ISLANDS

H. W. MENARD

ISLANDS

H. W. Menard

SCIENTIFIC
AMERICAN
LIBRARY

An imprint of Scientific American Books, Inc.
New York

This book is number 17 of a series.

Library of Congress Cataloging-in-Publication Data

Menard, Henry W. (Henry William), 1920–86
Islands.

Bibliography: p.
Includes index.
1. Islands. 2. Island ecology. I. Title.
GB471.M46 1986 551.4'2 86-6573
ISBN 0-7167-5017-1

Printed in the United States of America

Book design by Malcolm Grear Designers

Scientific American Library
An imprint of Scientific American Books, Inc.
New York

Distributed by W. H. Freeman and Company,
41 Madison Avenue, New York, New York 10010
and 20 Beaumont Street, Oxford, OX1 2NQ, England.

2 3 4 5 6 7 8 9 0 KP 5 4 3 2 1 0 8 9 8 7

1 *Finding Islands*

Charles Darwin was one of the first scientists to learn the advantages of investigating oceanic islands. The scientific method in the laboratory is to isolate a sample of known properties and then observe the effects of systematic changes in pressure, temperature, or some other variable. Nature rarely conducts her experiments under such controlled conditions, but for some studies islands provide her closest approximation to a laboratory. Oceanic islands are small, young, isolated, simple, and subjected to a limited range of environmental factors. Thus, in nature's young, isolated laboratory of the Galapagos Islands, Darwin found the glimmerings of biological evolution. Likewise, the simplicity of several widely separated islands helped him to realize that their differences were largely a consequence of a single geological factor—subsidence.

Consider the continents. They are aggregates of every type of rock produced for billions of years, and most of their history is obscure. Their rocks have been deformed repeatedly, fractured, and warped up and down. They have been eroded and weathered by every type of changing climate, and older rocks are partially buried by thick sedimentary rock derived from them. The whole is obscured by every type of soil and by plants. Across the continents migrate animals and plants in constant flux. One can have little reason to hope that nature has conducted many controlled experiments on the continents. Consider the arsenic that modern chemistry has identified in Napoleon's hair. If he had died in Paris, his poisoners might have been anyone and their motives unknown. However, he died on St. Helena, a small, isolated, volcanic island in the South Atlantic, and all his food came from his British gaolers or his few friends.

The intersection of Polynesian and European cultures painted by William Hodges, who was with Captain Cook at Tahiti.

Maiao Island in the Society Island group—an isolated peak in a vast sea.

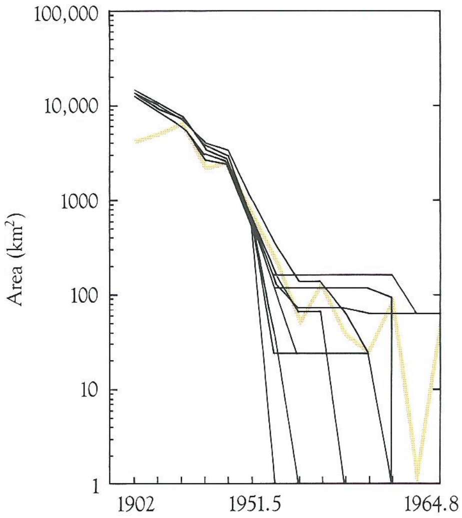
Some islands are merely continents in miniature, and they are difficult to understand for the same reasons. Among these are all the islands rising from the shallow waters of the continental shelf, islands such as Ireland and Newfoundland. Likewise, more isolated Japan, New Zealand, and many other islands have all the geologic characteristics of continents except size. Even the tiny Seychelles Islands in the Indian Ocean must be excluded from our story despite their tropic beaches and coconut palms. They are composed of a granite 700 million years old—both the type and the age of the rocks show that the Seychelles are a tiny fragment of drifting continent.

The remaining oceanic islands and their submarine counterparts, seamounts, are remarkably similar. They arise in deep water on normal oceanic crust. All of the thousands of islands, about 20,000 larger seamounts, and countless smaller ones grew as volcanoes composed of rocks of very similar types—at least to the nonspecialist. All have come into existence during the last few percent of the history of the earth. The older ones that grew high enough to become islands have now sunk beneath the waves. The only major variable affecting the present appearance of such islands is that some of them have been in tropic waters and remained there, so they are now capped with coral reefs in the form of atolls. With such a large and uniform population of islands, it is relatively easy to isolate the effects of single variables in nature's experiments. One can compare erosion in the belt of the trade winds with erosion by polar ice. Likewise, one can compare the number of species that can drift across an oceanic gap of 100 miles with the number that can cross 1000 miles.

THE PROBLEM OF DISCOVERY

The plant and animal life of small isolated islands, like their geology, has intrigued scientists since it was first discovered. How could insect species typical of North America and Asia have reached the Hawaiian Islands? How could an odd creature like the dodo come to be on only one island in the world? Darwin studied the different finches on individual islands in the Galapagos, and Alfred Wallace studied the life of islands in general; between them they produced the theory of biological evolution. No theory ever generated more controversy, but, in more modest ways, almost all ideas about island life have been controversial.

How did plants and animals find and populate oceanic islands? The range of ideas on the subject is remarkable. At one extreme is the idea that most of the biota of islands consists of waifs who drifted there on air or water. At the other extreme is the idea that the islands are peaks of former continents, on which animals walked dry-shod carrying seeds with them. Moreover, it is not just the nonhuman discovery of islands that is controversial. Anthropologists have waxed hot about the Polynesian discovery and occupation of the islands of the central Pacific. It is well to remember that almost every island was successively found and populated by plants, animals, non-Europeans, and Europeans. As in most matters, the less information available, and the narrower the focus, the greater the range of speculation about causes of phenomena. Consequently it seems reasonable to consider what we know least about—the migrations of plants and animals—only after an analysis of the migration of humans. Likewise, it seems only reasonable to consider how Europeans found islands before thinking about how Polynesians did it. It might seem that we need go no further than the history of European voyages to understand how islands are discovered, but, regrettably, even that history is flawed. Imaginative scholarship has worked out when each Pacific island was found by Europeans. (That is the sort of date that appears in history books, the recorded date of the last discovery by any species.) However, data are scanty about the total number of voyages, the efficiency of the discovery effort, and much else that would be useful for generalizations about discovery by other cultures and species. Thus, to obtain an adequate data set, we must go farther afield.



Comparison of the actual history of exploration for oil in the United States with ten random searches by a computer. The actual rate of discovery per unit effort was no better than a random search. Horizontal units are not equal time periods, but periods of equal exploratory drilling effort. A few times are indicated.

Exploration for Oil

Oceanic islands are small objects that generally occur in clusters separated by vast empty spaces. So are oil fields, and the history of discovery of oil fields is known in great detail, especially in the United States, because of legal requirements for disclosure. The significance of that history was first understood by M. King Hubbert, who developed a measure of effort for oil exploration—the total length of holes drilled with the objective of seeking new oil fields. (Holes that merely expanded known oil fields did not count.) He could estimate the volume of oil discovered each year and compare it with the drilling data. All the oil ultimately found in a field he credited to the year that the field was discovered. Hubbert found that the discoveries per unit effort had declined exponentially with time for more than 80 years. Assuming that history would repeat itself, he could determine the volume of undiscovered oil by simple extrapolation, and in 1967 he predicted a calamitous drop in oil discoveries in the United States. That prediction, properly interpreted, was correct.

In 1975, George Sharman and I applied Hubbert's basic idea to the same problem, namely, how much oil remains to be discovered in the forty-eight contiguous United States, but our analysis can be extended to discovery in general.

We assumed that the chance of discovering an oil field by purely random drilling was simply the area of the oil field divided by the area being explored. For example, the total area of all known giant fields was 23,455 km^2 and the area of sedimentary basins being explored was 4,700,000 km^2. Therefore the chance of hitting a giant field with one hole was about 1/200. If most of the oil were in the biggest fields, purely random drilling would discover those fields first. Moreover, the probability of discovering a given area of oil field per unit effort would decline exponentially with time. Considering that, in fact, practically all the oil discovered in the forty-eight states was in giant fields and that the discoveries per unit effort had declined exponentially with time, it was apparent that the history of oil exploration could be modeled by Monte Carlo simulation of random drilling.

We programmed a computer to sample randomly the whole area of the contiguous states including all known oil fields. At the end of each unit of "drilling," (10^8 feet, or 20,000 holes about a mile deep) we determined which fields had been "discovered." In this simple way, we made ten Monte Carlo simulations of the discovery of oil as it would have occurred by random drilling at the historic rate. When the actual history of discovery was plotted in comparison, it lay within the envelope of simulated histories. In brief, the exploration for oil had been no more successful than random drilling.

The computer was searching for *area* of oil fields, which is not exactly related to the volume of oil in fields. In fact, the simulated search did much better than industry in finding some types of fields—those with large area. The largest field by area or volume in the contiguous states is the East Texas field, which was discovered by industry in 1930. In nine of ten simulations, the computer found the field before that time. (Moreover, that giant field was not actually found by the geologists of organized oil companies but by a small-time wildcatter who was drilling on a hunch.) This could have been predicted without Monte Carlo modeling. The area of the field (f) is 567 km^2; the area to be explored (A) is 4,700,000 km^2; if the number (n) of holes drilled is 20,000, the probability of finding the field is

$$1 - \left(1 - \frac{f}{A}\right)^n = 0.91$$

by drilling at random. In fact, industry had already drilled 300,000 exploratory holes when the East Texas field was found. The probability of *not* finding the field with that number of random tries is 2×10^{-16}. The cause for this bad luck is not wholly understood, but it seems clear that, in organized exploration by Western civilization, doing as well as pure chance may be something of an achievement.

Some leaders in the oil industry were hardly surprised, although they had not had a quantitative evaluation of efficiency before. They already knew from their own unpublished analyses that they would have done better by drilling on a grid or even at random in some unexplored provinces. It is evident that geologists and geophysicists can identify the kinds of rocks and structures in which oil may accumulate, and they are efficient at finding small oil fields in known oil provinces—which are equivalent to island clusters. Apparently, the lack of efficiency in finding giant fields derives from an institutional persistence in drilling for oil in one of the possible types of oil-bearing structures when in fact the oil in a province is in another type. Thus, having found oil in anticlines, industry might drill one anticline after another in a province where the oil is in ancient coral reefs. It is rather like generals refighting the last war. Meanwhile, the naive computer is just as apt to drill the first exploratory hole in a reef as in an anticline.

The correspondence between the model of random drilling and the actual history of oil exploration seems to justify some general conclusions regarding exploration for oil fields or islands:

1. The largest objects tend to be discovered first.
2. There is an exponential decline in the probability of finding an object of a given size with a unit effort of searching.
3. Once the first object in a cluster has been discovered, the remainder are easier to find.
4. The ideas of explorers can greatly affect their chances of success.

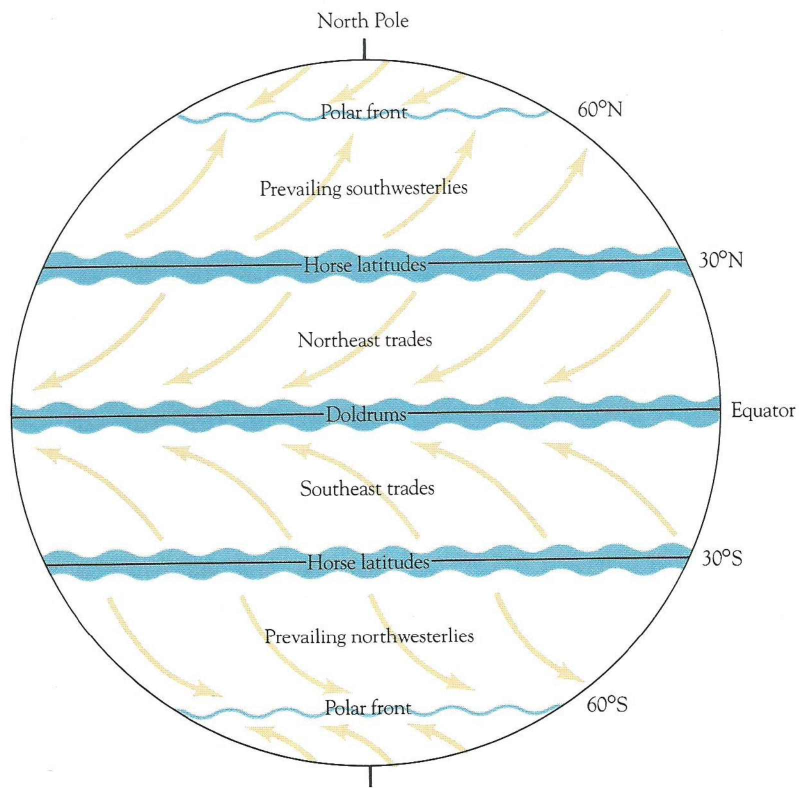
EUROPEAN DISCOVERIES

As far as explorers are concerned, islands differ in one fundamental way from oil fields—they are capable of killing the unwary. Thus, the attitudes of sailors regarding uncharted waters are always mixed. In the late nineteenth century, navigational charts were full of chimerical islands because every possible hazard to navigation, however questionable the information suggesting its existence, went on the charts. As late as the 1960s, charts of the South Pacific were full of the notations "P.D." for "position doubtful" and "E.D." for "existence doubtful," regarding rocks and shoals. The only prudent course for a captain was to avoid the site of any possible hazard. So it has always been, except for those few surveying and oceanographic ships whose job it is to deliberately seek and survey such hazards or disprove their existence. It took Western civilization about 1500 years to discover all the oceanic islands, and it appears that Captain Cook and his lieutenants were almost the only people in all that time who took their surveying job very seriously.

The probability that an island will be found by sailors depends on its size, its distance from a home port, the number of voyages from the port, the freedom of action and spirit of adventure of captains, the likelihood of ships' being driven long distances by storms, and so on. All in all, it is not surprising that the largest oceanic volcano, Iceland, was the first to be discovered, in the fourth century A.D., by the Norsemen, who lived not far to the east. They colonized the island by the ninth century and roamed the northern seas—which contain few oceanic islands.

The next phase of discovery was in the fourteenth and fifteenth centuries, when Portuguese, Spanish, and other European explorers began to seek a sea route to the spice and silk of the East. Just as Columbus accidentally found the vast area of the Americas, so others sighted tiny oceanic islands or ran aground on them. In 1420 the Portuguese Zarco discovered the Madeira islands, for the last time, when storms drove him west from his exploration of the coast of Africa. A Genoese map of 1351 shows that contact had been made before—the islands are only 670 km west of Africa

Global wind patterns that determine sailing courses and migration paths.



and the Straits of Gibraltar. The Azores, even farther west, were already known to the Carthaginians, who left coins, and Arabian geographers. They were discovered for the last time in 1432, when Van der Berg was driven on the islands by a storm. Although the Azores are in three widely separated groups, all nine islands were found and some even colonized by the Portuguese within twenty-five years. We may generalize that, like oil fields, once one of a cluster of high islands is found, the rest will be discovered quickly if there is any desire to do so. Among other reasons, each high island is commonly visible from the peaks of another in the cluster.

As the Europeans sailed farther south, further discoveries were made apparently for the first as well as the last time by man. These included the cluster of the Cape Verdes in 1456; the tiny, isolated, midocean islands of Ascension, in 1501, and St. Helena, in 1502. Clearly, the explorers were tacking far into the Atlantic to follow the latitudinally zoned winds. The Portuguese reached oceanic islands in the Indian Ocean soon after: Mauri-

The cliffs of ironbound St. Helena.

tius in 1505, and Reunion in 1513. All of the islands discovered to this time had several features in common. They were high volcanoes, active or dead, uninhabited, and wholly lacking gold, diamonds, or anything else offering quick profit. Some were ironbound by great cliffs but even these had a few protected anchorages and fresh water, so the islands had some use. Moreover, being high, they were visible from great distances and thus hardly hazardous to navigation.

So when Magellan entered the Pacific, in 1520, he had some knowledge of oceanic islands. We may pause to consider what else he knew and his situation. He knew about the trade winds. After beating his way through the straits that bear his name it could hardly have escaped his attention that he was in the wrong latitude to sail west. Not to mention that the known riches of the East were in the Northern Hemisphere. His ship was marginal for the voyage and his supplies were already low. Considering all these factors, his only logical course was to sail northwestward until he reached the tropics and the gentle, persistent easterlies of the trade winds. This he did.

The state of the science of navigation in Magellan's time enabled him to determine latitude at sea, but not longitude. Indeed, in those days before surveying by triangulation, no one knew longitude very well on land, either. The course being steered and speed made good through the water could be measured, but wind and sea drift were always uncertain, and often hopelessly so after a series of storms. As a consequence, the longitudinal positions of ships not infrequently were in error by hundreds of kilometers and occasionally by more than two thousand kilometers. Not until Captain Cook's time, in the late eighteenth century, were nautical chronometers accurate enough to permit determinations of longitude. Even two centuries after Cook, positioning errors of 15 km to 30 km were common in celestial navigation. Not until the invention of electronic and artificial satellite navigation in the 1960s and 1970s did a ship at last know where it was most of the time. Then, naturally, almost everything that had been discovered had to be relocated.

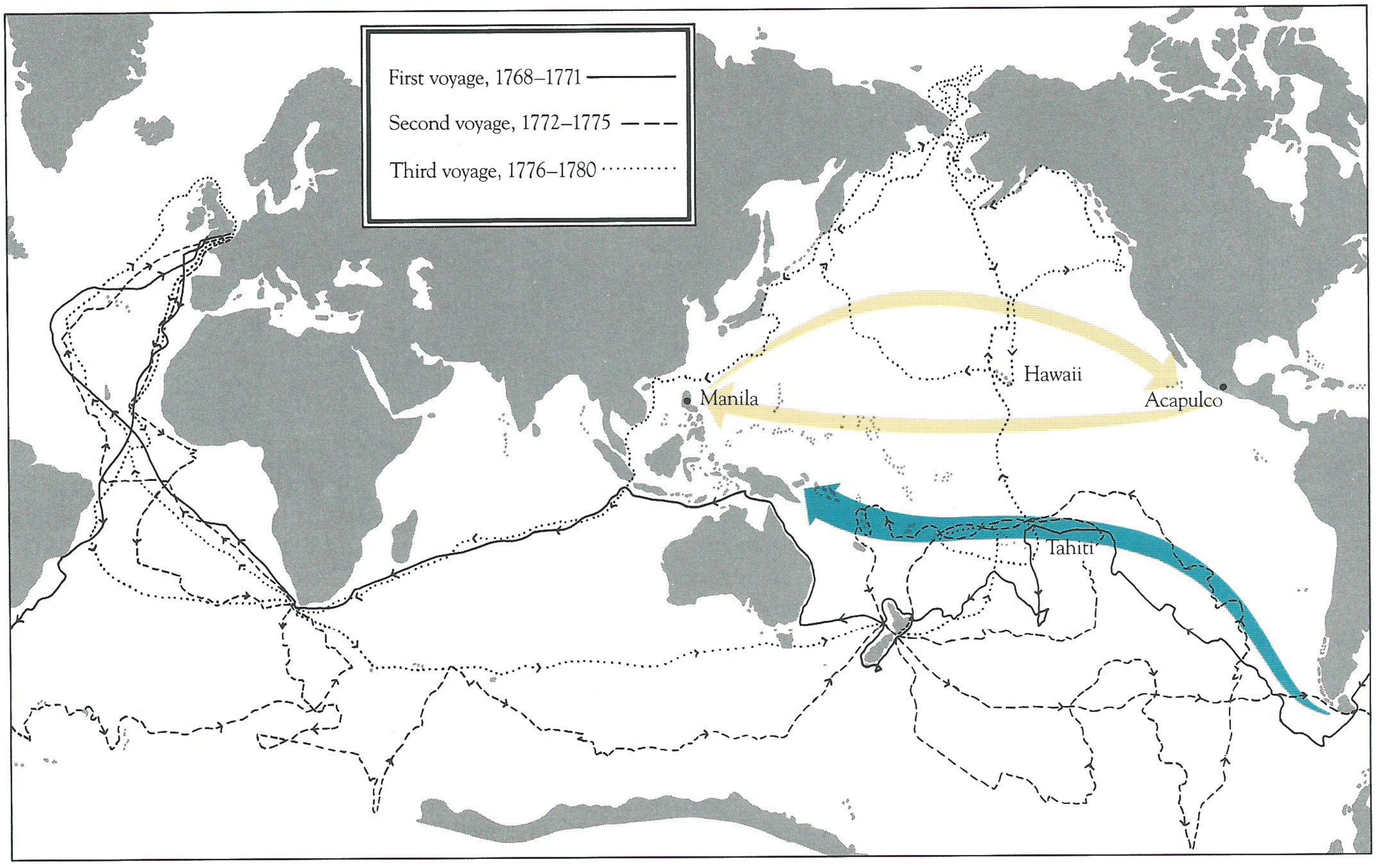
Explorers of the Pacific

Magellan made the first European discovery of a Pacific island on 24 January, 1521, but we do not know which one, for lack of a longitude. From its latitude and its description as a low island fringed with trees, we know it was an atoll in the northern Tuamotus, but whether Fangahina, Angatau, or Pukapuka is uncertain. (This ingenious method of identifying island discoveries by combining latitude and island description was developed by Andrew Sharp, and his chronology is used here.) Magellan saw no sign of inhabitants and could not anchor on the steep coral bottom, so he sailed on. He had found a small, low, surf-bound, valueless hazard to navigation. The last oceanic island in the main Pacific basin, the 267th, was discovered in 1859 by Captain N. C. Brooks of the Hawaiian barque *Gambia,* and for some time the uninhabited island took the name of the ship. Then it was renamed and in due course gave its new name to the most famous naval engagement of World War II, the Battle of Midway.

The whole period of discovery lasted 338 years. If we divide it into 50-year intervals, it is evident that there were two major phases of discovery. The first began with 32 discoveries before 1550 and tapered off to the interval 1651–1700, when only three islands were discovered. The second and greater phase began with 12 discoveries in 1701–1750 and peaked at 113 in 1751–1800. Two-thirds of all the islands were discovered in the century beginning with 1751. The variations in discovery rate were due to improvements in ships and navigation, concern with hazards, variations in the frequency of voyages, and changes in the motivation for voyaging. Of these the last apparently was dominant.

Rebotel Reef, in the Palau Islands, is the kind of navigational hazard that Pacific explorers avoided for centuries.

It appears that voyagers from 1521 to 1700 viewed Pacific atolls and volcanoes with more fear than hope. The famous explorers Quiros, Mendaña, Schouten, and Le Maire all followed routes of easy sailing, west on the southeast trades and home either around the world or east on the westerly winds in high northern latitudes. Sir Francis Drake sailed across the Pacific from California, presumably on the northeast trades, and reported no islands at all. Thus he confirmed the wisdom of the Spanish



The voyages of that uniquely determined explorer Captain James Cook. Most so-called explorers followed the safe and easy highway in the South Pacific. The prudent Spanish merchants followed the safe loop in the North Pacific.

conquerors who, beginning in the late sixteenth century, sent galleons from Acapulco to Manila along 13°N latitude and back at 40°–60°N latitude. For centuries they sailed the same route because exploration had shown it to be safe. It was all as routine as the P&O sailings from England to India in the days of empire, although the best accommodations were not POSH but SOPH. Naturally, the Spaniards discovered few islands as they sailed in a vast loop around the unknown Hawaiian Islands.

With the dawn of the eighteenth century came a thirst for geographic knowledge, science, and, perhaps more important, a final hope for territorial expansion on a continent thought to lie in the South Pacific. The British troops who surrendered at Yorktown later in the century played a tune, "The World Turned Upside Down." That is what theoretical geographers once thought would happen if the many continents in the Northern

Hemisphere were not balanced by equal continents to the south. Thus a new wave of explorers moved through the Pacific basin. Roggeveen with two ships found eleven islands from isolated Easter through the Tuamotus, Society and Samoan archipelagoes. Byron, Wallace, Carteret, and Bougainville followed with comparable discoveries. Unfortunately for territorial hopes, they more or less followed the same old explorers' turnpike.

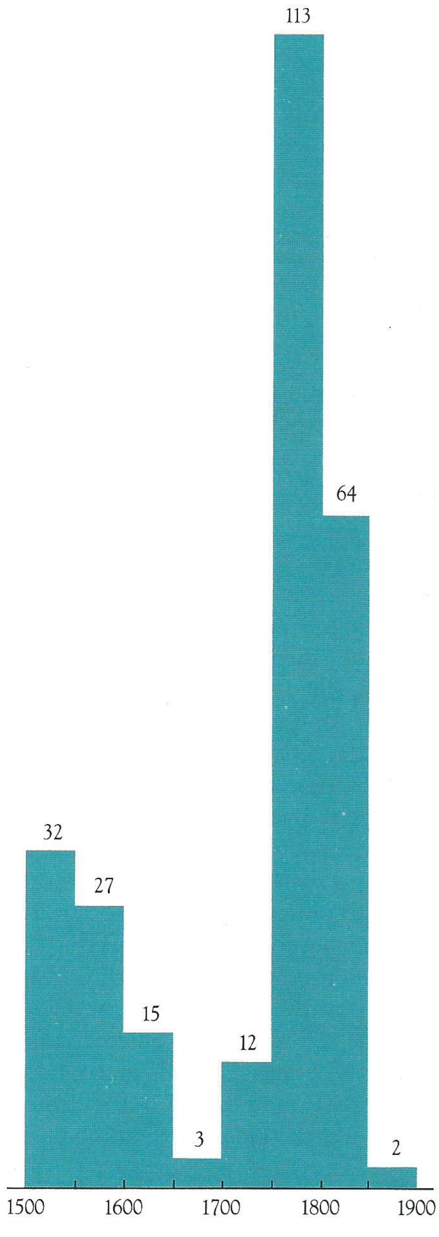
Enter the incomparable Captain James Cook, who made three voyages from 1768 to 1779, when he was killed in Hawaii. Even he followed the turnpike on his first voyage, but thereafter he followed logic and took the west winds to crisscross the South Pacific. In this he was preceded by Tasman, who sailed on the westerlies south of Australia in 1642 and (after the Maoris and the kiwis) discovered New Zealand. Cook came the same way, and between 1772 and 1775 he eliminated the possibility of a southern continent outside polar waters. He did a similar search of the North Pacific on his last voyage; he bisected the Acapulco–Manila loop and found the Hawaiian Islands.

In the central Pacific basin, Cook found and surveyed 30 islands. Through his unique influence and training, his lieutenants and their lieutenants, seemingly everyone associated with him, continued to explore. His lieutenant Clerke found the last two high Hawaiian Islands. A decade later, his former navigator, Captain Bligh, discovered two islands with HMS *Bounty.* When the mutiny occurred, Bligh and the loyal sailors were placed in an open boat. They then made the longest recorded voyage in such a boat, all the way to Batavia, seldom touching land for fear of the Melanesian cannibals, who even paddled out from shore to intercept them. In the midst of all these hardships and perils, Bligh discovered—and surveyed one side of—eleven islands in the Fiji and Banks groups. (Cook had once remarked that to survey an island he frequently had to expose his ship on a lee shore, which was contrary to all his training. He did so because the Admiralty had sent him out not to preserve his ship but to survey.) His chief mutineer, Lieutenant Fletcher Christian, discovered fertile Raratonga (and the Raratongans) with *Bounty* before reversing course and eventually burning the ship off the landing on isolated, uninhabited Pitcairn. To complete this log, Captains Edwards and Oliver, searching for the mutineers, discovered three more islands in the central Pacific and four more among the continental islands of the Solomons.

The western shore of Pitcairn Island has the high cliffs typical of even very young volcanic islands in reefless seas.

The Efficiency of European Exploration

The oceanic islands of the main Pacific Basin east of the island arcs comprise 184 atolls or rocks barely above sea level and 83 high islands, including elevated atolls. The distinction is made between high islands and low because height is what determines how far an island can be seen—its



The number of islands discovered in the Pacific in each fifty-year period from 1500 to 1900. Clearly by 1700 no one was looking for islands.

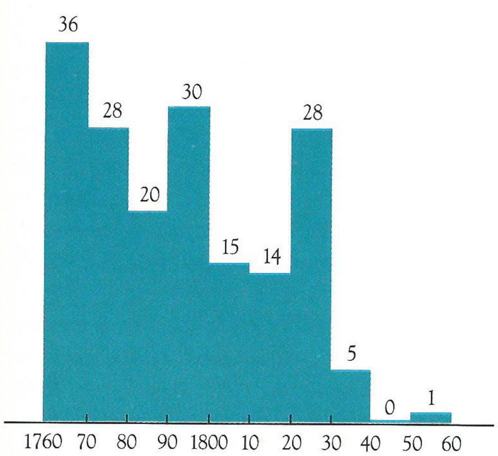
"size," for the purpose of discovery. Thus, the history of discovery of the finite population of high and low islands in this circumscribed area may be compared to the better known history of the population of giant and small oil fields in the United States.

In the first phase of exploration, from 1500 to 1700, the number of islands discovered per 50 years systematically declined. Presumably this reflects both a decline in interest in the Pacific and the fact that its Spanish masters were content to conduct commerce along known, safe routes. As far as island discoveries go, therefore, the heroic first phase did not amount to much. Nothing of value was thought to exist in the main Pacific basin, so it was pointless to search for islands.

In the second phase, beginning in 1700, discoveries per fifty years averaged about four or five times the rate in the previous two centuries. However, within this phase, particularly from 1760 to 1860, there was hardly any systematic trend in the rate of discovery per decade until the 1830s, by which time almost all the islands had been discovered. Even if the discoveries by the unique Cook are eliminated, the rate varied randomly from 10 to 29 per decade for 70 years despite the almost complete exhaustion of the finite population of islands available for discovery. Random searching at a constant rate would have produced an exponential decline in the rate of discovery. If, indeed, random searching is an appropriate model for European exploration for Pacific islands, there must have been a balancing exponential increase either in the rate of exploration or in its efficiency.

It is easy enough to devise simple models of random searching and apply a Monte Carlo method to generate simulated histories of discovery. All that is necessary is to determine the size and position of the targets and then have a computer run straight lines or random sailing courses through the search area. Two models might be necessary because the size of the target varies with the objectives of the searcher. We define "finding" as seeing an island. A voyager who is trying to avoid islands discovers one only if it chances to come in sight. However, islands give many signs of their existence besides being visible. The orographic rain clouds that tower above high islands are often visible long before the island comes in sight. Likewise the milky blue-green color of a still-invisible atoll may be reflected on the clouds of the trade winds. Inasmuch as the temperature of a lagoon is higher than that of the surrounding water, the pattern of the little tropical clouds over the lagoon may also be revealing. Land birds, floating vegetation, seals, wave and swell patterns, even smell can indicate the nearby presence of land yet undiscovered. Thus, one computer program would sail straight on and the other would begin a box search until the discovery was made. The latter would be much more successful because, effectively, it would be seeking much bigger targets.

Orographic rain clouds over Palau. The high, stationary clouds presented large targets for explorers seeking islands.

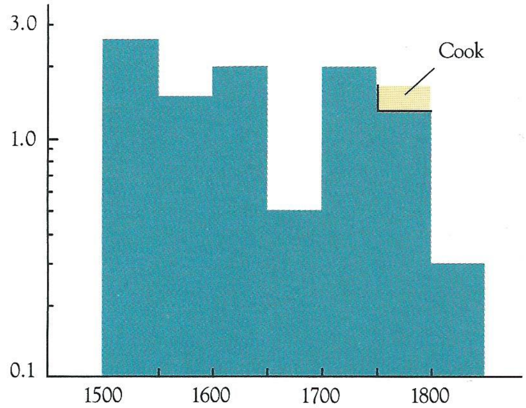


Number of islands discovered in the Pacific per decade, 1760–1860. Evidently, there was no systematic trend.

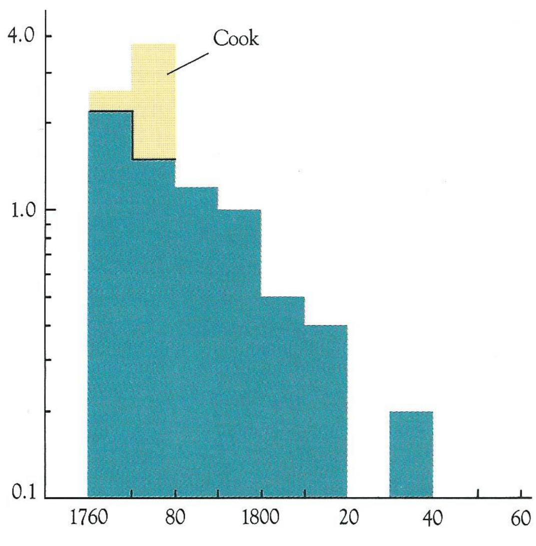
The problem in measuring the rate and efficiency of European exploration is that the total length of all Pacific voyages is unknown. Thus, there is nothing comparable to the total length of exploratory drilling for oil fields. Consequently, the actual efficiency of exploration—number of islands discovered per unit effort—cannot be determined for comparison with random searches.

What can be determined from Sharp's chronology of discovery is how many islands were found on each voyage that found any islands at all. Consequently, it is possible to see how this number varies per unit effort, even though the sample is very small compared with all the voyages that discovered nothing at all. An appropriate measure of success would then be the excess number of islands (that is, in excess of one) discovered per successful voyage per ship. Small though it is, the sample suggests that this number declined exponentially from 2.5 in the first fifty-year period to 0.5 in the last fifty-year period of the first phase of exploration. Considering that two-thirds of the islands were still undiscovered in 1700, it appears that either no one was looking for them or that the searches had bad luck comparable to that in the search for the giant East Texas oil field.

The more voluminous data for the period from 1760 to 1840 are quite consistent in suggesting that chance was a major factor in the discovery of



The number of excess islands discovered per successful voyage per ship was relatively constant in the fifty-year periods from 1500 to 1800.



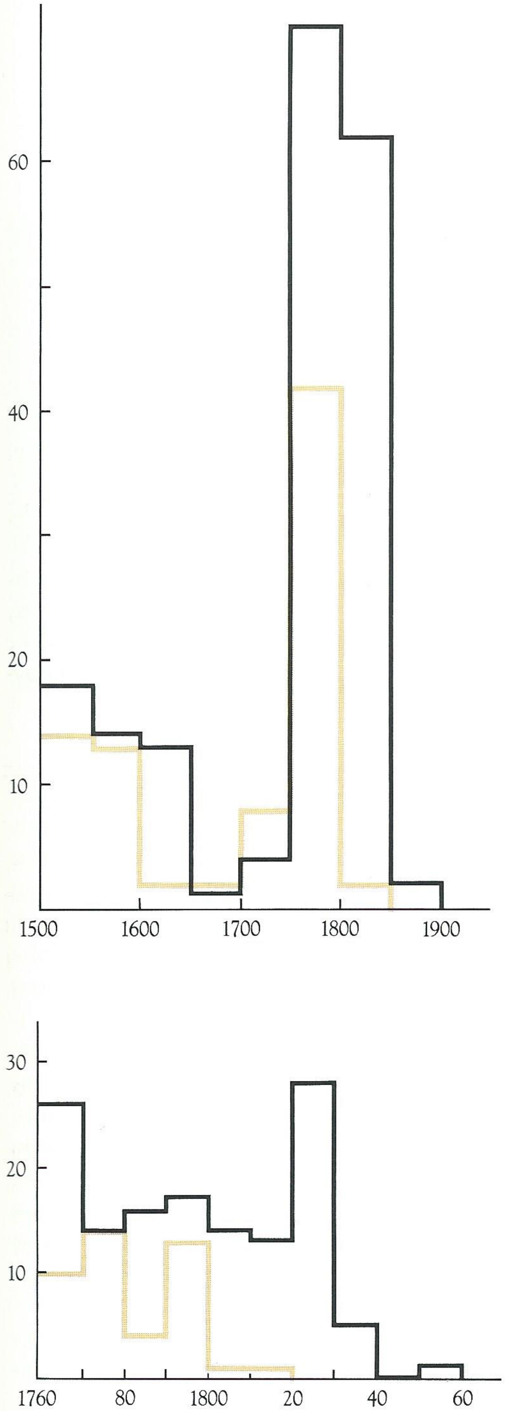
The number of excess islands discovered per successful voyage per ship per decade during the intense second phase of exploration. The number declines exponentially as it would in a random search for a finite population.

Pacific islands. Excluding Cook's discoveries, the excess number of islands discovered per successful voyage per ship declined exponentially from 2.2 to 0.2 in each ten-year period, with only a gap from 1820 to 1830 to mar the picture. Even including Cook, whose searches were far from random, an exponential decline is apparent. It appears that in the second phase of Pacific exploration the actual rate of discovery per unit effort declined as it would have in a random search. Thus, if the rate per decade remained fairly constant, it must have been because the amount of searching, whether deliberate or random, increased exponentially.

In each phase of exploration, the high islands were found generally before the low ones. This is best seen in the last century of discovery. All but two of the high islands were found by 1800 and the last, Rimatara, by 1811. In contrast, more low islands were found in the 1820s than in any other decade in the two phases of exploration. Atolls continued to be found for 48 years after the last high island. It seems that, like the discoverers of oil fields, European and later American explorers found the big targets first.

The first high island to be discovered in the Pacific region of interest here was Ponape, 786 m high, in 1529. Ponape is one of three widely separated high islands among the abundant atolls and drowned atolls of the Caroline group. The atolls surrounding Ponape were discovered in 1529, 1568, 1773, and 1824. It is evident that atolls can easily escape notice. There are curious anomalies in the other direction. We may recall that Darwin on HMS *Beagle* missed seeing the nearby phosphate island of Makatea but saw Tahiti in the distance at dawn; yet Makatea, only 110 m high, was discovered in 1722 and Tahiti, 2228 m high, not until 1767. In general, the high islands of the eastern Pacific were discovered before the far more abundant and clustered high islands to the west. The Galapagos were the first group found; all twelve were discovered in 1535. The eastern islands along the return loop from Manila were discovered early, even the tiny but high spire of Alijos Rocks off Baja California was found in 1558. The only other group found in the sixteenth century were the southern Marquesas. Only eastern high islands were discovered in the seventeenth century, and the last two of these sparse eastern islands, Easter and Sala y Gomez, were found by 1722.

The Society and Samoan groups, if not all of their islands, were discovered before Captain Cook's time, but thereafter most of the high islands were discovered by him and his lieutenants. After their time, little was left. The remote phosphate islands of Nauru and Ocean were almost the last, in 1798 and 1804 respectively. Curiously, on those islands was what the Spaniards and their successors despaired of finding—a fortune in ore.



The rates of discovery of high (color) and low (black) Pacific islands by fifty-year period (above) and by decade in the period 1760–1860 (below).

POLYNESIAN COLONIZATION

The Europeans who entered the Pacific for more than 300 years came from an unwashed, polluted, disease-ridden culture that had passed from the Bronze Age to the Iron Age several millennia earlier, a culture that had cannon, cathedrals, and the printing press. The people they found on the tiny isolated islands were clean, healthy, and generally friendly, and they seemed exceedingly handsome to sailors long at sea. Polynesians had a materially simple stone-age culture with only three domestic animals—the pig, cat, and the chicken. There were no wild mammals or reptiles to hunt or defend against. There were no machines, no wheels, no pottery—because atolls and volcanic islands lack clay. Food was abundant but the variety of fruits and vegetables limited. The sea provided a wide variety of limitless protein. These cultures had complex social structures with kings and nobles, property rights, warfare, and religion. Islanders built temples in the form of uncemented but sand-filled stone platforms. On some of the high islands, they ornamented the temples with large stone statues resembling the well-known ones on Easter Island. The statues were carved of volcanic tuff, easily worked with obsidian or pitchstone hand axes, so little technology was involved.

The first scientist to encounter Polynesian culture was Joseph Banks, who was with Cook on his first voyage. The future Sir Joseph would long be the President of the Royal Society, but on Tahiti he was a young man in paradise. He studied the botany, but his journals make it clear that he spent more time enjoying than analyzing the complaisant society of Tahiti. Scientists who later visited the islands began to devote themselves to the origin, history, and culture of the Polynesians. Evidence was derived from oral traditions, physical anthropology, serology, domestic plants and animals, artifacts, and analysis of cultural evolution. A very strong consensus among diverse specialists was that the Polynesians had come from southeast Asia, probably from what is now Indonesia. If so, they had peopled the Pacific by sailing into the trade winds. The magnitude of their achievement can be perceived from the number and desperation of the European attempts to deny that it happened.

A long European tradition proclaimed that in general one did not sail east into the trade winds. The European way to go east was to do so on the westerlies at high latitudes, but to do that was a comparatively difficult technical feat. Europeans and, later, Americans could not believe that a Stone-Age culture was capable of a large-scale migration by either route. Almost every conceivable alternative was proposed, and it seemed that the wilder the idea the greater its popularity. It was proposed, by a scientist, that the sailing simply had not taken place. A gigantic, Pacific-wide

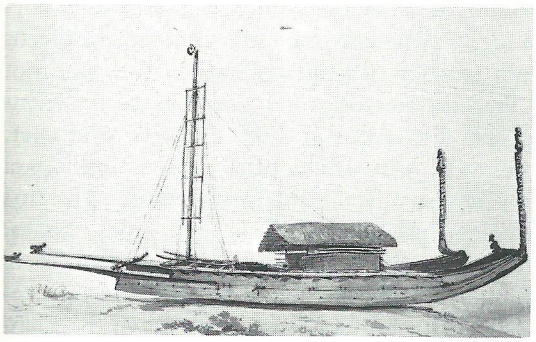
The ecologically well-adjusted Polynesian culture as portrayed by John Webber, who was with Captain Cook on the third voyage.

Hawaiian warrior, engraved from a sketch by John Webber.

continent had been submerged and what were now islands had once been its mountains. The Polynesians had walked on their migration and merely retreated to the peaks when submergence separated them. A drowned continent was a popular idea among biologists, particularly botanists, but few would have agreed that it had submerged while man was on earth. A nonscientific enthusiast gave the continent a name, "Mu," and wrote several books comparing its history with that of the other imaginary sunken continent—Atlantis.

Some people allowed migration by ship, but surely not by a Stone-Age culture. It followed that the Polynesians were little more than the feral remnant of a high culture. But what high culture? Among the possibilities considered were a lost tribe of Jews, or of Aryans, or the mysterious but doubtless technologically mighty inhabitants of Mu. In yet another interpretation, the Polynesians themselves did migrate by sea, but this was not much of a technical achievement because it was done downwind on the trade winds from South America. Thor Heyerdahl demonstrated that the voyage could be made on a properly provisioned raft that was towed across the near-shore currents. His account, *Kon-Tiki,* went through seven printings in its first year, 1950, and ultimately more than twenty-five printings.

The idea of a *simulated* Polynesian voyage from South America would not have surprised Sir Peter Buck, who in 1938 published the concept that there were real voyages. Buck, however, assumed that the voyagers had first sailed from Polynesia to South America. The return downwind would



Polynesian double-hulled canoe from the Society Islands.

then have been easy. Sir Peter Buck was a Maori, born Te Rangi Hiroa, who left a position as a Maori medical officer to pursue the origins of his people. Speaking a Polynesian dialect as his mother tongue, he made extensive use of interviews to obtain oral traditions, histories, and genealogies, some of which went back 92 generations. With Buck the pendulum at last swung. The title of his book *Vikings of the Sunrise* referred not to the antecedents of the Polynesians but their abilities as sailors and navigators. It went through two editions and additional printings and has become widely accepted, especially in Polynesia. He visualized fleets of double-hulled sailing canoes that set sail, according to plan, bearing hopeful emigrants and the provisions to support them. On the broad platforms between the twin hulls were the domestic animals, plants, and seeds to establish new settlements. The voyages counted on rain to supplement water, and upon fish to supplement food.

The great canoes were seen and illustrated by early European voyagers, so Buck's interpretation of Polynesian history began on firm ground. He knew the South Pacific well and was scornful of the "nonsense" in print about the impossibility of sailing east in the latitude of the trade winds. The trades sometimes ceased and were replaced by westerly winds from time to time. He cited the experience of the pioneering Christian missionary John Williams, who sailed east from Samoa to the Cook Islands on a straight course without changing tack. In any event, sensible sailors preferred to explore by beating against prevailing winds because, if no new island was discovered, they could speed home to food and water. The only weak link in this appealing history of noble human achievement was the possibility that the island hopping was accidental. Perhaps the Polynesians populated new islands only when their sturdy canoes were driven who knows where by great storms. Buck cinched his analysis by pointing out that, although women swam, dove, fished and sailed, it was only within lagoons. They did not accompany men in fishing in the open sea where they could have been blown away. No women, no new colonies; it was as simple as that. If the women were at sea, it could only have been with the great colonizing fleets.

Sir Peter Buck had painted an attractive picture, consistent with mainstream science and based on a personal compilation of oral history in the 1930s. In 1956, Andrew Sharp pointed out that the picture was not consistent with earlier observations of Polynesian culture. Sharp observed that once the Europeans arrived they grossly changed Polynesian life. Polynesians on some islands were almost exterminated by European diseases. Cultures were rapidly corrupted, as they were all over the world, by the awesome European technology. The isolated Polynesian society was exposed to the world. For example, Captain Cook's Tahitian translator,

The Polynesian culture was quickly intermixed with and overwhelmed by European culture. Captain Cook's Tahitian interpreter, Omai, was painted in London by Joshua Reynolds. Within a few years, Omai and other Polynesians had returned home with new versions of Pacific geography and history.

Omai, had spent two years in London before sailing on Cook's third voyage. Even within the Pacific, Polynesians traveled with the Europeans and, moreover, could learn of many islands with which they had not necessarily been familiar. Thus the memories and, possibly, the traditions of Polynesians after the great discoveries of 1760–1780 were suspect.

It is prudent, therefore, to go back to European journals and logs of voyages to Polynesia before any significant changes occurred. The first scientific voyage was Cook's on *Endeavour* in 1768–1771. Cook, Banks, and Solander were all curious and qualified observers, and the journals of the first two have something to say about Polynesian origins. Banks believed that the Polynesians had come from the west because of their language and their domestic plants and animals. Cook, the master mariner, saw not the slightest problem in accepting that the migration was against the trade winds. He found that the inhabitants of the Society Islands were familiar with islands "laying some 2 or 300 Leagues to the westward of them." He assumed, in those days early in the second phase of European exploration, that island succeeded island to the west. Thus the inhabitants of the islands west of Tahiti would in turn know of the islands west of them, and so "we may trace them from Island to Island quite to the East Indias."

By his third voyage (1776–1779), Cook had more data and a more complete hypothesis of Polynesian migration. Polynesia was divided into two main regions: western Polynesia, consisting of the Tonga, Samoa, and Fiji groups, and eastern Polynesia, which included the Society and Tuamotu islands. The Polynesians told the early explorers that *deliberate* voyages were made only within the two regions. How voyages were made between groups or to islands outside the groups was suggested by what Cook learned at Atiu, in what are now the Cook Islands. Omai, the interpreter, found three of his fellow Tahitians on Atiu, 1100 km from home. They were the survivors of a party of twenty who had expected to have a brief sail from Tahiti to Raiatea, barely over the horizon at sea level. Cook knew of many other accounts of accidental voyages such as one in 1696, when a large canoe was driven by storms from the Caroline Islands to the Philippines, 1800 km away. Men, women, children, and babies survived. Cook reasoned that such accidental long voyages by family and tribal groups attempting easy interisland trips

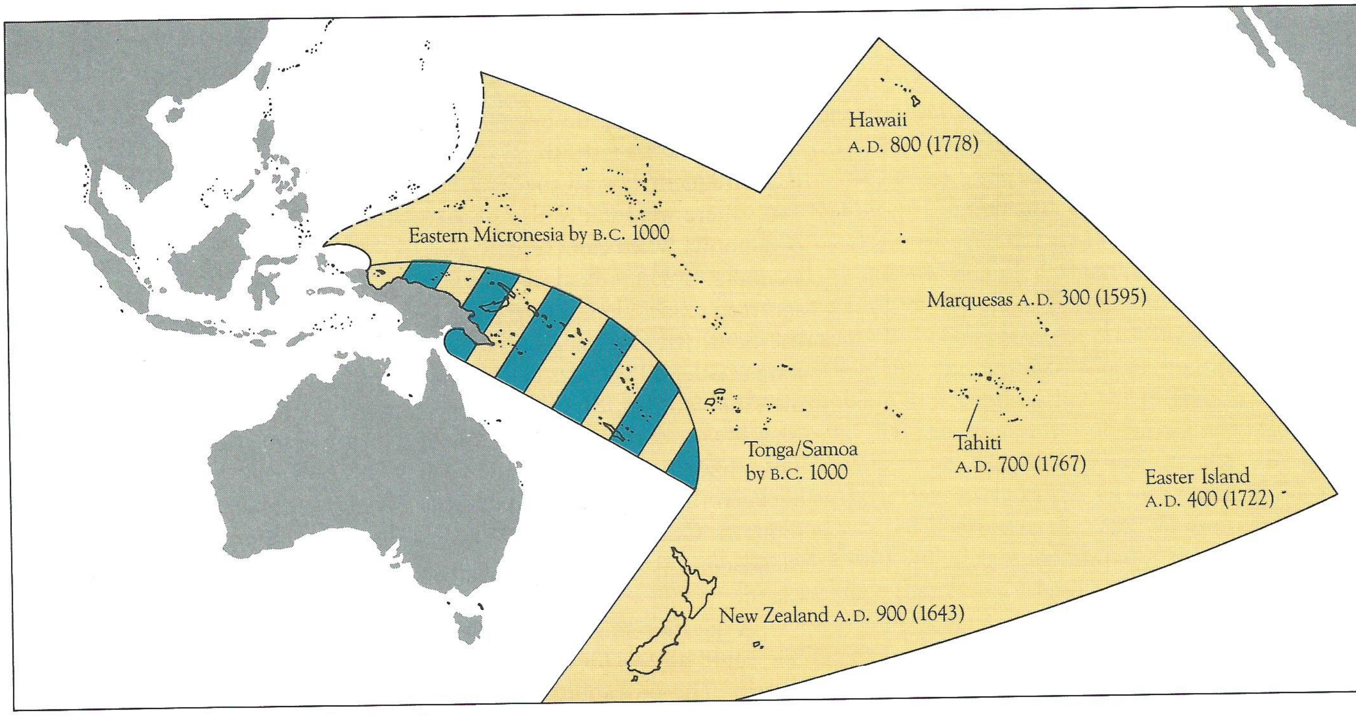
> will serve to explain, better than a thousand conjectures of speculative reasoners, . . . how the South Seas, may have been peopled; especially those [islands] that lie remote from any inhabited continent, or from each other.

In short, Cook proposed that the islands were peopled not by hypothetical great fleets of migrators but by an essentially random search, which was still going on.

Andrew Sharp fleshed out this skeleton of an idea with data from the time after Cook's death, on his third voyage. Accidental voyages were more frequent toward the west because of the normal trade winds. However, there were many also to the east during lulls in the trades or, more commonly, when gales or typhoons overwhelmed the normal weather. For example, a canoe-load of people from Manihiki in the Northern Cooks survived an accidental voyage of 1100 km to the southeast to Aitutaki in the Southern Cooks. Another important influence on the probability of long accidental voyages is the frequency of inter-island travel by groups of men and women. Sharp showed that family and group voyages to nearby islands were commonplace in the nineteenth century just as they are now. The population of one pair of islands moved *en masse* back and forth between them every few years; their use of the islands was rather like crop rotation. Other people would go off to visit family connections on nearby islands; or to colonize a less desirable and thus unoccupied area of a nearby island.

A question might be raised about the probability that a group of families would survive for weeks when they had supplies on board for only a day or two. The probability cannot be assessed; perhaps most of those swept away were drowned or died of exposure, hunger, and thirst. Nonetheless, successful storm-driven, accidental voyages may have been numerous enough to populate the islands. In any event, the ability of the ancient Polynesians to survive at sea defies the modern urban imagination.

Some faint idea of what can be done is provided by the little book *Survival on Land and Sea,* prepared for the U.S. Navy by the Ethnogeographic Board of the Smithsonian Institution. I have read my copy many times since I received it on shipboard in 1944. After a few special sections about not drowning in a parachute and about surviving under burning oil from a ship, it presents a manual for staying alive in a life raft that would apply to anyone adrift. You can live for weeks without food and 8 to 12 days without water. A pint of water a day keeps you fit if you are not active. Moreover, fish hooks can be made from many materials, including wood, and fish line from cloth or rope. Small pelagic sharks collect under and around boats, and birds, flying fish, and squid may land aboard. Rain can be expected to provide water; and potable water, rather like oyster juice, can be squeezed or chewed from freshly caught fish. Exposure can be a problem; I would never abandon ship without a hat. However, awnings can be improvised and clothes minimized, so that perspiration is free to evaporate but the sun is still screened. Clothes should be dipped in



Dates of discovery of central Pacific islands by Polynesians (Europeans). The area of Polynesian settlement after 1000 A.D. is shown in color. North and east of New Guinea, Polynesian settlements coexisted with Melanesian cultures.

salt water to provide cooling by evaporation, although care should be taken not to be chilled.

With this kind of information, and determination, young men from the fields of Iowa and the streets of Chicago have survived for weeks in open boats and rafts. The Polynesians were as nautical a culture as ever existed, swimming like otters, sailing from infancy, and fishing for a living. They started on their inter-island cruises or inter-archipelago expeditions with just the sorts of gear, rigging, and sails that were most useful for long survival at sea. Even after destructive storms, enough voyagers could have survived to people the Pacific.

Thus, the random-voyage hypothesis seems entirely adequate to explain the peopling of the Pacific, although it has evoked a mixed response. A troubling aspect is that it seems to diminish the Polynesian achievement—in fact, it is not known that large-scale planned migrations did not occur. However it was accomplished, what was the chronology of Polynesian exploration and colonization?

The Polynesian culture apparently developed among people who migrated from Indonesia through Melanesia to the Samoa-Tonga region per-

Stone heads on Easter Island mark the easternmost occupation of Polynesian colonists. However, plants and mineral specimens indicate noncolonizing voyages on to South America.

haps 3000 years ago. Yet radiocarbon dating so far has not shown any occupation of the central South Pacific islands until the first millennium A.D. Presumably, human waifs were coming and going east with storms and home again with the trade winds. Given a seagoing people in western Polynesia for at least 1000 years, it seems impossible that they did not accidently learn of the islands farther east. Nonetheless they neither deliberately nor accidentally populated Tahiti or the other islands. Could it be that home in Tonga or Samoa was so ideal that every group of shipwrecked waifs merely built a new boat and sailed back on the trade winds?

Apparently, something changed, perhaps population pressure, and Polynesians occupied the incredibly distant Marquesas islands about 300 A.D. They were on Easter Island by 400 A.D. and throughout the Society, Tuamotu, Austral, and eastern Cook islands by perhaps 700 A.D. In 800 A.D. they probably were in Hawaii and a century later in New Zealand. The Polynesians also discovered, although they did not permanently occupy, numerous isolated islands—probably more than once. There are ancient ruins in the interior of some high islands in the Carolines, and an abandoned temple on Pitcairn. Skeletons, artifacts, and ruins are spread from the Line Islands to Henderson, which is southeast of Pitcairn. Polynesians not only reached the Galapagos but somehow made contact with South America, whence the sweet potato was brought to New Zealand.

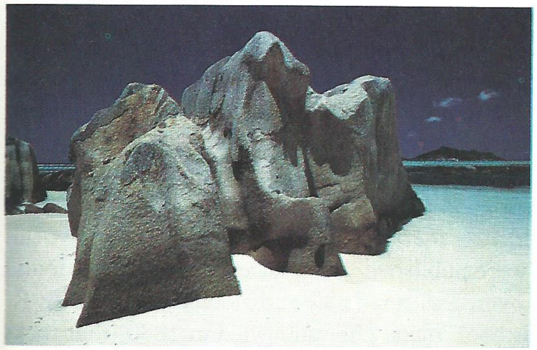
In sum, Polynesians discovered and colonized the islands of the open South Pacific as well as Hawaii in about 600 years. They had gone everywhere from New Zealand to South America. It took Europeans with much better ships almost half as long just to find the islands, and they never have colonized many of them. We have no way of knowing how much of the colonization was deliberate and how much accidental, but regardless of how the Polynesians peopled the Pacific, it seems to have been reasonably efficient—pigs, chickens, and all. Considering that in exploration it is no small achievement to do as well as pure chance, there is no way to diminish the greatest maritime feat in human history.

POPULATION BY PLANTS AND ANIMALS

A large number of biologists have studied island life in the past hundred years, including many specialists in subjects that rarely overlap. Inevitably there is a great diversity of apparently conflicting evidence and thus a range of opinion on how plants and animals populated oceanic islands. Even so, there is agreement on the one point that is most controversial regarding human exploration: Plants and (non human) animals found the islands accidently, without intent, and entirely according to the laws of chance. One might reason that chance would favor those waifs biologically more capable of dispersal, like the Europeans and Polynesians, who were culturally prepared to discover oil fields and islands. We have seen that such human discoveries may be inevitable even if there is a large element of chance. Regarding other species, biologists also seem to have achieved a consensus that organisms capable of long-distance dispersal are more apt to be on an island than not.

On many other points, controversy continues. For example, faunal affinities indicate that different organisms reached such islands as Hawaii from different continents, but when and by what routes is less certain. In the last chapter of this book, we shall view island life in the light of plate tectonics and insular geology, which have some bearing on the history of dispersal to islands. Here, however, we shall focus on the paths by which colonizing plants and animals reached the islands. Many, perhaps all, possibilities have enjoyed scientific support; these include migration across former continents or former linear continental fragments called "land bridges," hopping along former island chains, and simple dispersal to the islands as they are now distributed.

The hypothesis that ocean basins and continents were not permanent had widespread support from the early nineteenth century until fairly recently. Many of the most eminent geologists believed that dry land had been where the ocean basins are now and that subsidence had merely transformed one into the other. Thus, biologists could cite expert geological opinion to explain the modern distribution of plants and animals. The geological evidence that was explained by the hypothesis was of two types,



Granite outcroppings amid the coral sands of the Seychelles Islands in the Indian Ocean. The Seychelles are a tiny fragment of drifting continent quite unlike the volcanic and coral islands typical of ocean basins.

and by the late nineteenth century the facts were hardly in dispute. First, marine fossils and sedimentary rocks occur widely on continents, including what are now the peaks of the highest mountains. Clearly, the land that can be seen has once been the sea floor. It once seemed only reasonable that the sea floor, which could not be studied in such detail, might once have been land. Second, Paleozoic and early Mesozoic fossil assemblages of the Atlantic coasts of Africa and South America are very similar, and this is true of Northern Europe and North America as well. Furthermore, the sequences of sedimentary rocks on opposite sides of the Atlantic are also very similar, and the geological structures of the two coasts trend out to sea. It is obvious that at one time Africa and South America, for example, were connected by dry land.

To plant geographers, the idea of foundered continents was particularly attractive. J. D. Hooker, Darwin's friend and one of the earliest supporters of evolution, did not see how the "peculiar endemics" of insular floras could be explained by random dispersal over water. Moreover the insular floras reflected a "far more ancient vegetation than now prevails on the mother continents." All manner of problems about dispersal from continents to isolated islands were identified by botanists and other biologists as well. These problems posed no difficulties if the islands were merely peaks of foundered continents. All was explained by land distributions that had now vanished. On the other hand, all these problems were acute for a second group of biologists who believed that ocean basins and continents were not interchangeable. To be convincing, they would have to prove that long-range dispersal over water was not only possible but going on now.

The pioneer in the second group of biologists was Charles Darwin, whose reasoning derived from his hypothesis on the origin of atolls. He had proposed that the coral atolls were reefs built on the tops of isolated submarine volcanic edifices. If the bases of the volcanoes had once been connected by dry land, as parts of a continent, the coral would have grown up like the Great Barrier Reef off Australia, only the Pacific reefs would have been even more extensive. Furthermore, with very few exceptions, the only rocks found on islands in deep ocean basins are volcanics, such as basalt, and coral limestone. If the islands were peaks of foundered continents, they should be like the peaks of unfoundered continents. Many should have outcrops of Paleozoic or Mesozoic fossiliferous sedimentary rocks like the Alps or Himalayas, or granite and metamorphic rocks like the Sierra Nevada. Darwin said that they did not, and if everyone had accepted his conclusion, the foundered-continent hypothesis might have been abandoned. However, as Darwin himself noted, the Seychelles Islands, rising from the deep Indian Ocean, are in fact coarse granite. Moreover, many of the pioneering geologists who followed the discoverers of islands seem to have had very bad luck in sampling and describing rocks. On many islands they found what were interpreted as metamorphic and igneous rocks more like continental granite than oceanic basalt. How they did this on what are now obviously youthful volcanoes rising from oceanic crust is mystifying to nonpetrologist. However, the samples were few and the interpretations made in good faith, so as late as 1950, Darwin's conclusion was based on evidence that was widely perceived as equivocal.

After Darwin's ideas were published, the *Challenger* expedition found that the deep sea floor is covered with red clay and globigerina ooze. A. R. Wallace pointed out in his book *Island Life,* published in 1880, that rocks made of such materials do not exist on continents, and this suggested that continents and ocean basins are permanent. When Wallace had sent his first, brief manuscript outlining the theory of evolution by natural selection to Darwin, he had believed the foundered-continent hypothesis. This was hardly surprising, because much of his field work was in the Indonesian islands, which are in fact continental in composition and arise from a shallow continental shelf. In times of lowered sea level, animals could migrate about with dry paws. Darwin wrote to Wallace that he agreed with everything that Wallace proposed except for the populating of islands in the deep sea. On that point Darwin would defend his own views "to the death." Wallace soon appreciated the difference between continental and oceanic islands and supported Darwin, but other scientists did neither.

Further evidence for the permanence of continents came not from the tiny oceanic islands but, like the *Challenger* data, from the broad, deep sea. Geophysicists would show that continents and oceanic crust are too different for one to be changed into the other. By about 1900, O. Hecker had made enough measurements to show that the Atlantic, Indian, and Pacific ocean basins are as close to isostatic equilibrium as the continents are—both types of crust float buoyantly on denser material below. Thus, the ocean basins, which ride much lower than the continents, must be made of much denser rock. In the 1950s, Russell Raitt and Maurice Ewing, among others, began to measure cross sections of the oceanic crust from ships by explosion seismology. They discovered that the standard oceanic crust is much thinner than the standard continental crust and that crust of intermediate thickness is very rare. The result of half a century of geophysics at sea was a complete confirmation of Darwin's conclusion that ocean basins are not foundered continents. What then of the compelling evidence that Africa and South America had once had a land connection? Alfred Wegener had explained it all in 1915 by continental drift. The stratigraphic and paleontological evidence of trans-Atlantic linkages was undisputed, but it now had no bearing on the dispersion of animals and plants to oceanic islands.

If Darwin did not immediately convince everyone about the populating of islands, it was not for lack of his usual valiant try. He conducted a lengthy series of experiments to determine how long seeds and plants would float in sea water and still be fertile. Ripe hazel nuts, he found, sank immediately but if dried first they would float 90 days and still germinate. Dried asparagus with berries floated 85 days, and so on. He also amassed an enormous collection of observations of plant and animal dispersal. Coconuts drift across oceans, and West Indian beans regularly beach on Scotland. Birds cross oceans and carry fertile seeds in their crops. A blob of mud from a partridge's leg contained the seeds of 82 plants of five species. These experiments and observations proved that a surprising range of plants and animals could survive long-distance transportation by air or sea and reproduce on islands.

Darwin did not show that breeding pairs or genetically diverse groups of mammals or reptiles could populate islands. But there are no mammals and few reptiles on oceanic islands, except for those that were brought by people. Indeed, a correct explanation of the origin of insular populations must include a filter that eliminates species incapable of long-range migration, and that is one of the virtues of the waif hypothesis.

Among the last common island organisms to be proved capable of distant dispersal were insects. Even on the Hawaiian Islands, with their large human population, there was no way to detect an insect that had just been blown in from California. J. L. Gressitt solved the problem in the 1950s by towing a large fine-mesh net behind an airplane near the islands. It was like the discovery of plankton in the sea a century earlier. Insects and spiders are abundant even high in the air, and the species represent groups in the same proportions as those of the insect faunas of oceanic islands.