branches unbroken. These corals, including *Pocillopora meandrina* and *Acropora* spp. occur normally only in the surf zones of reefs.

2. The presence of the remains of surf inhabiting organisms, such as the rock oyster, *Chama*, and the slate-pencil sea urchin, *Heterocentrotus*. The shells of the oysters were not beach-worn but fresh with the nacre of the surface unweathered. Numerous fresh, uneroded spines of the urchin were found, and in one case a section of the test with spines attached was seen.

3. The presence, on old dead fragments of coral and over-grown coral heads, of fresh bright red patches of colonial Foraminifera, a form that grows abundantly upon the fragments found on the outer shelf of the reef.

4. The presence of the largest coral boulders on the reef at the seaward edge of the bar, while the landward edge was composed of the smallest fragments.

5. The report by the Marshallese that for a period after the typhoon the bars gave off a strong stench of decomposing organic material, a condition which could not obtain were the bars composed of long-dead corals from the boulder ridge.

However, not all of the material in the bar originated in the outer reef area. On Jabor and Mejatto, where the bar was most carefully examined, the following were found:

1. Old blackened coral fragments that had obviously been buried in the soil of the islet.

2. Coral, usually old and partially overgrown but, in some instances, fresh and recently killed, of species characteristic of lagoons, for example *Fungia scutaria*.

3. Rounded basaltic rocks with calcareous deposits on the

surface, brought by man to the atoll either as ballast or as ornamentation, and pieces of iron and cement (several of which had fresh tubes of marine worms attached), that would most logically be found in the lagoon where ships anchored, not off the turbulent windward reef.*

The bulk of the material in the bar was not recognizable as to source; however, as, of the pieces that could be so recognized, most were from beyond the outer edge of the reef flat, it is logical to conclude that most of the bar was from there.

At low-low tide level and below on the lagoon side of the windward islets few storm effects could be seen. Those few that were observed include the new offshore bars, either exposed at low tide or a few feet below the surface; the presence of storm-carried trees on the reef flats and on the slopes beyond the reef flats; and the presence of fine organic sediments in a few restricted areas.

Those familiar with Jaluit Atoll state that the offshore bars along the lagoon reef flat were built during the typhoon. The highest and most conspicuous of these was found near the outer edge of the lagoon reef flat off the northeast end of Jabor. The bar started in the north close to shore on the slope leading to the depths of the pass and continued southward, swinging away from the islet and lying near the outer edge of the reef flat, and finally curved back towards shore near the anchorage of Jabor in a rough "C"-shape. Its base rested on the reef flat slightly below the low-low tide level, and its top rose two to three feet, the top thereby being exposed at mid-tides. The slope towards the lagoon was gradual; the slope towards the islet was abrupt, being at the approximate angle of repose. The bar was usually about 50 feet wide. It was composed of rubble derived from long dead coral and other calcareous debris mostly of small size, an inch or less in diameter, several inches long; scattered about its surface were some larger pieces, up to about 6 inches in diameter. The source of the bar material was questionable, for all was old and discolored; however it would be logical to presume that some, at least, came from the northwestern tip of Jabor, which was cut away in the typhoon, and other portions, probably the bulk, came from the channel slope where similar pieces may still be found. The shape of the bar, no matter what the source, indicates it was formed by onshore waves from the lagoon.

It should also be noted that on the reef flat behind the bar, and at some spots in the bar, there were occasional larger heads of dead coral, up to several feet in diameter. These must have been carried on to the reef flat by previous storms, for all examined were found to be surrounded by delicately branching and unbroken live coral.

A bar, about 450 feet from shore, was found in the lagoon south of the anchorage at Jabor. It was similar in size, shape and composition to the one north of the anchorage, but differed in that its base was lower, and its top, about two feet higher than the base, lay near low-low tide level.

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* Pieces of glass were also found (see pp. 12, 23).

Aerial inspection showed that the reef was an off-shore feature of most of the length of the long isthmus connecting Jabor with Jaluit. The source of the material in the bar could not be ascertained, but it is likely that it came from the detritus of the gradual slope into the depths of the lagoon.

No offshore bars were noted off the northern and leeward islets.

Along the shore, in the high intertidal zone, and continuing out to deep areas of the lagoon, were found storm-carried trees with their root masses intact. Most of the trees were either coconut or pandanus. Near shore most were lying on their sides, but some near shore, and all in the deeper water, were standing erect; the ones in deeper water were obviously buoyed by the trunks and sunk by the rocks captured in the root mass. Off the southern portion of Jabor, the only deep water inspected, they were found up to a thousand feet from shore, resting on a bottom eighty feet deep.

In only a few places were sediments composed of organic matter observed. They were most conspicuous in the lagoon off the middle of Mejatto. Here, on a ripple-marked sand bottom in ten to twenty feet of water, the depressions between the ripples contained thin deposits of loose black sediment, so low in specific gravity that it was stirred by the slight currents. Identifiable fragments of the sediment appeared to be decomposed plant material. No similar deposits were seen in gravel portions of the bottom.

Aside from these features and the bars built out from land, no observable change was found below the low-low tide level in the lagoon. In the zone of extreme low water even the delicately branching lagoon corals were unbroken. In none of the sectors examined were there any deposits of fresh sand, as indicated by the absence of recent sediment burying the lower portions of coral heads or lying between the bases of the dense coral patches on the reef flats, as for example within the new bar off the northern end of Jabor.

Similarly, inspection of both the ocean and lagoon sides of the leeward islets showed no obvious damage below low-low tide level. The gradually sloping flats on the lagoon side were of sand and had isolated massive complexes of many genera of corals, and these, including the fragile staghorn coral (Acropora grandis), were not broken. On the ocean side beyond the edge of the reef flat the gradually sloping bottom, covered with a continuous layer of growing coral, also showed no signs of damage. It is true that on the ocean reef flat there were scattered boulders of dead coral and that in the depressions on the flat there were coral fragments; but all of the former appeared to have rested long in their present locations, and fragments of coral, often rather fresh, are a common feature of such depressions.

XII. MARINE RESOURCES

A. H. Banner

There is nothing to indicate a lessening of the fishing potential of Jaluit except possibly on the outer slopes of the windward ocean reef. The windward reef is not used for fishing except for torch fishing at night and in times of exceptionally calm water. The actual fishing potential within the lagoon may increase, because additional fertilizer in the form of organic detritus has been carried into the lagoon where it can stimulate the production of fixed algae and phytoplankton. Moreover, the masses of tree roots in the water are already covered with a film of algae that is being browsed upon by small herbivorous fish and the roots offer hiding places for small fish. These small fish are the food of the larger carnivores.

The Marshallese on the atoll have reported that even immediately after the typhoon the fishing was better than before. It is likely that this merely represents a greater fishing effort rather than any true increase in larger fish, for if the postulated mechanisms do increase the fishery, it would be only after a lag of a number of months.

If there is an increase in productivity in the lagoon, it should last for several years, the length of time for the recycling nutrients to be flushed to sea and for the root masses to decompose entirely.

Another possible effect of the typhoon would be to increase the toxicity of the fish in the lagoon. Before the typhoon, Jaluit Atoll had the reputation of having more poisonous fish than any other atoll in the archipelago. Several workers (Randall 1958, Dawson 1959) have suggested, without any direct proof, that the toxicity of the fish results from direct feeding upon poisonous algae, or feeding upon herbivores that eat the poisonous algae. If the fertilization of the lagoon increases the amount of the hypothetical poisonous algae there may be an increase both in the toxicity of the species now known to be dangerous and in the number of species found to be toxic. However, the Marshallese eating the fish from the lagoon report no change in toxicity patterns.

Note: For information on poisonous fishes in Jaluit reference may be made to Hiyama 1943 and Bartsch et al 1959.--Ed.

XIII. POPULATION AND ECONOMY OF JALUIT

J. B. Mackenzie

Population and economy prior to November 8, 1957

Population Distribution

Prior to World War I, the Marshall Islands were under German Administration with headquarters on the island of Jabor, in Jaluit Atoll. After 1918, the Marshall Islands were officially turned over to the Japanese, who took over all German properties in the Marshalls under a League of Nations Mandate. The Japanese Civil Administration continued to use Jabor as headquarters for the Marshall Islands.

The Japanese immediately started setting up a large center in Jaluit, with independent trading companies and small businesses run by the Japanese themselves. They drew their man-power from the surrounding islands for the labor needed to build and maintain their center on Jabor. This, of course, resulted in large forces of Marshallese coming into Jaluit from the other atolls. The attraction of Jaluit to the Marshallese continued up into the 1930's. After 1935, with the Japanese Military moving into the Marshalls, the need for labor forces again started a sharp rise of population influx into Jaluit.

Two large concentrations of people were at Imroj Islet and Jabor Islet. The islet of Imroj was established as the Japanese Naval Air Station, where large labor battalions were put to work on the building of a major air station. Jabor became the headquarters for the Army, with small Army units stationed on the larger islets in Jaluit Atoll. Just prior to the war, the Civil Administration started construction of a new center three miles south of the Army center on the islet of Jabor.

United States Forces moving across the Pacific to the Marshalls in 1944 cut off the Japanese supply lines to the large military atolls, causing another shift in population. It was necessary to move people to islets where they could get native foods. All imported food items were cut off from the Marshallese to enable the military to feed their army and navy personnel. With the U. S. forces striking in the Marshalls and creating a shortage of food for the Japanese military forces, the Marshallese were again moved to larger islets where they were put to work gathering food and where they could be under close surveillance.

The surrender of Japan in 1945 and the taking over of the administration of the Marshall Islands by the U. S. Navy caused another shift of people. Imroj Islet was set up as the central government seat for the Marshallese in Jaluit Atoll. This shifted the main concentration of people to Imroj. The approximate population of this village numbered between three and four hundred. This was considered the main village on Jaluit, with smaller villages or settlements scattered throughout the atoll.

The atoll is divided into four divisions, which could be called political centers, or as referred to by the Marshallese, "Mountain

Marshalls" (which in our local government are called precincts). The population in these four divisions are usually concentrated on one large islet within each section, with one or two families on the smaller islets that are part of this section and many of the other islets uninhabited. The four centers are: 1) Jaluit Islet on the south tip including Jabor, Ewo and Moni islets, 2) Majurirek Islet off the south-west pass, with Ai, Pinlep, and some small uninhabited islets, 3) Wotle Islet in the northern part of Jaluit including several uninhabited islets south-east up to Mejatto Islet, and 4) Imroj Islet, the atoll council seat, including the islets south-east of her down to Enejet Islet, across the pass from Jabor.

Total population of Jaluit was approximately 950, as shown by the Navy census taken in 1949; Imroj had the greatest concentration of 300 to 400 people and the other three divisions with about 150 people in each.

In 1955, the Marshalls Import Export Company, the Protestant Intermediate School, the Catholic Mission School and the Trust Territory's Jaluit Project moved to Jabor, causing a shift of population within the atoll. Jabor, which had been uninhabited for almost ten years, came to life again and the population at the end of 1956 was 250. The Kwajalein Import Trading Company moved into Jabor in the early part of 1957, increasing the population to 280 people. The large majority of the people who moved to Jabor were from the surrounding islets of Jaluit, with probably 20 people coming from other atolls in the Marshalls.

The Marshallese have always considered Jabor as the main islet in the atoll, since the Germans and Japanese built and developed there the administrative center for the Marshalls. It was, therefore, only natural for them to return to Jabor in large numbers. The only reason that the council seat was not moved over to Jabor was the scarcity of private land owned by the Marshallese. Most of the land on Jabor is government owned with title coming all the way from German times. The government needed all of its land for an experiment station in lowland agriculture.

The rebuilding of Jabor caused a constant movement of people across the lagoon into Jabor. The two trading companies and the headquarters of the Trust Territory representative at Jabor changed the port of call for ships from Imroj to Jabor. The people came across on their sailing boats and canoes with copra to sell to the trading companies and returned to their islets with trade goods. Many of the people came to Jabor to wait for a ship or just to be there while the ship was in port. At such times, there were anywhere from four to five hundred people on the islet.

There has always been a considerable amount of movement within the atoll itself. Each year for the Christmas holidays, people from all of the islets go to Imroj. The majority of the people belong to the Protestant Church and move to Imroj where the central Protestant Church and Minister are located. At the same time, election of new officers is held for the atoll. There are usually seven to eight hundred people present on Imroj during the holidays. They move in with all of their worldly possessions, prepared to remain from one to two months until the limited available transportation can take them home again.

Food resources

I. Indigenous

a. Agriculture

1. The primary food resources which the people depend upon are locally grown and collected. The main food items used in each household are coconuts, jekaro (coconut sap), breadfruit and pandanus. Breadfruit is a seasonal fruit. Most breadfruit trees bear twice a year. The heaviest crop is from May to July with a very light crop in December and January. The surplus breadfruit is usually preserved and used between seasons. Pandanus, another seasonal food, is used between breadfruit seasons. The pandanus can also be dried and kept for long periods of time. Coconuts are used daily by each household. The dry, ripe coconut is grated and the milk squeezed out, to be used with other foods. The iu (embryo) is taken from the sprouted nut and is usually eaten right from the nut or cooked for a meal. The sweet water of the young green coconut is used for drinking and the soft meat is eaten with a spoon. The flesh of the dry, ripe nut is also eaten at meals.

2. The secondary foods are taro, banana, and arrowroot which are usually used between breadfruit and pandanus seasons. There was very little cultivation of taro in Jaluit and it was found only on a few of the islets. The coconut was emphasized by the Japanese and many of the taro pits were put into coconut groves. Arrowroot is cooked like a potato and eaten at meals with other foods. The people also make a candy by grating the arrowroot and boiling it into a spongy ball then covering it with freshly grated coconut meat. Most of their bananas are eaten between meals and occasionally cooked and eaten at meals. There is also a small amount of sweet potato and pumpkin grown and used as a secondary food. Limes and papayas are grown in very small amounts. Lime juice is used to spread over raw fish. Papayas, when ripe, are usually only eaten by children while the green papayas are cut up and boiled as a vegetable.

b. Fisheries

1. Fish has always played a very important part in the Marshallese diet. It was their sole source of protein before livestock were introduced. The early method of catching fish with a fish trap is very rarely used today. Most of the fishing is done by hand line and trolling in the lagoon. When the weather permits it, they fish for tuna on the outside of the lagoon off the deep water passes.

Most of the edible fish are caught in the lagoon or on the outer reefs, with nets or, at night, with coconut torches. The night fishing along the reefs is usually done in groups of three or four men, when the tide is low. The fish caught on the outer reef are of many varieties that can be found all through the south Pacific. The fish caught in the lagoon are of various types, some of which are poisonous. The Marshallese in Jaluit know which are the poisonous types and are very rarely poisoned. Some of the types caught in the lagoon are the sea bass, parrot fish, surgeon fish, mackerel, squirrel fish, trigger fish, butterfly fish, mullet and sardines. The red snapper family is also a very large group that is caught in the lagoon, but the majority of them are poisonous. This same fish is a safe food in many lagoons of the Marshalls.

2. Shell fish in the Marshalls can be considered as secondary, as the amount caught is negligible and is not eaten daily. The clams along the inside reefs are gathered and usually placed in salt brine, and kept in bottles, and eaten when no other protein food is available for meals. The larger shell fish are occasionally caught and eaten. Langusta (Lobster) are rarely caught in Jaluit. There is an occasional langusta gathering, which is usually held during the night, with torches.

II. Food imports

The Marshallese import a great part of their food, as they have become accustomed to do from Japanese times. The trading companies from Japan opened up a whole new line of imported foods and consequently the Marshallese depend on the import of these foods. A small amount of these items was introduced during the German times, so the people were somewhat familiar with new foods. In order to stimulate the production of copra to meet the demand in Japan, consumption of store food was encouraged.

There are two large trading companies in the Marshalls: Marshalls Import Export Company and Kwajalein Import Trading Company. There are numerous smaller companies and private individuals that import trade goods. The two large companies import the greatest amount of foods. Marshalls Import Export Company has been granted the only Trust Territory license to purchase copra for export. The same company owns and operates a trading vessel in the Marshalls, and the Trust Territory operates an AKL to help cover the entire Marshalls.

The imports of food from the United States and other countries in the world total $414,000.00 per year for the entire Marshalls. Jaluit Atoll annually imports about $25,000.00 worth of foods. The main imports are rice, flour, sugar, canned milk and canned meats and fish.

Cash crops and products

1. Copra

Copra is the largest export item that the Marshallese have in Jaluit. Before the typhoons struck Jaluit in November 1957 and January 1958, they exported approximately 500 to 600 tons of copra a year at $100.00 a ton. This in dollars was $50,000.00 to $60,000.00 a year and was the largest source of income.

The men in the atoll do most of the work in producing copra with the women helping them. The coconuts are husked and carried from the groves, usually to the homes, where the women open them and spread them out to dry. The nuts are left in the sun for two or three days after which they are cut into small pieces and left on mats to dry. The coconut meat is spread out each morning and taken in every evening or when it rains. When the meat is thoroughly dry, it is packed into bags and stored under the house or taken to the trading company. The trading company usually exchanges the value of the copra for trade goods, or if the producer chooses, gives him cash for the copra brought in.

2. Trochus

Trochus is considered the second cash crop, but the total amount of money received for the gathering of trochus is relatively small in comparison to copra. About two tons of trochus are harvested each year in Jaluit. The world market for trochus fluctuates to such an extent that it may be $800.00 a ton one year and $400.00 the next. The trochus season comes once a year and usually falls in July or August. The length of season for gathering trochus is limited by law to fifteen days in Jaluit. Trochus is found in three areas of Jaluit Atoll where the divers gather them and leave them on the beaches until the animal inside the shell either rots or is eaten by ants. The harvest is then taken into Jabor to be sold at the trading companies. Trochus under three inches diameter are not to be taken from the beds, and a heavy fine is imposed if anyone is caught with shells under three inches.

Cash uses

The people of Jaluit use their cash primarily for the purchase of imported food items such as rice, flour, sugar, canned milk and canned meats and fish. The balance of their money is usually spent on soft beverages, tobacco, clothing, building materials, boats, boat parts and gear, kerosene, household items and sundries such as perfume, hair oil and soap. Most of this merchandise is purchased from the trading companies' representatives on the boats that come into the area. Many of the people order radios, ready-made dresses, and other miscellaneous items from mail order houses in the United States.

Effects of typhoons LOLA and MAMIE (November 8 and 14, 1957)

The effects of these two typhoons were felt very little by the majority of the people on Jaluit. Damage from these typhoons was relatively slight and was practically confined to Jabor. In Typhoon LOLA, the south end of the islet was under water, but there were little damage and no injuries. Typhoon MAMIE caused very little damage on Jaluit and again its effects were confined to the islet of Jabor.

The Jaluit Project, a Trust Territory Agriculture Experiment Station, suffered the highest amount of damage and that was in plant loss. This damage was not great, however. During Typhoon MAMIE, U. S. Navy Sea Air Rescue Plane 909 on a sea rescue mission, was badly damaged at Jaluit.

Situation after Typhoon OPHELIA

On January 10, 1958, immediately after Typhoon OPHELIA struck Jaluit, the Island Development Officer was sent from the office of the District Administrator to survey conditions at Jaluit. OPHELIA struck Jaluit on January 7, 1958. Upon the arrival of the Island Development Officer at Jaluit, a report on conditions that existed was immediately forwarded to the District Center at Majuro. Immediate aid in the way of water, food, clothing and temporary shelters was brought in by the joint efforts of the Navy at Kwajalein and the Trust Territory.

The people had gone through a period of extreme physical hardship, but their mental attitude was quite healthy. They accepted the storm as something that happens and did not question why it had happened or how such storms occur. They were able to joke, sing and laugh, and accept the situation. They were ready to start rebuilding their homes with whatever material was available on the islands. They understood the scope of the problems before them, were cooperative and shared what little they had with others who were more unfortunate than they. There was no aimless wandering around as one might expect after such a devastating storm. Fourteen people were lost in the storm. (Two more died later.) Their loved ones showed some grief and sorrow, but accepted it as an act of God.

The survey of damage showed that the islets in the eastern part of the atoll suffered complete flood damage where three to eight foot waves of sea water had come over the islets. All houses and 95% of all trees were destroyed on the east coast. The majority of the cement cisterns were either destroyed or filled with salt water, creating an extreme shortage of drinking water. The west coast of Jaluit suffered approximately 60% damage to all trees and foliage. All of the sail boats which had been used to haul copra and passengers around the atoll were completely damaged or lost; fifty to sixty canoes were damaged beyond repair. It was impossible for people to move within the atoll. With the exception of the old concrete structures that were left by the Japanese, houses and other buildings in the atoll were destroyed.

Immediate aid was dispatched to the people of Jaluit by the U. S. Navy at the request of the District Administrator. A medical team was flown from Navy Station Kwajalein, 200 miles away, to examine the critically injured people and deliver additional medical supplies and food. Three injured people were flown to the Trust Territory Hospital at Majuro for surgery and hospitalization. An average of two flights a day came in with food, water and clothing. The Trust Territory vessel, M/V ROQUE, arrived five days later with additional food and water. On board were medical teams made up of two doctors, sanitarians, dental practitioners, health aides, the District Administrator, the Director of Agriculture and Fisheries, the Director of Coconut Operations and the Marshalls District Director of Public Health.

A complete survey was made of Jaluit, covering every phase of damage to the atoll. A program was put into effect immediately for the relief of the people at Jaluit. This involved movement of food, water, clothing, beddings and building material.

Adjustments in typhoon situations prior to American times

Spanish and pre-Spanish times

In the Marshall Islands after the Spanish claimed the islands in 1668 until 1885, there were no changes in the traditional rehabilitation methods following a typhoon. After a typhoon, the Marshallese were directed by their Iroij (King) with respect to the rehabilitation of the islands damaged by the storm. Food and tools were provided by the islanders in the atolls that were able to help. In many cases where damage was to all of the islets in one atoll, the weak, the women and the children were moved to atolls close by. Food was brought from the neighboring atolls to help support the workers while they rehabilitated the atoll. At the completion of rehabilitation the majority of the workers were moved to join their families on one of the neighboring atolls. A very small group of workers were kept in the damaged atoll, where they maintained the plantings. When the first of the subsistence crops came into bearing, people slowly moved back into the islands. In many cases, a destructive typhoon was followed by a period of famine, sickness and great loss of life.

German times

During the occupation of the Marshalls by Germany, very little was done to help the people through typhoon rehabilitation. In 1905, Jaluit was struck by a typhoon that caused considerable damage to the northeastern side of the atoll. At the time of the storm, a German ship unloading cargo at Jabor, left to ride the storm out and returned to finish unloading. The food aboard the ship was the only food used to give temporary help and the Marshallese returned to the old system of rehabilitating themselves.

Japanese times

The Japanese, during their occupation of the Marshalls, carried out a program of rehabilitation of islands after any typhoon devastation. They usually helped the people struck by the storm with enough food to get them started on a rehabilitation program. They also sent in men to help them plan the replanting and feeding of the people. This program usually lasted about a year. No charge was made directly to the people, but a small tax was applied to the copra coming out of the atoll to cover the monies spent in helping with the rehabilitation.

Note: Attention should be directed to the beds of phosphatic hardpan (B-horizon) in the Jemo soil areas on Imroj and Kinajon (see p. 47) because of their potential economic value to the inhabitants as coconut plantations begin to show signs of phosphate deficiency. Analyses of samples of these phosphate rocks in the laboratories of the U. S. Geological Survey show 14 to 16% P_2O_5. While these small beds are insignificant commercially they should serve the needs of the local inhabitants for many years to come and render costly importation of commercial phosphates unnecessary. These beds are not, of course, in any way related to the typhoon under investigation, but their discovery by F. R. Fosberg was a valuable by-product of the expedition.--D.I.B.

GLOSSARY OF TERMS

Algal ridge. The relatively slight ridge, dominantly of calcareous algal composition, typically found at or near the edge of the reef flat on the ocean side.

Apron. See sand aprons.

Bar. Bar, spit, and hook are used in the usual sense. A bar is usually straight but may be curved or arcuate. An offshore bar is not tied to the land even at low-low tide. A spit or hook is a form of bar attached to the land, at least at low-low tide.

Beach rock. Rock formed from beach deposits, whether a beach sandstone or a beach conglomerate.

Boulder. A rock over 10 inches (25 cm.) in greatest diameter.

Boulder tracts or gravel tracts. Scattered patches or small fields of boulders or gravel lying on the reef flat.

Channel. See scour channel and surge channel.

Depression. See elongate depression and mangrove depression.

Elongate depression or longitudinal depression. Specifically, an elongated depression or trough between a bar, spit, or hook resting upon the reef flat and a shore ridge or shore slope that is part of an islet.

Erosion ramp. The gently sloping, relatively plane surface that lies just to landward of the reef flat, typically on the seaward sides of islets.

Foreslope. The steeply sloping surface between the reef margin and the deep ocean.

Gravel. An unconsolidated aggregate whose particles are dominantly larger than 2 mm. in diameter.

Gravel, small. An unconsolidated aggregate whose particles are dominantly between 2 and 100 mm. in diameter.

Gravel apron. See sand apron.

Gravel bar. See gravel and bar.

Gravel sheet. A gravel deposit in distinctly sheet form. More extensive in general than boulder tracts or gravel tracts (which see) and lying on an islet rather than on a reef flat.

Gravel tracts. See boulder tracts.

Hole. See plunge hole.

Hook. See bar.

Intertidal zone. The vertical zone between high-high and low-low tide levels.

Islet. An island of an atoll, most commonly upon the encircling reef but also one upon a pinnacle or reef patch in the lagoon.

Knoll. A coral growth comparable in size to a reef patch but rounded in aspect and whose summit is usually below low-low tide level.

Lime mud. Mud with calcium carbonate as a dominant constituent.

Longitudinal depression. See elongate depression.

Mangrove depression. A depression occupied by mangrove trees, but with a hard bottom rather than one comprised of muds or oozes, which is called a mangrove swamp.

Marsh. A depression containing grasses or sedges and with a mud or ooze bottom.

Muck. Mud that is dominantly organic.

Mud. Unconsolidated materials, sticky and cohesive when wet, whose particles are dominantly less than 1/32 mm. in diameter. See also lime mud.

Patches or patch reefs. Detached reefs, normally within the lagoon.

Pinnacle. A patch reef with a height greater than its maximum diameter.

Pit. See scour pit.

Plunge hole. A hole formed by running water on the downstream, down-slope side of a topographic break (steep slope).

Plunge pool. A deep plunge hole, approximately circular, containing water.

Ramp. See erosion ramp.

Reef. An eminence on the sea bottom rising to within 6 fathoms of the surface.

Reef flat. A relatively flat area of reef rock whose surface lies near low tide level.

Reef margin. The outer edge of the reef flat, usually marked by an abrupt change in slope.

Ridge. See algal ridge, also, shore ridge.

Rubble. Gravel of predominantly angular fragments.

Sand. An unconsolidated aggregate whose particles are dominantly between 1/32 and 2 mm. in diameter.

Sand apron or gravel apron. Apron-shaped deposits of sand or gravel, usually on lagoon reef flats.

Sand horn. A horn-shaped sand-bar typically found on the reef flat at the inner corner or end of an islet.

Scour channel. A channel across or partly across an islet, formed by the scouring action of water cutting through unconsolidated or consolidated material that lies above the reef flat.

Scour pit. A depression formed by running water on the downstream side of an obstruction, such as an uprooted palm.

Shore ridge. A ridge upon or immediately adjacent to a shore. (Also called beach ridge.)

Spit. See bar.

Submarine terrace. The relatively flat, almost horizontal surface sometimes found at depth on the ocean side of the foreslope.

Surge channel. A channelway in the reef, typically normal to and across the reef margin and foreslope on the ocean side.

Swamp. A depression containing woody plants and with a mud or ooze bottom. See also mangrove depression and marsh.

Terrace. See submarine terrace.

Typhoon. A storm that forms over the tropical oceans and has sustained windspeeds greater than 73 m.p.h. (Same as hurricane.)

Woodland. An open stand of trees.

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APPENDIX I.

TABLE OF PLANT SPECIES BY ISLETS

F. R. Fosberg

The following table includes recent reports (from 1946 on) of species known from Jaluit by islets, the 8 islets listed being the ones definitely examined since 1946. There are various additional earlier records of plants from the atoll, but mostly without record as to the islet where they occurred.

Added in the last two columns are indications of origin and of growth habit.

Sources		Origin		Habit	
Fosberg	F	Native	I	Epiphytic herb	E
Mackenzie	M	Aboriginal introduction	A	Terrestrial erect herb	H
St. John	S	Naturalized	N	Creeper	C
Lyman	L	Cultivated or persisting from cultivation	C	Climber	V
Unverified but probably present	X			Shrub	S
				Tree	T
				Seedling	(s)

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON (after typhoon)	MAJURIREK (after typhoon)	PINLEP (after typhoon)	RIBON (after typhoon)	LIJERON (after typhoon)	Origin	Habit
Asplenium nidus	X	F	FS	F	X	F	F	F	F	F	F	I	EH
Nephrolepis acutifolia			FS	F	X	F	F	F		F		I	E
Nephrolepis biserrata var. furcans	M											C	H
Nephrolepis hirsutula			FS	F			F	F	F			I	H
Polypodium scolopendria			FS	F	X	F	F	F	F	F		I	ECH
Pteris tripartita			FS					F	F			I	H
Vittaria incurvata			FS					F		F		I	E
Cycas circinalis	L	F										C	ST
Pandanus tectorius	M	F	FS	F	F	F	F	F	F	F		CIA	T
Thalassia hemprichii									F			I	C
Cenchrus echinatus	F	F		F					F			N	H
Cynodon dactylon								F				N	C
Digitaria pruriens var. microbachne	F	F	S	F		F	F	F	F			I?	H
Echinochloa crus-galli									F			N?	H
Eleusine indica	F	F	S	F		F	F	F	F			N	H
Eragrostis amabilis	F	F	S	F			F	F	F			N	H
Lepturus repens vars.	F	F	X	F	X	F	F	F	F	F	F	I	HC
Paspalum conjugatum									F			N	HC

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON (after typhoon)	MAJURIREK (after typhoon)	PINLEP (after typhoon)	RIBON (after typhoon)	LIJERON (after typhoon)	Origin	Habit
Paspalum distichum		F										N	HC
Sorghum bicolor	F	F	S									N	H
Thuarea involuta	F	F	SX	F	X	F	F	F	F			I	C
Cyperus alternifolius	M											C	H
Cyperus compressus		F										N	H
Cyperus javanicus	F	F					F		F			I	H
Cyperus kyllingia	F	F										N	H
Cyperus odoratus									F			I	H
Cyperus rotundus	X	F										N	H
Eleocharis geniculata									F			IA	H
Fimbristylis cymosa	F	F	XS	F	X	F	F	F	F			I	H
Cocos nucifera	F	F	XS	F	X	F	F	F	F	F	F	AC	T
Elais guineenis	M											C	T
Phoenix canariensis	M											C	T
Pritchardia pacifica	M											C	T
Alocasia macrorrhiza	M	F	FS	F	X	F	F	F	F			A	H
Colocasia esculenta		F							F			AC	H
Cyrtosperma chamissonis			S						F			AC	H
Epipremnum pinnatum	M	F										N	V
Scindapsus aureus	L	F										N	V

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON after typhoon	MAJURIREK after typhoon	PINLEP after typhoon	RIBON after typhoon	LIJERON	Origin	Habit
Xanthosoma sagittifolia	X	F	F					F				C	H
Rhoeo spathacea	M	F										C	H
Agave sisalana	X	F										C	H
Cordyline terminalis	L	F										C	S
Sansevieria roxburghii?	L	F										C	H
Crinum asiaticum?	M	F	FS	F	F	F	F	F	F			CA	H
Hippeastrum puniceum				F				F				C	H
Hymenocallis littoralis	M	F	F					F	F			C	H
Zephyranthes rosea	X	F	X	F			F	F				C	H
Dioscorea sp.			S									A	V
Tacca leontopetaloides	M		FS	F	X	F	F	F	F			A	H
Musa nana			S		F			?				C	H
Musa sapientum	M	F	S	F	F		F					C	H
Canna indica?	L							?				C	H
Peperomia pellucida	X	F										N	H
Peperomia ponapensis			F					F				I	H
Casuarina equisetifolia	L	F										C	T
Artocarpus altilis (incl. A. mariannensis)	F	F	FS	F	F	F	F	F	F			AC	T
Ficus elastica	F	F										C	T
Ficus tinctoria	X	F										C	T

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON after typhoon	MAJURIREK after typhoon	PINLEP after typhoon	RIBON after typhoon	LIJERON after typhoon	Origin	Habit
Fleurya ruderalis	F	F	F	F	X	F	F	F	F	F		I	H
Pilea microphylla	F	F	S				F					N	H
Pipturus argenteus			FS	F(s)	X	F	F	F	F			I	ST
Procris pedunculata								F				I	HE
Coccoloba uvifera	M											C	S
Boerhavia tetrandra								F				I	C
Bougainvillea glabra	M											C	V
Bougainvillea spectabilis	M						?					C	V
Mirabilis jalapa		F	FS	F				F				CN	H
Pisonia grandis			FS		X	F		F	F	F	F	I	T
Amaranthus viridis		F					F					N	H
Celosia argentea			FS									C	H
Gomphrena globosa		F						F				C	H
Portulaca oleracea	F	F		F		F	F	F				N	H
Cassytha filiformis			F	F			F	F	F			I	VC
Hernandia sonora	X	F		F	F			F				I	T
Brassica acanthiformis	M											C	H
Nasturtium sarmentosum		F										I?N	H
Kalanchoe pinnata			FS	F			F					N	H
Albizia lebbek	M											C	T

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON (after typhoon)	MAJURIREK (after typhoon)	PINLEP (after typhoon)	RIBON (after typhoon)	LIJERON (after typhoon)	Origin	Habit
Canavalia microcarpa	F					F	F	F		F(s)	F(s)	I	V
Caesalpinia pulcherrima			FS									C	S
Cassia occidentalis		F										C	H
Crotalaria incana	F	F										N	H
Delonix regia	M	F										C	T
Erythrina variegata var. orientalis	M	F										C	T
Inocarpus fagiferus	M	F										C	T
Intsia bijuga					F	F	F	F			F	I	T
Leucaena glauca	L	F						?				N	S
Samanea saman	X	X										C	T
Sophora tomentosa					F							I	S
Vigna marina	X	F	FS	F		F	F	F	F	F(s)	F(s)	I	CV
Citrus aurantifolia	M	F						F	F			C	S
Citrus maxima	M											C	S
Citrus sinensis	M	M										C	S
Citrus reticulata	M											C	S
Acalypha wilkesiana	M	F							F			C	S
Codiaeum variegatum								F				C	S
Euphorbia chamissonis								F	F			I	H
Euphorbia glomerifera	F	F										N	C

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON (after typhoon)	MAJURIREK (after typhoon)	PINLEP (after typhoon)	RIBON (after typhoon)	LIJERON	Origin	Habit
Euphorbia hirta	F	F					F		F			N	H
Euphorbia prostrata		F							F			N	C
Euphorbia pulcherrima	M											C	S
Phyllanthus amarus	F	F					F		F			N	C
Ricinus communis	M											C	S
Allophylus timorensis	F		S		F		F	F	F			I	ST
Triumfetta procumbens	F		FS	F		F	F	F	F	F(s)		I	C
Hibiscus esculentus	M	F										C	H
Hibiscus mutabilis	M											C	S
Hibiscus tiliaceus	X	F	FS				F		F			IA	ST
Sida fallax					F							C	S
Thespesia populnea	M											C	T
Bombax ellipticum	M											C	T
Ceiba pentandra	M	F	F									C	T
Calophyllum inophyllum	X	F	FS	F	F	F	F	F	F		F(s)	A	T
Passiflora laurifolia	M											C	V
Carica papaya	M	F	FS	F			F	F	F			CN	ST
Citrullus vulgaris	M											C	C
Cucumis sativus	M											C	C
Cucurbita maxima	F?	F		F?				F?	F			C	C
Cucurbita pepo	M		S									C	C

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON after typhoon	MAJURIREK after typhoon	PINLEP after typhoon	RIBON after typhoon	LIJERON after typhoon	Origin	Habit
Pemphis acidula	F	F			X	F		F		F	F	I	ST
Sonneratia alba	F											I	T
Bruguiera gymnorhiza	F		F	F	X	F	F	F	F			I	T
Lumnitzera littorea			F									I	T
Terminalia catappa	M	F			X	F						A	T
Terminalia samoensis			FS		X	F		F	F	F	F	I	S
Barringtonia asiatica			FS	F	X	F				F(s)	F(s)	I	T
Miconia sp.?	M											C	S
Brassaia actinophylla	M	F										C	T
Polyscias fruticosa	M											C	S
Polyscias guilfoylei	L		S									C	S
Polyscias scutellaria			S					F				C	S
Polyscias tricochleata									F			C	S
Centella asiatica			FS	F				F	F			A	C
Jasminum sambac								F				C	S
Catharanthus roseus									F			C	H
Cerbera manghas	M	F										C	T
Nerium indicum					F			?				C	S
Nerium oleander			F					?				C	S
Ochrosia oppositifolia			F	F								I	T
Plumeria rubra	M		FS			F	F	F	F			C	ST

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON (after typhoon)	MAJURIREK (after typhoon)	PINLEP (after typhoon)	RIBON (after typhoon)	LIJERON (after typhoon)	Origin	Habit
Asclepias curassavica			F						F			C	H
Ipomoea batatas			F									C	C
Ipomoea littoralis		F	FS						F			I	C
Ipomoea pes-caprae	F	F								F(s)		NI?	C
Ipomoea tuba	F	F	S				F					I	C
Cordia subcordata	F	F	FS	F				F	F	F	F	I	T
Tournefortia argentea	F	F	XS	F	X	F	F	F	F	F	F	I	TS
Clerodendrum inerme	X	F	F	F				F				I	S
Lantana camara	M											C	S
Premna obtusifolia	X	F	F	F	F	F		F				I	T
Stachytarpheta urticifolia	F	F										N	H
Ocimum sanctum			FS						F			AC	H
Nicotiana tabacum	F		S									C	H
Physalis angulata	F	F				F	F	F	F			N	H
Solanum nigrum		F							F			N	H
Jacaranda filicifolia	M											C	T
Beloperone guttata	M											C	S
Blechum brownei	F	F										N	H
Hemigraphis reptans									F			N	C
Pseuderanthemum carruthersii v. carruthersii	X	F			F	F		F				C	S

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON after typhoon	MAJURIREK after typhoon	PINLEP after typhoon	RIBON after typhoon	LIJERON after typhoon	Origin	Habit
Pseuderanthemum carruthersii v. atropurpureum	X	F	FS	F	X	F	F		F			C	S
Dentella repens	M	F										N	C
Guettarda speciosa	F		XS	F	X	F	F	F	F	F	F	I	T
Hedyotis biflora		F	FS	F	F							IN	C
Ixora casei			S									C	S
Ixora fraseri	M											C	S
Morinda citrifolia	F	F	XS		X	F	F	F	F	F		I	ST
Hippobroma longiflora		F										N	H
Scaevola sericea	F	F	XS	F		F		F	F	F		I	S
Adenostemma lavenia			FS				F					A	H
Ageratum conyzoides		F										N	H
Cichorium endivium	M											C	H
Spilanthes iabadicensis	M											N	H
Synedrella nodiflora		F					F		F			N	H
Tagetes sp.								F				C	H
Vernonia cinerea		F	FS			F		F	F			N	H
Wedelia biflora	F	F	XS	F	X	F	F	F	F	F		I	CHV

APPENDIX II

GASTROPOD MULLUSCS COLLECTED BY J. L. GRESSITT

List prepared by Yoshio Kondo

Marine species

Turbinidae : Turbo argyrostomus L.? --Mejatto (2 specimens).

Neritidae : Nerita plicata L. --Mejatto (1 spm.).

Nassariidae : Nassarius cf. papillosus L. --Mejatto.

Planaxidae : Planaxis sulcatus Born ? --Lijeron

Land species

Realidae : Omphalotropis fragilis Pease --Imroj (1 dead); Jabor (1 dead juvenile, probably this sp., Bernese funnel from Pandanus).

Assimineidae : Assiminea nitida Pease --Jabor (1 dead, Berlese funnel from Pandanus); Imroj (2 dead).

Truncatellidae : Truncatella guerini Villa --Jabor (16 live; 1 dead juvenile in Berlese funnel may be this sp.); Imroj (4 dead).

Melaniidae : Melania sp. --Pinlep (5 dead; fresh or brackish water).

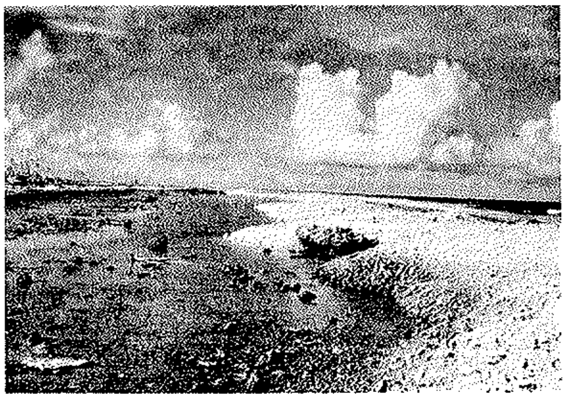
Ellobiidae : Melampus luteus Quoy & Gaimard --Imroj (2 dead; littoral).

Tornatellinidae : Tornatellinops variabilis Odhner --Kinajon (about 150 live and 3 dead)

Pupillidae : Gastrocopta pediculus Shuttleworth --Jabor (1 dead, Bernese funnel from Pandanus); Imroj (1 dead).

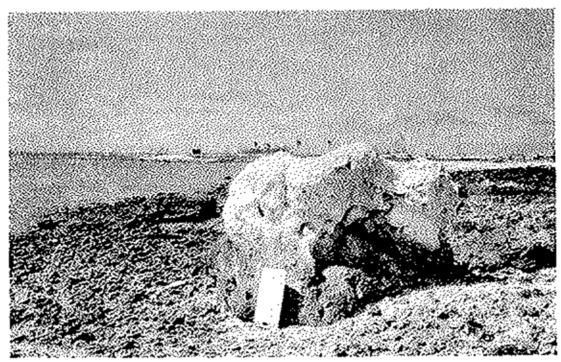
Stenogyridae : Lamellaxis oparanum Pfeiffer --Jabor (1 dead).

Zonitidae : Liardetia sp.? --Jabor (1 dead juvenile, obtained from Berlese funnel, in Pandanus).



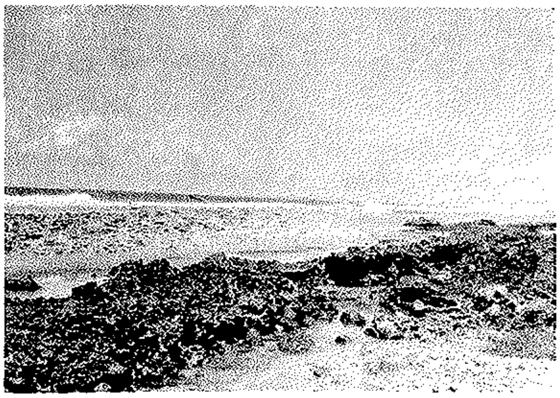
a. Ridge of boulder gravel thrown up on reef flat. Jabor I. (Fosberg photo).

b. Same ridge, close-up showing imbrication of slab-like boulders of coral, principally *Acropora* sp. (Fosberg photo).

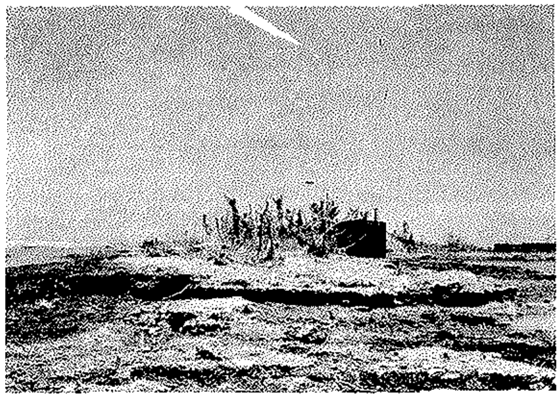


c. Aerial view of Sydneytown area showing large tank surrounded by rubble embankment covered by vegetation and two smaller tanks which have been moved by the storm waves from the two circular foundations visible just beyond the farther tank. Scour channel across reef to left of nearer small tank. (Gressitt photo).

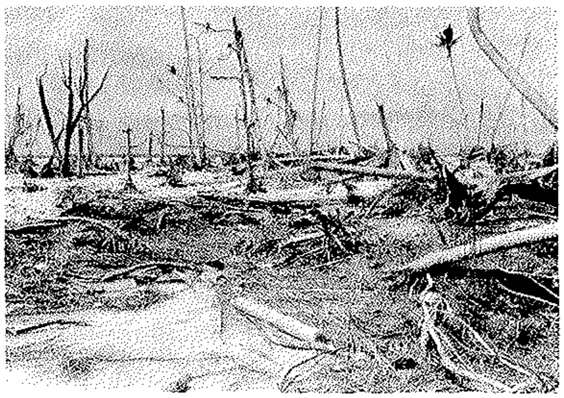
d. Large boulder resting on lagoon bar, Jaluit Islet, 3000 feet north of Blockhouse No. 4. The white upper half and stained lower half suggest that it has been overturned, that the white half was previously buried, the stained half exposed. The board leaning against it is 2 feet long. (Wiens photo).



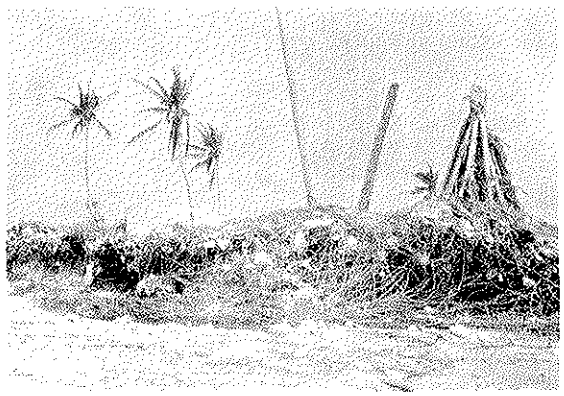
a. Eroded beach rock ridge with depression landward of it, boulder gravel ridge on reef in background, Jaluit Islet south of Jabor. (Wiens photo).



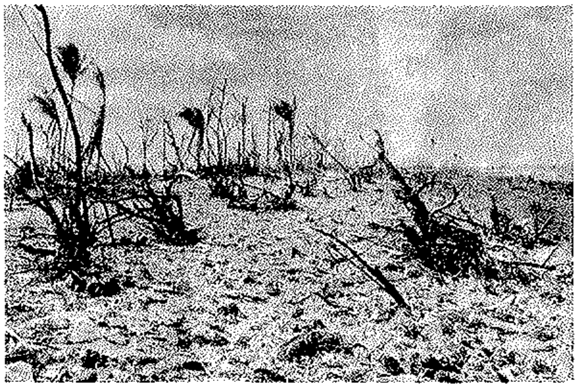
b. Scour channel cut through about 4 feet of conglomerate rock, displaced tank and typhoon-battered vegetation in background; near Sydney-town. (Wiens photo).



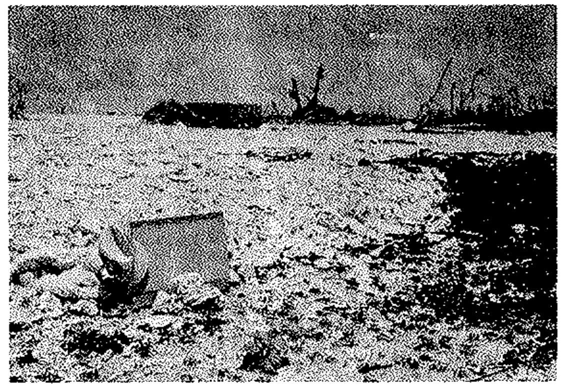
c. Scour pit, showing extensive exposure of root systems, battered Pandanus and coconut trees, gravel sheet in background, some original soil surface in right foreground; Mejatto, south of "Station 4". (Wiens photo).



d. Root masses of coconut and Pandanus trees; the height of these (about 5 feet) suggests that a very substantial thickness of soil has been scoured away in the foreground; about 3000 feet from north end of Mejatto. (Wiens photo).



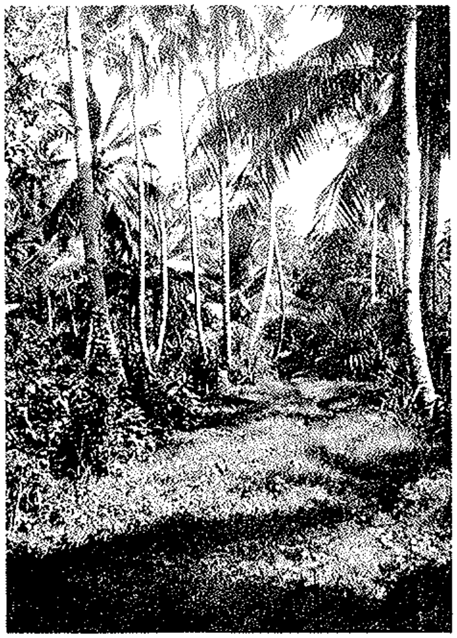
a. Pemphis partly washed out and partly buried by gravel sheet; Jaluit I. about 1000 feet north of steel towers. (Wiens photo).



b. Lagoonward front of gravel sheet; just south of Jabor. (Wiens photo).

c. Lagoonward front of gravel sheet encroaching on small mangrove depression and partly filling it in; Mejatto I. (Wiens photo).

d. Another such depression, partly filled by gravel sheet; Mejatto I. (Wiens photo).



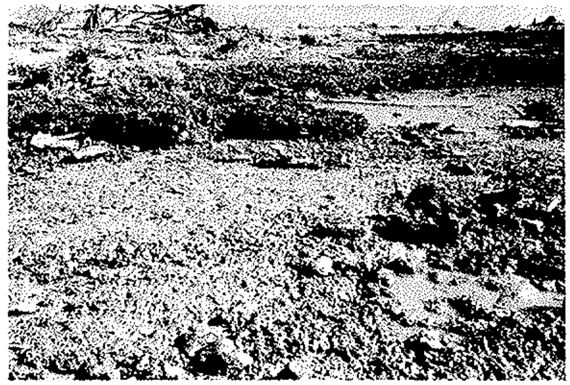
a. Path in coconut-breadfruit plantation before typhoon OPHELIA; Mejatto I. (Fosberg photo, 1946).

b. Opening in coconut-breadfruit plantation, breadfruit tree in center, before typhoon OPHELIA; Mejatto I. (Fosberg photo, 1946).

c. Opening in coconut plantation, Pandanus tree in center; Mejatto I. (Fosberg photo, 1946).

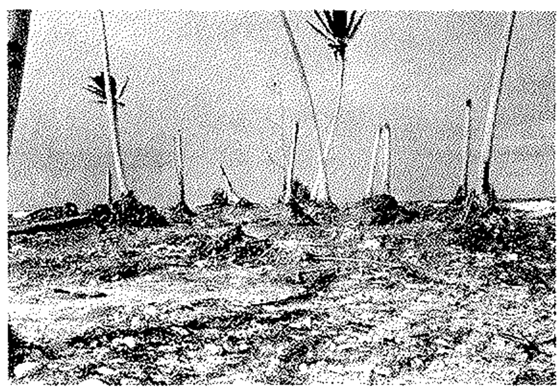
d. Mangrove depression, partly cleared by typhoon OPHELIA, showing Bruguiera trees bare of leaves above, accumulated vegetable debris in foreground; Mejatto I. (Fosberg photo).

a. Marshallese thatched house, surrounded by Pandanus trees, before typhoon OPHELIA; Mejatto I. (Fosberg photo, 1946).



b. Area with vegetation and loose material completely scoured off; South of Jabor. (Fosberg photo).

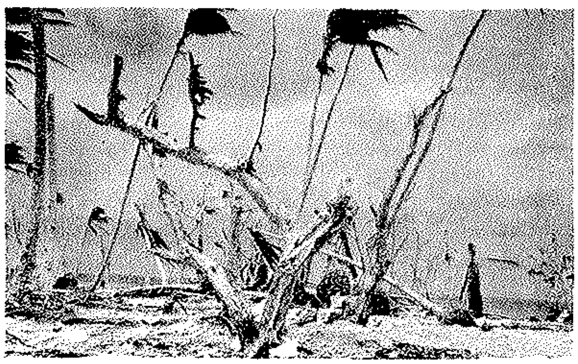
c. Trash thrown into mangrove depression; Bruguiera in background beaten down; Mejatto I. (Fosberg photo).



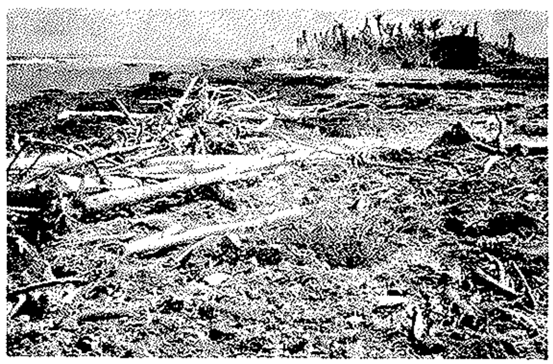
d. Coconut trees snapped off by typhoon OPHELIA; Mejatto I. (Fosberg photo).

a. Uprooted breadfruit and coconut trees, broken Pandanus, battered coconut plantation. (Gressitt photo).

b. Partially uprooted young coconut tree and snapped coconut trunk in destroyed coconut plantation. (Gressitt photo).

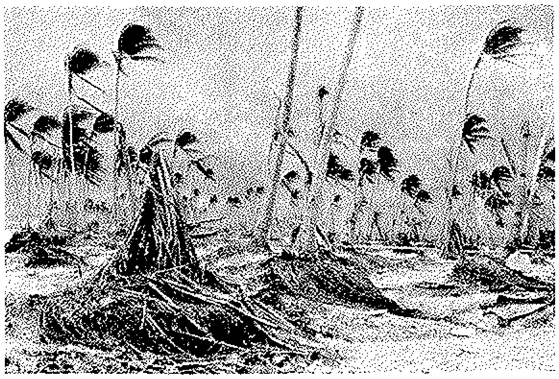


c. Battered but still standing Barringtonia (?), Pandanus, and coconut trees, snapped off coconut trunks. (Gressitt photo).

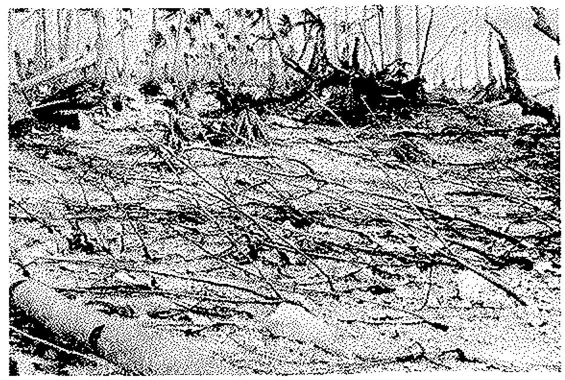


d. Vegetable debris on wave-swept ground, north of Sydneytown; old tank in background. (Gressitt photo).

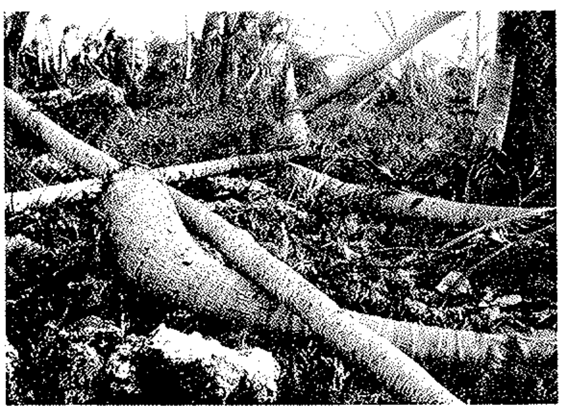
Plate VI



a. Coconut and Pandanus root systems exposed by removal of soil, base of snapped-off Pandanus and snapped off coconut trunks in battered coconut plantation. (Gressitt photo).

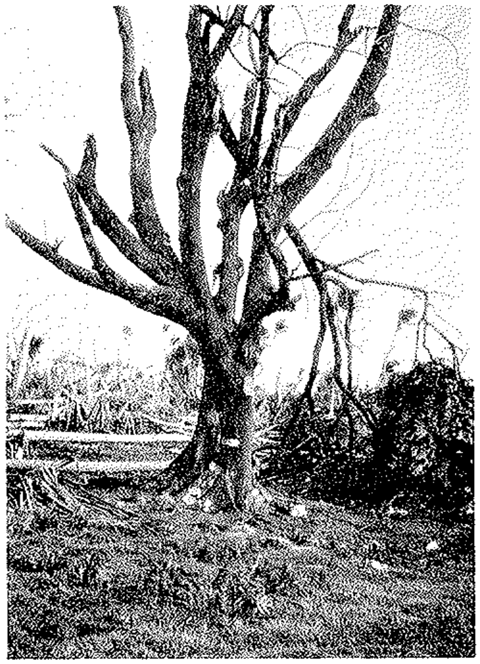


b. Partially buried vegetation, broken Pandanus and other trees, battered coconut plantation. (Gressitt photo).



c. Coconut trunks fallen in several directions; Imroj I. (Fosberg photo).

d. Area hit by wind only, showing broken Pandanus and coconut trees, but relatively undisturbed ground vegetation; Pinlep I. (Fosberg photo).



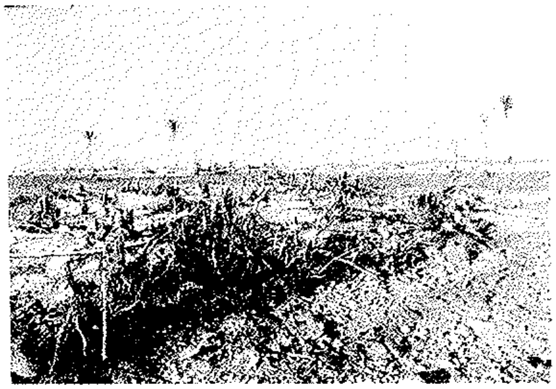
a. Breadfruit tree damaged by wind, broken Pandanus and coconut trees in background, relatively undamaged ground vegetation, area affected by wind only; southeast end of Imroj I. (Fosberg photo).

b. Breadfruit tree with branches stripped off by wind, sending out sprouts with new leaves, ground vegetation of Wedelia favored by increased sun light resulting from typhoon damage to other vegetation, area not inundated; Pinlep I. (Fosberg photo).

c. Pemphis clump with small branches stripped off but sprouting abundant new twigs and leaves; just south of Jabor. (Wiens photo).

d. Phosphate boulders, part of bed discovered during this investigation; northwest end of Imroj I. (Fosberg photo).

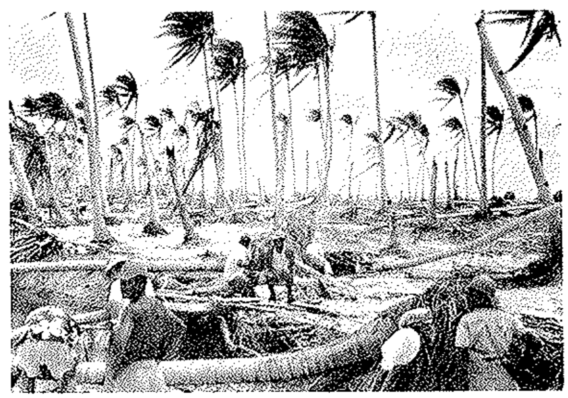
Plate VIII



a. Broken off *Pemphis* bushes on conglomerate platform on lagoon shore south of Sydney-town. (Fosberg photo).

b. Taro pit, with *Cyrtosperma* tops killed by typhoon but otherwise not seriously damaged; Pinlep I. (Fosberg photo).

c. Coconut plantation in unin-undated area, showing damage by wind alone; Pinlep I. (Fosberg photo).



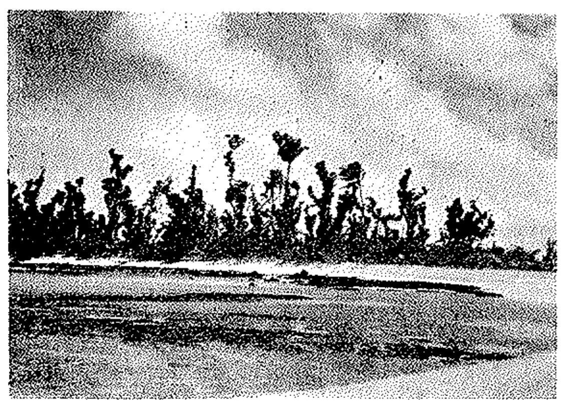
d. Coconut plantation damaged by wind and waves, many trees snapped off, some up-rooted, root systems ex-posed, gravel deposited on soil; showing Marshallese inhabitants. (Gressitt photo).

Plate IX

a. Coconut plantation destroyed by wind and waves; Mejatto I. (Wiens photo).

b. Inner margin of fresh gravel sheet; Mejatto I. (Fosberg photo).

c. Pandanus grove destroyed by wind; Majurirek I. (Fosberg photo).



d. Pisonia forest battered by wind, but sprouting vigorously; Lijeron I. (Fosberg photo).

Plate X