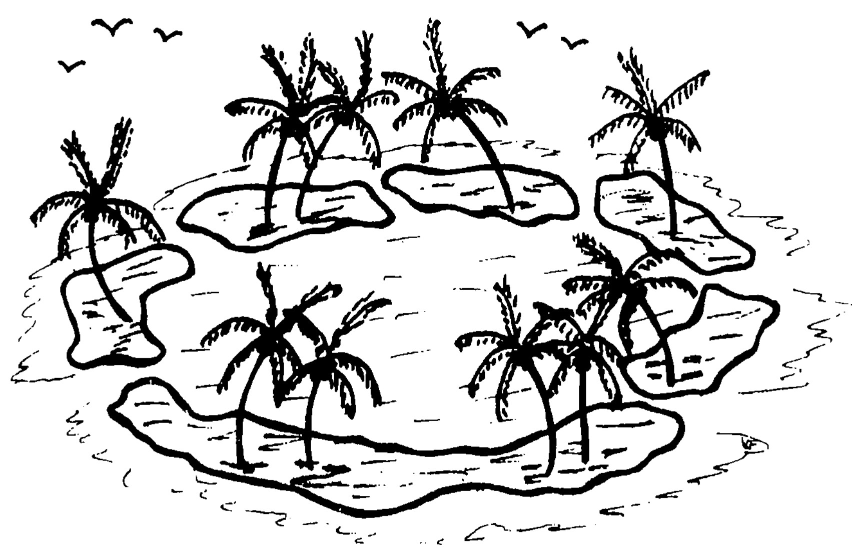
No. 86 February 28, 1962

ATOLL RESEARCH BULLETIN

Geography and land ecology of Clipperton Island

by

Marie-Hélène Sachet



Issued by
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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Washington 25, D. C., U.S.A.

CONTENTS

PREFACE

During the International Geophysical Year, Scripps Institution of Oceanography, a branch of the University of California, organized several research cruises in the Pacific, as part of the world-wide program. Several previous cruises had called attention to Clipperton Island, and during the Doldrums Expedition of the summer of 1958 it was decided to study the biogeography of this little-known island. A group of 13 persons were left on the island by the Research Vessel Spencer F. Baird on August 7, 1958 and were taken aboard again on August 26, except for four who remained until September 25 to continue their studies of sharks. I had the great good fortune to be one of the group and to study plant life on the island. In addition I made observations on the land fauna and geology, and some collections of animals, soils and rocks.

It will not be easy to thank adequately the many persons who have contributed to the success of my work on Clipperton. In the first place of course I want to express my gratitude for this unique opportunity to Scripps Institution of Oceanography and to its Director, Dr. Roger Revelle. I owe much also to Dr. Carl Hubbs, from whom the invitation was received, to Mr. John A. Knauss, leader of the Doldrums Expedition, to the late Conrad Limbaugh, chief of the Clipperton field party, to all my companions in the field and to the Master and crew of the Baird. Our visit could not have taken place without the authorization of the French Government, and without the intervention of Dr. Jean Delacour, then Director of the Los Angeles County Museum and Professor Roger Heim, Director of the Muséum National d'Histoire Naturelle in Paris, who helped procure this authorization. The French Embassy and the Office of the Naval Attaché in Washington were also very helpful.

For permitting me to join the expedition and encouraging me to work up the material, I wish to thank my superiors in the U. S. Geological Survey and in the Pacific Science Board, National Academy of Sciences--National Research Council. The Academy also provided very welcome help in the form of a grant from the Joseph Henry Fund. I cannot name here all the persons who have contributed identifications, analyses, and suggestions and to whom I am deeply grateful. They will be mentioned in the course of the paper. In assembling bibliographic material and photographs I have benefited from the facilities of many individuals and several organizations: the U. S. Navy's Naval History Division, Hydrographic Office and Office of Naval Research, the Service Historique de la Marine Nationale of France, the U. S. Weather Bureau, the U. S. National Museum, the U. S. National Archives, the Library of Congress, the California Academy of Sciences, and the Bibliothèque Nationale of France.

Miss Evelyn L. Pruitt, Head of the Geography Branch, Office of Naval Research, gave me much help in searching for photographs and documents in the U. S. Navy files. Messrs. E. C. Allison, Ted Arnow, Willard Bascom, A. I. Cooperman, A. S. Hambly, Lester F. Hubert, W. L. Klawe, John Knauss, H. S. Ladd, Conrad Limbaugh, W. E. Malone, H. E. Maude, C. S. Ramage, Waldo Schmitt and R. E. Snodgrass gave me unpublished information, lent me photographs and documents, or read and criticized parts or all of the manuscript. Mr. V. A. Rossi gave me advice and help with the illustrations, and Dr. Gilbert Corwin examined the samples of volcanic rocks.

I wish to make special mention of Mr. Obermüller, Géologue en Chef de la France d'Outre-Mer, who worked on Clipperton a few months before I went there and gave me copies of his reports even before their publication, as well as samples of his rock collections.

Finally I wish to express my appreciation and gratitude to Dr. F. R. Fosberg who helped and encouraged me in every step of this work.

The appearance of this paper has been delayed by various circumstances, as has that of a more extensive and profusely illustrated memoir on Clipperton (Sachet, in press).

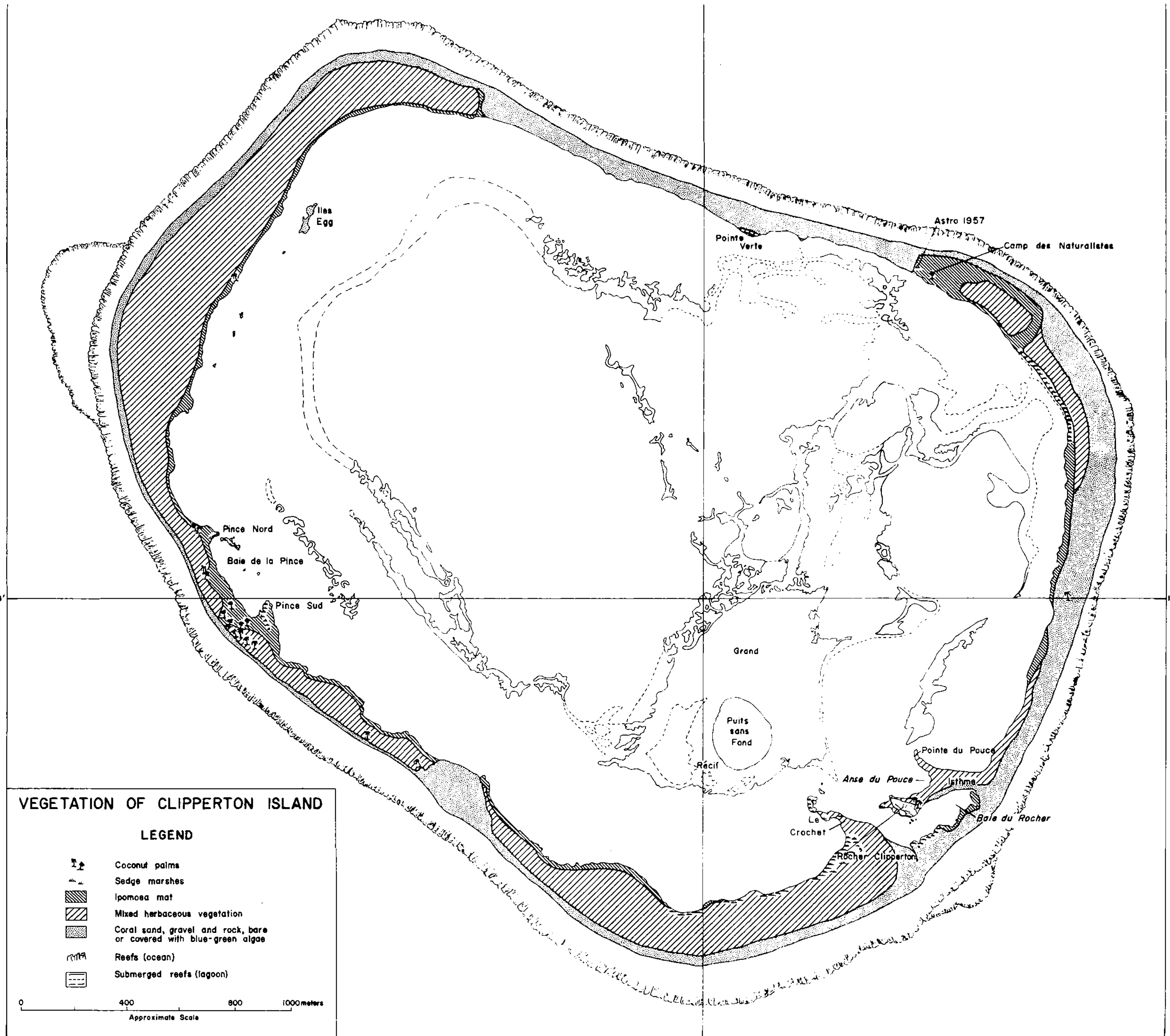

Iles Egg
Pointe Verte
Astro 1957
Camp des Naturalistes
Pince Nord
Baie de la Pince
Pince Sud
Grand
Puits sans Fond
Récif
Pointe du Pouce
Anse du Pouce
Isthme
Baie du Rocher
Le Crochet
Rocher Clipperton
10°18′
109°13′
VEGETATION OF CLIPPERTON ISLAND
LEGEND
Coconut palms
Sedge marshes
Ipomoea mat
Mixed herbaceous vegetation
Coral sand, gravel and rock, bare or covered with blue-green algae
Reefs (ocean)
Submerged reefs (lagoon)
0
400
800
1000 meters
Approximate Scale

Fig. 1

INTRODUCTION

Geographic location, general description

Clipperton Island (Fig. 1), one of the few oceanic islands in the Eastern Pacific, excites the interest and curiosity of naturalists especially because it is the only coral island in that part of the ocean. The nearest atoll, Pukapuka in the Eastern Tuamotus, lies 2300 nautical miles to the southwest.

Here are some other figures that will give an idea of the isolation of Clipperton, the coordinates of which are 10°18'N and 109°13'W (adjusted position for Astro 1957, a monument placed by the U. S. Hydrographic Office on the northeast side: 10°18' 41"N, 109°12' 34"W). The nearest land is the Mexican west coast, 600 nautical miles to the north-north-east. The nearest islands to the north are the Revillagigedo Islands of which Soccoro is 530 miles from Clipperton. The Galapagos lie 1300 miles to the southeast and Easter Island 2250 miles due south.

In its general form, Clipperton is a low closed ring of coral limestone, but the island does not exactly qualify as an atoll as a small volcanic rock rises at the end of a short peninsula in the lagoon. This type of island has been called an "almost-atoll," but this category is not very natural and formations have been placed in it which may have nothing in common beyond the fact that they include both coral and volcanic features. For the purposes of this description it seems practical to consider the island as an atoll, the only one in the eastern third of the Pacific Ocean. In area, Clipperton Rock is very small, compared to the coral ring, and observations so far seem to indicate that it has little influence on the ecology of the island. No macroscopic plants grow on the Rock, except for some lichens.

The coral ring is somewhat egg-shaped and symmetrical along a northwest-southeast axis. This axis falls a little north of the Rock, which is close to the southeast coast of the island. The ring is continuous and encloses a brackish lagoon. Only a small minority of atolls are closed and few of these have a rim as narrow as Clipperton's, around such a comparatively large lagoon. The greatest dimension of the atoll, along the NW-SE axis is 4 km and the circumference of the atoll ring about 12 km. The emerged land strip is widest along the northwest coast, with a maximum width of about 400 m in the west corner. The average width is under 200 m, and in narrow places it is much less. In August 1958 the northern part of the northeast coast measured only 45 m from lagoon to ocean. That area of the land was also the lowest, rising only 0.65 m above estimated mean high tide level. Generally the ground slopes up from the ocean to the tops of the beaches or boulder ridges, and gently down again toward the lagoon so that the highest point of any given ocean-lagoon section is the crest of the outer beach or boulder ridge. This crest varies in altitude, reaching a maximum of about 4 m. The volcanic Clipperton Rock listed on charts as 29 m high, is visible from every part of the atoll. From a small boat in the lagoon the land rim is visible all around, but appears very low. In fact one has the impression of floating in an immense saucer full of water and with a very low rim. Oceanward, the land rim is surrounded by a reef-flat lying at about low tide level. On the ocean side, the outline of the atoll is practically featureless and smooth. The lagoon shores are more irregular, with several small peninsulas and bays. Half way along the northeast side the small triangular Green Point (Pointe Verte) juts into the lagoon (see map). On the southeast side, Clipperton Rock (Rocher Clipperton) rises at the end of a small peninsula, the Isthmus (Isthme); Thumb Point (Pointe du Pouce) extends northward from the Isthmus, separated from the Rock by Thumb Cove (Anse du Pouce). Between the Isthmus and the landstrip, the lagoon forms an arm called Rock Bay (Baie du Rocher). Just west of the Rock, another peninsula, The Hook (Le Crochet), stretches northwestward into the lagoon.

The abandoned quonset village and the large coconut grove on the southwest side of the atoll are located along a small bay, Pincer Bay (Baie de la Pince) formed by two peninsulas, North and South Pincers (Pince Nord and Pince Sud). Other recognizable features are the 5 Egg Islands (Iles Egg) along the northwest side, and the U. S. Hydrographic monument (Astro 1957) and small group of coconut palms marking Naturalists' Camp (Camp des Naturalistes) near the East corner of the island.

Historical sketch*

Clipperton Island is named after an English buccaneer, John Clipperton, who is reported to have seen it in 1705. Clipperton, who was travelling with the famous privateer and naturalist William Dampier, deserted and stole a Spanish prize bark in which he crossed the Pacific, a remarkable feat. There is no account of this voyage during which the island is supposed to have received its name (Burney 1816), and in the description of Clipperton's second voyage (Betagh 1728) no mention is made of the earlier discovery, but the name was indicated on maps about 1730 or 1735 (Moll).

Various authors (Toniolo 1919, Mexico [1911]) have suggested that Spanish navigators may have seen the island earlier, in the 16th or 17th centuries, or even that Magellan may have discovered it in 1521 (Nunn 1934). The island would then be identical with Medaños and San Pablo (Magellan). Historically, such considerations are of great interest but as far as our scientific knowledge of the island is concerned they are immaterial, as it is quite unlikely that ancient descriptions will come to light.

Our knowledge of the island, and the extensive literature concerning it, then begin in 1711. On April 3, Good Friday, two small French vessels, the Princesse and the Découverte, who had left Brest together in 1708, met with an unknown island which was named Ile de la Passion. The Captain of the Découverte, Michel du Bocage, and a passenger in the Princesse, Mr. de Prudhomme described the new island, the one in his log and the other

* For a more detailed treatment see Sachet 1960.

in his diary. Their discovery was first mentioned in print in 1725 (La Barbinais Le Gentil), while their accounts were published in extenso in a French report (France 1912). The original documents are kept in the French National Archives.

Mr. du Bocage described Clipperton as "A large Rock, cragged and jagged, at the south point of a very flat island..." The northeast side, "sandy with some brush and a dried-up tree on the north-east point, was but a very narrow tongue of land. The center of the island was a large lake reaching from one side to the other. The west side appeared to have some low brush with soil and some rock but very low, although a little higher than the east side." Mr. de Prudhomme also described the very low sandy island, without any trace of inhabitants, unwooded except for some very low bushes, and with some dead trees on the sea shore "as if they had been thrown up by the currents."

These brief accounts are remarkable in that they describe Clipperton much as it appears today from aboard ship, except for the recently added coconut trees and various traces of human activity.

There can be no doubt that Ile de la Passion is the island now called Clipperton. The coordinates given in 1711 were:

Du Bocage	10°28'N, 263°50'	(113°3'W Greenwich)
De Prudhomme	10°18-19'N, 268°11'	(108°27'W)

(From the latest observations, the coordinates are 10°18'N, 109°13'W).

Over a hundred years later (1832), an American sea-captain, Morrell, described the island as he saw it in August 1825: "It is low all around near the water, but a high rock rises in the centre, which may be seen at the distance of six leagues..." As far as known, Morrell and his men were the first to land on Clipperton.

Except for a small sketch map, poorly oriented, which Mr. de Prudhomme mentions and which is kept with his diary and reproduced in the French report (1912), Clipperton Island was first mapped by Sir Edward Belcher and the map published by the British Admiralty in 1849. In May 1839, when Belcher visited it, the island was (Belcher 1843): "a very dangerous low lagoon island, destitute of trees, with a high rock on its southern edge, which may be mistaken for a sail .../The belt of land/ literally constitutes two islands, formed by its two openings ..." (See fig.4, facing p.69).

A few years later, a French ship owner, Mr. Lockhart, arranged to take possession of the unclaimed island for France and to exploit its phosphate deposits. Thus it came about that in 1858, one of Mr. Lockhart's merchant vessels, l'Amiral, Captain Detaille, Master, arrived at Clipperton. Lt. Victor Le Coat de Kerveguen, who had received a special commission for the purpose, took possession of the island for the Second Empire on November 17, 1858. The Amiral then proceeded to Honolulu where the necessary papers were filed to announce to the world that the island was now a French possession. Le Coat de Kerveguen took notes on what was observed on Clipperton and his manuscripts, sketches and maps are reproduced in the French report (1912). In 1858 the coral rim was closed, the lagoon salty, there was no vegetation, but great numbers of sea birds. Some soil samples were collected, but exploitation of the phosphate deposits did not seem worth while and was not then undertaken.

In August 1861 (Pease 1868) a young American, Lt. Griswold, who later lost his life at Antietam, visited Clipperton Island and found it uninhabited, covered with birds but devoid of vegetation. The lagoon was closed, its water fresh and full of a water plant which he collected. This first botanical specimen from Clipperton was sent to the California Academy of Sciences in San Francisco and lost in the 1906 fire.

Just who discovered phosphate deposits on Clipperton Island is obscure. They were known to Lockhart in 1857, and Griswold was on a phosphate exploration trip. In 1892 Frederic W. Permien made several trips to Clipperton to survey the deposits and in 1893 the Oceanic Phosphate Company of San Francisco sent two men, Jensen and Hall, to survey the island and begin exploitation (Anon. 1893). The observations of Jensen, and his excellent sketch-map are reproduced by Agassiz (1894, pp. 174-175). Jensen had collected a piece of the volcanic rock, which was identified as a trachyte. At the same time, A. Churchill Fisher made observations on tides (U. S. National Archives). W. C. Erratt, of the Schooner Anna of San Francisco, surveyed the phosphatic deposits probably in 1897, and his map is available in the Archives. Also in 1897, P. J. Hennig (Anon 1897) prepared a map, which he forwarded to the U. S. Hydrographic Office. It was promptly published as an H. O. Chart (no. 1680), replacing the charts based on Belcher's sketch, and remaining in use by all navigators until the French survey of 1935.

Exploitation of the Clipperton phosphate proved difficult and not very profitable, and several companies were to attempt it one after the other before the island was abandoned during World War I. When the French war ship Duguay-Trouin arrived at Clipperton in Nov. 1897, a small camp was discovered with three employees of the Oceanic Phosphate Co., who hoisted the U. S. flag. France protested, the United States announced that they had no claim on the island and Mexico joined the excitement. The Duguay-Trouin was hardly out of sight when a Mexican gunboat, the Democratá, arrived (Dec. 13, 1897). Here started a diplomatic conflict which was to last until 1931, when King Victor-Emmanuel III of Italy awarded the island to France, and which has become a text-book case for students of diplomacy and International Law. France and Mexico had agreed to submit the case to the monarch's arbitration in 1909, and both countries published historical reports (Mexico [1911], France 1912) to present their cases. They are valuable documents, the French one especially, as it includes all the texts describing the island to date, some of them unpublished until then.

During this period, Mexico continued to lease the phosphate deposits of the island to various companies including the Pacific Islands Company Ltd. of John Arundel. Also during that time, several naturalists visited the island and made geological and zoological collections, among them John Arundel in 1897 (Wharton 1898, Garman 1899), Snodgrass and Heller in 1898, R. H. Beck in 1901 (Beck 1907), and the California Academy of

Sciences expedition in 1905 (Slevin 1931). Casual visitors added specimens, especially shells, to the collections of Clipperton animals. For instance a group of shells in the U. S. National Museum was received in 1897 from Mr. Arnheim, a ship chandler who had obtained them from sailors.

In 1906 a light was built on top of the Rock, but during World War I, the island was abandoned in a dramatic chapter of its history, and was forgotten. There are quite a few accounts of it for the period 1893-1906, but hardly any information between 1917 and 1935. According to a letter in the U. S. National Archives, several men from the Schooner Ethel M. Sterling from San Pedro landed on Clipperton on January 5, 1929, after several days of bad weather kept them on board ship off the island, and they collected samples of guano and lagoon water. The research vessel Velero III (Fraser 1943) stopped at Clipperton on January 6, 1934, but landing was impossible, although some biological specimens were dredged a short distance off shore. In January 1935, the French training ship Jeanne d'Arc after several visits when landing was impossible, came back to Clipperton, and a group of officers and midshipmen succeeded in making a landing on January 26. They drew a map, wrote descriptions of the island, and collected some plant and rock samples (Lacroix 1939, Gauthier 1949). The ship's seaplane took some photographs. A bronze plaque sealed on the east face of the Rock commemorated the visit and established French ownership.

The next well-known visit was that of President F. D. Roosevelt in July 1938, during a cruise on the USS Houston. Dr. Waldo Schmitt of the U. S. National Museum, who had been invited to travel with the President as expedition naturalist, landed on Clipperton for a few hours and made some very valuable collections of plants and animals which were described in a series of papers (Smithsonian Misc. Coll., 1939-1942).

During the second World War, Clipperton is said to have been visited by Japanese submarines; in 1943 and 1944, the U. S. Navy made several reconnaissances of the island and the famous Australian pilot Captain Sir P. G. Taylor landed his seaplane in the lagoon. Such visits resulted in valuable descriptions (Byrd 1943, Taylor 1948) and photographs. In Dec. 1944, a small U. S. Weather Station was established. The ship (LST 563) bringing most of the material for its construction struck the reef, and its great rusted carcass, battered and much dismantled was still a conspicuous landmark near the landing point on the northeast side in August 1958, and served as a breakwater for small boats effecting a landing. Rusting landing craft, fuel tanks and ammunition were scattered nearby across the land strip. The weather station lasted until October 1945, and its ruins are still recognizable as an abandoned quonset village in the southwest coconut grove, the roads marked by tracked vehicles during that period can still be followed most of the way around the island.

Since the end of World War II, French Navy ships have been visiting the island regularly (Goua 1952, Bourgau 1954) and when landing turned out to be possible, markers have been attached to the base of the Rock. In 1958, there were 4 such commemorative tablets. During the fifties, scientific groups from various institutions stopped at Clipperton and made observations or collections: the U. S. Navy Electronics Laboratory in May 1952 (Hertlein and Emerson 1953), Scripps Institution of Oceanography in Dec. 1954, and Oct. 1956 (Dawson 1957, Hertlein and Emerson 1957), and U. S. Hydrographic Office, Nov. 1957. This last group was making astronomical and geophysical observations, and determining the exact position of the island. A French Navy officer and Mr. A. G. Obermüller, chief geologist of the France d'Outre-Mer accompanied the American geophysicists. The geological collections have been described in an important report (Obermüller 1959). Another valuable result of this expedition is a collection of photographs taken from a helicopter. In May 1958, Mr. W. L. Klawe, of the Inter-American Tropical Tuna Commission visited Clipperton for a few hours and collected some plants. Finally in August and September 1958, the group of naturalists from Scripps Institution of Oceanography camped on the island and made observations as complete as possible on the flora, fauna, weather and other aspects. The group included four biologists using skin-diving equipment to study the marine fauna, three icthyologists, two entomologists, an ornithologist, two radio operators, and myself as botanist. The marine biologists working on the reef and in the surrounding ocean, collected marine animals and algae and made ecological observations and I concentrated my efforts on the land flora and terrestrial and lagoon habitats. However, to give a complete view of the atoll, I shall include brief descriptions of certain marine aspects from my limited observations completed from information communicated to me by my companions and extracted from the literature. A list of the recorded land flora and fauna, the latter largely compiled from the literature, will also be included, in-so-far as necessary to give an account of the land ecology. Extensive accounts of the zoology are being prepared by the zoologists of the expedition, and other specialists.

WEATHER AND CLIMATE

The weather and climate of Clipperton Island are very poorly known. The only weather records, outside of brief mentions by visitors, were collected from January to October 1945 when a U. S. Navy station operated on the island, and during August and September 1958 when Messrs. Limbaugh and Chess of the Scripps group made daily observations. The Navy records have never been used and are not available; the others will be utilized below (and see table 1).

The U. S. Hydrographic Office publishes climate and weather data for ocean areas from information transmitted by ships. However the ocean area where Clipperton Island lies is not included: The Weather summary for Central America (H.O. 531, U. S. Hydrographic Office 1948) has no information for areas west of 100° W long. so the 5-degree square for Clipperton is not discussed. Summaries of Pacific Ocean weather often do not extend far enough to the east to include the region of Clipperton. One reason for this state of affairs is probably the small amount of information available in an area where there are no recording stations and few ships records. According to the World Meteorological Organization (Anon. 1957) this is one of the poorly known ocean areas of the world, from which more reports are much needed.

Information on Clipperton must be gained from general sources such as the Weather Bureau's Atlas of climatic charts of the ocean (McDonald 1938) and the U. S. Navy Atlas (1956).

The climate of Clipperton Island is an oceanic tropical one, with little variation in temperature but with seasonal rainfall and storms. The seasonal variation is correlated with tropical cyclone activity which reaches a maximum in the eastern North Pacific in August, September and October. In these months the island frequently experiences winds from a southwest quarter, probably generated by tropical cyclones to the north.

Temperature

According to the most recent compilation (U. S. Navy 1956) the mean monthly air temperature is never below 80°F (26.7°C) and only in June is it equal to or above 82°F (27.8°C). From the same source, the mean air-sea temperature difference for 3-month periods is of the order of -1°F or at most -1° to -3° (air cooler than sea).

In the period August - September 1958, the lowest recorded air temperature was 75°F (23.9°C) at 1300 PDT (Pacific Daylight Time, which is the correct time for Clipperton Island) taken during or just after a rain storm. The highest recorded temperature was 87°F (30.6°C) also at 1300. On sunny days it was quite hot in the sun, but never unbearably so. Night temperatures were not recorded but seemed only slightly below day time temperatures.

Atmospheric pressure

Because Clipperton lies close to the equator and its belt of low pressures, the atmospheric pressure there is always low, with little yearly variation and with probably regular and slight daily variation in calm undisturbed weather. At Colon, Panama (U. S. Hydrographic Office 1948) the yearly variation of mean monthly pressure is only of 2 mb, the highest mean in February (1011.18 mb) and the lowest in June (1009.14 mb). In the same area of Panama, the total daily range at Cristobal averages 2.9 mb for the year, being about 3 mb for October to March and 2 mb for June to August. The highest pressures there occur at 1000 and 2200 local time and the lowest at about 0400 and 1600. From a large sampling of ships' reports, the maxima over the ocean at 10° lat. occur at the same times, and the diurnal range is 2.8 mb. From the short record available (August - September 1958) the daily variation at Clipperton seems to fit this pattern, with a usual daily range of the order of 2 mb. During the period of record, the total range of recorded pressures was 8 mb (1002 to 1010). The low values coincided with bad weather and probable cyclone activity in the area. Since the records are only for August and September nothing can be said of any yearly pattern of atmospheric pressure variations.

Winds

Surface winds at Clipperton Island vary greatly during the year. In the winter the dominant winds are the northeast trades, although they are far from exhibiting the type of constancy experienced on islands farther west. In the summer the winds change considerably and from August to October they blow principally from the SW quarter. During that time, as tropical cyclones dominate in the area, winds are extremely variable and their direction can change rapidly during the day. Table 2 is from MacDonald's atlas. Wind roses for the 5-degree squares are included in the Hydrographic Office's Pilot charts of the North Pacific Ocean and those for the square of Clipperton are reproduced from recent monthly charts in table 4.

Nothing more is known of the wind regime for the island beyond this generalized information except for the August - September 1958 data and the observations of Taylor in September - October 1944 (P. G. Taylor, 1948). In 1958, the recorded observations of wind direction (see table 1) indicate a predominance of winds from the southwest quarter, especially SSW to SW in August and SW to SWS in September. These observations fit well with the generalized data of McDonald's atlas (see table 2). Recorded speeds were up to 26 knots, but the majority of observations in August indicated speeds of 10 knots or less and in September a majority of observations below 20 knots. In August, at least, the strongest winds were not recorded. There is only one record of calm and indeed the almost constant wind, whatever its direction, made living on the island very comfortable.

Rains almost always came from the southwest; from the northeast land strip one could see the dark rain clouds engulf the coconut grove

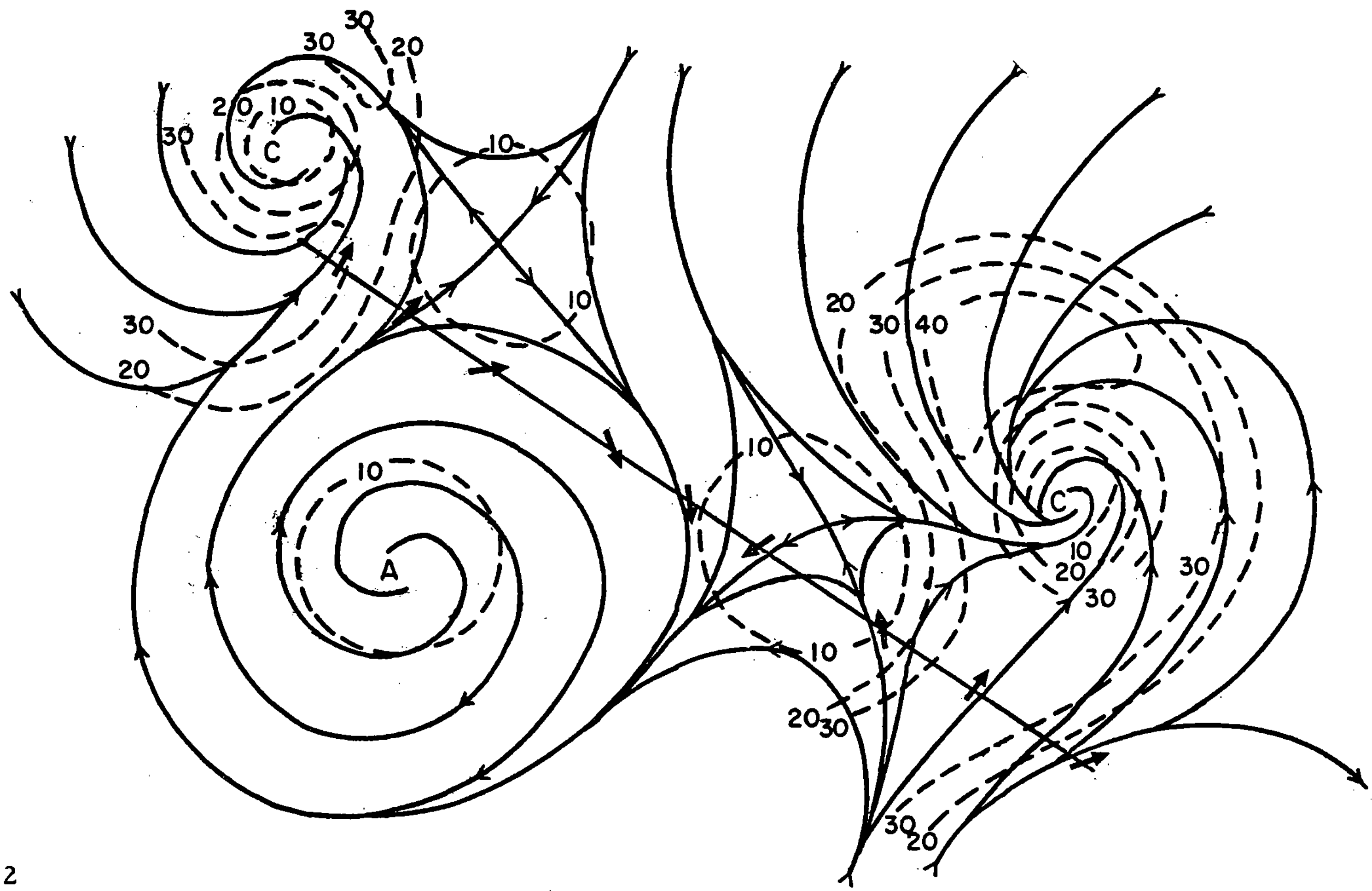


Fig. 2

Reconstructed streamline/isotach chart sequence fitting Taylor's (1948) observations at Clipperton Island. The solid-line curves represent the direction of wind-flow. The isotachs (broken lines) are labelled in knots. The systems (C cyclone, A anticyclone) move generally toward NW or WNW and the successive positions of the island relative to them lie along the straight line. The arrows on this line are observed winds at the island. This line is approximately 1500 miles (2400 km) long. The sequence begins at the top of the line and ends one week later at the bottom. Chart prepared by Professor Ramage.

on the opposite side of the atoll, which promptly disappeared from view, cross the lagoon and eventually reach the northeast side, drenching it with a downpour of incredible suddenness and violence.

In October 1956 (Limbaugh, personal communication) the winds were generally from the southwest, with velocities up to 13 knots.

During his first short stay on Clipperton (from September 9th, 1944) Taylor seems to have encountered reasonably good weather, sunny and clear much of the time, and he gives little information on it in his book (1948). During the second visit (September 21 - October 14) the weather was much worse, culminating in a hurricane (see p. 19). Strong winds from the southwest were common, with squalls up to 35 or 45 knots (estimated) and frequent and rapid changes of surface wind directions were noted.

After spending some time on the island, Taylor summarized the general pattern of winds and weather as follows (p. 194):

"From observations from the time we had been at the island, it seemed that there was a fairly regular weather cycle, with sometimes one period of the cycle more prominent than others.

"We had arrived the second time in the bad sector, when the wind was in the south-west and at a time when this phase was exaggerated, with stormy conditions.

"As the wind swung into north-west the weather had improved, and by the time it had come round to north the sky was clean with scattered cumulus, and the surface wind was seldom more than fifteen knots. Fine weather with light winds and little cloud then prevailed for several days as the breeze worked round east to south and back for south-west, when a high overcast would come over and the underlying cumulus would build up to cumulo nimbus with lightning and storms and the air was uneasy and wild till the wind shifted again toward north. The weather went round this cycle in about a week, and always there was rain from the south-west or west, and sometimes a shower from a local build-up of cumulus in the fine periods."

This sequence fits well the storm tracks commonly observed in the Clipperton region, and has been represented in a streamline/isotach reconstruction (fig. 2) prepared by Professor Ramage (personal communication 1960): "The cycle starts with a tropical cyclone (C), moving NW or WNW to the north of the station /Clipperton/. Winds veer to W and NW and the weather improves as the eastern portion of a small high pressure cell (A) follows the storm circulation across the station. Winds decrease further but weather stays fair as the divergent portion of a col preceding the next cyclone moves over. The cycle is complete when strongly convergent SW winds associated with the next cyclone set in." This reconstruction also compares well with the sequences recognized from the 1958 data (p. 16).

Tropical storms and hurricanes

While not as numerous and destructive as they are in the Caribbean area or the China Sea, tropical storms and hurricanes are common in the southeast North Pacific, with an average of at least 6 storms every year, two of which reach hurricane strength. Hurd (1929 p. 45, 1948) assembles the cyclonic storms of this region into 4 classes: 1. The coastwise storms, that run parallel to the Central American and Mexican coast, 2. those that strike perpendicularly upon the Mexican coast, 3. cyclones of the Revillagigedo Islands and 4. cyclones west of the 125th meridian. The last need not concern us here. The storms of the first class originate somewhere along the American coast, often in the Gulf of Tehuantepec or south of it, or sometimes perhaps as far south as the Gulf of Darien (Ives 1952). They travel usually northwestward in a course parallel to the coast; some swing inland over the Mexican west coast, some travel far into the Gulf of California; a few cross over to the Caribbean area, and conversely, some storms originating in the Caribbean travel to the Pacific side. The storms of this class are far to the east of Clipperton and probably never affect it.

The storms of the 2nd class occur farther west and travel in a northward direction. Those of class 3 travel in a west-north-west direction and are mostly observed north of 15°N. Some of the storms of these 2 classes may form near Clipperton, or pass by it. There are also storms in this area which do not readily fit in the 4 classes, such as some which travel in a westerly course or sometimes even somewhat south of west.

The occurrence of tropical storms in the southeast North Pacific is seasonal, and the monthly distribution is given by Visher (1925) as follows:

Dec. to Feb.	1% each
March to May	0
June	5%
July	11%
Aug.	15%
Sept.	34%
Oct.	24%
Nov.	5%

Because Clipperton is removed from shipping lanes and has only been inhabited occasionally and for short periods of time, historical records of storms and hurricanes are poor. However, some of the storms which are reported west of 110°W and travelling in a northwest direction may have originated near the island or passed it, either as storms or, rarely, as full-size hurricanes. A tropical storm, it must be remembered, need not score a direct hit, or even have reached its full development, to affect an atoll lying only a few meters above sea level. Even storms travelling several hundred kilometers away may generate storm waves high enough to batter the island and even to flood the lower areas of the land strip.

The older records of storms in the southeastern North Pacific are listed by Redfield (1856), the Deutsche Seewarte (1895), Visher (1922, 1925) and Hurd (1929, 1948). In recent years, tracks of storms have been plotted by the Weather Bureau in the National Summary of Climatological Data and the Mariners Weather Log, and by the Hydrographic Office on the Pilot Charts.

From these records the list on the following pages has been extracted. Some of the storms may have passed Clipperton Island close enough to affect it, or may have formed near it. Those marked with a * were reported very near the island, or experienced at it.

Date	Place reported		Source	Ship reporting, and notes
1849, June 21-22	15°55'N	116°16'W	Redfield	Sylph
1850, Aug. 5	14°20'	117°	"	Como; winds N, W, S
1850, Oct. 3-4	13°30'	116°50'	"	Amazon: winds SW, SE, E, N, W and SW again
1852, July 16-19	15°	115°	"	Panama, and Empire
1852, July	13°	112°	D. Seewarte	(same storm as above?)
1855, Aug. 8-9	15°	116°31'	Redfield	Gertrude Maria; winds NE, NNW, WNW, W, SW
*1857, June 20	11°	110°	D. Seewarte	Seamans Bride; storm in formation
1858, Aug. 17	13°	115°	"	Gellert; winds E, N, W, S
*1865, July 25	10°	109°	"	Zanzibar
1871, July 3	16°	117°	"	Shelehoff
1882, July 31	13°	118°	"	Dora, and Adelaide
1891, Aug. 7	11°	107°	"	Dorothea
*1895, Sept. 29-Oct. 1	9°	112°	Hurd 1929	"Strong southwesterly squalls were experienced by a vessel at anchor there [Clipperton] on the 29th."
1899, Aug. 27-31	14°	112°	Hurd 1929	
*1910, Sept. 8-11	10°37'	109°46'	Hurd 1948	
1913, Aug. 23	17°49'	121°22'	Visher 1925	Robert Searles

Date	Place reported		Source	Ship reporting, and notes
*1915, June?	Clipperton		Morris 1934	Storm destroyed Mexican camp
1915, Sept. 4-5	$15^{\circ}40'$	$109^{\circ}40'$	Kimball 1915	Calliope
1922, July 31	14°N	118°W	Visher 1925	
1922, Sept. 9-10	$16^{\circ}12'$	$113^{\circ}44'$	Visher 1925 and Hurd 1948	Bessemer City A very intense and very large hurricane
1922, Oct. 13-16	15°	110°	Hurd 1948	
1928, Oct. 15-16	$16^{\circ}34'$	$113^{\circ}29'$	"	
1936, Oct. 27-29	12°	106°	"	
1940, Sept. 22-24	14°	110°	"	
1940, Oct. 6-11	12°	110°	"	
*1944, Oct. 12	Clipperton		Taylor 1948	See below, p.
1955, June 5-8	14.5°	111.1°	N'al Summary	Hawaiian Citizen; moving N
1955, June 7-10	11.4°	107.4°	"	Hawaiian Fisherman; center charted at 11.5°, 109.7°, moving NW
1956, May 17-19	14°	111°	"	Arapahoe; center estimated at 13.7°, 111.6°, moving W
*1957, July 14-26	10.3°	109.5°	" and Mar. Weather Log, March 1958	Gravel Park; moving W then WNW

Date	Place reported	Sources	Ship reporting, and notes
*1957-1958	Clipperton		Vegetation destroyed and gravel sheet laid over northeast side of I. See pp. 70-72 . No storm on record (Mar. Weather Log, 1958) seems tocorrespond to that which must have hit the island between Nov. 1957 and May 1958. It is rather disappointing that this storm cannot be identified. It may have been a relatively minor or local disturbance, of course, and may have occurred at a time when currents and tides were such that they intensified the effect of its storm waves.
*1958	Clipperton		During the survey of the island in Aug.-Sept., there was some bad weather, including a storm in the middle of September. On Sept. 17, its effects could be observed on the southwest side of the island (Limbaugh, unpublished data): the shore had been cut, much gravel removed and redeposited at the northwest corner, and beach-rock exposed that had previously been covered by sand. The data collected in Aug.-Sept. (see table 1) also help backtrack storms observed later elsewhere. The following sequences were reconstructed by Professor Ramage (personal communication):
"(a) Aug. 8			"A depression or tropical storm moved toward WNW, the center passing just north of the station. /Clipperton/. Almost certainly this is the storm which was first located when the ship HAWAIIAN TOURIST reported NE 45 knots at 17.8 N, 120.8 W at 1800 GMT on the 12th.

Date	Place reported		Sources	Ship reporting, and notes
*1958 (b) Aug. 11	Clipperton			"A small depression or tropical storm moved on a westerly course just north of the station.
(c) Aug. 17-25				"The center of a small tropical storm passed across the station from SE to NW then possibly intensified not far to the NW.
(d) Aug. 27 - Sept. 3				"A depression appeared to develop and slowly intensify in the Clipperton area finally moving to the N of the station on the 3rd. It continued to move N and then NW being first located when winds on the island of Roca Partida (19N, 112W) increased to SE 40 knots at 1200 GMT on the 6th. By this time, or shortly thereafter winds of over 100 knots had developed near the storm center." /The storms mentioned are recorded in Mariners Weather Log for March 1959./
1959	Clipperton			None of the storms reported for 1959 in Mariners Weather Log, March 1960, seems likely to have affected Clipperton Island.
1960	Clipperton			None of the storms reported for 1960 in Mariners Weather Log, March 1961, seems likely to have affected Clipperton Island.
1961, July 10	16°N	113°W	Mar. Weather Log, Sept. 1961	Tropical storm Joanne moving westward; on the 11th, winds near center 60 knots.
July 14	17°	107°	"	Hurricane Kathleen moving northwestward; maximum winds 70 knots.

Date	Place reported		Sources	Ship reporting, and notes
1961, July 15	19°	109°	Mar. Weather Log, Sept. 1961	Kathleen
July 16	16°	112°	"	Kathleen moving west, 60 knot winds near the center.
July 14	14°	97°	"	Hurricane Liza, winds near the center 70 knots.
to July 15-18	20°	118°	"	Liza moving west-northwestward, maximum winds near 50-60 knots.
July 20	15°	109°	"	Tropical storm Madeline (see p. 23), moving westward, winds near center 55 knots.
1961, Aug. 4-5	18°	$115-120^{\circ}$	Mar. Weather Log	Tropical storm Naomi, winds 30-50 knots.
1961, Sept. 6-8	17°	110°	"	Tropical storm Orla moving northwestward, winds 60 knots.
	to 22°	114°		

The following is condensed from Taylor's book (1948, pp. 224-254), the only eye-witness account of a Clipperton Island hurricane. October 12, 1944. Soon after dawn, fresh breeze from the north, sky dark, heavily overcast, nimbus hiding the tops of cumulus, and fast moving clouds below. Altimeter of aircraft set at zero read 29.95 (1010.8 mb), low on the scale of earlier daily readings, but no lower than had already been recorded. At breakfast time, the fresh puffs on the lagoon had changed to squalls, the wind swinging around as its force increased soon reaching 50 knots. Rain came in blinding sheets, drenching the camp. The squall passed, but the wind hardened into a steady blow, and within an hour of coming ashore for breakfast, little remained of the camp. (This camp was on the west lagoon shore, just north of North Pincer). Suddenly the wind eased to 30 knots, but soon after swung into east and became worse. Half an hour later there was another slight easing of the wind, but soon it swung more towards south and became more violent. "About two hours after the first squalls the wind swung nearer to south... The Rock was blotted out and the lagoon was sweeping towards us in a wall of water like spray from many hoses, reaching from shore to shore and leaving no definition between sky and lagoon. It was a fantastic sight..." The wind was still blowing with hurricane force, estimated as between 80 and 100 knots. A little before noon it swung to south and the lagoon waves abated somewhat, but danger from the ocean became greater. In the coconut grove: "the heads of the palms were streaming back in windblown fronds like the hair of a girl in the wind. The taller palms were bent like tight-strung bows, and held till it seemed that their spines must break. Their fronds were awash in the blast of air... And now, instead of the horizon dark with cloud against the flat rim of the land, there was a cold white stream of breaking surf, visible above the land, and roaring madly at the island... Already only the reef was stopping the rollers, which ... were higher than the land." If the hurricane were to swing into southwest the ocean would flood the strip of land where the camp was. Trying to reach the coconut grove only 200 yards away, two men went first oceanward to seek some shelter on the ocean side of the beach ridge, but the sea was already far up the beach, and kept rising. "It was roaring by now not two feet below the top of the bank. The surge was sending little rivers trickling through the stones over the top... Now there were no rollers breaking on the reef. The whole ocean was tearing by in a roaring flood of water, clawing at the island." The pigs and some birds had taken shelter in the coconut grove.

About 3 p.m., there was a definite lightening in the sky and a slight easing of the wind, which definitely slacked up a few minutes later. Back in the aircraft, the altimeter showed steadily rising pressure. By 5 p.m., the wind had dropped to a hard blow of about 40 knots, and by night, eased to about 30 knots. The next day was sunny, with some showers and a light breeze from the south.

Two Catalina flying-boats were anchored in the lagoon during the storm and barely survived it. On the 14th, with fine weather and a light southerly wind, Captain Taylor took off in his flying-boat the Frigate Bird for the Marquesas and Bora Bora.

Rainfall

The Pacific coast of Central America and the ocean area between it and Clipperton Island have a decidedly seasonal pattern of rainfall, with the months from December or January to April or May drier than the summer and fall. This pattern apparently is still valid westward as far as Clipperton Island. The Sailing Directions (U. S. Hydrographic Office, 1951) indicate that there is a "dry" season in December to May, but just how dry is not known. This information is probably based, in part at least, on observations furnished by the guano workers who lived on the island during the last years of the 19th and the first years of the 20th centuries, as it was already included in the 1902 edition of the Sailing Directions. For instance, P. J. Hennig kept notes on the weather during his stay as "keeper" of Clipperton and is said to have forwarded them to the Hydrographic Office with his map (cf. p. 6). I could not find a record of his data, but a newspaper account (Anon. 1897) quotes excerpts from them:

"Mr. Hennig, who is a man of ability as well as patriotism, kept an accurate log of the island from October 1, 1896 to August 5, 1897. He has presented the log to the hydrographic office, and it is the first valuable record of the Clipperton conditions.

"October had almost daily rains, with southerly and southwesterly winds. There was about as much rain in November, several heavy thunder storms and a few hard squalls. December was sultry, with many rainy days. Little rain fell in January, and the weather was hot. The word 'pleasant' occurs frequently in the February records. Severe thunder storms were again noted in March, April and May. The record of the Kinkora disaster is as follows:

"Friday, April 30th--Wind N. N. S. Moderate breeze with squalls in first part; then gentle breeze with squalls and light rain, but mostly fair, hot, sultry weather. Heavy surf. At 8 a.m., stranger in W. S. W. in sight.

"Saturday, May 1st--Wind N. E. by E. Moderate weather; heavy surf. Stranger coming around east side of island, flying British colors. Proved to be ship Kinkora, Belfast, water-logged, and bad steering. Beached at 5 o'clock. All hands saved.

"Easterly and northerly winds prevailed from the beginning of November until June; then the south and southwest winds returned.

"June and July were hot months, with occasional rains and squalls."

In addition, the manuscript diary of John Arundel for July and August 1897 (which I have seen by courtesy of Mr. H. E. Maude, and which is quoted here with the permission of Mrs. Sydney Aris) includes this observation of one of the workmen, who "says it rains nearly every day - showers - though you may have 2 or 3 days without - but the winter months are as a rule the driest - though he has never known a month without rain ... In the winter dry season - 3 or 4 mos. you have North East trades."

The only recent observation bearing on this "dry" season is the fact that the vegetation on Clipperton Island in August 1958, appeared to be recovering from a dry spell: many plants had dead twigs together with young new growth. In May 1958 (Klawe, personal communication) the dry condition of the plants was striking. Perhaps even more significant are the thick "trunks" (see p. 78 and Sachet 1962) of the beach morning-glory (Ipomoea pes-caprae) which suggest dying back of the vines during an unfavorable season. However, it must be kept in mind that with a very porous substratum such as is found on coral islands generally, effective drought may occur even with a rather high total precipitation if the latter is irregular. Certainly the dry season at Clipperton cannot compare with the intense droughts occurring on some desert atolls of the central equatorial Pacific where occasionally there is no rain at all for months. The drier season is indicated in the world atlases (McDonald, U.S. Navy) by a smaller number of observations reporting rainfall (table 3). While there are still many observations reporting rain during the winter and spring, they may correspond to light showers very different from the downpours of the summer months.

The maps in the same atlases, however, indicate that an area of very abundant rainfall lies to the west of Clipperton Island. In the Navy atlas, the January isogram for 40% of observations reporting rain forms a sort of ellipse to the southwest of Clipperton, between latitudes 5° and 9°N and longitudes 114° and 127°W. The size and position of this ellipse vary somewhat during the year and while it is formed by the 40% isogram from November to February, it is enclosed by the 30% or 35% isograms for the rest of the year. What the frequencies of observations reporting rain represent in terms of height of rainfall is not mentioned. However, Möller (1951) published quarterly maps of rainfall based in part on the frequency of rainfall figures of McDonald's atlas, which are comparable to those of the Navy atlas, but based on fewer observations and compiled only from Greenwich noon observations (5 a.m. Clipperton time).

Corresponding to the wet region of the Navy atlas, Möller shows for the quarter December - February the isohyet for 400 mm forming a wide strip in the space 0° to 10°N and stretching east to about 97°W. Clipperton Island is halfway between the 400 and 200 mm lines. In the March to May quarter, Clipperton is still between those lines, and the 400 mm tongue scarcely reaches east of 100°W, but is wider than before. On the June - August map it extends eastward all the way to the Atlantic side of Central America, and Clipperton Island is in the middle of it. During that quarter, according to the map, the Gulf of Panama has over 600 mm of rain and the area of the isthmus over 1000 mm. In the last quarter, the 400 mm isohyet still extends to the Atlantic side of Central America, but it crosses the meridian of Clipperton only a short distance north of the island which presumably receives something over 400 mm of rain in that quarter.

Such calculated figures cannot give an idea of the exact pattern or amount of rainfall, but are useful as indications of general trends. Clipperton Island is situated between an area of year-round high rainfall to the southwest and one of marked seasonal rainfall to the east, and retains in attenuated form the seasonal pattern of the latter, with lower rainfall in the winter and spring. The rains during that period "probably result from persistent low-level wind convergence but in the summer... cyclonic depressions or storms seem to be the cause" (Ramage, personal communication).

In August and September 1958, exact measurements of all rainfall could not be taken, but an ordinary tin can was kept in the open during the heavy rainstorms which occurred with southwesterly squalls. As much as 125 and 150 mm of rain were recorded during 24 hour periods of violent rain. The total amount recorded for the period August 11 - September 17 was 890 mm.

No one who is not familiar with the wet tropics can imagine this type of rain. There is warning from the approaching dark cloud, but when the rain starts, it is with its full intensity and in two seconds one is completely drenched. Protecting notebooks and films is a haunting worry. Because of the strong winds which bring the rain squalls, there is much of what we called "horizontal rain" which seems wetter and more able to get into shelters than the usual kind. Some such downpours last for hours.

In October 1956 (Limbaugh, personal communication) it rained almost every afternoon or evening. The amount of rain was quite variable, probably never exceeding an inch (25 mm) in any one day.

The measurements made by Limbaugh in 1958, his observations in 1956 and those of Taylor's indicate that much more rain falls in the Clipperton area than Möller deduces (about 300 + 350 + 600 + 450 = 1700 mm). Professor Ramage therefore has suggested another hypothetical calculation which may give a better idea of possible rainfall distribution on Clipperton.

"Palmyra Island, also a coral speck is located at 5°53' N, 162°05' W in the western part of the heavy rainfall region which also affects Clipperton. Between 3 and 5 years' rainfall measurements at Palmyra give an annual mean of 4445 mm with little apparent seasonal variations in rainfall intensities. We might assume that average rainfall intensities are about the same for Clipperton and that the mean rainfall in both areas is proportional to the average number of observations of rain recorded in the Navy atlas. The atlas shows that over the year 19.7% of observations in the Palmyra area and 22.2% of observations in the Clipperton area recorded rain. We might then estimate the annual rainfall at Clipperton as

$$\frac{4445 \times 22.2}{19.7} = 5020 \text{ mm}$$

and then by prorating among the months in accordance with their rain observation frequencies, come up with this hypothetical distribution:

J	F	M	A	M	J	J	A	S	O	N	D"
347	192	211	186	404	539	501	484	427	631	559	539

It must be pointed out that the difference in the vegetation of Palmyra and Clipperton is much more striking than would be expected from these figures, and that even the somewhat greater seasonality indicated for Clipperton would scarcely account for it. Although an absolute correlation between vegetation and rainfall is not expected where such small floras are involved, and considering that tree species may never have reached Clipperton, still this discrepancy suggests that caution should be observed in accepting these hypothetical figures.

A new source of information has recently become available in the photographs taken by the weather satellite Tiros III. The following paragraphs describing this type of information were contributed by Mr. Lester F. Hubert, Meteorological Satellite Laboratory, U. S. Weather Bureau.

"Meteorological observations made on Clipperton Island have been inadequate to provide a reliable climatology. A small sample of observations is especially vulnerable at this location because several years in succession may display a single type of meteorological regime, followed by a year of radically different weather. This is due to the fact that Clipperton Island is situated on the boundary of the Pacific dry zone--a tongue of desert-like weather lying just north of the Equator. Approximately each decade, during the El Niño* years, this zone is disturbed, that is, becomes more rainy and shifts its position.

"The meteorological satellite now provides a means of obtaining the information necessary to reveal the rainfall regime, and the exceptional cases that are sometimes more important than the "average." TIROS pictures have demonstrated the potential of detecting and tracking cyclonic disturbances near Clipperton. They show that many more cyclonic storms occur in the area than were previously known from inadequate conventional weather observations. The picture obtained by TIROS III on July 22, 1961, from an altitude of approximately 450 miles, shows the curvature of the earth, the approximate location of Clipperton Island, and that of hurricane Madeline, with bright curved cloud bands that are believed to produce precipitation. Infrared measurements from the satellite can be used to approximate cloud heights, thereby distinguishing between the thick shower-producing clouds reaching up to 15-18000 ft. and higher, even up to the tropopause, and the shallow clouds reaching to 4-5000 ft that usually yield no significant precipitation. During the anomalous (El Niño*) years, we may find that disturbances (cyclonic storms) pass over Clipperton Island. We are now in a position to commence accumulating data for this neglected part of the ocean."

The photograph of Madeline represents a typical summer cyclone situation in that part of the world. The orientation of the cloud bands seems to indicate that the winds at Clipperton were probably from the southwest (cf. pp. 10-11).

* El Niño is a warm tropical current from the north, that flows along the north coast of South America (Ecuador, northern Peru) down to about 6°S, during the southern summer. Some years, at more or less regular intervals, it reaches farther south, pushing away from the coast the cold waters that usually flow along it. At the same time, important atmospheric disturbances take place, especially unusually abundant rains that may affect vast regions.

Atmospheric humidity

As could be expected in a wet tropical climate, atmospheric humidity is very high. The lowest relative humidity recorded in August - September 1958, as calculated from the depression of the wet bulb was 69%.

Cloudiness and visibility

The U. S. Navy Atlas presents data on cloudiness over the oceans on monthly charts including two series of isograms, one representing "% frequency of low cloud amounts 6/10 or more," i.e. cloudy, the other representing "% frequency of total cloud amount 2/10 or less," i.e. relatively clear. Extraction of positions of Clipperton Island in relation to these lines gives, for low clouds, monthly figures ranging from between 20 and 30% in November, in the neighborhood of 30% for most months, and approaching or exceeding 40% in July, September and October.

The same extraction of positions for total cloudiness gives figures less than 20% for the months from May through December, and ranging between 20 and 30% for the remainder. Thus both sets of isograms indicate a high degree of cloudiness throughout the year, with the summer months, from April to October, even more cloudy than the winter.

On the basis of 85 observations between August 9 and September 16, 1958, the sky was completely cloud-covered over 3/4 of the time and half or less covered less than 1/5 of the time. The clouds were generally cumulus or cumulonimbus, occasionally stratus or altostratus, with cirrus usually visible when there were breaks in the lower cloud layers. The bases of the principal clouds were usually estimated at between 600 and 2000 m altitude.

Visiblity is generally always good at Clipperton Island except during rain storms.

Table 5. Sea and swell roses for Clipperton's 5-degree square

The number of observations for sea is shown in the upper left hand corner of the area and the percent of calms for those observations in the upper right hand corner. The number of observations for swell is shown in the lower left hand corner and the percent of calms for those observations in the lower right hand corner.

The sea conditions are represented by the light line arrows, while the swell conditions are represented by the heavy line arrows. No arrow is shown when the percent of directions is less than 7. The arrows point in the directions toward which the seas or swells move. The length of the arrow measured from the center mark, when placed on the attached scale, and the numeral at the tail of the arrow, give the number of times in each 100 observations that the seas or swells have been moving from or near the given point.

When the percent of direction is 15 or over, the condition within the direction are shown along the shaft of the arrow in percentage of low and medium seas or swells, the first figure from the center is always the percent of low. The percent of high seas or swells within the direction is the remainder of the percentage. When the percent of direction is less than 15 but more than 6, the conditions within the direction are shown by the letter L, M, or H (meaning predominantly low, medium or high) beside the percentage figures for direction. The conditions of seas and swells (low, medium and high) within each direction are defined as follows: low seas and swells, those of amount 1 and 2; medium seas or swells, those of amounts 3 and 4; high seas and swells, those of amounts 5 and above.

Ocean temperatures

Schott (1935) presents surface temperatures in maps XX-XXIII, by means of isograms. For Clipperton, the February temperature is over 27°C, that for May over 28°C, that for August over 27°C and that for November 27°C.

Agassiz (1906) includes information on water temperature at stations a little distance from Clipperton (see p. 29). At station 4543 the surface temperature was 79.5°F (26.4°C), the bottom temperature (at 2058 fathoms, 3775 m), 34.7°F (1.5°C). At station 4544, surface temperature 80°F (26.9°C), bottom temperature 34.4°F (1.1°C) at 1955 fathoms (3570m).

Water temperatures are also listed in the results of the Swedish Deep-Sea Expedition (see p. 30) and at station 70 surface temperature was 26.93°C while at 905 meters depth it was 4.83°C (bottom at 3690-3860 m). These figures are included in a table of analyses of sea water at varying depths (Bruneau et al., 1953, appendix, p. VII).

In August-September 1958, the sea temperature measured in a bucket of surface water collected on the reef ranged from 79°F (26.1°C) at 0900 to 84.9°F (29.4°C) at 1100.

as table 5. Seas may be conveniently defined as reasonably large waves, in the area of their generation, and are characterized by steep sides and sharp crests. Their energy content is generally being augmented by the wind. Waves that have left the area of generation--no new energy being added by the wind--are called swell. They have less steep sides, rounded crests and longer periods than are general for seas. They are gradually losing energy while travelling over great distances, often thousands of kilometers from their area of generation.

In any oceanic area the wave pattern is extremely complex, resulting from seas generated locally and swells arriving simultaneously from several directions and points of origin. The effects on atoll morphology are correspondingly difficult to unravel, but are nevertheless very important. No attempt has been made to establish any correlation on Clipperton except to point out that beach ridges, resulting from wave action, occur around most of the island, as do reef-front grooves and spurs (all around), also correlated with wave directions (Munk and Sargent 1954).

Tides

No recent published information could be found on tides at Clipperton Island so an inquiry was made at the U. S. Hydrographic Office. The summary of information compiled by Mr. W. E. Malone is quoted below.

"Tidal data for Clipperton Island are not given in either British or U. S. tide tables indicating a lack of recent reliable observations. H. O. Publication 84 does contain the notation regarding Clipperton Island that high water occurs 8 hours and 40 minutes after an upper or lower lunar transit of the local meridian and that the spring rise is 4-$\frac{1}{4}$ feet [1.30 m] while the neap rise is 2-2/3 feet [0.80 m]. The basis for this information is obscure. However, extrapolation from tidal data for surrounding areas indicates that high water at Clipperton Island should occur about 8 to 9 hours after an upper or lower lunar transit of the local meridian and that mean spring tidal range should be between 3 and 4 feet [0.90 and 1.20 m]. It appears then that the information contained in H. O. Publication 84 is fairly accurate. Tidal currents are reported to flood eastward and ebb westward, however, tidal currents are probably dominated or obscured by the general ocean currents."

The information in H. O. 84 (U. S. Hydrographic Office 1951) is the same as that given on H. O. Chart 1680, Clipperton Island. This chart, based on the 1897 survey of P. J. Hennig, Master Mariner, bears the information: "H.W.F. & C. VIII h. 40m. Springs rise $4\frac{1}{4}$ feet. Neaps rise 2 2/3 feet." The chart also bears arrows indicating direction of ebb and flow currents, ebb arrow pointing westward, flood arrow eastward. Whether this information was collected by Hennig himself, compiled from his observations and those of others such as Fisher (cf.p. 6) or calculated, is not known. Since that time various visitors to the island have made casual observations on the tides, but their results are not available. In 1956, a tide gauge was installed by a party from a Scripps Institution vessel but the gauge functioned only a very short time before it was removed for repairs. In 1958, its emplacement was found to have been destroyed during the 1957-1958 storm.

as it reaches central America and flows back toward the west with the North Equatorial Current, therefore it is not impossible that some Indo-Pacific organisms might reach Clipperton Island by this roundabout way rather than by direct eastward flow.

Waves

There are many ways in which ocean waves of various types affect oceanic islands and coral atolls especially. For example, the very growth of the living reef is linked to the amount of surf and consequent varying oxygenation of the surface water; wave erosion and deposition are major factors in the arrangement of materials that form atolls. The reverse influence of an island as an obstruction to swells is also well known theoretically and has been demonstrated for some (Arthur 1951). In a detailed study of an atoll, therefore, a knowledge of ocean wave patterns is necessary, but it has not generally been feasible, so far, to obtain such knowledge. Only for a few atolls has information on waves been available to be correlated with data on the morphology or ecology (Munk and Sargent, 1954, Guilcher, 1956).

In the case of Clipperton, hardly anything is known of the pattern of waves and their influence on the atoll. Yet, besides the more general effects alluded to above, waves have one very practical role on Clipperton, that of entirely preventing landing on the atoll more often than not. The Sailing Directions (U. S. Hydrographic Office 1951) as well as most accounts of visits to the island are replete with warnings of the dangers and difficulties that may be encountered, and make it clear that it is often impractical to attempt a landing: "On the reef, the sea breaks heavily and continually; the surf is terrific and at times covers the whole island" (this last observation is exaggerated, although storm waves can cover the whole width of narrow parts of the atoll ring and pour into the lagoon). There are times, however, when sea and wind are calm and when it is possible to land easily with a small boat over the shallow reef. This was the case when I landed on Clipperton and when I left the island.

Waves approaching the island, because the reef front falls off very rapidly, suddenly find themselves over a very shallow area, and break with great violence, the continuous line of such breakers forming the surf (for a general discussion of this and related phenomena, see Bascom 1959).

Goua (1952) considers that the swells coming from the southwest to southeast 9 months of the year are refracted around the reef and break on the north part of the atoll, while in February, March and April the northeast trade wind prevails and the southern swells diminish, spring therefore being the best time to effect landings. This is also rather overgeneralized and simplified.

Except for these remarks, and for some observations made from shore by Limbaugh in 1958 (ined.) the only available information on waves applicable to Clipperton is that generalized from ships' observations in the form of roses for the 5° square (10°-15° N, 105°-110° W) in the U. S. Hydrographic Office Charts of Seas and Swells (1944), and reproduced here

HYDROGRAPHY

Surface currents

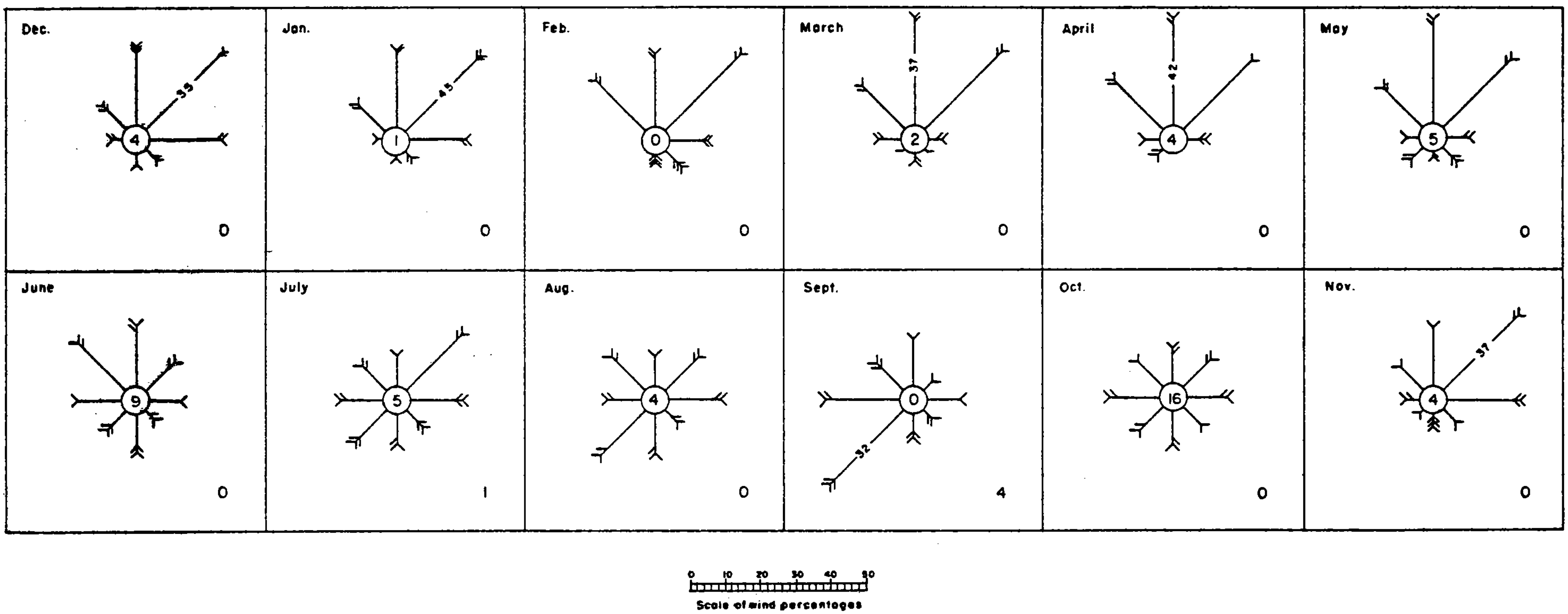
Clipperton Island is located in an ocean area of variable surface currents. In the eastern part of the tropical Pacific ocean, the North Equatorial Current flows in a general east-west direction around latitude 10° N. The South Equatorial Current flows in the same general direction, straddling the equator and with a large part of its water moving in the northern hemisphere. The Equatorial Countercurrent, flows from west to east between the other two and always in the northern hemisphere. The exact position of these currents varies seasonally. Information on the currents around Clipperton can only be derived from very general charts and summaries applying to the eastern part of the Pacific and the central American region. Most of the available data of this sort are compiled from ships' reports and published for the use of ships (U. S. Hydrographic Office 1947). They have also been summarized by Schott (1935, maps 29, 30). Very little of such information has been collected near Clipperton Island because it is removed from shipping lanes.

According to Schott, the North Equatorial Current flows westward around Clipperton during the winter months, and according to data in the U. S. Hydrographic Office (Mr. W. E. Malone, personal communication) at speeds from 0.5 to 1.0 knot. At this season the Equatorial Countercurrent is well to the south of the island and, according to some authorities, it is weak and at times nonexistent as a well-defined current.

During the summer months the Countercurrent is better developed and according to Malone (personal communication) the island lies in the shear zone between it and the North Equatorial Current. Schott's map would indicate that the Countercurrent itself always flows past Clipperton in the summer but this generalization is probably only occasionally valid. In the summer of 1958 (Knauss and Pepin 1959) the Countercurrent was 250-300 km wide.

During the IGY there was a great increase in the work on ocean currents and particularly on those of the Eastern Pacific. Indeed the main purpose of the Doldrums Expedition was to study the Equatorial Countercurrent. Most of the data from such recent surveys are not yet available but John Knauss, leader of the Doldrums Expedition, considers (personal communication) that the Countercurrent runs about 50 miles south of Clipperton most of the time and probably does not move as far north as Schott has it, in fact probably does not even move as far north as Clipperton every year. The Countercurrent is irregular, can change its direction or speed, or can even disappear within a very short period (Knauss 1960). Besides the seasonal variation in the surface currents around Clipperton, the situation may be complicated by the occurrence of transverse flow between the North Equatorial Current and the Countercurrent. These variable currents during the summer show a slight predominance of east and northeast sets with speeds of 0.5 knot or less (Malone, personal communication).

With regard to the transport of propagules of plants and animals by surface currents it must be kept in mind of course that when the Countercurrent is well developed, much of its water mass is deflected northwestward



Dec.
4
35
0
Jan.
1
45
0
Feb.
0
0
March
37
2
0
April
42
4
0
May
5
0
June
9
0
July
5
1
Aug.
4
0
Sept.
0
32
4
Oct.
16
0
Nov.
37
4
0
0 10 20 30 40 50
Scale of wind percentages

Table 4. Wind roses for Clipperton Island's 5-degree square (10-15°N, 105-110°W) from Pilot charts

The wind percentages are concentrated upon 16 points of the compass. The arrows fly with the wind. The length of the arrow, measured from the outside of the circle on the wind rose, when compared with the attached scale gives the percent of the total number of observations in which the wind has blown from or near the given direction. In some instances the full length of the arrow cannot be shown. In such cases the arrow is broken and the percentage is shown numerically, between the broken lines. The number of feathers shows the average force of the wind on the Beaufort scale. The numeral in the center of the circle gives the percentage of calms, light airs, and variable winds. The numeral in the lower right corner shows for the month the percentage of ship reports in which gales have been recorded.

Table 3. Rainfall for Clipperton Island 5-degree square, adapted from atlases

Months	% observations reporting precipitation (isograms) (Navy Atlas)	% observations reporting steady rain for 5 degree square (MacDonald Atlas)	% observations reporting thunderstorms (MacDonald Atlas)
Dec.	Clipperton between 20 & 25% isograms		
Jan.	Clipperton between 20 & 25% isograms	5	1-5
Feb.	10		
March	5-10		
April	5-10	5	1-5
May	20		
June	25-30		
July	above 25	10-15	5
Aug.	20-25		
Sept.	20-25		
Oct.	30-35	10	1-5
Nov.	25-30		

Table 2. Winds in Clipperton Island 5-degree square. Adapted from McDonald 1938 and U. S. Navy 1956

	Wind, dominant dir. from quarter	Dominant constancy: 1 = 25-40% from quarter 2 " 41-60% from quarter 3 " 61-80% from quarter 4 " 81% and over quarter	% frequency wind speed Beaufort 3 or less (10 knots or less) from Navy Atlas	Computed resultant wind from quarter	Resultant wind velocities (Beaufort 1-4).	Average velocity in knots for 3-months period	% observ. indicating dead calm	% observ. indicating gale or stronger (Beaufort 7 and higher)	% observ. indicating fresh gale or stronger (Beaufort 8 and higher)	% observ. reporting haze
Dec.	NE	3	60	NE	1-2			below 1		
Jan.	NE	3	40	NE	2-3	10-12	1	below 1	below 0.5%	below 1
Feb.	NE	2-3	over 70	NE	2-3			1-5		
March	NE	3	60	N	2-3			below 1		
April	NE	3	70-80	N	2-3	8	1-5	1	below 0.5	1-5
May	N	3	over 70	N-NE	1-2			below 1		
June	N	1	70-80	NW	0-1			1-5		
July	NE	1	50	N of E	1	8-10	1-5	1-5	1	1-5
August	SW	2	60	SW	1-2			1-5		
Sept.	SW	1-2	40	WSW	1			5		
Oct.	W	1	50	N of W	0-1	8-10	5-10	1-5	1	below 1
Nov.	NE	3	60-70	NE	1-2			below 1		

Day of the Month (Sept. 1958)	13			14		15			
Time (PDT)	0800	1800	1900	0900	1400	0700	0800	1300	1600
Wind direction	265-274	315-324	315-324	265-274	235-244	225-234	195-204	235-244	205-214
from	W	NW	NW	W	WSW	SW	SSW	WSW	SSW
Wind speed Knots	04	22	21	12	14	17	20	02	17
Atmospheric pressure mb: 1010									
1009	x								
1008									
1007									
1006									
1005		x	x	x				x	
1004						x	x		
1003					x				
1002									x

Day of the Month (Sept. 1958)	16		17	
Time (PDT)	0700	1100	0600	1100
Wind direction	215-224	225-234	225-234	205-214
from	SW	SW	SW	SSW
Wind speed Knots	24	23	17	19
Atmospheric pressure mb: 1010				
1009				
1008				
1007				
1006				x
1005		x		
1004	x		x	
1003				

Table 1, p. 5

Day of the Month (Sept. 1958)	7		8	9	10	11	
Time (PDT)	0700	2200	0700	0600	0700	0500	0700
Wind direction from	215-224 SW	235-244 WSW	245-254 WSW	245-254 WSW	345-354 NNW	215-224 SW	calm
Wind speed Knots	15	9	9	8	2	02	00
Atmospheric pressure mb: 1010							
1009							
1008					x		x
1007		x	x	x			
1006						x	
1005	x						
1004							
1003							

Day of the Month (Sept. 1958)	12								
Time (PDT)	0700	0800	0900	1100	1300	1600	1900	2000	2100
Wind direction from	235-244 WSW	235-244 WSW	235-244 WSW	245-254 WSW	255-264 WSW	255-264 WSW	245-254 WSW	245-254 WSW	245-254 WSW
Wind speed Knots	06	06	06	06	06	05	07	05	04
Atmospheric pressure mb: 1010				x					
1009		x	x					x	x
1008	x				x		x		
1007									
1006						x			
1005									
1004									
1003									

Table 1, p. 4

Day of the Month (Sept. 1958)	1	2			3		
Time (PDT)	0700	0500	0700	1700	0600	0800	0900
Wind direction from	145-154 SSE	105-114 ESE	215-224 SW	225-234 SW	215-224 SW	235-244 WSW	255-264 WSW
Wind speed Knots	4	1	4	10	21	22	26
Atmospheric pressure mb: 1010							
1009							
1008							
1007							
1006							x
1005	x					x	
1004			x		x		
1003		x		x			

Day of the Month (Sept. 1958)	4						5		6		
Time (PDT)	0600	0700	0800	1000	1100	2300	0700	1800	0700	1000	2200
Wind direction from	215-224 SW	205-214 SSW	205-214 SSW	205-214 SSW	215-224 SW	225-234 SW	205-214 SSW	225-234 SW	215-224 SW	215-224 SSW	205-214 SSW
Wind speed Knots	24	20	19	20	18	16	19	23	18	18	16
Atmospheric pressure mb: 1010											
1009											
1008											
1007											
1006				x	x					x	
1005		x	x			x	x				x
1004	x							x	x		
1003											

Table 1, p. 3

Day of the Month (Aug. 1958)	16				17	18	19	20		21	22
Time (PDT)	0900	1300	1700	2100	0900	2100	0900	0900	2100	0900	0900
Wind direction from	35-44? NNE?	45-54 NE?	55-64? ENE?	115-124 ESE	225-234 SW	245-254 WSW	275-284 WNW	205-214 SSW	245-254 WSW	85-94 E	235-244 WSW
Wind speed Knots	5	5	8	1	10	10	8	5	5	9	5
Atmospheric pressure mb: 1010											
1009											
1008	x									x	x
1007		x		x	x			x			
1006			x				x		x		
1005											
1004						x					
1003											

Day of the Month (Aug. 1958)	23		25	26	27	28	29	30	31
Time (PDT)	0900	2100	0900	2100	0700	0700	1000	0800	1100
Wind direction from	185-194 SSW	235-244 WSW	215-224 SW	145-154 SSE	225-234 SW	205-214 SSW	155-164 SSE	235-244 WSW	45-54 NE
Wind speed Knots	8	12	3	5	4	20	5	10	4
Atmospheric pressure mb: 1010									
1009									
1008	x		x						
1007		x		x			x		x
1006					x	x		x	
1005									
1004									
1003									

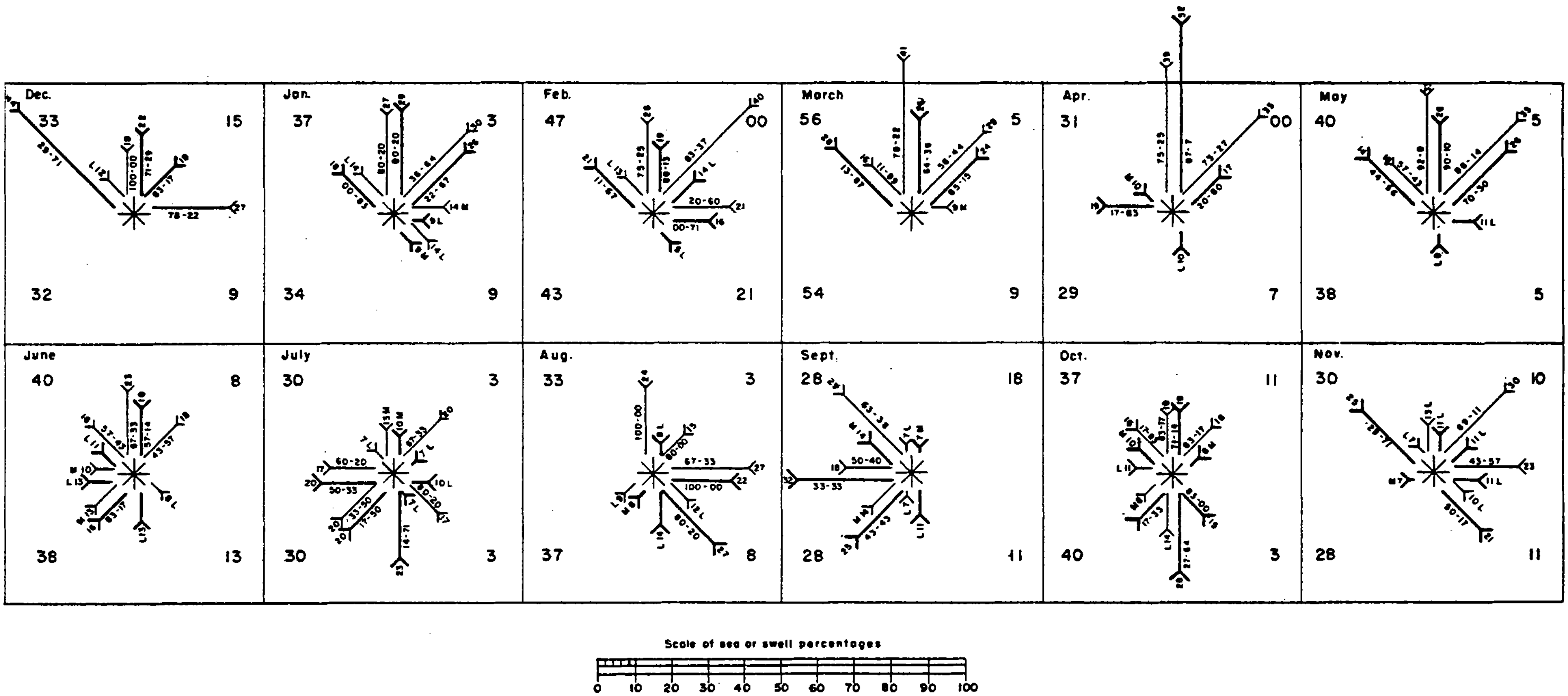
Table 1, p. 2

Day of the Month (Aug. 1958)	8	9				10			11	
Time (PDT)	2100	0900	1300	1700	2100	0900	1700	2100	0900	1700
Wind direction* from	315-324 NW	275-284 WNW	215-224 SW	215-224 SSW	195-204 SSW	195-204 SSW	195-204 SSW	215-224 SW	215-224 SSW	90? E?
Wind speed Knots	10	6	8	8	10	13	14	14	9	8
Atmospheric pressure mb: 1010										
1009								x		
1008						x			x	
1007										
1006	x	x			x		x			x
1005			x							
1004										
1003				x						

*Direction from which wind is blowing, in degrees, clockwise from 0° = North

Day of the Month (Aug. 1958)	12		13		14		15	
Time (PDT)	0900	1700	0900	1700	0900	1700	0900	2100
Wind direction from	205-214 SSW	215-224 SW	205-214 SSW	175-204 S	195-204 SSW	205-214 SSW	195-204 SSW	5-14? N?
Wind speed Knots	10	13	18	12	18	11	3	8
Atmospheric pressure mb: 1010								
1009								
1008	x		x		x			
1007							x	x
1006		x		x		x		
1005								
1004								
1003								

Table 1. Winds and atmospheric pressure at Clipperton Island, 1958, from data collected by C. Limbaugh and T. Chess


Dec.
33
15
32
9
Jan.
37
3
34
9
Feb.
47
00
43
21
March
56
5
54
9
Apr.
31
00
29
7
May
40
5
38
5
June
40
8
38
13
July
30
3
30
3
Aug.
33
3
37
8
Sept.
28
18
28
11
Oct.
37
11
40
3
Nov.
30
10
28
11
Scale of sea or swell percentages
0 10 20 30 40 50 60 70 80 90 100

SUBMARINE TOPOGRAPHY

Ocean floor, Clipperton Ridge

The Pacific Ocean between Clipperton Island and the central American coast shows regional depths not exceeding 2000 or 2100 fathoms (3660 to 3840 m) except for some deeper basins and trenches reaching (Middle America Trench) 3000 fathoms (5500 m). The topography of this area has been studied in detail by Menard and Fisher (1958). The same paper describes the Clipperton Fracture Zone, which extends roughly east-west for 3,300 miles (5,300 km) between longitudes 96° and 127°W, and shows for the first time that Clipperton Island is one of the peaks of a ridge, called Clipperton Ridge, 8,000 to 10,000 ft (2500 to 3000 m) high above the ocean floor, and which represents the fracture zone between 107° and 113°W. The roughly east west ridge is about 60 miles (95 km) wide and 330 miles (530 km) long and is bordered along part of its north side by a narrow deep trough. Clipperton is the only feature reaching the ocean surface, but there are at least two other seamounts on the ridge, one to the northwest, the other to the southeast, of the atoll. To the north-northwest of Clipperton another group of seamounts and deep troughs called the Mathematicians Seamount Range occurs between latitudes 13° and 16°N. The paper by Menard and Fisher includes many maps and sections and should be consulted for further detail and general interpretation. Recent exploration of the Clipperton area thus reveals that the atoll is part of an east-west ridge, but remains isolated from other emerged areas, in particular is well separated from the nearest group of islands, the Revillagigedo Is., which belong to a different system, and from the American continent. The features of the ocean bottom and the location of the fracture systems in the East Pacific are very well shown in the maps accompanying a recent article on the East Pacific Rise (Menard 1961).

Ocean bottom

Some information on the character of the ocean bottom in the general area of Clipperton can be derived from the records of the *Albatross* Eastern Tropical Pacific Expedition of 1904-1905 (Agassiz 1906). On the return part of the voyage the *Albatross* sailed just to the east of Clipperton. Stations 4543 at 8°52'2"N and 108°54'W and 4544 at 10°38', 106°47'6" are the nearest to the island. At station 4543 at 2058 fathoms (3775 m) the bottom sample was described as "rd. cly. dk. choc. br. stky. M., few glob., many sm. blk. Mang. part., few Rad., Sponge spic., transp. min. crys. mass of yel. floc. mat." At station 4544 at 1955 fathoms (3570 m) the bottom was described as "stky. dk. choc. br. M., many blk. Mang. part." In the general discussion and in plate 3 (character of the bottom) the Clipperton area is at the limit of a zone to the south and west, where manganese nodules are very abundant, and one to the northeast of "brown and green mud." It is also beyond the northern edge of the area where radiolarians are found, and north of the zone where diatoms are abundant, which zone corresponds well with the cold waters of the Humboldt current (p. 6).

More recently (1947-1948), the Swedish Deep-Sea Expedition explored the Eastern Tropical Pacific with another Albatross and collected information, including soundings of various types and bottom cores, near Clipperton (Pettersson, pp. 50, 117 and pl. I, 1957). Among the many papers collected in the Expedition's Reports, that of Arrhenius (1952) concerns the ocean bottom of the Eastern Tropical Pacific and the Clipperton area in particular (station 70, Sept. 20, 1947, core 47). From his very detailed studies, Arrhenius recognizes (pp. 189-190) various environmental subdivisions in the East Equatorial Pacific, represented in a map included in each part of his work (Figs. 1.0, 2.0, etc.) Clipperton falls in the North Equatorial Carbonate Facies of the East Pacific Ridge, with a calcium carbonate content of the surface sediments between 50 and 75% (map, fig. 1.1.3.1. p. 14). Core 47 (9°14'N, 109°39'W), from the top of a seamount near Clipperton Island, is described in detail pp. 133-136 and in pl. 2.47. While the core was unsatisfactory for Arrhenius' general correlations of geology and paleobiology of the East Tropical Pacific, it is interesting in the study of Clipperton Island. Arrhenius summarizes his study of core 47 as follows: "Core 47 consists of chalk ooze /Globigerina/ with a few marl ooze layers. The topography of the surroundings, the lack of normal stratification, and the faunal composition make probable that redeposition strongly influences the sequence. The redeposited material appears partly to be of shallow water origin. This is understandable as high peaks rise from the East Pacific Ridge in this area, some of them extending above or close to the surface of the sea (Clipperton Island and Germaine Bank).

"The manganese present is to an unusually high degree concentrated to macroscopic nodules. As a result the blackness of the deposit is comparatively low and the hue yellowish."

Undersea mountain

No information is available on the mountain upon which Clipperton Island is perched beyond the data given by Menard and Fisher (1958). Their fig. 3 shows the 1400 fathom (2560 m) contour surrounding the base of the Clipperton mountain and that of another seamount to the northwest. The Clipperton mountain is elongate in a NW-SE direction which is also that of the longer axis of the atoll on top of it. According to the same figure, the emerged atoll is located in the southeast part of the mountain top. This had been suggested by earlier fragmentary observations: for instance in 1942, the USS Atlanta reported the 500 fathom (900m) curve as being about one mile off the southern half of the atoll and twice that off the northern half. The existence of submerged peaks to the north-northwest was also reported by the 1957 U. S. Hydrographic Office survey (Obermüller 1959, p. 48).

The general slopes of the mountain form the asymptotic curves commonly found on atolls, but nothing is known of their aspect, detailed relief or composition, as there has been no dredging or detailed sounding along them. The only undersea mountains that have been explored in some detail are in the northern Marshalls (Emery et al. 1954).

Upper slopes and terrace

Some information on the upper part of the underwater slopes of Clipperton was collected during the 1958 survey by the marine biologists equipped for diving (Allison 1959a, 1959b, and personal communications). The intertidal reef flat slopes off at its outer edge to about 6 m, forming the reef-front (also called fore-slope). This feature is cut by deep grooves or channels. At the base of this steeper part the slope flattens out somewhat and a surface a few hundred meters wide extends outward and down to 12 or 18 m depth. This has been termed the submarine terrace. It was observed all around the island, but varied in width, becoming narrower on the north side, to the west of the northeast sandwash. At the edge of the submarine terrace, the slopes become more precipitous, and have been estimated as between 25° to 40° or even 60°. The divers were able to make some observations down to 40-45 m along this steep outer slope. Its surface is very rough with channels and crevices around the loosely-piled coral heads and boulders. Some boulders are loosely cemented to the slope and slides can be started by loosening the cement.

The marine biologists found that, while some coral and algal growth occurs on the reef front and submarine terrace, it is at the edge of the latter and on the outer slope just beyond that organisms are most abundant and luxuriant. That area was reported as 100% covered with living corals.

It is very unfortunate that these extremely valuable observations could not have been extended and documented by soundings and by dredging, and it is to be hoped that such work will be included in future studies of Clipperton. The discovery by the marine biologists of a submarine terrace around Clipperton is of great interest in view of the fact that similar shallow terraces have been well mapped at Bikini (Emery et al. 1954, p. 68 and pl. 68), Eniwetok (p. 95) and Rongelap (pp. 109, 191, pl. 71). The average depth of their edges are of the order of 45 ft (14 m) (Bikini), 40 ft (12 m) (Rongelap) or deeper (8-12 fathoms) (15-18 m) at Eniwetok, where the terrace has been called 10-fathom terrace. The Bikini and Rongelap terraces have a maximum width of 360 m, that at Eniwetok reaches 3500 m between some of the reef projections. A 10-fathom terrace has also been reported, although not described in detail, in Newell's study of Raroia atoll in the Tuamotus (1956, pp. 334, 341), and is apparently found around other atolls, such as Ifaluk in the Carolines (Bates and Abbott 1958, Tracey et al. 1961), and along other coral reefs.

In the northern Marshalls the distribution of live reef forming organisms on the slopes has been described by Wells (1954, p. 398). Little is known of growth on the reef-front, but apparently few corals grow in this zone, while beyond the 10-fathom terrace growth is more luxuriant. Growth on the terrace is poor probably because it is an area of deposition of debris. Tracey et al. (1948) suggested this explanation for Bikini. These observations cannot be compared in detail with those made at Clipperton but similarities are evident.

Interpretation

In the northern Marshalls, the 10-fathom terrace, which occurs also along lagoon shores, has generally been interpreted as representing an ancient erosion surface, formed during a glacial epoch when the ocean level had been lowered, and upon which a reef grew during the postglacial period following, when the ocean became warmer and its level rose slowly. This interpretation is confirmed by the fact that in the detailed examination of the cores taken in the drill holes on Bikini islet, sections at depths corresponding to the level of the terrace contain shallow-water organisms, some of them in position of growth and indicating lagoon edge or reef environments (Emery et al. 1954, pp. 215, 224, 257.)

Reef

In a typical atoll the reef is the upper, flat part of the limestone structure capping the undersea volcanic mountain. It usually reaches the intertidal zone and is the seat of dynamic phenomena affecting the atoll: erosion and growth. In most atolls the reef, if not circular, is at least a closed geometric figure encircling the lagoon. The reef may be depressed in some places, forming relatively shallow passages or, especially in some very large atolls, may be interrupted so that deep openings occur. In some atolls, the reef extends at about the same level all around the lagoon and, while there is some water transport between ocean and lagoon over the reef between islets, such inter-island channels are very shallow and cannot be used by boats. In the majority of atolls, dry land consists of islets, discontinuous little patches scattered along the reef surface. Such islets are of two main types (Fosberg and MacNeil 1956): some are only small mounds of unconsolidated debris piled up directly on the reef, others have a core of reef rock forming a sort of obstruction around which the loose material is accumulated (Tercinier 1955, p. 98). Such cores are usually erosion remnants of a higher reef surface the greatest part of which has been destroyed.

In the case of Clipperton Island, a closed oval-shaped continuous reef is topped by a continuous land area. None of the closed atolls has been well studied, and the reasons for the occurrence of a few atolls with a continuous land strip have never been examined in detail. Of some of these atolls, various authors have said that they have been uplifted, and while this may be true in some cases, in others there seems little factual evidence demonstrating uplift. "Uplift" and "raised" are here used to mean only absolute uplift due to a change in the sea-floor in the vicinity of the undersea mountain, excluding the relative change in height in regard to ocean surface which is brought about by changes in ocean level. There is no evidence that Clipperton Island has been raised and no reason to think that its continuous land rim occurs as a result of uplift. I suggest that its closed form may be a reflection of its position in the ocean. The best known of atolls, the northern Marshall Islands, are very strongly asymmetric, a line separating two very different windward and leeward "sides." This line is perpendicular to the resultant of certain vectors, the more or less constant directions of predominant winds, waves, and currents. The asymmetry does not affect so much the shape of the atolls as the characters of their reefs: the location of openings in the reefs, of islets on the reef, of areas of maximum growth and other such features.

Clipperton Island may be looked upon, on the contrary, as being to a certain extent radially symmetric, because the predominant winds, waves and currents vary throughout the year and fail to form the sort of oriented "field" which surrounds assymetric atolls. This explanation may fit other atolls with a continuous land rim and its applicability will be studied. If this theory is valid for Clipperton Island, it may explain, not only the presence of emerged land all around the atoll, but some ways in which the reef differs from the reefs of many well known atolls, particularly the northern Marshalls.

Around Clipperton Island, the reef flat lines the shore in a regular belt, but with some variation in width. The greatest width, about 130 m, is at the south corner of the atoll and the reef tends to be narrower on the east side of the atoll with a minimum width of about 50 m. During my stay on Clipperton the reef was almost always under some water at low tide. Living corals cannot survive long out of water but in some atolls coral heads or massive algae are sometimes left dry for very short periods by the receding tides. This was only once observed at Clipperton but probably occurs during some spring tides. Landward, the surface of the reef is often covered with sand, especially opposite the sand washes. Coral patches extend over some of the area. Seaward, coral colonies and various algae occupy the reef surface. The striking characteristic of the Clipperton reef is the practical absence of an algal (or "lithothamnion") ridge. In atolls such as the Marshalls or Tuamotus, the seaward edge of the reef, at least on the windward side of the atoll, rises conspicuously in a rough ridge, of a bright pink color, principally made up of massive coralline algae. At low tide this ridge can be seen very well. Immediately on its landward side a moat of slightly deeper water separates it from the main part of the reef flat. At Clipperton, this ridge is very poorly developed and when observed from a distance the edge of the reef is marked only by the breakers. However, the marine biologists who were working on the reef-flat or diving outside the atoll noted that the outer edge of the reef was slightly raised, with a vigorous growth of corals and algae. The deep grooves and channels, observed by the divers on the reef front and mentioned earlier, rise to the edge of the reef, and form surge channels. On the vertical air photographs of the atoll the surge channels can be seen well, and appear to have approximately the same importance all around the island. In other atolls, surge channels cut through the algal ridge, and form passages, often roofed-over, between pillars and masses of fast-growing coralline algae, and through which the surf rushes toward the reef, and the backwash retreats. At Clipperton, the surge channels cut through the slightly raised reef edge, but they were not studied in detail. The greater amount of dissolved gasses in the breaking waters is no doubt responsible for the more active growth at the edge as is believed to be the case in other atolls.

At low tide, the reef flat at Clipperton Island can be seen as strewn with a great many boulders which were probably torn off the slopes of the reef and thrown up by storm waves. These boulders are of various sizes, mostly less than a meter in diameter, which is generally rather small compared to those on some other atolls. They occur all around the island but are especially abundant and concentrated in certain areas, such as near the north corner where they form a boulder field that lies opposite the gravel ridge on shore. The boulders are colored brown or partly bright green by various algae and many organisms grow on their lower parts, including sponges, encrusting Foraminifera, corals, many algae, molluscs, as well as associated free living animals.

When an atoll reef dries or almost dries, at low tide, patterns of erosion, channels, cracks, pools or other forms normally can be observed. Such patterns were not recognized at Clipperton, partly because most of the landward side of the reef flat is covered with fine sand. Much of this is only a thin film or is replaced by pebbles or cobbles, with interstices filled with sand. These areas can usually be identified by the abundance of algae growing on the pebbles. In certain places however, the reef is bordered by beach rock, which will be described below, and occasionally the beach rock is located in such a way that it is the seat of active erosion and forms typical erosion ramps. Such a ramp occurs along the northeast coast. A slightly sloping slab of beach rock several meters wide stretches between reef and beach and exhibits a polished surface unevenly pitted into shallow, rounded depressions, which are probably the site of mechanical erosion (abrasion). The walls between the depressions are not sharp and cutting as sometimes happens on other atolls, but form gently rounded, low shoulders between pits. Some of the pits are joined together in shallow troughs, elongated in a beach-reef direction. The landward side of the ramp borders on the sandy beach and, at times, sand may be deposited over the ramp and hide it from view. The reef side of the ramp is occupied by algae, forming a brown felt or an orange crust. In some areas along the northeast coast of the atoll pieces of this ramp, undercut, broken and loosened by storm waves, have been displaced and rest on top of the sandy beach. In some parts of the atoll, small remnants of a ramp occur which may have been derived from an old reef surface rather than from old beach rock.

Presumably the reef flat surface extends lagoonward under the island sediments, but nowhere inland did I see any indurated material that could be interpreted as an exposure of this surface. Obermüller (1959, p. 50) makes the same remark. At the lagoon edge, a gently sloping, irregular surface of consolidated rock sometimes forms the bottom for at least a little distance under water; what was seen of this seemed little different from the consolidated phosphatic rock above water, and none of it suggested either a reef surface or lagoon beach rock. Judging from the sample brought back (no. 35), broken from a rough place in this surface, it consists of coral debris indurated with a phosphatic cement.

SURFACE FEATURES OF LAND STRIP

Outer shore

Beaches

Above the reef flat, often edged by beach rock, the island is surrounded by a beach of sand or gravel; usually this is a narrow stretch of fine coral sand, pinkish in color, sloping up from the beach rock exposures. Above it in most areas is a ridge of white coral fragments, in places branched even-sized pieces, elsewhere larger cobbles or boulders. In some areas, as on the southeast part of the island, south of the Hook, there is no sand beach but a steep ridge of coral fragments rises directly above the reef flat. In other places, the beach is wider and steeper and forms the whole oceanside slope, up to the crest of the land strip. In 1958, along a region 430 m long of the narrow northeast side of the atoll, sand had washed all the way from the ocean across the land strip to the lagoon. The beach here was lined oceanward by well-developed slabs of beach rock and on the landward side merged into a lagoonward sloping area, but the break in slope was faint, since the highest point was less than 1 m above estimated mean high tide level. This area will be referred to as the great sand wash. The sand was stained green at the surface and for the first 0.5 cm in depth, by blue-green algae. Below it was pale pink. Transverse lines of pebbles stretched across the wash, probably marking the direction of water flow. Any doubt that the ocean waves poured into the lagoon at this place when it was denuded of vegetation between November 1957 and May 1958, would be dispelled by the fact that marine shells, drift seeds and drift pumice had been carried across to the lagoon edge. In the lagoonward part of the wash two low rocky ledges stretched parallel to the shore. Their upper surface was hidden but the sand had been removed from under their lagoonward free edges, so that each protruded slightly over a longitudinal depression several decimeters deep. That nearer the lagoon shore formed a moat full of water green with algae.

There were several other, less spectacular, sand washes. Near the East corner of the island, the beach sand reached up to the crest of the island and spilled over the land in a very gentle (about 3°) lagoonward slope. The beach here was especially mobile and, at the time of our visit, one day formed a slope of about 12° for most of its width, topped by a little vertical cliff, about 30-50 cm high, cut in the sand at high water mark; on a later day the cliff had disappeared and the beach sand sloped regularly up from the ocean to the break in slope. On the southeast side, along Rock Bay, sand also spilled over from the beach onto the gentle lagoonward slope; this sand wash probably marked the location of one of the ancient passages into the lagoon, as the great northeast wash marked the other. Still another area occurred on the southwest side: The sandy beach occupied the whole width of the area between ocean and land crest and the dry land was again covered by a stretch of sand gently sloping to the lagoon.

In all these places, the sand was white or pale pink-orange where it was usually washed by seawater, and above the reach of ordinary waves the pink sand was hidden under a layer, 0.5 cm or more thick, of sand stained green by blue-green algae and sometimes slightly compacted into a friable crust. Except for this algal material, and for a very few seedlings of Ipomoea pes-caprae as well as occasional seedlings from drift seeds, there was no vegetation in 1958 on Clipperton Island beaches. However, on photographs taken in 1938, 1943 and 1957, Ipomoea vines can be seen to creep down the beaches from the land strip, at least on the east side of the atoll, and in 1958 masses of dead vines hung over the undercut edges of the land strip. The beaches are very mobile and even their upper regions, which could be called storm beaches, are constantly changing under the action of frequent storm waves. In contrast to this mobility, the relative permanence of the sand washes is worth investigating. Two of them mark the former shallow openings into the lagoon and most of them can already be seen on photographs taken in 1935 and recognized in older descriptions. They evidently correspond to particular configurations of the modern reef and underwater slopes and probably also of ancient, higher reef flats, that facilitate erosion and sand deposition but not gravel or boulder accumulation.

Beach Rock

Typical exposures of beach rock are well-marked along most of the seaward northeast coast of Clipperton. They can be clearly seen on the air photos of 1943, and were followed on the ground along most of their course. On the same photos, a dark line about the middle of the southeast coast may represent beach rock, but in 1958 this area was covered by a deposit of boulder or cobble gravel and no consolidated material was seen. Beach rock was also observed in 1958 by other members of the party (personal communication) on the southwest coast, after a storm washed off the coral sand and gravel which had accumulated over it. The several slabs had approximately the same slope as the present beach, and pieces of iron, including part of an old anchor, were embedded in it. Nothing that could be interpreted as beach rock was observed anywhere on the lagoon shore.

Along the northeast side, some little distance northwest of the camp, the beach rock presents the following aspect: the beach consists of a thin layer of sand, occasionally removed and exposing a pavement-like layer of white rock. Over part of this pavement, lies another smooth slab also apparently in situ with a small overhang on its landward side. Further north, the upper surface of this slab becomes pitted with shallow pot holes and takes on the aspect of an erosion ramp. Over it lie other thin, broken and displaced slabs, very sonorous when hit with the hammer. A piece of one was collected (no. 17) which seemed to be softer on its undersurface than on top. Some small tufts of green algae were attached to its top surface. Other slabs were colored orange-brown by a felt of algae (no. 306). All the beach rock slopes oceanward, with a general dip of about 10°. Some slabs are cracked parallel to the coast line. In spite of the sandy nature of the beach, almost all of this beach rock is not a sandstone but a conglomerate of small fragments of coral and material from a few other organisms, such as shells, with a sandy cement. Therefore beach conglomerate is the approprbte term for this rock. The thin, sonorous slabs are very like typical beach sandstone except for the difference in texture.

Continuing along the ocean side, northwestward of the area just described, similar groups of slabs occur, with the lowest one again forming a white pavement about 4 m wide in places covered with beach sand. Above this and immediately landward of it lies a thicker strip over 6 meters wide of coarser conglomerate, also sloping oceanward, with a dip of 17° in its lower part. Its lower edge is undercut and dissected in deep scallops, perhaps somewhat overlapping the pavement. Numerous blue-black Littorina shells are attached to the crevices, as well as a very few specimens of Nerita. Because of its dip and because it is well indurated at its lower edge and over most of its surface, this thick bed shows at least a superficial resemblance to typical beach conglomerate. At its upper edge, in its texture and poor induration, it shows a strong resemblance to the flat beds of coarse, poorly indurated material lying to landward and extending across the island. Unfortunately no samples were collected. The material might be interpreted as resulting from the same induration process as formed the flat beds to landward, but applied to the seaward face of a beach ridge. If, on the other hand, it is interpreted as beach rock, the fact that it stretches well above present high tide levels would suggest that it was formed during a previous higher stand of the sea. The thin slabs and the pavement below this layer are intertidal and probably represent modern beach rock.

The area of the island here described is part of the land strip which had recently been affected by a violent storm. It may be as a result of this that a long depression, parallel to the shore, about one meter deep and lined with broken coral gravel, was formed between the thick sloping bed just described and the landward flat ledge of indurated gravel. The highest elevation in this general area is 2.25 m above estimated mean high tide level. The longitudinal depression flattens out as one continues to walk northwestward along the beach and, farther on, only a regular slope of loose gravel stretches from the flat landward ledge of consolidated gravel to the thick beach rock; still farther, the latter disappears under the gravel slope which extends all the way down to high water mark.

The thick elevated "beach rock" was not seen in any other part of the island but stretches of it may be hidden under some of the beach ridges.

Along much of the northeast coast where intertidal beach rock occurs, broken and displaced slabs, many too heavy to be moved by one person, are found at the top of the beach which is presumably reached only by storm waves, and are also strewn over the land area. These dry slabs are smooth and white, some with a marble-like glitter. Generally, like those in situ, they are made up of coral fragments of varying size, but none were fine enough in texture to be properly called beach sandstone (cf. sample no. 28).

Land

Beach ridges

Seaward of the Naturalists' Camp, there is no well-defined boulder ridge. Boulders and slabs of beach rock, some of them quite thick and heavy, are scattered at the top of the sandy beach, and above it rises the cliff-like edge of the consolidated rock layer which forms the land area: this is undercut and evidently has rather recently receded under the action of storm waves, as dead Ipomoea vines hang over the cliff; they must have formerly extended farther toward the ocean. Elsewhere around the atoll, especially on the south and west sides, outer beach ridges are well developed and consist of well-sorted coral fragments, most commonly about 7-10 cm long. The sorting is apparently facilitated by the fact that the coral fauna is rather poor, and in most places practically the whole mass of gravel comes from one species or a small number of related species.

Around the north corner of the island, the ridge includes material of more varied size and also from a greater number of species. The range is from pebbles to cobbles and a few boulders. In that area, the beach ridge is an enormous one and extends inland into a narrow pebble and cobble field, which may have been reworked somewhat at a recent date, as some of the blackened cobbles have been displaced and some of their lighter undersurfaces are exposed. In the same area, a secondary ridge or gravel bar has been formed on the seaward side of the reef flat, and cuts off part of the flat as a reef pool. This is reminiscent of a feature observed on Jaluit atoll after the typhoon of January 1958 (Fosberg, personal communication and Blumenstock, ed., 1961). This secondary ridge may be a fugitive feature and will perhaps move landward until its material is added to the main ridge. This is what is happening on Jaluit (Blumenstock et al. 1961). There are areas on the southwest coast where the beach ridge of even-sized gravel has a double crest, with a slight longitudinal depression, indicating that the ridge may have been added to secondarily. However it is not absolutely sure that this double-crested ridge is natural, as further north, along the main coconut grove and the abandoned quonset village, the ridge has obviously been artificially added to, in order to provide greater protection for the camp. Double crested ridges, however with very different profiles, are well known from other atolls (Fosberg, personal communication).

All the beach ridges are white on their ocean facing slopes. Their flat tops, sometimes depressed in the center in the case of the double-crested ridges, and their shorter landward slopes are blackened. The line of demarcation between blackened and white coral is sometimes very sharp. The discoloration is due to microscopic algae. The under surfaces of the coral pieces are usually paler and range from white to dark gray. In some areas and under certain lighting conditions, the dark coral looks very much like a desert of black volcanic lava.

On the Isthmus leading to Clipperton Rock, and more particularly on the land strip parallel to it on the other side of Rock Bay, the pigs had worn conspicuous pale trails in the dark gray coral gravel. These trails can be seen very well in the same area on the air photos taken in 1943. It will be interesting to see how long they will persist now that the pigs are gone.

Land surface

As mentioned earlier, the land slopes from the top of the beach ridges lagoonward all around the island. Generally the slope is steep at first, along the landward side of the beach ridge, then becomes more gentle. Obermüller (1959, p. 50) estimates the latter as 5-10%. In many areas the grade is slight but a series of step-like ledges bring the level down. The surface of the land strip may consist of loose or consolidated material.

Unconsolidated material:

The sand washes and the inland slopes of the gravel and boulder ridges, as well as the boulder fields, have already been mentioned as landward extensions of shore features. Other areas of the land, generally rather flat, are sandy or covered with a very weakly developed soil and often sprinkled with a thin layer of coral fragments. The predominant soil is a mixture of small coral gravel and pale brown silt (cf. samples 5, 34, pp 57 56), shown by analyses to be highly phosphatic. In places this may be covered by gravel sheets of varying thickness, by linear ridges or stripes of loose blackened coral fragments, or by a layer of sand. Where the consolidated material is exposed, a thin irregular deposit of sand or scattered gravel usually lies in depressions or on the surfaces. Of course, due to the extensive disturbance by guano digging, little can be said about the natural characteristics of the soil profiles or the original disposition of the older loose sediments.

The more characteristic physiographic features of the land are formed by consolidated sediments. These occur in three main aspects: ledges or steps, pavements, and cliffs at the lagoon edge.

The ledges:

There are actually two kinds of ledges, both probably exposures of the same flat or almost flat consolidated beds. The first type is exposed only on the ocean side of the northeast land strip: Stretching between Naturalists' Camp and the beginning of the sand wash, the seaward margin of the flat bed just mentioned forms a wide ledge with an abrupt vertical or overhanging escarpment, 0.5 to 1 m high, but with the lower part covered by gravel deposits. This ledge occurs opposite and just above the thick coarse oceanward-sloping conglomerate described on p. 37. The upper surface of the ledge has a scarcely perceptible slope toward the lagoon. This exposed surface varies in width from almost nothing to perhaps as much as 1/3 or 1/4 of the width of the land strip. In most areas, the consolidated layer is covered landward by a storm-deposited sheet of white gravel composed of somewhat rounded coral branches (see p. 71). Very possibly, the consolidated bed, and its oceanside edge forming the first type of ledge, were exposed at the time of the same storm by the removal of loose material and elsewhere are hidden under the beach ridges.

Around the far greater part of the periphery of the atoll, except for the sand washes, runs an interrupted and irregular series of a second type of very low concentric ledges of what appears to be the same material as the first type. Their scarps face the lagoon and are never more than 2 or 3 dm high. Where they are well developed, as on the northeast side just west of the wreck and in some areas of the southwest side, the ledges, from the lagoon shore, look like the bleachers of an amphitheater and one can walk up them as a series of irregular steps. They are often arranged in groups, several steps very close together, then a wide pavement and another group of steps above it. The free edges of the steps often form overhangs sheltering cavernous spaces inhabited by many land crabs. Seen from below, the free edges of a group of steps look somewhat like those of bedded beach rock slabs, but as far as can be told from their irregular surface the ledges do not dip as beach rock would. This agrees with Obermüller's observations (personal communication and 1959, p. 50). Seen from above, the ledges show a consolidated surface often covered in places by loose sand or fine gravel, especially near the base of the next upper ledge. Plants sometimes grow on the surface of the ledges, particularly in this loose material.

In some areas, for instance near the East corner, the lines of ledges are rather regularly parallel to the shore. Elsewhere, they may follow the line of the shore for a while then swing inland away from it. Near the south corner at the base of the Hook there is a vast area where vegetation is rather sparse, and where low ledges are very conspicuous. They form a complicated pattern of arcs which have little relation to the present lagoon coast line. On the other side of the Rock, some series of low ledges swing away from the Isthmus to form the low rocky Thumb Point. Some of the ledges can be followed for considerable distances and it is not impossible that by digging some could be shown to extend more or less continuously all around the island. Measuring their height in relation to a fixed point (for instance the marker on top of Astro 1957) and mapping their courses might give useful information and help understand their origin. Where they were shown to be absent it might be assumed that a passage once existed, now filled with loose sediments.

Exposed pavements:

These are especially well developed in the southern part of the atoll, i.e. on part of the Isthmus and on Thumb Point, and on the other side of the Rock, at the base of the Hook. In most areas, they appear as the top surface of ledges, in others they are less obviously connected with them, and disappear under loose material or denser vegetation. Their surfaces often seem horizontal. In places they are rather smooth, more often they appear dissected by erosion, particularly by rain water, into a miniature karst surface a few centimeters high. According to Obermüller, they represent a rich phosphate deposit.

Lagoon shores

Lagoon cliffs:

When they reach the lagoon, groups of ledges and pavements may end abruptly above the level of the water forming "cliffs."* Both on the northeast lagoon coast, a little north of Naturalists' Camp, and almost diagonally opposite, on the southwest side of the atoll, north and south of the coconut groves, lagoon cliffs occur which are up to 1.50 m high above lagoon level. The rock forming these cliffs is uneven in structure and hardness so that the cliffs may present overhangs or, on the contrary, be cut back at the top. Commonly they have been worn by erosion and blocks have fallen off from the overhangs, or harder parts have occasionally been left in place in front of the new cliff face as "mushrooms." These small remnants, surrounded by water or by loose gravel, are much used by sea-birds as nesting sites as they afford protection from the pigs. On the northeast side, such cliffs extend for a long distance, arising somewhat back from the water's edge and separated from it by a slope or beach of gravel. Some of this probably originated from the erosion of the cliff and some may have been deposited by the 1957-1958 storm. The cliff was apparently much damaged by this storm and large overhangs of its upper, more firmly consolidated, part lay broken off and tilted near the lagoon shore.

Other lagoon shore types:

Along most of the lagoon shore, the land is not so high above water level and rocky overhangs a few decimeters above water level replace the cliffs. They are often hidden under a thick blanket of Ipomoea pes-caprae. They appear to consist of the same type of consolidated rock as the upper part of the taller cliffs. Elsewhere, as in the vicinity of the Rock, a low pavement may extend to the water's edge, forming a very low rocky shore. Consolidated rock or pavement may continue under water for some little distance into the lagoon. In other areas, fine sediments or plant debris accumulate on the bottom at the edge of the lagoon. Mud flats may also form the lagoon shore. Because of the constantly fluctuating level of the lagoon (tides and perhaps rainfall and evaporation) their width varies and their material may be reworked with the movement of the water. Often, however, they are held by vegetation, i.e. beds of sedges.

Near the east corner of the island, and for a long distance southward, the consolidated rock layers and ledges swing inland and a low lying area of generally fine sediments spreads between them and the water. The lagoon shore here is of fine white sand or small gravel forming a narrow beach or more often arranged in a low (a few decimeters) and narrow beach ridge. Lower land often lies behind this ridge and may be covered by stagnant pools of water and occupied by sedges. Strong

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* "Cliff" perhaps gives an exaggerated idea of such low features, but it describes well their abrupt faces, and avoids confusion with some other miniature atoll landforms.

lagoon waves during storms keep reworking the ridge and at times cut channels across it and flush the pools. The sand seems to extend from the beach for some distance under water into the lagoon. Because of the very gentle slope, the lagoon water covers and uncovers sand flats with every small change in water level. During our visit, there were many wind and rain storms from the southwest which drove great quantities of water plants, principally Najas, toward the eastern half of the atoll. They formed thick masses in the shallow edge of the lagoon and were often deposited in windrows along the beach and beach ridge. Some dried up lines of this material on the top of the beach ridge, or curling crusts of lagoon algae some distance behind it in the mud flats, indicated that at times the lagoon must reach higher and spread farther inland than we ever saw it. The sand beach ridge had probably been relatively stable for a while before our visit, as Ipomoea pes-caprae vines were creeping across it from a large patch inland. The sand was alive with tiger beetles.

Mobile sandy beaches and low beach ridges occur also on the north part of the northeast shore, at the lagoon edge of the great sand wash. Here sand or gravel bars often form scallops sometimes closing off temporary ponds, especially at low lagoon levels. Between the camp and the great sand wash, gravel bars often occur at the foot of the cliffs or, at Green Point, along low lying ground, and may cut off from the lagoon some stagnant ponds or moats usually full of algae. These bars occasionally are cut by channels and the ponds or moats flushed by lagoon water. The gravel is similar in size and appearance with that of the recent gravel sheet and probably was deposited at the same time.

Clipperton Rock

In the southeast part of the atoll, a narrow tongue of land called the Isthmus juts into the lagoon in an east west direction and at its free western end rises the irregular volcanic mass called Clipperton Rock. Its height has been variously indicated as from 19 m to 29 m or even 80 m. The latter was estimated from the distance at which the Rock disappeared from view, and is certainly wrong. None of the recent scientific and other surveys included measurements of the Rock, as far as could be ascertained. The most recent figure that is based on well-described surveys is that of 29 m above ocean level obtained in 1935 by the officers of the Jeanne-d'Arc (Lacroix 1939, Gauthier 1949) but it may be a bit high. Many visitors have been struck by the resemblance of the Rock to a distant sail, or from closer up, to a ruined castle. Indeed these are apt comparisons.

The base of the Rock is roughly lozenge-shaped, with its long axis in a general east west direction. The highest pinnacle is near the center of the mass. Seen from the Isthmus, the east face rises as an almost vertical wall, as does the north face when seen from the lagoon. As one walks around the Rock, several passages, mostly roofless, roughly parallel and separated by thick vertical walls, are seen to lead into it. The floors of these passages slope upward and are covered by fine material mixed with coral pebbles, guano, feathers and other debris (cf. sample 15 p. 56). Some of the passages can be followed completely through the Rock. The parallel walls separated by open passages are well shown on some of the photos taken from helicopters.

From a superficial examination, the most obvious possible origin for the Rock is that it is part of the crater of the undersea volcano, and this was suggested by Geikie (in Teall, 1898, p. 233). The detailed study of the lithology of the volcanic material, and of descriptions and photographs of the structure of the Rock, led A. Lacroix (1939) to describe it as an extrusive dome, comparable to that of Bogosloff, and formed in the same manner as that of Montagne Pelée. This would make it a cumulo-dome or better, a plug dome (Cotton 1952), that is, a mass of very viscous acid lava slowly squeezed out of the volcano and cooled without ever flowing. This is how the Pelée spine was formed. The Bogoslof volcano in the Aleutians forms small islands or rocks in the ocean in this way. The main difference between Bogoslof and Clipperton is in the fact that the former is in an unstable and very active area, and its various peaks and islands have been formed and have been destroyed by erosion or explosion within the last century (Byers 1960). The Pelée spine also was destroyed soon after its formation. By contrast, the Clipperton volcano has been inactive for a very long time and the Rock has been stable for at least as long as it has taken the coral cap to form over and around it. It might be more evocative to compare Clipperton Rock with some land domes such as some of the trachyte domes or phonolitic plugs locally called "sucs" in the French Massif Central (Williams 1932). Obermüller, after studying his samples and examining the Rock itself concurs with the interpretation of Lacroix.

Nothing is known of the roots of the Rock, nor of the thickness of the limestone which caps the other parts of the undersea mountain.

The very striking ruin-like aspect of the Rock, as seen on photographs or as visualized from descriptions, gives the impression that it is a crumbling pile of loose eroded material. Nothing could be further from reality. When one climbs into the Rock, its massive walls appear as solid and impervious to the elements as possible. There are no joints or cracks, no loose pieces of rock, no areas of scree or talus. To one accustomed to the "rotten" rocks of the Alps for instance this is very striking. It is known of course that the volcanic rock has been modified by the combination of bird guano and rain water and that much of it, to an unknown depth, is more or less phosphatized, but this is not apparent to the casual observer, nor does it result in obvious disintegration of the rock, which is very difficult to break with a hammer. Handholds and footholds are precarious as most of the surface is very slippery, with rounded rather than sharp edges; climbing is made more hazardous by the great abundance of nesting birds who snap at the intruder and can make him lose his grip not so much from pain as from surprise at the sudden attack. Indeed the whole Rock is alive with birds, mostly noddies and brown boobies. Their nests occupy every small shelf, crevice and projection of rock and many noddies also lay eggs on the floors of the passages without any nesting material at all. The generally reddish surface of the Rock is in many places splashed with white guano, often in trickles below the nests, or is glazed with a white crust. The "corals" mentioned by Pease (1868 p. 201) could not be found. However Obermüller points out that the birds carry coral pebbles to the very top of the Rock as part of their nesting activities, and that in places these might become cemented to the volcanic Rock. Another possible explanation for Pease's remark is the occurrence, in some caverns or along some walls of the Rock, of areas where water trickles down and encourages the formation of a tapestry of green algae, and the deposition of mineral incrustations (cf. sample 16 p. 64) which could be said to look like some coral skeletons.

The base of the Rock, and therefore the manner in which it joins the coral substratum, is generally hidden by piles of coral debris and soil, similar to the material on the floor of the passages, and sloping down to the level of the lagoon. On the south side of the Rock, there is, however, one striking contact between volcanic rock and coral conglomerate. This is a small limestone shelf or ledge a meter or less in width, distinctly undercut to form a notch or nip, 0.7 to 1 m above lagoon level. The upper surface is approximately horizontal, and was estimated at 1.20 m above the lagoon water level. Despite oscillations which are apparently of the order of a decimeter, the lagoon level can be grossly estimated as near mean sea level and this would place the nip within the 5-6 foot (2 m) level (above mean low water) associated with the Abrolhos Terrace of Teichert and Fairbridge (Fairbridge 1958 p. 479). How the shelf was formed and what exactly it represents in terms of past aspects of the atoll could not be investigated but it certainly must have been undercut by lagoon, or possibly ocean, water at a time when the level was higher. Such undercut benches, remnants of ancient higher reefs or coral conglomerates, are common on limestone islands in the Pacific. However, it is often difficult to recognize them with certainty on atolls, and to be sure of the relative ages of various features. In this case the coral shelf is at least much more recent than the volcanic Rock, and one can tentatively suggest that its material may have been deposited and cemented during a post-glacial slightly higher sea-level, and that later the shelf was undercut at a level lower but still higher than present sea. It deserves detailed investigation. On the larger of the volcanic islets located a short distance off the south face of the Rock, another coral limestone shelf is present, almost directly opposite the one just mentioned. This may be part of the same feature, perhaps a bench of conglomerate that extended across the present arm of the lagoon and was broken and undercut. The notch is less obvious on the islet than along the Rock, and the present surface of this bench slopes along the side of the islet from approximately the height of the one opposite down to near lagoon level.

Lagoon

The closed lagoon of Clipperton Island forms a great lake, oval in shape, with an arm on the south side, around the Rock (Rock Bay). In fair weather it is smooth but strong winds can make its surface very choppy.

Lagoon water

Since the time of Griswold's visit in 1861 (Pease 1868), visitors have been surprised to find the lagoon water "fresh" (Taylor 1948) or almost so. There is some indication that it may, in times of drought, become more salty and unpleasant to drink. Some laborers are even reported to have died from drinking it (Slevin 1931). In September 1943 (Byrd 1943) the salt content of surface water was given as 70 grains per gallon (about 1200 parts per million). In October 1956 water was collected at a depth of 10 meters (Limbaugh, unpublished report, 1957) and found to contain 2.97‰ salinity (about 3000 parts per million). Surface water collected in November 1957 (Obermüller 1959) had a salt content of 4 or 5 g per liter (4000 or 5000 parts per million). In May 1958 surface water collected opposite the wrecked LST gave the following (Klawe, personal communication, 1959):

	Chlorinity ‰	Salinity ‰
Bottle 1	2.595	4.71 (= 4700 parts per million)
Bottle 2	2.59	4.69 (= 4700 parts per million)

This water was said to be supersaturated with oxygen, as it was collected in an area full of aquatic plants.

The water collected in August 1958 was analyzed by the Quality of Water Branch, U. S. Geological Survey, and found to have a salinity of 3840 parts per million (see p. 46 for complete analysis). Samples collected by C. F. Harbison in August 1958 and by Conrad Limbaugh in his dives in September, were titrated in the laboratory at Scripps Institution of Oceanography and showed:

			Chlorinity ‰	Salinity ‰
a)	Lagoon (sample slightly murky, slightly yellow, fermented odor, gelatinous substance at bottom)		1.17	2.15(=2000 ppm)
b)	Pond filled with sedges, at base of the Hook [probably after rain]		0.01	0.05(50 ppm)
c)	Lagoon, surface	(Sept. 1)	2.36	4.29(4300 ppm)
d)	Lagoon, 4.5 m depth (15 ft)	"	2.45	4.45(4500 ppm)
e)	Lagoon, 20 m depth (65 ft)	"	17.45	not calculated by the laboratory because of the abundance of sulphites but estimated as 31.5 ‰ (31500 ppm)
f)	Lagoon, surface (green fibrous substance at bottom)	(Sept. 8)	2.39	4.35(4300 ppm)
g)	Lagoon, surface	(Sept. 17)	2.28	4.16(4000 ppm)

Analysis of Clipperton Lagoon Water

by Quality of Water Laboratory, U. S. Geological Survey

(in parts per million)

Laboratory Number 55153 - Lagoon; Clipperton Island, eastern Pacific Ocean

Date of collection...........1958

Silica (SiO_2).....................	1.2
Aluminum (Al).....................	.3
Iron (Fe).........................	.06
Manganese (Mn)....................	.00
Copper (Cu).......................	.00
Zinc (Zn).........................	.08
Calcium (Ca)......................	65
Magnesium (Mg)....................	133
Sodium (Na).......................	1220
Potassium (K).....................	16
Lithium (Li)......................	.4
Bicarbonate (HCO_3)................	72
Carbonate (CO_3)..................	0
Sulfate (SO_4)....................	80
Chloride (Cl).....................	2270
Fluoride (F)......................	.0
Nitrate (NO_3)....................	20
Phosphate (PO_4)..................	.3
Dissolved solids	
Calculated......................	3840
Residue on evaporation at 180°C.	4370
Hardness as $CaCO_3$.................	709
Noncarbonate hardness as $CaCO_3$....	650
Alkalinity as $CaCO_3$...............	59
Free Carbon Dioxide(CO_2)(Calc.).	18
Specific conductance	
(micromhos at 25°C).............	6690
pH................................	6.8
Color.............................	5
Ignition loss....................	364

Another sample taken at 0.60 m depth (2 ft) by W. Baldwin and J. Wintersteen also had a salinity of 4300 ppm (Baldwin, personal communication). How comparable the different figures are is difficult to say. Even those obtained in 1958 may not be comparable, because of the different methods used in obtaining them, and cannot show definitely whether there is a significant seasonal change. Yet if there is really a marked dry season on Clipperton (U. S. Hydrographic Office 1951) it is to be expected that with continuing evaporation and lack of replenishment by rain water the lagoon might become noticeably saltier.

Lagoon level

The lagoon level has been variously reported as being much lower, or much higher, than the surrounding ocean. One of Captain Taylor's companions studied it and decided (1948, p. 173) that it was "on the mean tide level of the ocean." During our visit the level was oscillating continuously and it was obvious that in addition to possibly minute changes due to heavy rainfall and evaporation, a tidal effect was present. No absolute measurements could be made but generally the lagoon level was never so conspicuously higher or lower than the ocean that an observer standing between the two could notice it on casual observation. There is no doubt, however, that during storms the ocean can pour over low and narrow areas of the atoll rim and add water to the lagoon. This would affect both salinity and level for a while. Seepage through the walls of the undersea mountain eventually brings the lagoon level down but with a lag, and shortly after a storm and paticularly at low ocean tide, the lagoon may appear to lie higher. Some open lagoons are well known to present this phenomenon: in Pokak atoll, Marshall Islands, with every high tide the ocean pours over the reef; at low tide the current out through the narrow opening and seepage do not suffice to empty the lagoon and establish an equilibrium and the lagoon can always be seen to have a higher level at low tide than the ocean.

In an ideal circular island (Wentworth 1947), considered as a porous mass rising through sea water to above sea-level, the fresh water derived from rain forms a lens (called the Ghyben-Herzberg lens) floating on top of sea water and extending downward to below sea level. Tidal effects through the porous mountain push the lens up and down with but little mixing if the tide range is low and the fresh water lens is thick enough. The best known undersea atoll-mountains, Bikini and Eniwetok, have been shown from the drill cores taken from them and from geothermal measurements (Swartz 1958) to be extremely porous. Nothing is known of the Clipperton mountain. Much of it probably is very porous, although the occurrence of the volcanic Rock indicates that part of its mass all the way up to sea level must be of less porous volcanic material.

In an ideal situation, with distilled water versus sea water of a specific gravity of 1.025, the fresh water would extend 40 times as far below sea level as it did above (Cox 1951, Arnow 1954, Tracey et al. 1961). Atoll islets in wet climate areas have shown themselves to be examples of this phenomenon and their ground water bodies form Ghyben-Herzberg lenses, though by no means ideal examples since the water is never pure nor the porosity even. A comparable effect perhaps occurs in Clipperton lagoon.

The slightly salty water rests on saltier, heavier water occurring either in the bottom of the lagoon or in the mountain under it. Unfortunately it was not possible to dig wells, and nothing is known of the ground water on Clipperton. It may or may not be fresher than the lagoon water, and may or may not form a separate water body. Perhaps the brackish water lens extends from the lagoon sideways under the dry land rim as ground water, and the water bodies in both lagoon and island might together be regarded as a single large Ghyben-Herzberg lens. Or the two may function independently. It would be very important to study ground water in wells and to collect lagoon-bottom water samples. Determining how far lagoon and ground water levels are above mean sea level would also help speculate on the depth to which brackish water may extend in the lagoon and in the land.

The scientists who were skin-diving in the lagoon reported (Hambly, Allison personal communication) that the lagoon water was usually turbid near the surface, where it was warm; a clear layer of cold water began at depth of about 6m. In a hole, the total depth of which could not be measured, a layer of inky black water, smelling strongly of hydrogen sulfide, was encountered at 20 meters. It was noticeably saltier (sample e, p. 45).

The numerous dead reefs which occur in the lagoon, especially in its southern half, and rise to near the surface, divide the lagoon into compartments. Even though the reefs must be porous, their presence must impede circulation and mixing.

Lagoon depth and nature of bottom

The maximum reported depth of the lagoon is 55 fathoms (100 m) for a point in the southwest part of the lagoon (sounding by Hennig, 1897, U. S. Hydrogr. chart no. 1680, 1897 ed.) Various French sources quote depths of 100 m, probably based on the same record. If Hennig's figures are reliable and still apply, only a few local areas reach such depths. During recent visits, several parties (Byrd, Taylor) made soundings but the results are mostly not available. On a photo map prepared from the airphotos taken in 1943, the soundings made by Byrd (1943, vol. 1 p. 22) are written in, apparently in feet. On a traverse from Pincer Bay to the east corner, depths from 38 to 60 ft (11.5 to 18 m) are recorded in the open water in the middle of the lagoon. Another traverse due south from the North corner gives a miximum depth of 32 ft (9.7 m) for the northwest part of the lagoon. The traverse from Naturalists' Camp south to the Rock includes the greatest depths from 42 ft (12.8 m) just north of the Rock to 120 ft (36.5 m) in open water near the East corner. Where the traverses pass over the submerged lagoon reefs, the recorded depths are between 4 and 7 feet (1.2 and 2.1 m). In 1958, the biologists dived to depths of 20 or 25 m. Much of the lagoon is probably between 10 and 20 m deep with deeper holes, and becomes shallow as shores are approached. Nowhere is the lagoon very deep close to shore. There the bottom is sandy or muddy, or made up of consolidated coral rock extending from the shore. This cannot be observed very well, however, as the water is generally turbid and great masses of water plants, living or dead, obscure vision. Away from the shore, however, in areas of deep and open water, the bottom is described (Hambly, Allison, personal communications, Limbaugh unpublished report, 1957) as follows:

Past the fringe of plants growing in thick muddy sediments, the layer of sediment becomes thinner, with occasional sandy patches. On such sand and on some coral pinnacles dead marine lamellibranchs (Codakia sp.) and gastropods (Cypraea moneta, Hipponix antiquatus) can be found in place.* Farther into the lagoon, in deeper clearer water, thick layers of sediments are found. Occasionally, coral pinnacles rise clear of this muck, which covers the bottom around them. E. C. Allison (in lit.) writes: "coral ridges parallel to the shore and situated in water 1 to 10 meters deep are made up of a single species of Pocillopora...Great fingers of coral which rise from depths at least as great as our deepest dives (25 meters) were built by a horizontally frondose form of Porites which now lives around the outer edge of the 10 fathom terrace" (ocean side of atoll).

Lagoon reefs and islets

As shown on charts, and more accurately on air photos, the lagoon is crossed by a number of large reefs, the most conspicuous of which is a flat triangular one, located near the Rock and called Grand Récif. At times it is apparently emerged and it was probably part of it that Belcher saw and marked on his sketch as a round reef in the middle of the lagoon. Hennig's soundings give depths of only a few (3-6) inches (7-15 cm) of water over this reef. Snodgrass and Heller found nowhere less than 2 feet (60 cm) and at the time of our visit in 1958 Grand Récif was certainly more than just 7-15 cm below the surface although the divers occasionally scraped their knees against such reefs. The most conspicuous character of this reef is the presence in its center of an egg-shaped hole, Bottomless Pit (Puits sans Fond) where depths of 20 fathoms (36 m) have been reported (Arundel, ex Wharton, 1898). From its aspect on air photos, the Pit with its very abrupt change in photo density must have rather steep walls.

When traced from the air photos (see map) the reefs, including Grand Récif, have very dissected edges and are reminiscent of a karst surface. They may represent a karst now submerged but formed at the time when the reefs were emerged, during an epoch of lowered ocean level. A feature perhaps comparable to these reefs is the "Maze" of Pelsart Island described by Dakin (1919) and illustrated and interpreted by Fairbridge (1948 pp. 17, 28, and pl. III). In this case live organisms are growing on an older, eroded limestone platform. The suggested karst, in Clipperton lagoon, presents a curious feature in that there is a roughly concentric arrangement of the reefs. This would bear careful further investigation as possibly indicating more than one episode in the fluctuation of sea-level during the Pleistocene. It may, on the other hand, correspond to what Tayama (1952 pp. 255-256) calls "double ring atolls"; he discusses possible modes of origin of these but arrives at no firm conclusion.

Besides the reefs which may, at times, be partly emerged, there are in the lagoon a number of small rocky islets. The more important group is the line of 5 Egg Islands strung parallel to the northwest shore of the atoll, only a little distance off shore. Four of them are quite small, the fifth and largest is about opposite the north corner of the island.

* Species now living on the outer reef (Hertlein and Allison 1960a, 1960b); see also note p. 73.

There are also some islets across Pincer Bay and across Thumb Cove. The latter were often under water at the time of our visit but birds stood on them nevertheless. All these islets consist of consolidated phosphatized coral material as do the adjacent rocky shores. The three small islets located close to the south side of the Rock, on the contrary, are formed of the same volcanic material as the Rock.

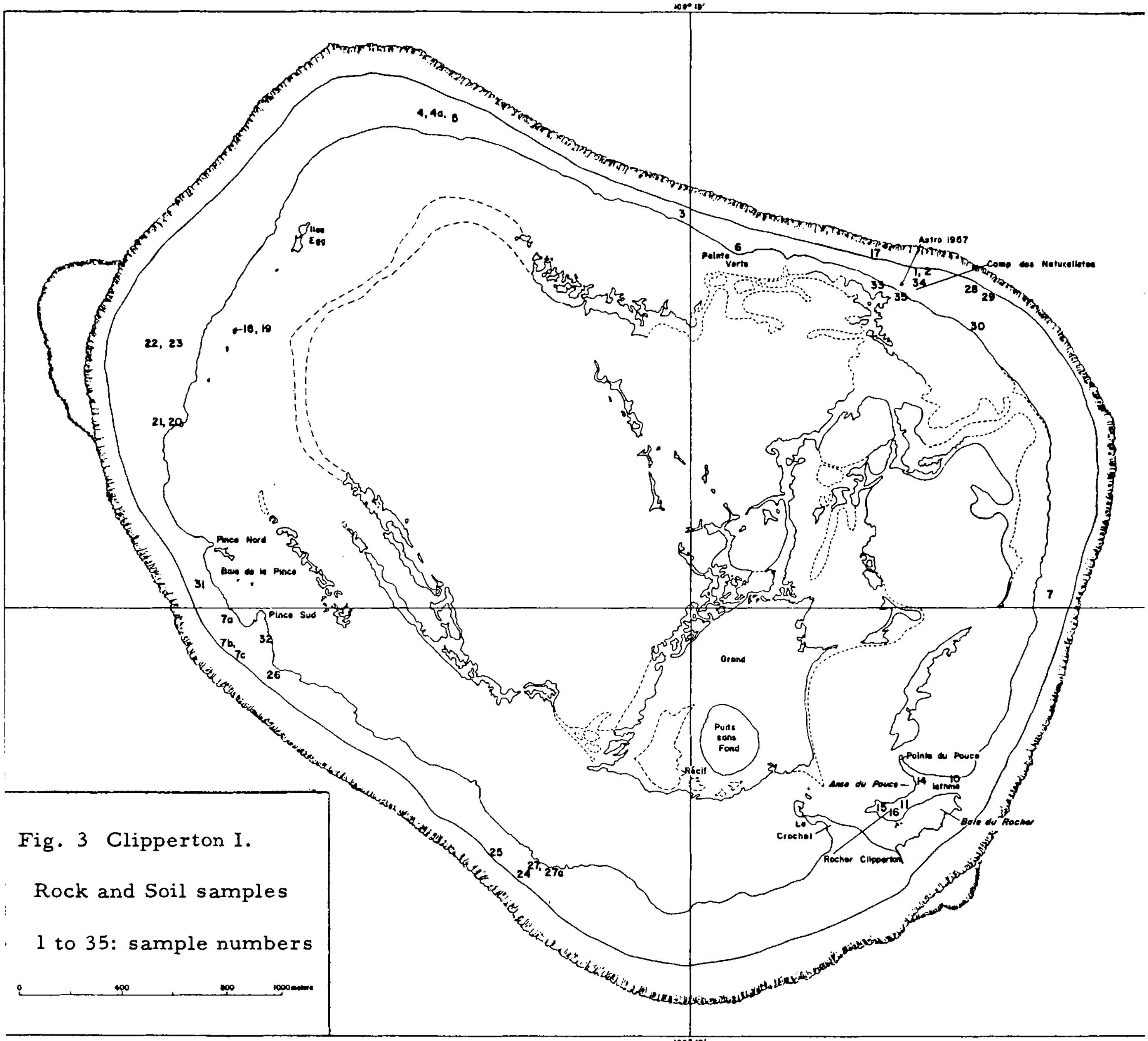


Fig. 3 Clipperton I.

Rock and Soil samples

1 to 35: sample numbers

LITHOLOGY

Except for Clipperton Rock, the rocks on Clipperton Island above the reef flat are almost entirely of organic origin and derived from the calcareous skeletons of animals and plants, and from guano deposited by sea birds. By far the more important original constituents are corals; mollusks, foraminifers and other animals, coralline and other algae, and pumice, are relatively minor constituents, much less important than in many other atolls such as the Marshalls. Phosphate has been added in substantial amounts. The sediments range in size from silt and fine sand to large boulders. Many are loose and almost fresh, some have been weathered into soil, some have been altered to phosphorite, and some are consolidated into various types of rocks, the inland ones mostly phosphorites, the beach rocks calcarenites.

Sufficient samples and detailed enough field observations to construct a reliable lithologic map were not collected. The locations of the samples are indicated by numbers on the map (fig. 3) and the distributions of rock types are roughly indicated in the descriptions of the land surface given above under Surface Features of Land Strip. Obermüller (1959) presents a geological map indicating the areal distribution and arrangement of loose calcareous materials and two grades of phosphate ores. In a few areas I collected unconsolidated materials where ores are indicated on his map. His discussions of phosphate ores deal only with consolicated types.

Only brief summaries are given of the occurrence of the groups into which my samples are arranged. More detail may be obtained by reference to the description of surface features and to Obermüller's map. The results of chemical analyses of my samples are given together at the end of this chapter, p. 66. Detailed petrographic studies have not been completed, and will not be included in this paper. Obermüller gives descriptions of some of his samples, analyses, and excellent photos of typical rock samples with photomicrographs of thin sections. His report may be consulted to supplement the present account, at least until studies of the samples are more advanced.

Reef sediments were not studied. Lagoon sediments were collected by E. C. Allison.

Loose sediments

The greater part of the island surface is covered by loose material, ranging in depth from very thin layers of sand or gravel partly covering consolidated formations to large masses several meters thick forming the boulder ridges. It was not practical to determine the thickness of the layers in most cases.

Sediments have been roughly arranged in size classes as follows:

Boulder and cobble gravel

Deposits of limestone debris of boulder or cobble size occur in various parts of the ocean side of the island forming high beach ridges (e.g. at the north corner) or boulder fields (southeast side). These deposits may be well sorted or with smaller gravel and sand filling the interstices. Most of the boulders are smaller than a child's head, and worn and rounded. Occasionally larger, more irregularly shaped boulders occur, either among the others or more often as storm-cast isolated blocks. One such block observed on the northeast gravel sheet measured 90 cm along its base and was 75 cm high. It was a chunk of coral, veneered with a layer of shells of vermitid snails. Other blocks of similar sizes have been cast up far inland. Large blocks and rounded boulders are pieces of massive coral colonies, and appear to represent a very small number of species. No sample of this rock type was collected.

Gravel

A very important sediment on Clipperton Island is a type of gravel made up almost entirely of branched coral pieces, probably one or several species of Pocillopora. Some of the fragments are perhaps large to be classed as pebbles, but the majority fit better in this size class than with cobbles. Such gravel forms a great part of the beach ridges around the island, as on the northwest side, outside the southwest coconut grove, and in the south, between Rock Bay and the reef. Some of these ridges, as described above (p. 38), extend for some distance inland in wide gravel sheets especially on the northeast side, at the north corner and on the Rock Bay side of the Isthmus. The gravel in these sheets was probably spread over the land at the time of storms, and occasionally was poured as far as the lagoon edge, where it forms gravel bars (see p. 42). The following samples were secured:

Sample 7c:

Consists of pebbles 4 to 7 or 7.5 cm long and up to 3 or 5 cm wide, rather well sorted and mostly white in color. The pebbles are mostly somewhat branched pieces of apparently unaltered coral, most of them rather worn and rounded but some quite fresh, or rounded fragments overgrown with other organisms such as snails or algae. The sample is perhaps too small to be quite representative, as it should include larger fragments. It was collected on the ocean side of a beach ridge, opposite the southwest coconut grove.

Sample 4:

Pebbles 3 or 5 to 7 or 7.5 cm long, varying in width up to 4 cm, stained gray (gray-black when fresh) by microscopic algae. The pieces are branched fragments of coral, somewhat worn, but with very sharp edges and angles. While in size they compare well with sample 7c, their sharp cutting edges are in great contrast with the rounded outlines of the pebbles of that sample. The gravel represented by sample 4 was strewn over the ground in a thin interrupted layer, often only one pebble thick, at the north corner of the atoll. Underneath was a consolidated pavement (cf. sample 4a) or a fine soil.

Sample 25:

Gravel very similar to that in sample 4, but with pieces 6 to 13 cm long and 3 to 6 cm wide or more. The coral fragments are much branched, with sharp edges, and stained dark gray or almost black with an encrustation of microscopic algae. When knocked with a hammer or against one another, such pieces gave a somewhat ringing sound. The coral is partly altered and easily breakable, or in places friable. This type of gravel, made up of large branches, is extremely unpleasant to walk on. The sample came from the landward side of the gravel ridge in the southwest part of the island.

Fine gravels, sand, silts and mixtures of these:

The majority of sediments on Clipperton are of these size classes, but, except for beach sand, they are rarely well sorted, and occur most often in mixtures of materials of several different sizes. Much of the vegetated part of the island is occupied by such mixtures. Most of these sediments, except the beach sands and those making up the surface layers of the washes, are highly phosphatic and have some accumulation of organic matter showing some differenciation to soils. Soils as such are discussed below (p. 75).

Sample 19:

Poorly sorted mixture of fine gravel of altered coral, and phosphatic crust fragments up to 2 or 3 cm greatest diameter, mostly rather thin, with a small amount of coarse sand made up of the same material. Light brownish gray, mottled with paler. Some pebbles stained with algae. A few dead shells and shell fragments, fish bones, and feathers. From a depression in the consolidated rock (sample 18) forming one of the small Egg Islands.

Sample 34:

Unsorted mixture of small pebbles of coral up to 3 cm greatest diameter, somewhat altered but still resistant to crushing, and pieces of phosphatic coral conglomerate, fine to coarse sand and small amount of silt. Gray-brown color mottled with paler to white when dry. Fine fractions (34a) highly phosphatic, coarse (34b) less so. Sample completely loose in structure. Occasional dried undecomposed leaves, occasional sub-fossil land shells.

This material formed the surface deposit in the vicinity of Naturalists' Camp, and where collected, between the camp and the lagoon, was at least 20 cm deep. Nearby, it was buried under a layer of sand locally 8-10 cm thick but of varying thickness.

Sample 36:

Mixture of small, partially altered, coral fragments and what appears to be fragments of phosphate cement, gray to grayish white in color. Highly phosphatic.

The material is a sample of commercial phosphate from Clipperton, received from the Pacific Chemical and Fertilizer Company in Honolulu through the courtesy of Mr. Ronald Q. Smith. This sample is included here with some doubt, as it is recognized that it is perhaps not in its original condition but may have been derived, at least in part, from a conglomerate by crushing.

Sample 7B:

Fairly well sorted fine lime sand, almost white but with scattering of brown particles, completely loose in structure. When boiled in a cobalt nitrate solution (Meigen's reagent) which stains aragonite purple while calcite remains white, this sand becomes almost entirely purple, with only a very small fraction of white grains. Generally corals have skeletons of aragonite, molluscs have shells of varying proportions of aragonite and calcite, depending on the species, red coralline algae, echinoderms and foraminifers have skeletons or tests of calcite. Sample 7B is from the beach on the southwest coast, opposite the coconut grove.

Sample 1:

Medium to fine lime sand with occasional coarse particles and shell fragments, finer material partly coral debris but with material of many other origins, the whole pale brownish gray but slightly stained with greenish, pale green when fresh, entirely loose in structure except for occasional fragments several mm in diameter of fine material bound by algae which probably formed a thin crust on the surface. Layer 0.5 to 1 cm thick lying on top of sand represented by Sample 2.

Sample 2:

This is essentially similar except for possibly a slightly larger proportion of coarse to medium grains and a pinkish cream color with no trace of green and no fragments of algal crust. Most of the grains are stained purple by Meigen's reagent, but the proportion of white grains is greater than in sample 7B. From top of storm beach, opposite Naturalists' Camp, on northeast side.

Sample 7A:

Unsorted mixture of altered coral fragments up to 2.5 cm long, with small amount of coarse to fine sand and a considerable proportion of silt, either loose or coherent in small friable granules up to the size of coarse sand, with admixture of dried roots and grass, frequent small land shells. The whole a brown gray color somewhat mottled with pale. Forming surface layer in southwest coconut grove, between clumps of palms.

Sample 14-1:

Mixture of small fragments, from coarse sand size up to 1 cm in diameter, of very much altered friable coral, and silt mostly aggregated into firm but friable crumbs up to coarse sand size, a few small root fragments. Gray brown mottled with whitish when dry, light brown when fresh, forming a layer 10-15 cm thick lying on Sample 14-2.

Sample 14-2:

Coarse irregular coral fragments up to 5 cm or more in length, outer layers (14-2a) dull gray-brown, and altered to phosphate, inner part (14-2b) preserving structure of coral, whitish, friable; interstices filled with fine to coarse sand with some silt particles, apparently made up of the same material, light gray brown. Samples 14-1 and 14-2 from Isthmus, at the base of Thumb Point.

Sample 11-1:

Dark brown highly humic silt, with numerous fragments of leaves, crustacean shells, bird bones, small pieces of decomposed coral, roots, decomposed wood and other miscellaneous organic remains, somewhat sticky when fresh, caked and cloddy but friable when dry. Forming a layer 8-10 cm thick. Many earthworms. Abruptly overlying Sample 11-2.

Sample 11-2:

Mixture of highly altered coral fragments up to several cm long (11-2b), a fine to coarse sand and much silt coherent into firm but friable sand-size particles (11-2a). Medium to light brown in color; outer layer of coral fragments yellow to ochre color, and friable; inner part white, less friable, preserving the structure of the coral. Considerable admixture of roots and small fragments of decomposed wood and other organic matter. Forming layer at least 10 cm thick, coral fragments becoming more abundant and paler downward. Samples 11-1 and 11-2 collected under coconut palms, at the base of the East face of Clipperton Rock.

Sample 21:

Grayish-brown silt, partially aggregated into crumb-like particles, friable when dry, mixed with a considerable proportion of whitish chalky particles up to 1 cm in diameter, ranging from quite friable to so hard that although they can easily be broken, they will not crush between the fingers. Fine roots fairly numerous. Many of the chalky particles appear to be pieces of phosphatic cement. Greatly resembles sample 22, but has even higher phosphate content and much more numerous chalky particles. Forming surface layer in bottom of long shallow trench near west corner of island. Material was apparently dug out of this trench and piled up into some mounds nearby, from one of which sample 20 was collected.

Sample 20:

Resembles sample 21, paler color, greater proportion of chalky fragments, some of which still show coral structure. Both samples are highly phosphatic.

Sample 22:

Uniform brownish gray (pale chocolate color when fresh) silt aggregated into crumb-like particles which are friable under some pressure when dry, with a few paler fragments of chalky friable material, occasional roots. Forming a surface layer 8-15 cm thick overlying Sample 23.

Sample 23:

A layer of irregular aggregates of pale gray firm but friable chalky material of silky texture when crushed, embedded in finer grades of apparently the same material. On close examination this material presents the appearance of a semi-consolidated coral sand which has undergone a chalky alteration. Analysis shows that it is highly phosphatic. These two samples came from a wide area of fine soil in the oceanside half of the northwest land strip.

Sample 31:

Broken up material of the same sort as sample 23. From a mound at the north end of the southwest coconut grove, perhaps a pile of phosphate ready for shipment.

Sample 15:

Dark brown loamy material, partially aggregated into friable clods, mixed with highly altered coral pebbles up to 2 or rarely 3 cm in diameter. Various fragments of plant tissues, bones, egg shells, feathers, etc. Forming surface layer in passageways within Clipperton Rock.

Sample 32:

Dark brown partially decomposed litter, made up chiefly of fragments of coconut leaves, roots and other parts, mixed with more or less altered coral fragments and what appears to be fragments of phosphate cement, some of the coral pieces up to 3-4 cm long, most very small. Forming thick layer on the surface of the ground within the dense coconut grove on the southwest side.

Sample 3:

Pale creamy gray silt, powdery but some loosely aggregated into friable particles up to a cm across, mixed with a very small amount of fine to coarse sand and scattered rounded coral pebbles, these highly altered and chalky in appearance and somewhat friable under strong pressure. Forming a patch among the coral pieces of the northeast gravel sheet, and probably extending under it and representing part of the former surface layer.

Sample 5:

Fine light grayish-brown silt, somewhat aggregated into crumb-like friable particles up to 5 or rarely more mm in diameter, mostly less than 3 mm, in which are embedded a considerable proportion of worn coral pebbles up to 3-4 cm greatest diameter, these apparently not highly altered. Very few sand-size particles. Surface layer on emerged land strip, near north corner of island.

Sample 6:

A silt, dark brown mottled with pale brown and with a thin surface layer of a very pale gray, with a slight admixture of sand-size particles, small land shells and occasional small angular rock fragments. This material is plastic when wet and smelled slightly of H_2S when fresh. When dry it is from pale gray to gray-brown, friable. It is highly phosphatic. From mud flat occasionally inundated by lagoon water, and lined with a bed of sedges, on north end of northeast side.

While several piles of material which may represent stock ready for shipment consist, in part at least, of fine highly phosphatic material (cf. samples 20, 31) it has generally been implied that the commercial phosphate was obtained from conglomerates. This may be borne out by the small sample of exported material, no. 36. In any case, the occurrence on Clipperton of finely divided phosphatic sediments, including large amounts of silt, has never before been unequivocally reported.

Arundel, in his unpublished journal (cf. p. 20), speaks of a sample from Clipperton which, if dried down to 10% moisture, "would then be like flour and very difficult to ship." Later, in discussing his own explorations and sampling, he repeatedly mentions "alluvials," brown in color or sometimes lighter, which apparently are unconsolidated phosphatic materials but which, however, he nowhere describes.

Consolidated sediments

Except for the reef rock of the intertidal reef-flat, which was not studied, the consolidated sediments belong to two main types: beach conglomerate and phosphatic conglomerate.

Beach conglomerates

Sample 17:

Rounded small coral gravel, pieces mostly 1-2 cm in greatest diameter, some larger, some smaller, in a matrix of medium to coarse lime sand and shell fragments, firmly indurated at the surface, becoming less so downward, so that at a depth of 2-3 cm they can be somewhat crumbled between the fingers. General color pale pink, surface 5-10 mm stained green by algae. From one of the slabs of beach rock on the northeast ocean coast (see p. 36).

Sample 28:

Loose slabs, similar in nature to sample 17, but some with finer texture, harder, much more compact, well indurated, somewhat polished by wave action. General color pinkish white, upper surface slightly greenish, stained with algae but much less so than in similar material in place. Collected on the emerged land strip on the northeast side, where they were evidently thrown up by a storm as they were lying over the *Ipomoea* vines.

Sample 29:

Semi-indurated medium to coarse sand, the surface rather even and hardest, but easily broken with the fingers. Bonded by what appears to be a coarse silt. Induration extending downward to 2 or 2.5 cm, but becoming less firm. General color creamy pink. The surface stained greenish-gray by algae to a depth of as much as 5 mm, this also true of the vertical surface of the free edge of this material. Embedded coral pebbles common. Lying on loose material that is essentially similar to the indurated part but with perhaps less fine components. This may not be beach rock in the strict sense since it is only semi-indurated and lies above high tide level. Collected at the top of the sandy storm beach, opposite the camp on the northeast side.

Phosphatic conglomerates

The mode of occurrence of consolidated rock over major areas of the land strip has been described in the chapter on Surface Features of Land Strip, pp. 35-50. The original distribution and extent of these conglomerates, as well as that of the phosphatic silts and gravels which sometimes cover them or replace them on the surface of the island cannot be known, because phosphatic material was removed from the island over a period of about 20 years.

As mentioned above, the commercial phosphate is generally believed to have been derived from consolidated rocks. Snodgrass and Heller (1902) say that "where good formations are found the mixture is dug up, broken into small pieces, dried, sacked and shipped without further preparation." Snodgrass collected some samples but they have not been described or analysed. Elschner (1913) published an analysis (see p 67) of a sample by Gilbert, which is reproduced by Lacroix (1939). Elschner writes that the material which he saw in a plant in Honolulu was in part a white, chalk-like material, in part a coarse yellowish gray powder, together with rather hard stones. The phosphatic conglomerate in its natural condition has not been described in detail until recently, when Mr. A. G. Obermüller published a report (1959) on his survey. I failed to find some of the types of conglomerate which he describes and conversely, I have not been able, in all cases, to refer my samples with confidence to his classes, although he has kindly given me portions of his samples. My collection contains some types of conglomerate which he did not obtain. This is easily understood, since neither of us spent enough time on the island for an adequate study, and our purposes were very different. Our collections overlap and complete each other. In the following descriptions of my samples, they are related, where possible, to the types described by Obermüller.

He recognizes 3 main types of phosphatic conglomerates: cuirasse, carapace and coral aggregates, but indicates that intermediate types occur and that the 3 types are stages in the consolidation and enrichment in phosphate of the coral material, the aggregates being the early stage and the cuirasse the latest and richest in phosphate.

Aggregates consist of pieces of coral, slightly phosphatic and cemented, where they touch, by a phosphatic substance. Carapace is a more compact rock, cream or brownish white, with a more or less compact phosphatic cement, often friable; spaces usually remain between the cemented coral pieces. In the cuirasse phosphatization is more advanced, the conglomerate is more compact. When in place, it is usually still somewhat vesicular, but spaces between coral pieces and cement are small. Samples taken by Obermüller from piles of phosphate stock are the most massive and include a type (AO-15-Cl.57) which is practically pure calcium phosphate without any remnant of coral pieces. In other samples (cf. AO-14-Cl.57), comparable material occurs between remnants of corals (at least between cavities with marks of coral pores) and together with a banded phosphatic material of a different texture. Comparison of samples 14 and 15 seems to indicate that what Obermüller interprets as possible traces of rootlets in sample 15 are rather the last narrow traces of the original vesicular structure remaining after spaces have been filled in by cement. These two samples of Obermüller's are two types of rock which I failed to find in my collecting.

Of the types which I did not see in his collection, the most striking is that represented by my samples 27A and 18. In this material, cementation of coral pieces by a hard, porcelain-like, banded phosphatic material has apparently been followed by the solution of the coral pieces, and only casts of their pores seem to remain on the surfaces of the phosphatic walls. Such rock is heavy, but not compact, and looks more like a hard sponge than anything else. Samples 27A and 18 were collected not far above lagoon level, and solution may have been effected by lagoon water. Other samples approaching these and with remnants of pieces of coral still present and "rattling" within the spaces between the walls (cf. sample 4a) were collected or observed on top of the land strip. In this case, of course, superficial solution may be due to rain water.

This type of rock is very striking, but not abundantly distributed over the island. I have not seen any description of a comparable material in the literature on coral atoll or Pacific Island phosphates.

Sample 4a:

Formed of small coral pebbles in a rather abundant porous cement, probably phosphatic; the top surface seems to consist only of this cement, remaining to form the partitions of a shallowly alveolar surface and bearing casts of the coral pores. The color is from gray to black, stained by microscopic plants. On the underside, the sample is white to pale brown. Several fragments of coral can still be seen embedded in the cement. A broken one has a crystalline structure in the center while its outer surface has been in part dissolved so that the coral piece rattles and could probably be removed from its mold of cement. This sample cannot be very well fitted in Obermüller's categories, but is probably an aspect of the carapace type. It came from an area mapped as carapace. It was too small to be analyzed.

The rock represented by sample 4a is a type of consolidated pavement, rather thin and overlying a silty material (sample 5); sample 4a is 2-5 cm thick and was part of a rather extensive area of such pavement, in places overlaid by gravel (sample 4) or sand, at the north corner of the island.

Sample 10:

A conglomerate of coral branches of varying size embedded in a cement which is filled with sand and fine coral fragments partially dissolved away. The coral branches have become friable. The top surface of the sample is very uneven and rough and is stained from pale brown to greenish and black by microscopic algae. It is deeply alveolar, some of the holes representing molds of coral pieces which have been dissolved, or partly so, and loosened, leaving the hard phosphatic cement. The broken under surface is white or yellowish, very porous, showing the inner structure of the broken coral fragments. The lower part is probably nearest a carapace or intermediate between it and cuirasse, but the upper, alveolar part is of the type not described by Obermüller. The phosphate content (%P_2O_5) is more comparable to those given for cuirasse than carapace. The sample comes from an overhang of consolidated rock above the lagoon water, in the area just east of Thumb Point along the Isthmus.

ample 27A:

This is a deeply vesicular rock, formed of walls generally 1-2 mm hick, locally more. These walls are very clearly marked with casts of oral pores and the whole rock may be what remains of a coral conglomer-te from which all of the coral pieces have been dissolved, leaving the ement. The shape of the holes indicates that the coral fragments were ather large, many of them branched; some casts of branches are 4-7 cm ong. Such fragments then must have compared in size with the loose coral aterial which forms much of the gravel ridges (cf. samples 4, 7c, 25). he whole rock is of a pale reddish brown, in places stained by algae. The ections of the walls are of a pale brown, somewhat banded or layered, very ompact and fine textured, almost porcelain-like. Analysis shows this ce-ent to be almost pure calcium phosphate. This rock does not fit the lasses described by Obermüller. The sample was collected in the same eneral area as sample 27, but near the lagoon ledge.

ample 18:

Very similar to sample 27A: Coral branches which had been cemented n a conglomerate have been almost entirely dissolved and the deeply esicular mass of fine hard brown cement remains, showing the hollow casts f the corals. The marks of the coral pores are visible along some of the asts. In a few places the coral structure is still visible, but the ragments are apparently phosphatized. This rock had the highest phosphate ontent of all samples analyzed. The walls of cement have the same banded ppearance and porcelain-like section of those in sample 27A but may in laces be thicker. The principal difference between this sample and 27A s the fact that the upper surface is glazed with a thin, white shiny eposit very likely derived from fresh guano and perhaps polished by irds' feet. A similar glaze occurs on the surface of Obermüller's sample 3 (from the Isthmus), and a comparable one, but made up of aluminum phos-hate (Lacroix p. 301) is common on the Rock. Sample 18 was knocked off he top of one of the Egg Islands, which was covered by nesting boobies nd noddies with a few sooty terns. There was no vegetation on this or ny of the other 4 Egg Islands.

ample 27:

A dense conglomerate of small, worn coral pebbles embedded in an bundant sandy cement. As in sample 4a which it resembles somewhat, xcept for differences in the size and shape of the coral pieces, the top urface is alveolar, the coral pebbles having been dissolved out leaving he cement to form the low walls of the alveolae with casts of the coral ores. This alveolar surface is light gray to greenish, probably stained y microscopic plants, and is only about 2 cm thick; the walls of cement re very thin at the very surface, thicker (2-3 mm) below; under the sur-ace material, the rock is compact, with white pieces of coral embedded n a coarse, somewhat friable, creamy cement. Analysis shows that the oral pebbles (27-1) are slightly phosphatized, while the cement (27-2) s highly phosphatic. The material should probably be considered as ntermediate between carapace and cuirasse, because the lower part is quite comparable to samples of carapace, but the upper part, except for the alveolar surface structure, is similar to some aspects of cuirasse. This sample is rather typical of much of the areas of ledges and pavements. It came from the southwest side of the atoll, in an area where several series of rock ledges are aligned parallel to the rocky lagoon shore. Sample 27 is from the group of ledges nearest to the lagoon.

Sample 24:

The pieces of conglomerate in this sample are rather light and friable. They consist of coral fragments of varying size embedded in a coarse cement containing coral grains. The coral pieces are rounded cobbles 8 cm or more along their greatest dimension, and pebbles. Pebbles and cobbles are white and some are so softened that they can be deeply scratched with a finger nail. The outer surface of the conglomerate is dark gray and in places covered with a thin crust, pale gray-bluish in color, and perhaps formed by microscopic plants. The cement and coral grains in it are white or pale yellowish. Except in a few small places of its roughly alveolar upper surface, this rock lacks the hard porcelain-like cement walls of samples 10, 27 and especially 18 or 27A. Analysis shows a lower phosphate content than in these samples. Sample 24 should probably be classed with the carapace, but it tends downward toward the coral aggregate category. This conglomerate forms a series of low steps separated by rather wide areas of flat pavement, farther inland than the ledges from which sample 27 was collected but in the same general area of the atoll.

Sample 35:

The upper surface of this conglomerate is stained green or brown by a dried crust of blue green algae (Lyngbya). The broken sides show white or yellowish pieces of coral embedded in a coarse, darker cement. The alteration of the coral branches varies. Some of them, freshly broken, are still crystalline inside, with a dull white layer 1-3 mm thick all around. Others are dull throughout and at times very friable. Some of the pieces collected are formed only of cemented large branches of coral, but in others a very small gravel, with grains of various sizes embedded in the same yellowish cement, fills the interstices between the branches. In places the coral grains seem to have been partly dissolved and the cement remains as the paper-thin walls of a miniature alveolar structure in formation, similar to that seen in sample 27 and others. Some rather fresh-looking coarse sand grains may have been deposited in the interstices between the coral branches after cementation. The rock is phosphatic but less so than previously described samples. It fits between carapace and coral aggregates, parts of the sample being nearer the one or the other. It was collected underwater, at the edge of the lagoon, a little north of Naturalists' Camp. There the coral conglomerate forms low banks above the lagoon and extends under water.

ample 33:

Several pieces of a poorly consolidated coral rock. White, rolled, orn pebbles of coral, 1.5 to 5 cm long are covered over part of their urface by a yellowish crust which holds them together where their orners or edges touch, leaving empty spaces between the pebbles. Occas-onally the cement is more abundant and the empty space much reduced, or he spaces may be partly filled with a pale milk-chocolate colored fine and, probably phosphatic. In some of the pieces in the sample, a begin-ing of the formation of an alveolar surface can be seen: some of the oral pebbles are superficially dissolved and loosened from the thin alls of cement. Except for this aspect, the sample is typical of the oral aggregate type of Obermüller's. Analysis shows that the phosphate ontent of this sample is low.

This sample is from the lagoon shore cliff northwest of Naturalists' amp (described above p. 41). The upper part of the cliff, 15-20 cm hick, is similar in structure to the ledges of other regions of the atoll, onsisting in a conglomerate of coral fragments in a dense dark cement. his changes downward to a much thicker material of loosely cemented ebbles; in the upper part at least, the interstices are filled with fine and. Sample 33 represents this part of the cliff. The more lightly emented pebbles can be loosened from the cliff face by a moderate stroke f the hammer. The lagoon cliffs of the northeast side between Green oint and Naturalists' Camp form the edge of the area affected by the 957-58 storm and covered with a layer of fresh coral gravel. The loosely emented material represented by sample 33 was evidently exposed at the ime of the storm by the breaking off of the harder, more compact cliff ace. Detached blocks of a harder, darker rock were lying at the base of he cliff, and some jutting pillars, not recently broken, had the same ppearance. Parts of these pillars, as well as the upper part of the cliff op, consisted of a type of alveolar hard rock similar to that represented n sample 27A, i.e. with much or most of the coral dissolved away, leaving he dark reddish-brown hard phosphatic cement walls. On cliffs not affec-ed by the recent storm, the exposed top surfaces and vertical faces con-ist of a dark conglomerate comparable to the more compact ledges.

Between the cliff damaged by the 1957-1958 storm and the lagoon shore tretched a bank of coral pebbles. Most of this material was probably hrown over the whole width of the land strip by the storm but some appear-d to consist of pebbles detached from the newly exposed, poorly consoli-ated cliff face. Time was not available to study the material in the ank in detail to ascertain its origin.

Clipperton Rock

The volcanic material which forms Clipperton Rock is generally, on resh surfaces, of a rather light gray, sometimes with bluish or reddish inges. Unaltered rock has never been found, the dome being superficially ltered to unknown depths, at least 30-60 cm, and phosphatized. Even the reshest-looking samples have shown some alteration.

Descriptions and analyses of this rock have been given by Agassiz (1894), Teall (1898), Lacroix (1939) and Obermüller (1959). The latter two authors include very detailed petrographic descriptions of samples with, in the case of Obermüller's report, fine photographs of samples and thin sections. Following his classification of lavas, Lacroix describe the Clipperton material as a "rhyolitoïde à la limite d'un trachyte." Most authors call it a trachyte. My specimens have not yet been studied, and the detailed descriptions of Lacroix and Obermüller can be consulted. They include information on the progressive phosphatization of the rock.

From Obermüller's summary description (p. 54) the principal characteristics of the rock may be listed as follows:

--pseudo porphyritic texture
--abundance of sanidine
--xenomorphic character of quartz which is secondary and is probably pseudomorphous after tridymite
--existence of primary sodic pyroxenes as indicated by the occurrence, however sporadic, of unaltered aegirine-augite within an intact crystal of sanidine
--existence of fresh sodic amphibole molded on the sanidine microlites, and often associated with decomposition products of the pyroxenes
--probable absence of plagioclase as a component of the lava
--presence of fresh katophorite, xenomorphic and neogenetic in character.

This rock may be considered an alkaline trachyte; this is not essentially different from Lacroix' identification as a slightly more acid rhyolitoide, the slight difference being due probably to the fact that his samples were more altered than those collected in 1957.

The phosphatic solutions from the guano affect especially the superficial part of the rock, perhaps to a depth of one meter, leading to the phosphatization of the lava:

--either by formation of variscite in the leucocratic zones
--or by formation of strengite (or barrandite) in the melanocratic zones.

While I failed to find them, Obermüller reported the presence of minute fragments from the volcanic rock on the coral rim, and explained the rare occurrence, in the phosphatic coral conglomerate, of variscite, an aluminum phosphate, as being derived from them.

Sample 16:

Collected from the encrustations mentioned in this paper on p. 44. It appears to be a water-deposited material, perhaps comparable to that described by Lacroix as superficial encrustations representing aluminum and calcium phosphates of varying composition and relatively recent origin Sample 16 is a piece of a large crust, in places loosened from the vertica volcanic wall on which it has been deposited. The sample is pale brown, 1-3 cm thick, the underside paler and powdery, the upper surface made up of small branched efflorescences.

Pumice and other extraneous materials

The occurrence of drift pumice and rafted rocks on atolls is well ɿown, and takes on special significance in the ecology of these is- ɜnds in view of the limited number of chemical elements otherwise ɾesent in an organic limestone environment. Examples of such occur- ɜnces have been listed by Sachet (1955) and by Emery (1955).

Pumice was found on Clipperton, although it occurred as relatively ɜw scattered pieces, rather than as large fields or windrows as de- ɜribed on other islands. Most of the pumice was collected on the east ide, which was visited more often because of the location of the camp, ɿd where pumice was more easily located in the washes on the large ‹panses of sand. It may be equally common elsewhere on the atoll. ɾundel, in his unpublished diary, describes an area at the base of the ɔok that he sampled for phosphate, and where a layer of "alluvial" ɔhosphate) about 12 inches thick overlies a layer (?) of "Pumice or lay - very white". This is a rather puzzling reference, unless the ɿmice were extremely decomposed.

The pieces collected in 1958 range from pea-size fragments to ɔbbles of 15-20 cm greatest diameter. On superficial examination, they ɜem to represent several different types, as follows:

The large cobbles, as well as some smaller pieces, have a dense ɔongy structure, with visible criss-crossing fibers. They are dis- ɔlored, but if the surface is scratched, the pumice appears pale gray, ɾ almost white.

Most of the pea-size and some larger pieces are of very finely ɔrous texture, rather than fibrous. They are white or gray and some ɿclude numerous crystals of both white and dark minerals. Several ieces consist of long shiny fibers, all arranged parallel to one another, ɿe whole piece having a silky appearance. Fragments of these types ɜre collected at the edge of the lagoon, and have been so altered that ɿey can be crushed to a very fine powder between the fingers.

Several pieces of shiny black vesicular material may be slag from ship's furnace rather than volcanic rock. A flat piece of dark, com- ɿct, heavy rock found not far from the camp is perhaps boiler scale. ɩ the base of the Rock are large pieces of coal, possibly dating from ɿosphate mining days, or from a wreck.

Near the east corner of the island, in an area where much drift ɜ present, and arranged along ocean-lagoon lines of flow, there are ɱong other things planks and other pieces of wood, bottles, Japanese lass floats, small pieces of charcoal, and also some small flat pebbles ith rounded edges of volcanic or possibly metamorphic rock. The ɜbbles may have come from ballast, or have been rafted by drift trees. beautiful example of a rafted boulder was photographed near the north ɔrner of the atoll by E. C. Allison. A large drift tree base holds a ɔunded piece of greenish volcanic rock.

Analyses of Clipperton Island Samples

Samples were analyzed by the Geochemistry and Petrology Branch, U. S. Geological Survey, by methods similar to those described in U. S. G. S. Bulletin 1036-C; Paul L. D. Elmore, Samuel D. Botts and Ivan H. Barlow, analysts.

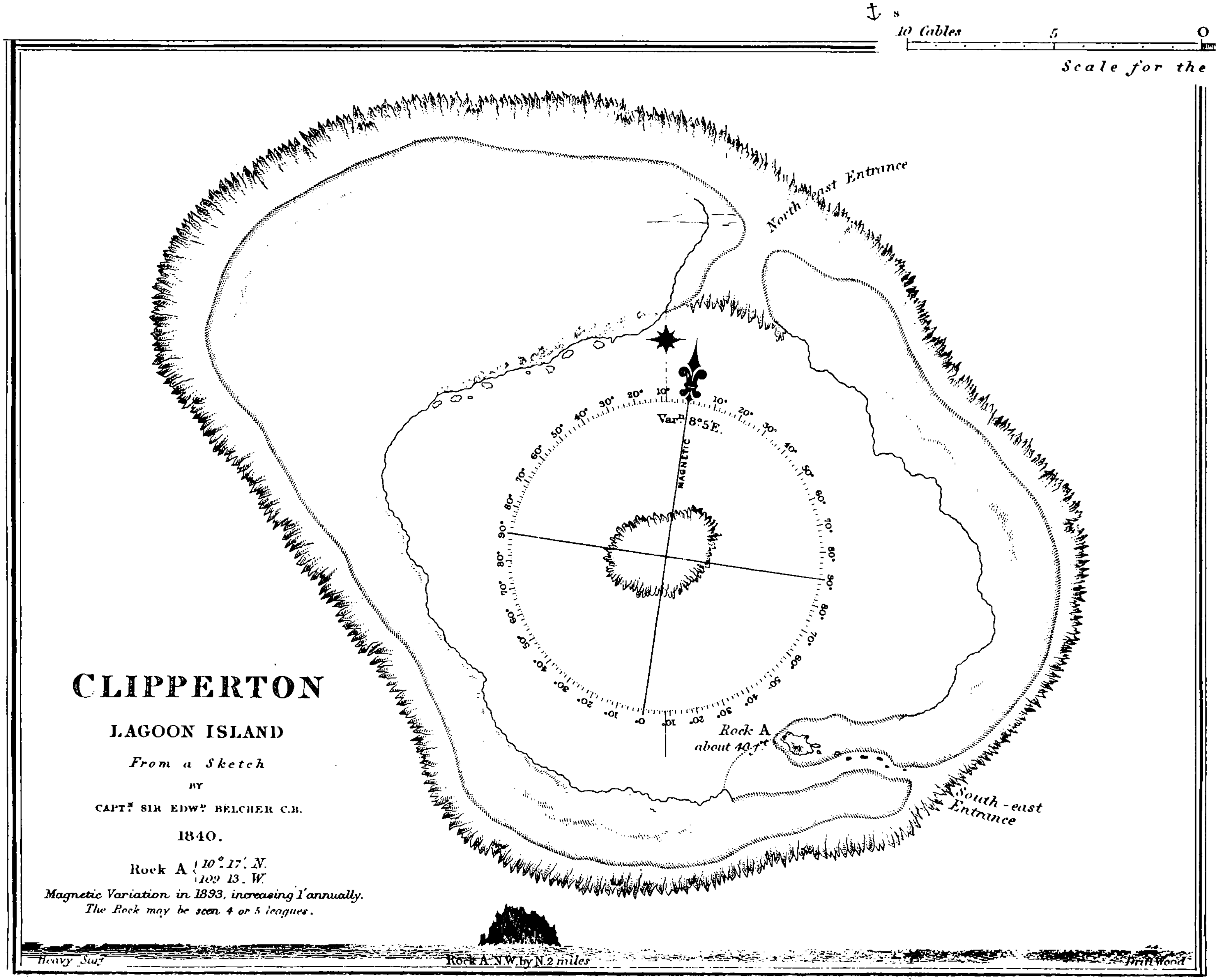
Lab. No.	Field No.	% MgO	% CaO	% P_2O_5	% CO_2
154383	3	.46	50.4	14.6	25.3
154384	5	.28	48.5	27.4	10.9
154385	6	.77	44.6	30.4	5.2
154386	7A	.16	50.2	20.8	18.9
154387	10	.85	49.3	36.8	3.6
154388	11-1	.16	32.2	23.6	.48
154389	11-2a fine part of sample 11-2	.16	45.2	35.6	2.0
154390	11-2b coral fragments from sample 11-2	.20	50.4	24.8	16.4
154391	14-1	.54	46.0	34.7	2.6
154392	14-2a outer part of coral fragments	.32	49.8	37.1	2.8
154393	14-2b inner portion of coral fragments	.12	53.7	.60	41.7
154394	15	.13	53.0	1.1	40.9
154395	16	.17	30.0	29.0	.14
154396	18	.46	50.7	39.4	.30
154397	20	.18	49.5	37.0	1.7
154398	21	.10	47.5	36.1	1.0
154399	22	.19	46.1	34.6	.79
154400	23	.16	50.1	38.6	1.0

ab. No.	Field No.	% MgO	% CaO	% P_2O_5	% CO_2
154401	24	.19	51.2	16.0	24.6
154402	26	.56	53.5	2.1	41.1
154403	27A	.62	50.0	38.8	.54
154404	31	.18	50.8	38.5	1.2
154405	33	.17	53.0	5.0	36.6
154406	34a fine fraction	.16	48.4	21.4	17.3
154407	34b coarse fraction	.06	52.9	6.3	35.6
154408	35	.28	53.1	10.0	32.0
154409	36	.44	50.8	31.2	9.3
154410	4	.14	53.0	.17	41.7
154411	27-1 coral fragments from conglomerate no. 27	.42	54.2	2.2	40.2
154412	27-2 cement from conglom-erate no. 27	.28	50.9	28.9	11.5

Analysis of Clipperton Island Commercial Phosphate

(from Elschner 1913, p. 91, reproduced in Lacroix 1939, p. 303)

$3CaO\ P_2O_5$	78.09	NaCl	0.15
$3MgO\ P_2O_5$	0.55	SiO_2	0.28
$CaOCO_2$	6.73	Al_2O_3, Fe_2O_3	0.04
CaO	2.84	Organic matter	4.83
$CaPO_3$	0.78	Loss on ignition	3.80



10 Cables
5
0
Scale for the
North east Entrance
Var.n 8°5'E.
MAGNETIC
Rock A
about 40 f.t
South-east Entrance
CLIPPERTON
LAGOON ISLAND
From a Sketch
BY
CAPT.N SIR EDW.D BELCHER C.B.
1840.
Rock A { 10°. 17'. N. 109 13. W.
Magnetic Variation in 1893, increasing 1' annually.
The Rock may be seen 4 or 5 leagues.
Heavy Surf
Rock A. N.W. by N. 2 miles
Drift Wood

PHYSIOGRAPHIC CHANGES

Geological change

In terms of geological history, atoll islets may be regarded as ɔhemeral, or at least very changeable, features, even though their ıbmarine foundations are in certain cases known to date back to the ɔcene or even the late Cretaceous (Ladd 1960). On most of them are ɔund some features which record or indicate some of the later changes ıat have taken place. The principal difficulty at present is to read ıd interpret this record. On Clipperton, features which may be signif- ːant in this respect are the "karst" topography of the lagoon bottom lescribed on p. 49), the step-like concentric ledges of consolidated ɔck (described on p. 40) and the two tiny remnants of an old consoli- ıted surface persisting as undercut shelves or ledges on the side of ıe volcanic Rock at between one and two meters above low tide level lescribed on p. 44).

The karst-like lagoon bottom suggests one or more earlier periods ? considerable emergence and subaerial erosion, a history which has, ıdeed, been suggested for coral islands generally (MacNeil 1954). ːesent inadequate knowledge of the details of this lagoon bottom pre- ludes any more adequate discussion of this aspect.

Both the concentric ledges and the shelf remnants suggest a more ːcent period of somewhat greater submergence, or higher sea level. ːtailed study of these, including careful levelling, might make pos- ible a more adequate outline of the post-glacial history of the atoll ıd perhaps a correlation with similar features on other atolls, and ɔasts in general. The concentric ledges should be studied in the con- ːxt both of the phosphatization of the coral and the possibility of ıanges in salinity and acidity, as well as in level, of the lagoon water.

The fact that the shelf on the small islet of volcanic rock slopes ːom a level of a meter or more at one end to about lagoon level at the ːher can scarcely be explained on the assumption of changed sea levels ıly. Without careful excavation, the only suggestion that seems tenable ; that the rock fragment may be a loose one, lying on coral gravel which ɔuld have been washed out, somewhat, during a storm, permitting the .umping of one end of the rock.

Historical change due to natural causes

Historic data show that the island has undergone changes in certain ? its features. The most important one is the closing of the reef open- ıgs and the consequent freshening of the lagoon. Unfortunately, neither ? the earliest accounts of Clipperton Island remark on the condition of ıe atoll ring or the lagoon in 1711 (France 1912) or 1825 (Morrell, 1832). ıe map furnished by De Prudhomme does not show any opening, but is such sketchy draft that no absolute reliance can be placed on it. Morrell ınded on Clipperton, and it is tantalizing that he should not say more ıan he does. He makes no mention of openings or lack of them, or of the ıste of lagoon water.

Clipperton was first seriously mapped by Sir Edward Belcher in 1839 (Belcher 1843) and two openings were seen from the masthead (fig. 4). In November 1858, Le Coat de Kerveguen found the coral ring continuous (France 1912) and, as far as known, it has remained so ever since, although ocean waters pour over the land strip and into the lagoon with some frequency. Belcher is the only author to have seen the openings if we except a not too reliable report by Permien (Anon. 1897-98, Aug. 19) who wrote: "There was, at the time I first saw it [in May 1881], a channel connecting the lagoon with the ocean, but on my later visits [1892] I found that this had been choked by logs and drift. The lagoon is now a body of fresh water not connected with the sea, and the pearl oysters in it have died." The validity of Belcher's observations cannot be doubted. The nature of the openings, and the manner of their closing may be discussed, however. At present the areas where the 1839 openings were located can easily be recognized. One is the great northeast sand wash, the other is across the land strip opposite the Isthmus. The absence of high consolidated rock, either as elevated beach rock, or island phosphate rock, is notable in both. In 1958, the great sand wash had a maximum elevation of 0.65 m above estimated mean high tide level, and while the southeast spot was covered by a gravel beach ridge topped in part by a recent small sand spill, it was not very high, and apparently was entirely made up of loose, removable material. Griswold (Pease 1868) described this area as "a heap of fragments, piled in windrows by the waves and some photos taken in 1897 show it as a composite gravel ridge. It is quite easy to imagine that a storm, or several storms, could have closed the openings by piling up sand or coral gravel across them. However, the outer reef of Clipperton does not show any important interruption near the former openings. It is narrower on the northeast side, and its surface may be somewhat depressed near the northeast landing place, but this is probably south of the former opening. My impression is that the 1839 openings were not boat passages, but only reef-surfaces temporarily cleared of accumulated material, and therefore extremely shallow, and perhaps quite short-lived. This interpretation is compatible with Belcher's description which says: "There are two entrances, which at high water may be safe; but at the moment we passed, the surf was too heavy, and the reflux showed the rocks bare." These rocks must be the surface of the reef, the bottom of the entrances. The storm or storms which closed the 1839 openings may well have changed the surface of the reef and, more especially, the reef front, in such a way as to facilitate the accumulation of material so the openings have never formed again. This interpretation might seem to disregard the fact that the lagoon, with coral heads and other marine animals in position of growth, has obviously for long periods of time, been in communication with the ocean. My impression is that the closing and freshening of the lagoon had started before the disappearance of the 1839 openings, and that the period when it was in ample communication with the surrounding ocean was probably much earlier, perhaps dating back to a time of higher sea-level. A detailed study of the topography of the present reef, and of the nature of the dead marine fauna of the lagoon, including the physical condition of the dead shells and corals, could help reconstruct their history. At the same time, the lagoon reefs should be investigated (see p. 49, note p.73).

Another instance of historical change in the Clipperton land strip is that observed on the northeast side, and attributed to a storm occurrin etween November 1957 and May 1958. On the air photos taken in September 943, the area northwest of Naturalists' Camp and to the far side of Green oint exhibits fine lines parallel to the shore, similar to those marking he phosphatic ledges elsewhere. The vegetation cover appears irregular ut continuous and probably consists of mixed herbs, with Ipomoea patches ecognizable in some places. A sedge marsh occupies the tip of Green oint. Beyond Green Point, and as far as the area where the land strip egins to widen and curve to form the north corner of the atoll, no ore lines are visible, there is much exposed sand and the vegetation ppears to consist only of Ipomoea vines.

The photos taken from the helicopter in November 1957 do not cover ll of this area but show very well the vegetation extending for several undred meters northwestward of Naturalists' Camp with Ipomoea vines reeping down the beach and a small coconut palm near Green Point.

In August 1958 changes from these conditions were spectacular. ost of the northeast side of the atoll was denuded of vegetation and overed with fresh coral material. Going northwest from Naturalists' amp and past Astro 1957, the ocean to lagoon cover of Ipomoea pes-caprae ines stopped abruptly 45 m from the Monument, and gave way to a sheet of oral gravel, in places at least, lying over coral sand or phosphatic silt. he gravel was rather evensized but mixed with occasional larger cobbles nite, and somewhat imbricated from ocean to lagoon. Here and there arge boulders had been tossed up onto the land strip. Some gravel had oured into the lagoon and was being reworked into low banks by the lagoon aves. Where the old land surface ended in a cliff at the lagoon edge, he cliff face in places had been undermined and broken up and the fresh ravel was mixed with material detached from the cliff (see p. 63). On he ocean side, the edge of the land surface was undercut and broken up orming a ledge, and coarse sand or gravel sloped down from it to the each, except where a thick formation of conglomerate, also eroded and roken up at the top, formed the ocean slope (see p. 37).

Some sandy areas near the lagoon edge of the gravel sheet, elon- ate in an ocean-lagoon direction, seemed to mark channels along which he water drained off. Some were occupied by fresh plants of Cenchrus or pomoea pes-caprae. Otherwise the gravel sheet was bare of vegetation, nd obliterated any earlier surface features of the area, such as ledges.

Somewhat beyond Green Point, the gravel sheet was interrupted, and he land strip formed an escarpment along the ocean-lagoon section, 1.40 at its highest point, and with a slope of gravel below it. Beyond this luff, northwestward of the gravel sheet, the land strip became very ow (0.65 m above estimated mean high tide level) and sand stretched cross it from ocean to lagoon forming the great sand wash and extending or 430 m toward the north corner of the atoll. At its far end, it gave ay to a boulder field, and finally to an area covered with vegetation hich appeared undisturbed.

The storm then has deposited coral debris over a strip several undred meters long, and across it into the lagoon, at the same time ndercutting and eroding the ocean shore. Drift seeds and pumice were ollected on the lagoon beach, if proof were needed that ocean waves eached the lagoon.

Southeast of the most spectacularly affected area, opposite Naturalists' Camp, the storm had eroded and undercut the island rock, and deposited boulders and slabs of beach rock at the top of the beach, and even over the vegetation of the land strip. Some sand was spread over the Ipomoea vegetation and, washing down among the vines, covered the phosphatic silt. A buried soil was found, near the small group of palms, under 8-10 cm of sand.

The emplacement of a tide gauge installed near the wrecked LST in 1956 was demolished, most probably by the same storm, and the wreck itself was so battered that the mast and much of the stern fell in the ocean. These changes were observed, together with the conspicuous white coral strip on the northeast side, in May 1958 (W. L. Klawe written communication).

That the storm waves did not affect only the land and the upper parts of the underwater slopes is demonstrated by observations made by the marine biologists. Allison (personal communication) was able to observe some species of corals which grow only below the edge of the 10-fathom terrace; the large boulders made up of their skeletons and thrown up onto the reef and even the land strip had therefore been lifted from this depth, at least. This effect of the waves at considerable depth is confirmed by some observations of the divers along the undersea slopes. They observed great differences in aspect between the northeast slopes and those elsewhere around the atoll and believed that they were seeing storm effects as far down as 30 to 45 meters. Detailed descriptions of such observations, when available, will be of great interest indeed. Newell (1956, p. 344) also suggested that some of the coral debris thrown up by hurricanes on the reef and islets of Raroia Atoll originated on the terrace.

Elsewhere on Clipperton, along the southeast side, a vast area of sand may have been deposited, or at least reworked, by a storm, as suggested by the black coral boulders partly buried in fresh sand, and which must have been there for some time. The sand covers also the road marked in 1945. The surface of the sand is littered with great amounts of drift material, pieces of wood, dead coconuts, bottles, a very few glass floats, pumice, drift seeds, often arranged along ocean-lagoon lines of flow. Some white coral boulders were probably deposited at the same time. On the 1957 photos, this area is not very well shown, but it does not appear very different from what it was in 1958, so the fresh-looking material may have been deposited or re-arranged by a storm earlier than the 1957-1958 one.

In the southwest sand wash, black boulders partly buried in sand, also seem to indicate that the sand has been reworked, or added to. In this relatively small and rather permanent sandy area (see p. 35), the effect may be due mostly to wind, however.

Recent changes due to man

Some changes in the aspect of the island are due to man's activities. While most traces of phosphate collecting have been obliterated, some mounds of phosphate occur near the southwest coconut grove and the west orner of the lagoon. Plants arranged in "lines" along the northwest ide, may follow hidden trenches along which phosphate was dug (cf. p. 7). John Arundel (Anon. 1897-98, Aug. 20) wrote rather disdainfully f some early prospectors: "some one ... chipped off some big blocks of he /volcanic/ rock under the hallucination that it was hardened guano, nd hauled them two miles across the lagoon to the place where it was ntended to ship the stuff. It lies there still. One might just as well se cobble-stones for a fertilizer as to use that rock." The chunks are till piled up on the lagoon shore, opposite the LST. Two sand mounds ear the east corner may also date back to that period, as they were al-ead noticed in 1943. The phosphate workers in the 1890's had several ouses and sheds on the northeast side, near the present Naturalists' amp or somewhat northwest of it. Later, the camp was moved to the south-est side, and before 1945, ruins of huts and machinery could still be ound. The trace of a ruined pier across the reef, opposite the south-est camp, can still be seen on air photos. Some shelters had also been rected near the Rock. In 1958 a low wall at the base of the east face f the Rock, some excavations and some large pieces of coal scattered near-y remained; the ruins of the phosphate digging establishments had disap-eared, except for piles of phosphate, pieces of narrow-gauge rail track nd a large iron mooring buoy; but the remnants of the U. S. Weather Sta-ion buildings were conspicuous on the southwest side, in the much-nlarged coconut grove. Roads had been built from the Station around the toll, and can still be seen in most places, the vegetation having a dif-erent appearance and the plants growing lower on the compacted material. hotos taken in 1945 show a large cleared area where the Weather Station uildings were being put up, and a bank of coral on the ocean side of the amp, probably intended to protect it from storm waves. This bank is till recognizable today, although the coral has turned black and plants over it in parts.

Another important change wrought by man of course is the intro-uction of animals and plants, which will be briefly discussed below.

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ote: After the above was written, I received the following information. Dr. Carl Hubbs, in a letter dated Dec.27, 1961, says:" We have just eceived the radiocarbon date of 370 $\pm$ 100 years from the UCLA Radiocarbon aboratory (their test No. UCLA-115) ... The test was made on a complete pecimen (both valves) of a clam identified by Allison as Spondylus cf. acificus, taken from a depth of 18.3 meters in the lagoon, in September 958, by Limbaugh.

"The exact date, even within the indicated margin of error, is not be trusted too implicitly, because there are expected fluctuations, nd for other reasons." The date will be included in the 1962 Radio-arbon Supplement to the American Journal of Science.

This interesting result, in spite of the wide margin of error marine carbonates offer serious problems in radiocarbon dating), in way weakens the remarks made on p. 70, and confirms the view that ithin relatively recent times, the lagoon of Clipperton was sufficiently aline to support some strictly marine organisms. It also suggests that he present meager brackish water flora and fauna of the lagoon are of elatively recent origin.

GENERAL LAND ECOLOGY

Habitat

The outstanding ecological characteristics of Clipperton Island are the rigorous environment and paucity of habitats and land biota. The climatic conditions have been described above and can be summarized as follows: extreme insolation; moderate temperature, with little change throughout the year; high humidity; high rainfall probably with a dry period; variable but often strong winds; seasonal but frequent storms and hurricanes and incidence of storm waves.

The landscape as a whole is rather uniform and provides only a few habitat types: uniformly low altitude and little variation in topography, lack of much variation in chemical composition in the substratum, poor development of soils, little shade, all contribute to reduce the number of possible habitats, even more on Clipperton than on other atolls. For instance in the northern Marshalls, which are perhaps comparable in many respects, a greater variety of habitats results from the denser, more mature vegetation which includes several native trees providing shade, more differentiated soils, increased soil moisture locally, etc.

On Clipperton Island the surface soils are mostly very immature--coral sands and gravels only slightly discolored by organic matter. In some areas the surface material is phosphatic gravel derived apparently from the indurated phosphatic rock, but in many places the surface is of only slightly modified recently deposited material.

On the broad northwest corner are large areas of phosphatic silt with slight admixture of coral gravel, this especially scattered in a thin layer over the surface. The silt is differentiated into a brownish or brownish gray upper layer as much as 15 cm thick, lying on a pale creamy white layer, more compact, of undetermined thickness. The two layers are almost entirely calcium phosphate, but the percentages of both P_2O_5 and CaO are somewhat lower in the darker upper layer, perhaps indicating some profile development (cf. samples 22 and 23 p.56). Comparable material (cf. sample 3, p. 57) underlies the gravel sheet on the northeast side, at least in some places. Judging by the similarity of the material in old stockpiles on the west corner near the lagoon, this silt may be one of the kinds of phosphate that were mined commercially. Therefore its present extent is probably much more restricted than it must once have been.

Otherwise no significant profile development was observed in any well drained site except in the coconut groves where a thick surface horizon of partly decomposed litter and humus had accumulated on the coral (cf. sample 32, p. 57). Crab holes are abundant and doubtless there is a continual stirring up and turnover of the soil material, making any incipient horizons less distinct. Earthworms are locally abundant. Drainage seems generally excellent except on ground lying at about lagoon level. Here the soil, in its upper layer at least, is a dark highly organic silty mud (cf. sample 6 p.57).

The soil generally calcareous and phosphatic, may be locally enriched by small amounts of material from the volcanic rock and of drifted pumice and extraneous rock carried in drifted trees.

There is little visible evidence of the influence of soil on vegetation or the reverse, except in the soils of the coconut groves mentioned above, in the correlation of silty, highly organic mud with sedge beds in low places, and that of silty sand with Heliotropium and Conyza stands. Of course the continuing enrichment of the soil by guano and the past enrichment which led to phosphate formation undoubtedly make the soil a more fertile substratum for plants than the pure carbonate parent materials. Since this enrichment is a general feature, its effects are not revealed in the vegetation patterns. Recently deposited sands and gravels, not so enriched, have very little vegetation as yet but this is probably related to time and other factors rather than to lack of fertility.

Land Biota

The paucity of habitats on atolls in general and Clipperton in particular is matched by the poverty of the flora and fauna. In Pacific atolls, there is an obvious attenuation of the fauna and, more especially, the flora as one travels eastward, away from the land masses of Indo-Malaysia. This trend is complicated by the rainfall gradients. Despite the enrichment from the east, Clipperton Island's impoverished biotas fit well at the "end of the line."

Plant life

The floraand vegetation of Clipperton have been described in detail elsewhere (Sachet 1962) and only a summary need be given here.

While the present survey increased the number of plants recorded from Clipperton, only some fungi (mostly isolated from soil samples), lichens and blue-green algae, 3 mosses and 26 phanerogams could be found, with the addition of a few drift seedlings. All the species are listed below, pp. 89-94. There were several drift trees, or large branches, thrown upon the beaches or beach ridges.

Probably all the cryptogams present are of very wide distribution but too little is known of their general occurrence to draw useful information on phytogeography. The three mosses, at least, are pantropic. Of the phanerogams, some are pantropic and their place of origin cannot be determined (e.g. Ipomoea pes-caprae), a few are American (e.g. Heliotropium, Scirpus, Solanum). Only one drift seed, if its identification, Strongylodon sp., is correct, appears to be definitely of Indo-Pacific origin. Most of the land plants were probably introduced by man, a few deliberately (e.g. Cocos, Nicotiana, Brassica) others by accident (e.g. Waltheria, Corchorus, Solanum, Sida, Cenchrus, Eragrostis). The lagoon phanerogams and perhaps some algae (Proctor 1959), and the sedges may have been introduced from America by water birds.

There are no native trees or shrubs on the island. Except for the coconut palms introduced about 1897 and forming a few groups about the coral ring, the vegetation is uniformly low, only a few centimeters or in places a few decimeters tall, and made up of herbs, some of them suffrutescent.

The larger coconut grove on the southwest side, is too dense to allow any undergrowth or ground cover. No plants grow under the palms at the East face of the Rock either, possibly because of trampling by the pigs. The other groups of palms are so small that the surrounding vegetation simply extends to the palms or among them, without any perceptible change in character. Therefore, shade, humus, and the protection from wind, salt and evaporation provided by trees, are of little importance as factors influencing the vegetation. The slightly more luxuriant condition of some plants near the larger grove may just as well be due to the presence of the ruined camp and attendant disturbances of the soil, addition of chemical elements useful to plants, and other effects. Similarly, it is not known whether the taller, more luxuriant condition of Sida and Solanum around the base of the Rock is related to shade, disturbance of the soil, or addition of chemical elements from the volcanic rock or of organic matter from other sources.

The most extensive vegetation type on Clipperton is a herbaceous cover, a few centimeters to a few decimeters tall, made up of a varying mixture of grasses and suffrutescent perennials. The plants most commonly present are Cenchrus--a grass with spiny burs, Sida, Corchorus, and Solanum. Other plants occur, but less generally, mixed with these. Two plants appear to prefer sandy habitats and may form pure patches in such places; they are Heliotropium and Conyza. The mixed herbaceous vegetation is best developed on the northwest side of the island, which also appears to have been least disturbed in recent years. The density and composition vary and over large areas, some taller plants, densely growing together, form long narrow lines, roughly parallel to the shores. A thin layer of dark gray coral gravel covers most of the soil in this part of the atoll, hiding differences in soil, if any, along the lines of plants. Very likely, however, the lines indicate buried features; some may be the continuation of the phosphatic ledges found elsewhere around the atoll, and the majority probably are old trenches or furrows along which the phosphate was collected. One such trench is still clearly visible a little south of the west corner of the atoll, not far from the lagoon. On the 1943 air photos, it shows as a long dark gray strip, with four round spots along it. In 1958, the spots were found to be piles of phosphatic sand and gravel (cf. sample 20, p. 56), with a cover of taller vegetation, including much Brassica. Three piles are on the west side of the trench, the other on the lagoon side. The trench is 30 or 50 cm deep, several meters wide and at least 100 m long. The obvious impression is that the piled up material was dug out of the trench. This may be how the phosphate was mined. This interpretation appeared strengthened by some of Arundel's remarks in his diary (cf. p. 20). When he was on Clipperton in July-August 1897, he surveyed very minutely the phosphate resources of the island, and, in his notes on surveying and phosphate sampling, he often mentions trenches, apparently parallel to the shores, found mostly in the northwest part of the land strip, the only area exploited at the time of his visit. His notes are too sketchy however to give an exact idea of the method of exploitation and to permit correlations with present observations.

The mixed herbaceous vegetation is also well developed on the southwest side and around the south corner of the land rim, but is generally lower. The former roads running from the old U. S. Weather station are marked by low, primarily grassy, vegetation. On some areas of phosphatic pavements, especially at the south corner, the mixed herbaceous vegetation consists mostly of clumps of Sida and Solanum,or large cushions of moss (Bryum sp.) with much bare ground exposed.

Another important vegetation type is a blanket of Ipomoea pes-caprae. The long thick vines, with their bright green leaves notched at the apex and purple morning glory flowers, cover the whole width of the land strip near the wrecked LST and Naturalists' Camp, blanketing abandoned boats and other equipment, and form thick masses of stems over lagoon cliffs or banks around most of the island, except in the south. Here and there these creepers extend into the mixed herbaceous vegetation, as on the west side where they cover the ruins of the weather station and on the northwest landstrip where they grow from old gnarled "trunks" several decimeters high. These have been interpreted as a sign of seasonal dryness, when the vines probably die back. I have found no reference to such thickened woody bases for this species, but somewhat similar, even larger, woody trunks of another species, Ipomoea tuba, have been observed on Pokak Atoll in the northern Marshalls (Fosberg 1955), where there is a very marked dry season.

Low muddy areas or small ponds and ditches along the lagoon shores are occupied by a vegetation made up of pure stands of several sedges. Tall, dark blue-green plants of Scirpus rubiginosus form a few small patches on the Hook and here and there along the east shore of the lagoon. They are rooted in mud, under water. In similar habitats, but much more abundant, occur the bright green dense stands of Eleocharis mutata, lining the shores with narrow strips or scallops and filling shallow ponds. The low pale green Eleocharis geniculata forms stands around the former, growing on wet mud, but not in water. Hemicarpha micrantha, the last species of sedge, prefers still drier habitats, and its small gray-green tufts are found outside the Eleocharis geniculata zone or alone in quite dry areas. The different requirements for wetness of substratum of the three last-named species sometimes lead to a striking concentric arrangement as at the base of the Hook in (E. mutata) and around(E. geniculata and Hemicarpha) a small pond. The dense stand of Eleocharis mutata in the pond is the habitat of the damsel fly Ischnura ramburii (det. C. F. Harbison). This same sedge and the Scirpus are used for nesting sites and material by the coots.

A type of vegetation which is not always recognized as such by the casual observer is represented by the crusts and films of blue-green algae which stain the sand green and blacken the coral around the atoll. Their role in the ecology of atolls is not known, although some possible effects of their occurrence have been suggested: the species growing in sand may have a role in binding the sediments (Cloud 1952, p. 61; Doty 1957). Nothing is definitely known of the role of blue-green algae in nitrogen fixation on atolls, and yet it may be of great significance in view of the paucity of nitrogen sources in such environments. This has been suggested by Doty (1957) and Newhouse (1954, p. 53). In gypsum sand, a similar type of very sterile habitat, an increased amount of nitrogen in algae-bound crusts has been demonstrated by Shields and collaborators (1957).

Little is known of the ecological significance of soil fungi on atolls, but they doubtless play a considerable role in the decomposition of organic matter and a large flora of soil fungi is known from Clipperton (see p. 89 and Sachet, 1962).

Vegetation of the lagoon

In addition to various attached and floating algae, the vegetation of the lagoon is made up of aquatic phanerogams tolerant of salt. These plants, when alive, form great beds of weeds in the shallow parts of the lagoon, especially along the Isthmus and around the Rock, in Pincer Bay and around the Egg Islands. The most abundant is *Najas marina*, the stems of which, several meters long, are presumably rooted on the bottom. *Potamogeton pectinatus* was found around one of the Egg Islands, while *Ruppia maritima* is common attached to rocks just below the surface of the water together with filamentous algae. Great tangled masses of these plants float at the surface of the lagoon and are deposited on the shores in long rolls after periods of strong steady winds. On this plant material feed lagoon invertebrates especially the very abundant isopod, a species of *Cirolana*.

At least two plants are known to have been present in the lagoon, which could not be found in August 1958. One is the *Chara* collected in 1938 (W. R. Taylor 1939) the other is a phanerogam resembling *Zostera marina*, visible in great abundance on a photo taken in 1943 (Byrd 1943, vol. 4 photo 15). What caused the disappearance of these plants can only be guessed at. They may never have become really established but only have flourished for a brief period after their introduction. Or they may have suffered from changes in the salinity of the lagoon water, or other less obvious causes.

Animal life

Mammals:

In 1825 Morrell visited Clipperton and wrote (1832, p. 219) "Fur-seal and sea-elephant resort here in small numbers in the proper seasons ... After taking what few fur-seal could be found about the island ..." This is the only record of seals from Clipperton Island. Recent works (Allen 1942, p. 440, Scheffer 1958 p. 78) discuss Morrell's records of fur-seals on other islands of the East Pacific but make no mention of his Clipperton observations. However, Dr. Carl Hubbs (personal communication) believes there is no reason to distrust Morrell.

In the eastern Pacific, there are three fur seals, the Galapagos fur-seal (Arctocephalus australis galapagoensis Heller), the Philippi fur-seal of Juan Fernandez (A. philippi philippi (Peters)) and the Guadalupe or California fur-seal (A. philippi townsendi Merriam). All have been slaughtered ruthlessly for their skins and the Juan Fernandez seal may be extinct. The Guadalupe fur-seal was feared to be extinct or almost so when Dr. Hubbs (1956) found a small group of them on Guadalupe Island in 1954. Which of the three fur-seals could have occurred on Clipperton can only be conjectured, but the location of the atoll partway between the home of the different fur-seals makes the problem especially intriging.

The northern elephant seal (Mirounga angustirostris (Gill)) now occurs only on some of the islands off the coasts of California and Baja California but formerly had a much larger range and could have reached Clipperton. With the disappearance of the seals, no native mammals remained on Clipperton.

Pigs were introduced to Clipperton Island around 1897, when a photo was taken showing two of them with the first two coconut palms, on the northeast side of the island. According to newspaper reports, these two pigs were survivors of the wreck of the British ship Kinkora (cf. p. 20). In 1917, when the phosphate works had been abandoned and the few remaining inhabitants were discovered and rescued by the U. S. gunboat Yorktown, about a dozen pigs were running wild on the island, the people being unable to catch and kill them (Morris, 1934). All visitors between that time and 1958 mentioned the pigs, most of them estimating their number as around 50, although the crew of the Ethel M. Sterling (cf. p. 7) reported nearly one hundred. In August 1958, all 58 of them were killed, because they seemed to molest the nesting birds. The pigs had lived in the Rock and hid in the larger clumps of plants near it, in the coconut grove, or in thick Ipomoea beds at the lagoon edge. They had worn white tracks on the dark coral gravel, or narrow paths in the vegetation. Their droppings showed that they ate plants and crabs, and probably also eggs and perhaps young birds. Some of the pigs were black, others a dirty pink, and spotted.

Unlike many other oceanic islands, Clipperton has been protected from the accidental introduction of rats and mice by the fact that ships cannot tie at the shore, but passengers and goods must be taken ashore by small boats. However, in August 1958, Mr. David Peterson (written communication) saw a mouse in a ruined quonset hut of the weather station.

Birds:

Most of the early visitors to Clipperton Island mention the great numbers of seabirds roosting or nesting there. Morrell in 1825 saw "the whole island ... literally covered with seabirds," and Belcher used almost the same words. Others mention myriads of birds. In 1958, even the most abundant species of birds occurred only in groups of perhaps a few hundred and it was obvious that there had been a serious decrease in numbers at some time. The common species were boobies, noddies and other terns, and frigate birds.

The brown boobies in 1958 were nesting and in addition to eggs, they had young of all ages. They were very abundant on the Rock, which they shared, almost exclusively, with white-capped noddies. They also occupied ledges and projections of consolidated phosphatic rock forming cliffs around the lagoon. Whenever a piece of such a cliff had fallen down, forming an isolated pinnacle in front of the cliff face, boobies could be found on it. Brown boobies also roosted in the coconut palms, and on the wrecked LST, with other species. The nests were of dry Ipomoea runners and grass, sometimes with a fresh green branch of Heliotropium, perhaps for decoration. Along the cliffs, the nests seemed more substantial than on the Rock, and were very clean because boobies can expell the guano a long way from the nest.

In November 1898 (Snodgrass and Heller 1902), they were common, breeding on the flat coral beach along the lagoon. In August 1905 (Gifford 1913), they were nesting abundantly all around the island.

The blue-faced or masked boobies in 1958 were much less abundant than the brown boobies. One with a red-orange beak had an egg on the northwest land strip. This part of the island, together with the Egg Islands, is where they were most abundant, but a few roosted elsewhere. These birds make no nest, only a slight depression in the ground. In November 1898 they were "breeding in immense numbers," in November 1901 Beck (1907) saw thousands of them, and in August 1905 a large colony was scattered among the brown boobies but not nesting. It may be that they are more numerous in the fall when they breed than during the summer months.

The absence of red-footed boobies from Clipperton was attributed by Snodgrass and Heller to the lack of bushes. In August 1958, Dr. Stager saw one on a palm near the Rock.

With the boobies, the most conspicuous birds on the island were the noddies. The common noddies occurred all around the island, sharing the rocky cliffs with the brown boobies and the Egg Islands with the blue-faced boobies and sooty terns. They also nested on all the abandoned rusting boats and vehicles on the island. Their crude nests included a few twigs of Ipomoea and sometimes a green Heliotropium branch. A few of them nested on the ground, with only a depression or a few pebbles and twigs marking the site among the Ipomoea vines. They had eggs, and the chicks started hatching during our stay. In 1898 they were very abundant on the Rock, and in 1905, on the Rock and the lagoon islets.

The white-capped noddies are not easy to distinguish from the others, unless they are seen together. The white-capped are somewhat smaller, the plumage is darker and the white cap in sharper contrast with it. In 1958, they nested all over the Rock in great numbers, on all the projections and in crevices too small for boobies. Some had nests of twigs and Heliotropium, others had no nest at all; some thick, guano-incrusted nests appeared to be old ones being re-used. Below the nesting places, trickles and splashes of guano covered the Rock. Some noddies were seen picking up Ipomoea vines, pulling on them or flying with them, the vines sometimes much longer than the bird. There may have been some confusion with common noddies, here. The noddies in the Rock had eggs and, toward the end of our stay, chicks. The white-capped noddies nested also in the coconut palm near the Rock, where they badly damaged the fronds and especially young inflorescences by sitting on them and covering them with guano. There were noddies nesting also in the large southwest coconut grove. In November 1898, only immature birds were recognized, associated with the common noddies. In 1905 white-capped noddies nested in great numbers on the Rock, with nests of algae (or more likely lagoon phanerogams).

The sooty terns, or wide awakes, roosted in small numbers in the southeast part of the landstrip, opposite the Rock, and on the Egg Islands. A larger colony moved a little distance west from the north corner, to just landward of the beach ridge top, a few days after we arrived at Clipperton, and started laying eggs directly on the ground, among coral rocks. In 1898 and 1905 sooty terns were nesting in thousands on the Egg Islands. These birds sometimes occur in incredible numbers but have been known to abandon some islands where they were once very numerous, such as Canton Island (Murphy et al. 1954). They are very noisy and when approached shriek and scream in a deafening manner. Very little guano accumulates in sooty tern rookeries because they usually drop it only over the ocean. The rain of guano, so unpleasant when noddies, boobies or frigate birds are disturbed, is noticeably absent under a flight of sooty terns.

Fairy terns have never been very abundant on Clipperton, all observers mention only a few pairs. In 1958 they had eggs in different parts of the island, on isolated large boulders, and in the coconut palms and ruined quonsets of the southwest side. There is no nest at all, the fairy tern being famous for balancing its egg on a branch or rock, in such a precarious way that it is hard to understand how the bird gets on and off the egg, and how the chick hatches without moving the egg and falling. The chicks of the beautiful little white terns were hatching in the latter part of our stay. When disturbed, adults would flutter about the visitor's head, just beyond reach, and chatter.

Frigate birds in 1958 roosted on the east corner of the island, in a sandy area with scattered boulders and drift material. The adults had almost grown juveniles with them. At the end of our stay, they seemed to be preparing to nest in the coconut trees on the southwest side. Frigate birds had been recorded in 1898 and 1905 and Belcher (1843) had mentioned "frigate pelicans."

The last species of bird to be seen in large numbers at Clipperton in 1958 was the American coot. These dark birds with their curious white beaks were swimming in the lagoon, or walking on shore, and some had built their nests in the sedge beds. Some had chicks swimming behind them. Coots had been observed by Beck in 1901. Together with the ducks reported as common in winter by Snodgrass and Heller and by Beck, but of which we saw none, the coots have probably been very important in increasing the flora of the lagoon. Perhaps all the water phanerogams, the lost Chara and the sedges were brought by these birds in their stomachs or in mud on their feet. The shore birds which were observed in 1958 only as isolated strays (golden plover, bittern, wandering tattler, sand pipers, and perhaps godwit, etc.) may be more numerous at other seasons and may also transport seeds of water plants. Seabirds are also known to eat plants at times, especially seeds (Guppy, 1906; Ridley, 1930; Fosberg, 1957) and may be responsible for some plant introductions in this way, although transport of prickly or sticky fruits or seeds attached to feathers is probably more frequent. The boobies and noddies may help spread some plants, especially Heliotropium, around the atoll because of their habit of carrying small branches.

Besides their probable role in bringing plant species to the island, the birds of Clipperton may have had other effects on the vegetation. On other widely separated islands it has been shown that birds can damage or even kill vegetation. Vesey-Fitzgerald (1941) suggests that sooty terns may destroy low vegetation or inhibit its growth. Tree-nesting birds damage trees and bushes: On Canton Island frigate birds and red-footed boobies appear to kill some trees or bushes of Scaevola, Cordia and Messerchmidia (Hatheway 1955, pp. 5, 8). On Kapingamarangi, a much wetter atoll, white-capped noddies damage or perhaps kill breadfruit trees (Niering 1956, p. 19). Another interesting example is that of the Chesterfield Islands in the Coral Sea (Cohic, 1959). The small flora of 20 phanerogams forms a vegetation somewhat comparable to that of Clipperton, except for the occurrence of shrubs less than 2 meters tall of Sophora tomentosa, Scaevola sericea and Colubrina asiatica. These woody plants, as well as the few introduced coconut palms, are very much damaged by roosting and nesting frigate birds and red-footed boobies. It is conceivable that on Clipperton, where the seed sources are obviously very poor, the birds, when they were much more numerous in the past, could have prevented the establishment of certain plants, including shrubs and trees. Supposing that rare seeds of such plants could have arrived on the island in drift or by other means and that a few seedlings could have survived in spite of the crabs and developed to maturity, those birds which can nest indifferently on the Rock or on trees would probably have moved over to them and destroyed them. At present the number of birds on Clipperton is small and they have little recognizable direct effect on the vegetation. As mentioned above, they do affect the condition and perhaps multiplication of coconut palms near the Rock. Conversely, the complete absence of trees on the atoll until recent years has successfully precluded the presence of birds that nest exclusively on trees. Whether the recent development of coconut groves will lead to the establishment of new tree-nesting birds, such as red-footed boobies, is of course not known; too many factors are involved. However, this is one of many questions which will make periodic resurveys of the atoll very valuable.

The birds of course have an indirect effect on the vegetation through the enrichment of the soil in phosphate. On other atolls (Cohic 1959), it has been suggested that the very high concentrations of phosphates and nitrates in soils may have deleterious effects on plants. This could not be determined one way or the other on Clipperton.

The impact of the bird population on the island is most striking when one considers the large phosphate deposits, particularly the deep phosphatization of the volcanic rock. Perhaps a detailed study of the phosphatized trachyte could lead to an estimate of the duration of the process. In any case it is obvious that staggering numbers of birds must have lived on the island for long periods of time. Whether any perceptible phosphate formation occurs at present with the much reduced bird flocks is not known. Fresh guano of course is deposited.

Reptiles:

Morrell (1832) mentioned that green turtles came to Clipperton to deposit their eggs, but there has been no other such report since his time. While the beaches at Clipperton are not the most favorable for turtle nesting, it is not impossible that they once came there. On the voyage from San Diego to Clipperton in 1958 occasional turtles were observed, swimming in the open ocean. In 1934, from the Jeanne d'Arc, thousands of them were observed between Panama and Clipperton (Diben, 1935).

The skinks, Emoia cyanura arundeli, on Clipperton Island were apparently not noticed until collected by Arundel in 1897 (Garman 1899). In 1898 (Heller 1903), and 1905 (Van Denburgh and Slevin 1914) they were especially numerous all over the Rock, rather than on the coral ring. This is a curious observation as the reverse was true in 1958 and the lizards were very numerous in the low vegetation of the island, especially in the Ipomoea blanket. It may well be that they were living in the Rock when lack of vegetation, scarcity of insects, and abundance of crabs made the coral ring too uninviting for them. Their coloring is variable, from almost black to brown with golden-bronze stripes. None of those seen had the blue tails commonly seen on this species elsewhere. Mr. Harbison and I found their oval eggs in old hollow coconuts in the coconut groves and once under a large boulder.

I was working with Mr. Harbison when he doubled the known lizard fauna of Clipperton by catching a gecko (Gehyra mutilata det. W.C. Brown). The protective coloration of this small animal was remarkable, and it took the discoverer's experienced eye to detect its presence among the exposed roots of an old rotting coconut stump. We each caught two, all in daylight, and all near the East face of the Rock, but saw no others.

Invertebrates:

Of the land invertebrates of Clipperton, the great majority were found together in the coconut groves, especially in the small grove at the base of the Rock. Ants, isopods, collembola, spiders, geophilids, earwigs and even small land snails occurred together in the base of coconut fronds, inside damp, rotting husks of old coconuts and in the surface soil. In the old coconuts, a scolopendrid was common and earthworms were extremely numerous in the surface soil and in coconut husks. Flies were common, particularly since dead pigs were lying in the grove. Cockroaches were running through the ruins of the American weather station. Arundel in his diary for 1897 already had mentioned these insects that must have been brought accidentally to the island by man, as have many of the other land invertebrates. On the northwest side of the island, most of the same invertebrates were also found together under boulders or in soil under vegetation. The two land snails (Opeas sp. and Succinea sp.) often occurred together, live specimens and many empty shells lying on top of the ground, under the layer of coral branches. On the plants, a coccinellid, some grasshoppers, ants and spiders were found, but the invertebrates most obviously affecting the plants were the moths. One small brown moth was very abundant on Cenchrus plants. Larvae of Prodenia sunia (det. H. W. Capps) were eating Corchorus and Sida leaves, those of the tomato hawk (Protoparce sp.) were abundant on Solanum. Most conspicuous was the beautiful large morning-glory hawk moth (Herse cingulata, det. C.F. Harbison), brown with pink wings, hovering in large numbers over the Ipomoea and drinking out of the flowers through its long proboscis. The full grown caterpillars are very large, bright green with brown triangular markings on the sides. After I left Clipperton, they became more numerous and according to Hambly (personal communication) devoured all the leaves and flowers of the morning glory. The cicindelids were extremely abundant along the low lagoon shore, and the damsel flies in the sedge beds.

Among the insects, only the cicindelids, some flies and agrionid dragon flies had been mentioned earlier (Snodgrass and Heller, 1902). In addition bird lice, an earwig and an extremely abundant Machilis had been collected. Early zoological collections, to be sure, were all gathered in a few hours, and some insects may have been missed, but at the same time, it is likely that many insects and other land invertebrates were unable to establish themselves when there was no vegetation on the island, and consequently that the fauna has become larger only recently, in part from accidental introductions by man. Conversely it is curious that some species seem to have disappeared: Machilis mutica (Banks 1901) was extremely abundant in 1898 under the coral pieces scattered on the surface on the island according to Dr. Snodgrass' field notes (personal communication) but has not been collected since.

Two Crustaceans were especially noticeable on Clipperton in 1958. One was the isopod (Cirolana sp.) extremely abundant in the lagoon or at least in its shallow zones near the shores. They were apparently scavenging among the abundant plant material floating in the lagoon, and attached themselves in numbers to legs and bodies, their numerous little bites making it very unpleasant to wade or swim in the lagoon. Here again a species collected in 1898 (Tanais stanfordi) has not been found since.

The red-orange Clipperton land crabs (Gecarcinus planatus) were common in 1958, but infinitely less numerous than in the past, when they covered the land in millions. Their reduction in number was first noted in 1938 by Dr. Waldo Schmitt. In 1958, they lived in holes in the ground, under the vegetation cover, the holes often opening under pieces of coral. They also inhabited what appeared to be natural cracks and holes under the edge of the ledges of consolidated phosphate rock. During the heat of the day, they were mostly hidden, although some could be seen peering from under the ledges if their overhang gave a little shade. In the late afternoon, or during cool, cloudy periods, they would come out, and scramble down lagoon cliffs and over beach ridges apparently on their way to the water. Some were definitely seen dropping into the lagoon waters.

Some shore crabs venture on the land strip and are sometimes found on the lagoon shores. Several species of hermit crabs occur in reef habitats, but the absence of land hermit crabs on Clipperton is striking; yet one or more species are abundant on the majority of other atolls.

Other invertebrates that had not been found before the 1958 survey of Clipperton were the earthworms. Numerous specimens, of rather small size, were found in the dark brown surface soil in the coconut grove at the base of the rock. They also occurred in the damp husks of old coconuts. Elsewhere on the land strip, they could be found under boulders among the vegetation, or, immediately after a rain, on the surface of bare wet sand. According to Dr. G. E. Gates, they represent at least two species (cf. p. 94).

Ecological history

Reconstructing the history of the flora and fauna of Clipperton in detail is of course not feasible, but some changes and interrelations are revealed by an examination of the literature and of the present condition of the island. A chain of ecological cause and effect can thus be tentatively reconstructed. This was discussed in some detail in a paper presented in the Symposium on Modification of biotic balance of island faunas and floras at the Tenth Pacific Science Congress (Honolulu, August 1961) and will be published in the Proceedings of the Symposium. Only the highlights will be given here.

When the island was first described there was some vegetation on it, but in 1858 the vegetation had disappeared, and land crabs were extremely abundant. This condition persisted until 1917 at least. At present, the island has a low, but almost continuous plant cover, and the crabs are much less numerous. Another noticeable change is the fact that the lizards, formerly almost confined to the Rock, are now rare on it, but very numerous in the vegetated area. I believe these phenomena are linked, and can be tentatively explained with the data available. The vegetation disappeared between 1839 and 1858, in the same period when the passes observed by Belcher did. Perhaps the same violent storm that blocked the passes flooded much of the land strip and destroyed most of the vegetation. The land crabs may have eaten the rest, and thereafter devoured every plant that managed to establish itself on the island, meanwhile increasing in number. The large bird colonies may also have helped keep the vegetation from reappearing. The land strip, devoid of vegetation and overrun with red crabs, was not a very suitable habitat for lizards, and they became instead more abundant in the passages and cavities of the Rock. What happened to reverse the process was probably the intervention of man, directly, or more likely indirectly. The guano diggers no doubt destroyed quantities of crab holes, killed many crabs, and at the same time, introduced more plants, for their gardens or by accident, thus already changing the balance somewhat. The multiplication of their pigs, however, which went wild after 1914 is probably the important factor. The pigs had little to eat except crabs, when they were first brought to the island, and must have killed quantities of them. In 1958, some of their droppings were entirely made up of crab shells, and it seems very likely that the immense numbers of crabs, which gave the island a red color according to some old reports, disappeared in this way. The plants developing from various seed sources, including the added source of human introduction, slowly became too numerous for the remaining crabs and few pigs to keep in check, and the vegetation cover of the island reestablished itself. Meanwhile, the pigs were also feeding on birds' eggs, frightening the nesting birds and apparently bringing about a decrease in the number of seabirds living on the island. The guano diggers must have initiated and helped the process by scraping phosphate rock among bird rookeries, slaughtering birds and taking quantities of eggs. In 1958, the pigs were killed so the birds could make a come-back. Whether this aim will be achieved, or other consequences result, cannot be predicted. It will be interesting to watch the experiment. Quite possibly, the ecological situation had reached a certain stable point, and could have persisted as it was, except for catastrophic changes such as storms. There is no assurance that the bird population will increase, in the absence of the pigs, and other changes may take place instead.

A really complete description of the land ecology of Clipperton, obviously, should include a study of biotic communities, or biocoenoses. In the present state of our knowledge, however, this is not feasible. Too little time was spent on the atoll, and, while the vegetation was studied in some detail, even those animals which could be observed in their association with plants and substratum are mostly not identified, and details of their biology, which presumably were recorded and will be published by the zoologists, are not available.

Similarly, a treatment of the biogeography has had to be omitted. The main purpose of the 1958 collections was to make possible a study of the biogeography of the Clipperton floras and faunas. Earlier papers (e.g. Dawson 1957, Hertlein and Emerson 1953) had called attention to the fact that the marine floras and faunas exhibited an interesting duality of origin: in part Western American (Panamic forms), in part Indo-Pacific. Some notes on the floras are given in my paper on Clipperton Botany (Sachet, 1962), but the land flora (cf. p. 76) failed to be very indicative. The land fauna will probably turn out to be similarly rather disappointing when all the identifications are completed, because many species are probably of human introduction. The first papers to be published on the marine forms collected in 1958 (Allison 1959, Hertlein and Allison 1960a, 1960b) indicate that the duality of origin of the Clipperton fauna is a reality. When all the identifications are available, a general biogeographical description can be written and will undoubtedly be of great interest.

CATALOGUE OF LAND AND LAGOON PLANTS AND ANIMALS

Listed below are systematic enumerations of plants and animals known from Clipperton. Only the land and lagoon species are given here, but a similar catalogue for marine forms will be added elsewhere (Sachet in press.) The list of plants is taken from my paper on Clipperton botany (Sachet 1962) and based on my own collections as well as lists of algae given by Dawson (1957, 1959) and W. R. Taylor (1939). In the case of the animals, it must be pointed out that the collections made prior to 1958 were very small, and that those of 1958 have not yet been reported upon or even completely studied. A few animals collected by myself are included in the list along with the names of the zoologists who identified them. So as to give an indication, at least, of the nature and size of the land fauna, I asked the specialists working on it to give me some preliminary data on the groups under study, and they have kindly done so. Lists of orders, families or species in various groups were provided by Messrs. E. C. Allison (mollusks, ostracods); Wayne Baldwin (fish); T. E. Bowman (isopods); J. S. Garth (crabs); C. F. Harbison (insects and other invertebrates) and David Peterson (rodent). I wish to express to them, and to others with whom I have discussed the Clipperton biota, my most sincere appreciation. Messrs. Allison and Harbison have been especially patient and gracious in answering my numerous queries. Their papers, as well as other systematic treatments of the 1958 collections, are eagerly awaited.

PLANTS

Fungi

Myxomycetes

Dictydiaethalium plumbeum (Schw.) Rost.

Phycomycetes

Cunninghamellaceae
- *Cunninghamella echinulata* (Matruchot) Thaxter
- *Cunninghamella elegans* Lendner

Mucoraceae
- *Absidia scabra* Cocc.
- *Rhizopus arrhizus* Fischer

Piptocephalidaceae
- *Syncephalastrum racemosum* (Cohn) Schroet.

Ascomycetes

Eurotiaceae
- *Eurotium chevalieri* Mangin
- *Sartorya fumigata* Vuill.

Basidiomycetes

Telephoraceae

Corticium lactescens Berk.

Agaricaceae

Fungi Imperfecti

Dematiaceae

Haplographium sp.?

Moniliaceae

Aspergillus flavus Link
Aspergillus flavus-oryzae group
Aspergillus fumigatus Fres.
Aspergillus micro-virido-citrinus Cost. & Lucet
Aspergillus niger series
Aspergillus phoenicis (Cda.) Thom
Aspergillus sydowi (Bain. & Sart.) Thom & Church
Aspergillus sydowi or *versicolor* (intermediate form)
Aspergillus terreus Thom
Aspergillus terreus new var.?
Aspergillus versicolor (Vuill.) Tiraboschi
Aspergillus violaceo-fuscus Gasp.
Geotrichum sp.
Hyalopus sp.
Paecilomyces sp.
Penicillium chrysogenum Thom
Penicillium citrinum Thom
Penicillium commune Thom
Penicillium cyclopium Westl.
Penicillium funiculosum Thom
Penicillium funiculosum series
Penicillium lanosum Westl.
Penicillium meleagrinum Biourge
Penicillium oxalicum Currie & Thom.
Penicillium (near *P. piscarium* Westl.)
Penicillium sp.
Trichoderma viride Pers. ex Fr.

Tuberculariaceae

Fusarium sp.

Lichenes

Pyrenocarp lichen

Buelliaceae

Rinodina sp.

Physciaceae

Pyxine sp.

Algae

Myxophyceae

Chroococcaceae

Anacystis aeruginosa (Zanard.) Dr. & Daily
Anacystis montana (Light f.) Dr. & Daily
Chroococcus turgidus (Kützing) Nägeli
Gomphosphaeria aponina Kützing
Microcystis flos-aquae (Wittrock) Kirchner

Chamaesiphonaceae

Entophysalis deusta (Menegh.) Dr. & Daily
Entophysalis granulosa Kützing

Stigonemataceae

Mastigocoleus testarum Lagerh.

Nostocaceae

Nostoc sp.

Scytonemataceae

Scytonema hofmannii Ag.

Rivulariaceae

Amphithrix violacea (Kütz.) Born
Calothrix crustacea Thur.
Calothrix parietina (Naeg.) Thuret
Calothrix stellaris Bornet & Flahaut

Oscillatoriaceae

Lyngbya aestuarii (Mertens) Liebmann
Lyngbya semiplena (Ag.) J. Ag.
Lyngbya confervoides Ag.
Lyngbya guaymasensis Drouet
Lyngbya lagerheimii (Möbius) Grunow
Lyngbya versicolor (Wartmann) Gomont
Microcoleus chthonoplastes (Fl. Dan.) Thur.
Plectonema nostocorum Born.
Plectonema terebrans Born. & Flah.
Schizothrix heufleri Grun.

Chlorophyceae

Desmidiaceae

Closterium parvulum Nägeli
Closterium parvulum Nägeli forma
Closterium parvulum near var. majus West
Cosmarium clippertonensis Taylor
Cosmarium subprotumidum Nordstedt, forma

Oocystaceae

Oöcystis solitaria Wittrock approaching forma major Wille

Oedogoniaceae
Oedogonium sp.
Oedogonium sp.

Sphaerellaceae
Protococcus grevillei (Ag.) Crouan

Characeae
Chara sp.

Pyrrophyceae

Peridiniaceae
Glenodinium sp.

Bryophyta

Musci (Mosses)

Bryaceae
Bryum sp.
Bryum argenteum Hedw. var. *lanatum* (Palisot de Beauv.) BSG.

Leucobryaceae
Octoblepharum albidum Hedw.

Spermatophyta

Potamogetonaceae
Potamogeton pectinatus L.
Ruppia maritima L.
Zostera marina var. *latifolia* Morong?

Najadaceae
Najas marina L. var. *latifolia* A. Br.

Gramineae
Cenchrus echinatus L. (glabrous form)
Dactyloctenium aegyptium (L.) Willd.
Eragrostis amabilis (L.) W. & A.
Eragrostis ciliaris (L.) R. Br.

Cyperaceae
Eleocharis geniculata (L.) R. & S.
Eleocharis mutata (L.) R. & S.
Hemicarpha micrantha (Vahl) Pax
Scirpus rubiginosus Beetle

Palmae
Cocos nucifera L.

Portulacaceae
  Portulaca oleracea L.

Cruciferae
  Brassica juncea L.

Leguminoseae
  Caesalpinia sp.
  Canavalia sp.
  Mucuna sloanei Fawc. & Rend.?
  Phaseolus adenanthus Mey.?

Euphorbiaceae
  Phyllanthus amarus Sch. & Thonn.

Sapindaceae
  Sapindus saponaria L.?

Malvaceae
  Sida rhombifolia L.

Tiliaceae
  Corchorus aestuans L.

Sterculiaceae
  Waltheria indica L.

Convolvulaceae
  Ipomoea pes-caprae subsp. *brasiliensis* (L.) v. Ooststrom
  Ipomoea triloba L.

Solanaceae
  Nicotiana glauca Graham
  Solanum nigrum L. var. *americanum* (Mill.) O. E. Sch.

Boraginaceae
  Heliotropium curassavicum L.

Compositae
  Conyza bonariensis (L.) Cronq.
  Eclipta alba (L.) Hassk.

Drift seeds

Palmae
  Astrocaryum sp.
  Several unidentified endocarps from cocoid palms

Leguminosae
  Caesalpinia bonduc (L.) Roxb.
  Caesalpinia major (Medic) Dandy & Excell
  Canavalia rosea (Sw.) DC.
  Dioclea megacarpa Rolfe?

Leguminosae (con't)
- Dioclea reflexa Hook.?
- Entada gigas (L.) Fawc. & Rendle
- Mucuna mutisiana (HBK) DC.?
- Mucuna sloanei Fawc. & Rendle
- Mucuna urens (L.) DC.?
- Strongylodon lucidus (Forst.f.) Seem.?

Sapindaceae
- Sapindus saponaria L.

Convolvulaceae
- Merremia tuberosa (L.) Rendle

ANIMALS

This list is compiled mostly from the literature, but includes some unpublished records. References or other sources of information are given in parentheses for each species or any higher group to which they apply. When several papers list the same species, usually only the most recent one is mentioned. The species or groups recorded from Clipperton for the first time as a result of the 1958 survey are marked with an asterisk.

Annelida

*Oligochaeta
(Earthworms, det. Dr. G. E. Gates, cf. p. 86)

Megascolecidae
- Dichogaster bolaui (Michaelsen)
- Pontodrilus bermudensis Bedd.?--(specimens poorly preserved).

Mollusca

Gastropoda
(Bartsch and Rehder 1939, Hertlein and Emerson 1953)

Aspidobranchia

Neritidae
- Nerita plicata L.--just above high tide

Pectinibranchia

Littorinidae
- Littorina schmitti Bartsch and Rehder--just above Nerita level

Pulmonata

Subulinidae

Opeas oparanum Pfeiff.--common on ground

*Succineidae

Succinea sp. --common on ground (det. E.C. Allison).

Arthropoda

Crustacea

Ostracoda

*3 species found in lagoon in 1958

Malacostraca

Tanaidacea

Tanaidae

Tanais stanfordi H. Richardson--lagoon (Richardson 1901, not found again in 1958).

Isopoda

Flabellifera

*Cirolanidae

Cirolana sp. --lagoon (det. Thomas E. Bowman).

Oniscoidea

Ligiidae

Ligia exotica (Roux)--splash zone (Richardson 1901).

*Terrestrial isopods of several species collected in 1958.

Amphipoda

Talitridae

Orchestia marquesana Stephensen--old bird nest (Shoemaker 1942).

Decapoda

Brachyura

Grapsidae

Geograpsus lividus (M.-E.)--lagoon (Rathbun 1902).
Pachygrapsus minutus (M.-E.)--shore (Schmitt 1939).

Gecarcinidae

Gecarcinus planatus Stimpson--land (Schmitt 1939).
Gecarcoidea lalandei (M.-E.)--in guano from Clipperton (Lenz 1901).

Caridea

Palaemonidae

Palaemon (*Palaemon*) *gladiator* Holthuis--lagoon (Rathbun 1902, Holthuis 1952, not found again in 1958).

Arachnida

*Araneida

Argiopidae

Araneinae

Tetragnathinae

Tetragnatha sp. --(det. R.E. Crabill, Jr.)

Pholcidae

1 species

Saltícidae (Attidae)

Acarina--old booby nest (Wharton 1941)

Mesostigmata

Parasitoidea

Ascaidae

Asca quinquesetosa Wharton

Laelaptidae

Atricholaelaps clippertonensis Wharton

Eulaelaps roosevelti Wharton

**Cosmolaelaps* sp.--(det. E.W. Baker).

*1 new species of Parasitoidea obtained in 1958

Uropodoidea

Uropodidae

Uropoda spp.

**Fuscuropoda* sp.--(det. E.W. Baker).

*Sarcoptiformes

Analgesidae

Proctophyllodidae

3 species, one new.

Oribatei

Oribatulidae

Scheloribates fimbriatus calcaratus Jacot

Scheloribates indica Oudemans

Chilopoda

(Chamberlin 1914, 1924)

Geophilomorphia

Mecistocephalidae

Mecistocephalus parvus Chamberlin

Scolopendromorpha

Cryptopidae
Cryptops navigans Chamberlin

*Scolopendridae
Rhysida sp. --(det. R.E. Crabill, Jr.).

Insecta

Thysanura

Machilidae
Machilis mutica Banks--abundant on land (Banks 1901, not found in 1958).

*Collembola

Entomobryidae
2 species obtained in 1958

Sminthuridae
1 species

Odonata

Coenagrionidae--(Snodgrass and Heller 1902 as "agrionid")
Ischnura ramburii ramburii (Selys)--(det. C.F. Harbison).

Blattaria

Blattidae--(cockroaches mentioned in Arundel's 1897 diary)
1 species taken in 1958.

*Orthoptera

Tettigoniidae
Conocephalinae
1 species taken in 1958

Dermaptera

Forficulidae
Anisolabis annulipes Lucas--(McNeill 1901).

*Hemiptera

Homoptera-Fulgoroidea
Areopodidae
1 species taken in 1958

Heteroptera

Pentatomidae

1 species

Lygaeidae

1 species

Nabidae

1 species

Gerridae

1 species

*Corrodentia

Perientomidae

1 species

Procidae

1 species

Mallophaga--from sea birds (Thompson 1938-39).

Menoponidae

Actornithophilus milleri (Kellogg and Kuwana)
Colpocephalum angulaticeps Piaget
Menopon incertum Kellogg
Menopon singularis Kellogg and Kuwana

Philopteridae

Anatoecus dentatus (Scopoli)
Columbicola columbae (L.)
Degeeriella birostris (Giebel)
Degeeriella gloriosa (Kellogg and Kuwana)
Degeeriella lepida (Kellogg and Kuwana)
Degeeriella obtusa (Kellogg and Kuwana)
Degeeriella separata (Kellogg and Kuwana)
Degeeriella vulgata (Kellogg)
Pectinopygus gracilicornis (Piaget)
Pectinopygus sulae (Rudow)
Saedmundssonia peristictus (Kellogg and Kuwana)
Saedmundssonia melanocephala (Nitzsch).

*Lepidoptera

Heterocera

Sphingidae

Herse cingulata Fabr.--(det. C.F. Harbison)
Protoparce sp.--(det. H.W. Capps).

Noctuidae

Prodenia sunia (Guinée)--(det. H.W. Capps).
7 species obtained in 1958

Pyralidae

2 species obtained in 1958

Diptera--(recorded as Diptera by Snodgrass and Heller 1902).

*Sciaridae
1 species obtained in 1958

*Dolichopodidae
1 species

*Phoridae
1 species

*Drosophilidae
1 species

*Tethinidae
1 species

*Milichiidae
Desmometopa sp.--(det. C.W. Sabrosky).
2 species taken in 1958

*Chloropidae
1 species

*Ephydridae
2 species

*Sphaeroceridae
1 species

*Muscidae
1 species

*Sarcophagidae
1 species

*Hippoboscidae
1 species

Coleoptera

Cicindelidae
Cicindela bifasciata [probably misspelling for trifasciata Fabr.]--(Van Dyke 1953).

*Staphylinidae
1 species

*Coccinellidae
Hippodamia convergens Guér.--(det. E.A. Chapin).

*Tenebrionidae
1 species collected in 1958

*Hymenoptera

Formicidae

Tetramorium simillimum (F.Sm.)--(det. M.R. Smith).
Triglyphothrix striatidens (Emery)-- " "
4 species taken in 1958

Chordata

Pisces

*Acanthuridae
1 species

*Pomacentridae
1 species

Gobiidae

Bathygobius arundelii (Garman)--lagoon (Ginsburg 1947).

Reptilia

Testudinata

Cheloniidae

Chelonia mydas L.--green turtle (Morrell 1832, not reported on island since).

Sauria

*Gekkonidae

Gehyra mutilata (Wiegmann)--(det. W.C. Brown).

Scincidae

Emoia cyanura arundeli (Garman)--(W.C. Brown 1954).

Aves

Procellariiformes

Procellariidae

Pterodroma spp.--petrels (several spp. recorded from vicinity of Clipperton, at sea, by Loomis 1918).
Puffinus auricularis Townsend--Townsend's shearwater (Am. Ornith. Union 1957).

Pelecaniformes

Phaetontidae

Phaëton spp.--tropic-birds (several spp. recorded from vicinity of Clipperton, at sea, by Gifford 1913).

Sulidae

Sula dactylatra californica Rothschild--masked booby, blue-faced booby (Am. Ornith. Union 1957).

Sula leucogaster nesiotes Heller and Snodgrass--brown booby (Wetmore 1939).

Sula variegata Tschudi--Peruvian booby (Beck 1907).

Fregatidae

Fregata minor Gmelin--great frigate (Snodgrass and Heller 1902, as *F. aquila*).

Ciconiiformes

Threskiornithidae

Plegadis ?--a black ibis sighted (Beck 1907).

Anseriformes

Anatidae--(Beck 1907, Am. Ornith. Union 1957).

Anas acuta L.--pintail

Anas discors discors L.--blue-winged teal

Aythya valisineria (Wilson)--canvasback

Mareca americana (Gmelin)--baldpate, American widgeon

Spatula clypeata (L.)--shoveller

Gruiformes

Rallidae

Fulica americana americana Gmelin--coot (Beck 1907)

Charadriiformes

Charadriidae

Squatarola squatarola (L.)--black-bellied plover (Beck 1907, Am. Ornith. Union 1957).

Scolopacidae

Heteroscelus incanus (Gmelin)--wandering tattler (Gifford 1913)

Numenius phaeopus hudsonicus Latham--Hudsonian curlew (Beck 1907).

Laridae--(Wetmore 1939)

Anous stolidus ridgwayi Anthony--common noddy

Anous minutus diamesus (Heller and Snodgrass)--white-capped noddy

Gygis alba candida (Gmelin)--fairy tern

Sterna fuscata crissalis (Lawrence)--sooty tern

Passeriformes

Hirundinidae

Hirundo rustica erythrogaster Boddaert--barn swallow (Heller and Snodgrass 1902)

Small land birds were recorded on Clipperton by Morrell (1832) and Taylor (1948). In 1958, some new records of land, shore and sea birds were made, 16 species in all according to Stager (1959).

Mammalia

Pinnipedia

Otariidae

Arctocephalus sp.--fur-seal (Morrell 1832, not reported since).

Phocidae

Mirounga sp.--sea elephant (Morrell 1832, not reported since).

Artiodactyla

Suidae

Sus scrofa L.--pig (introduced about 1897, destroyed in 1958).

*Rodentia

Muridae

Mus sp.--mouse (1 mouse seen in ruins of Weather station in 1958).

Primata

Hominidae

Homo sapiens L.--occasional visitors.

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