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REPORT OF INVESTIGATION OF ISLANDS IN THE TERRITORY OF PAPUA AND NEW GUINEA PHOSPHATE SURVEY, 1958

by

O.N. Warin and A.R. Jensen.

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Summary.

Islands visited during the 1958 field season of the Phosphate Survey are described. Five islands and one island group, of the twenty two islands or island groups inspected, had phosphate deposits. These deposits are described in detail and placed in two groups; phosphate deposits consisting of a crust of phosphatically cemented sand on low lying sand cays, and those consisting of phosphatic clay and phosphatic sand between limestone pinnacles on elevated coral atolls.

Deposits of the first type on four scattered islands and one island group probably amount to 146,000 tons with an average grade of 25.5% P_2O_5, while the only deposit of the second type discovered contains about 125,000 tons of low grade clay averaging 16% P_2O_5 and 15,000 tons of oolitic phosphate averaging 32.5% P_2O_5.

Deposits of the first type are unlikely ever to be important exonomically because of their shallow depth and small tonnage. Those of the second type are of much greater tonnage and likely to be important economically although their high content of alumina and iron oxides preclude their use, by present methods in the manufacture of superphosphate fertilizers.

Further search should be directed towards raised coral islands.

Introduction

During the six months from early March to early September, 1958, a Bureau of Mineral Resources field party was engaged in a search for phosphate deposits on islands in the Territories of Papua and New Guinea and in the British Solomon Islands Protectorate.

The purpose of the survey, of which this field season was a part, is to discover new sources of phosphate suitable for the manufacture of superphosphate fertilizer to supplement, in the future, the material at present obtained from Ocean and Nauru Islands in the Pacific Ocean and from Christmas Island in the Indian Ocean.

Part of this field work has already been recorded in a previous report, (White and Warin, 1959), which dealt with a specific deposit, that of Bellona Island, British Solomon Islands Protectorate.

The phosphate survey is under the supervision of W.C. White, supervising geologist. The field party consisted of two geologists, O.N. Warin and A.R. Jensen, two field assistants and twelve Papuan labourers.

The writer wishes to acknowledge the ready help given at all stages of the survey by officers of the Administration of the Territory of Papua-New Guinea.

Phosphate Deposits of the Western Pacific

The conditions necessary for the deposition and retention of guano and its conversion into phosphate deposits have been exhaustively studied by G.E. Hutchinson. His

bulletin, (Hutchinson, G.E., 1950), contains detailed descriptions of island guano and phosphate deposits throughout the world. He stresses the importance of three factors controlling the formation of phosphate deposits:

(a) The proximity of the islands to a food supply for the birds

(b) The rainfall

(c) The physical shape of the island

In some areas of the ocean, currents rise from the depths and bring nutrients to the surface. The availability of nutrients causes an enormous increase in the concentration of plankton in the surface waters and plankton swarms develop. Shoals of fish, feeding on the plankton are also concentrated in these areas with rising bottom currents. Islands close to such rich areas are likely to become the home of colonies of guano-producing birds feeding on the fish. Proximity to feeding grounds is probably therefore a broad general control of the regional distribution of phosphate islands.

Rainfall is the second factor controlling the preservation of guano deposits. Where rainfall is excessive any guano formed would be constantly washed off into the sea. At the present time, on islands off the coast of Peru which are virtually without rain, guano is being preserved with only the loss of volatiles. The intermediate rainfall condition under which guano is converted into phosphate is not known in this area today but Hutchinson considers that the process would only occur when the rainfall is less than 60 inches per annum.

The topographic form of an island obviously has a bearing on the retention of the guano on its surface. In the case of a raised coral atoll, with a markedly saucer shaped cross section, guano might be retained even in a higher annual rainfall than 60 inches. Obviously steep sided volcanic islands do not favour the retention of guano.

These considerations are demonstrated in practice by Hutchinson in a review of all the known phosphate deposits and their location. On the basis of this review he postulates a shift of the climate belts in the fairly recent geological past to account for the distribution of islands which have ancient phosphate deposits but are not receiving guano today. A number of these islands are in areas that now have a high rainfall.

Rainfall figures are not available for many of the small islands visited during the present survey. Probably all have an annual rainfall greater than 60 inches however. Table 1 gives the mean annual rainfall for a number of localities shown on Plate 1 that are in the area of the survey.

TABLE I.

Locality	Mean Annual Rainfall (in inches)
MANUS, Admiralty Islands	151
KAVIENG, New Ireland	124
MADANG, New Guinea	155
RABAUL, New Britain	87
TROBRIAND Is., Papua	140
SAMARI, Papua	117
MISIMA, Papua	158
PORT MORESBY, Papua	38

(Taken from Pacific Islands Year Book, 1950)

The conversion of guano into an insoluble phosphate deposit is complex and evidently occurs in different ways. Clearly however phosphate solutions from the guano will react with whatever it overlies or with whatever they come into contact. On islands of raised coral this usually produces a deposit predominantly of calcium phosphate; all the deposits in the Pacific that are worked at the present time consist of calcium phosphate and are on islands of raised coral.

The few recorded examples of phosphatization of volcanic rocks are of theoretical rather than economic interest. (Teall, 1898).

History of the Search for Phosphate Deposits in Papua/ New Guinea

Phosphate must have been discovered in New Guinea before 1890 for in that year 1000 tons were exported from the Purdy Islands to Germany. (Seidel, 1891, quoted by Hutchinson, 1950).

A search was undertaken in 1909 by the Hanseatic Pacific Expedition, led by Dr. Georg Friederiei, who explored a number of islands in New Guinea apparently without finding any new sources of phosphate, (Hutchinson, R.C., 1941). R.C. Hutchinson also says that export of phosphate from the Purdy Islands began again in 1910. Probably this export was only for a short time as Ocean Island began to be worked in 1900 and Nauru in 1906, (Power, 1925), and it was the coming into prominence of these two sources of high-grade phosphate that caused the Purdy workings to be abandoned.

In 1929 the British Phosphate Commissioners sent Mr. K.M. Fennell to New Guinea to investigate the phosphate deposits and in 1941 Mr. R.C. Hutchinson, an officer of the Administration's Agriculture Department, examined the known

phosphate islands to assess the reserves with a view to their local utilization.

Less attention has been paid to the islands of Papua. In 1917 E.R. Stanley, the Government Geologist of Papua, visited Cannac Island (See Page 4), and examined the small guano and phosphate deposit on it. In his report (Stanley, 1917), he also mentions an island he calls Entrance or Ginara Island (Probably Ginetu Island, near Woodlark Island - see Plate 1), on which he found many birds nesting in the trees but only a trace of phosphate in the limestone.

Present Survey

The object of the 1958 survey was to inspect all known and reported phosphate islands in Papua and New Guinea. (The work in the British Solomon Islands is the subject of another report - White and Warin, 1959). Also included in the search were islands which it was thought might have phosphate deposits. These were mostly little known islands believed to be of raised coral, (e.g., the Marshall Bennett Group). In two instances islands not previously reported were found to have phosphate deposits, (Sae Island and Nauna Island).

The islands are shown on Plate 1.

The survey was carried out using a 270 ton vessel with a cruising range of 1000 miles which was chartered for six months.

The islands investigated are small, steep and with only poor anchorages. Landing was normally by surf boat onto the edge of the reef or onto the beach, depending on the state of the tide.

The area has two seasons which are named from the prevailing wind directions: the south-east season (April to November) and the north-west season, (December to March). The wettest in most places is the north-west season, but some rain, from less violent storms, falls during the south-east season. In certain areas, such as the south coast of New Britain, the distribution of rainfall is reversed, i.e., rainfall is heaviest in the south-east season.

Close to the equator the seasons are less well marked and alternating short periods of calm and bad weather are common.

Method of Search

A search was made on all the islands for coherent and incoherent phosphate occurring at the surface. Hand augers were used to test the depth and to obtain samples from phosphatic clay deposits and also to test the depth of the shallow cemented phosphate deposits, (e.g., Purdy Islands). These hand auger holes were put down at regular intervals along existing tracks and along cut traverse lines on uninhabited islands or islands poorly served with tracks.

Some of the samples collected, either from the surface or from auger holes were estimated chemically for phosphate by a field method (Appendix 1). Other samples were retained for testing in Canberra.

THE PHOSPHATE DEPOSITS

Two types of phosphate occurrences were encountered during the survey:

(a) Hard cemented phosphate, (Purdy Islands, Sae, Manu, Aua and Wuvulu islands).

(b) Phosphatic clay underlain by oolitic phosphatic sand (Nauna and the N.W. deposit of Wuvulu island).

These two types of phosphate deposits are quite different in their physical properties and their mode of occurrence. Deposits of the first type are restricted to low sandy islands, the second to islands of raised coral.

A. Cemented Phosphate Deposits

The cemented phosphate consists of a crust of a medium to dark brown porous material seldom more than three feet thick, occurring in blocks that are light to handle and can be easily broken. The phosphate is formed directly on the coral sand which it overlies, by solutions leaching downward from bird guano.

A collophane cement is first formed in the interstices between the sand grains - making a low-grade light coloured phosphate rock. As phosphatization proceeds further the individual grains of the sand are replaced by more collophane, giving a darker brown material of high grade. The structure of the coral fragments, foraminifera and shell fragments is often preserved during this replacement. Some specimens collected from Sae island have coarse fragments of coral only partly replaced. In places the carbonate sand grains are dissolved after the first collophane cement has formed - this gives a very porous rock of high grade but low specific gravity.

These deposits occur on sandy islands which are not raised above sea level. A little banked-up coarse storm beach material creates a low rampart no more than six feet above high tide level. Behind this rampart the ground falls slightly towards the centre of the island. On most of the islands of this type the whole of the inland part of the island behind the storm beach rampart has a crust of phosphate. Exceptions are Aua and Wuvulu where the crust is restricted and on some of the Purdy group where the phosphate has been removed.

Swamps occur in the interior of some of these islands. The hard cemented phosphate is, in these swamps, covered with a thin veneer (about two inches) of humic, highly phosphatic, black mud. In other places the water table was encountered in the hand auger holes within the cemented phosphate, sometimes below it.

The mode of formation and economic potential of these deposits will be discussed after the deposits on the individual islands have been described.

The Purdy Islands

Position and Size. The Purdy Islands, North and South Bat Island (2°50'S, 146°14'E), Mole Island (2°51'S, 146°26'E.), Mouse Island (2°52'S, 146°23'E.), and Rat Island (2°57'S, 146°20'E.), lie about fifty miles south of Manus Island in the Admiralty Group of New Guinea (see Plates 1, 2 and 3).

The islands are small and uninhabited. The land area of the four islands added together is less than a third of a square mile. Rat island is a small sand bank surrounded by a reef but without any vegetation; the other islands of the group are larger and have been planted with coconuts but the plantations have been neglected.

Previous investigations. As already noted the islands were worked for phosphate in 1890, when 1,000 tons were exported to Germany, and again for a short time in 1910 (Hutchinson, G.E., 1950). The islands were visited by Dr. G. Friederiei of the Hanseatic Pacific Expedition in 1909 and by Mr. K.M. Fennell of the British Phosphate Commissioners in 1929. These two visits are noted by R.C. Hutchinson in his account of his own work on the islands in 1941 (Hutchinson, R.C., 1941).

R.C. Hutchinson's account describes the islands, the nature of the phosphate occurrence and broadly its distribution. His estimate of the tonnage of phosphate present was probably inaccurate because he does not seem to have recognized areas from which phosphate had been stripped.

The islands and the phosphate deposits. The outlines of the islands are shown in Plates 2 and 3. All are of similar form. They show no sign of emergence, being simply vegetated sand banks with wide fringing reefs. The sand banks are protected along their edges by a rampart of storm beach material which gives them a slightly saucer shaped cross section.

The phosphate, which occurs as a crust of hard, porous, brown material, evidently used to occupy the central area of each island. The only islands which have their phosphate deposits intact are North and South Bat. Mouse Island has been completely worked out. Only a few scattered lumps of phosphate and a slight phosphatic enrichment of the top inch of the sand remain to show the area that was once occupied by the phosphate deposit (see Plate 3). Mole Island also has been completely worked out. However, a heap of phosphate blocks, awaiting shipment, remains at the west tip of the island. As on Mouse Island the original area of the phosphate deposit can be easily traced.

The deposits on North and South Bat do not occur exactly in the centre of the islands but are displaced towards the west. No phosphate occurs along the east edge of each island but phosphate crops out along the south west shore of South Bat and along the south west and north shores of North Bat (see Plate 2). The shape of these two islands has probably changed a little since the phosphate was laid down. Islands such as these would have little ability to withstand erosion by storms.

At the time of the survey a recent storm had evidently caused severe erosion along the south west shore of North Bat. A number of palms had been undercut and had fallen into the sea.

The phosphate on North and South Bat is of fairly uniform thickness. The average thickness in the five hand auger holes on North Bat which intersected phosphate was 15 inches; the maximum was 27 inches. On South Bat the average seen in 9 holes was 21 inches with a maximum of 36 inches. A thin phosphatic mud, grey to black in colour and with a peaty texture, overlies the hard phosphate in the centre of South Bat. This mud is highly phosphatic, about two inches thick and occurs where the conditions are swampy.

The hard phosphate is a medium to dark brown colour and very porous. It plainly consists of cemented and replaced coral sand. Small unreplaced fragments of sand are visible throughout the rock. Collophane replacements of foraminifera are visible in thin sections cut of the phosphate.

Tonnage and grade of the deposits. Field assays of the hard phosphate showed an average of 27.5% P_2O_5 (7 analyses). The phosphatic mud which overlies the hard phosphate is higher grade; the average of three analyses being 38% P_2O_5. Sand immediately below the hard phosphate shows only a trace of P_2O_5.

The tonnage of hard phosphate on North Bat is estimated to be 12,000 tons, on South Bat 36,000 tons. The phosphatic mud overlying the phosphate on South Bat is estimated to be 1,200 tons. The only other reserves in the group are contained in the two heaps of phosphate at the west end of Mole Island which are together estimated to contain about 1,000 tons. These estimates of tonnages and grades are summarized in Table 2.

R.C. Hutchinson estimated the average depth of the phosphate to be five inches, on the basis of 32 determinations. The eighty auger holes put down during the present survey have made it possible to define the areas where the phosphate crust is intact and to ignore, in the determination of the size of the deposit, those places where the phosphate has been stripped. The hard phosphate was found to be deeper than he supposed but of smaller areal extent.

Sae Island.

Position and Size. Sae Island (0°45'S, 145°17'E.), sometimes called Commerson or the Anchorites, lies 120 miles north-west of Manus Island in the Admiralty Group (see Plate 1 and Plate 4). One small uninhabited island with an area of about 56 acres is surrounded by a fringing reef which extends out to the west to enclose a small islet. It is evidently the presence of this small islet that has led to a certain amount of ambiguity in the naming of the island or islands.

Previous investigations. The island was evidently not visited by Dr. Frederiei, Fennell or R.C. Hutchinson. There is some evidence that the island is known to masters of small ships operating in these waters as an island with a large bird population and a phosphate deposit.

The island and the phosphate deposit. The form of the island and the phosphate occurrence are almost exactly similar to those of the Purdy Islands. The maximum height of the piled

up beach material round the shores of the island is about 4 feet above high tide level. There is no raised coral on the island and the centre is very close to sea level. The island has not been planted with coconuts but it has a cover of rain forest with the usual beach fringe of coconut palms.

The phosphate, as on the Purdy Islands, occurs as a crust formed of the cemented and replaced coral sand which it overlies. The phosphate occupies all the interior of the island and has not been disturbed by man. Locally, uprooted trees have destroyed the original profile. There is no overlying mud and the interior of the island was dry, not swampy, at the time of the survey. In places the phosphate has evidently formed on coarse coral debris and specimens showing partial replacement were found.

Tonnage and Grade. Ten auger holes passed through the hard phosphate. The average depth of phosphate in these holes was 28 inches with a minimum of 9 inches and a maximum of 48 inches. Eleven analyses of the phosphate gave an average value of 25% P_2O_5. The tonnage estimated for an average depth of 24 inches is 70,000 tons. (Table 2).

A few Boobies were found nesting at the south-east tip of the island but no accumulation of their droppings appeared to be taking place.

Manu Island

Position and Size. Manu or Allison Island (01°18'S, 145°35'E.), lies about 180 miles west-north-west of the west tip of Manus Island, in the Admiralty Group. It is the first of the three isolated islands running in a south-westerly arc from the Ninigo Group towards the New Guinea mainland (see Plate 1). It is roughly circular with a diameter of about 800 yards and an area of about 93 acres (Plate 4). It is a copra plantation and has a small population of indentured workers.

Previous investigations. R.C. Hutchinson makes a brief mention of Manu Island. He landed there and saw the phosphate deposit but did not test its depth or make any estimate of its tonnage. He evidently know before his visit that a phosphate deposit existed on the island which suggests that Frederiei or Fennel had investigated the island previously.

Physiography. Like other islands that have been described with this type of phosphate deposit Manu is a low island, with no raised coral exposed. Its maximum elevation above high tide level is about 5 feet. Storm beach material is concentrated on the east and north-east side of the island.

Phosphate deposit. The phosphate deposit occupies most of the interior of the island. In the north-west it is composed of hard cemented phosphate, in the south-east of soft phosphatic mud. These two types of phosphate may be due to a slight difference in elevation between the two parts of the deposit. However, this was not satisfactorily established. Some of the hard phosphate may have been removed, but no indigenous islanders remain who might recall such an event.

The hard phosphate is exactly the same as the material already described from the Purdy islands. The phosphate

from Manu is lighter in colour than that from the Purdy islands but this does not seem to reflect a difference in phosphate content. The phosphatic mud is similar in appearance and texture to that from the South Bat deposit.

Tonnage and Grade. The average depth of both the phosphatic mud and the hard phosphate is 6 inches with little variation. The tonnage of hard phosphate is estimated to be 15,000 tons with an average grade, from seven analyses, of 26% P_2O_5. The phosphatic mud deposit is estimated to contain 11,000 tons and to have an average grade of 31.5% (six analyses).

Aua Island

Position and Size. Aua Island (1 27'S, 143 03'E), is the second of the three isolated islands of the west Admiralties. It is about 200 miles from the west tip of Manus Island, and some 40 miles south-west of Manu Island (Plate 1).

It is a larger island than Manu having an area of about 2 square miles (Plate 5).

It is inhabited by people of Polynesian descent who live in villages round the west and south coasts.

Previous investigations. Aua Island was visited by Fennel in 1929 and by Hutchinson in 1941. Hutchinson described the position of the deposit but did not estimate the tonnage.

Physiography. The island is low and sandy, the maximum elevation being no more than six feet above the level of high tides. It is shaped like a right-angled triangle with the hypotenuse oriented south-west (see Plate 5). The whole island is surrounded by a fringing reef usually about 50 yards wide. It was possible for the charter vessel to 'hang on' at the edge of the reef, at a point half-way along the west coast, for the period of the survey, but no true anchorage exists.

The phosphate deposits. The phosphate deposit occurs along the south-west coast about 100 yards inland. A search over the rest of the island failed to show any further trace of phosphate. The phosphate crust, which is exactly like that of the Purdy deposits, has been broken up by the digging of Taro pits. These pits are six feet deep and individual pits may be as big as 100 yards square. The excavated material, consisting of phosphate boulders, coral boulders, coral sand and soil, was heaped on the divide between adjoining pits. The Taro grown in these pits was used to feed the labourers who worked the Copra plantation, now neglected, which covered the rest of the island.

Tonnage and Grade. No estimate of the tonnage of phosphate present can be made. The phosphate blocks are inextricably mixed with soil, coral boulders and coral sand. Remnants of the phosphate were found over an area of about 100,000 square yards and at one locality where the phosphate appeared to be undisturbed it was 18 inches thick.

142°50'E

Wuvulu Island

Position and Size. Wuvulu, Maty or Tiger Island (1 43'S, 143 22'E), is the farthest ~~west~~ of the western group of the Admiralty Islands. It lies 250 miles west of the western tip of Manus Island and about 140 miles north of the town of Wewak on the north coast of New Guinea (Plate 1).

Wuvulu has a surface area of about 5 square miles and is of a very irregular shape. The north coast is fairly straight but the south coast has two promontories which form a wide bay, Maloe Bay, in the centre (Plate 6).

A copra plantation, Agita plantation, occupies the greater part of the island; the owner and his wife live on the island at Agita homestead, on the shore of Maloe Bay.

There are two main villages, at the north and south ends of the west coast. The island people are of Polynesian descent.

Access throughout most of the island is easy.

Previous investigations. R.C. Hutchinson visited Wuvulu Island and saw the main phosphate deposit. He evidently knew of its existence before going there and it therefore seems certain that Fennel visited the island during his 1929 investigations.

It is possible that some phosphate was exported. A heap of phosphate occurs between two Taro pits near Auna village; this may be a heap prepared for shipment, or it may simply have been heaped there for convenience during the Taro pit excavations.

The older village people seem to think that some phosphate was removed from the island during the German mandate over the Territory.

The villagers have cut and shaped phosphate blocks and used them to make gravestones and the walls of wells.

Physiography. In the main the island is exactly like Manu, Aua and the Purdy Islands; low-lying coral sand nowhere more than six feet above high tide level. It differs from them in that some raised coral, eroded into pinnacles, does occur along the north shore and at the south-west phosphate deposit. The raised coral along the north shore is about twelve feet above sea level and does not persist inland for more than about one hundred and fifty yards. Lumike Island, off the north coast, is also of raised coral (see Plate 6). Wuvulu Island has evidently been tilted slightly to the south-east.

The Phosphate deposits. Phosphate deposits occur at two places on the island. The main deposit is similar, though not identical, to the Purdy occurrences, and is on the south-west promontory; the second deposit is very small in area and is of phosphatic clay between pinnacles of raised limestone in the north-west corner of the island.

The main deposit has been disturbed by the digging of Taro pits, as on Aua, and only remnants of the phosphate remain. At P_1, (see Plate 6), along the track leading west from Auna village an 18" thickness of cemented phosphate, very similar to the Purdy material, is overlying limestone directly. The same type of exposure occurs at P_4 and P_7. At P_8 and near

P_2 a thickness of about 2 inches of phosphatic sand which appears to have formed by the mechanical weathering of the cemented phosphate, was found. This sand directly overlies the limestone. This phosphatic sand may, of course, have resulted from the breaking down of phosphate blocks after the Taro had been dug and the phosphate blocks heaped up. At P_9 limestone was intersected at a depth of 30 inches below coral sand.

It seems that uplift of the island has brought limestone to the surface or close to the surface but that cementation and phosphatization of an original thin cover of coral sand has given rise to material very similar to that of the Purdy Islands.

The northern deposit is quite different. It simply consists of small pockets of phosphatic clay occurring over a very limited area between pinnacles of raised limestone. This deposit is of the same type as that on Nauna Island which is described later. The deposit is undisturbed. Just north of the clay deposit small pockets of phosphatic oolites cemented together occur in cracks along the sea cliff. The limestone here is raised about 12 feet above sea level. The maximum depth of clay between the pinnacles is no more than 4 feet.

Tonnage and grade. The northern deposit is very small indeed, occurring as scattered pockets over about 5000 sq. yards, none of the pockets deeper than 4 feet. The tonnage therefore is of the order of a few hundred tons.

The main deposit has been disturbed by Taro pit digging and it is no longer possible to say what tonnage of phosphate is present. It seems likely that some phosphate was exported. The original deposit probably occupied an area of about 100,000 sq. yards and was of the same order of thickness as the Purdy deposits.

B. Phosphatic Clay Deposits.

Deposits of phosphatic clay are quite different from the cemented phosphate deposits previously described. They occur on islands of raised coral limestone as a clay and oolitic phosphatic sand infilling between pinnacles of limestone. These deposits seem to be restricted to raised coral islands with a well marked saucer shaped structure.

Three islands investigated during the present survey had deposits of this kind: Wuvulu Island, described above, which has a small clay deposit associated with an area of slightly raised limestone; Bellona Island in the British Solomon Islands Protectorate, which is the subject of another report (White and Warin, 1959), and Nauna Island, which is described here.

Nauna Island

Position and Size. Nauna Island ($2^{\circ}11'S$, $148^{\circ}09'E$) lies about 60 miles east of Lorengau (Manus Island) (Plate 1). It is the most easterly of the Admiralty Group, about 1700 yards long (north/south), and about 1000 yards wide (east/west). Its total surface area is a little under half a square mile (Plate 7).

The island has a small population who live in one village near the sea shore at the south end of the island.

The interior of the island is of raised coral and in places rugged. All the villagers' gardens are near the sea shore on the flat terrace behind the village but there were at one time gardens in the interior on the area of the phosphate deposit.

There is no anchorage.

Previous investigations. There is no record of previous investigation of the island for phosphate deposits. It was included in the present survey because the available evidence suggested that it was of raised coral, and because of its fairly isolated position on the extreme east of the Admiralty group.

Physiography. The island is an elevated coral atoll, elliptical in form. The uplift was apparently accompanied by tilting to the south-east so that the north end of the old lagoon floor is 320 and the south end 270 feet above sea level. The coral rim surrounding the old lagoon floor is well marked on the north and west sides. On the east and south sides the rim is not appreciable, and the gently sloping old lagoon floor falls away suddenly in precipitous cliffs. There are no watercourses on the island.

Phosphate deposits. The deposit is of phosphatic clay occurring in a crescent-shaped area slightly to the south-east of the centre of the old lagoon floor. The clay is underlain along the north-west half of the area by an oolitic phosphatic sand grading upwards into the clay. The contact of the sand and the clay with the underlying limestone is everywhere sharp though very irregular. Sections established by hand auger drilling are shown in Plate 7A. The limestone is a field of pinnacles and chimneys and the phosphatic clay and the oolitic phosphate occur as infilling between them. Over most of the deposit the tops of the pinnacles do not appear at the surface. Some clay occurs in chimneys outside the area shown on Plate 7.

The clay is a yellow brown colour darkening somewhat on exposure to air and with a consistency like that of drying putty or plasticine. The oolitic phosphate is made up of small round oolitic grains all about 1/10 inch in diameter. The grains are in a matrix of the phosphatic clay and all gradations from 100% clay to 100% oolitic phosphate are found.

Tonnage and grade. It is estimated that the deposit contains 125,000 tons of the phosphatic clay with an average grade of 15.9% P_2O_5 (from 13 field analyses and 10 laboratory analyses). This estimate has been made allowing a deduction of 1/2 for the volume occupied by the limestone of the pinnacles in determining the volume of the clay. The oolitic phosphate is estimated to make up 15,000 tons with an average grade of 32.5% P_2O_5 (from 5 field analyses and 5 laboratory analyses). Again the same supposition has been made regarding the volume occupied by the limestone pinnacles. The density of the clay and oolitic phosphate has been taken to be 1 ton to 25 cubic feet.

ISLANDS WITHOUT PHOSPHATE DEPOSITS

The Marshall Bennett Group

Position and size. The group consists of four islands of raised coral whose latitude and longitude and area are listed below.

		Area	
Gawa Island	(152°00'E, 9°01'S)	5 sq.ml.	(Plate 8)
Kwiawata Island	(151°55'E, 8°55'S)	2 sq.ml.	(Plate 9)
Iwa Island	(151°45'E, 8°44'S)	1 sq.ml.	(Plate 9)
Dugumenu Island	(151°56'E, 8°49'S)	1/2 sq.ml	(Plate 9)

They lie between the Trobriand Islands and Woodlark Island; and close to the east end of Papua (see Plate 1).

The three larger islands, Gawa, Kwiawata and Iwa are inhabited by a people related by language and customs to the Trobriand Island people. Dugumenu is not inhabited.

There is no record that the islands of the group have previously been investigated for phosphate deposits.

Physiography. The three larger islands are very similar in form - they are raised coral atolls with well marked coral rims and old lagoon floors. They are elevated to different heights; on Gawa the rim is about 450 feet above sea level, on Kwiawata 500 feet, in Iwa 250 feet.

On these three islands an aluminous clay, derived from the weathering of the limestone, occurs in patches on the old lagoon floor. Some samples of the clay are phosphatic (maximum 16% P_2O_5) on Kwiawata, but these samples were isolated and did not constitute a deposit.

Testing was by evenly spaced hand auger holes along tracks. No chemical testing was done on the islands but a representative number of the samples collected were tested in the laboratory.

Dugumenu Island does not show the clearly defined rim and old lagoon floor of the other islands. It has only a small area of raised coral near the north-west shore, with a maximum elevation of about 50 feet. About a quarter of the island near the east shore is low lying and swampy, the rest is composed of coral sand.

The Alcester Islands

Position and Size. The Alcester Islands (152°25'E, 9°33'S) are a group of two, the first is an east-west trending island, six miles long by one mile wide; the second is a small islet situated off the east tip of the main island (Plate 10).

A very few people live in one village situated half-way along the north shore of the larger island.

There is no report of any previous investigation of the island for phosphate.

Physiography. The islands, which are physiographically a single unit, are of raised coral, with a maximum elevation of 200 feet above the present sea level. The islands form a long narrow arc concave towards the south.

The islands appear to have been tilted at the time of the uplift, because the cliffs along the north coast are about 120 feet high (Aneroid barometer readings) and the surface of the island slopes gently towards the south. The cliffs along the south coast are certainly lower than those on the north but they were not measured.

The limestone in the interior of the island is cavernous and pinnacled and only small patches of humic soil occur. The island has a dense cover of rain forest.

None of the limestone or soil specimens showed any trace of phosphate.

The Laughlin Islands

Position and Size. The Laughlin Islands (153 40'E, 9 18'S), are an atoll group situated 35 miles east of the eastern tip of Woodlark Island (Plate 1). The islands of the group ring a circular lagoon about 2 miles in diameter and are low-lying and sandy. They are about 100 yards wide but were not surveyed and their areas are not known.

There are two villages on Budelun Island, the largest island in the group.

Physiography. The islands are mainly composed of coral sand. Budelun Island has slightly raised coral along its seaward, easterly-facing, edge and good exposures of cemented 'beach rock' along its lagoonward shore.

Bedulun and the second largest island were both traversed. No phosphate was discovered.

Cannac Island

Cannac Island, or Cannac Rock as it is also known, is about 11 miles west of the Laughlin Group (Plate 1). No landing was attempted on the island during the present survey owing to bad weather, but the island is the subject of a report by E.R. Stanley (Stanley, 1917). He described the island as a large triangular shaped rock with sides less than 100 yards, rising steeply to a gently sloping top whose highest point is 130 feet above sea level. The island is composed of slates with a few fine-grained basic igneous intrusives, which Stanley considered were similar to rocks outcropping along the south coast of Woodlark Island.

He described the phosphate as being partly of fresh guano and partly of phosphatized slate and igneous rock, the whole forming a cover about three feet deep over the island. He estimated the total tonnage at about 8,000 tons; and the average grade (three analyses) was 39% P_2O_5.

Sable Island

Sable Island (154°40'E, 3°44'S), in an isolated position 120 miles north-east of Cape St. George, New Ireland (see Plate 1), was found to be a small sand bank, about 30 yards long and 15 yards wide. No landing was attempted as the

bank could obviously not carry an important quantity of phosphate. No birds were seen in the vicinity.

The Saint Matthias Group

Tench Island

Tench Island (150°45'E, 1°35'S), is the smallest island of the group. It is 900 yards long (north-south) and 650 yards wide with a central swampy area.

A few people live in a small village on the north-west coast.

The island is of coral sand and coarse beach material. No trace of phosphate was found.

Emirau Island

Position and Size. Emirau Island (150°0'E, 1°40'S) has an area of 7 square miles and a very irregular outline (Plate 11). The island was visited by Fennell in 1929 (noted by Hutchinson, R.C., 1941), but no phosphate was found.

The people of the island live in villages mainly along the south-east coast. A copra plantation occupies much of the west part of the island. The owner lives on the island.

Emirau was used during the Second World War as an airbase. Roadways and runways built then simplify access to much of the island.

Physiography. About 70% of the island is formed of a raised coral platform which has an average elevation of 100 feet above sea level. The whole of this platform was examined (see Plate 11), but only limestone or limestone under very thin soil cover was found.

Mussau Island

Position and Size. Mussau (149°35'E, 1°25'S) is the largest island in the St. Matthias Group. It is 22 miles long (northwest/south east) by 10 miles wide with an oval outline (Plate 12).

Several villages are situated along the north-east coast. An important centre is opposite the best anchorage, Schadel Bay, on the south coast. Good tracks connect the villages and continue round the coast but few used tracks go into the interior.

The island was visited by Fennell in 1929 and is included in his list of islands not thoroughly investigated (Hutchinson, R.C., 1941).

Physiography. The island consists of a central ridge of hills rising to 2118 feet (Mt. Eunainaun) surrounded by a dissected terrace of raised limestone with an average height of 500 feet in the south-east and 300 feet in the east and north-east.

The central hills are of volcanic origin. Basalts and tuffs were recognized.

The traverse of the present survey and the geology of the island are shown on Plate 12.

No phosphate was found.

Alim Island

Alim Island (147°07'E, 2°51'S), is ¾ mile long and 300 yards wide, elongated north-north-east. The east side and the north end of the island are of coral sand; the west and central areas are of mangrove swamp. The island is surrounded by a wide fringing reef.

The island was visited by Friederiei during his 1909 reconnaissance but no phosphate was found. However, G.E. Hutchinson in his review of the Pacific Islands listed Alim as 'doubtfully phosphatic' (Hutchinson, G.E., 1950, p.226).

The present survey showed that there is only a trace of phosphate in the upper layers of the coral sand of which the major part of the island is made.

Rambutyo Island

Rambutyo Island (147°50'E, 2°15'S) is the second largest of the Admiralty Group. It is about 30 miles east-south-east of the east tip of Manus Island (Plate 1).

A reconnaissance of the island was made after a deposit of phosphatic clay was found on Nauna Island which is 20 miles to the east. Rambutyo consists of a central core of hills of volcanic rocks surrounded by broad terraces of raised limestone (see Plate 13). A clay, derived from the weathering of the volcanic rocks, spreads out over parts of the limestone terraces and fills in between limestone pinnacles. This clay was extensively tested by hand auger drilling but in no place was it found to be phosphatic.

Pak Island

Pak Island (147°37'E, 2°04'S), is a low-lying island, five miles long and half a mile wide, trending east-west (Plate 14). It lies about 15 miles from the east tip of Manus Island in the Admiralty Group. It is composed of coral sand with a small area of slightly raised coral. No phosphate was found.

Tong Island

Tong Island (147°45'E, 2°00'S), is another low-lying island, almost circular in shape, 3½ miles east-west by 2½ miles north-south (Plate 14). It is about 20 miles to the east of the east tip of Manus Island in the Admiralty Group.

The island was found to be composed of coarse coral debris with areas of slightly raised coral. No phosphate was discovered.

Mode of Formation of the Phosphate Deposits

(a) Hard Cemented Phosphate Deposits

This type of deposit consists essentially of a thin crust of cemented phosphate on a low sandy island. Two possible modes of formation of this type of deposit are discussed.

(1) They may be ancient deposits formed when the islands first came into existance as low sand cays. At such time, with no vegetation, the islands could have been the breeding ground for colonies of guano-producing birds. Later the conditions may have favoured the development of a rain forest cover and the birds may have abandoned the islands.

(2) Fosberg (1954, 1957), suggests that similar deposits in the Marshall Islands are at present forming where bird droppings are accumulating under groves of the forest tree Pisonia grandis. (Taylor, 1950, p.177). Fosberg thinks that without the acid humus, developed under this particular tree, phosphatic solutions leached from bird droppings would be washed through the coral sand and no deposit would be formed.

In the case of the islands described in this report the first explanation seems the more likely.

Clearly the deposits are not being added to at the present day as virtually no birds were seen on any of the islands.

The deposits on North and South Bat Islands are ancient deposits in so far as they were certainly developed prior to the change in the outline of the islands that has been already described. In the same way the relationship of the phosphate occurrences to the total area of Aua and Wuvulu Islands may be due to subsequent increase in the surface area of these two islands by sand accumulation.

(b) Phosphatic Clay Deposits

The phosphatic clay deposit on Nauna Island is very similar to that on Bellona Island, British Solomon Islands. The mode of formation of this type of deposit is discussed fully in the report on the Bellona deposit (White and Warin, 1959), and only a summary is given here.

A raised coral atoll, such as Nauna, is saucer shaped in section, with an old lagoon floor surrounded by a limestone rim. The saucer shape leads to the retention within the central hollow of phosphate derived from the guano and the products of erosion of the limestone. The resulting phosphate deposit is, in the case of Nauna, a low-grade clay, in which the main impurity is alumina.

Economic Significance of the Deposits

The calculated tonnages and grades of the deposits described are contained in Table 2.

The deposits of the cemented phosphate type are all too small to have anything more than local significance. The islands on which such deposits occur are small, the phosphatic

crust is thin and therefore the tonnages are alsays small. The possibility of the local exploitation of these deposits within the island groups on which they occur should not be overlooked. Fosberg (1957) suggests utilization of deposits in the Marshall Islands in this way.

Deposits of the second type - phosphatic clays of the Nauna and Bellona type - hold greater economic potential because they contain much greater tonnages. Present methods of superphosphate manufacture, however, require higher grade material than the clays of these deposits.

Future search should be carried out on raised coral islands in the hope of finding further deposits of this type either of higher grade or with a larger proportion of the higher-grade oolitic phosphate sand which accompanies the clay in these deposits.

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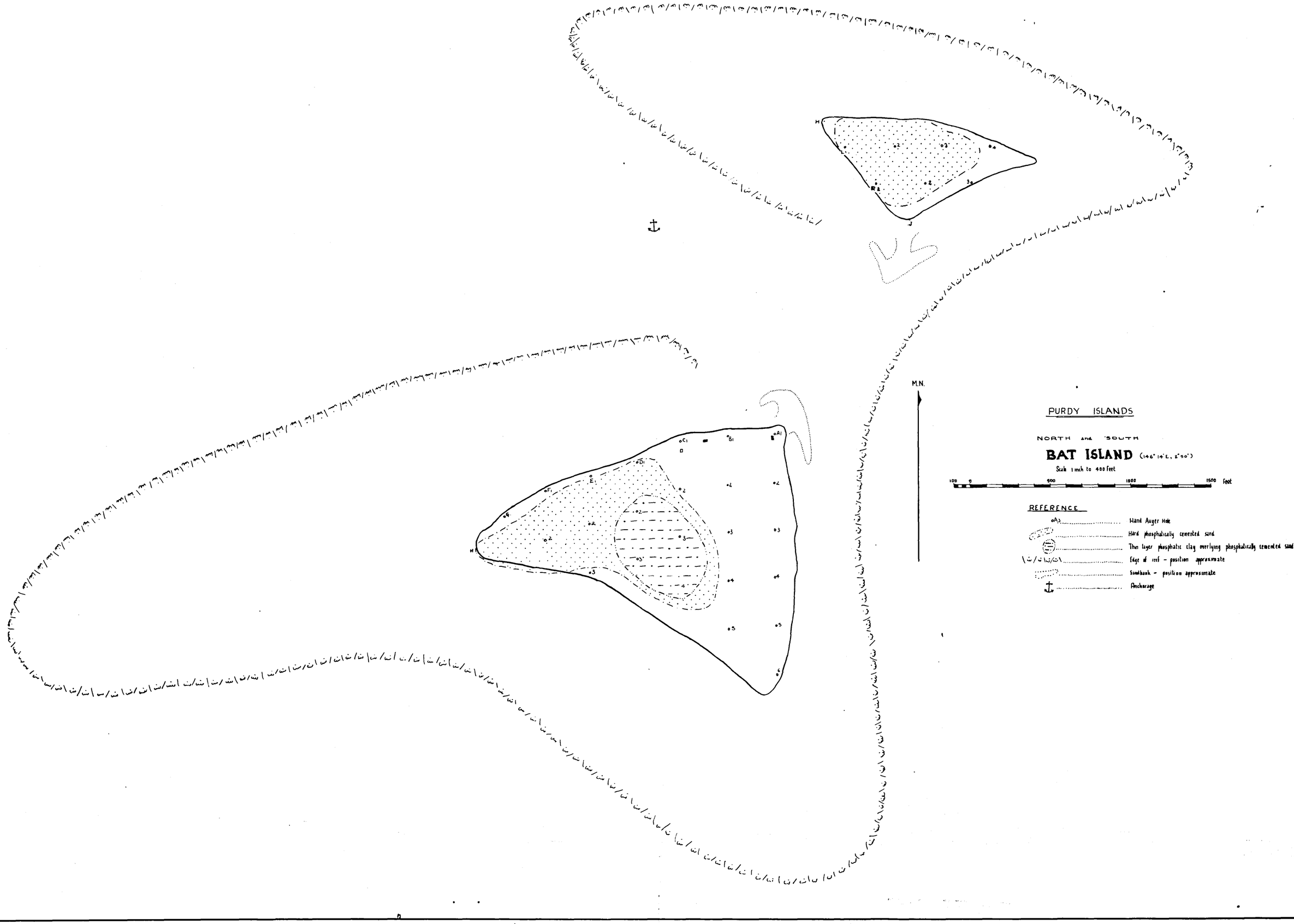
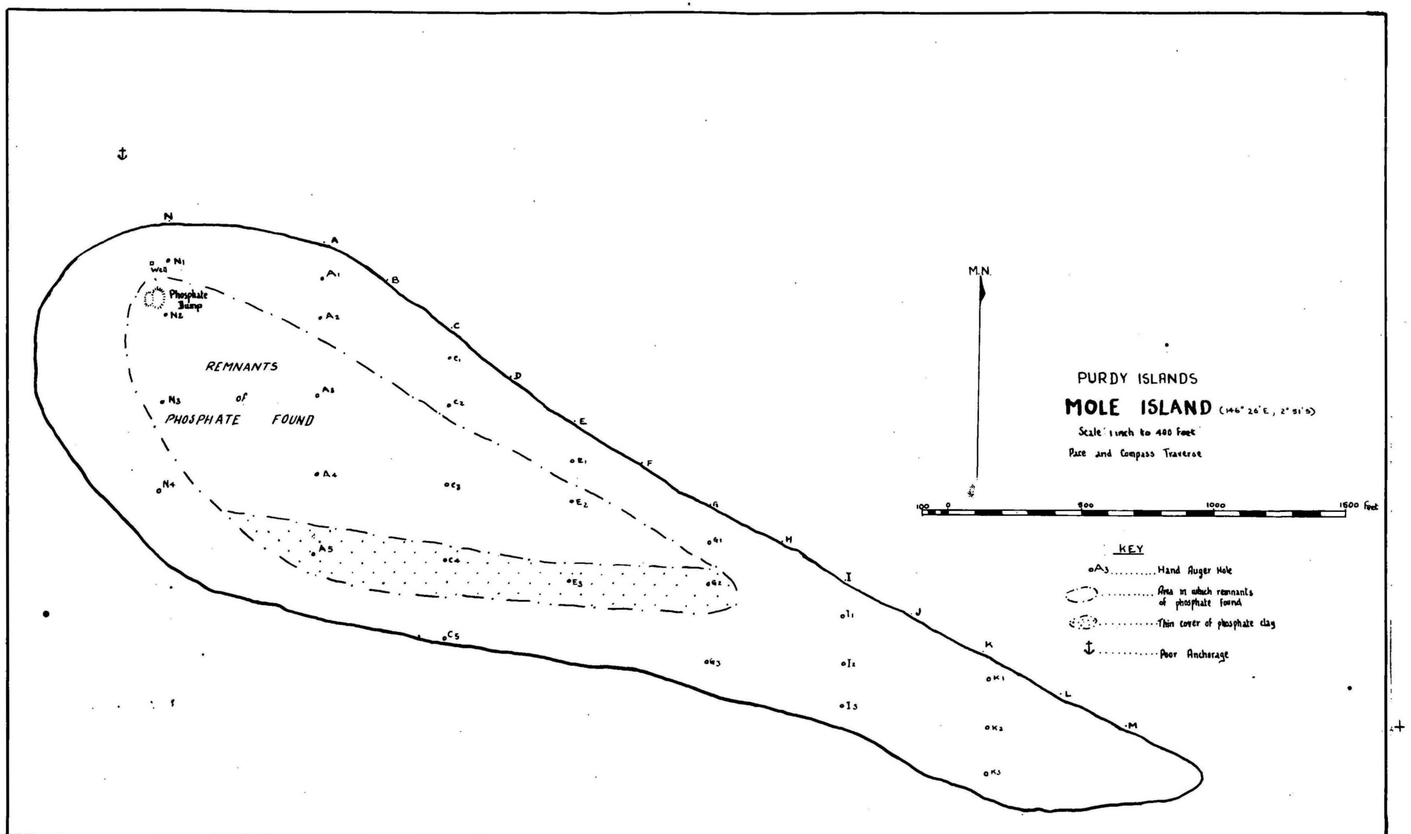
TABLE 2

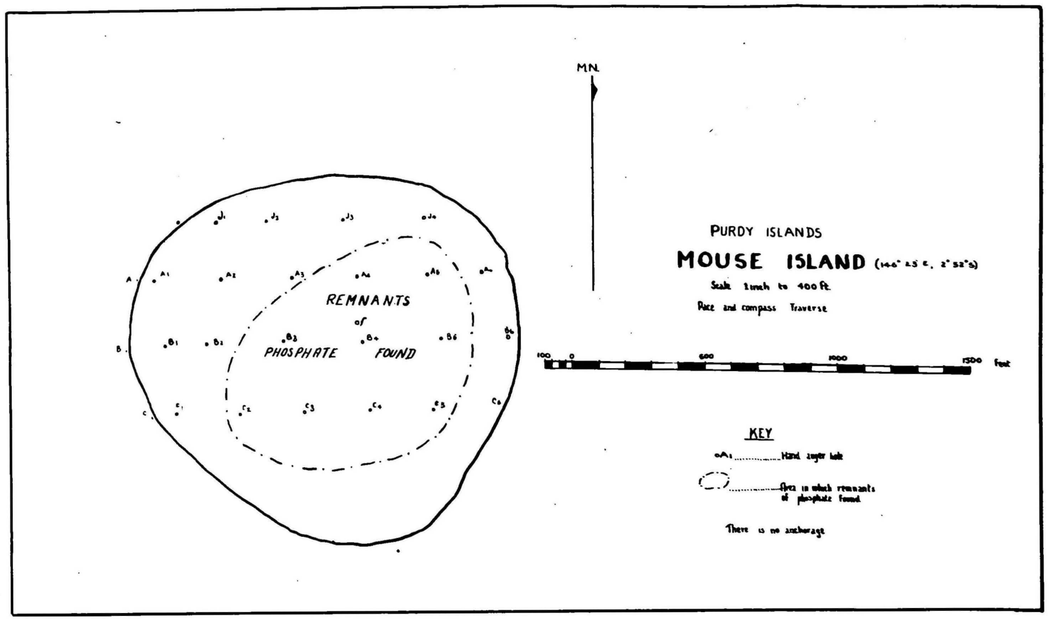
Island	Type of Phosphate	Approximate Tonnage	Average Grade (% P_2O_5)
North and South BAT	Cemented	48,000	27.5%
	Phosphatic mud	1,200	38.0%
MOLE	Cemented (heap)	1,000	23.4%
MOUSE	-	-	-
SAE	Cemented	70,000	23.0%
MANU	Cemented	15,000	26.0%
	Phosphatic mud	11,000	31.5%
AUA	Cemented	small	
WUVULU	Cemented and clay	small	
NAUNA	Clay	125,000	15.9%
	Oolitic	15,000	32.5%

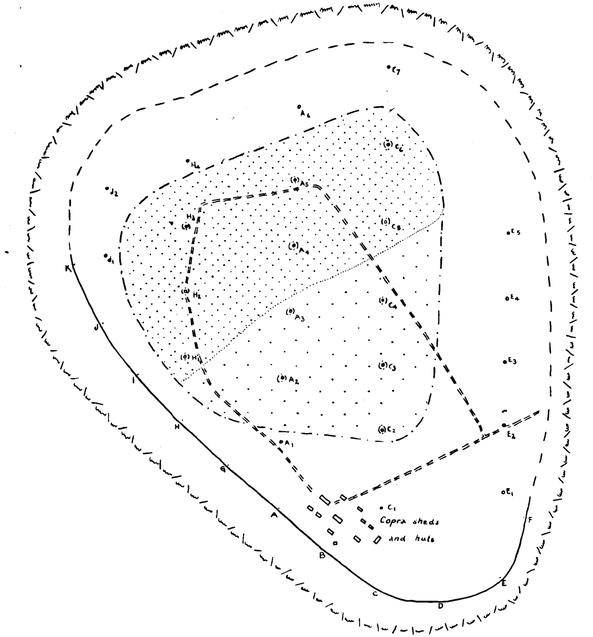
PLATE 1.


S.W. PACIFIC
ISLANDS INVESTIGATED DURING
PHOSPHATE SURVEY 1958.
SCALE 1:2,534,400
Laghlin I ....Islands investigated
ADMIRALTY ISLANDS
Manus I
LORENGAU
St. Matthias Group
Mussau I
Emirau I
Tench I
New Hanover I
KAVIENG
NEW IRELAND
RABAUL
NEW BRITAIN
N E W G U I N E A
P A P U A
WEWAK
MADANG
LAE
FINSCHAFEN
PORT MORESBY
SAMARAI
D'ENTRECASTEAUX ISLANDS
LOUISIADE ARCHIPELEGO
Bougainville I
BRITISH SOLOMON ISLANDS
Choiseul I
Santa Isabel I
New Georgia Group
HONIARA
Guadalcanal I
Ontong Java I
QUEENSLAND


M.N.
PURDY ISLANDS
NORTH and SOUTH
BAT ISLAND (146° 14'E, 2° 50')
Scale 1 inch to 400 feet
100 0 500 1000 1500 Feet
REFERENCE
oA3 Hand Auger Hole
Hard phosphatically cemented sand
Thin layer phosphatic clay overlying phosphatically cemented sand
Edge of reef - position approximate
Sandbank - position approximate
Anchorage


N
A
B
C
D
E
F
G
H
I
J
K
L
M
N1
N2
N3
N4
Phosphate Bump
REMNANTS
of
PHOSPHATE FOUND
M.N.
PURDY ISLANDS
MOLE ISLAND (146° 26' E., 2° 51' S)
Scale 1 inch to 400 Feet
Pace and Compass Traverse
100 0 900 1000 1500 Feet
KEY
Hand Auger Hole
Area in which remnants of phosphate found
Thin cover of phosphate clay
Poor Anchorage


M.N.
REMNANTS
of
PHOSPHATE FOUND
PURDY ISLANDS
MOUSE ISLAND (146° 25' E., 2° 52' S)
Scale 1 inch to 400 ft.
Pace and compass Traverse
100 0 600 1000 1500 Feet
KEY
Hand auger hole
Area in which remnants of phosphate found
There is no anchorage



M.N.

WESTERN ADMIRALTY GROUP

MANU ISLAND

(01° 18' S 145° 35' E)

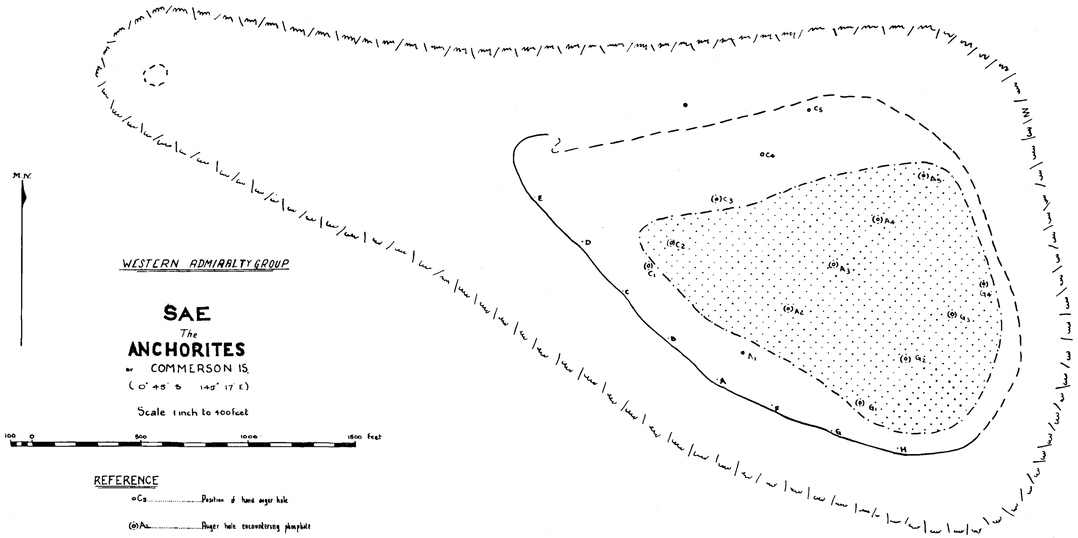
Scale 1 inch to 400 feet

100 0 500 1000 1500 Feet

REFERENCE

- Position of hand auger hole
- Auger hole encountering phosphate
- Bicycle track
- Hard phosphatically cemented sand
- Thin layer of phosphatic clay

Note: Survey by pace and compass. The position of the reef is approximate. There is no anchorage.



M.N.

WESTERN ADMIRALTY GROUP

SAE
The
ANCHORITES
or COMMERSON IS.

(0° 45' S 140° 17' E)

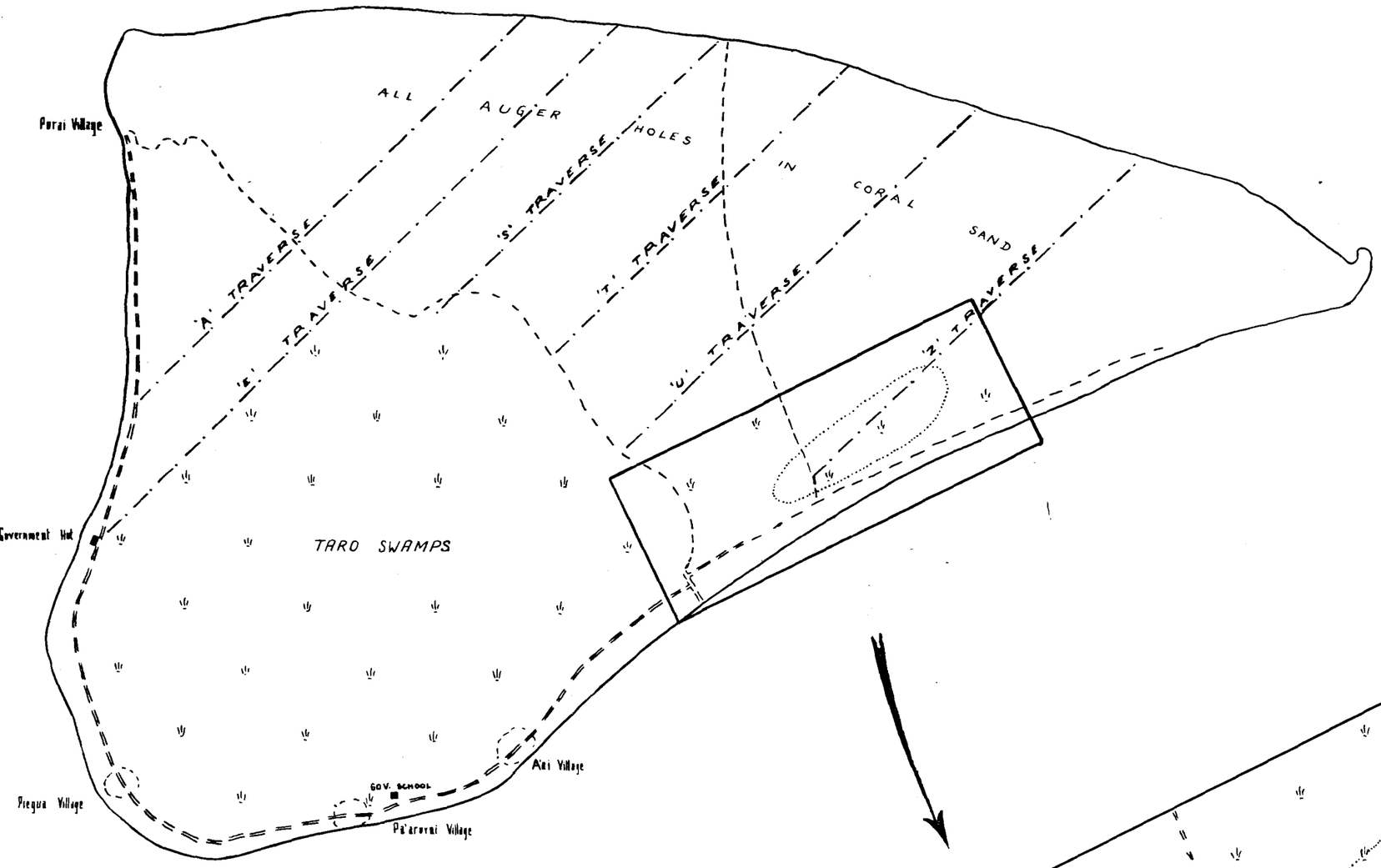
Scale 1 inch to 400 feet

100 0 500 1000 1500 feet

REFERENCE

- Position of hand auger hole
- Auger hole encountering phosphate
- Phosphatic deposit
- Anchorage

Note: Survey by pace and compass. The position of the small islands and reef are only approximate.



WESTERN ADMIRALTY GROUP

AUA ISLAND (1° 27' S 145° 05' E)

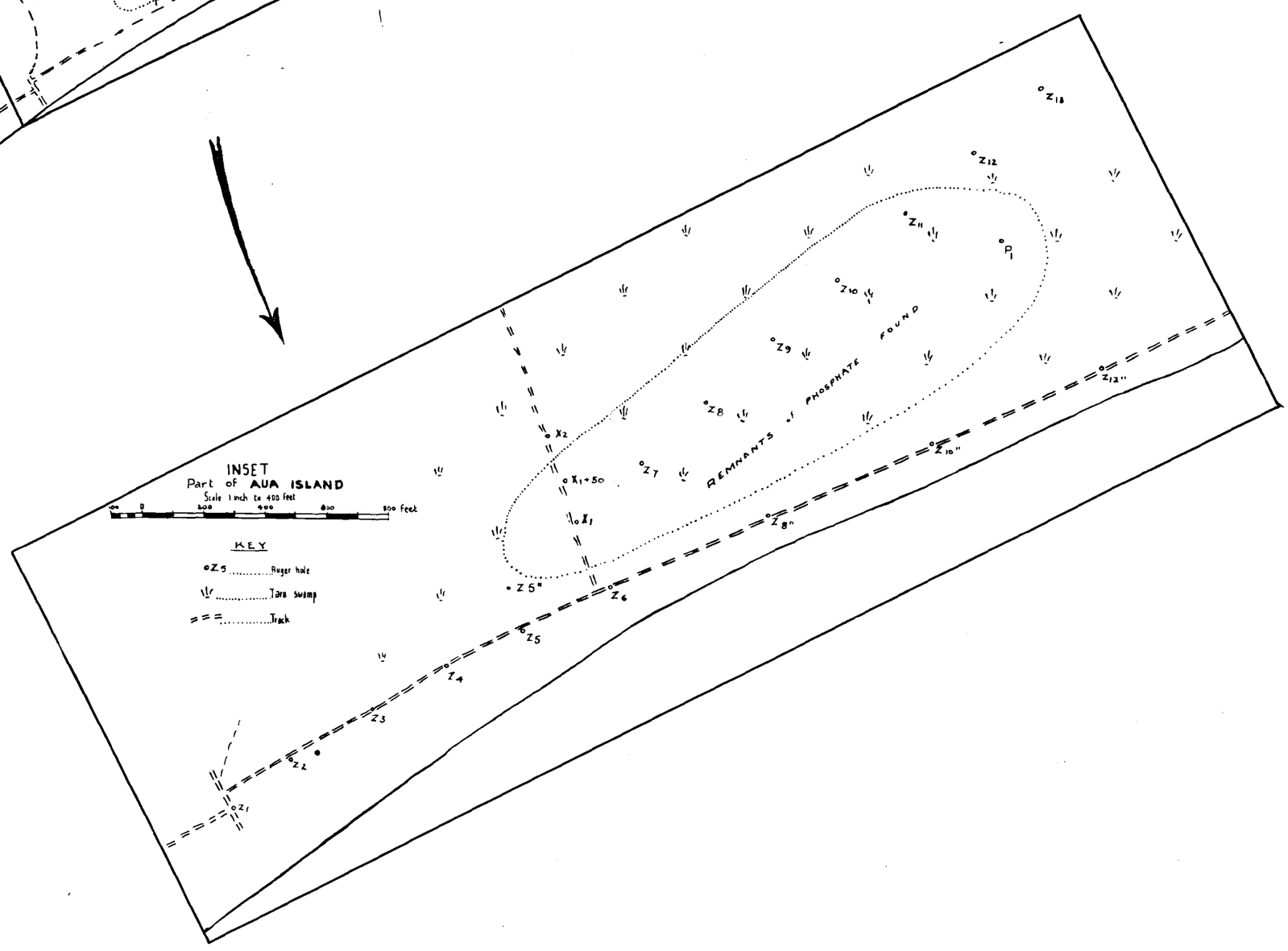
Scale 1 inch to 1200 feet

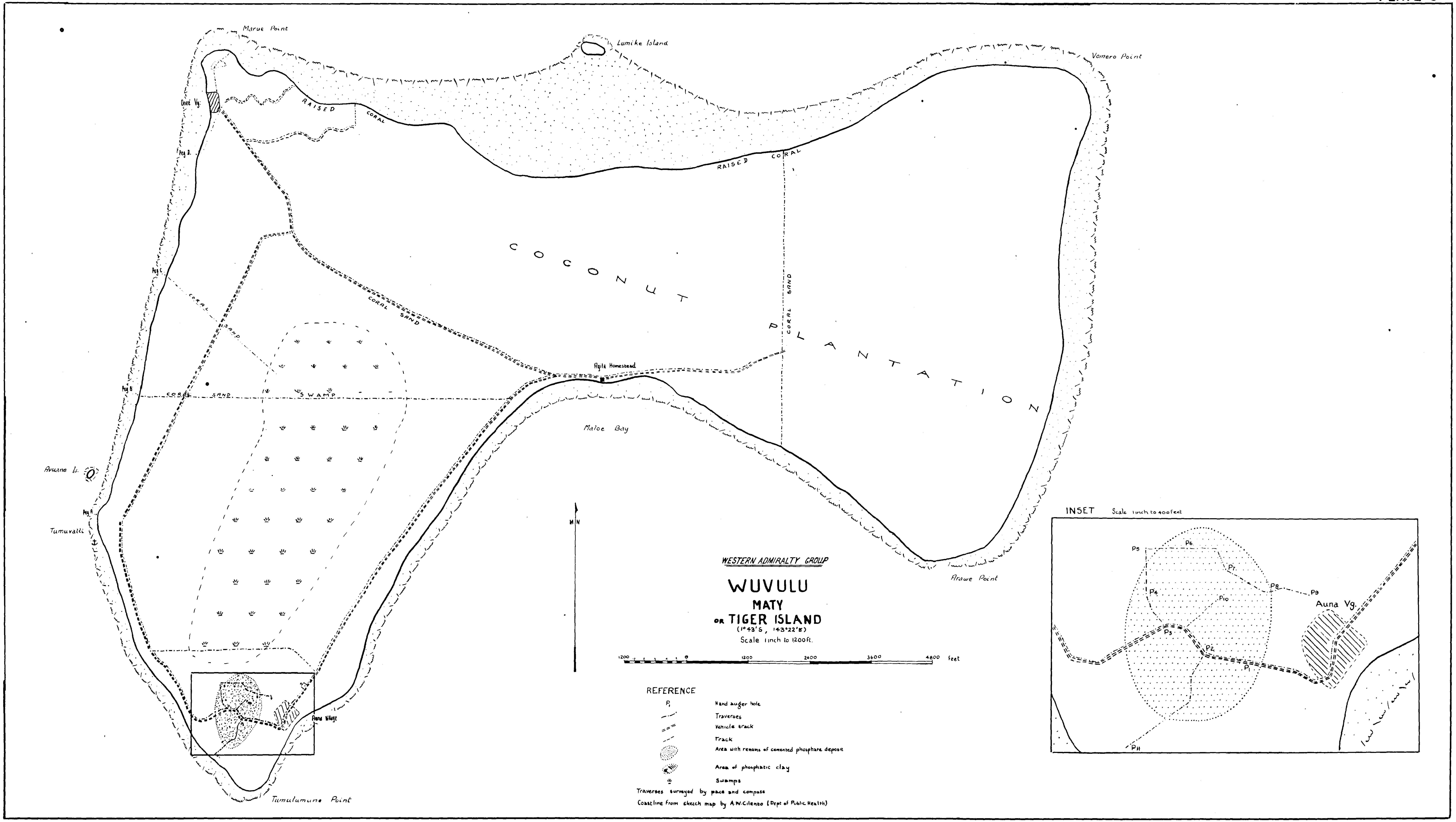
3600 2400 1200 0 2 4 6 8 10 feet

REFERENCE

- Tracks
- Traverse lines (Auger holes every 200 feet)
- Taro swamps

Survey by chain and compass




WESTERN ADMIRALTY GROUP
WUVULU
MATY
OR TIGER ISLAND
(1°43'S, 143°22'E)
Scale 1 inch to 1200 ft.
1200 0 1200 2400 3600 4800 feet
REFERENCE
Hand auger hole
Traverses
Vehicle track
Track
Area with remains of cemented phosphate deposit
Area of phosphatic clay
Swamps
Traverses surveyed by pace and compass
Coastline from sketch map by A.W. Cilento (Dept of Public Health)
Marue Point
Lumike Island
Vomero Point
RAISED CORAL
COCONUT PLANTATION
CORAL SAND
SWAMP
Maloe Bay
Arawe Point
Avuane Is.
Tumuvalli
Tumulumune Point
INSET Scale 1 inch to 400 feet
Auna Vg.

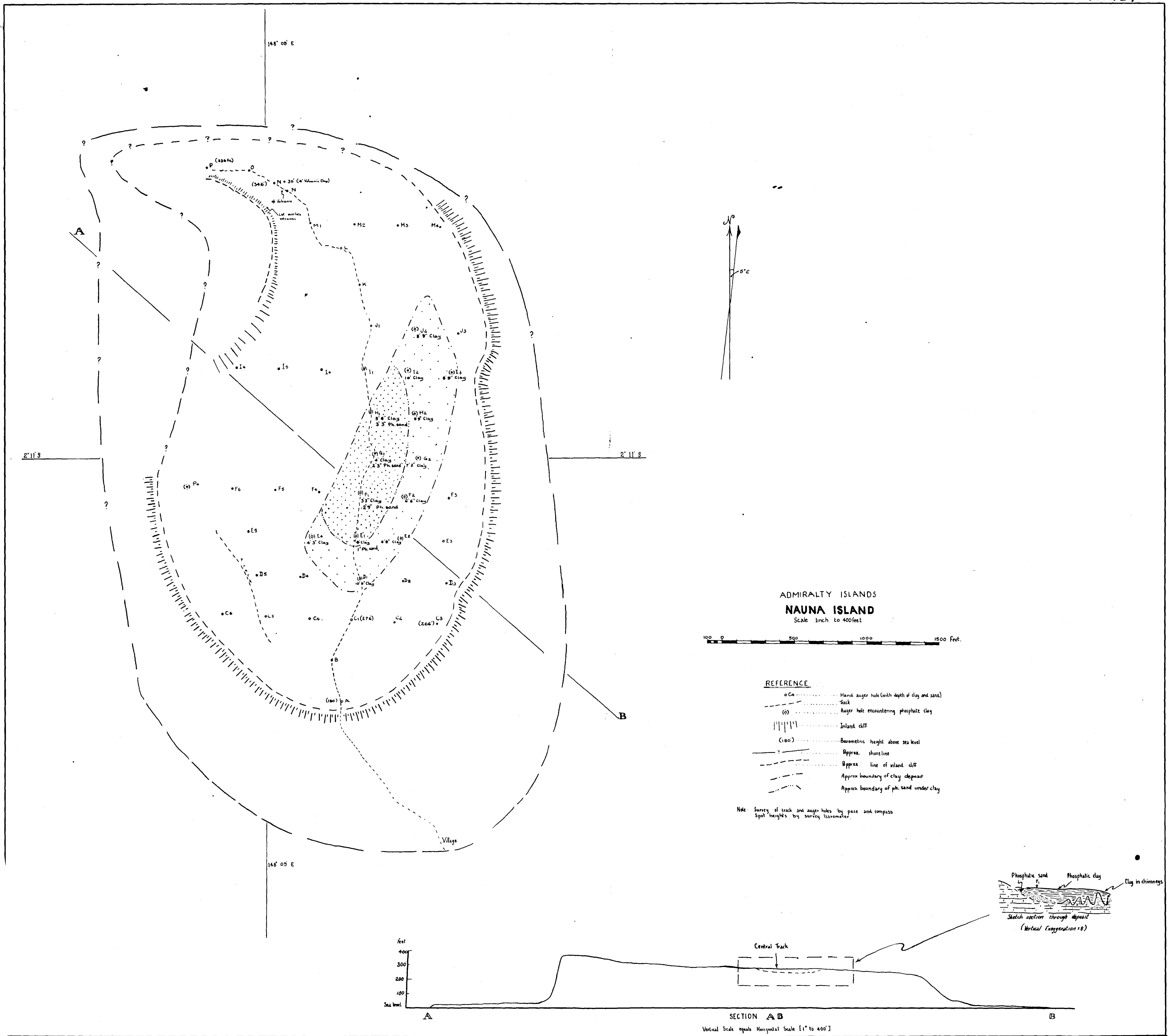
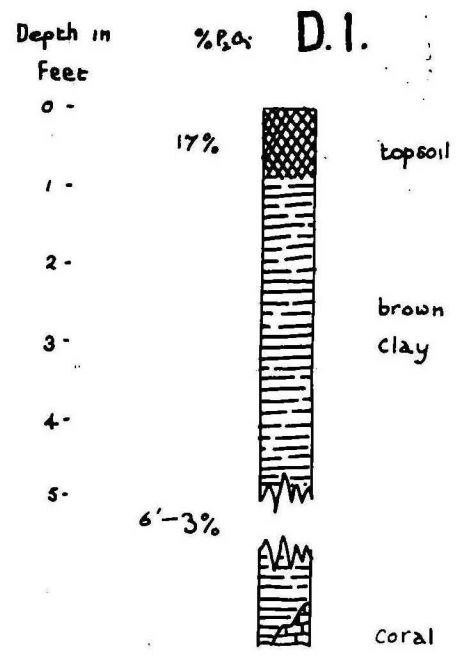
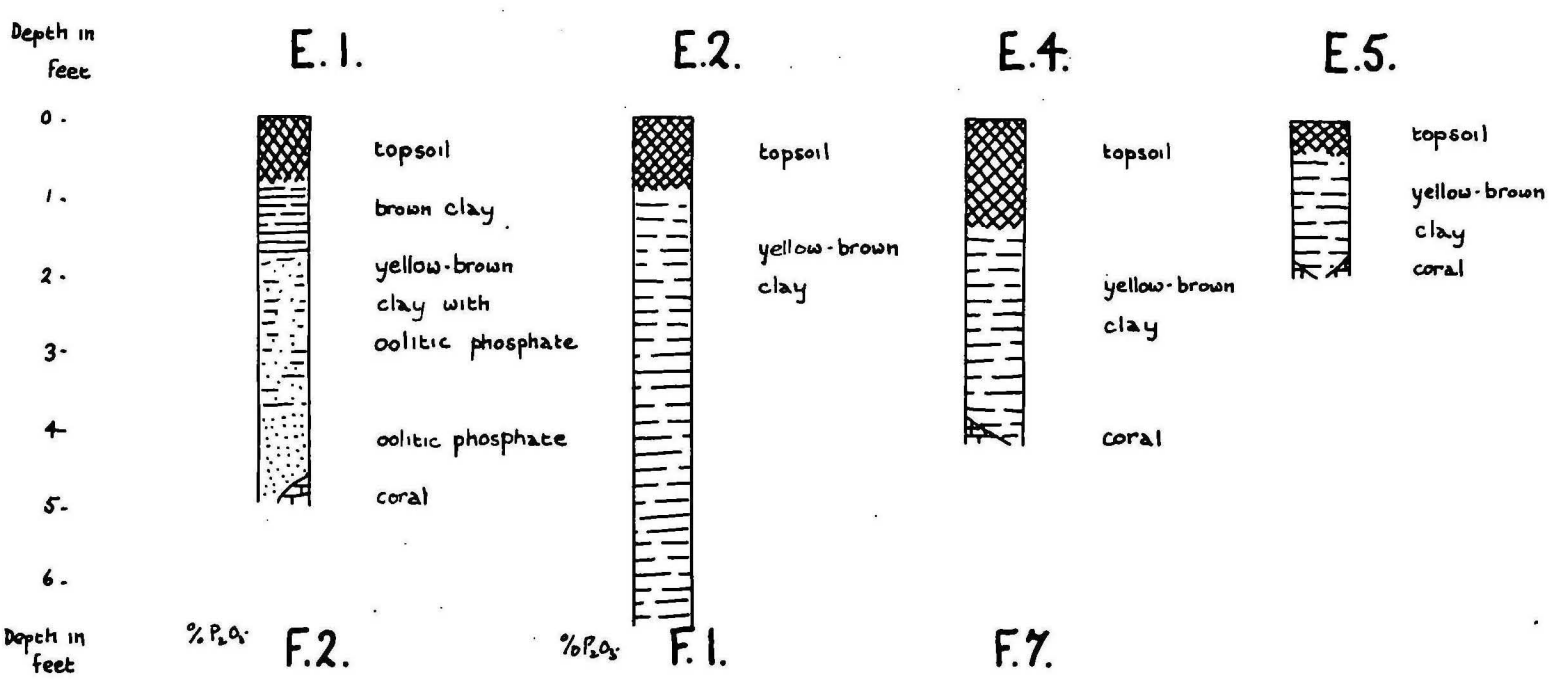
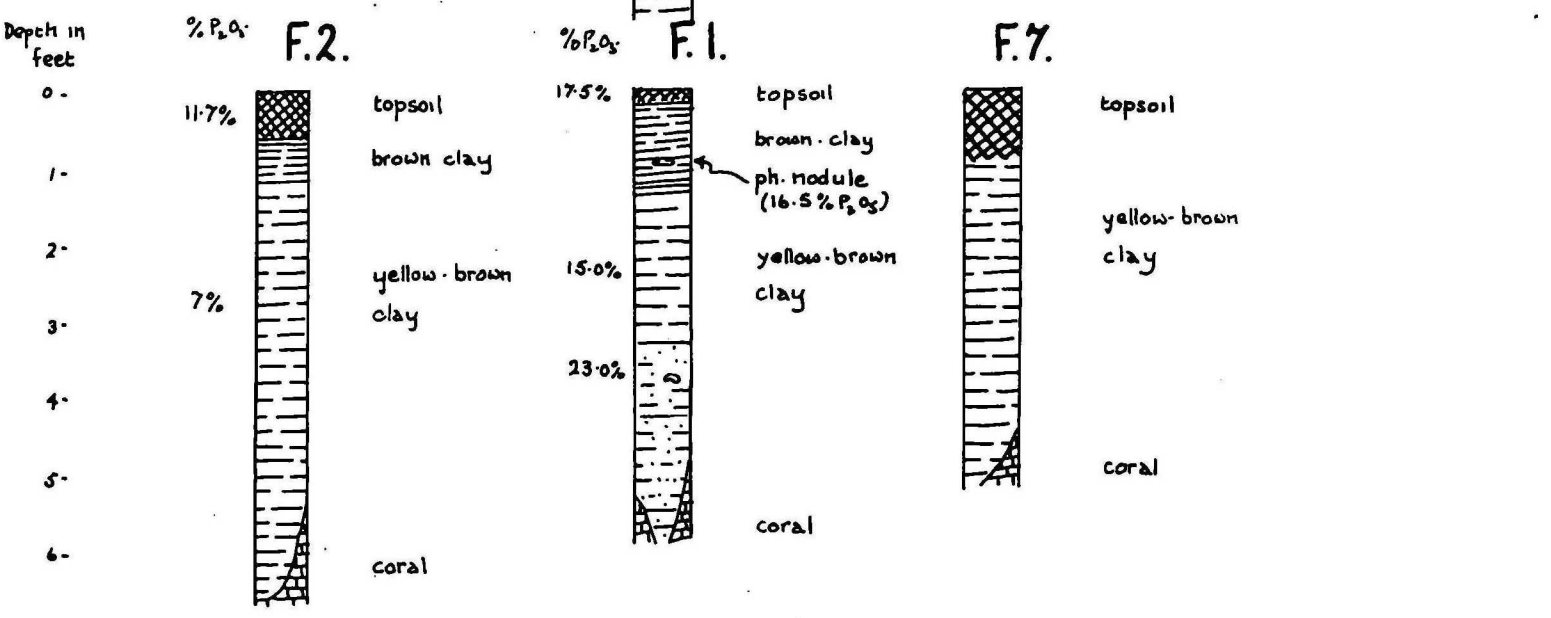
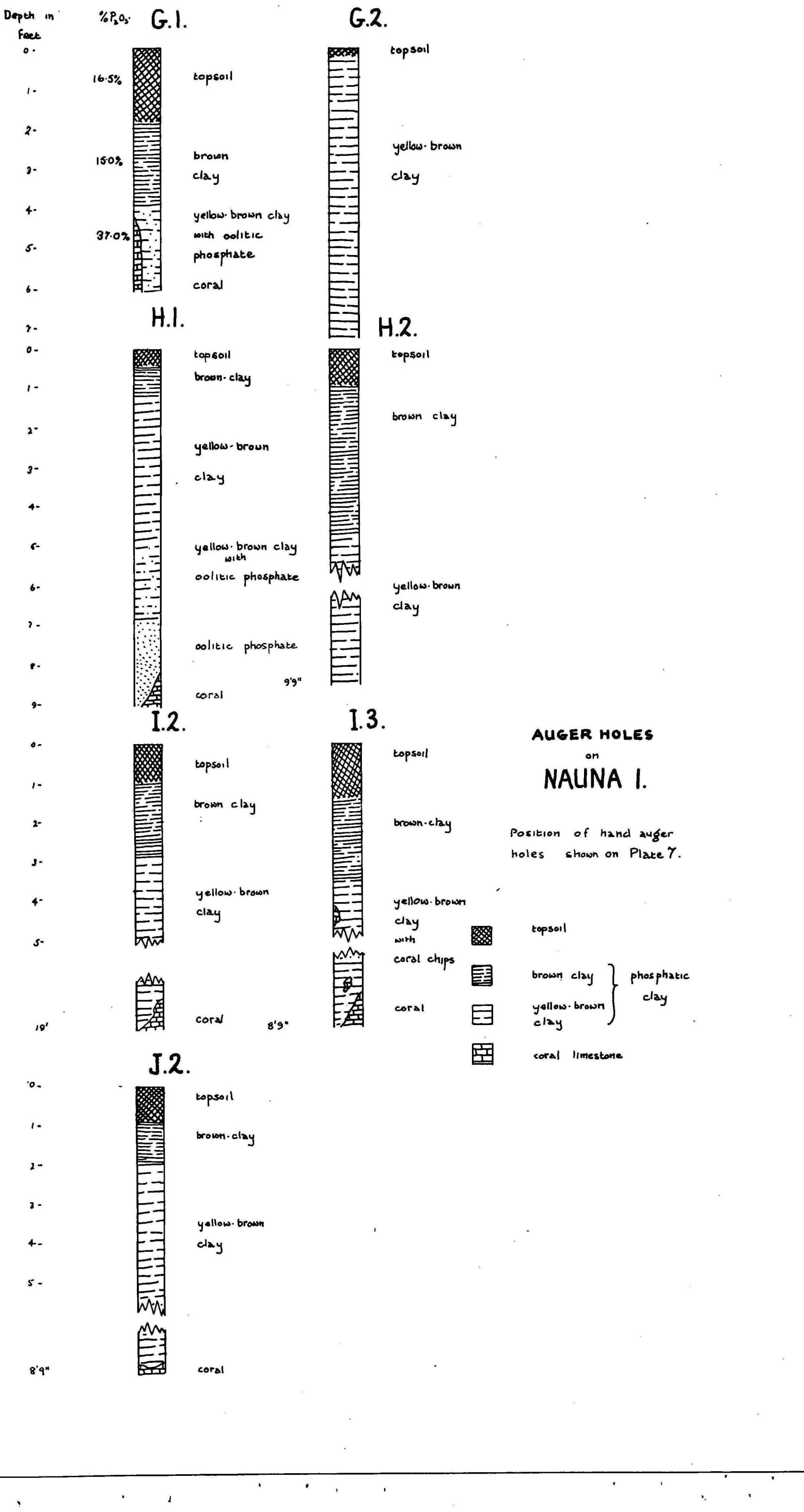

ADMIRALTY ISLANDS
NAUNA ISLAND
Scale 1inch to 400feet
100 0 500 1000 1500 feet.
REFERENCE
Hand auger hole (with depth of clay and sand)
Track
Auger hole encountering phosphate clay
Inland cliff
Barometric height above sea level
Approx. shoreline
Approx. line of inland cliff
Approx boundary of clay deposit
Approx boundary of ph. sand under clay
Note: Survey of track and auger holes by pace and compass
Spot heights by survey barometer.
148° 05' E
2° 11' S
Village
Phosphatic sand
Phosphatic clay
Clay in chimneys
Sketch section through deposit
(Vertical Exaggeration ×8)
Central Track
feet
400
300
200
100
Sea level
SECTION AB
Vertical Scale equals Horizontal Scale [1" to 400']

PLATE 7A


Depth in Feet
%P2O5
D.1.
0
1
2
3
4
5
17%
6'-3%
topsoil
brown clay
coral


Depth in Feet
E.1.
0
1
2
3
4
5
6
topsoil
brown clay
yellow-brown clay with oolitic phosphate
oolitic phosphate
coral
E.2.
topsoil
yellow-brown clay
E.4.
topsoil
yellow-brown clay
coral
E.5.
topsoil
yellow-brown clay
coral


Depth in feet
%P2O5
F.2.
0
1
2
3
4
5
6
11.7%
7%
topsoil
brown clay
yellow-brown clay
coral
%P2O5
F.1.
17.5%
15.0%
23.0%
topsoil
brown clay
ph. nodule (16.5% P2O5)
yellow-brown clay
coral
F.7.
topsoil
yellow-brown clay
coral


Depth in Feet
%P2O5
G.1.
0
1
2
3
4
5
6
7
16.5%
15.0%
37.0%
topsoil
brown clay
yellow-brown clay with oolitic phosphate
coral
G.2.
topsoil
yellow-brown clay
H.1.
0
1
2
3
4
5
6
7
8
9
topsoil
brown clay
yellow-brown clay
yellow-brown clay with oolitic phosphate
oolitic phosphate
9'9"
coral
H.2.
topsoil
brown clay
yellow-brown clay
I.2.
0
1
2
3
4
5
10'
topsoil
brown clay
yellow-brown clay
coral
I.3.
topsoil
brown-clay
yellow-brown clay with coral chips
coral
8'9"
AUGER HOLES
on
NAUNA I.
Position of hand auger holes shown on Plate 7.
topsoil
brown clay
yellow-brown clay
phosphatic clay
coral limestone
J.2.
0
1
2
3
4
5
8'9"
topsoil
brown-clay
yellow-brown clay
coral

MARSHALL BENNETT ISLANDS

GAWA ISLAND

(152° 00' E 09° 01')

Scale 1 inch to 800 feet

1000 0 1000 2000 feet

REFERENCE

- 09 — Drill hole showing survey number
- Track
- Village
- (388) — Altitude
- 4' — Depth of drill hole
- Inland cliff

M.N.

A

B

Okawaga

Simboya

Gov. Rest Hut

Sawa'edi

Gitaiya

Kaimutu

O'ilawa

Symo'eni

Ibushy

Salyba

Budoya

Umasya

Kumkalesi

A-Traverse

B-Traverse

C-Traverse

D-Traverse

E-Traverse

F-Traverse

G-Traverse

H-Traverse

RAISED CORAL RIM

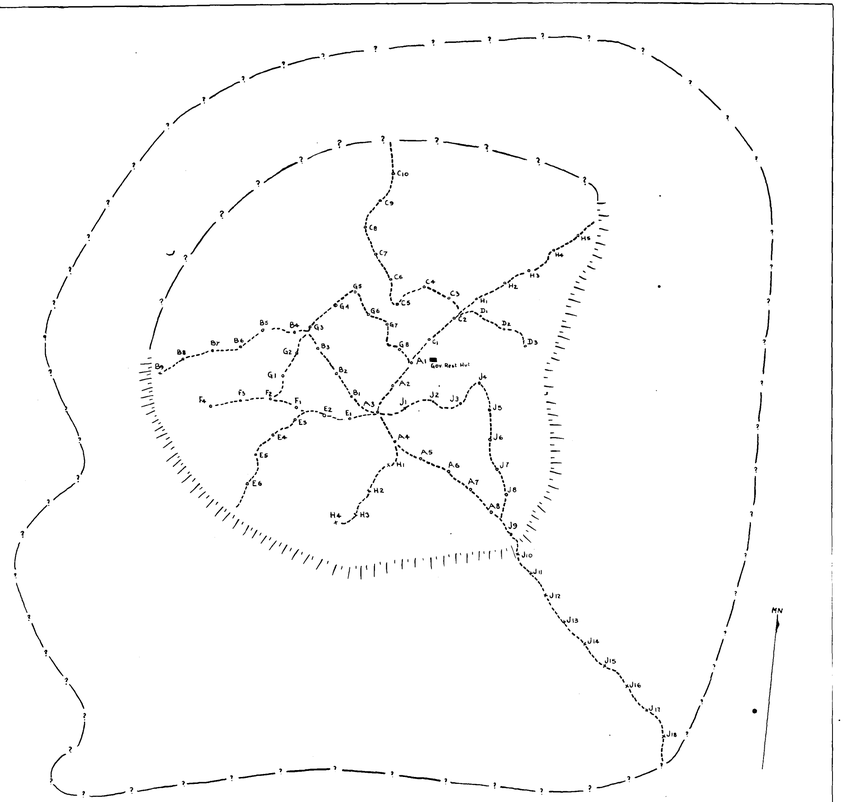
OLD LAGOON FLOOR

LOW CORAL PLATFORM

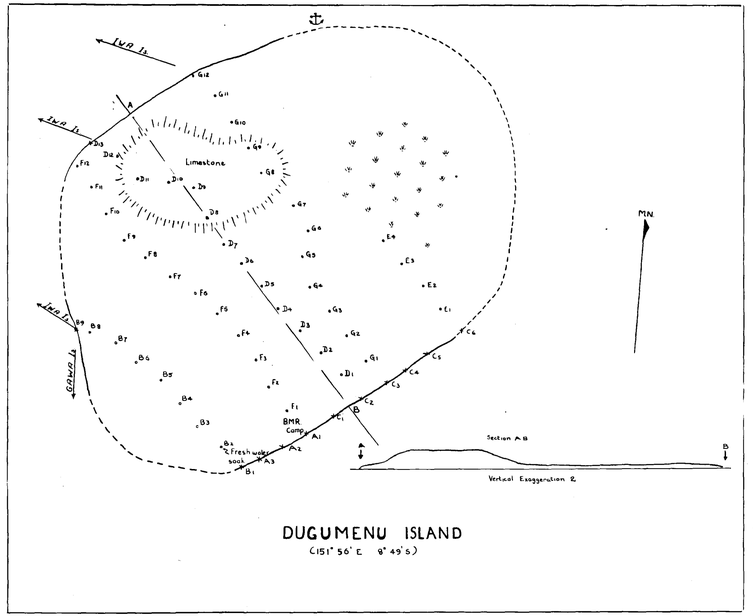
SECTION A-B

500 feet
400
300
200
100
Sea level

Horizontal scale 1 inch to 1600 feet
Vertical exaggeration 2



KWAIAWATA ISLAND
(151° 55' E 8° 55' S)



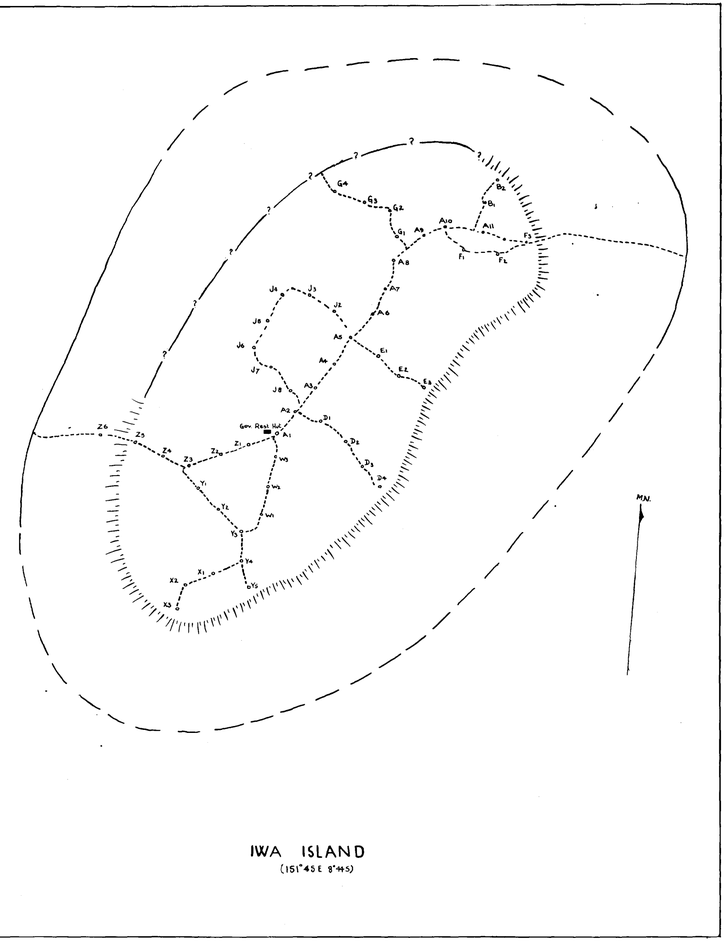
DUGUMENU ISLAND
(151° 56' E 8° 49' S)

ISLANDS IN THE
MARSHALL BENNETT GROUP
SCALE 1 INCH TO 800 FEET

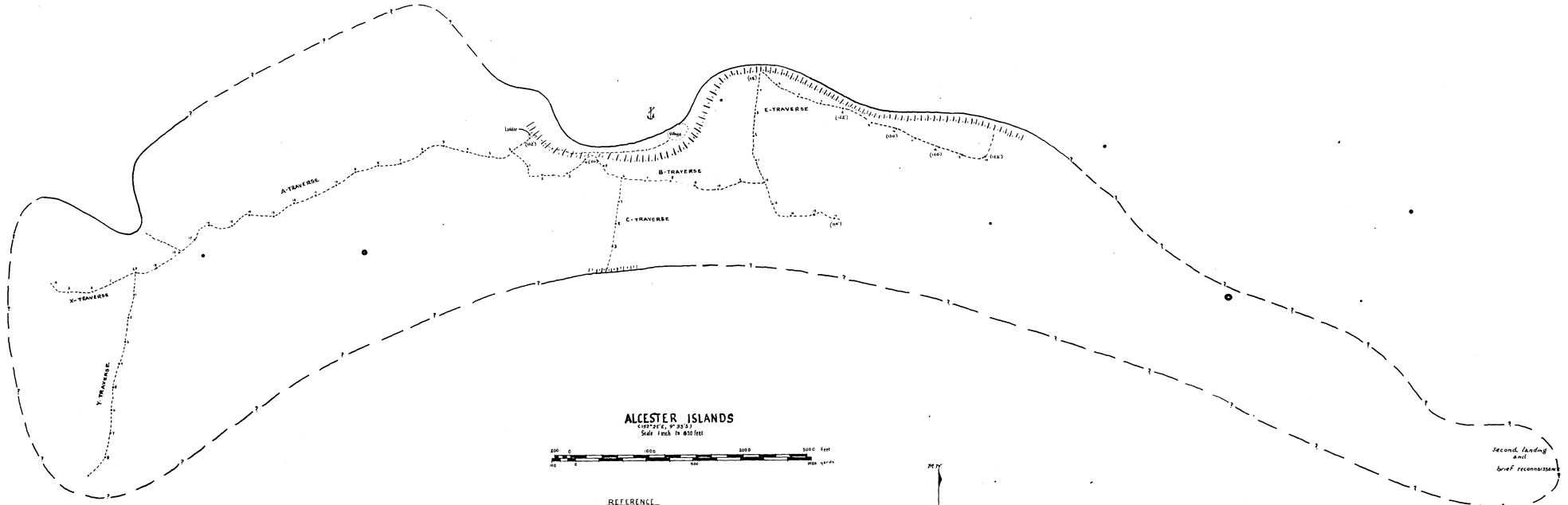
1000 0 1000 2000 3000 4000 5000 Feet

REFERENCE

- Hand auger hole
- Survey Peg
- Inland Cliff
- Track



IWA ISLAND
(151° 45 E 8° 44 S)



ALCESTER ISLANDS

C152°25'E, 9° 33'S

Scale 1 inch is 830 feet

200 0 1000 2000 3000 Feet

500 0 500 1000 Yards

N.P.

REFERENCE

- Hand auger bolt
- Known outline of island
- Supposed outline of island
- Cliff
- Line of traverse
- Survey peg
- Anchorage

Note. Outline approximate only. Modified from survey by Lieut Pim 1905

ST. MATTHIAS GROUP

EMIRAU ISLAND

SCALE : 1 in to 800 yds

0 200 400 600 800 1000 2000

REFERENCE

- M.T. roads
- Airstrips
- Cut traverse lines
- ·39 Survey pegs (Pace and compass)
- Anchorage
- Cliff

Magnetic variation 6°21'E (1944)

HAMBURGER BAY

ELEVATED CORAL LIMESTONE PLATFORM (100 ft)

Natural arch

Government rest hut

TABELU

PAKANE

Pakane lagoon

CORAL SAND

EMIRA

Homestead

ENUSAU I.

Marauruanga Pt.

ELEVATED LIMESTONE PLATFORM (100 ft)

Enungiagila I.

EMALAITE I.

ENUKATASI I.

TAKAKUMSE I.

MATAUREWAUN I.

TASINGINA

ELEOA

ETUITUI I.

Four Eulalou Harbour

Jetty

ELOMUSAO I.

CAPE HOLTHUS

ETALAT

EUTAO

ETASITEL

CORAL (about 300ft)

TERRACE

DISSECTED

volcanic pebbles in creeks

shoal

CAPE THILENIUS

DISSECTED CORAL TERRACE about 500 feet

CAPE SIEMER

EMARGEN

DISSECTED

CORAL

150'

ELIUKE

TERRACE

CENTRAL RIDGE of VOLCANICS

Eunainaun Mt. (2118 Ft)

CAPE FORSTER

Lake

EPALAKAU

BOLIU MISSION (G.D.A)

Schadel Bay

TAMAKEOMAI I.

ETAPATURAU I.

EABOLU I.

EBOLIU I.

EMUSAU I.

ENOANAULU I.

EKAEU I.

ELOAUE I.

Juanita Hafen

EUNAKURU I.

Schooner Passage

EMANANUS I.

N

Sr. MATTHIAS GROUP

MUSSAU Is.

Scale of miles

1 ¾ ½ ¼ 0 1 2

Based on uncontrolled photo-mosaic

REFERENCE

- Geological boundary, position approximate
- Inland cliff.
- Reconnaisance traverses
- Fringing reef
- Anchorage

RAMBUTYO Is.

ADMIRALTY GROUP

SCALE 2 inches to 1 mile

miles 0 ¼ ½ ¾ 1 2 miles

Tracks

Traverse lines

+B, Position of hand auger holes

Edge of raised coral platform

Anchorage

M.N.

Swamp

Swamp

R. TRAVERSE

CENTRAL HILLS (VOLCANICS) 700'

Deserted Vg

S. TRAVERSE

P. TRAVERSE

mangroves

Benchal Vg

B. TRAVERSE

Z. TRAVERSE

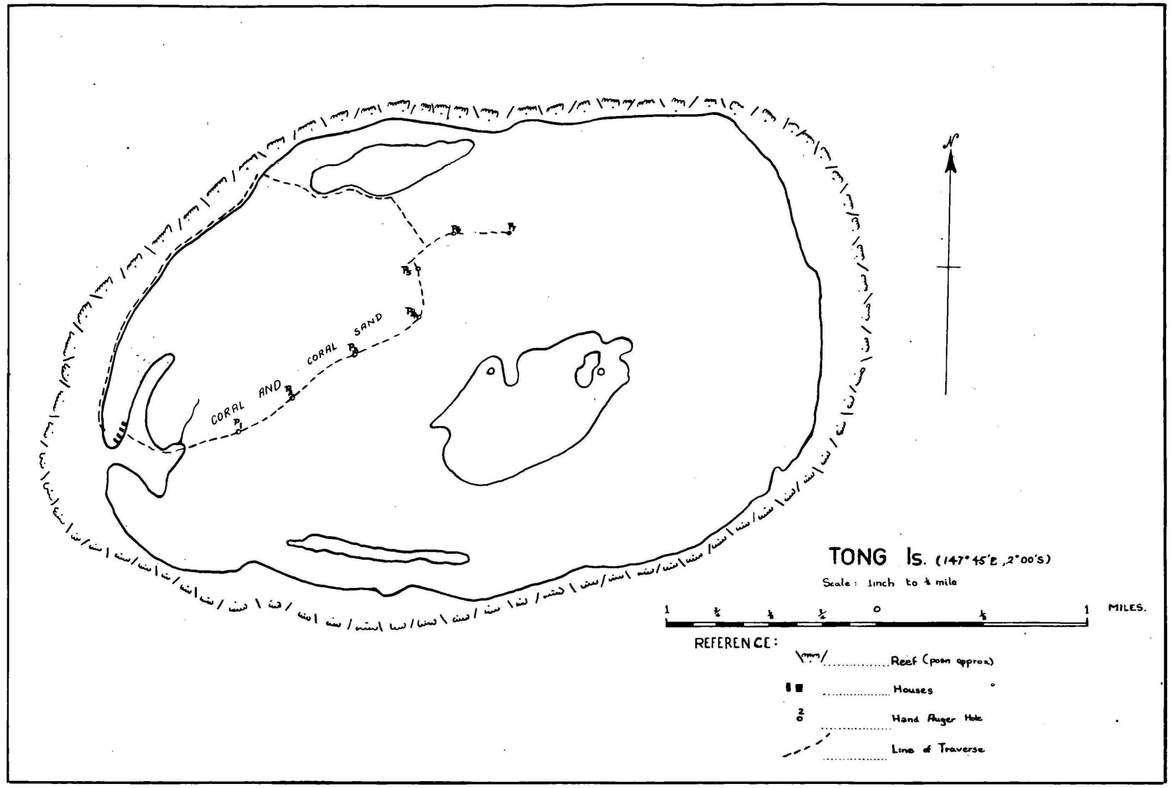
A. TRAVERSE

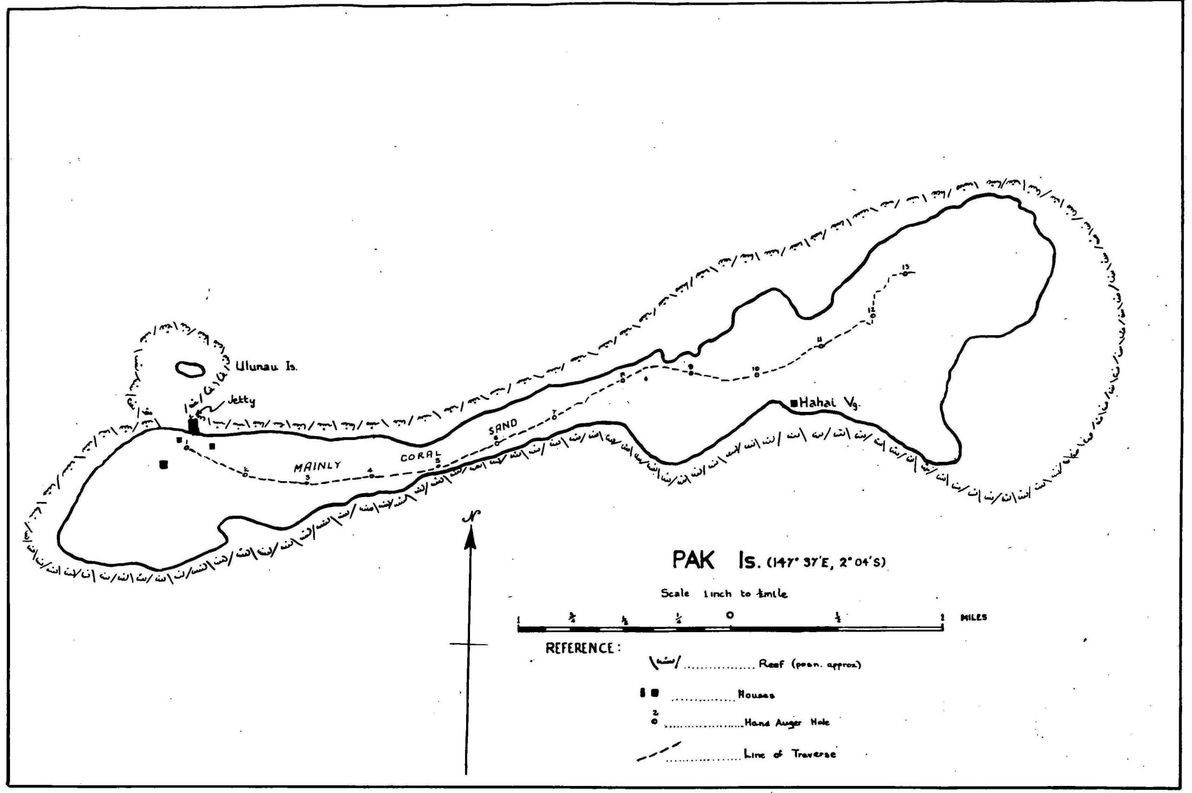
Angendrowa

RAISED CORAL LIMESTONE (ABOUT 100')

PLANTATION

Langembulos Is.


CORAL AND
CORAL SAND
TONG Is. (147° 45'E, 2° 00'S)
Scale: 1 inch to ½ mile
1 ¾ ½ ¼ 0 ½ 1 MILES.
REFERENCE:
Reef (poss approx)
Houses
Hand Auger Hole
Line of Traverse


Ulunau Is.
Jetty
Hahal Vg.
MAINLY
CORAL
SAND
PAK Is. (147° 37'E, 2° 04'S)
Scale 1 inch to ½ mile
1 ¾ ½ ¼ 0 ½ 1 MILES
REFERENCE:
Reef (poss. approx)
Houses
Hand Auger Hole
Line of Traverse