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A RECONNAISSANCE SURVEY OF PHOSPHATE DEPOSITS IN THE GILBERT AND ELLICE ISLANDS.

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SUMMARY

A reconnaissance of the low atolls and reefs of the Gilbert and Ellice Islands showed that small deposits of phosphate occur on many of the islands, particularly in the drier Gilbert group. The deposits all consist of a thin surface layer or crust of phosphatized lime sand. The unconsolidated sands composed of foraminifera and reef debris have been cemented and partly replaced by phosphates derived from accumulations of avian guano. The grade of the deposits is not high and the deposits are small, patchy and widely scattered, and are of no economic importance. The phosphatization is believed to be a relatively recent event.

INTRODUCTION

A reconnaissance survey of the Gilbert and Ellice Islands was carried out during 1959 as part of the Bureau of Mineral Resources' search for phosphate deposits in the Western Pacific. From the beginning it was recognized that these flat, low-lying atolls and table reefs offered very poor prospects of workable deposits, but their relatively isolated position in the vicinity of the organically productive South Equatorial current and the comparatively dry climate of many of the islands made their inclusion in the phosphate survey desirable. It was known also that many of the islands had been visited by guano prospectors in the 19th century, but no records seem to have been preserved. More recently, small amounts of phosphate and doubtfully phosphatized sand were recorded by Catala (1950) and Cloud (1952).

The Gilbert and Ellice Islands form a long north-north-west trending chain of atolls and low lying reefs between latitudes 4°N. and 11°S. and longitudes 172°E. and 178°E. Tarawa atoll, the main port of entry and administrative centre of the colony, which includes also the Phoenix Islands, Christmas, Fanning and Washington Island and Ocean Island, is 1200 miles north of Suva and 240 miles east of Ocean Island. Access is normally through Ocean Island which is well served by British Phosphate Commission ships, but communications within the colony are infrequent and irregular.

CLIMATE

The climate of the islands is warm and fairly humid, but pleasant. The prevailing winds are easterly, with occasional strong westerlies between November and March. The rainfall is very variable. In the Gilbert group annual rainfall ranges from a few inches to 150 inches. The northern Gilberts, Makin, Butaritari, Marakei and Abaiang, generally have the heaviest rainfall, but even these islands are subject to serious droughts sometimes lasting for several years. From the available figures droughts seem to affect all of the group rather than individual islands. As an example of the extreme variability of the rainfall, the annual figures for Kuria, in the central Gilberts, for the years 1954 to 1958 are: 22.13, 8.84, 19.91, 78.23 and 109.72 inches.

The Ellice group farther to the south has, in general, a heavier and rather more reliable rainfall. Although the severe droughts of the Gilbert Islands are reflected in the rainfall figures for the Ellice group actual droughts are rare.

Island	Latitude	Phosphate Deposits
Makin	3°16'N	v small
Butaritari	3°02'N	not known
Marekei	2°03'N	small
Abaiang	1°45'N	not known
Tarawa	1°20'N	trace
Maiana	1°00'N	v small
Abemama	0°23'N	5 - 10,000 tons
Kuria	0°14'N	originally fairly large
Aranuka	0°12'N	not known
Nonouti	0°40'S	not known
Tabiteuea	1°15'S	50 00 tons
Beru	1°20'S	not known
Nikunau	1°21'S	nil
Onotoa	1°47'S	small (?)
Tamana	2°29'S	200,000 tons
Arorae	2°39'S	? 1000 tons
Nanumea	5°39'S	trace
Niutao	6°06'S	nil
Nanumanga	6°18'S	nil
Nui	7°16'S	3000 tons
Vaitupu	7°30'S	35.000 tons.
Nukefetau	8°00'S	5000 tons
Funafuti	8°31'S	trace
Nukelaelae	9°22'S	nil.

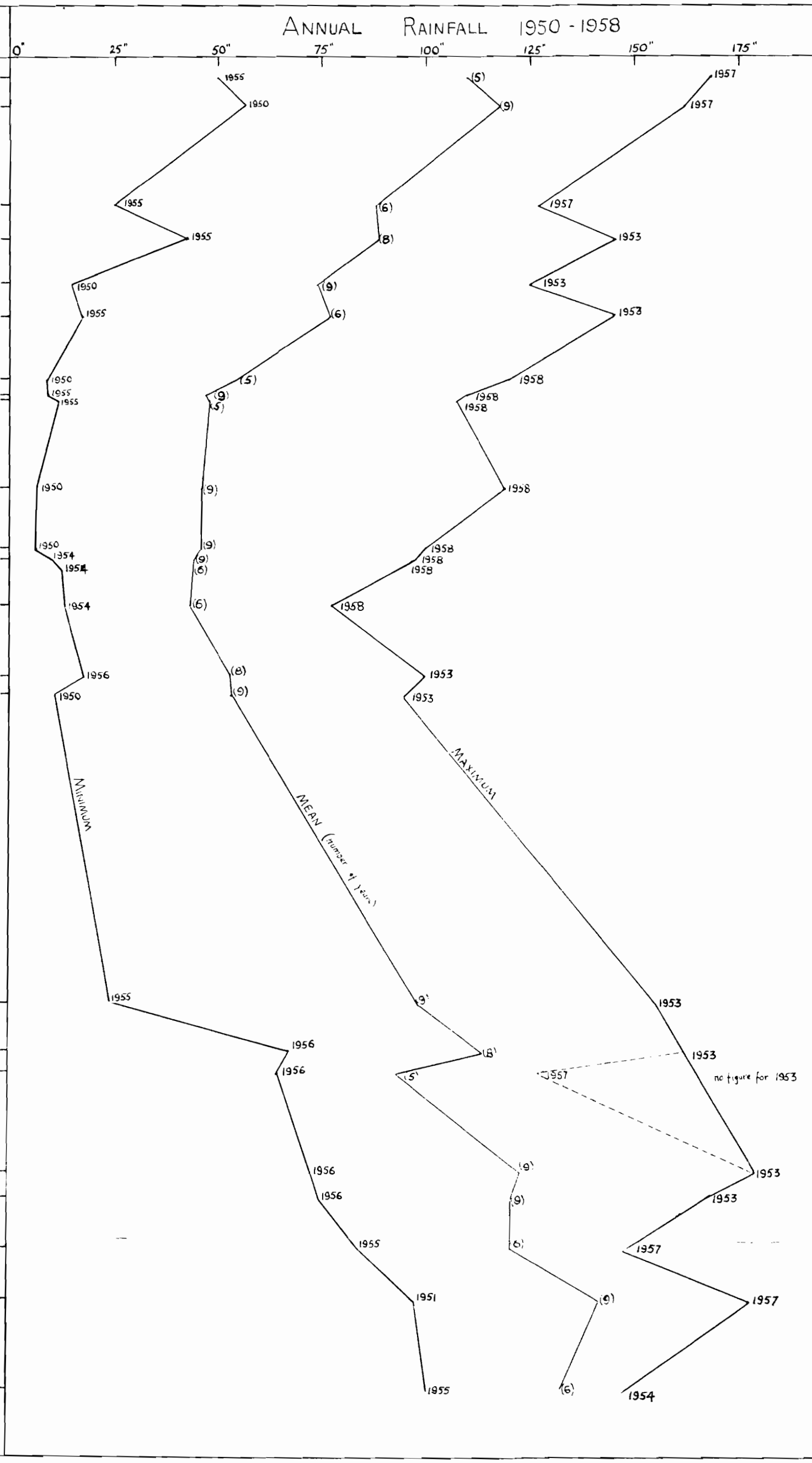

Figure 1

The accumulation of avian guano and the formation of deposits of calcium phosphate by the interaction of solutions leached from the guano and calcium carbonate is thought to be seriously affected by rainfall. Hutchinson (1946) has shown that with an annual rainfall of more than 2000 mms. (85 inches) it is unlikely that any phosphate would remain, and that with a rainfall of 1000 mms. (42 inches) it is unlikely that deposits of any appreciable size would be found. The Ellice Islands normally have a rainfall exceeding 85 inches and the mean annual rainfall in the Gilberts appears to approach closely the lower figure (42 inches).

Rainfall figures for the years 1950 to 1958 are given in Table I, and annual maximum, minimum and mean rainfall for these years is plotted as a function of latitude in Fig. 1, with the location of phosphate deposits shown.

SCOPE OF THE SURVEY

The Gilbert islands comprise 16 atolls and table reefs and the Ellice Islands nine. The atolls range from 2 or 3 miles in length to over 30 miles and are generally of very irregular shape. Land area is small, consisting usually of a narrow strip or a chain of small islets, usually only on the east (windward) side of the atoll, the westward reef being submerged. The table reefs, of which there are four in the Gilbert group and three in the Ellice, appear to have been small atolls in which the lagoon has become filled, or almost filled with calcareous sediments and reef debris.

Twenty of the twenty-five islands were visted during the present survey. Of the Ellice Islands only Nuilakita was not visited. In the Gilbert Islands it was not possible to get to Nonouti and Beru; Butaritari was visited by night only, and an attempt to reach Aranuka by canoe from Kuria was defeated by bad weather.

The time available for the investigation on the islands visited varied from two hours to two weeks and depended mainly on the available shipping in the area. As far as possible a longer visit was made on one island of each type (atoll and table reef) in each of the distinct rainfall belts. Thus, a fairly thorough examination was made of Tamana and Tabiteuea in the southern Gilberts, of Kuria and Abemama in the central, and Marakei in the northern Gilbert, and of Nanumea and Nui in the wetter Ellice Islands.

Sufficient time was available on most of the other islands for a reasonable assessment of the phosphate potentialities to be made.

The investigation attempted on each island involved an examination of the land surface for signs of phosphatization and drilling of hand auger holes to water level in likely areas or to obtain information on the subsurface material. In most cases observations were plotted on enlargements made from Admiralty chart No. 731, with topographic corrections made by tape and compass survey.

Samples were assayed in the field by rapid colorimetric method using ammonium molybdate and benzidine which gave an accuracy of $\pm$ 5%. A representative number of samples has now been checked by more accurate laboratory methods and found to be within the range given by the field method.

TABLE I

GILBERT AND ELLICE ISLANDS COLONY

ANNUAL RAINFALL

STATION	1950	1951	1952	1953	1954	1955	1956	1957	1958
LITTLE MAKIN					77.23	52.06	106.92	168.81	147.04
BUTARITARI	56.86	153.83	149.05	157.77	119.01	60.35	90.13	159.94	158.87
MARAKEI				124.42	70.71	25.57	65.78	127.21	107.20
ABAIANG		87.33	97.53	146.20	71.08	42.99	48.38	111.90	98.90
TARAWA	15.34	103.88	73.55	124.73	50.47	25.42	38.89	120.97	116.82
MAIANA				146.99	51.24	18.54	23.35	112.46	114.11
KURIA					22.13	8.84	19.91	79.23	109.72
ABEMAMA	7.69	78.90	49.00	84.68	31.27	12.33	19.55	86.90	119.15
ARANUKA					16.41	11.67	17.70	87.59	107.88
NONOUTI	6.46	47.43	40.90	84.74	18.40	10.95	12.05	76.09	118.27
TABITEUEA	6.67	55.98	40.13	71.90	24.88	17.08	11.43	84.28	101.15
BERU	9.77	61.35	45.43	61.56	12.95	15.24	17.15	72.14	97.51
NIKUNAU				73.03	13.78	16.75	14.24	72.53	95.97
ONOTOA				64.78	12.48	19.97	15.35	72.10	77.66
TAMANA		70.51	60.09	99.92	20.22	27.65	17.04	69.85	58.08
ARORAE	11.43	82.79	67.93	95.09	17.79	23.55	17.11	66.57	95.96
NANUMEA	79.25	99.29	111.04	155.23	97.27	23.57	58.08	121.91	141.99
NIUTAO	84.98		122.77	163.90	110.22	74.69	67.42	144.37	143.87
NANUMANGA					92.03	66.91	64.75	115.98	127.42
NUI	98.16	124.64	142.64	178.93	122.47	93.80	72.08	148.58	129.27
VAITUPU.....	74.52	104.19	157.27	167.50	120.78	98.02	80.90	143.65	148.92
NUKUFETAU				118.07	127.66	84.81	103.30	148.19	144.68
FUNAFUTI	99.66	98.81	143.20	166.74	135.88	160.89	116.46	178.87	176.72
NUKULAELAE				142.59	147.54	100.44	119.69	141.05	145.84

PREVIOUS INVESTIGATIONS

No records of their findings appear to have been left by the guano prospectors of the late nineteenth century who undoubtedly visited these islands prior to the discovery of rock phosphate on Ocean Island. Nuilakita, in the extreme south of the Ellice group was apparently worked for guano about the end of the last century, but no records of production are available. Later the island was taken over as a plantation and was densely planted with coconuts.

Sollas and Edgworth David (1904) recorded the presence of phosphate in swamps and in a limestone conglomerate on Funafuti. Catala (1950) in a general survey of the Gilbert Islands recorded trace of phosphate near Bikenebue on Tarawa atoll but does not appear to have noticed it on any of the other islands visited. Cloud (1952) in the course of a detailed investigation of the reefs of Onotoa recorded "indurated, phosphatized (?) limesands (old dunes)", but gave no indication of the extent of this material.

The occurrence of phosphate of similar appearance to that occurring on Ocean Island is, however, well known to the people of the islands.

THE PHOSPHATE DEPOSITS

Deposits of calcium phosphate were found on three islands in the Ellice group and on ten of the Gilbert Islands. In addition, small deposits are known to occur on Funafuti, but were not seen during the present survey, and several of the islands not visited may also have small deposits.

All the deposits examined, with the exception of a small fresh guano deposit on Tabiteuea atoll, are essentially very similar. They have been formed by phosphatization of a thin surface layer of the calcareous sands and gravels forming the islands, producing a relatively tough, coherent crust composed of tricalcium phosphate and calcium carbonate.

The phosphatic material is typically a pale to dark brown porous rock with a distinctly oolitic appearance. It is light in weight and rather friable in the hand, but in the mass it is fairly tough and tenacious. It is composed of round to ovoid grains usually one or two millimeters in diameter, but occasionally coarse, with more angular fragments of shell, coral and coralline algae. In general the rounded grains are predominant, but in some examples finely comminuted Halimeda debris forms the bulk of the rock. Deposits of the latter type commonly contain a fairly large proportion of coarse coral gravel.

The grains are loosely cemented by pale brown to reddish-brown, more or less translucent collophane, which has also replaced much of the finer fragmentary material. Under the microscope the rounded grains show no trace of concentric or other oolitic structure other than a thin outer rim or shell of darker, iron stained collophane. Many of the grains, however, are incompletely replaced and it is clear that while some of them represent small abraided coral fragments the majority are small foraminiferal tests, the commonest being the reef-dwelling form Calcarina.

The percentage of unreplaced calcium carbonate varies considerably from deposit to deposit and within a single deposit, the unreplaced cores of small grains giving the rocks a characteristic speckled appearance and reacting vigorously with

acid. In a few instances, such as the southern deposit on Vaitupu Island, the original sand was fine and probably contained a high percentage of lime sand. In these cases replacement by collophane is more complete than in the uniformly coarse sands, but the percentage of phosphate in the deposit as a whole is kept low by the amount of scattered coarse shell and coral gravel embedded in the fine groundmass.

The grade of all the deposits is remarkably uniform. Most of them carry between 15% and 20% P_2O_5 (determined by field assay) and any variation from this range can usually be attributed directly to the amount of unaltered coral gravel present (where coarse coral gravel was present it was not possible to include this in the sample assayed). The percentages of iron and alumina present were not determined, but, judging from the very small insoluble residue left after dissolving the samples in dilute hydrochloric acid, these are small.

The deposits examined vary considerably in size, from a few tons to a few thousand tons. This is, without exception, a function of areal extent rather than thickness, the mean thickness of each deposit being almost identical. The actual thickness of any one deposit varies from a few inches to 25 to 30 inches, often within a very short distance, but the mean thickness in each case is around 10 to 12 inches. The continual and, in places, sudden changes in thickness are due to a very irregular lower limit of phosphatization, the upper surface of the deposits being flat. The reasons for this are not clear, but may be related to the position of suitable nesting trees at the time of guano accumulation.

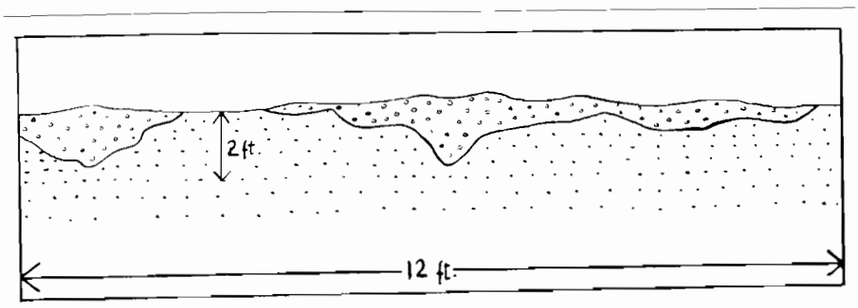

FIGURE 2.

Figure 2. Sketch cross-section of phosphate deposit at Kabangakei, Abemama atoll, from well and test fit section.

The base of the zone of phosphatization is commonly sharp, with an abrupt change from the coherent phosphate rock to unconsolidated sand. In some deposits it is gradational over four or five inches, due, it is believed, to the continued dampness of the surface brought about by a thick cover of natural vegetation.

In only one instance, on Arorae, was a deposit buried, and in this case the thin cover of sand was almost certainly scattered over the deposit during the excavation of nearby babai* pits. Nor is there any evidence that the deposits have been eroded since their formation, and the often patchy distribution of the phosphatized sand, with areas of loose sand between outcrops must be very largely an original feature.

Downward leaching of phosphate by percolating rainwaters, and reprecipitation at the water table is not much in evidence. A calc-arenite rock at the water table on Tamana was found to be weakly phosphatic but elsewhere no phosphate was recorded below the base of the surface crust. This was so even in the case of those damp deposits which have a gradational base.

Small deposits of fresh guano was found to be accumulating on Tenon and Namurae islets, Tabiteuea atoll, but no phosphatization of the underlying calcareous material was apparent. A similar guano deposit on Numatong islet, Nonouti atoll, was not examined.

THE GILBERT ISLANDS

TAMANA

Lat. 2°29'S; long. 175°58'E.

Tamana lies in the extreme south of the Gilbert Islands, some 300 miles south-east of Tarawa, and is typical of the small table reefs or "reef islands" of the southern Gilberts and northern Ellice Islands. It also contains the largest phosphate deposit in the group and was therefore investigated in more detail than the other islands.

The island is just over three miles long and three-quarters of a mile wide with the long axis lying west-north-west. It is bordered by a wide fringing reef consisting of a broad zone of algal flats with a prominent, slightly raised lithothomnium ridge, cut by numerous surge channels, at its seaward edge. Inside the reef the island is encircled by a broad, flat storm beach, 12 to 14 ft. above mean sea level, the interior of the island forming a shallow saucer shaped depression which is deeper and more marked in the south-eastern half of the island.

A well developed boulder rampart forms the outer part of the storm beach at the southern end and extends northwards, along both sides of the island, for more than a mile, becoming progressively thinner and lower. The boulders, which are entirely of coral, are fairly uniformly about 12 to 15 inches long and are oval shaped and slab-like. They are tightly packed and form a steep seaward slope. Towards the north the boulders become smaller in size and the boulder rampart passes laterally into the normal coral gravel and sand storm beach. At the extreme southern end of the island a second, smaller boulder rampart, representing an earlier storm beach, occurs 50 to 100 yards inside the later one.

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* babai: a root vegetable similar to taro and grown in swamps and pits.

In the south of the island the wide flat central depression is no more than one to two feet above the high tide level. Damp black humic soil overlies a thin layer of loose gravel and pebbly sand and the water table is, in places, only a few inches below the surface. The area is wet and swampy following high spring tides.

In the northern half of the island the average elevation is slightly higher. Along the east side, directly behind the storm beach there is a broad shallow "trench", extending northwards from the low lying southern area, in which a dark damp humic soil overlies loosely cemented coral gravel. To the west of this the ground slopes gently up towards the western storm beach and the loosely cemented coral gravel and sand at the water table is overlain by an increasing thickness of unconsolidated, clean foraminiferal sand on the top of which most of the phosphate occurs.

The typical crust of phosphatized sand forms patches from a few feet to several hundred square yards in extent and varies in thickness from an inch or two to just over two feet. That it formerly covered most of the northern half of the island is shown by the widely scattered blocks and fragments of phosphatized sand on the surface and in the sand excavated from the babai pits, and by the weakly phosphatic nature of the spongy black humic soil between outcrops of phosphatized sand (Plate 1).

The phosphatic material is uniform in appearance and field assays indicated a fairly uniform grade of between 15% and 20% P_2O_5. There is little coarse shelly material and when gravelly layers are included in the phosphatized zone, the coral fragments are unaltered. The lower limit of phosphatization is generally sharp and clear cut, but very irregular with no sign of a gradation into the underlying unaltered sand.

The underlying loose sand and thin gravel layers of which the island is formed, are near the water table, loosely cemented by calcium carbonate to form a relatively tough calcarenite which extends for several feet at least, below the water table. In those areas where the phosphatic crust is well developed the topmost portion of the calcarenite is weakly phosphatic due, apparently, to reprecipitation, at the water table, of phosphatic solution percolating down from the surface deposit. In places the calcarenite assayed as much as 10% P_2O_5, but was generally much lower in phosphate. By carefully crushing a sample of phosphatic rock and separating the shell and gravel fragments, it was shown that the phosphate is largely confined to the cementing material; no replacement of the detrital fragments could be detected. Despite a careful examination of all the babai pits however and the excavation of several large test pits, no compact layer of good grade, chemically precipitated amorphous collophane, such as is commonly found under phosphate deposits, could be found.

Typical sections, from pits and test holes, and an approximate profile across the northern half of the island are shown in Figure 3.

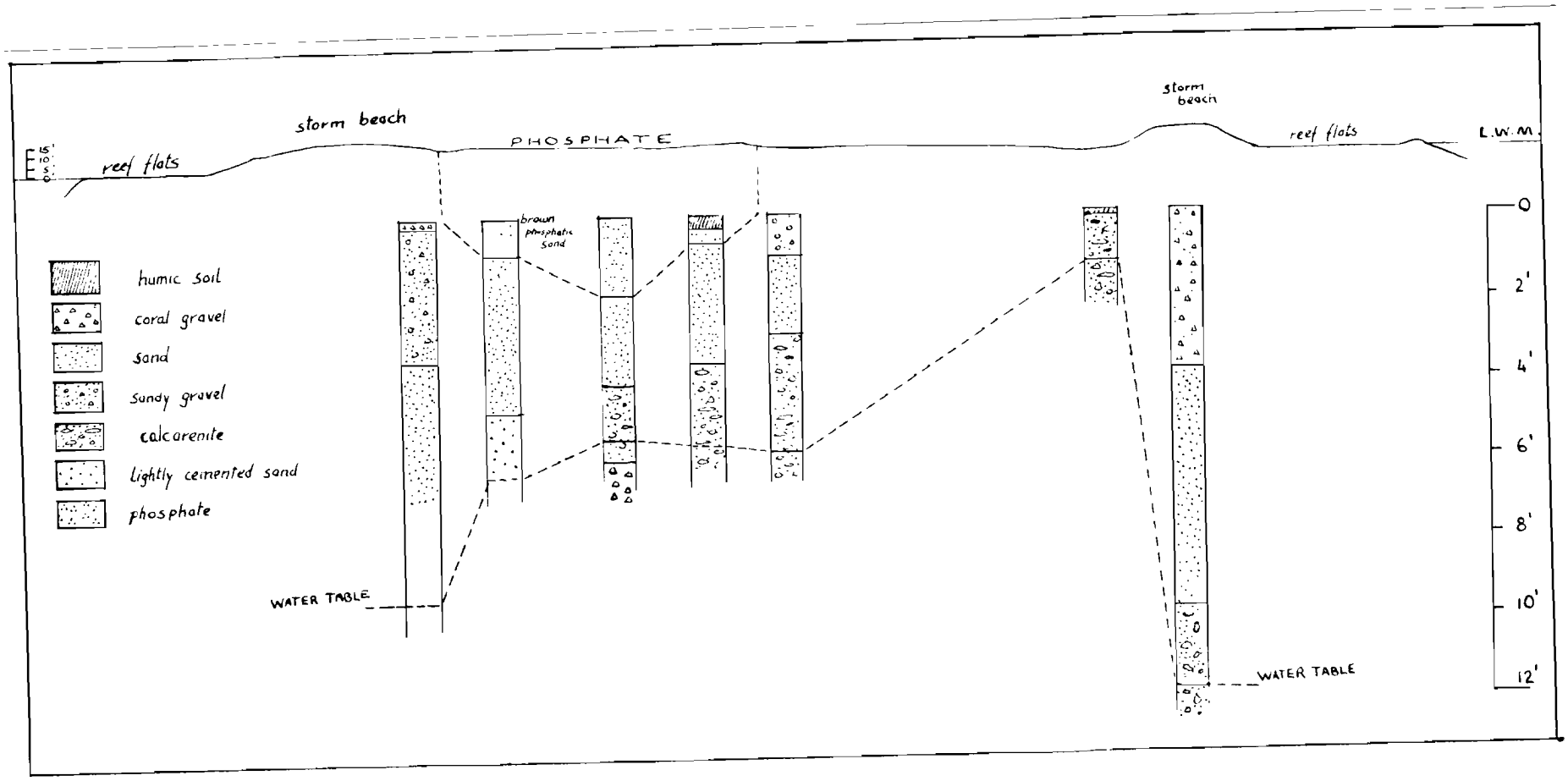

FIGURE 3

Figure 3. Surface profile and vertical section, Tamana Island.

The phosphatic crust extends, in the southern half of the island, for a short distance to the south of the trench between the government station and the hospital, but is thin and irregular. The remainder of the southern half is low-lying and, in part, swampy, with a thin black humic soil overlying loose gravel and pebbly sand. Neither the sands and gravel, nor the black soil contain any detectable trace of phosphate.

Estimation of the tonnage of phosphatic material is made difficult, in a deposit such as this, by the very irregular thickness of the deposit and by the large number of man made excavations which have broken through the phosphatic zone into the underlying sand. Assuming, as seems reasonable, that the phosphatized sand was originally continuous over most of the northern half of the island, then drilling and pitting results suggest that the average thickness was about 12" and the total tonnage of phosphatic material approximately 200,000 tons containing 15 to 20% P_2O_5. However, allowing for the patchy nature of the deposit, the very variable thickness and the large areas now or in the past under babai cultivation, it is doubtful if even half this figure could ever be extracted. Mining and handling of the phosphate would be difficult due to the patchy nature of the deposit, and the high calcium carbonate content would make treatment expensive and direct application ineffective. It is not recommended that any attempt be made to utilize this phosphate, even for local use.

ARORAE Lat. 2°39'S; long. 176°49'E.

This, the most southerly of the Gilbert Islands, is approximately 6 miles long and 1½ to 2 miles wide. It is a typical "reef island", very similar in form to Tamana. It is made up largely of fine unconsolidated sands with coarse gravel layers and is encircled by a low, sandy, storm beach and a wide fringing reef.

Towards the northern end of the island, some two miles north of the government station, a thin crust of phosphatized sand and gravel occurs over an area of about 400 square yards. The crust is a few inches to 10 to 12 inches thick. It is partly buried under a layer of loose sand and gravel, but this appears to have been thrown up from nearby babai pits, and is not a natural feature.

Near the northern end of the deposit a section exposed in a shallow trench illustrates the irregular nature of the deposit (Fig. 4). In this section the base of the deposit is clear-cut except in the deeper portions where the phosphatized sand grades into unaltered sand. This may be related to the position of nesting trees at the time of deposition of the guano.

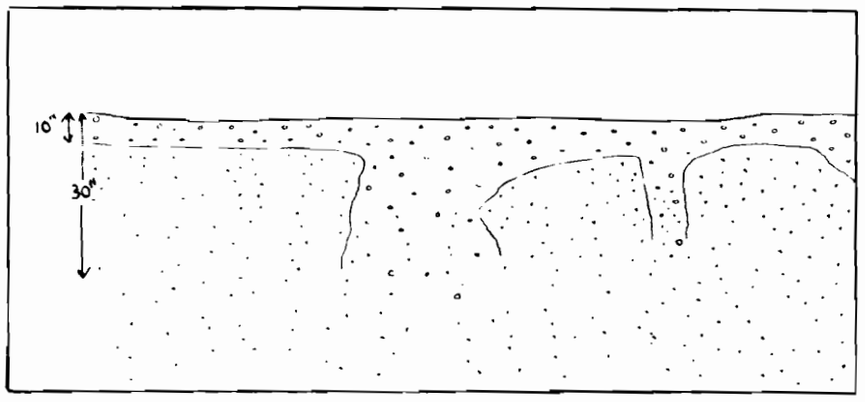

FIGURE 4

Figure 4. Sketch section of phosphate deposit, Arorae Island.

The grade of the phosphate is relatively good at round 20% P_2O_5, but the tonnage available is negligible.

The southern part of the island was not examined, but local inhabitants knew of no phosphate deposits on the island apart from that described above.

NUKUNAU Lat. 1°20'S; long. 176°28'E.

Nukunau is a reef island or table reef, approximately eight miles long by one mile wide, with the long axis lying north-west - south-east. The island is low-lying and sandy, with a wide fringing reef and a low, poorly defined storm beach. There is a small, shallow, completely land-locked

lagoon at the northern end.

The central section of the island, a distance of 5 miles south of the northern lagoon is made up of loose sands and coral gravel. Coarse gravel with scattered large blocks of coral occurs near the government station, but gives way, towards the south, to fine, loose, slightly angular coral-foraminiferal sands. At the surface the sand shows much evidence of redistribution by wind, and auger holes drilled to just below the water table were still in loose sand, suggesting that this island may be somewhat younger than others in the group.

No trace of phosphatization was seen, but the extreme northern and southern ends of the island, which may be older than the narrower, sandy central section, were not examined.

(please see10a)

TABITEUEA — Lat. 1°15'S; long. 174°45'E, at Peacock Anchorage

Tabiteuea is an elongated, irregularly shaped atoll and one of the largest in the Gilbert Islands. It is approximately 30 miles long in a north-westerly direction and to 12 miles wide.

The eastern (windward) reef is occupied by a great many small, sandy islands with the longer, but narrow, islands of Eanikai and Nuguti at the northern and southern ends. The lee reef, which is entirely submerged, is close to the windward reef at the northern end, forming a long, narrow, shallow lagoon, but opens out towards the south to enclose a lagoon some 6 to 10 miles wide. There are two passes into the southern lagoon.

The northernmost island, Eanikai, is seven miles long and has a greatest width of half a mile. It is low lying, with only a poorly defined storm beach, and is made up of unconsolidated reef debris; foraminiferal and shelly sand, coral sand and gravel and, in the lower lying parts, lime mud. At its northern end Eanikai sweeps round in a westerly direction to enclose the small shallow lagoon "Te Kapuipui" which, like the extensive flats around it, is floored by foetid lime mud and fine sand.

About half way along Eanikai, close by the village of Buota, there is a small deposit of the typical phosphatized sand. It occurs as a series of small, low outcrops over an area approximately 600 feet in diameter and has a maximum thickness of only 18 inches. The phosphate content as determined by field assays is 18% P_2O_5 and the total tonnage of phosphatic sand is of the order of 5000 tons.

Between the outcrops the unaltered loose sands are covered by a thin layer of black oolitic looking humic soil which is weakly phosphatic and was probably derived, in part, from phosphatized sand. A similar black soil, also weakly phosphatic, extends for a considerable distance beyond the phosphate deposit and, at one point, was drilled to a depth of 5 feet. This soil appears to have a considerable influence on the vegetation and the cultivation of coconuts, the people of Eanikai claiming that coconuts do not normally grow well at Buota, but that in times of severe drought Buota is the only village with a plentiful supply of nuts.

ONOTOA Lat. 1°47'S.; long. 175°29'E.

Onotoa is the southernmost of the true atolls in the Gilberts and lies in the dry belt. A very thorough investigation of the atoll was made by Cloud (1952), who recorded the presence of "indurated, phosphatized (?) limesands".

The localities at which these indurated sands occur are not shown on Cloud's map and they were not found by the present survey in the few hours that were spent here. It seems likely, however, that the indurated limesands referred to are indeed the crust of phosphatized sand seen on the other islands, as no other truly indurated deposits were seen at the surface anywhere in the group, except where the water table reaches the surface. It is unlikely that any considerable tonnage is available since the occurrence is apparently too limited to be shown on Cloud's very detailed map.

The chain of small islets to the south of Eanikai is mainly sandy and no trace of the typical phosphatized sand was found. On the uninhabited islets of Tenon and Namurae, however, just south of Aiwa about half way down the atoll a small quantity of fresh guano is being deposited at present by breeding sea birds. Both these islets are flat and low-lying and are formed almost entirely of coarse coral debris without any soil. A few coconut palms have been planted but there is no intensive cultivation. On the eastern (windward) side of both islands there are small stands of large, spreading Pisonia trees (P. grandis ?) in which large numbers of sea birds, chiefly noddies, with fewer frigate birds, roost. Beneath the trees the ground is carpeted with a thick spongy layer of black or darker brown humus containing a large proportion of guano. Pebbles, coral fragments, tree branches, etc., are commonly whitened by the bird droppings, but otherwise the deposit has the appearance of a normal acid humus deposit some 6" to 12" thick. Rough field assays however, showed that the P_2O_5 content varied from 5% to nearly 20%. Distribution of the material is patchy, being thickest directly under the trees and thinning out to almost nothing between trees in much the same way that the thickness of the phosphatized sand deposit varies. The base of the deposit is sharp and clear, and there is no evidence of any replacement of the underlying coral gravel by phosphate. This may be partly due to the coarseness of the gravel.

The southernmost islet, Nuguti, was not visited.

ABEMAMA — Lat. 0°23'N; long. 173°55'E.

A roughly rectangular atoll approximately 15 miles long and 6 miles wide. A narrow strip of land, half a mile wide, occupies the reef on the eastern side, broken only by narrow, shallow channels at Binoinano and Tebanga. Only two small islands, Bike and Abatiku lie on the western reef, in which there are two ship passes.

Most of the land on the eastern reef consists of the typical loose foraminiferal and coral sands some 8 to 10 feet thick and resting on solid reef. Close to the water table which is seldom more than about 12" above sea level, the sand is commonly cemented to a coarse calcarenite.

Towards the south of the atoll, close to the village of Kabangakei, a series of low outcrops of phosphatized sand extends over an area approximately half a mile in diameter. The thickness of this material varies from a few inches to more than two feet, with an average thickness of approximately 15 inches. The outcrops are nearly continuous and it is estimated that there is approximately 5000 to 10,000 tons of phosphate containing 15 to 20% P_2O_5.

A small quantity of similar material was reported to occur on Bike, on the western side, but this was not examined. A few traces of phosphate found near Tebanga after a prolonged search proved to have been brought from Ocean Island for application to a former storekeeper's garden.

KURIA — Lat. 0°14'S; long. 173°29'E.

Kuria and the adjacent island of Oneke lie together on the one reef separated by only a narrow channel. Together they are five miles long and two miles in greatest width. Both

are typical reef islands, encircled by a broad storm beach with a lower central area underlain by loose sands and gravel. There is a small brackish lagoon at the northern end of Oneke.

On Kuria, the southern island, a broad zone along the western side is entirely covered by old babai pits. Most of them have collapsed and are now partly filled in, and, with the mounds of loose sand dug from them, give rise to a tract of hummocky country devoid of any vegetation except for clumps of salt-bush (Scaevola). Throughout this area many fragments and large blocks of phosphatized sand occur scattered over the surface, in the loose sand and in the pits. A few flat dabs of this rock are apparently in situ, and it seems likely that there was formerly an extensive thin crust of phosphatized sand over most of the western half of the island, but that it has been broken up, scattered and mixed in with the sand during the excavation and subsequent infilling of the babai pits. The old pits are almost entirely confined to this area which was probably more fertile than the rest of the island.

Possibly more than 100,000 tons of phosphate rocks formerly existed, but the amount now remaining in a recognisable form is negligible. Samples collected from loose blocks assayed 15-18% P_2O_5 and a brown humic soil from the sides of some pits and apparently derived from the phosphatic crust assayed 11% P_2O_5.

No trace of phosphatization could be found on the eastern half of Kuria or on Oneke and there is no sign of intensive babai cultivation in these areas.

MAIANA — Lat. 1°00' N.; long. 173°01'E.

Maiana atoll is rectangular, 10 miles long by seven miles wide, with the longer side lying north-west - southeast. The north-east and south-east sides of the rectangle are formed by a broad reef on which lies a continuous narrow strip of sandy land. On the north-west and south-west side the reef is awash at low tide and there is no break in the reef to allow ships to enter the lagoon. Three shallow passes in the north-east reef can be used by small vessels at high spring tides, but the lagoon itself is shallow and contains many patch reefs.

The islands on the reef are typically sandy, with a thin covering of black humic soil. There is a low storm beach on ocean and lagoon sides, the former composed largely of coarse coral gravel, with a very shallow, trough-like depression between them.

At the south end of the atoll, south of Bubetei village, where the reef is abnormally wide, there is a cluster of small islets on one of which several small patches of phosphatized sand occur on the surface. The deposit is thin and discontinuous and the tonnage of phosphate negligible.

It is interesting to note that this small occurrence is very well known to the islanders who have a legend regarding its origin. It is said to have been brought from Ocean Island by a powerful ghost.

TARAWA — Lat. 1°20'N.; long. 172°55'E.

Tarawa atoll, the administrative centre of the colony, is triangular in shape. It is 22 miles long and 9 miles wide

across the base of the triangle. The reef forming the southern and eastern sides of the triangle carries an almost continuous chain of small islets, but the western side is entirely submerged and is broken by two ship passes.

Along the southern side of the atoll some traces of phosphatization of the loose, shelly sand and coral gravel were noted near Bikenibeu, but the amount of phosphate is very small and much has probably been removed during the construction of babaipits, roads, etc.

A hard, compact layer of indurated, fine lime sand a few feet below the surface on Betio islet, and at Buota was found to be due to downward migration of oils used in the construction of wartime airstrips.

Islets to the north of Tabiteuea were not examined, but a very small amount of phosphatized sand is believed to exist near Buariki.

ABAIANG — Lat. 1°45' N.; long. 172°59'E.

Abaiang is a large, rectangular atoll, 16 miles long by 5 miles wide and elongated in a north-north-westerly direction. The wide reef on the eastern side is occupied by a continuous, narrow strip of low lying land formed of loose sand and coral gravel, stretching from the northern tip of the atoll to the southern boat passage, a distance of 20 miles. On the northern and western sides there are numerous small separate islands and many passes in the reef, several of which are navigable.

Less than two hours was spent on this atoll during which time no phosphate was observed. Small deposits reported to occur on some of the small islands on the western reef are probably the typical surface crust of phosphatized sand. From the little that was seen of Abaiang and from questioning of the local inhabitants it is reasonably certain that no large deposits exist.

MARAKEI — Lat. 2°03'N.; long. 173°25'E.

This is a small pear shaped atoll measuring approximately 5 miles by 3 miles. The narrow land rim is almost continuous, being broken by only two very narrow channels which are dry at low tide. The seaward margin of the rim has a wide rampart of coarse coral debris, while the lagoon beach is commonly low and swampy with a long narrow inner lagoon parallel to the shore.

Phosphate occurs as a fairly widespread but discontinuous surface deposit on the southern part of the atoll. The phosphatized foraminiferal and shelly sand, and sandy gravel forms several low outcrops 40 to 60 feet in diameter, but is more commonly represented by loose blocks and scattered boulders, the remnants of an originally continuous phosphatic crust. Traces of the phosphate rock are found for more than a mile along the atoll but it is largely concentrated on the lagoon side and probably not more than 50,000 tons originally existed. Of this only a small fraction now remains and very little of this is recoverable. Samples of the phosphatized sand assayed 20% P_2O_5, but the overall grade must be considerably less due to the great number of large unphosphatized coral fragments present.

A large number of sea birds (noddies and frigate birds) still roosts on this part of the island, but there does not appear to be any appreciable concentration of fresh nitrogenous guano, nor any trace of contemporaneous phosphatization.

A small patch of phosphatized sand reported to occur near the northern end of the atoll was not examined.

MAKIN (Little Makin or Makin Meang) Lat. 3°16'N.; long. 172°58'E.

Makin, the most northerly of the Gilbert Islands, is separated from the large atoll of Butaritari by a channel little more than a mile wide. Together with the small islets of Kiebu and Onne it lies on a narrow north-north-east trending reef that is virtually a continuation of the Butaritari reef.

Makin itself is a sandy reef island with slightly raised storm beach round the periphery and a shallow saucer shaped central area. There is a small enclosed lagoon at the northern end and much of the central area is swampy as a result of the excavation of very large, shallow babai pits.

No phosphate was seen on Makin, but fragments of phosphatized sandy gravel which had been carried from Kiebu for the fertilization of gardens were examined. This material assayed 15-20% P_2O_5. It was reported to occur as scattered fragments and small surface patches. Time did not permit a visit to Kiebu.

OTHER ISLANDS

Beru, Nonouti and Aranuka could not be visited during the survey due to lack of time and suitable transport. Butaritari was visited during the night, when no work was possible. All of these are low lying atolls on which no deposits of any greater magnitude than those already described can be expected. It is probable that small deposits do occur, but they are unlikely to be of economic importance.

THE ELLICE ISLANDS

NANUMEA Lat. 5°39'S.; long. 176°06'E.

This is the most northerly of the Ellice Islands. It is an atoll of roughly crescentic shape, with a very broad reef and a relatively small, shallow lagoon. There are two main islands on the reef; Nanumea proper in the south and Lakena in the north. The reefs connecting these islands are exposed at low tide, and the westerly or lea reef is partly covered by low sandbanks. The central portion of the lagoon is shallow, with many patch reefs some of which are dry at low tide. The entrance is narrow and difficult.

The main island, Nanumea, is V-shaped and forms the southern rim of the atoll. It is approximately three miles long and three-quarters of a mile wide and is low-lying and sandy. The maximum elevation of 12 ft. above mean sea level is on the storm beach on ocean side of the island. The lagoon beach, inside the V is shallow and muddy and shows evidence of rapid sedimentation by foraminiferal and shelly

debris and by precipitation of lime mud.

Lakena, in the north, is oval, about 2 miles long, and contains a small freshwater lagoon. The island is sandy and is so studded with babai pits that little, if any of the original surface of the island can be seen. Close to the small lagoon, however, traces of phosphatization, in the form of a few broken blocks and small fragments of phosphatized sand, were seen. Similar material is believed to have existed on Nanumea island, but was destroyed by construction of the wartime airstrip.

NANUMUNGA Lat. 6°18'S.; long. 176°20'E.

Nanumunga is a small table reef approximately 1 by 1½ miles in area, surrounded by a narrow, unbroken fringing reef. Maximum elevation is approximately 14 ft. above mean sea level, at the beach crest on the western (lee) side, which is several feet higher than the windward beach crest. From this encircling storm beach the ground drops gently towards two small brackish-water lagoons near the centre.

The island consists entirely of coarse loose coral and foraminiferal sands with infrequent gravel layers. Several auger holes were drilled to depths of 7 to 8 feet below which the sand was too loose for further drilling. Sections in a large pit near the eastern shoreline show that loose sands, containing a high percentage of foraminiferal tests, continue to well below groundwater level and below the level of the present fringing reef, suggesting that this table reef was formed by filling up of the lagoon of a small atoll with calcareous sediments.

No indication of phosphatization was seen.

NUITAO Lat. 6°06'S.; long. 177°16'E.

This triangular shaped table reef a short distance to the east of Nanumunga is similarly surrounded by a narrow, unbroken fringing reef and encloses a small brackish water lagoon. There is a well developed boulder rampart along the windward (east) beach and broad sandy storm beach on the lee side. The flat centre of the island is floored almost entirely by coarse coral gravel with scattered large blocks of coral. In places there is a thin cover, 3" to 6" thick, of gravelly humic soil.

No phosphate was found.

NUI Lat. 7°16'S.; long. 177°10'E.

Nui atoll is crescent shaped and some three miles long by one mile wide. There are two main islands situated at the north and south ends, with a chain of small islets strung out along the eastern reef. The western reef is awash at low tide, but supports several low sandbanks near the northern end. There is no entrance to the lagoon which is shallow and contains many patch reefs, and which shows evidence of infilling by deposition of calcareous debris and muds, particularly at the northern and southern ends.

Fanutapu, the largest island, is one and a half miles long and half a mile across at the widest point. It is roughly U-shaped, following the southern rim of the atoll. Maximum elevation is 14 feet at the beach crest on the ocean side, from where the surface slopes gently down to a low, indistinct storm beach on the lagoon shore. A measured profile across the island just south of the church is shown in Figure 5.

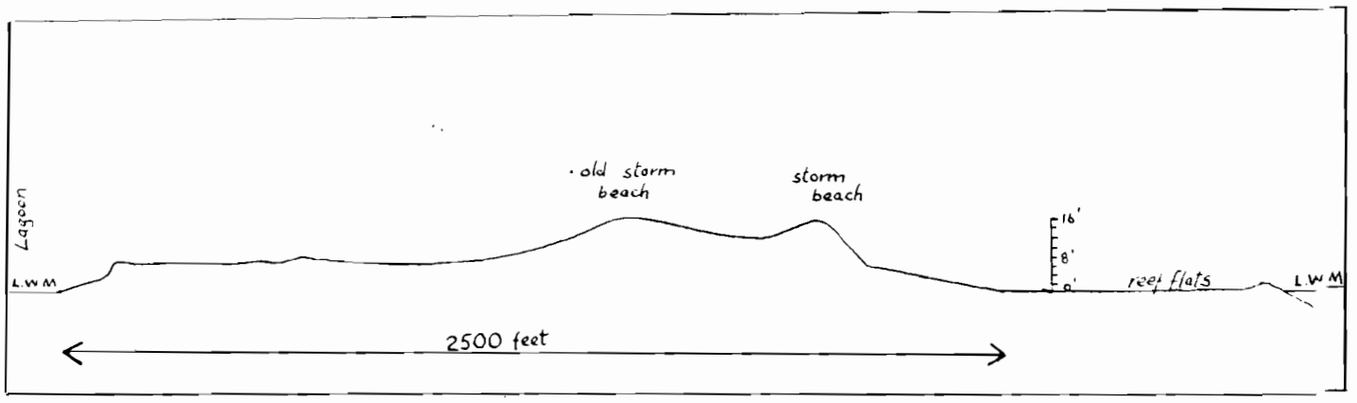

FIGURE 5.

Figure 5. Profile across Fanutapu Islet, Nui Atoll.

In the centre of Fanutapu, some three-quarters of a mile east of the village a small deposit of phosphatized sand occurs under a thick cover of "salt-bush". The material is the normal oolitic looking phosphate formed by replacement of coarse foraminiferal sand and differs from the typical deposits on other islands only in that the base of the deposit is everywhere gradational into the underlying loose sands. This is thought to be due to the thick cover of natural vegetation which keeps the phosphatized zone in a continually moist state permitting some downward leaching of the phosphate.

The deposit measures 300 feet by 250 feet and the average thickness is about 10 inches. Maximum thickness is 15 inches, but the base of the deposit is irregular and gradational. The tonnage available is approximately 3,000, containing 10-15% P_2O_5. Traces of similar material were found in gravelly sand 300 yards to the south-east of the village church.

The islets along the eastern side of the atoll are all small and of relatively recent origin. Many of them are partly submerged and swampy at high spring tides. Meang, the larger island at the north end of the atoll is completely covered by very large babai pits, many of them 100 to 200 yards across. Coarse sand and gravel dug up from the pits is heaped between them, and little of the original surface can be near. No phosphate other than that on Fanutapu was found.

NUKUFETAU Lat. 8°00'S.; long. 178°29'E.

Nukufetau atoll is almost square in shape, with sides measuring approximately 7 miles and the diagonal lying north-south. A very narrow, almost continuous strip of land occupies most of the south-eastern side of the atoll, with a large number of separate small islets on the north-eastern and south-western sides. There is a good ships' passage into the lagoon on the western side, and a good anchorage off Te Anamu, the only inhabited islet.

Only two islets were examined. Te Anamu, at the western end of the atoll is a low sandy islet almost entirely occupied by the village and adjacent babai pits. Coal Islet, a small sandbank near the entrance to the lagoon, measures 1,000 ft. by 500 ft. and is no more than 4 to 5 feet above mean sea level. Almost the entire surface of the islet is covered by a layer of phosphatized sand to an average depth of twelve inches. At the margin of the island this passes laterally into a tough calcareous beach rock dipping gently down the beach.

The phosphatic crust is fairly uniform in appearance and, although the island has been lightly planted with coconuts, it is completely undisturbed. The gradation into beach rock at the edge of the island shows that there has been little, if any, erosion of the surface of the island, but phosphatization is nevertheless patchy indicating that the original guano deposition was not uniform over the entire island.

Between 5,000 and 10,000 tons of phosphatic material are probably present, containing 15% P_2O_5, but the patchy distribution, unpredictable thickness and the thin cover of black humus reduce any estimate to little more than a guess.

VAITUPU Lat. 7°30'S.; long. 178°41'E.

Vaitupu is perhaps the most populous and productive of the Ellice Islands and probably owes its high productivity as much to an extensive, but thin, covering of phosphatic material as to its relatively high and reliable rainfall.

The island is roughly pear-shaped, about 3½ by 2 miles in size, and is surrounded by a broad fringing reef over which landing can be difficult in bad weather. There are two small lagoons, Te Loto at the northern end and Te Namo to the south. Both are landlocked with only a narrow, shallow entrance across the reef to the east. Both are bordered by wide flats of fine calcareous debris and lime mud.

Most of the island consists of coarse to fine, loose coral and foraminiferal sands, coarsest on the low storm beach surrounding the island and grading into very fine material near the lagoon edge. In the centre of the island, about half way between the two lagoons an area of approximately 75,000 square yards is covered with a thin crust of phosphatized sand. The material forms low blocky outcrops and is a few inches to 20 inches thick. The average grade as determined by field assays is 20% P_2O_5 and the total tonnage of phosphatic material is estimated at 25,000 tons.

In the south-east of the island, on the eastern shore of Te Namo, surface phosphatization is again apparent. It occurs over an area approximately 1,000 ft. in diameter

and the average thickness is about 8 inches. The material is, on the whole, finer grained and more compact than the other deposit, but contains much broken shell and fine coral gravel which is only partly phosphatized. The average grade for the bulk material is therefore lower at 10-15% P_2O_5. Estimated tonnage of this deposit is 10,000 tons, but, as with the northerly deposit, not all of this would be recoverable due to the shallowness of the deposit, the very variable thickness and patchy distribution, and to the heavy growth of vegetation rooted in the phosphate.

FUNAFUTI Lat. 8°31'S.; long. 179°12'E.

This is the largest atoll in the Ellice group and geologically the best known, having been very fully described in "The Atoll of Funafuti" by Sollas, David et al. (1904).

It is roughly pear shaped, with the narrow end to the south. The lagoon, 10 miles long by 8 miles wide, is approximately 25 fathoms deep and can be entered by three ship passes on the south-east and north sides. A chain of islets form an almost continuous line on the eastward (windward) reef but are more scattered on the lee reef. There are about 30 islets altogether of which the largest, Funafuti, extends for seven miles.

Sollas, David and Judd, in "The Atoll of Funafuti" (1904) described phosphatic material from several localities. Sollas recorded a phosphatic conglomerate on Amatuku Islet on the northern rim of the atoll in which coral pebbles up to 5 inches in diameter (average 1 inch) are cemented by a reddish brown phosphate. The rock was said to contain up to 26% calcium phosphate, the matrix carrying 32.5% and the pebbles 5.8%. Sollas believed that the deposit had originated by precipitation of guano solution percolating down through the pebble bed.

The conglomerate crops out in a low cliff up to 5 feet above high water mark as two beds separated by lime sandstone, but no estimate of the tonnage has been given. A similarly coloured sandstone at Mateika was also thought to be phosphatic, but this does not seem to have been verified.

Samples of a dark brown rock from behind the mangrove swamp on Fongafale yielded 21.64% and 29.07% of calcium phosphate, while soils from the taro swamp near this point were found to contain 6% P_2O_5.

The present writer's visit to Funafuti, lasting only a few hours, was too brief to get more than a general idea of the geology of the largest islet (Funafuti), and it was not possible to examine the recorded phosphate occurrences. The deposits do not, however, appear to be of any economic significance.

NUKELAELAE Lat. 9°22'S.; long. 179°50'E.

Nukelaelae is a long, rather narrow atoll elongated in a north-westerly direction, with dimensions 8 miles by 3 miles. There is a very narrow, almost continuous strip of land along the windward reef, several small islets at the northern and southern ends and one, Fangawa, the only inhabited islet, on the western reef. There is no entrance to the lagoon and only a poor anchorage outside the reef in the lee of the atoll.

No trace of phosphate was seen on Fangawa which is little more than a flat sandbank, nor on Motuloa on the northern side. Motuloa is a long, very narrow islet made up of low sandy and gravelly storm beaches on the ocean and lagoon sides with a narrow, slightly swampy trough-like depression between them.

The remainder of the atoll was not examined and questioning of the island people did not reveal any knowledge of typical phosphate deposits.

NUILAKITA Lat. 10°45'S.; long. 179°30'E.

This island, the most southerly of the Ellice Islands, was not visited. It is a low sandy island about 3 miles by 2 miles in extent on a low table reef. Guano is supposed to have been exploited on the island in the late nineteenth century, but no records have been preserved and it is believed that the deposit was worked out.

SUMMARY OF THE PHOSPHATE RESOURCES

The phosphate resources of the Gilbert and Ellice Islands (excluding Ocean Island) are small and too scattered to be of economic importance. Deposits occur on most of the Gilbert Islands and on several of the Ellice Islands, but in no case is either the tonnage or the grade of the phosphatic material sufficiently high to warrant commercial exploitation, particularly as handling and loading of the ore would be difficult.

The largest single deposit is on Tamana, where approximately 150,000 to 200,000 tons of ore containing 15-20% P_2O_5 was originally present, of which probably less than half could now be recovered.

Small deposits of nitrogenous guano at present forming on islets on Tabiteuea and Nonouti might profitably be used on local gardens, but use of the relatively insoluble phosphatized sand deposits in gardens and babai pits would not repay the labour of breaking it up and transporting it even a few yards.

ORIGIN OF THE PHOSPHATE DEPOSITS

There seems little doubt that the small phosphate deposits found in these islands are derived from avian guano deposited by sea birds. Features which point to this are localization of the deposits and their occurrence only on the surface, the nature of the phosphatic material, the irregular and sometimes gradational lower boundary and the patchiness of the phosphatization, and the presence, beneath the deposits of loose, unconsolidated sediments of undoubted reef origin.

The only alternative source of the phosphatization is by marine deposition at a time when the islands were submerged to a considerable depth. Marine phosphorite deposits found on the ocean floor, notably on the continental shelf and on seamounts, have a typical oolitic appearance similar to that of the Gilbert and Ellice Island deposits (and to the great Ocean Island and Nauru deposits) and contain foraminiferal tests many of which are replaced by calcium phosphate. The similarity of appearance is so great that a marine origin has

frequently been suggested even for the Ocean Island deposit. However, when the Gilbert & Ellice Island material is examined it is clear that the oolitic appearance is largely due to the replacement, often only partial, of foraminiferal tests the commonest of which is the reef dwelling form Calcarina. Other reef foraminiferae, fragments of shallow water mollusca, and Halimeda and Heliopora debris are common, indicating that the phosphatized sand is a typical reef deposit. The underlying loose sand is made up of the same foraminiferae and reef debris and a typical profile or section across almost any of the deposits shows quite clearly, from the general distribution of sands and gravels, storm beaches and other conspicuous features in relation to the reef, that these sands have been deposited since the emergence of the reef and that they were not subsequently resubmerged.

Cloud (1953) has correlated the emergence of the reefs forming the Gilbert and Ellice Islands with a six foot eustatic drop in sea level following the post glacial climatic optimum some 3,000 to 5,000 years ago. While the writer could find no indisputable evidence of this recent change of sea level the evidence from other Pacific islands (e.g. Stearns 1941, 1945; MacNeill 1950; Cloud 1953) strongly suggests that this is the case and the phosphate deposits must be of relatively recent origin. The presence of considerable numbers of breeding seabirds in the vicinity of some of the phosphate deposits such as Marakei, Nui and Vaitupu suggests that phosphatization may be continuing even now. The absence of deposits which are transitional between the common phosphatized sand and the small accumulation of fresh guano as on Tenon Islet, Tabiteuea is a puzzling feature which may be explained by the completeness with which reaction between calcium carbonate and phosphoric acid takes place, particularly during the wetter periods. It seems probable that the water plays an active part in the reaction.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance given by the many government officers of the Gilbert and Ellice Island Colony, the manager and staff of Colony Whoesale Society and the masters and crews of Colony and Wholesale Society vessels who, literally, went out of their way to be helpful.

To the native government officials and the people of the islands visited especial thanks is due for their willing assistance and their unequalled friendliness, generosity and hospitality.

Thanks are also due to Mr. J. Hylton of Tarawa Meteorological Station for supplying rainfall figures.

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PLATE 1

170°E

175°E

180°

0°

5°S

10°S

Makin

Butaritari

Marakei

Abaiang

Tarawa

Maiana

Abemama

Kuria

Aranuka

GILBERT ISLANDS

Ocean I

Nonouti

Tabiteuea

Beru

Nukunau

Onotoa

Tamana

Arorae

Nanumea

Niutao

Nanumanga

ELLICE ISLANDS

Nui

Vaitupu

Nukufetau

Funafuti

Nukulaelae

Nuilakita

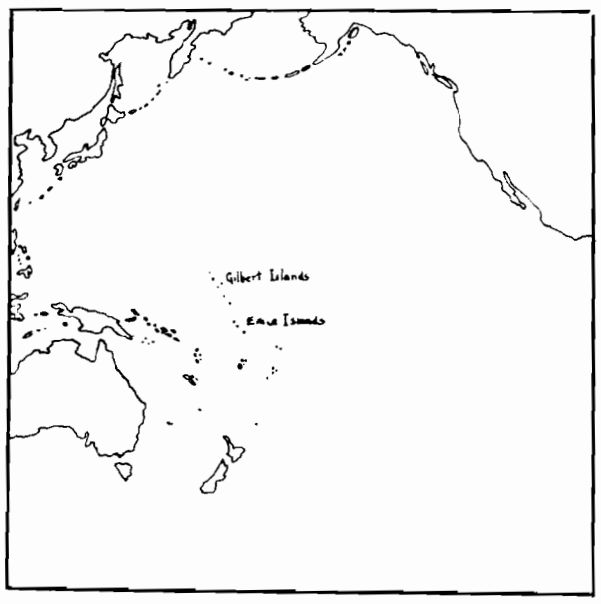


PLATE 2

TAMANA

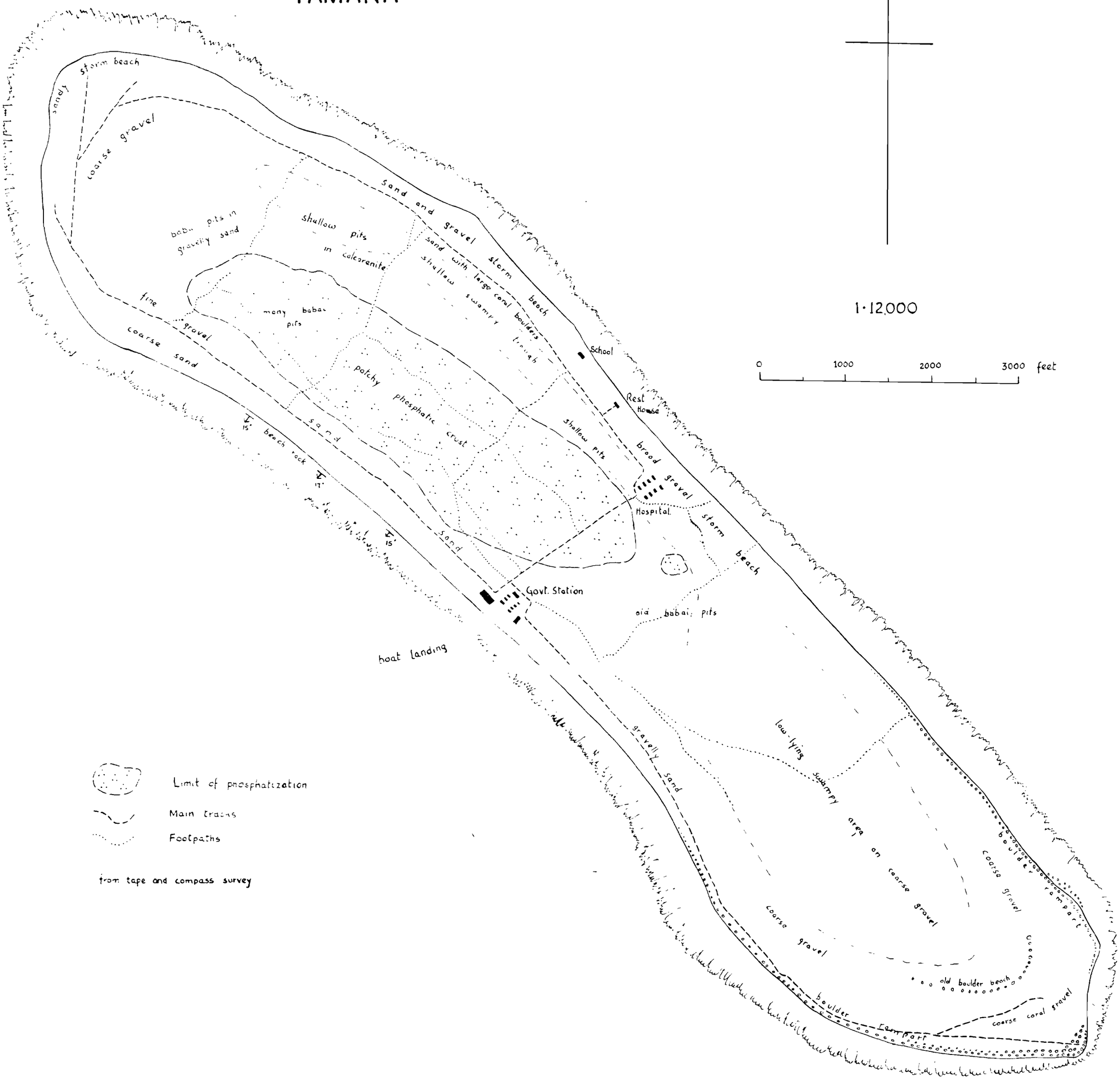


PLATE 3

ARORAE

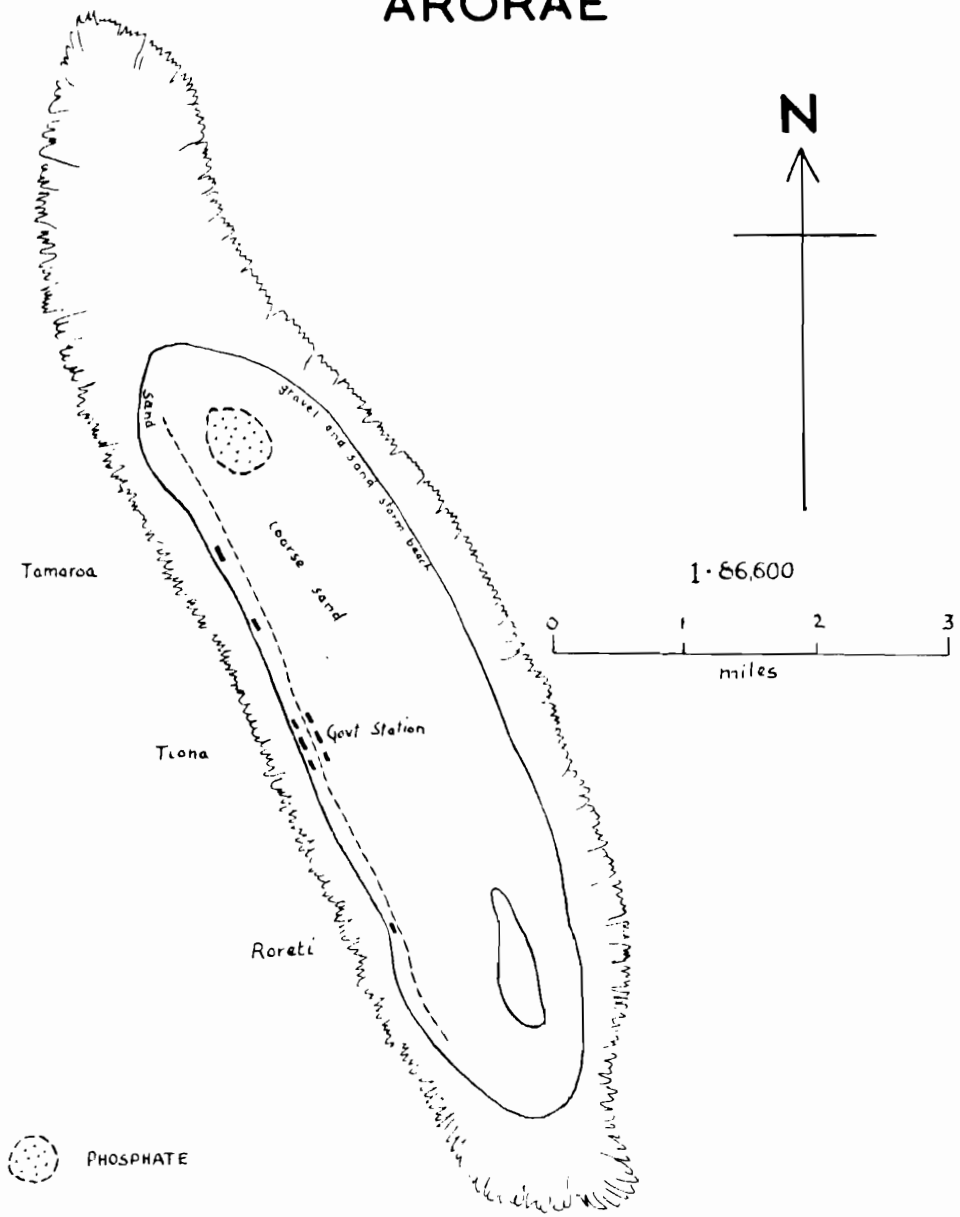


PLATE 4

ONOTOA

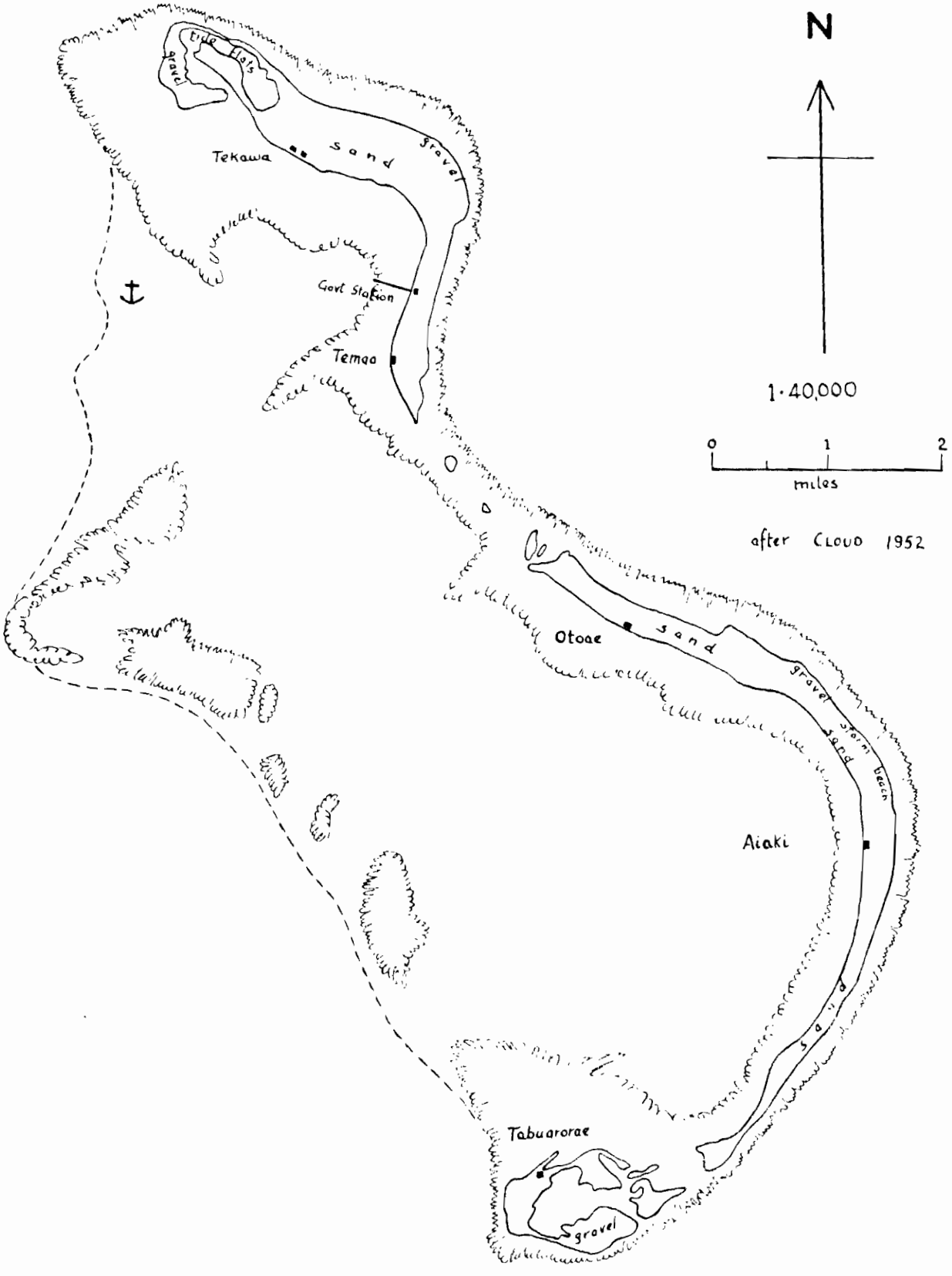


PLATE 5

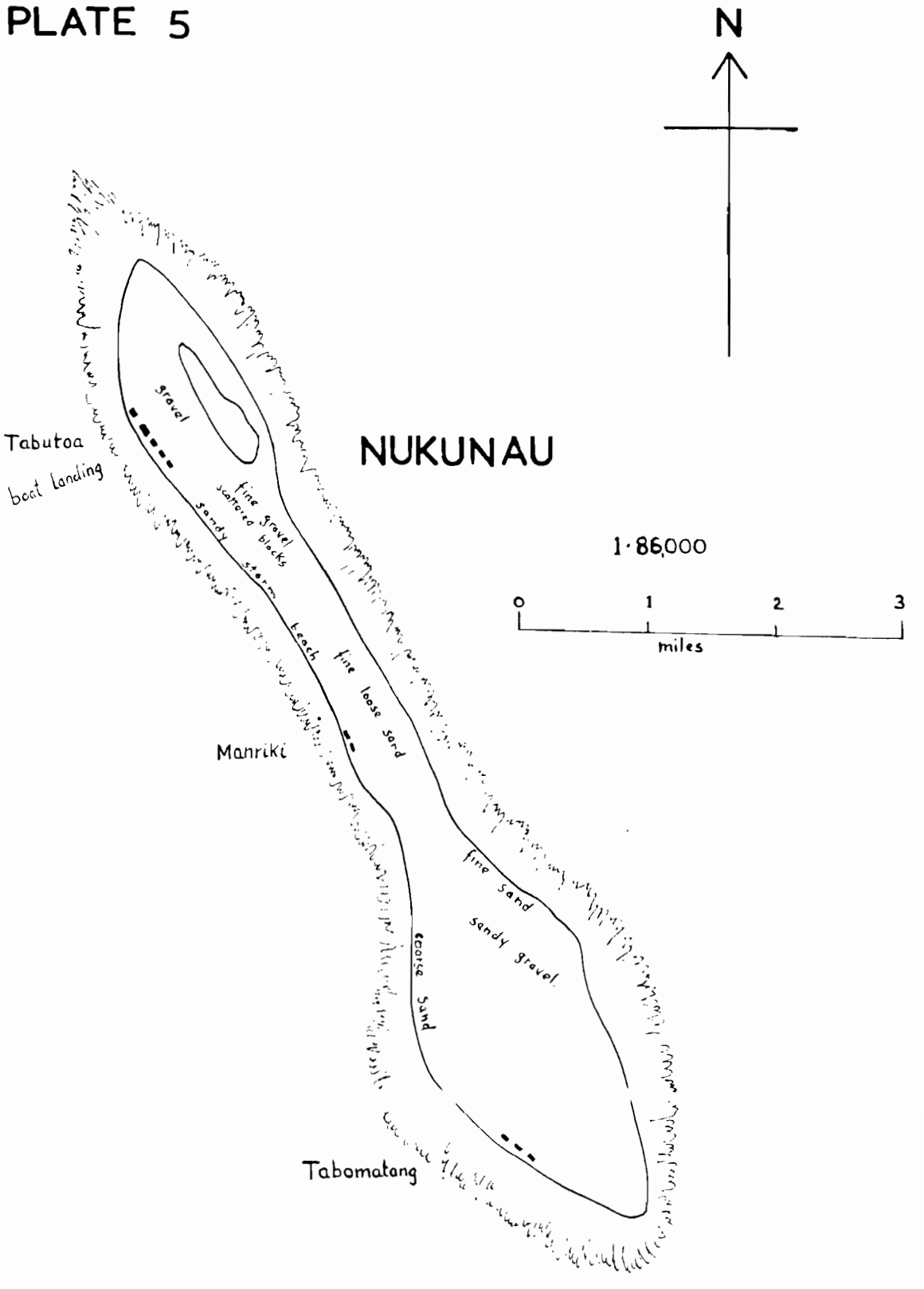

N
NUKUNAU
1·86,000
0
1
2
3
miles
Tabutoa
boat landing
gravel
fine gravel
scattered
blocks
sandy
storm
beach
fine loose sand
Manriki
fine sand
sandy gravel
coarse sand
Tabomatang

PLATE 6

N

TABITEUEA

Te Kapuipui

Buota

Eanikai

Peacock Anchorage

1·260,000

0 2 4 6 8 miles

Kabuna

Aiwa

Aumurae

Temon

Buariki

Nuguti

Taku

gravel

Te Kaputputi

Tanaiang

Buota

Terikai

EANIKAI

Utirca

boat passage

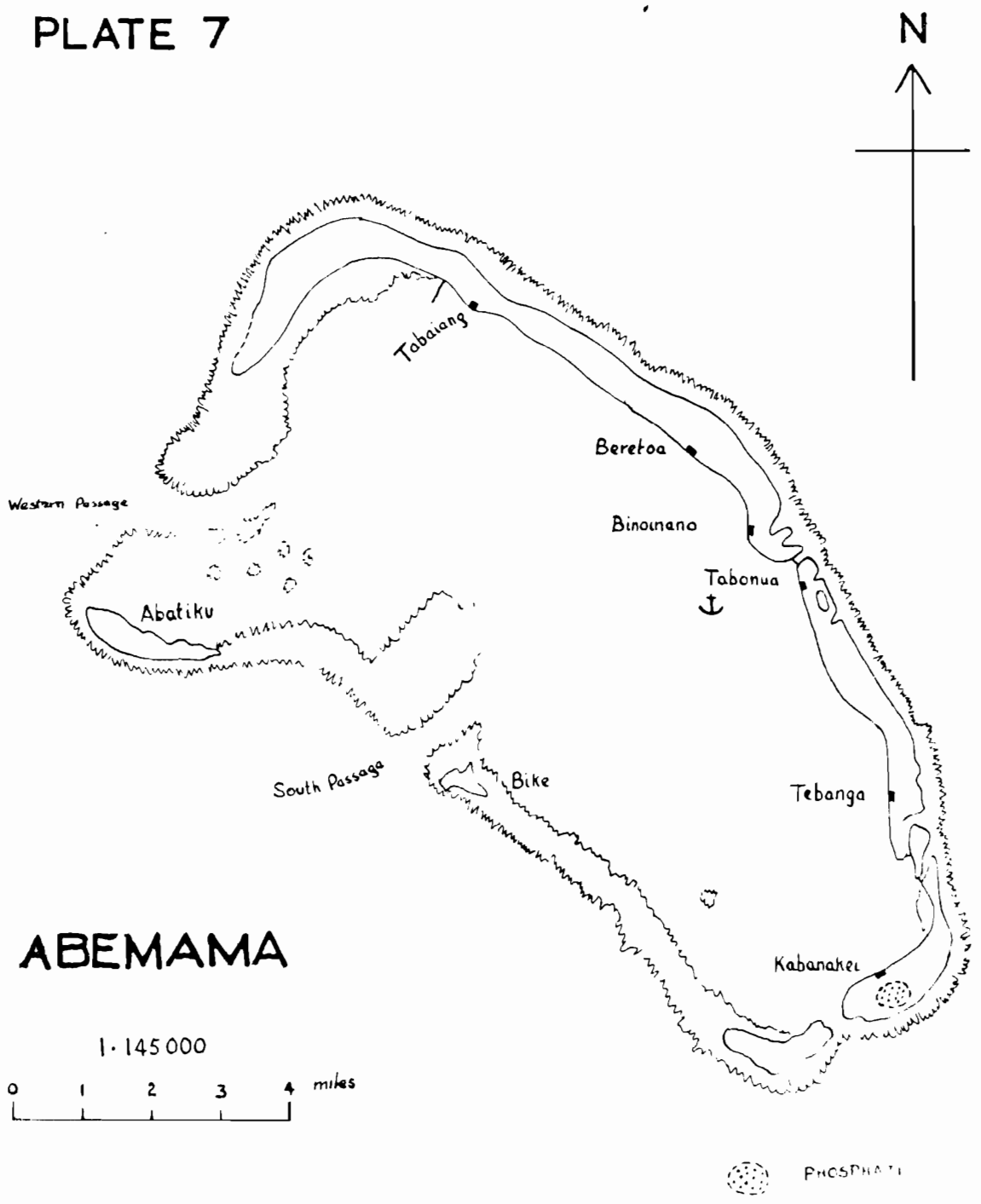
PHOSPHATE

PHOSPHATIC SOIL

1·72 500

0 1 2 miles

PLATE 7


N
Tabiang
Beretoa
Western Passage
Binoinano
Tabonua
Abatiku
South Passage
Bike
Tebanga
Kabanakei
ABEMAMA
1·145000
0 1 2 3 4 miles
PHOSPHATE

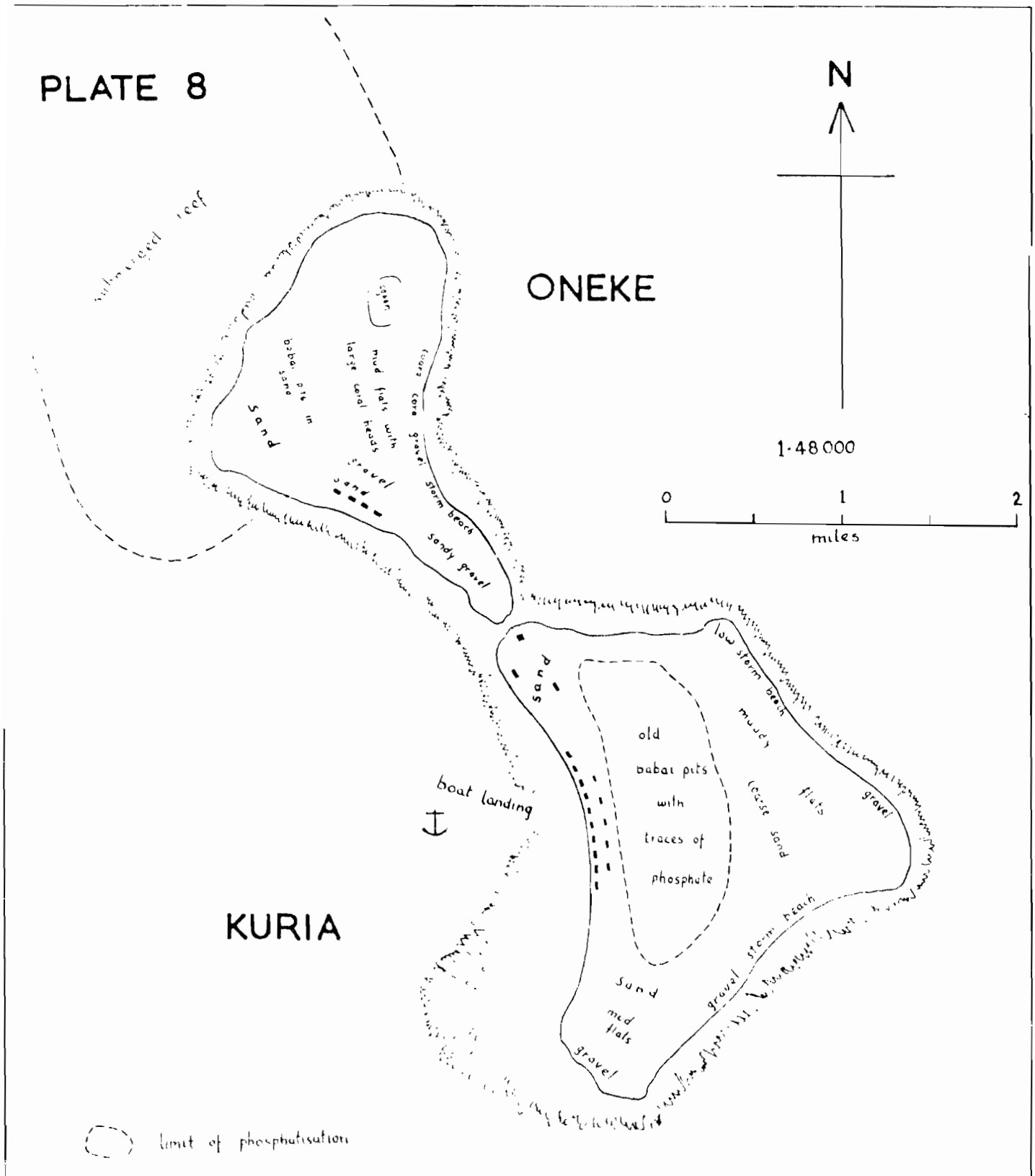


PLATE 8
N
ONEKE
1·48000
0
1
2
miles
submerged reef
mud flats with large coral heads
gravel
sand
coral gravel
storm beach
sandy gravel
babai pits in sand
sand
low storm beach
muddy fine sand flats
gravel
old babai pits with traces of phosphate
boat landing
KURIA
sand
mud flats
gravel
gravel storm beach
limit of phosphatisation

PLATE 9

MAIANA

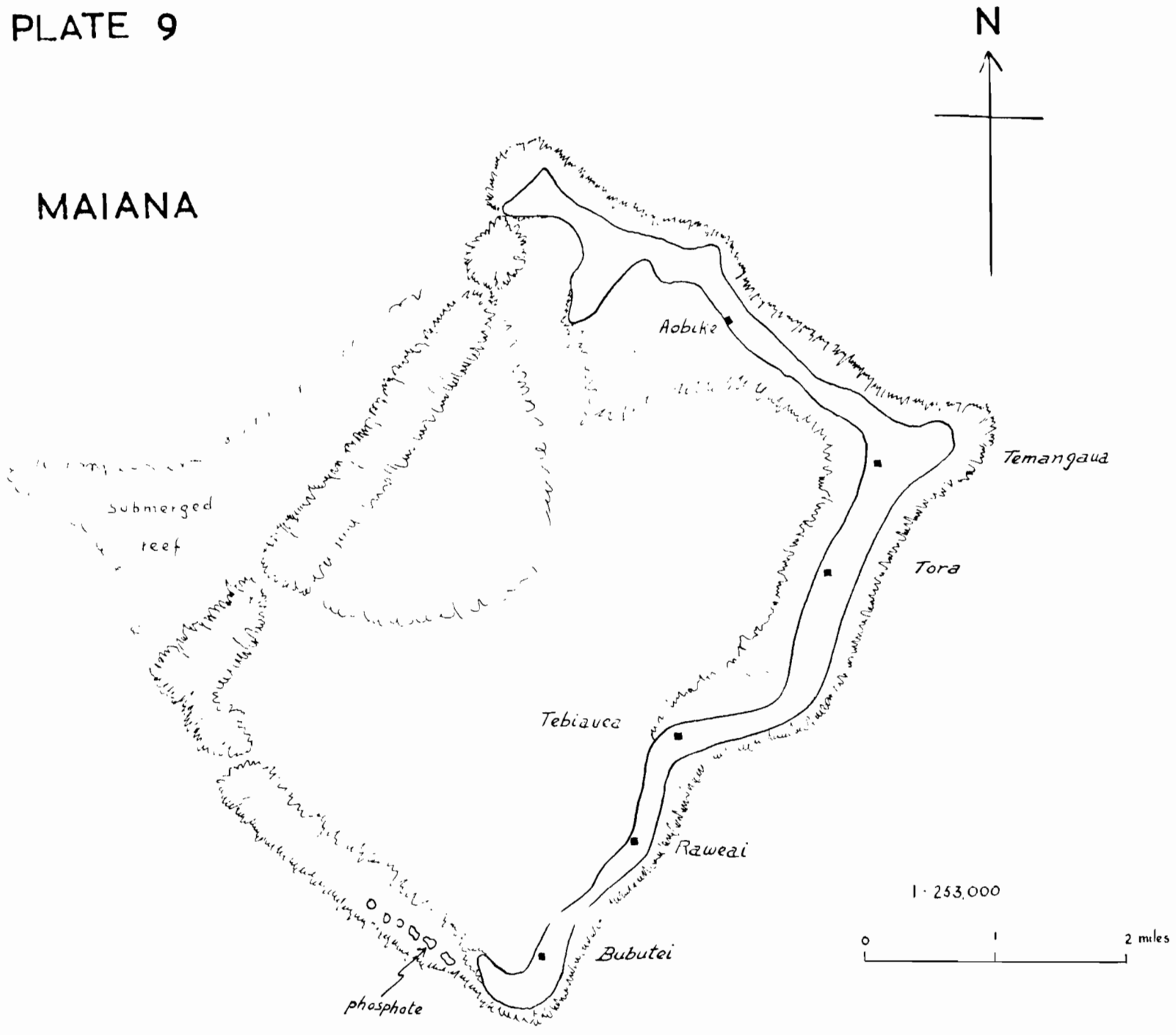


PLATE 10

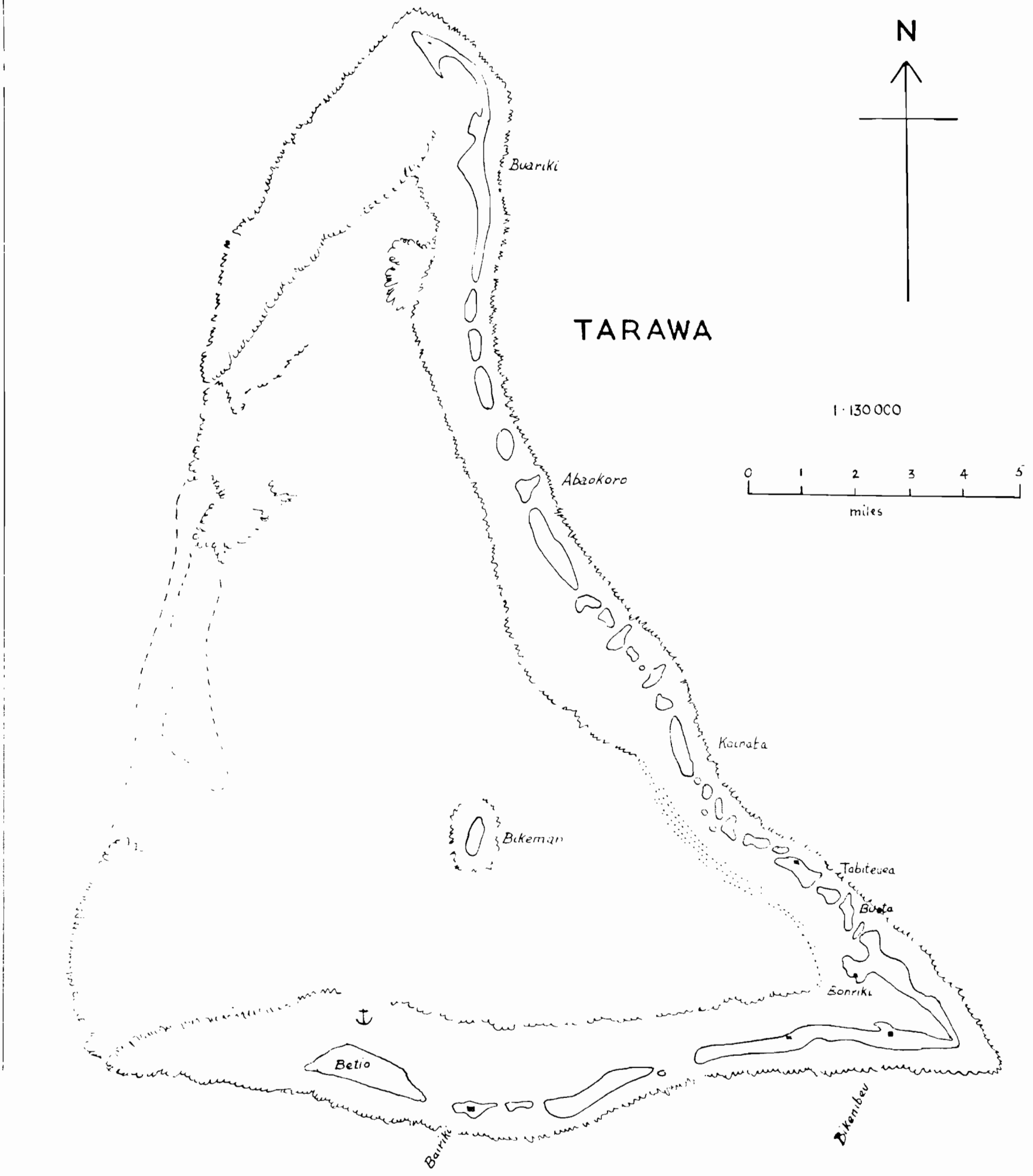

N
TARAWA
1 · 130 000
0 1 2 3 4 5
miles
Buariki
Abaokoro
Kainata
Bikeman
Tabiteuea
Buota
Bonriki
Betio
Bairiki
Bikenibeu

PLATE II

ABAIANG

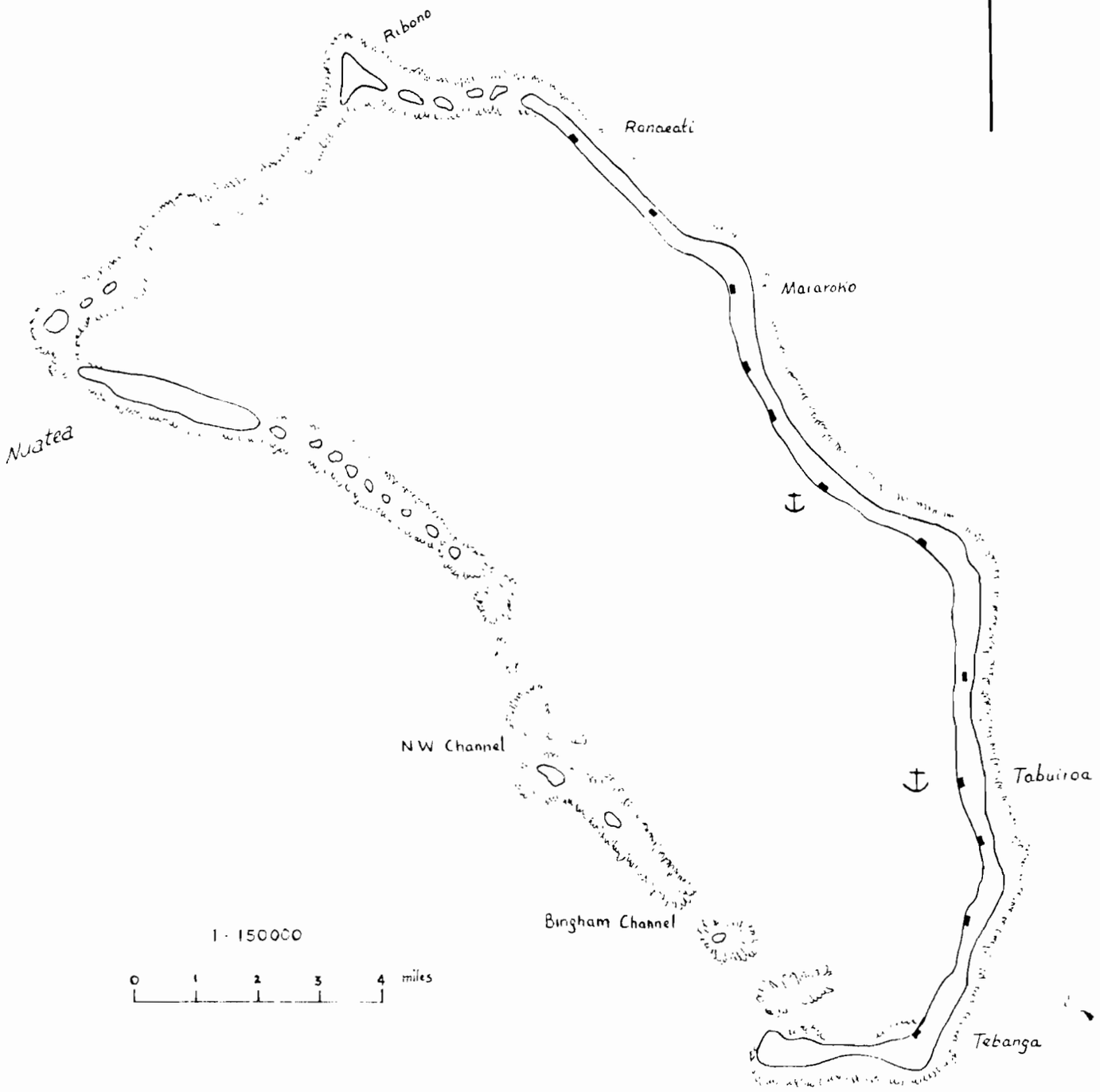
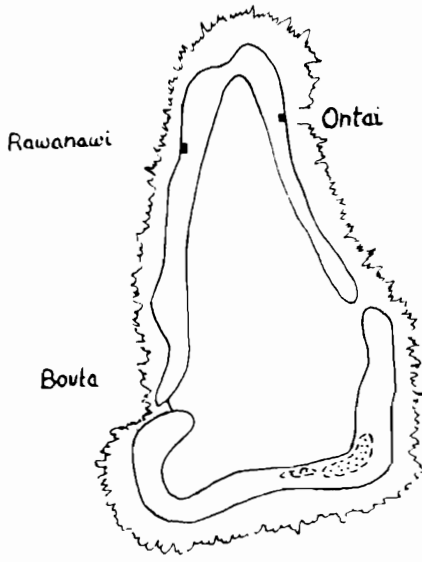


PLATE 12 MARAKEI



N

1·147,000

0 1 2 3

miles

SCATTERED PHOSPHATE

PLATE 13

MAKIN

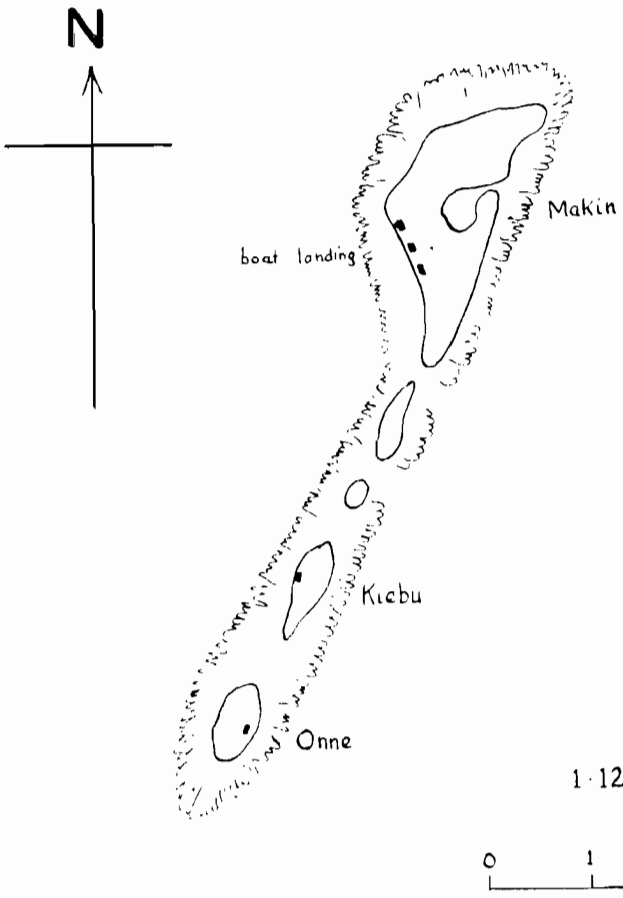


PLATE 14

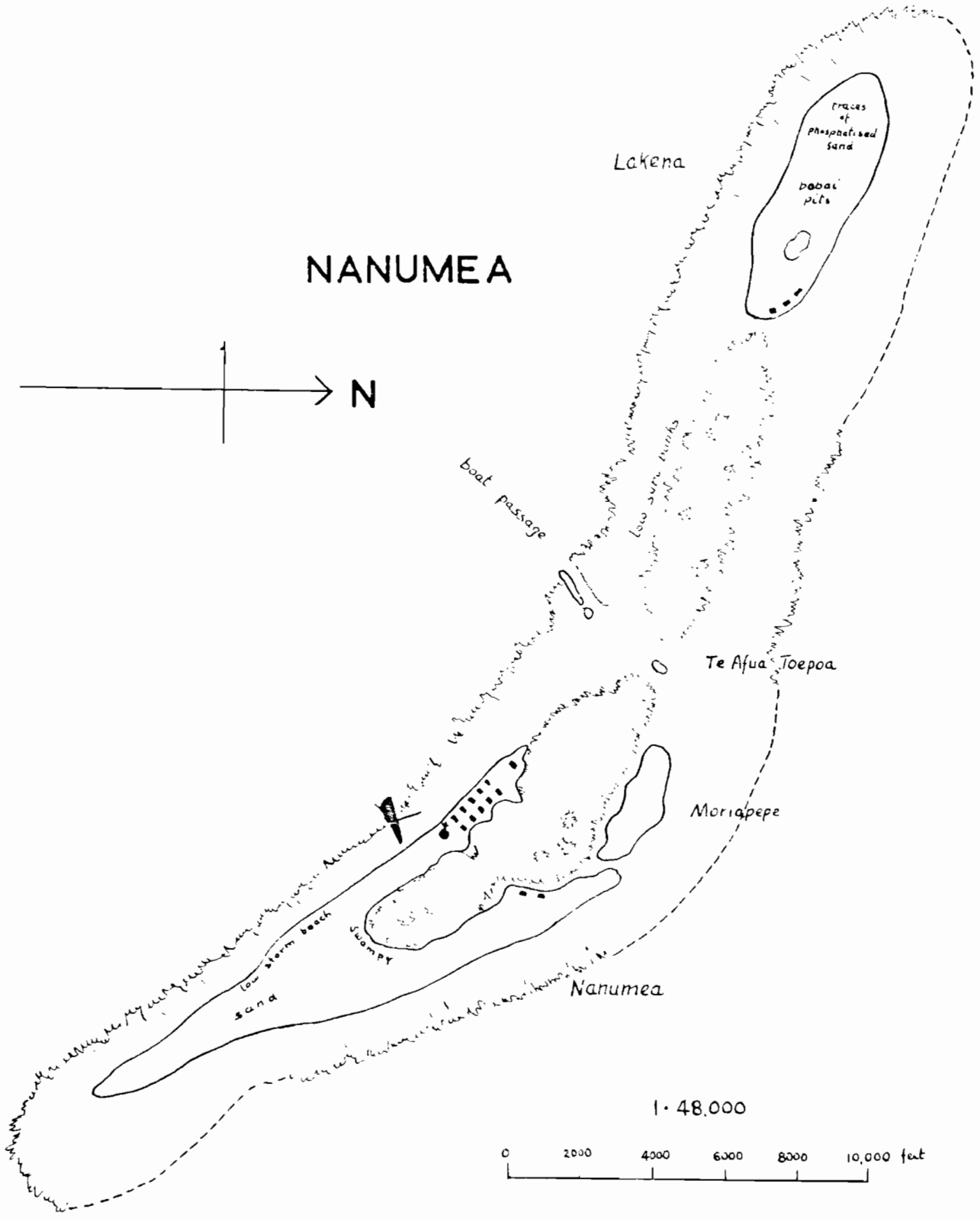
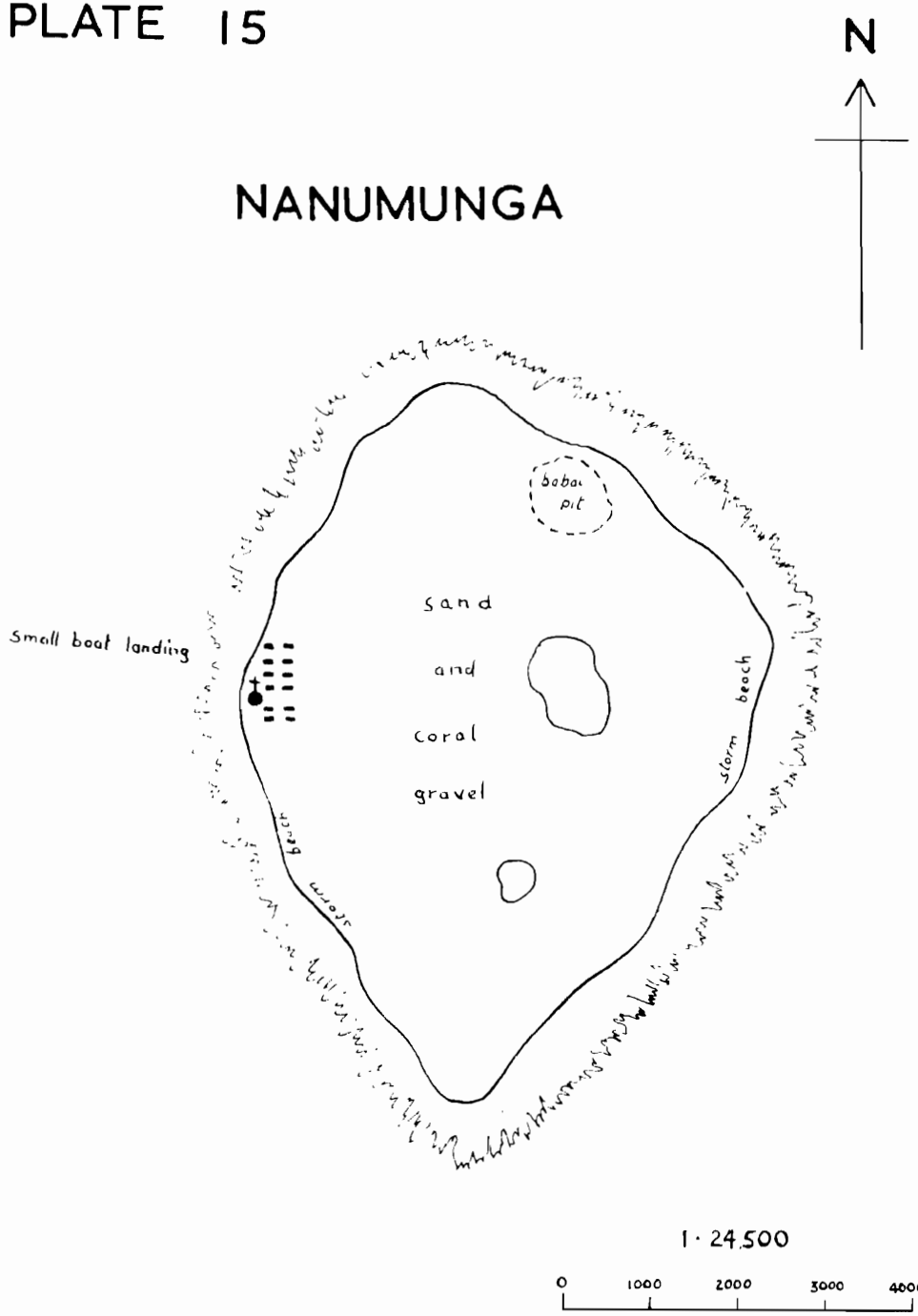

NANUMEA
N
Lakena
traces of phosphatised sand
Dobai pits
boat passage
low sand islets
Te Afua Toepoa
Moriapepe
Nanumea
low storm beach
sand
swampy
1 · 48,000
0
2000
4000
6000
8000
10,000 feet

PLATE 15


N
NANUMUNGA
babai pit
sand
and
coral
gravel
Small boat landing
storm beach
storm beach
1 · 24,500
0
1000
2000
3000
4000 feet

NIUTAO

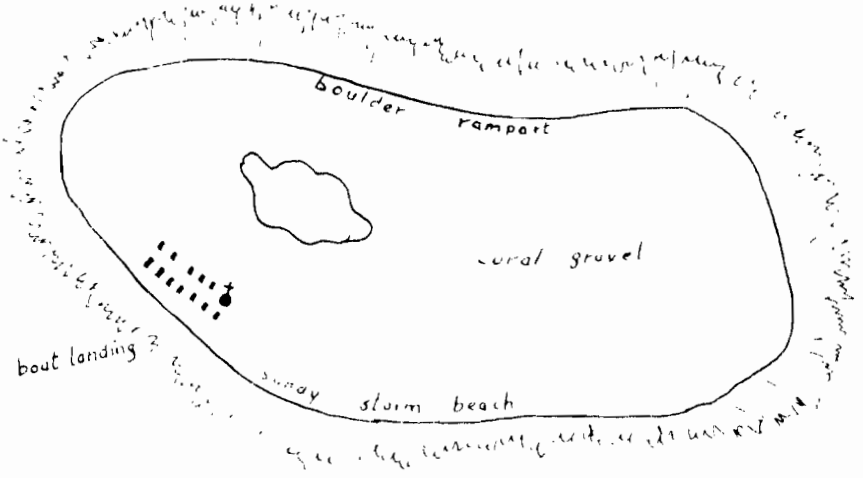


PLATE 16

PLATE 17

NUI ISLAND

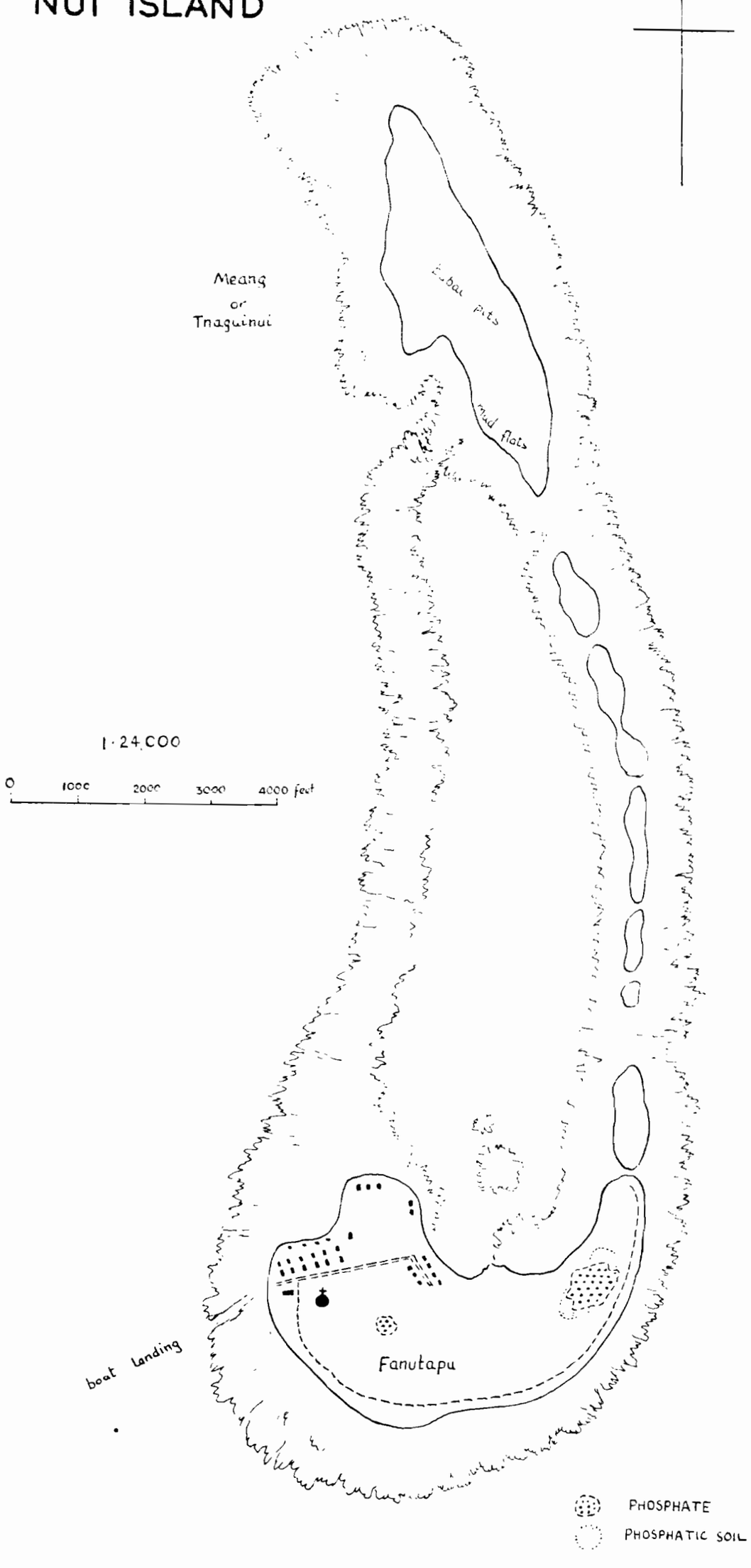


PLATE 18

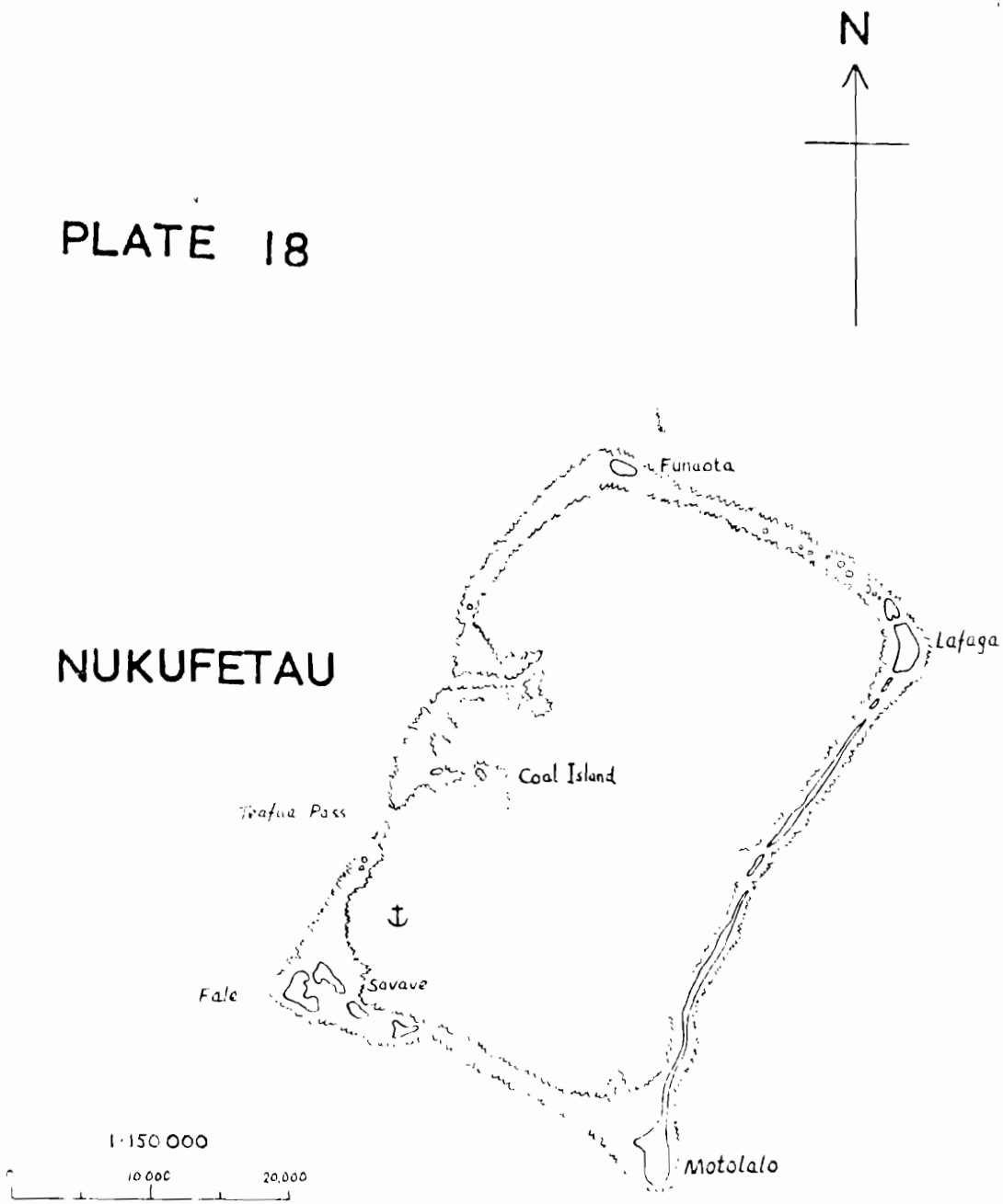

N
NUKUFETAU
Funaota
Lafaga
Coal Island
Trafua Pass
Fale
Savave
Motolalo
1·150 000
10 000
20 000

PLATE 19

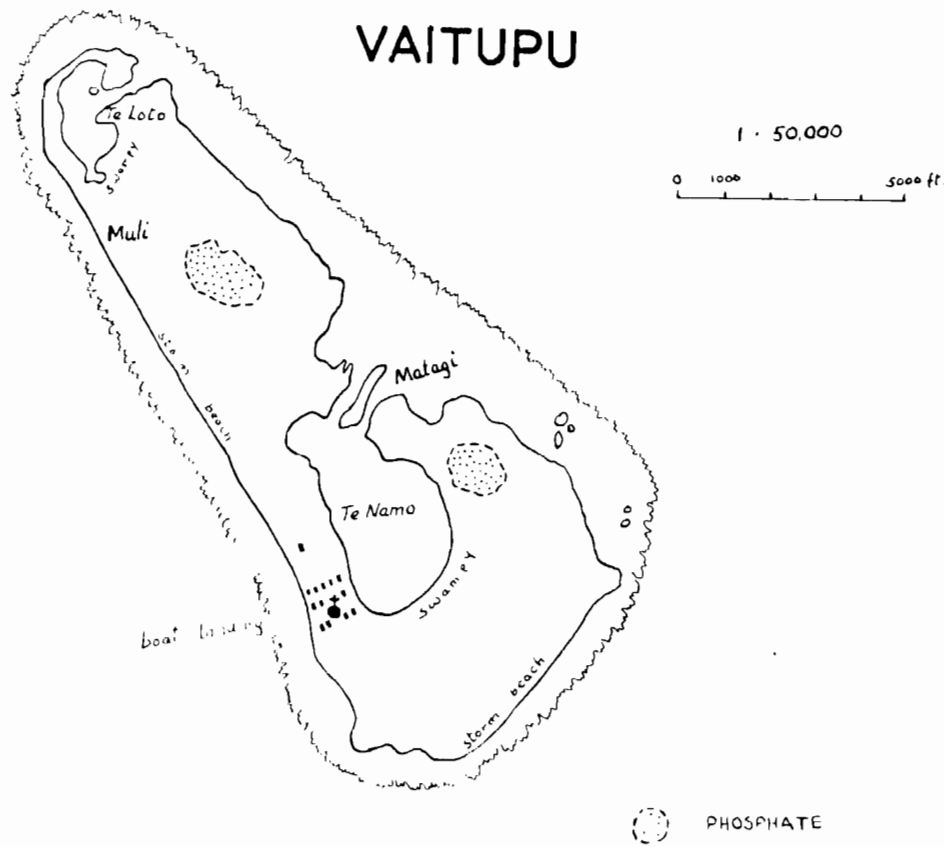

N
VAITUPU
1 · 50,000
0 1000 5000 ft.
Te Loco
swamp
Muli
sea
beach
Matagi
Te Namo
swamp
boat
storm beach
PHOSPHATE

PLATE 20

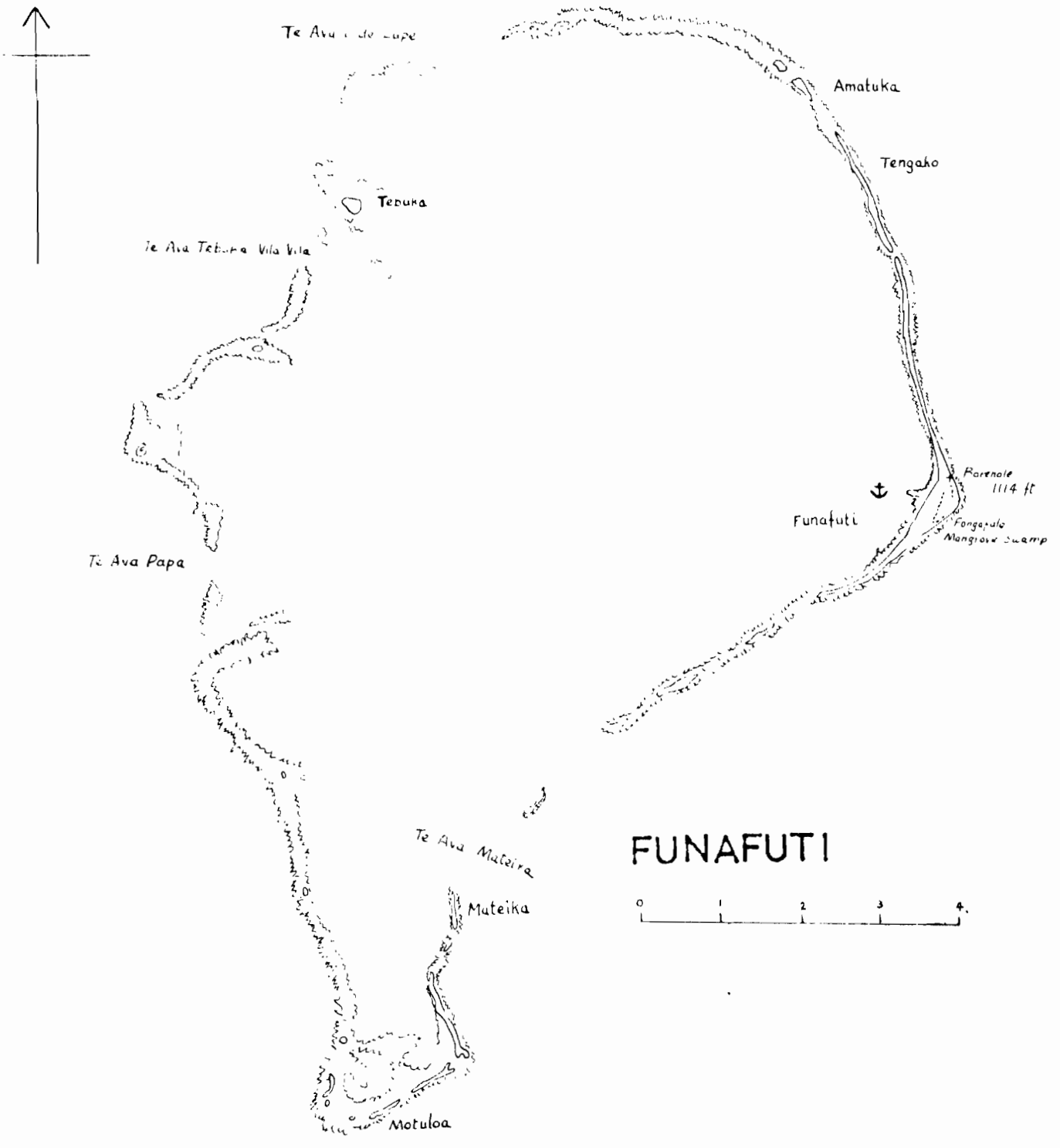
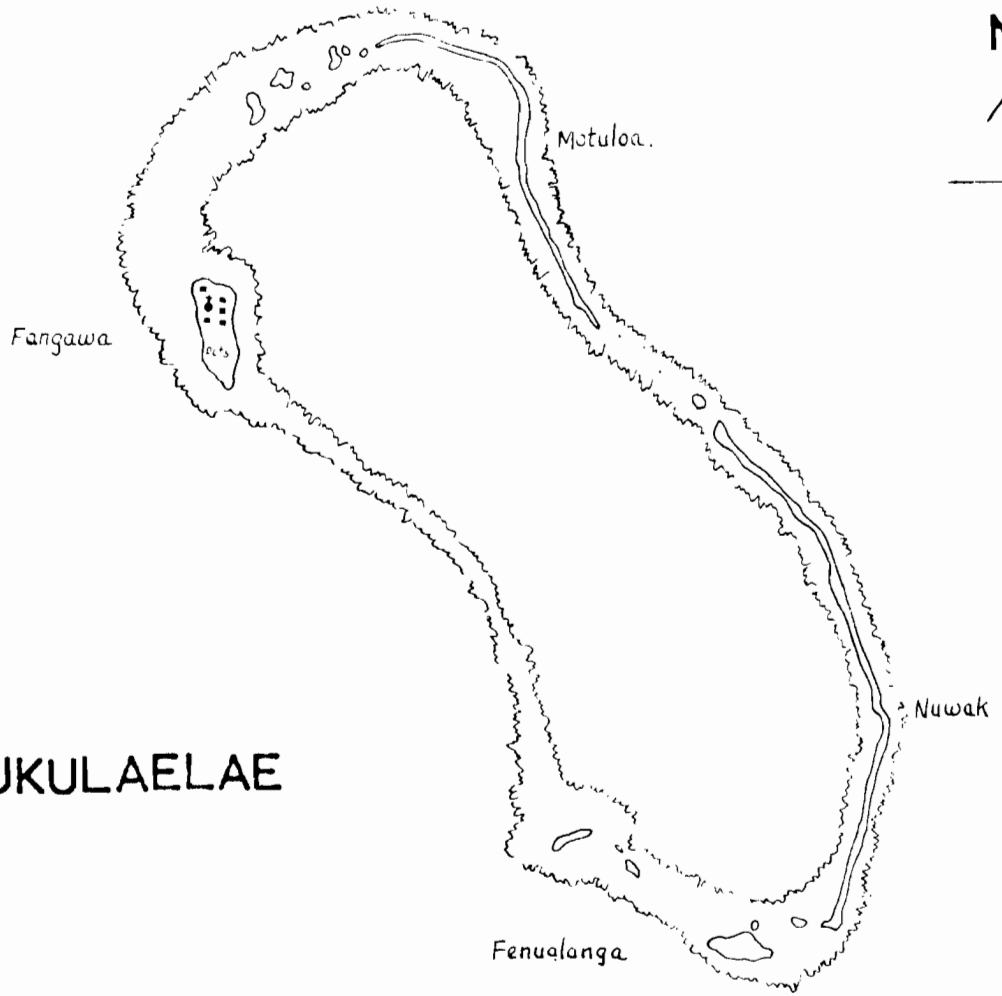

N
Te Ava i de Lupe
Amatuka
Tengako
Teduka
Te Ava Teduka Vila Vila
Te Ava Papa
Funafuti
Fongapule Mangrove Swamp
Te Ava Mateika
Mateika
Motuloa
FUNAFUTI
0
1
2
3
4

PLATE 21



NUKULAELAE

1 · 80,000

0 5000 10 000 15,000 feet