

# *Regional Geology of the Northwestern Hawaiian Islands*

THE NORTHWESTERN (or Leeward) Hawaiian Islands form a row of small islands and associated reefs and banks that extends west-northwestward for nearly 2,000 kilometers beyond Kauai and Niihau (figs. 1.1, 23.1). Those closest to Kauai are deeply eroded remnants of volcanoes. Farther northwest the islands are of limestone, but resting on deeply submerged volcanic pedestals. Kaula Island lies 37 kilometers southwest of Niihau (fig. 22.1), and belongs with Kauai and Niihau rather than with the rest of the Northwestern chain.

In order northwestward, the volcanic islands are: Kaula, Nihoa, Necker, French Frigate Shoals, and Gardner. The last two consist only of small residual pinnacles of volcanic rock surrounded by coral reef, and they constitute a gradation into the wholly limestone islands. Again in order to the northwestward, the limestone islands are: Maro Reef, Laysan, Lisianski, Pearl and Hermes Reef, Midway, and Kure. In addition, more than a dozen other reefs and shoals mark submarine peaks that do not quite reach the surface of the ocean. Comparatively little geologic work has yet been done on the Northwestern Hawaiian Islands.

## **KAULA**

Kaula Island is a tuff cone resting on a broad base that certainly is a large submerged shield volcano.

The cone lies near the southeastern edge of a shoal 13 kilometers long in a west-northwesterly direction, 7 kilometers wide, and on the average a little more than 60 meters below sea level (figs. 14.15, 22.1). This relatively flat platform must have been cut across the top of the shield volcano by wave erosion, probably during the minus-106-meter stands of the sea. A projection that rises to about 10 meters below sea level 5 kilometers N 60° W of Kaula is probably an erosional residual, rather than another cone rising from the platform. The general level of the platform probably was raised by a coral reef growing on it, but sinking of the shield became too rapid for reef growth to keep up, and the reef was submerged.

The contours in figure 22.1 show clearly that the Kaula shield is a part of the Kauai-Niihau massif. The three shields lie on a west-southwest-trending line that is essentially parallel to the southwest rift zones of Kauai and Niihau and appears to reflect one of the fundamental structural trends in the earth's crust in this part of the Pacific. It may have been controlled by one of the splays from the western end of the great Murray Fracture Zone (fig. 18.9).

Kaula Island is a crescentic erosional remnant of a tuff cone built on the wave-cut platform. It rises about 160 meters above sea level and is about 1.5 kilometers long from north to south. In composition

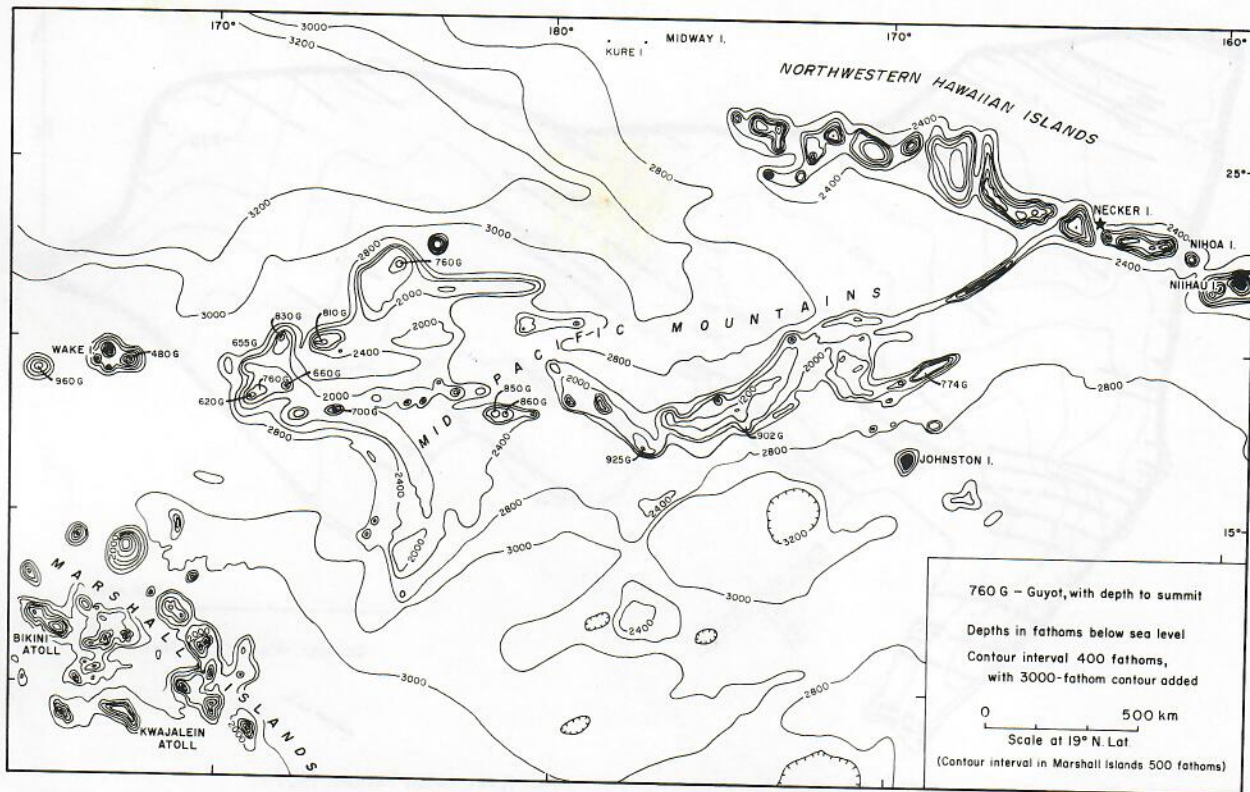


Figure 23.1. Map of the Northwestern Hawaiian Islands, and the Mid-Pacific Mountains. The star just east-northeast of Necker Island marks the site of a submarine volcanic eruption in 1956. (Modified after Hamilton, 1956.)

it resembles Lehua Island north of Niihau and such cones as Diamond Head and Koko Crater on Oahu, and like them it was formed by hydromagmatic explosions. The originally glassy ash is partly altered to palagonite. Many blocks of limestone, torn from the underlying reef, are enclosed in the tuff. Some bombs contain cores of olivine-rich peridotite (dunite and lherzolite). Angular blocks of both nonporphyritic basalt and basalt containing olivine phenocrysts also are present, probably derived from the old shield volcano beneath the reef. An unconformity in the tuff at the north end of the island indicates only a brief pause in the eruptions that built the cone. The composition of the erupting magma has not been determined, but the relationship of the cone to the underlying platform shows clearly that it is a rejuvenated period erup-

tion like those of the Kiekie Series on Niihau. Along much of the shore of Kaula a wave-cut bench lies 1 to 3 meters above sea level. Near the north point a large sea cave is said to extend inward more than 30 meters.

#### NIHOA

Nihoa Island, 275 kilometers northwest of Kauai, is approximately 1,350 meters long and averages about 450 meters wide. It has two peaks, with a broad swale between them (figs. 23.2, 23.3). Miller's Peak, on the west, rises to 269 meters above sea level, and Tanager Peak, on the east, to 256 meters. The northern side of the island is an abrupt sea cliff plunging directly from the crest of the island into the water. On the southern side the surface slopes

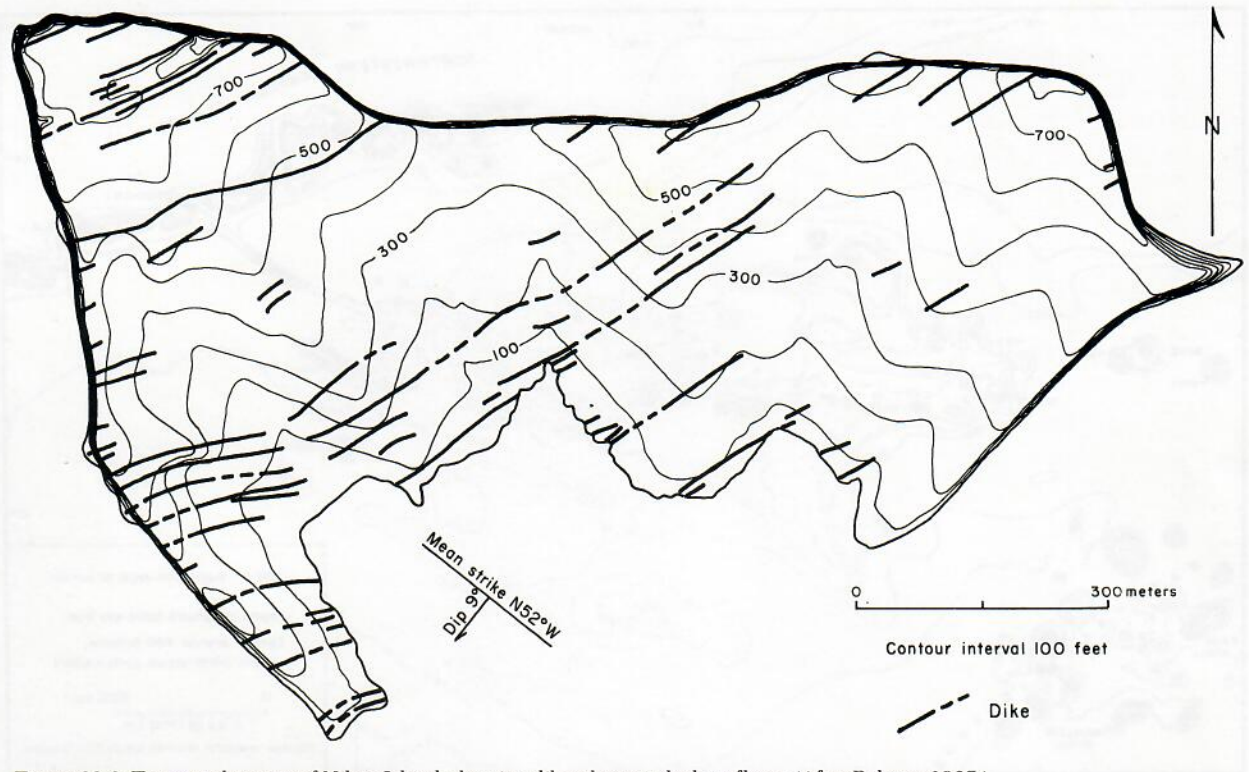


Figure 23.2. Topographic map of Nihoa Island, showing dikes that cut the lava flows. (After Palmer, 1927.)



Figure 23.3. Nihoa Island from the south. Miller's Peak, 269 meters high, is on the left, and Tanager Peak, 256 meters high, is on the right.

fairly gently to a line near the coast, where it is truncated by a sea cliff 15 to 30 meters high, with a wave-cut platform at its base 1 to 2.5 meters above sea level. A tunnel-like sea arch 90 meters long extends all the way through the promontory at the east end of the island.

Nihoa is the eroded remnant of a shield volcano composed of thin lava flows cut by dikes. All of the flows dip southwestward, and thus the island is part of the southwestern side of the shield. Palmer (1927) counted about 25 dikes in the western cliff, and others are exposed elsewhere. The dikes are nearly vertical, and trend about  $S 65^{\circ} W$ . A platform about 35 to 75 meters deep extends northeastward from the island for about 29 kilometers. Apparently the whole northeastern portion of a volcanic island some 32 kilometers across at sea level has been cut away by wave erosion. There is no indication of faulting, but the submarine topography is only poorly known. Another bank, about 27 kilometers long and 19 kilometers wide, with depths of 30 to 45 meters, lies 29 kilometers west-southwest of Nihoa.

The volcanic rocks of Nihoa are predominantly olivine basalts, with less abundant olivine-free basalts and at least one bed of oceanite. They appear to be tholeiitic.

Sea birds nest in great numbers on Nihoa, giving the island its former name, Moku Manu (Bird Island). Thin sheets of guano coat some of the cliffs, and just above the sea cliff on the southern side some of the valleys are partly filled with conglomerate in which the cement is a mixture of clay and guano.

Archeological remains are abundant evidence that the island was formerly occupied by people at least part of the time. Both house sites and terraces used for cultivation have been found, but how the inhabitants obtained their water is unknown. Several seeps are present on the island, the principal one at 81 meters altitude in the large valley on the eastern slope, but the water is somewhat brackish and heavily tainted with guano. Palmer (1927) commented that the taste was so strong that it seemed impossible that people could have used it, but no other source of water has been found. The bird population, however, probably was much smaller during the period of human habitation.

#### NECKER

Necker Island is a narrow bit of land less than 1,200 meters long and averaging about 150 meters wide (fig. 23.4). Its highest point is 83 meters above

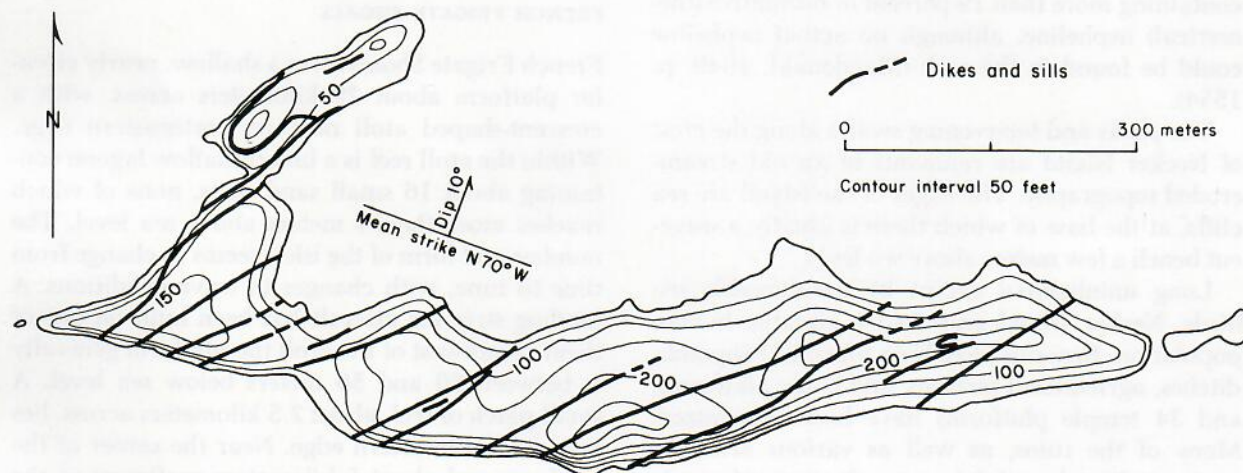


Figure 23.4. Topographic map of Necker Island, showing dikes. (After Palmer, 1927.)

sea level. At the east end is an islet about 60 meters long and 25 meters wide which is generally awash. Necker Island lies on a shallow, roughly oval platform about 60 kilometers long in a northwest-southeast direction and 32 kilometers wide. The island is an erosional remnant of a shield volcano, composed of thin lava flows cut by nearly vertical dikes. Palmer (1927) reports one dike connecting with a sill that loops around the peak on the northwest peninsula (fig. 23.4). Another sill, about 0.6 meter thick, was observed near the eastern end of the island.

The dip of the lava flows is north-northeastward, showing that the original center of the volcano was south-southwestward of the island. The platform on which the island lies unquestionably was cut by wave erosion across a large volcanic massif, but the position on the platform of the island and of the former center of the volcano from which it was carved indicates that the massif was not a single shield, but a group of shields similar to the present island of Hawaii. The rocks of Necker Island are mostly olivine basalt, but at least one flow of basaltic hawaiiite and several of ankaramite are present. The volcano had entered the late stage. One dike, analyzed by Washington and Keyes (1926), resembles the Hana volcanics of Haleakala and some of the rejuvenated period lavas of Oahu and Kauai in containing more than 19 percent of normative (theoretical) nepheline, although no actual nepheline could be found in the rock (Macdonald, 1949, p. 1554).

The peaks and intervening swales along the crest of Necker Island are remnants of an old stream-eroded topography. The edges of the island are sea cliffs, at the base of which there is usually a wave-cut bench a few meters above sea level.

Long uninhabited except by innumerable sea birds, Necker Island once had a sizeable human population. Remains have been found of fishponds, ditches, agricultural terraces, and house platforms, and 34 temple platforms have been recognized. Many of the ruins, as well as various artifacts, appear to have been left by an early group of people

("menehunes") who preceded the more recent Hawaiian population. The older remains are overlain by the remains of the work of the later people (Emory, 1928). As on Nihoa, the source of water for these people is a mystery. The present supply appears to be about 40 liters a day of acrid, guano-tainted water that we would consider undrinkable. Even allowing for the fact that primitive people apparently are able to adjust to very small amounts of very poor water, this quantity hardly seems adequate to support a population large enough to have built all the structures that have been found. Of course, if most of the birds were driven away or killed, the spring water would have been untainted by guano, and this spring supply, in addition to water condensed from the air and rainfall caught and stored in calabashes, may have been sufficient to maintain a small group of primitive people. The irrigation ditches probably operated only during occasional rainstorms. It is interesting to speculate, however, on the possibility of a change in climate. At the time it was discovered by La Pérouse, in 1786, the island had not been occupied for a long time. Perhaps 1,500 to 3,000 years ago there was more rainfall than there is now, and later the island had to be abandoned as the climate changed toward the present arid condition.

#### FRENCH FRIGATE SHOALS

French Frigate Shoals form a shallow, nearly circular platform about 29 kilometers across, with a crescent-shaped atoll near its northeastern edge. Within the atoll reef is a broad shallow lagoon containing about 16 small sand islets, none of which reaches more than 4 meters above sea level. The number and form of the islets seems to change from time to time, with changes in wave conditions. A landing strip for aircraft has been built on one of them. Southwest of the atoll the platform generally is between 20 and 50 meters below sea level. A small patch of reef, about 2.5 kilometers across, lies near its southwestern edge. Near the center of the platform and about 5 kilometers southwest of the

atoll, La Perouse Rock, a mass of lava rock 150 meters long and 25 meters wide, rises 36 meters above the water (plate 30). About 100 meters to the northwest another projecting mass of lava is 30 meters long, 12 meters wide, and 3 meters high. These tiny sea stacks are the only visible remnants of a great shield volcano.

La Perouse Rock consists of thin lava flows of olivine basalt dipping northwestward at an angle of only 1 or 2 degrees (Palmer, 1927, p. 30). It is largely coated with white guano.

Palmer (1927, p. 31) suggests that the unusual shape of the French Frigate atoll is the result of two generations of reef growth, the leeward reef having grown first, and the windward reef later.

#### GARDNER

Gardner Island consists of a pair of sea stacks rising from a shallow wave-cut platform. The larger is a steep-sided pinnacle about 50 meters high, 180

meters long north-south and averaging about 60 meters wide (fig. 23.5). Just northwest of it, the smaller pinnacle is about 30 meters high and 75 meters long. Both consist of thin lava flows dipping about 15° westward, cut by a few dikes that strike roughly east-west. The dominant rock is fine-grained, very dark gray basalt with a few small phenocrysts of olivine, but other specimens of basalt are nonporphyritic. A layer of tuff exposed near the center of the larger islet contains blocks or bombs of basalt and larger gabbroic blocks. A fragment of a cavity lining made up of quartz crystals was also collected. Parts of the island are bordered by a wave-cut bench a few meters above sea level.

Gardner Island is surrounded by a shallow platform extending out from the island 16 to 20 kilometers to the southwest, and about 8 kilometers in all other directions. Undoubtedly it is primarily a wave-cut platform, probably covered to some unknown extent with coral reef. Thus Gardner Island also is a remnant of another big shield volcano truncated by wave erosion.

#### LAYSAN

Laysan Island (fig. 23.6, plate 31) is about 3 kilometers long and a little more than 1.5 kilometers wide (Bryan, 1942, p. 183). It consists of an oval sandy ridge, reaching just over 12 meters above sea level at the north end, and enclosing a saline lagoon. The lagoon formerly was as deep as 5 meters, but it has been partly filled by drifting sand. Ledges of coral reef rock are exposed in places along the sides of the ridge. The island was once inhabited by great numbers of birds—many of them sea birds, but including also five species of land birds not known elsewhere. Captain John Paty, who annexed the island to the Hawaiian kingdom in 1857, wrote: "The island is literally covered with birds; there is, at a low estimate 800,000." W. A. Bryan estimated the bird population in 1902 to be nearly 10 million. Phosphates from the large deposits of guano were leached by water that moved downward into limestone, and reacted with it to produce calcium phos-

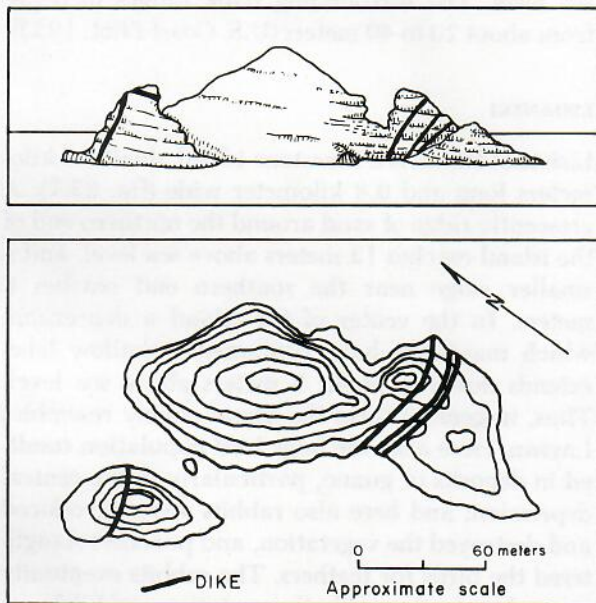


Figure 23.5. Topographic map and profile of Gardner Island, showing dikes. (After Palmer, 1927.)

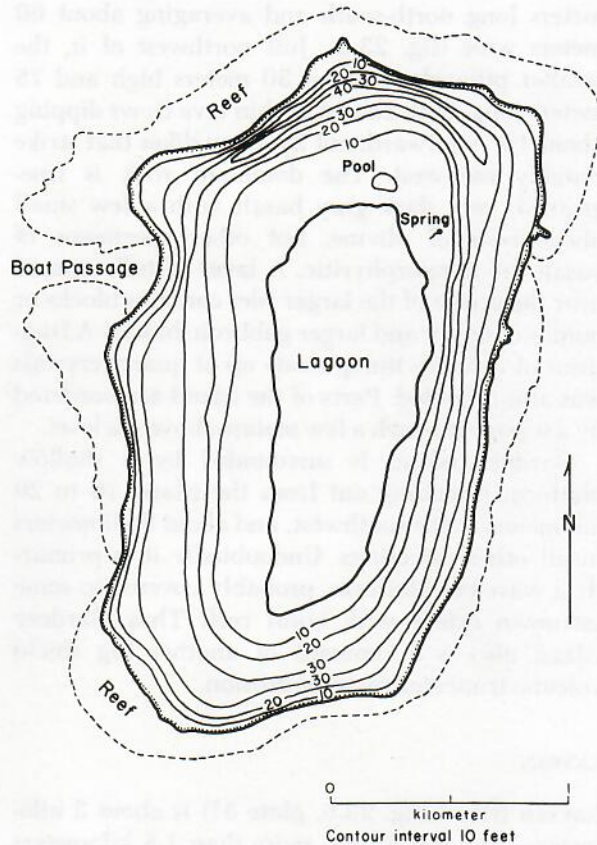


Figure 23.6. Map of Laysan Island. (After Bryan, 1942.)

phate rock. In 1890 the island was leased for the mining of guano, and by 1904 the deposits were so depleted that the project was discontinued. The unfortunate accompaniment was the wholesale destruction of the bird population, partly by poachers and partly by accidentally introduced rats. Rabbits and guinea pigs also were introduced, and these animals, together with the mining operations, destroyed most of the vegetation. By 1923 the island had become a desert of sand (Bryan, 1942, p. 188). At the present time the rabbits and guinea pigs have been killed off, and, with help from attempts at revegetation, the island is slowly returning to its former state.

No lava rock has been found in place on Laysan Island, but there are a few boulders of olivine basalt on the reef and beach. They may have come from some part of the basaltic underpinning of the island that is exposed near sea level and have been deposited there by wave action, but more probably they are ballast jettisoned years ago by sailing ships. Such rock ballast, some from as far away as New England, has been found throughout the central Pacific. There can be no question, however, that the Laysan reef rests on a great basaltic volcano.

#### MARO REEF

About 130 kilometers east-southeast of Laysan Island, Maro Reef lies on a shallow bank 50 kilometers long and 29 kilometers wide, believed to be the truncated top of another large shield volcano. The reef is about 19 kilometers long and 8 kilometers wide, and is generally under breakers. Only one small rock projects as much as 0.6 meter above sea level. The surrounding bank ranges in depth from about 20 to 40 meters (U.S. Coast Pilot, 1933).

#### LISIANSKI

Lisianski Island is a limestone island about 1.6 kilometers long and 0.8 kilometer wide (fig. 23.7). A crescentic ridge of sand around the northern end of the island reaches 13 meters above sea level, and a smaller ridge near the southern end reaches 6 meters. In the center of the island a depression, which may once have contained a shallow lake, extends down to about 3 meters above sea level. Thus, in general form the island closely resembles Laysan. Here also, the huge bird population resulted in deposits of guano, particularly in the central depression; and here also rabbits were introduced and destroyed the vegetation, and poachers slaughtered the birds for feathers. The rabbits eventually starved to death, and both vegetation and birds are returning.

Lisianski Island is surrounded by a reef, which

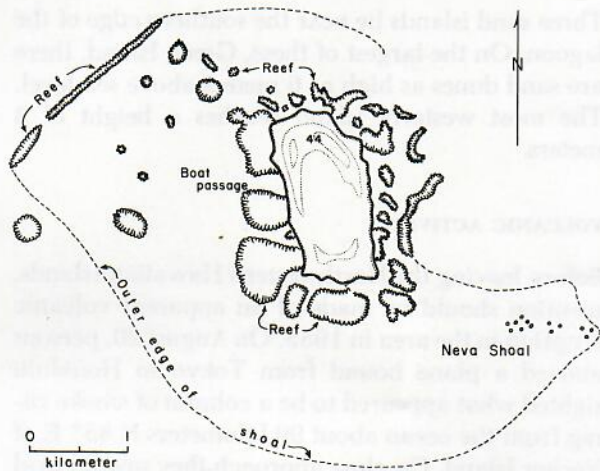


Figure 23.7. Map of Lisianski Island. (After Bryan, 1942.)

on the western side encloses a lagoon 4 kilometers wide; and the reef in turn is surrounded by a shallow bank 8 to 10 kilometers wide on all sides except the southeast, where it extends outward about 25 kilometers. Neva Shoal, named after the Russian exploring ship *Neva*, which grounded on the reef east of Lisianski in 1805, is a high part of the reef about 1.5 kilometers southeast of the island. The bank is believed to be the truncated top of a shield volcano, partly covered with reef.

#### PEARL AND HERMES REEF

Pearl and Hermes Reef is an atoll about 26 kilometers long east-west, and about 14 kilometers wide. The ring reef is lower and less continuous on the northwestern side, which generally is submerged to a depth of 2 to 10 meters. Within the lagoon are 12 small sand islands, the highest of which reaches about 4 meters above sea level. Pearl and Hermes Reef crowns a mountain that rises from more than 4,500 meters below sea level, and undoubtedly is a shield volcano. At the top of a similar mountain 56 kilometers farther northwest is Gambia Bank, which rises to within about 25 meters of the surface of the water.

#### MIDWAY

Midway is a nearly circular atoll 10 kilometers in diameter enclosing a lagoon 8 kilometers across (fig. 23.8A). Within the lagoon are two large and several small islands of calcareous sand. Eastern Island (fig. 23.9) is 1.9 kilometers long and reaches an elevation of 4 meters. Sand Island is 2.7 kilometers long and 13 meters high. The reef forms a nearly continuous wall except on the northwestern side. In places the reef rock extends as much as a meter above sea level. This has been attributed to a recent downward shift of sea level from a stand of the sea about 1.5 meters above the present one (Stearns, 1941, 1961; Ladd, Tracey, and Gross, 1967). Considerable portions of the platform at present sea level appear to have been formed by wave erosion of the older reef. A wave-cut nip is well developed on the lagoon side of the high reef remnants.

For more than a century we have believed that the coral reefs of the mid-Pacific rest on volcanic pedestals, but only recently has this belief been proved correct. First, geophysical evidence indicated that the limestone rests on volcanic rocks at relatively shallow depths; more recently, drilling through the limestone has brought up actual samples of the volcanic rock. The latest of these drilling sites is Midway. During 1965 two holes were drilled, one on Sand Island and the other at the reef on the northern edge of the lagoon. From these drill cores can be read the geologic history of Midway (Ladd, Tracey, and Gross, 1967). Both holes went through the limestone into underlying olivine basalt. In the Sand Island hole the top of the basalt was reached at a depth of 55 meters, and in the reef hole at 378 meters. Overlying the basalt are conglomerates of basalt cobbles and pebbles and volcanic clays, and these in turn are overlain by limestone. In the reef hole 51 meters of volcanic clays, some of them lignitic, were deposited under swampy conditions, and above these is 150 meters of reef limestone of early Miocene age (approximately 20 million years ago). The reef then emerged above sea level and was exposed to erosion



until late Miocene time (about 12 to 14 million years ago), when it again subsided and more than 300 meters of lagoonal limestone was deposited. The slow accumulation of limestone in the lagoon continued for several million years, into early Pleistocene time, when submergence became more rapid. Another 45 meters of limestone was deposited before the reef again emerged, this time presumably because of lowered sea level caused by the continental glaciation. Again the surface of the reef was eroded, but this was followed by resubmergence and deposition of another 60 meters of reef and lagoon limestone. This is the history read from the Midway drill cores.

#### KURE

Kure Island (also known as Ocean Island) is an atoll much like Midway. The ring reef is oval (fig. 23.8B), with a length of 9.5 kilometers and a width of 6.5 kilometers. The lagoon has an entrance nearly 1.5 kilometers wide on the southwest side.

Three sand islands lie near the southern edge of the lagoon. On the largest of these, Green Island, there are sand dunes as high as 6 meters above sea level. The most westerly island reaches a height of 3 meters.

#### VOLCANIC ACTIVITY

Before leaving the Northwestern Hawaiian Islands, mention should be made of an apparent volcanic eruption in the area in 1955. On August 20, persons aboard a plane bound from Tokyo to Honolulu sighted what appeared to be a column of smoke rising from the ocean about 90 kilometers N 85° E of Necker Island. On close approach they saw an oval patch of steaming turbulent water about 1.5 kilometers across, surrounded by a thin line of yellowish surf, with yellowish water drifting away from it. Near one end of the oval was an area of several thousand square meters of what looked like dry land. This probably was a raft of floating pumice which soon became waterlogged and sank. By the

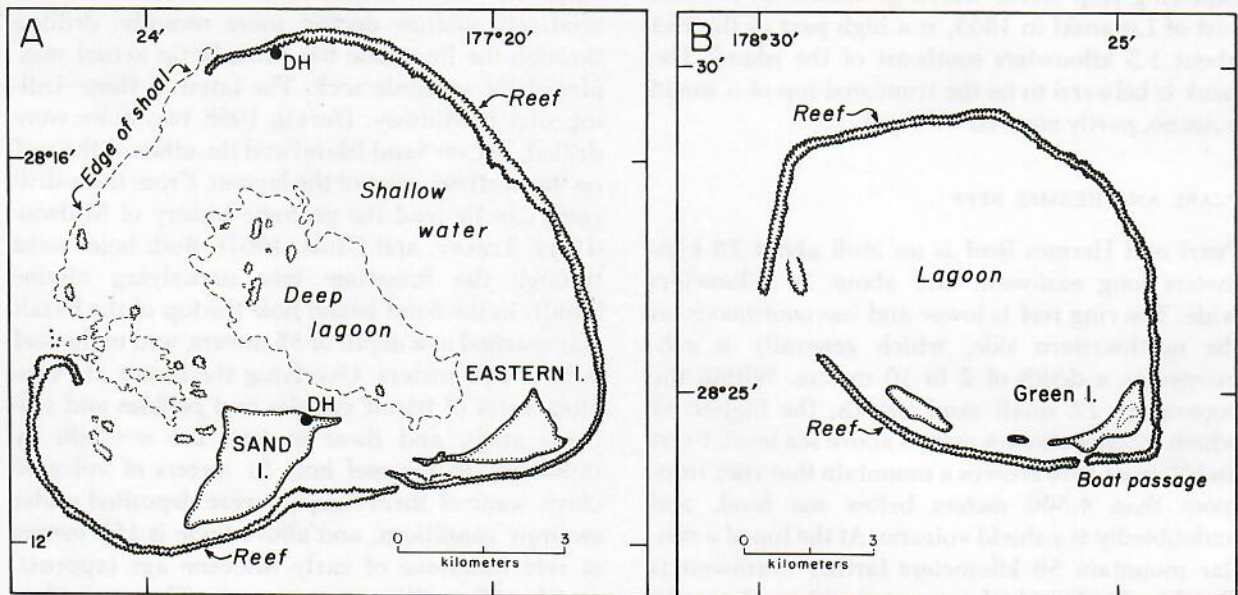


Figure 23.8. Maps of (A) the Midway Islands and Atoll; (B) the Kure Atoll. (After charts of the U.S. Navy Hydrographic Office.)



Figure 23.9. Eastern Island, Midway Atoll from the west. The Midway lagoon is to the left.

next day, when other planes visited the area, there were no further signs of disturbance other than a slick appearance of the water surface in the formerly turbulent area and a series of long swells sweeping outward from it nearly to Kauai. The locus of the eruption lies just north of the Hawaiian Ridge on the northeastward projection of the Mid-Pacific Mountains and the Necker Ridge (fig. 23.1), in a

depth of about 3,600 meters of water. This is the only volcanic activity which has occurred in the northwestern part of the Hawaiian chain in historic time.

*Suggested Additional Reading*

Bryan, 1942; Ladd, Tracey, and Gross, 1967, 1969; Palmer, 1927, 1936; Washington and Keyes, 1926

PLATE 30. La Perouse Rock, a small volcanic remnant at French Frigate Shoals, Northwestern Hawaiian Islands.



PLATE 31. Laysan Island, a coral reef that is the largest of the Northwestern Hawaiian Islands.



PLATE 28. Waimea Canyon, southwest Kauai, during a period of prolonged rainfall.



PLATE 29. Eroded Koko Crater, Oahu. Hanauma Bay is in the foreground.

S E C O N D E D I T I O N

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# *Volcanoes in the Sea*

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