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SPECIAL REPORT

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STRATEGIC ENGINEERING STUDY
No. 108

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KUSAIE (UALAN) ISLAND
CAROLINES

•

TERRAIN INTELLIGENCE

•

Prepared by

GEOLOGICAL SURVEY, U.S. DEPARTMENT OF THE INTERIOR

Under direction of

CHIEF OF ENGINEERS, U.S. ARMY

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MILITARY INTELLIGENCE DIVISION
OFFICE, CHIEF OF ENGINEERS
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MARCH, 1944

ARMY MAP SERVICE, U.S. ARMY, WASHINGTON, D.C., 201010
3-44 1944

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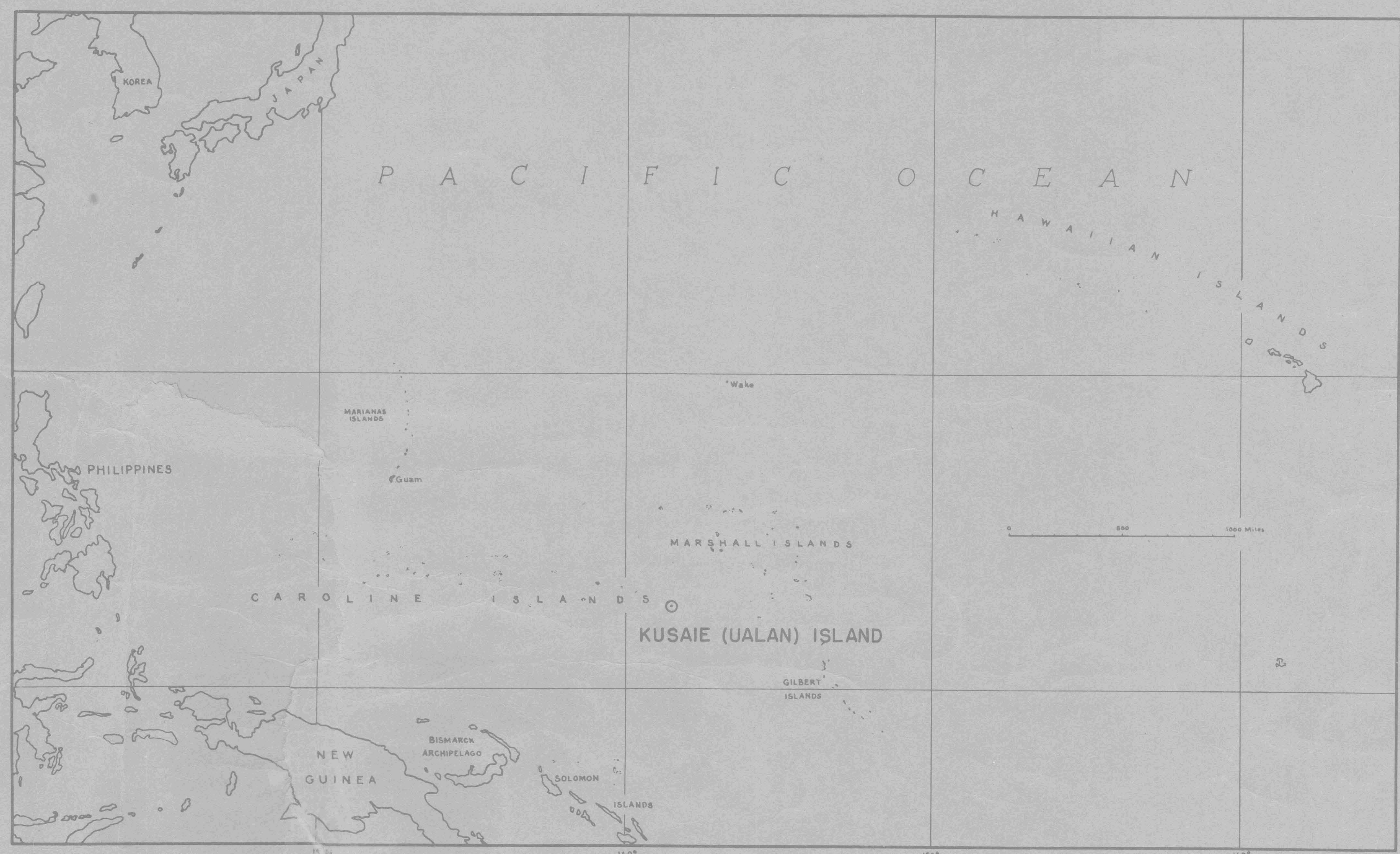

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TABLE OF CONTENTS

KUSAIE (UALAN) ISLAND (CAROLINES)

MILITARY ASPECTS OF TERRAIN[a]

General Statement:

Kusaie, easternmost of the Caroline Islands, is about 390 miles southwest of Kwajelein in the Marshall Islands and about 290 miles east-southeast of Ponape in the Carolines. Island has maximum width of 10 miles and area of 43 square miles. Mt. Crozer, altitude 2,064 feet, is highest summit.

Terrain:

The small mountainous island is surrounded by a narrow coastal lowland and coral reefs. Strategic terrain features are:

(1) Coastal lowlands and reef islands: Narrow coastal lowland surrounds mountains; maximum width about a mile, generally much less. Small reef islands on east and south separated from main island by narrow, shallow lagoon-canals. Mountain spurs extending to coast separate lowland into seven terrain compartments. Valleys of Innemu River on east coast and Okaato River on west coast are separated by steep, narrow divide; provide easiest route for cross-island communication. Four harbors: Lele, Lottin, Berard, and Coquille, located at mouths of largest streams. Swampy ground is major hindrance to movement within compartments; mountain spurs hinder movement between compartments. Soil in part thin, in part gravelly, some outcrops of underlying coral reef rock. Except for poorly drained areas, soil will permit free movement of personnel and motorized equipment. Thin soil may prevent excavation of slit trenches and fox holes. Swampy areas of plastic silt and clay are adjacent to shores and streams; support dense mangrove. These areas provide poor footing and are obstacles to movement. Fox holes and slit trenches cannot be dug because of poor drainage and slumping of soil. Limy sand and coral limestone of reef islands generally well drained. Sands may be thin and coral limestone bedrock will prevent excavation of hasty fortifications.

(2) Mountains: Barrier area; no terrain corridors. Densely forested mountain mass of high relief, steep slopes, and narrow valleys. Penetration difficult for foot troops. Soil generally thin, especially on steeper slopes; lacking in summit areas. Slit trenches and fox holes can be dug only where slopes are most gentle. Soil drainage good; only immediately after heavy rains is soil slippery and sticky.

Problems of Water Supply:

With regard to the availability of water supplies, Kusaie may be divided into 4 general areas:

(1) Fringing islands and narrow beaches have no surface water: Ground water is shallow but probably more or less brackish, except possibly on larger islands, and only small amounts are obtainable. Chief sources of fresh water will be catchment of rain water and importation or distillation. Green coconuts will provide emergency supply.

(2) Mangrove swamps: Have no local source of potable water.

(3) Coastal lowlands: Have a few streams with small perennial flow of potable water. Ample fresh water is obtainable by digging or drilling wells.

(4) Mountainous area: Has numerous streams which will provide ample supplies for any troop units likely to occupy the area. Wells are not recommended.

Problems of Construction:

Materials available:

Adequate supplies of construction materials are available on Kusaie. Compact basalt of mountains, when not deeply decayed, provides good construction material. Coral limestone of coastal lowlands, reefs, and reef islands readily available for light construction, road metal, and as source for lime. Character ranges widely from place to place due to amount of impurities and induration; can in part be worked with hand tools. Limy sand and gravel of valleys and beaches readily available. Abundant materials locally available for soil stabilization.

Foundations: Where relatively fresh, basalt provides good foundation; where deeply decayed provides poor foundation. Coral limestone provides moderately good to poor foundation, depending on purity and amount of induration. Beach sand, gravel, and swampy silt provide poor foundations.

Roads and airfields: Densely forested mountains difficult for construction of roads. Steep grades, sharp curves, and side-hill cuts are necessary. Ground generally well-drained. Many cuts will require blasting. Coastal lowlands and reef islands suitable for roads with low grades and long tangents. Dense vegetation and undrained ground, especially mangrove swamps, make construction of roads difficult. Possible sites for easily constructed airfields restricted to coastal lowlands, especially on east and southeast coasts. Coral limestone and sand to be mixed with clay-silt loam for soil stabilization are readily available. Vegetation, primarily of coconut palms, is readily cleared.

Operational Features:

(1) Movement confined to compartments of coastal lowlands and narrow reef islands.

(2) Steep slopes and dense forests make movement difficult in mountains.

(3) A single cross-island corridor from Lele to Coquille Harbor follows valley of Innemu River and crosses steep, narrow divide to valley of Okaato River.

(4) Mountain spurs separating coastal lowland into compartments are barriers.

(5) Steep, narrow stream canyons provide best routes into interior mountains.

(6) Narrow lagoon-canals between reef islands and main island in part concealed passages for movement of personnel in small craft.

(7) Mangrove swamps hinder movement from reef islands to main island.

(8) Terrain and ground conditions generally not suited for airfield sites except on narrow coastal lowland.

(9) Heavy rainfall and low cloud ceiling impede aerial operations.

(10) Harbors reported to be unsuitable for large vessels.

[a] For information on landing beaches consult other intelligence sources.

Prepared by U. S. Geological Survey
for Chief of Engineers, U. S. Army.

KUSAIE (UALAN) ISLAND (CAROLINES)

INTRODUCTION

This report, prepared during the period February 14 to March 1, 1944, by the Geological Survey, U. S. Department of Interior, for the Chief of Engineers, U. S. Army, describes the principal terrain features of Kusaie. Each map and table of the report is devoted to a specialized set of problems; together they cover such topics as: terrain appreciation, water supply, soils, construction materials, and problems of road and airfield construction. A brief summary of climatic conditions is included to complete the general picture. The report presents a general picture of terrain and engineering problems in a relatively unknown region.

A summary statement of the military aspects of the terrain is included.

RELIABILITY OF DATA

Most reports on Kusaie describe the populous Lele Island and restricted coastal area. Agassiz and Sarfert have given the most complete descriptions of the island in their reports, which emphasize especially the coastal areas. Elsewhere information is meagre. Little is known of the interior of the island which is inaccessible and reported to be unknown even to the natives. Aerial photographs, with partial coverage of the island (1943), have aided in interpretation of the terrain and checking of maps and reports.

Maps of Kusaie differ widely in detail. The H.O. chart 5420 and Sarfert's 1919 map of the island have been included in the report, together with detailed maps of Lele Island and the three main harbors. The base map used is a compilation of the J.I.C.P.O.A. map (1943), compiled from aerial photographs and showing some recent Japanese installations. The interior terrain, modified slightly, has been taken from the H.O. Chart 5420, reproduced from the Japanese Chart of 1922. Cross-island trails have been added from the Fleet Marine Force Staff map of 1934. The form lines used to indicate terrain are generalized and approximate 100-foot contour lines.

Included in this report is a topographic map of the south and east parts of Kusaie, prepared by the U. S. Geological Survey from aerial photographs and made available after completion of the report. This map, scale 1:20,000, contour interval 100 feet, is in essential agreement with the compiled base map. However, in detail there is a wide discrepancy in the character of the shoreline, the location of streams, valleys, ridge crests, and the width of the coastal lowland, especially on the southeast side of the island. However, no changes in the original compiled base map have been made. Reference to the detailed topographic map should be made for those areas covered, which are outlined on the compiled base map.

The information presented in this report necessarily involves interpretation by the compilers and reliability ratings have been given to the tables ranging from A (excellent) to D (poor).

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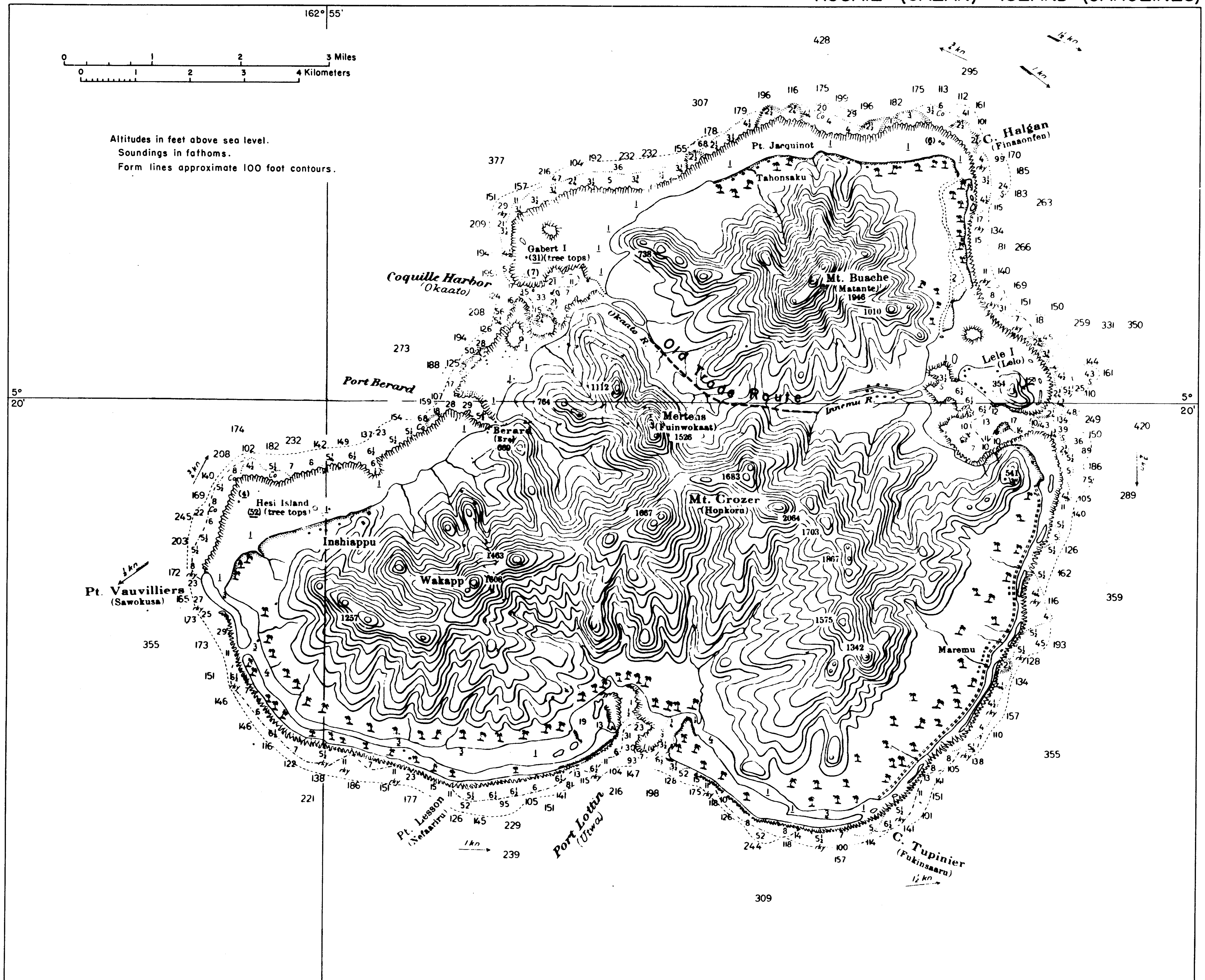
Prepared by U. S. Geological Survey
for Chief of Engineers, U. S. Army.

H.O. CHART 5420

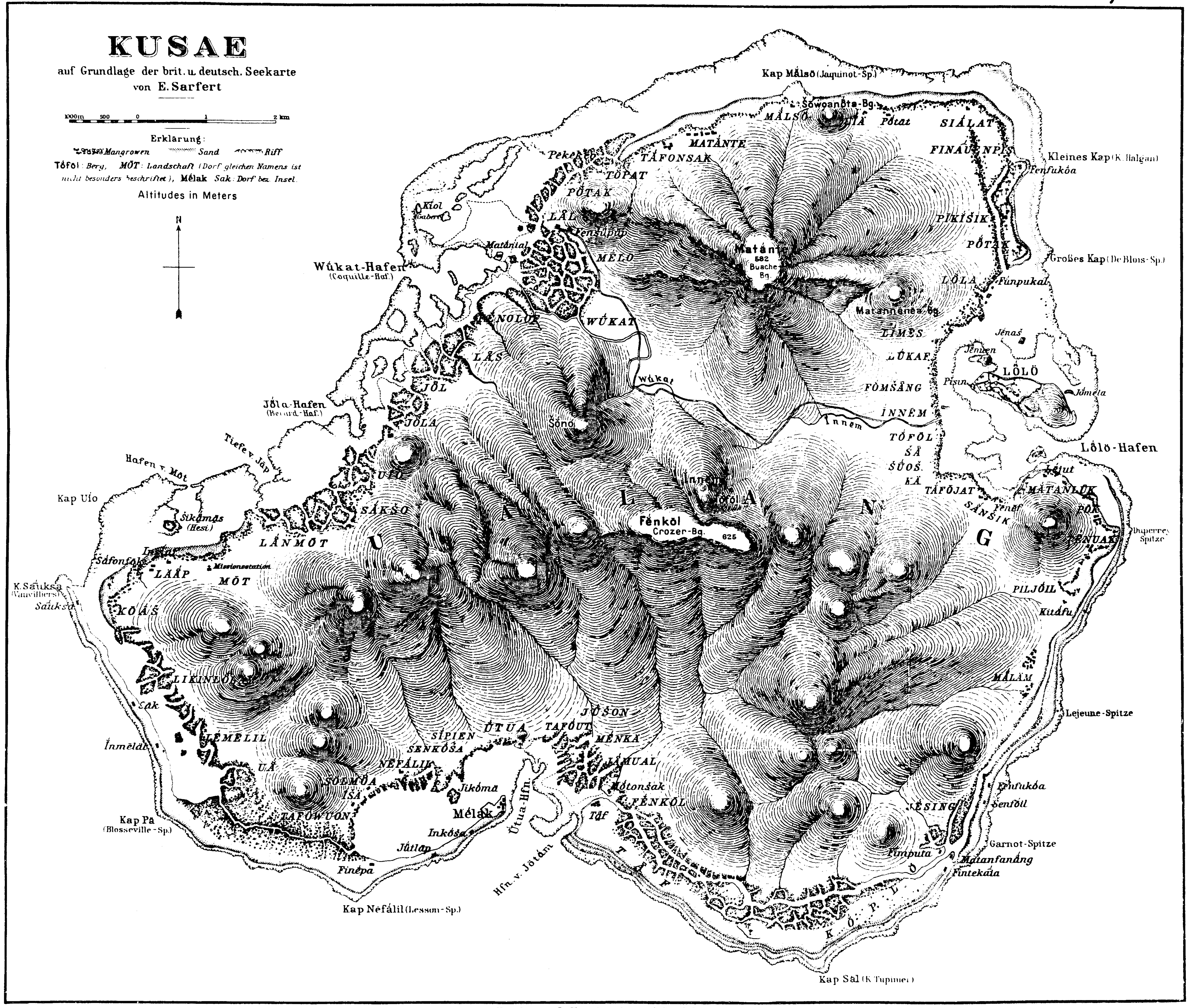
KUSAIE (UALAN) ISLAND (CAROLINES)



Source: H.O. Chart No.5420

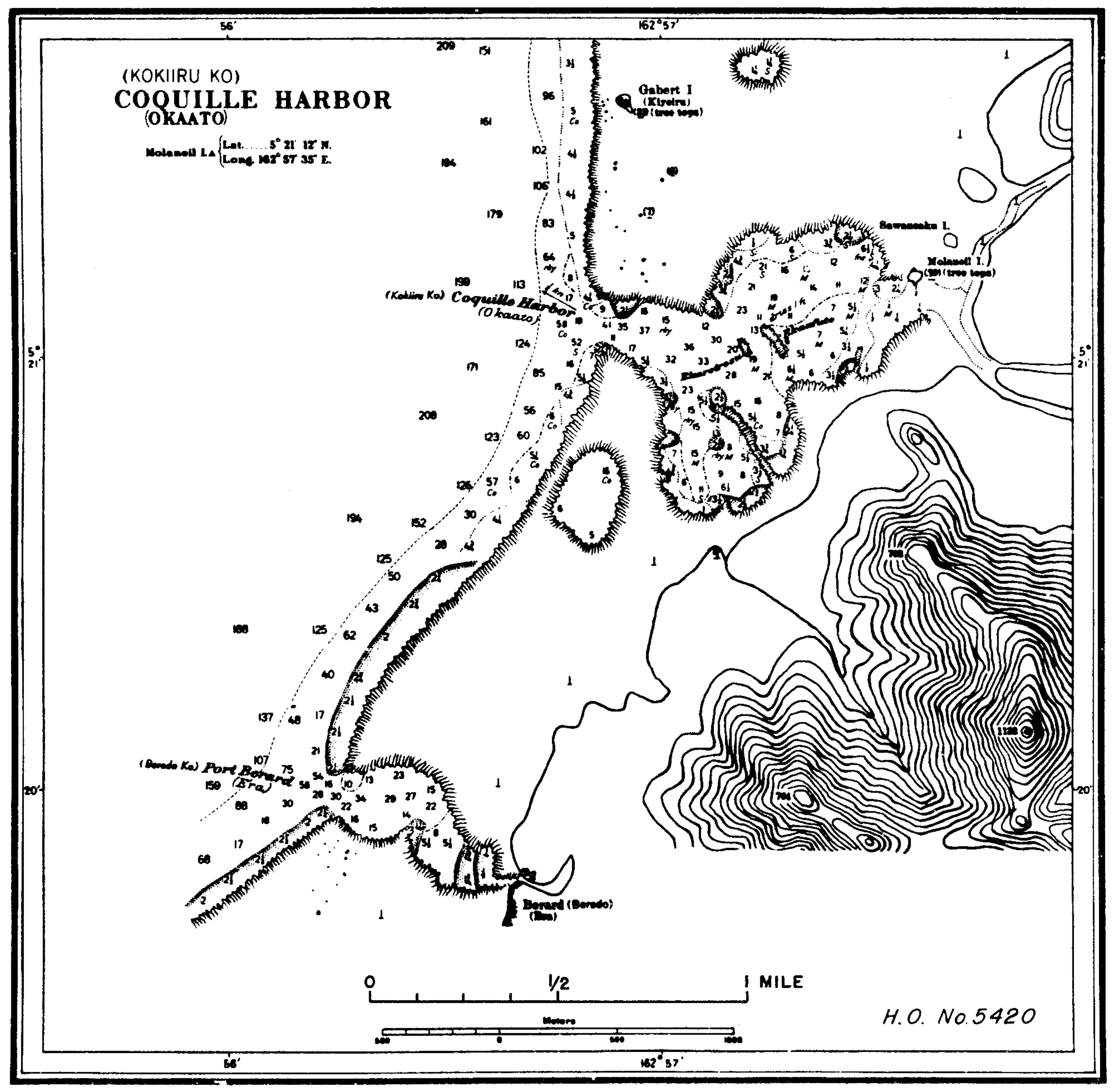
U. S. Geological Survey

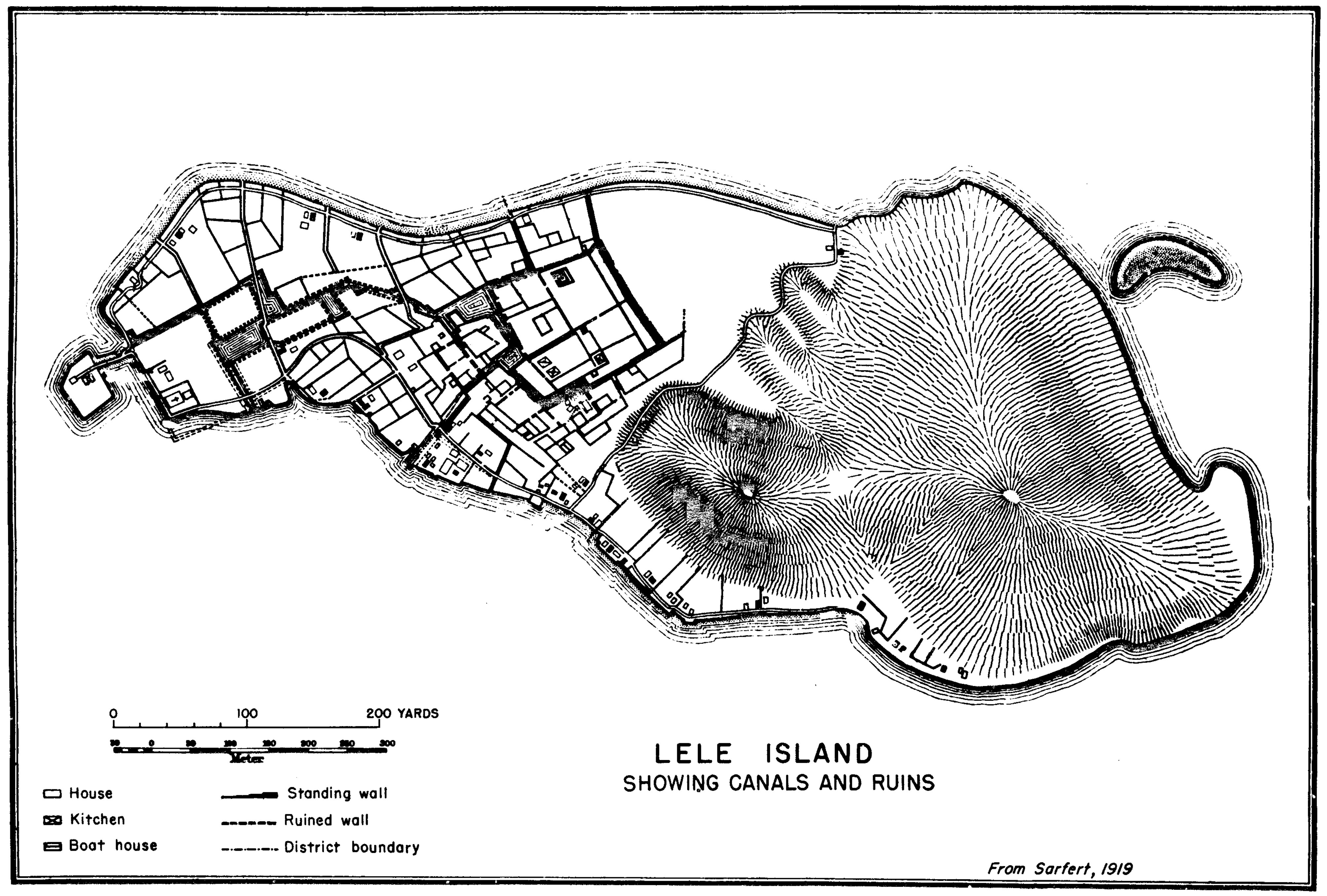
KUSAIE (UALAN) ISLAND (CAROLINES) SARFERT'S SKETCH MAP, 1919



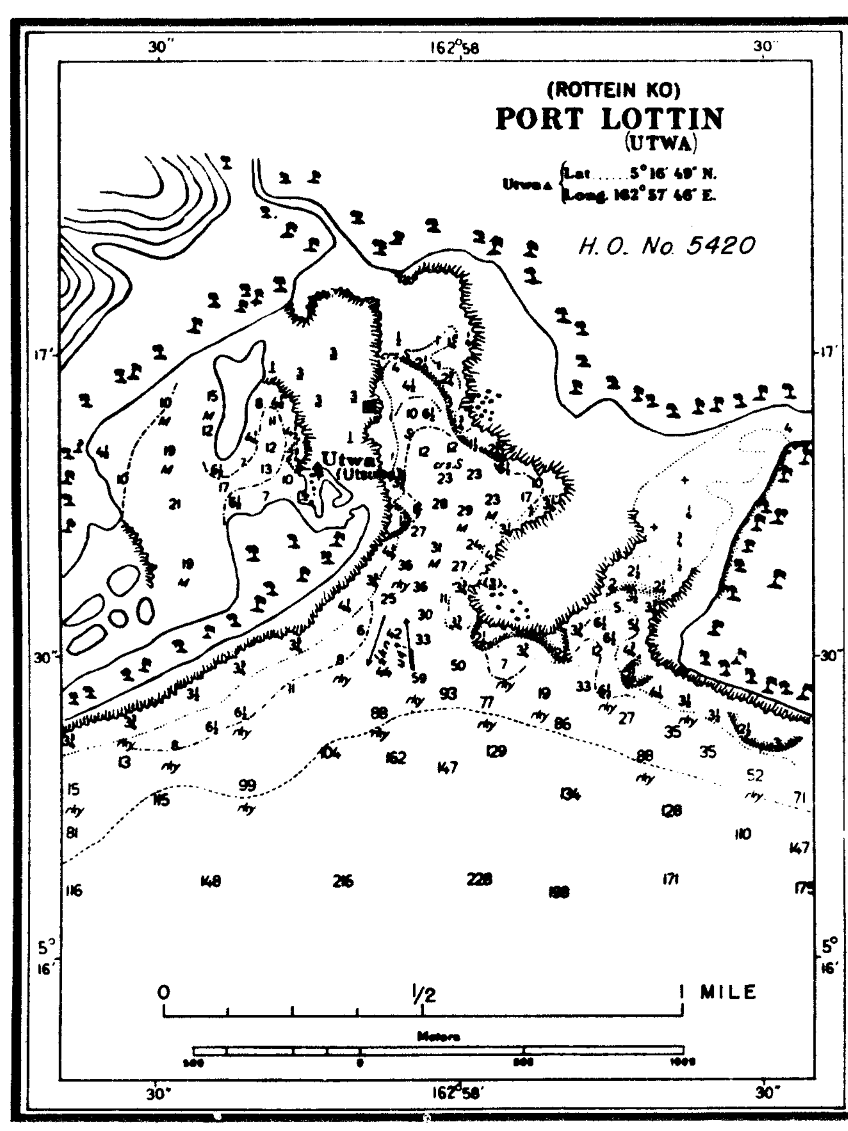
Hamburg: L. Friederichsen & C°. 1919.

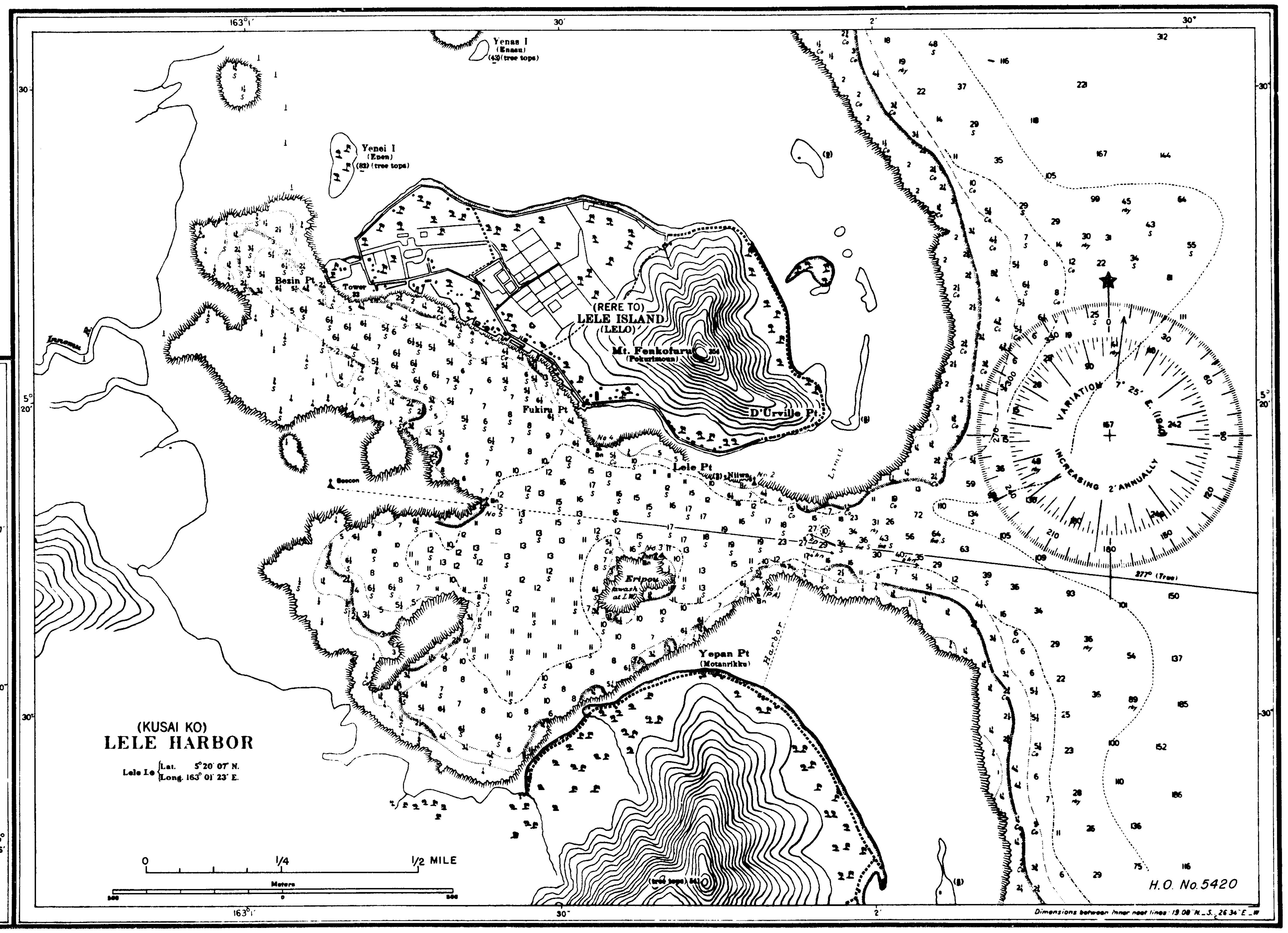
U. S. Geological Survey





Altitudes in feet above sea level.
Soundings in fathoms.

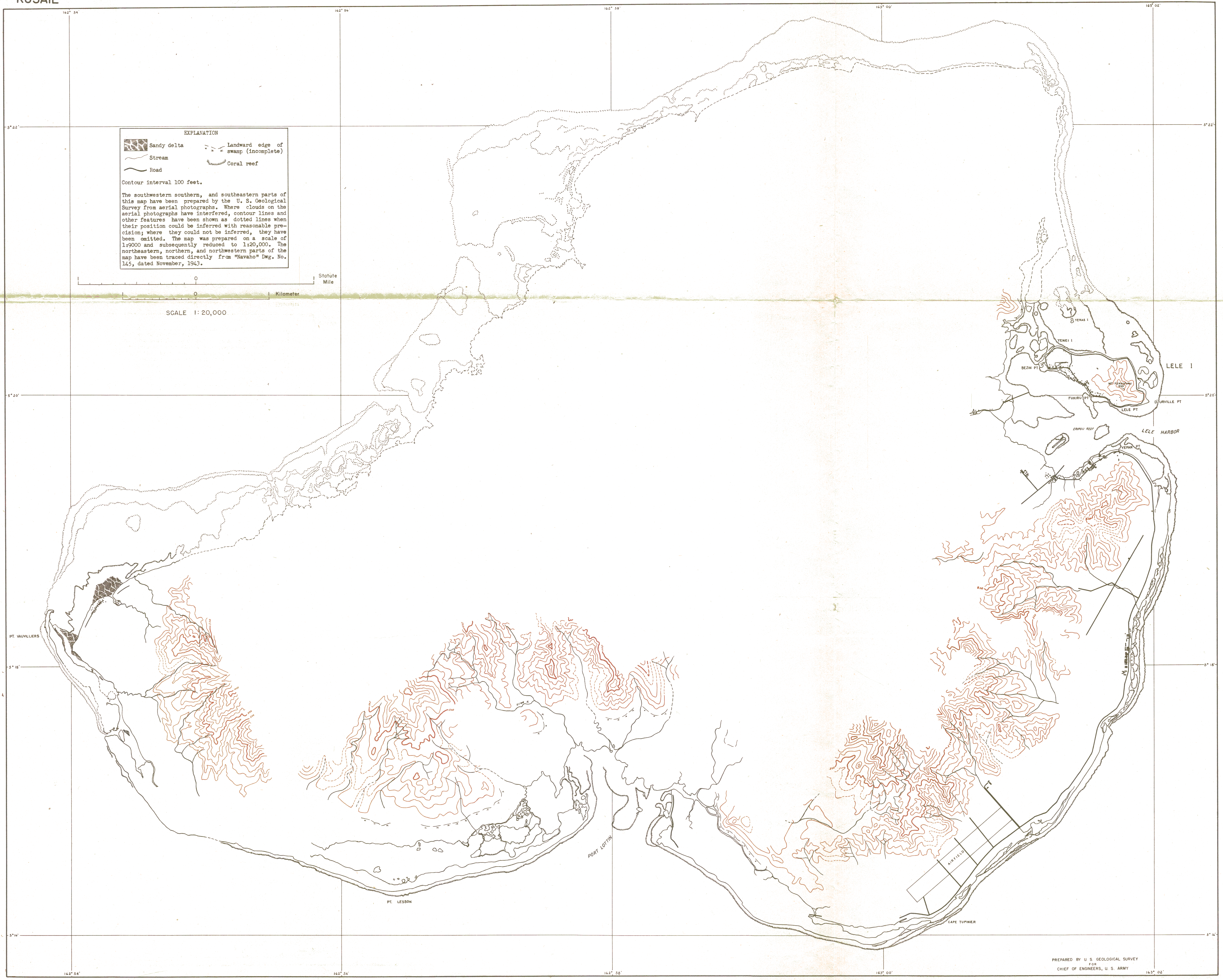




PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY

KUSAIE

TOPOGRAPHIC MAP OF SOUTHERN AND EASTERN COASTAL REGION



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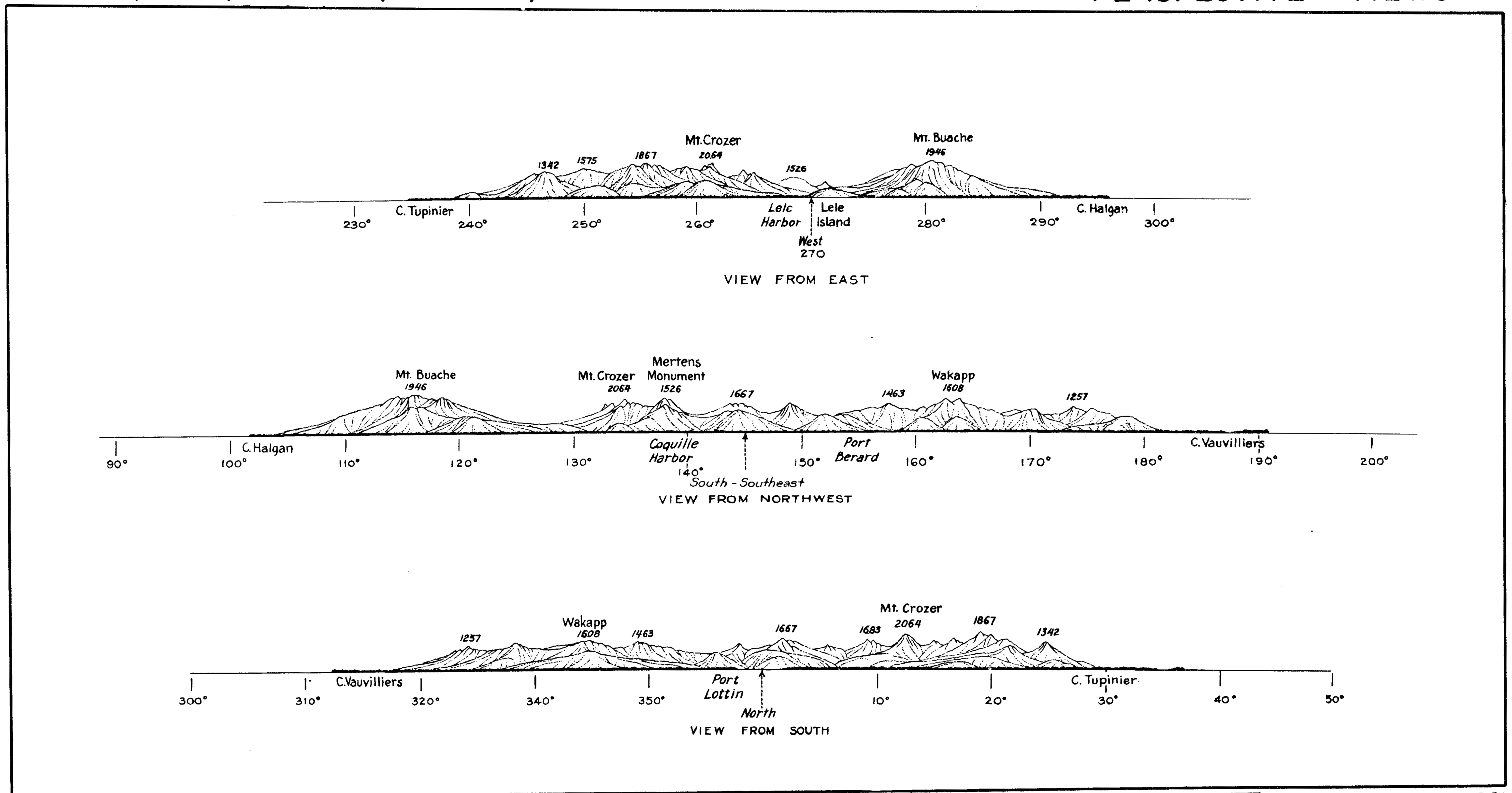
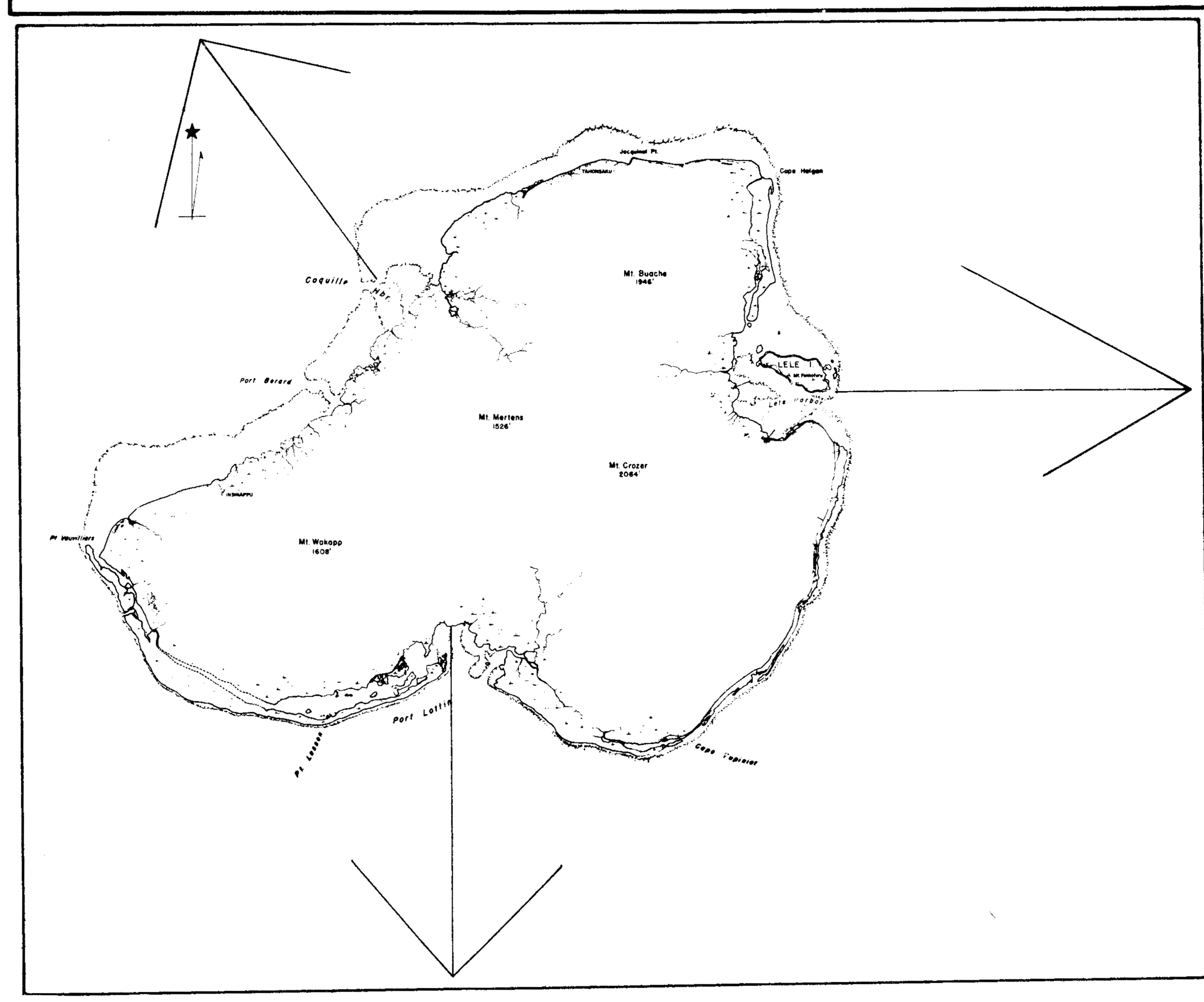
KUSAIE (UALAN) ISLAND (CAROLINES)

PERSPECTIVE VIEWS



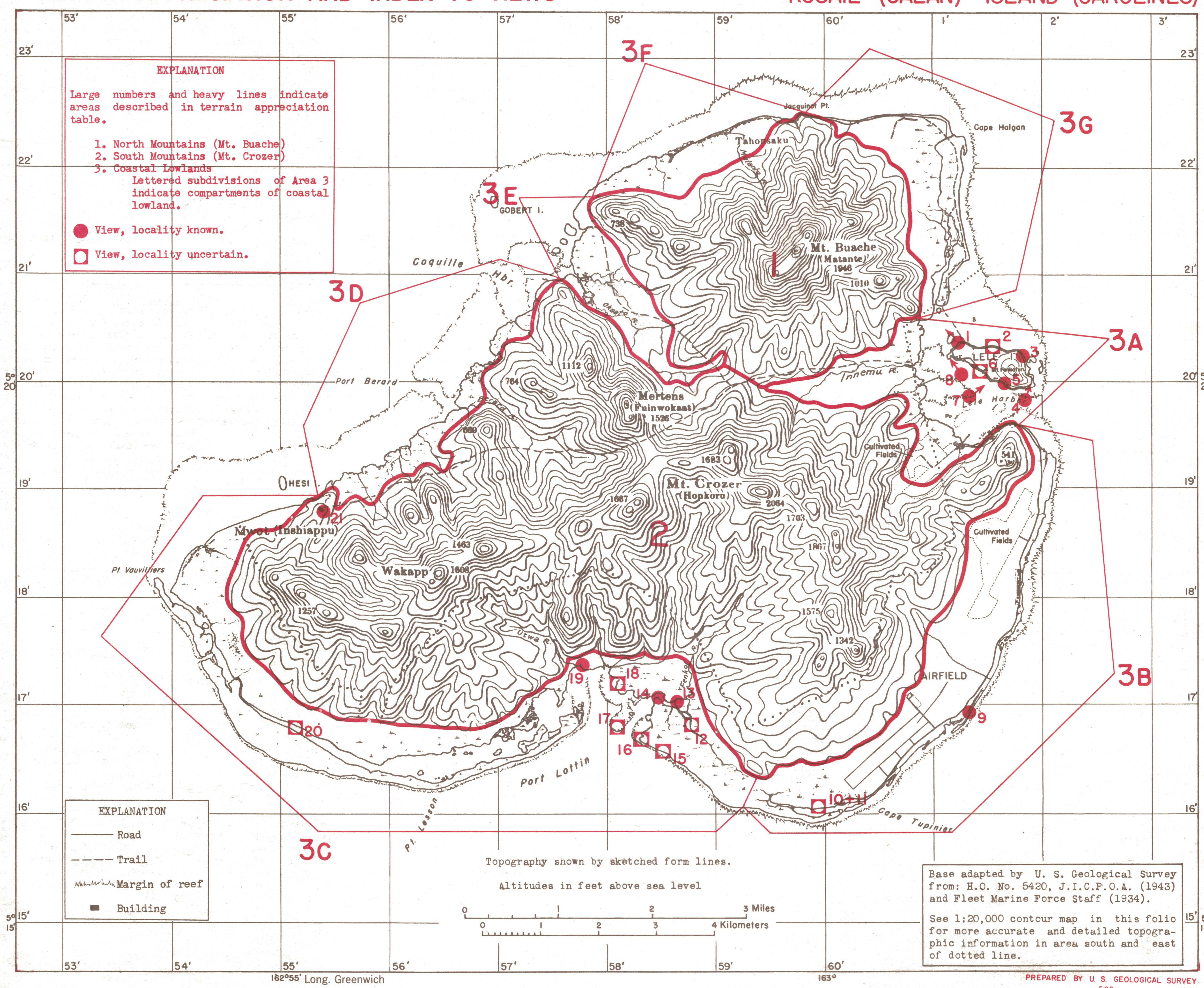


Perspective views projected from topography on H.O. No. 5420 by machine that gives true perspective and corrects for curvature of the earth and refraction. Details added from available sketches and photographs. Viewed from sea level at a point 4 nautical miles (8000 yards) from nearest point on shore. Vertical scale not exaggerated. Altitudes in feet above sea level.

PREPARED BY U. S. GEOLOGICAL SURVEY FOR CHIEF OF ENGINEERS, U. S. ARMY

TERRAIN APPRECIATION AND INDEX TO VIEWS

KUSAIE (UALAN) ISLAND (CAROLINES)



PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY

Reliability rating: Class C

Introduction

General Statement: The small mountainous island of Kusaie (lat. 5°16' to 5°23' north, long. 162°54' to 163°02' east) is at the eastern end of the Caroline Islands. It is about 390 miles southwest of Kwajalein in the Marshall Islands and about 290 miles east-southeast of Ponape in the Carolines. The nearest land to Kusaie is Pingelap, a small atoll 160 miles northwest. Kusaie, has a maximum diameter about 10 miles in a northeast direction and a maximum diameter about 7 miles in a northwest direction; the area is about 43 square miles. Relief is great; the maximum altitude is 2,064 feet (Mt. Crozer).

Information concerning the island, especially the interior, is relatively meager, and maps are generalized. The base map used has been compiled from the U. S. Hydrographic Office Chart No. 5420; the map compiled by the Intelligence Section, Fleet Marine Force Staff, Quantico, Va. (Nov. 1934); and the J.I.C.P. O.A. (Dec. 1943) map compiled from aerial photographs. In general, map elevations appear to be reliable. Generalized form lines showing topography are not contour lines, but roughly approximate 100 foot contour lines.

Map names are, in general, those used on the Hydrographic Office Chart, but some new names, commonly found in the literature, have been added.

Climate: Kusaie has a monotonous tropical marine climate with a small diurnal and annual temperature range (average about 82°F), and more or less constant winds from the northeast and east (Northeast Trades). Severe storms and hurricanes are relatively infrequent. Annual climatic changes are slight, although March, April, and May are the coolest months. June, July, and August, when winds have the greatest variability in direction, are the warmest months. Rainfall is heavy; the average at Mwot is more than 250 inches and the maximum reported 291 inches. The minimum rainfall, reported at Lele is 120 inches. Rainfall in the interior high mountains is appreciably higher than in the coastal areas. Summit areas are commonly cloud-covered. Local mountain and valley breezes, combined with land and sea breezes, frequently develop considerable strength.

Vegetation: Kusaie is completely covered by vegetation except for artificial clearings and steep pinnacled summits. A tropical rain forest of hard woods, bananas, banyans, and associated types cover the mountains; the growth is dense except on steep slopes. The higher parts of coastal lowlands support many coconut palms. Pandanus, mangrove, and associated swamp plants grow in low coastal areas. Coral reef islands support some coconut palms, pandanus, mangrove, and impenetrable swamp vegetation. Dense vegetation on some parts of coral reef islands conceal the fact that they are separated from main island by lagoon-canals. Canopies of mangrove conceal these narrow, boat channels from aerial observation. On the coastal lowlands near Lele and south to Cape Tupinier are a few cultivated areas. Breadfruit, taro, and coconuts grown in coastal areas form staple food of natives.

Settlements: Lele, the largest settlement on Kusaie, is on the small island of Lele on the east coast opposite the mouth of the Innemu River. Small settlements on the north and south coast lowlands are of little importance. Recently, the Japanese have constructed military installations on the southeast coast. Mwot, the mission settlement on the southwest coast, is the second largest settlement of the island. The population, estimated at 1,200 persons in 1935, was largely native. For information concerning Japanese installations consult other intelligence reports.

Map Unit	Topography	Ground Conditions	Movement	Cover	Concealment and Observation
1 North Mountains (Mt. Buache)	Small, rugged mountain group, culminating in Mt. Buache; altitude 1,946 feet. Mountain group almost circular in plan with average diameter about 2 miles. Mountains descend abruptly on all but south side to coastal lowlands. Three spurs extend from main mountain mass to coast, dividing the coastal lowlands into compartments. Largest spur on northwest, extends about a mile from main mountain mass to coast; average altitude about 500 feet, maximum 738 feet. Smaller spurs on north and east extend to coast; are lower and less steep than spur on northwest. Spurs may be cliffed at seaward ends; rise abruptly from coastal lowlands. To south, mountain mass is separated from mountains of Area 2 by valleys of Innemu and Okaato Rivers and low headwater divide between valleys. Relief and slopes: Relief great; maximum about 1,900 feet in a mile. Slopes steep, commonly 100%, sometimes 150% or more, especially in summit areas. Vertical cliffs common along stream valleys and near summits. Ridge crests sharp; generally knife-edge with pinnacles. Summits sharply pointed. Some slopes may be slightly benched at elevations from 100 to 160 feet above sea level. Streams and valleys: Perennial streams flow radially from Mt. Buache; drain directly into sea except on south where they are tributary to Innemu and Okaato Rivers. Stream gradients steep, especially in headwater courses; numerous cascades and waterfalls. Some bedrock exposed in stream courses; limited gravel and finer material in stream channels, some large boulders. Floodplains generally lacking. Near mountain margin, streams may flow through narrow steep-walled box canyons and gorges. Matante flows through gorge about 100 feet deep and 10 feet wide near margin of mountains; cascades near mouth of gorge. Valley walls steep, commonly more than 100%, rarely vertical. Caves: Some caves reported on lower mountain slopes; locations not definitely known. Four caves reported, one on either side of spurs extending from mountains on north and northwest. Cave entrances probably concealed by vegetation and rock debris. Caves probably shallow and tube-like. Guano deposits on cave floors are bird or bat excrement.	Bedrock: Mountainous area has basaltic bedrock; poorly exposed except in stream beds and on steep slopes, elsewhere covered by thick soil mantle and vegetation. Basalt properties may differ widely from place to place; composed of thin layers from a few inches to several feet thick. Hardest basalt layers break naturally into columns which may be about 8 to 12 inches in diameter and up to 4 feet in length. Layers of porous basalt, volcanic ash, and basalt gravel may be found between layers of hard and compact columnar basalt. Where exposed, basalt may be deeply weathered so that it crumbles easily. Deep weathering may result in total loss of strength. In general, bedrock is dark gray or black; may weather to chocolate brown and various shades of red. Soil[a/]: Thick mantle of residual soil grades into deeply weathered bedrock. Soil thickest on most gentle slopes; lacking on steepest slopes of summit areas. Maximum thickness may be several feet. Soil is dark chocolate red to brown; good drainage; moderately sticky when wet. In part high in iron or alumina (bauxite reported on island). In general, soil has properties of A-4 type, in part may be A-6.	Barrier area; all movement difficult because of lack of corridors, steep slopes, and dense vegetation. Steep stream channels best routes into mountains for personnel, but dense vegetation will hinder movement. Spurs extending from mountain mass to sea and separating coastal lowland into compartments, difficult to cross because of steep slopes and vegetation. No established routes for movement in this mountainous area which must be by-passed either along coast or by trail which crosses divide from Innemu to Okaato River valleys. Slopes generally too steep for tracked vehicles.	Terrain cover: Deep, narrow canyons afford excellent terrain cover for small personnel units. Small reentrants along mountain margin provide protection from cross-fire on coastal lowland. Excavation: Deep soil and decayed bedrock of lower mountain slopes easily excavated with hand tools. Fox holes and slit trenches may not need retaining walls but may require artificial drainage because of the heavy rainfall.	Concealment: Dense vegetation provides excellent concealment throughout area. Concealment of personnel and equipment on forested mountain spurs and slopes commanding compartments of coastal lowlands is good to excellent. Troops and installations can be concealed from aerial observation by dense vegetation. Observation: Observation difficult in dense vegetation; visibility only a few yards. Observation of adjacent coastal lowlands difficult from mountain spurs and slopes.
2 South Mountains (Mt. Crozer) (See View 21)	Rugged mountains, similar to Area 1; dimensions roughly 7 miles east-west by 4 miles north-south. Mountains form central core of island; rise abruptly with steeply cliffed margins from coastal lowlands; coastal lowlands on all but north side. On north, mountains bounded by valleys of Innemu and Okaato Rivers (Area 3) and separating headwater divide (Area 1). Maximum altitude (Mt. Crozer) 2,064 feet; several peaks more than 1,500 feet altitude. Four spurs extend from central mountains to coast; divide coastal lowlands into compartments. Relief and slopes: Relief great; ranges up to more than 2,000 feet. Slopes steep; commonly more than 100%. Many slopes approach vertical. Summit areas sharply pinnacled; many knife-edged ridge crests. Some broad ridge crests, especially on south, incised by narrow stream canyons. Some slopes may be slightly benched between 100 and 160 feet altitude. Streams and valleys: Drainage from central mountain mass directly across coastal plain to sea or directly to valleys of Innemu and Okaato Rivers. Ridge crest with generalized east-west trend forms drainage divide. Streams perennial; gradients steep, increasing in steepness in headwater courses where valleys may have cliffed headwalls. Probably many cascades and waterfalls; bedrock exposed in stream channels. Floodplains generally lacking; gravel and boulders in stream channels moved during periods of flood, following heavy rainfall. Valley walls steep, in places approach vertical; many steep-walled box canyons in lower stream courses. Few large reentrants along stream valleys at margin of mountains. Caves: Three caves reported in area; exact location unknown, one near Berard, one on coast about a mile south of Mwot, and one along west side of Port Lottin. Caves probably small, near margin of mountains.	Bedrock: Basalt, similar to that of Area 1, forms mountains. Bedrock poorly exposed except in stream beds, on steeper slopes, and in summit areas. Soil: Thick mantle of dark, chocolate-red to brown, residual soil, similar to that of Area 1. Soil merges with deeply decayed bedrock; thickness may be several feet on lower slopes, lacking on steepest slopes of summit areas.	Barrier area; movement extremely difficult because of lack of corridors, steep slopes, and dense vegetation. Area can be by-passed along coast, or through valleys of Innemu and Okaato Rivers across low but steep divide. A single trail is reported (Fleet Marine Force Map, 1934) to cross mountainous terrain between Mwot on coast and headwaters of Okaato River. Trail is probably narrow footpath with steep grades; unsuited to motorized movement. Mountain spurs, separating coastal lowland into compartments, are difficult to cross because of steep slopes and dense vegetation. In general, narrow stream canyons are easiest route into interior; ridge crests offer no advantages to movement because of narrowness and dense vegetation.	Terrain cover: Deep, narrow canyons provide excellent cover for small personnel units. Mouths of canyons provide cover from fire on coastal lowlands. Excavations: Deep excavations for fox holes and slit trenches may be dug readily with hand tools in soil and underlying decayed bedrock. Excavations may require artificial drainage because of heavy rainfall but may not require retaining walls.	Concealment: Excellent concealment provided for personnel and materiel by dense vegetation. Installations concealed from air observation by dense forests. Observation: Observation difficult because of dense vegetation. Forest trees generally of accordant height; unsuited for observation. Commanding spurs and prominences along margin of mountains will have to be cleared of vegetation for observation; will necessitate careful camouflage. Visibility poor in forests, generally only a few yards.

a/ Soil type symbols are according to the classification of the U. S. Public Roads Administration.

(continued)

TERRAIN APPRECIATION

KUSAIE (UALAN) ISLAND (CAROLINES)

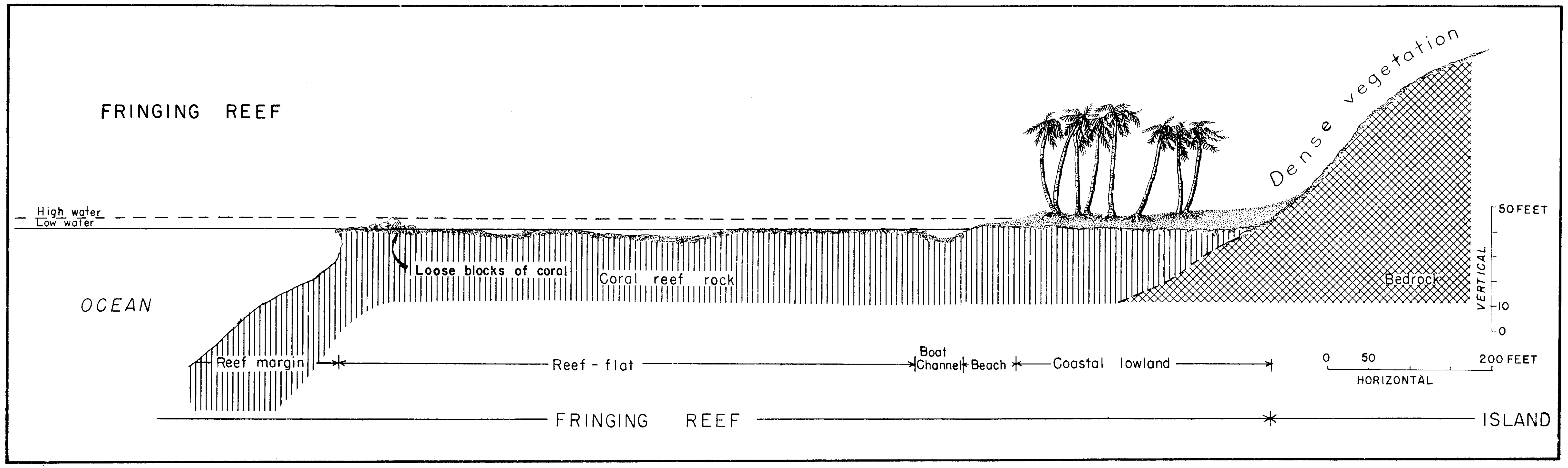
Reliability rating: Class C

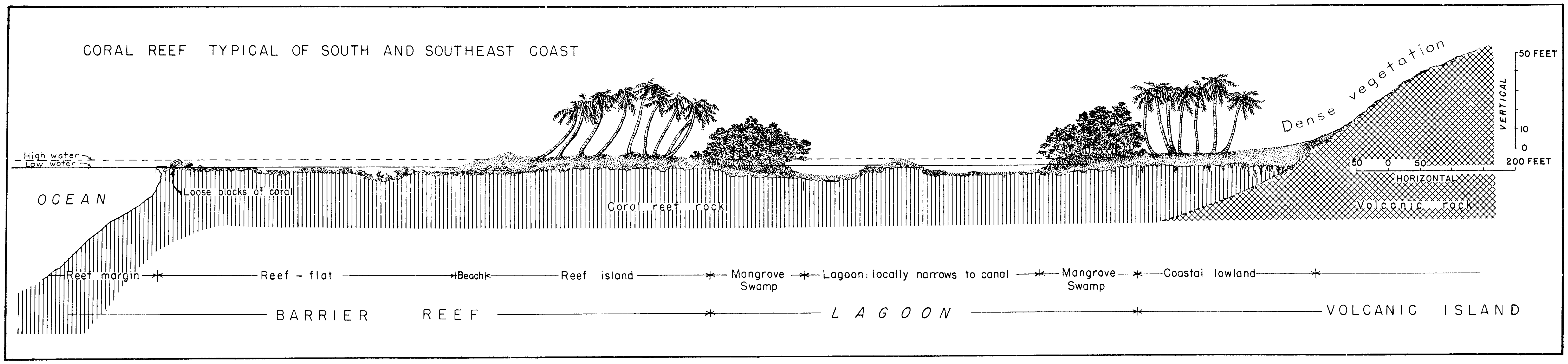
Map Unit	Topography	Ground Conditions	Movement	Cover	Concealment and Observation
3 Coastal Lowlands (See Views 1-8) (See Views 9-11) (See Views 12-20)	Narrow coastal lowland, maximum width about 1 mile surrounds mountainous interior of island (Areas 1 and 2). Inner border marked by abrupt, almost vertical mountain walls, outer margin in part swampy. In part coast bordered by narrow lagoon-canals and reef islands. Small mountain streams cross lowlands to sea in shallow, meandering courses. Coastal lowlands have little relief; slope gently from mountains to ocean. Mountain spurs extending to coast separate lowlands into seven compartments: Compartment A: Small delta and floodplain of Innemu River; swampy coastal margin. Lele Harbor (see detailed map) generally shallow with small coral reefs; shore in part sandy, in part muddy. Lele Island (see detailed map), most populous center of Kusaie, is lowland with shallow canals on west, rising to steep hill with altitude of 354 feet in east. See other intelligence reports for details of harbor and installations. Innemu River carries large quantities of silt, sand, and gravel in time of flood; clouds water of harbor. Compartment B: Broad, coastal lowland; maximum width almost 1 mile; slopes gently from mountain margin to sea level. Shoreline fringed with coral reefs; a few small reef islands in north part, elongate reef island in south part; separated from main island by small channels parallel to shore. Narrow lagoons in south part; width from a few to more than 100 feet; depth 3 to 6 feet; reported to be travel routes for canoes. Numerous small channels transverse to coastal channel. Fringing mangroves in part completely conceal channels from aerial observation; channels probably are more numerous than map indicates. Drainage ditches indicate that ground is low and swampy. Mangrove swamps have maximum development in south part; many small channels form network of passages suitable for canoes. Compartment C: Narrow coastal lowland along south and southwest part of island. Coastal lowlands featureless and narrow, seldom over a few hundred yards wide. Large areas of mangrove swamps along narrow, shallow, coastal lagoon, which is sheltered from open sea by low narrow reef island. Reef may be in part as much as 400 yards wide, generally about 250 yards wide. Outer margin of reef shelves rapidly; shore sandy and gravelly. Highest altitude only a few feet above sea level, but sufficient for growth of coconut palms to west of Point Lesson. Lagoon bordered by mangrove swamps. Small channels in swampy areas probably suitable for canoes at high tide; concealed from aerial observation by overhanging mangroves. Outer margin of reef sandy and exposed to surf; inner margin, adjacent to lagoon, muddy and sandy. Port Lottin Harbor is largest natural break in reef (see detailed map). Compartment D: Narrow, swampy, coastal lowland; largely mangrove swamp. Many small streams flow from mountains across featureless plain to irregular shore. Complex fringing reef, broken at Port Berard, and Coquille Harbor to north. Small areas of lowland rise a few feet above general level of mangrove swamps which may in part extend to base of mountains. Network of small channels in mangrove swamp. Compartment E: Coquille Harbor; low swampy delta and floodplain of Okaato River inclosed by mountains; connected with adjacent lowland compartments only by narrow swampy lowlands. Okaato River crosses lowlands in a network of gravelly, silty channels. During periods of flood, stream carries much fine detritus and some gravel into harbor. Broad fringing reefs offshore; width more than a mile. Single channel opens into Coquille Harbor (see detailed map). Compartment F: Broad coastal lowland; maximum width about one mile. In southwest part mostly mangrove swamp; higher ground in northwest part planted to coconut palms. Some small streams flow from mountains across lowlands in shallow meandering channels. Coconut-fringed coast may be slightly cliffed at margin by 6-foot sea cliff. Broad fringing reef, in part awash at low tide. No deep channels approach shore. Compartment G: Broad, featureless, coastal lowland, average width about half a mile. Sandy and gravelly along east coast; palms on outer margin of reef island. Lagoon behind reef island largely filled with detritus, mainly mud from adjacent mountains. Narrow channel, suitable for small boats and canoes, follows lagoon from Cape Halgan to Lele Harbor; in south part is suitable for larger craft. Shore exposed to surf; beaches sandy or gravelly; beach ridge built up by debris brought in during heavy storms. Mountains rise abruptly from lowland to Mt. Buache; a few small streams flow across lowlands from mountains; probably carry much debris in time of flood.	Bedrock: Coastal lowlands underlain by coral-reef rock lying on basalt. Coral-reef rock thickest at shore, thins out at mountain margin; not exposed except rarely in small cliffs along coast. Reef rock permeable; probably ranges from poorly to well-consolidated. Soils[a]: Coastal lowlands covered by deep mantle of alluvial soil; consists primarily of debris washed from adjacent mountains. Sand and gravel mostly concentrated in stream channels and on outer margin of reefs. No quartz sand on island. Beaches on outer margin of reef and main islands commonly gravel composed of coral fragments. On exposed east and northeast coasts, gravel and sand may be piled up by surf to heights of 6 feet. Soil of mangrove swamps is plastic silt; probably A-8 type; periodically flooded by tides. Reddish brown, plastic to friable, in part gravelly, loam on higher parts of lowlands probably A-2 and A-4, locally A-3, in type; drainage good although ground water table is high. Moderately sticky and slippery when wet. When soil is churned by traffic, becomes muddy. Coarsest gravel along small stream channels. Broad coastal areas consist in part of gravelly material, increasing in fines toward the coast.	Ground conditions are important factor influencing ease of movement in coastal lowlands. Mangrove swamps practically impenetrable; greatest development along northeast coast (Compartment G); elsewhere scattered more or less continuously along coast. Small stream channels crossing lowlands from mountains to sea may hinder movement; generally fordable but muddy bottoms may cause bogging of heavy vehicles. Small channels in mangrove swamps may be 3 to 6 feet deep; easily passable by canoes. Small coral reef islands generally have better footing than main island. Composed primarily of coral sand and fragments of coral reef rock, some scattered volcanic boulders and cobbles. In general, where there are coconut palms, footing is best; poorest on inner margin where there are mangrove swamps. Movement from compartment to compartment difficult because of mountain spurs which extend to coast. Narrow lowland of mangrove swamps reported to front spurs separating Compartments B and C, D and E, E and F, and G and A. Spur between A and B fronted by forested tract less than 100 feet wide; between C and D, and F and G, appears to lack any fronting lowland and mountain spur may be cliffed. In general, spurs are heavily wooded and can readily command narrow corridors joining compartments, as well as adjacent compartment lowlands. Movement through mangrove swamps at base of mountain spurs difficult because of poor footing. Established routes: A few roads and footpaths follow coastal area. Natives reported to follow beach rather than inland paths. Japanese reported to have constructed and repaired coastal routes. Lele Island encircled by coastal road; some interior roads (see detailed map). Trail follows Innemu River valley, crosses low headwater divide to Okaato River valley. Probably is only cleared trail; may be recently improved with corduroy log or fascine in low swampy areas. Coastal road south from Lele Harbor to Cape Tupinier recently reported to be 20 feet wide; probably surfaced with coral limestone; connects airfield and installations with Lele Harbor. No roads or trails known in Compartment C other than short coastal trail at cluster of houses northeast of Point Vauvilliers. Narrow trail leads from coast to mission settlement on mountain spur at Mwot. No roads or trails known in Compartment D. Trail up Okaato Valley to headwater divide, connects at divide with trail to Lele Harbor; may have been recently improved by Japanese as cross island route. A single coastal road from Tahonsaku (Compartment F) to Cape Halgan (Compartment G) ends at small inland channel connecting with Lele Harbor. This road, reported to have been widened to 12 feet, may be metalled with coral rock.	Terrain Cover: Lowland provides no terrain cover. Mountain spurs provide cover from adjacent compartments. Small reentrants where streams issue from mountain margin provide cover from fire on lowlands. Excavation: Alluvium of coastal lowlands easily excavated by hand tools, except in swampy areas where water-logged soil will slump. Artificial drainage will be necessary throughout lowlands because of high water table, heavy rainfall, and poor surface drainage. Walls of excavations will need support. Areas underlain by coral limestone may have thin soil cover and require blasting for excavations.	Dense vegetation of forested areas and mangrove swamps will provide excellent concealment from aerial observation. Ground visibility low in these areas. Coconut palm plantations and natural groves provide only moderate concealment. In general, dense vegetation on reef islands and coastal swamps provides concealment from sea. Observation: Observation of coastal lowlands from adjacent mountain slopes poor or impossible because of dense vegetation. Coastal installations and movement along beaches may be observed from open ocean but not from main island. Channels between fringing islands and main island suitable for movement in canoes, in large part cannot be observed from air because of canopy of foliage.

[a] Soil type symbols are according to the classification of the U. S. Public Roads Administration.

Prepared by U. S. Geological Survey for Chief of Engineers, U. S. Army.

DIAGRAMMATIC CROSS SECTIONS OF CORAL REEFS





CHARACTERISTICS OF CORAL REEFS OF KUSAIE

Coral reefs are narrow submarine platforms built of limestone made from lime-depositing organisms (calcareous algae and corals). In large part, the surface of the coral reef is slightly below the level of mean low water. Two main types are recognized: (a) fringing reefs which are attached to a landmass, usually an island, and (b) barrier reefs, which are submarine ridges enclosing shallow lagoons, commonly containing islands. All gradations may occur between the typical fringing reef and the typical barrier reef.

On Kusaie, typical fringing reefs are on the west and north coasts. On the south and southeast coasts, the fringing reef merges with a narrow barrier reef, separated from the main island by a narrow lagoon or lagoonal-canal. Small islands on the barrier reefs parallel the shore of the island.

Fringing Reefs

The accompanying generalized cross-section illustrates the principal characteristics of a fringing reef. Much of the reef is submerged, even at low tide. Width of reefs ranges from a few feet to about a mile. Coral grows best where water is strongly agitated and as a consequence, fringing reefs may be extensive at exposed headlands. At the mouths of larger streams fringing reefs are interrupted, for coral growth is hindered by fresh or brackish water.

Seaward margin: The seaward margin of a reef is a steeply inclined and possibly overhanging wall. The reef margin is fluted by many narrow, closely-spaced chutes, separated by smooth-fronted promontories of reef rock. These chutes are scoop-shaped depressions into which the sea wells at low tide, surging on to the reef flat. At high tide, waves break with full force on the reef margin, which is covered with living corals and calcareous algae. The surface of the reef flat near the seaward margin may be smoothly rounded, sloping gently seaward toward the abrupt break in slope at the submarine face.

Reef flat: The nearly level reef flat is a surface largely blanketed by sand and coral fragments broken and distributed by waves and currents. Much of the coral on the reef flat is dead. Part of the reef flat is a limestone pavement; the limestone exposed above tide is jagged and composed of sharp-edged ledges. Blocks of reef rock, deposited by storm waves, may be scattered over the reef flat near the outer margin. Tide pools as much as ten feet in diameter and several feet deep form depressions in the reef flat. Branching varieties of coral grow in these depressions to the low tide level. The reef surface may be separated from the mainland by a shallow "boat channel", a narrow discontinuous tidal channel that remains water-filled at low tide and is a few feet deep.

Inner margin: The inner margin of the fringing reefs of Kusaie may be a mangrove swamp or a beach of calcareous sand. In no place is the coast reported to be cliffed or overhanging.

Barrier Reefs

On the south and southeast coasts of Kusaie the typical fringing reefs merge with a barrier reef of a relatively uncommon type. Here there are narrow, elongate islands parallel to the shore, from which they are separated by a narrow lagoon or lagoonal canal. The typical fringing reef skirting the low mangrove shore is absent. The accompanying generalized cross-section illustrates the principal characteristics of this type of reef.

Seaward margin: In general similar to that of the fringing reef.

Reef flat: Essentially similar to that of the fringing reef, but generally lacking the "boat channel" characteristic of the fringing reef.

Islands: Low islands on the surface of the reef are built of sand consisting in large part of coral and algal fragments. The sand has been deposited on the reef flat by waves and currents and may be in part reworked by the wind. Few islands are higher than 15 feet; the chief irregularities on their surface are low dunes and beach ridges. The sand is permeable, drains quickly, and is dry almost immediately following a rain; it is firm even when saturated. There are no streams.

Lagoons and lagoon-canals: Narrow lagoons between the barrier reef islands and the Kusaie mainland, range in width from a few feet to about 300 feet, and to a maximum depth of 10 to 12 feet. In general the banks are mangrove swamps; lagoon floors are covered with calcareous sand and coral blocks; there are few living corals in these lagoons. Rarely small islets rise almost to high tide level from the floors of the lagoons.

Inner margin: On the south and southeast coast of Kusaie, the characteristic fringing reef is absent along the coast. The low coast is a mangrove swamp.

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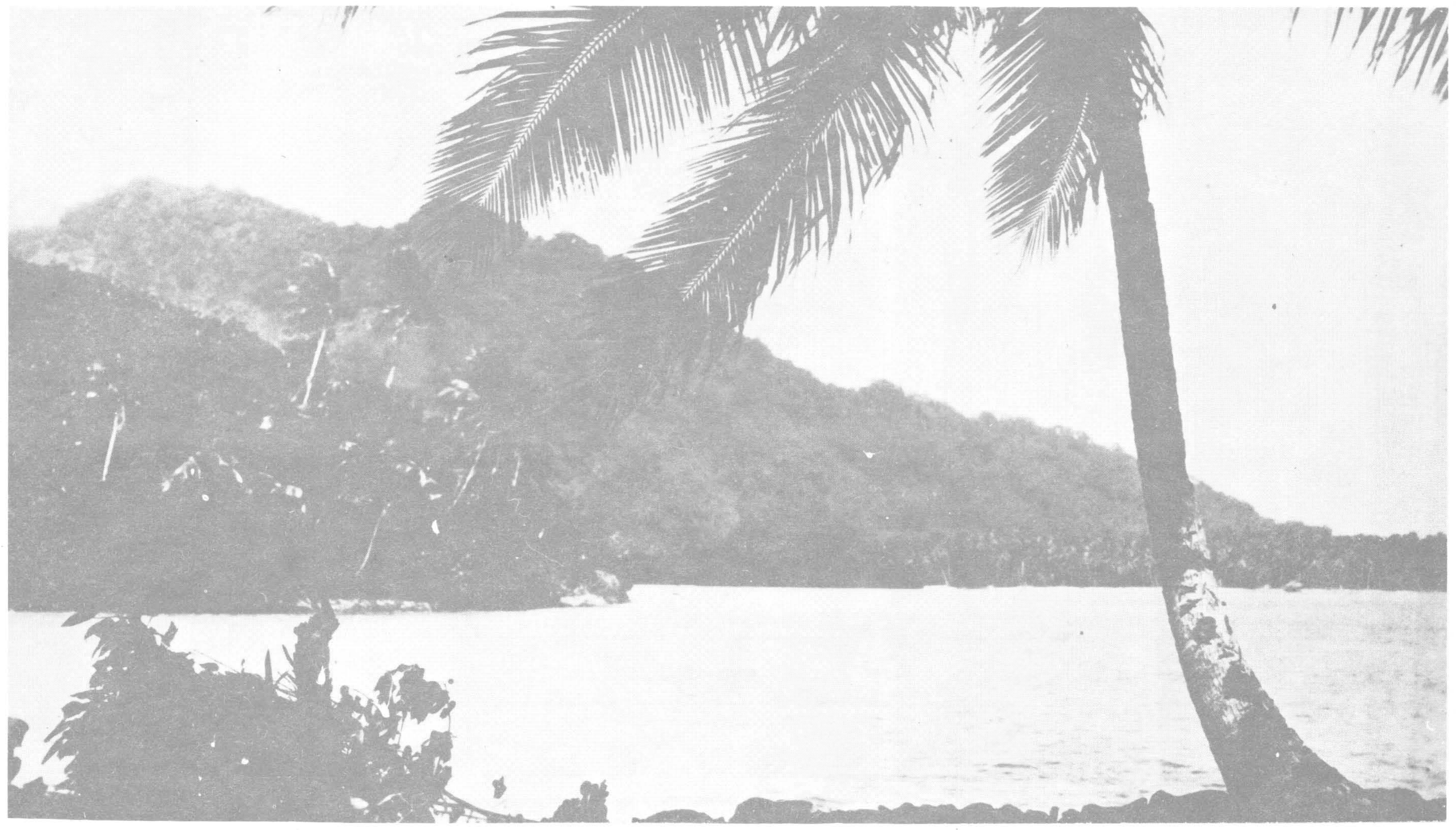
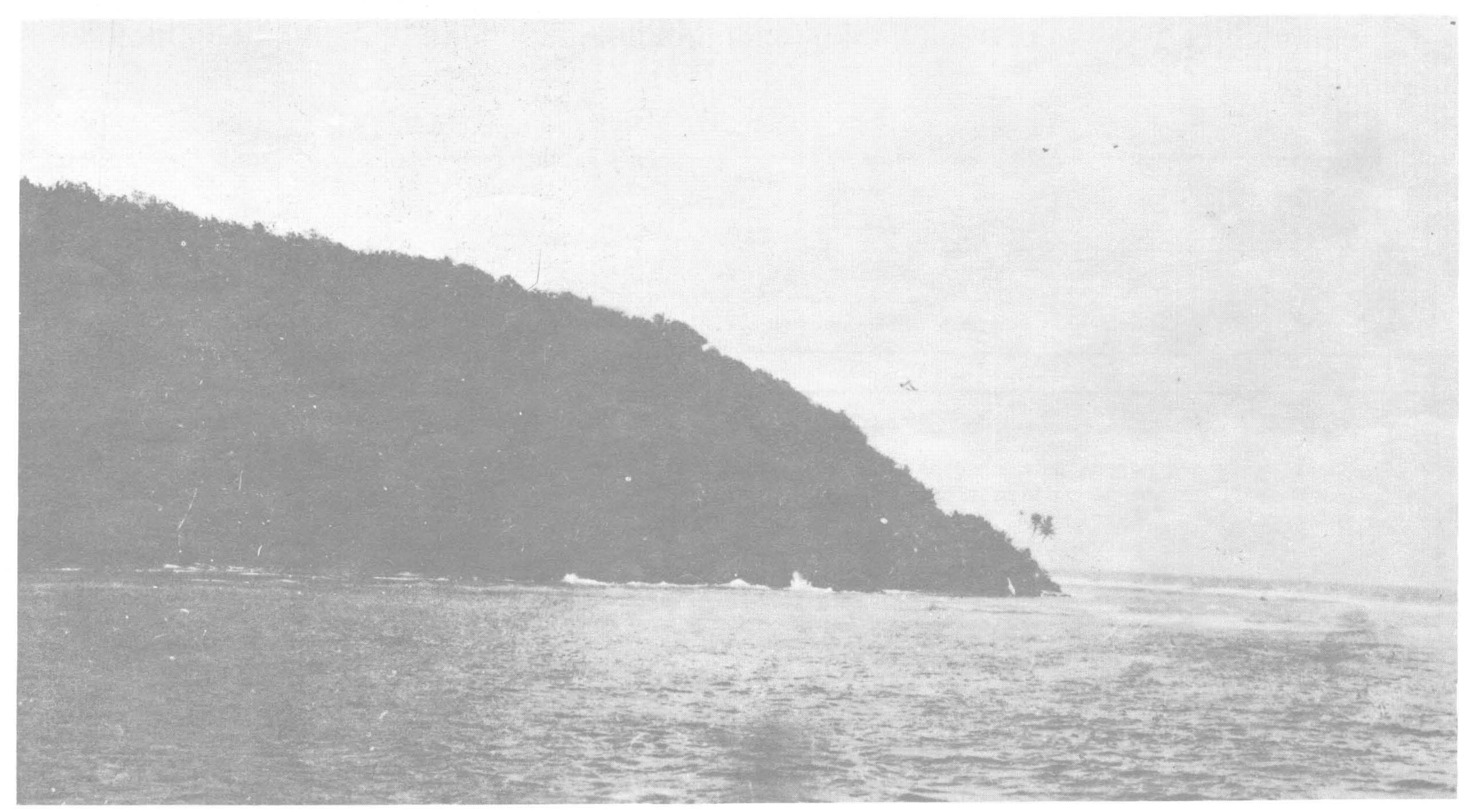


1 Dense vegetation of coasts and mountains of Kusaie. View from Lele Island looking towards spurs of Mt. Buache. Dark vegetation along coast in center background is mangrove swamp; coconut palms grow on drained sandy ground along coast. (ONI 171-023.)

3 Northeast shore of Lele Island. Typical narrow, gravelly beach covered at high tide. Coconut palms growing close to shore. In left background, low islands of coral sand and gravel on fringing reef of Kusaie lack dense vegetation. (ONI 12183.)

2 Typical coastal vegetation and sandy, gravelly shore of Lele Island. Sand composed of calcareous coral and shell fragments; gravel is dark volcanic rock (basalt). Coconut palms grow near shore on drained, sandy ground. (ONI 171-025.)



4 Southeast end of Lele Island at high tide. Volcanic rock (basalt) covered with dense vegetation which extends to strandline. Road cut into side of cliff; no lowland. Surf breaking on coral reef seen at right. View from entrance to Lele Harbor. (ONI 12184.)

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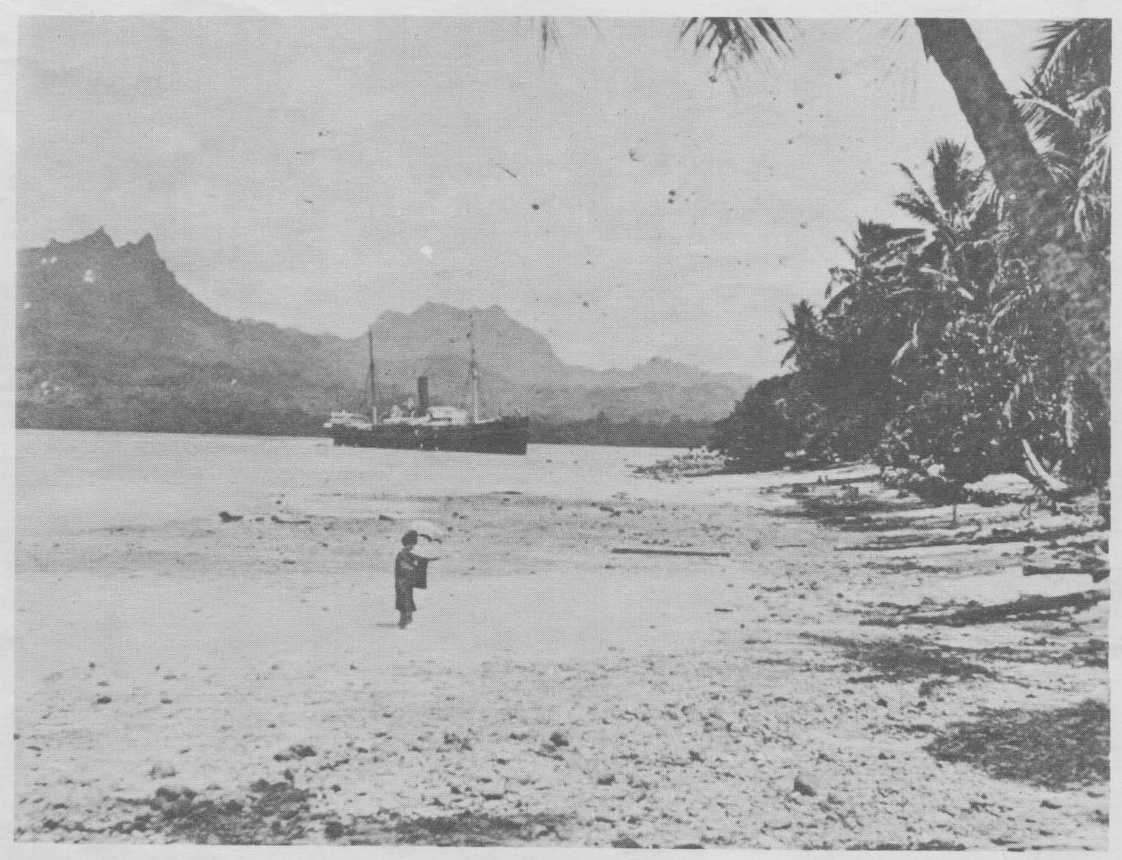
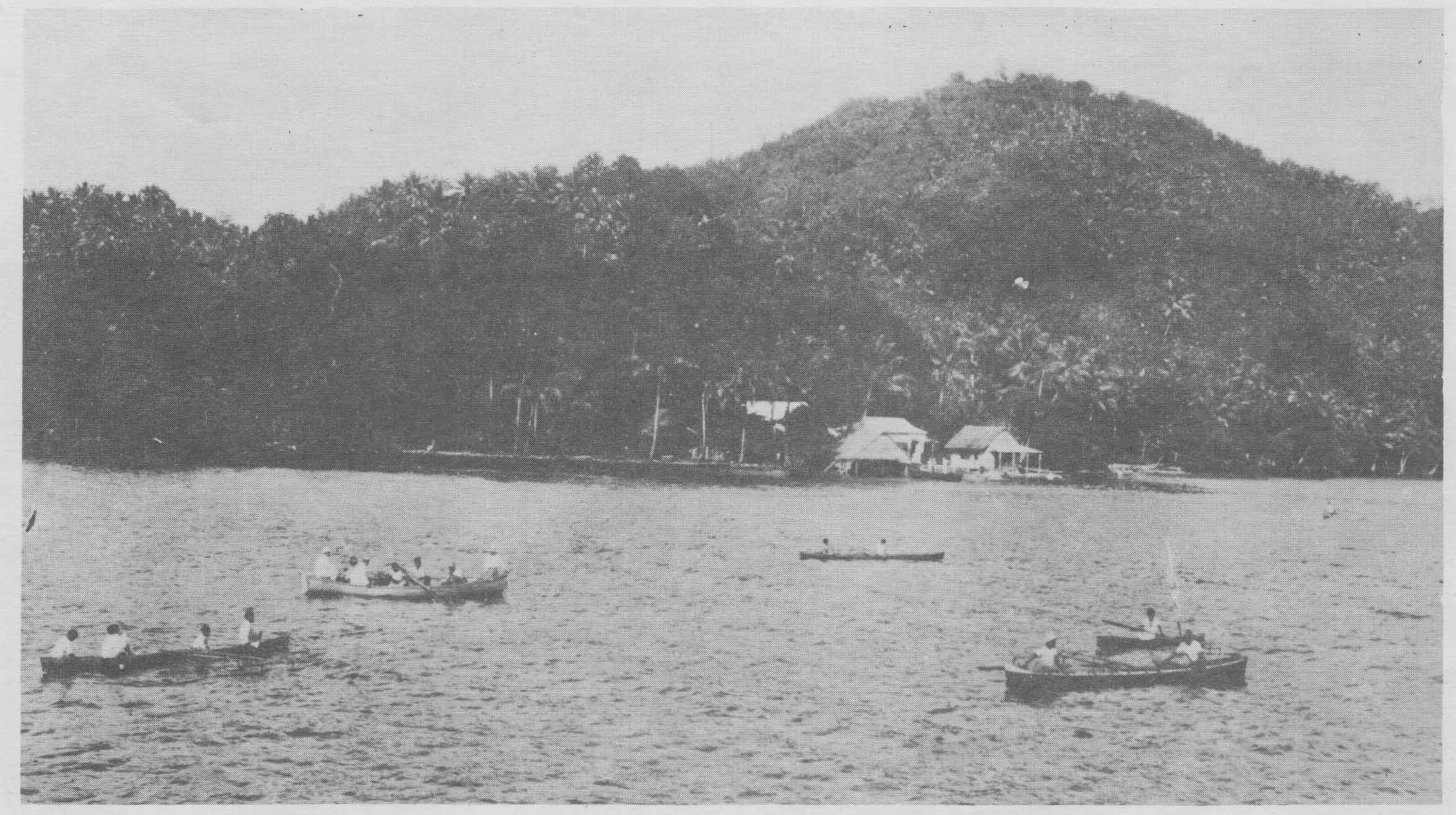
5 Trail through coastal coconut palm groves is typical of best trails of island. Follow slight rise above adjacent coastal swamps. Trail cleared of vegetation and maintained. (ONI 74700.)



6 Gravelly beach on south shore of Lele Island at low tide is typical of some coastal areas. Slope of beach steepens rapidly at strand-line which is marked by coastal vegetation of palms and brush. Rugged vegetation-covered mountains in background have steep slopes and sharply pointed peaks typical of tropical islands of volcanic rock (basalt). (ONI 12190.)



7 South shore of Lele Island at high tide; Mt. Fenkofuru (354 feet) in background. Basaltic rock of mountain extends almost to shore. Beaches are very narrow. Road extends around island near shore. Dense vegetation covers hill slopes. (ONI 12182.)

8 Lele Harbor at high tide; Lele Island and village in foreground, Mt. Buache in background. Dense mangrove on shore of Kusaie in background; dense jungle mantles steep mountain slopes that rise sharply from narrow coastal lowland. Such impenetrable vegetation and steep slopes, characteristic of Kusaie, are obstacles to movement. (ONI 12186.)

9 Southeast coast at low tide showing sandy, gravelly beach characteristic of Kusaie. Surf breaks directly on shore at high tide. (Sarfert, 1919.)

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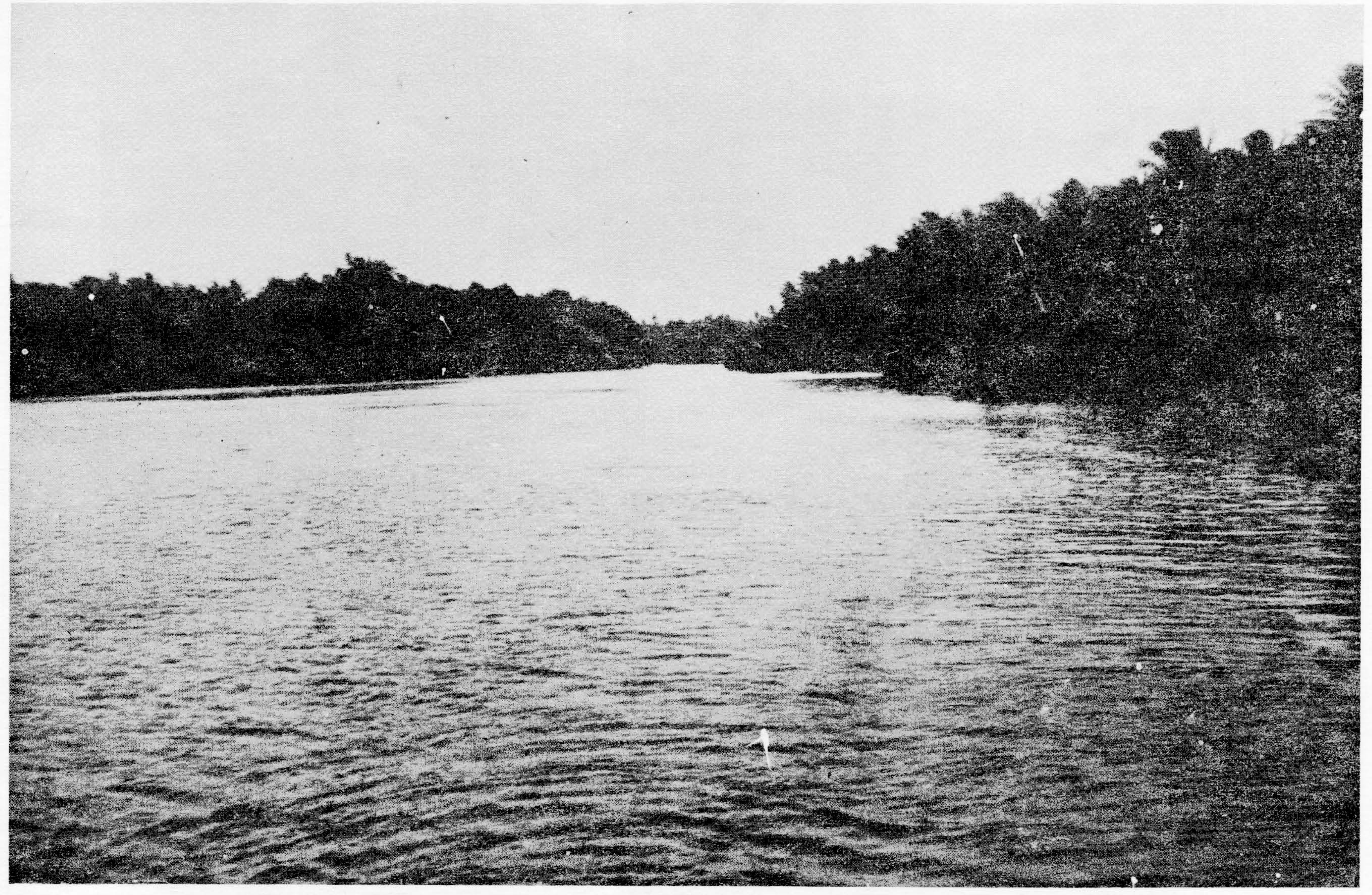
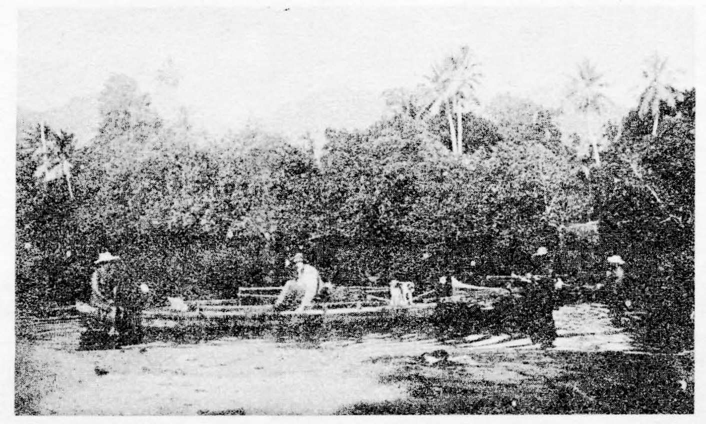
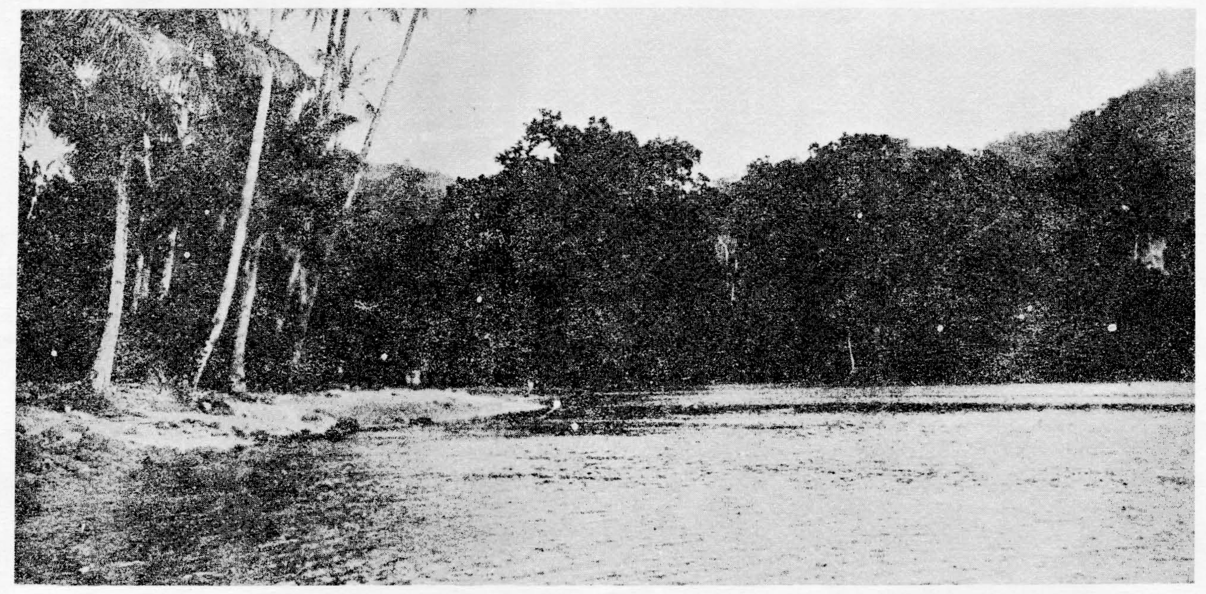


10 Southeast coast of Kusaie, looking west from Cape Tupinier. Channel between reef islands and coastal lowland, extending along most of south and southeast coasts. Width of channel is much greater here than is typical on south coast. Dense mangrove covers island and mainland. (O.S.S. 966.14 K9d.)



12 Narrow channel on south coast between coral-reef island and mainland. Shores are dense mangrove swamps. Steep hills in background are mountain spurs rising abruptly above coastal lowland. (Sarfert, 1919.)



13 South shore of Kusaie near Port Lottin. Mangrove-covered coastal lowland in midground. To left is small reef island of sand and gravel. Channel between mainland and island is generally shallow and narrow; only large enough for canoe or small boats. (ONI 71633.)

11 Typical view on south coast east and west of Port Lottin. Narrow channel flanked by mangroves of reef islands and coastal lowlands. Channel adequate for use by canoes or small boats. Adjacent land is swampy and difficult to penetrate because of dense vegetation. (ONI 14315.)

14 Fenkol Village on south coast of Kusaie. Gravel and sand island in foreground, separated from mainland by narrow lagoon. Swampy coastal lowland is built of alluvium and coral limestone. Vegetation-covered mountains of basalt in background have characteristic steep slopes and jagged peaks. (Natl. Geogr. Soc.)

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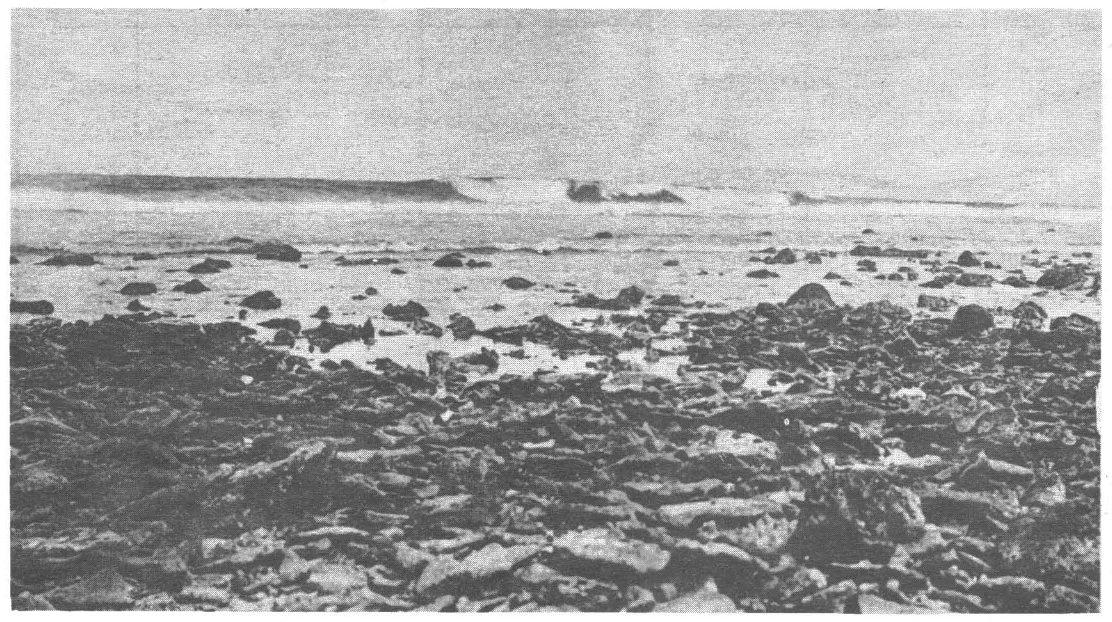
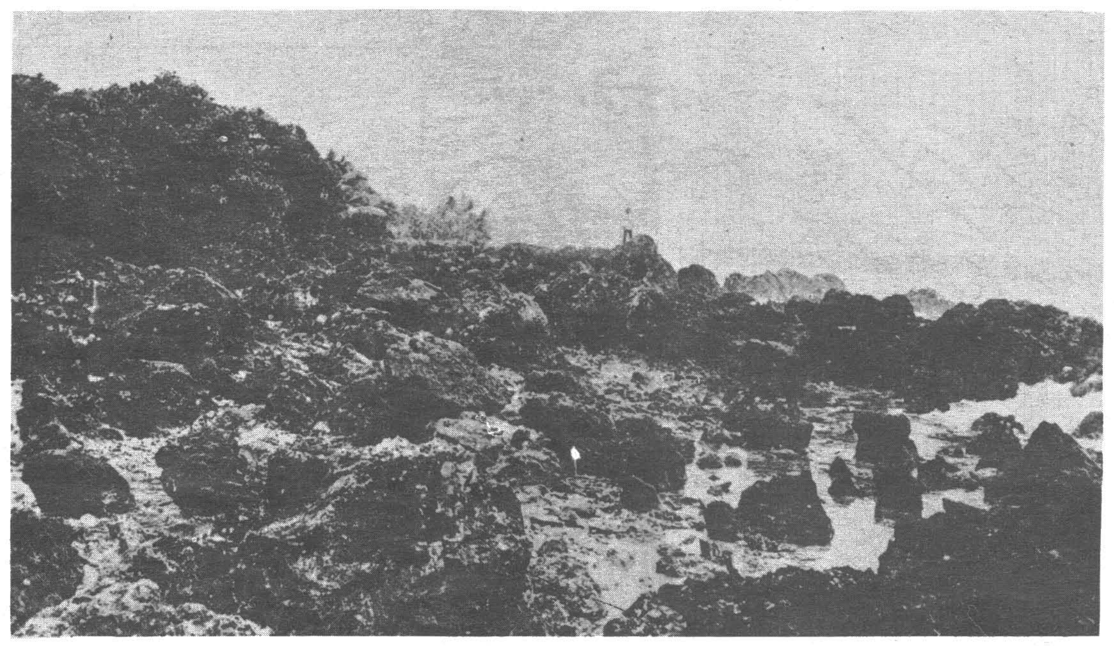
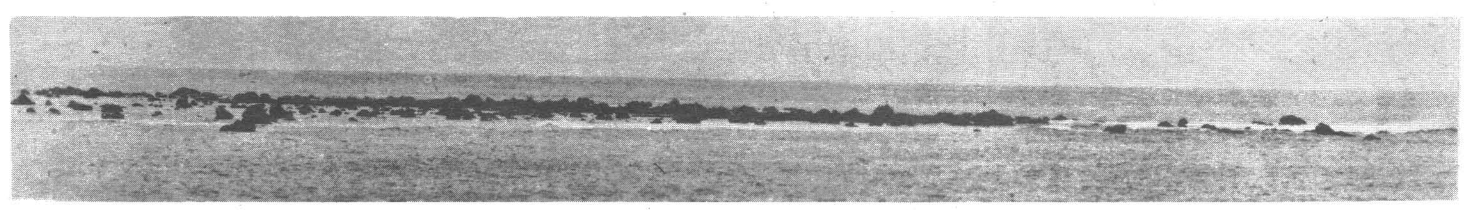


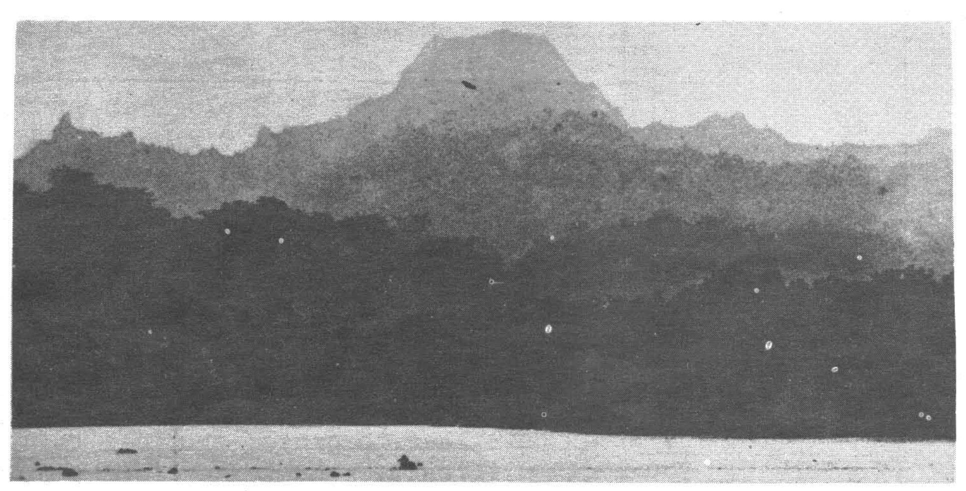
15 Surf on south coast of Kusaie breaks on shingle beach of coral rock. Noticeable lack of sand on this exposed beach. (Sarfert, 1919.)



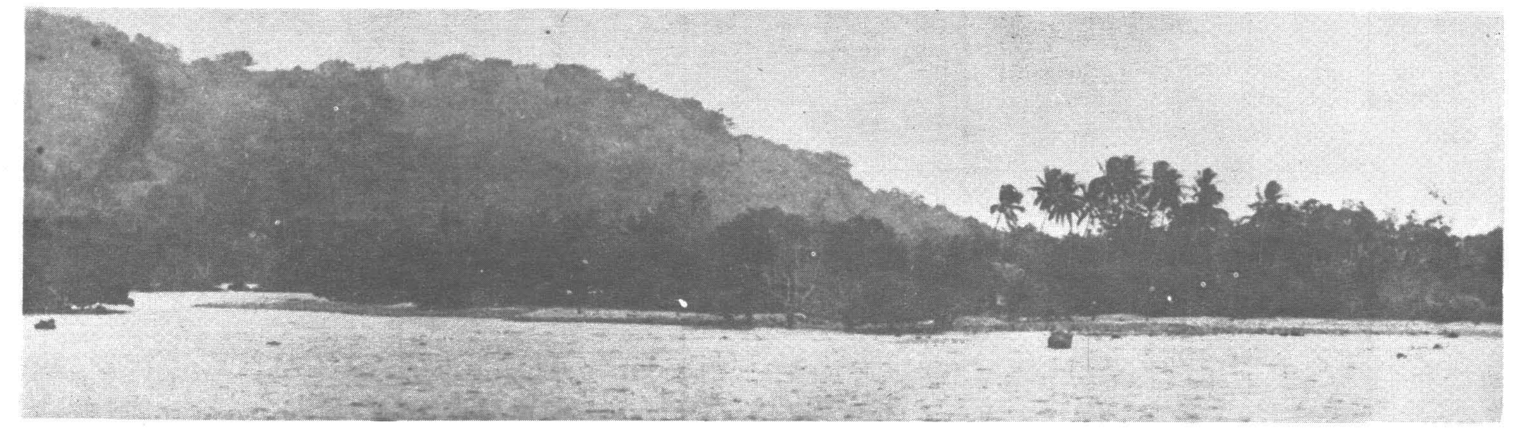
16 Large blocks of coral rock and basalt on south coast of Kusaie. Such concentrations of rocks are thrown locally on shore during large storms. (Sarfert, 1919.)



17 South coast of Kusaie. Low ledge of coral rock boulders on spit forming east entrance to Port Lottin. Slightly above water at all times. (Agassiz, 1903.)

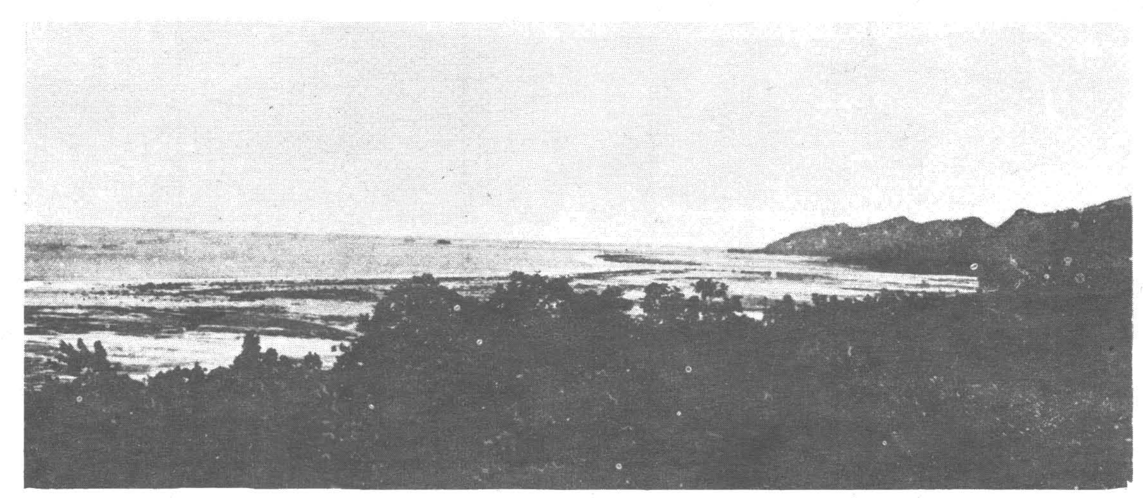


18 South coast of Kusaie at high tide. In foreground, boulders on coral reef are exposed. Dark strip of vegetation beyond water is mangrove belt growing on shore of main island. Mangrove and coconut palm grow on coastal lowland; sharp crests and peaks of volcanic mountains in background. Heavy growth of vegetation reaches almost to mountain tops. (Agassiz, 1903.)



19 South coast of Kusaie, west side of Port Lottin harbor. In foreground, typical low gravelly island on reef. Narrow, irregular channel into harbor at right. Coastal lowland of alluvium at head of channel. Volcanic mountains in background have steep slopes and sharp peaks. Mangrove swamps at low elevations; forest trees on mountain slopes. (Agassiz, 1903.)

20 South coast of Kusaie. Channel between gravelly reef islands and coastal lowland, extending along most of south coast. Vegetation is extremely dense, often concealing channel where it is narrow. Mangrove, reef bushes, coconut palms, and forest trees are present. (Agassiz, 1903.)



21 West coast of Kusaie at low tide. View from Mwot showing extensive fringing coral reef and narrow coastal belt at base of mountain spurs. (Sarfert, 1919.)

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WATER SUPPLY — KUSAIE (UALAN) ISLAND (CAROLINES)

1 — Beaches of Kusaie and coastal islands; chiefly permeable sand and gravel. Barren or palm covered. Water obtainable from dug wells not more than 6 ft. deep. Will be brackish on smaller islands; may be fresh on larger islands and on some parts of Kusaie beaches. Must be lightly pumped to minimize danger of salt water contamination. Surface water not available. Collection of rain water probably best local source. Supplies for large troop units will have to be imported or distilled.

2 — Mangrove swamps. Potable water not obtainable locally. Movement on foot difficult.

3 — Coastal lowlands and larger river valleys, sloping gently from low foothills to sea level. Dense to open tropical vegetation. Ample supplies of potable water obtainable from wells not more than 80 ft. deep. Area underlain by lens-shaped body of silt, and permeable sand and gravel. Near sea, wells will be only a few feet deep and will probably encounter limestone; must be pumped lightly to minimize the possibility of salt water contamination. Farther inland they will be deeper and may encounter water in sand or gravel. Near mountains they may encounter basalt before water is reached. In reef limestone or basalt drilling is hard; spare bits must be provided. Surface water not available in most places.

4 — Mountainous area covered with dense tropical rain forest. Movement difficult. Mountains formed of basalt beds of variable thickness interbedded with fragmental material. Stream water abundant. Springs fairly numerous. Ground water level may be as deep as 1,500 feet; in places may be much less. Wells not recommended; if drilled, sites should be selected by a ground-water geologist.

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Reliability rating: Class B

INTRODUCTION

Summary

Water resources on Kusaie are abundant, but nearly undeveloped. The Japanese are reported to have constructed a reservoir (for power and possibly water supply) on a small stream slightly less than a mile southwest of Lele Harbor, but this is not verified by aerial photographs taken in January, 1944. On Lele Island is a 950-gallon (40-ton) water tank probably for storage of rain water. A well on the north side of Lele provides water reported to be unfit for drinking and used only for bathing and washing. Most of the native and foreign population uses water from streams, springs or stored rain water for all purposes.

Most mountain streams on Kusaie are perennial, but fluctuate greatly in discharge. The larger streams would afford reliable supplies directly to purification units. On smaller streams storage facilities would have to be provided. On the coastal plain few streams are perennial; on the coastal islands there are no streams.

Abundant supplies of fresh ground water can be developed on the coastal lowlands of Kusaie. In the interior mountainous parts wells are not recommended unless the sites are selected by a ground water geologist. With the possible exception of Lele Island, only emergency supplies of ground water, probably brackish, are available on the small coastal islands and on some of the narrow beaches of Kusaie.

Rain water, collected from trees, roofs and other surfaces is an important source of water supply.

Topography and Geology

Kusaie, area about 43 square miles, has a mountainous interior surrounded by gently sloping coastal lowlands. The island is encircled by a fringing coral reef ranging from a few hundred yards wide on the southeast to almost a mile on the northwest; in places the reef supports long, narrow islands. The reef is broken only at the harbors of Lele, Lottin, Berard, and Coquille.

The Coastal Islands: Along the south and east coasts, separated from main island by narrow lagoons, are coral reef islands less than 6 feet high and ranging from a few feet to about three-quarters of a mile wide. The islands consist chiefly of permeable coral sand and gravel with some volcanic detritus. On the eastern end of Lele Island is a basaltic hill 354 feet high. The western end is low and flat and consists of intermingled silt and coral rock.

The Coastal Lowlands: The coastal lowland is level to rolling and ranges from a few hundred to about 1,200 yards wide. It is bordered by sand and gravel beaches, or mangrove swamps up to 600 yards wide. In the swamps intermingled silt, coral and volcanic debris are anchored by mangrove roots. The coastal lowland is underlain by silt, and permeable sand and gravel which are thinnest near the beaches and the foot of the mountains, and possibly 50 to 60 feet thick about 1/4 of the way from the mountains to the ocean. This alluvium overlies a raised coral reef of more or less cavernous limestone except near the foot of the mountains, where it overlies basalt. The coral limestone overlies basalt, and thickens from a few feet near the mountains to over 100 feet near the beach. A few large rivers cross the lowlands in wide channels; the beds consist of sand and gravel except near the sea where they are of mud.

The Central Mountain Area: The interior is mountainous with slopes up to 150%. The mountains are separated into a large southern mass and a much smaller northern mass by a valley occupied by the Okaato and Innemu Rivers. The highest peak is Mt. Crozer (2,064 feet) near the center of the island. Mt. Buache in the north, altitude 1,946 feet, is reported to have slopes less rugged than those of the southern mountains. The mountains are underlain by beds of basalt a few inches to several feet thick, interbedded with layers of porous basalt, volcanic ash, and gravel. Some basalt beds fractured into columns. The basalt (particularly on the gentler slopes) is covered with several feet of soil.

Streams are numerous. They flow in narrow, rocky gorges with many rapids and waterfalls. Near the borders of the mountains the gorges widen into valleys.

Vegetation

Coastal Islands: The ocean side of the islands on the south and east coast of Kusaie is barren gravel. Some of the broader islands have coconut palms in the interior and mangrove swamps on the landward side.

Main Island: Mangrove swamps 100 to 600 yards wide fringe the coast behind the offshore islands: from near Cape Tupinier westward to Pt. Vauvilliers, south of Cape Halgan on the northeast coast, and near the mouths of some of the larger streams. Elsewhere the coastal lowland is covered with heavy tropical rain forest or patches of lighter vegetation and coconut palms. The rain forest also covers most of the mountains.

Precipitation

The mean annual rainfall at Mwot, on the west coast, is 254.79 inches and at Lele Island, off the east coast, is 176.26 inches. (See precipitation graph in Climate section.) In the higher parts of the island the rainfall is probably greater. No distinct wet or dry season exists. Rain falls nearly every day and is likely to be torrential.

Population and Water Facilities

In 1935, the population of Kusaie consisted of 1,189 natives, 25 Japanese, and a few whites. Most of the natives live in villages at the mouths of streams along the coast; most important settlements are on Lele Island, at the mission station of Mwot (Inshiappu), and at Lottin, Coquille, and Berard Harbors.

No public water supply systems are reported on Kusaie. In 1942 water supplies on Lele Island were obtained from a 950-gallon (40-ton) tank, storing rain water; from a fresh water well on north side of the island (used only for washing and bathing); and from the Innemu River above the influence of tidal water (water carried to Lele by boat). Elsewhere the water supplies were obtained from streams, springs, and rain water stored in small cisterns. A small dam and reservoir with a hydroelectric plant have been reported on a stream about 1,500 yards southwest of Lele Harbor (not confirmed from aerial photographs of January 1944). If present, this reservoir could also provide a water supply.

Water Resources

Surface Water: No lakes are present on Kusaie or the adjacent islands. The only perennial streams are on Kusaie. Streams are numerous in the mountains of Kusaie, but only a few of the larger ones flow across the coastal lowlands; the smaller streams lose their water by seepage at the inner edge of the lowlands. Most of the mountain streams are perennial, but owing to the heavy and frequent precipitation their flows fluctuate widely. Rivers with flows adequate to yield reliable water supplies to large troop units are the Okaato, Matante, Innemu, Fenkol, Utwa, and Berard. The smaller streams will not provide sufficient water for troops unless their flood water is stored in reservoirs. The surface water contains little dissolved mineral matter but, especially during floods, carries a heavy silt load and must be filtered and chlorinated for human consumption.

Ground Water: The narrow sandy beaches of Kusaie and the low offshore islands (Map Unit 1) are underlain by pervious materials which, at depth, contain salt water. A lens of fresh or brackish water floats on the salt water (See Diagram 1). On the smaller islands this lens is brackish, but on some of the larger ones it may be fairly fresh and would supply small quantities of water to shallow wells. In the mangrove swamps (Map Unit 2) fresh ground water will not be found.

The coastal lowlands and river valleys (Map Unit 3) are also underlain by pervious materials which contain salt water at depth with fresh water above the salt water. The fresh water zone is thin near the shore, but thickens inland and would probably provide considerable quantities of water to wells, especially in the larger river valleys.

The water table ranges from a few feet beneath the surface near the shore to about 80 feet near the mountains.

In the mountains (Map Unit 4), the ground-water table is generally deep, 200 to over 1,500 feet; in places bodies of ground water are held up by impermeable beds at lesser depths, and in a few places there is fresh water in the alluvium of stream valleys. However, no general predictions as to the location of these places can be made and all well sites in this area should be selected by a ground water geologist. No springs are reported on the island but they are probably numerous in the mountains. Yields of even the largest ones will probably not exceed 50 gallons per minute.

Other Sources: Adequate water for small troop units can be obtained by collecting and storing rainwater from tree trunks, roofs, and other surfaces. Green coconuts will provide emergency drinking water.

DEVELOPMENT OF WATER FACILITIES

Map Unit	Surface Water	Ground Water	Other Sources
1 Beaches of Kusaie and Coastal islands	On Lele Island small supplies obtainable by capturing and storing in cisterns or tanks the runoff from numerous small gullies of Mt. Fenkofuru. Elsewhere in Map Unit 1 there are no streams or lakes. In general, the surface water must be clarified and chlorinated before use.	Small amounts of water obtainable by digging pits or shallow wells as far as possible from the sea. Wells dug within 250 feet of the shore will yield brackish water. Maximum depth of these pits will be about 6 feet; should not be dug below sea level and should be pumped very lightly to minimize danger of salt-water contamination (See Diagram 2). The water willprobably be brackish on the smaller islands and possibly on some larger islands, but can be used for emergency supplies. It is best to pump only during low tide. Hand tools will suffice for digging pits or wells.	Adequate water for small troop units can be obtained by collecting rain water from tree trunks (See Diagram 3), roofs, and other surfaces and storing it in tanks. Green coconuts will provide emergency drinking water in many places. Water supplies for large troop units will probably have to be imported or distilled.
2 Mangrove swamps.	No potable surface water available.	No potable ground water obtainable.	Collection of rain water, importation of fresh water or distillation of sea water or swamp water (Map Unit 3) will be necessary.
3 Coastal lowlands; large river valleys.	Many streams which cross this area flow only after heavy rains. Others lose their water by seepage near base of mountains. A few streams including Utwa, Okaato, Matante, Fenkol, Innemu and Berard probably have a small perennial flow in this area and may afford supplies for moderately large troop units if reservoirs are constructed. Seepage losses would be heavy in this area and reservoirs would have to be lined with clay or other impermeable material. Intakes would have to be placed above the limit of high tide, about 2½ feet above mean tide in this area, and protected against frequent high water. Water slightly polluted and frequently muddy; should be clarified and chlorinated.	Ample supplies of ground water can be developed, probably with less trouble than surface water supplies. Most favorable sites in valleys of perennial streams; supplies also obtainable from interstream areas. Well sites should be as far as possible from sources of salt water contamination. The minimum distance from the shore or from the mangrove swamps whould be at least 500 feet, and if possible 1,000 feet. Near shore, water level is within 20 to 30 feet of surface and wells could be dug or drive points installed with little difficulty. In places farther inland, it is 80 feet below the surface, and drilling with rotary drills would be preferable. Wells will have to be curbed or cased to prevent caving and should be provided with screens or strainers in water bearing beds. Near shore, water can be pumped with centrifugal pumps. However, excessive pumping may draw salt water into well; can usually be made fresh again by ceasing pumping for 12 to 24 hours. Thereafter, the rate of pumping should be decreased. Salt water contamination may occur more than once, but after a few trials, the safe rate of pumping can be determined. Farther inland hi-lift pumps will be needed. Well water good quality except where salt-water contamination occurs, and probably could be used without treatment. Within a few hundred feet of the mountains, wells will probably enter basalt or possibly raised reef limestone, before water table is reached. Rotary drills equipped with rock bits, or percussion drills will be needed to penetrate these rocks and an adequate supply of spare bits should be provided. Screens and casing will not be necessary in the basalt or reef limestone.	Water supplies could also be piped from streams or springs in the mountains. Collection of rain water will provide emergency supplies; green coconuts plentiful near shore.
4 Mountainous Area[a]	Adequate supplies obtainable in most places from the numerous streams; generally in steep walled valleys. Plunge pools at the base of falls provide stored water on many non-perennial streams. These pools can be enlarged, generally with local materials and little labor. Sites for small dams numerous.	Springs probably numerous on lower slopes of mountains and in certain parts of interior. Most rather small and issue at contact between a permeable rock bed and an underlying impermeable bed. Quantities can usually be increased by concentrating the flow in one channel. Ditching or tunnelling at spring site are the most effective methods. Native trees will supply suitable logs for timbering and lining. The spring area should be fenced off to prevent contamination by surface drainage. Wells are likely to be difficult to construct because of underlying hard rocks. At some sites, water may be close to surface; generally it will be several hundred feet. Wells should not be considered as a source of water supply in this area unless they are absolutely necessary; if drilled, the sites should be selected by a competent ground water geologist.	

[a] Movement and concentration of large bodies of troops will be extremely difficult in this area because of the rugged terrain and the dense vegetation. In seems unlikely that large supplies of water will be required. However, in places it may be desirable to develop water supplies in the mountains for use in the adjacent lowlands.

(continued)

DIAGRAM 1. OCCURRENCE OF GROUND WATER ON A CORAL ISLAND.

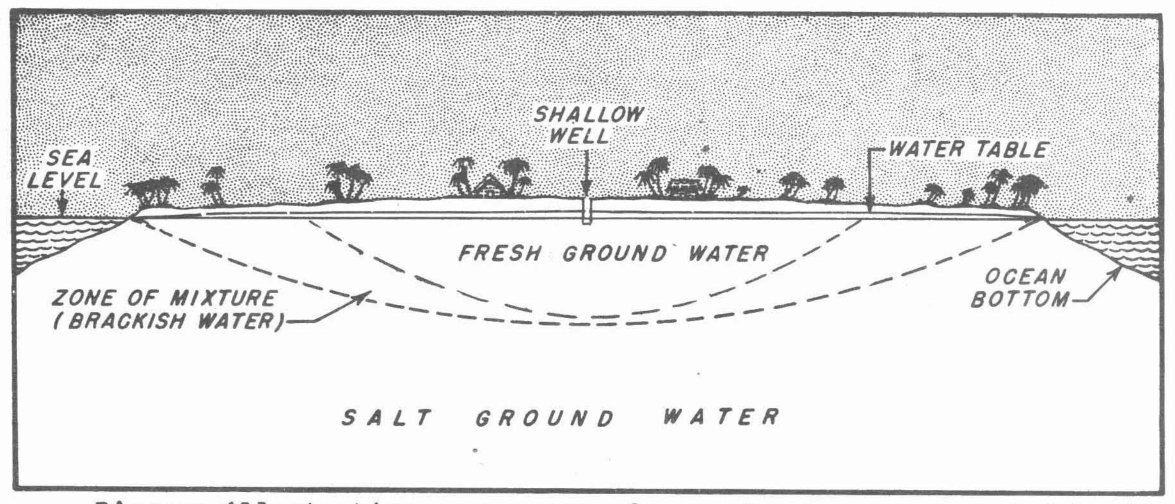


Diagram illustrating occurrence of ground water on a coral island. Fresh ground-water body, derived and replenished by downward percolation of local precipitation, "floats" in hydrostatic equilibrium upon salt water. Theoretically, fresh water should extend about 40 feet below sea level for each foot of fresh water above sea level. However, along contact fresh and salt water are mixed, chiefly because tidal fluctuations distu-b equilibrium, and the actual thickness of the fresh-water lens is always less than the theoretical thickness. The zone of mixture is thickest near the shore and thinnest in the center of the island. Wells should be located along axis of island and should not extend more than a foot below sea level. Pumping should be moderate because if water table is lowered more than 6 inches below sea level, salt water will enter well from below. Pumping only during low tide decreases possibility of contamination. Supply can be increased by using drainage galleries or several wells placed at intervals of 200 feet. On islands, less than one mile wide where tidal fluctuation is large, all ground water may lie within the zone of mixture and no fresh water will be available. The presence of consolidated corel sand or "beach rock" along the strand favors a thick, fresh ground-water body and a good water supply. Some vegetation, Taro plants, for example, indicates fresh or slightly brackish ground water; whereas others, such as mangroves and Nipa palms grow where ground water is brackish.

DIAGRAM 2. DEVELOPMENT OF WATER SUPPLIES IN COASTAL AREAS.

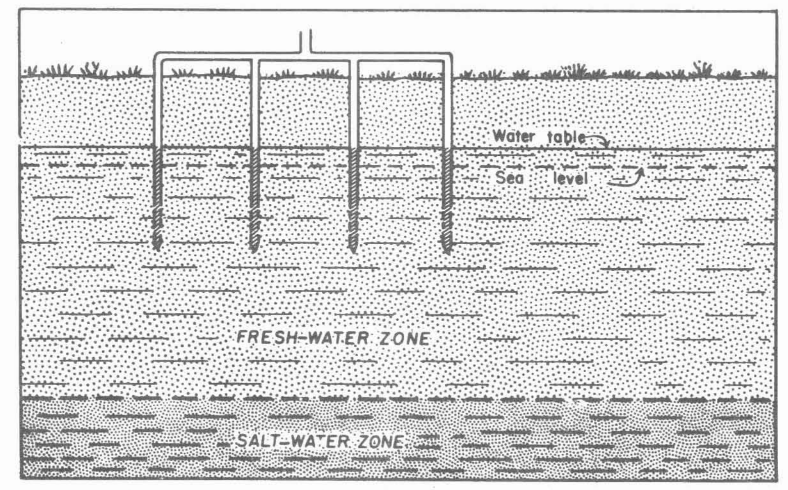


Figure A. Diagram showing relation of salt water and fresh water zones before pumping.

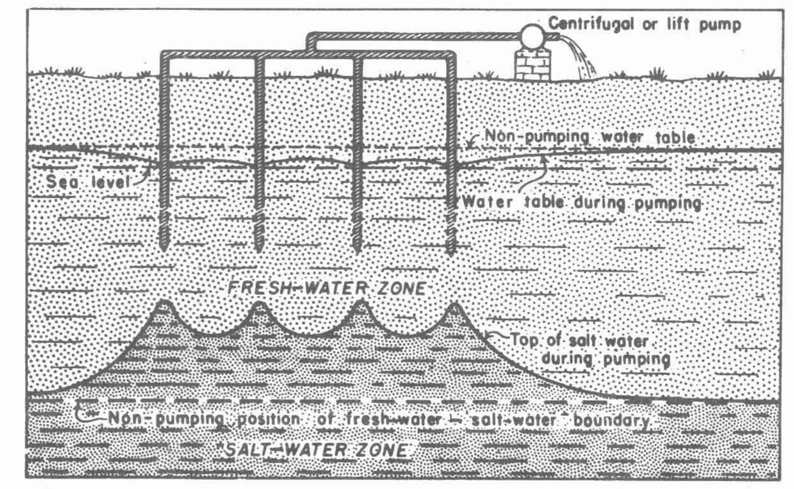


Figure B. Diagram showing relation of salt-water and fresh-water zones during pumping by sand point wells. Note that the rise of the salt water is many times the decline in the water table.

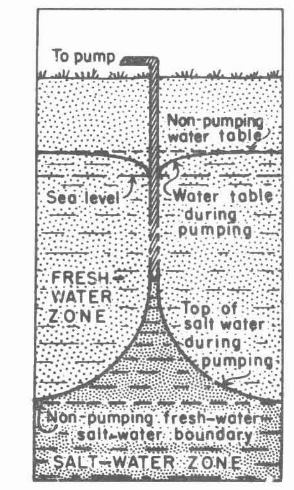


Figure C. Diagram showing how excessive pumping of wells may cause contamination by salt water.

EXPLANATION

In coastal areas where permeable material at sea level is thick, fresh water generally is encountered slightly above sea level and extends to a considerable depth below sea level. Shallow wells drilled in these areas obtain fresh water, but deep wells, even a considerable distance from the coast, obtain brackish or salty water. Furthermore, many wells that originally yielded fresh water begin to yield salty water after a period of pumping. In many coastal areas, however, large quantities of potable water are pumped from shallow wells and in many places this is the only source of potable water. Consequently, the occurrence of fresh water under these conditions has received much careful study.

The underground fresh water floats on salt water because of the difference in density. The thickness of the fresh-water zone is roughly a function of the height of the water table above mean sea level and the density of the sea water. In permeable materials, about 40 feet of fresh water lie below sea level for each foot of fresh water above sea level. Hence the thickness of the fresh-water zone may be roughly determined if the height of the water table above sea level is known. Also, if the water table is lowered the contact between the fresh water and the underlying salt water rises in the ratio of about 40 to 1, so if a well is pumped excessively salt water will enter the well and ruin it, perhaps permanently (see figure C). Therefore, in obtaining water supplies in coastal areas the water level should be lowered as little as possible by spreading the pumpage over a wide area. Where the fresh-water zone is relatively thick and pumping by suction is possible, widely spaced sand-point wells provide an effective and economical means of spreading the pumpage (see figures A and B). Where the zone of fresh water is thin, the fresh water can be skimmed off by infiltration galleries, as illustrated in figure D, or by sand points driven horizontally from the bottom of the shaft. Where the water table is close to the land surface, the fresh water can be collected from trenches. The diagrams are not to scale.

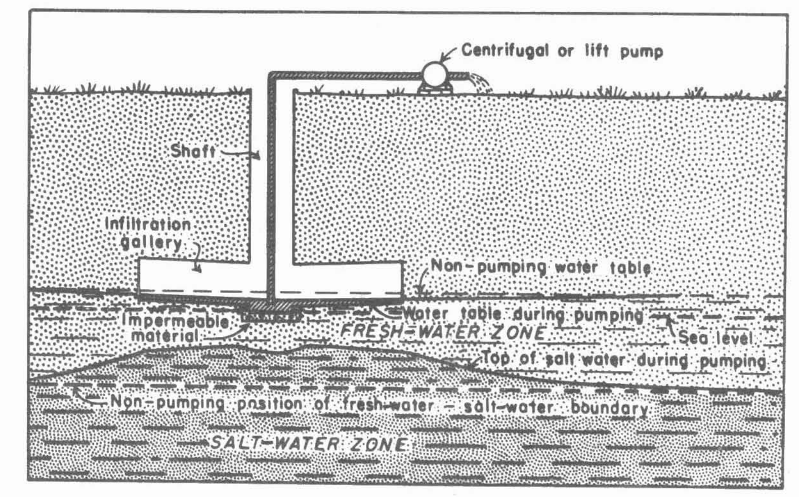
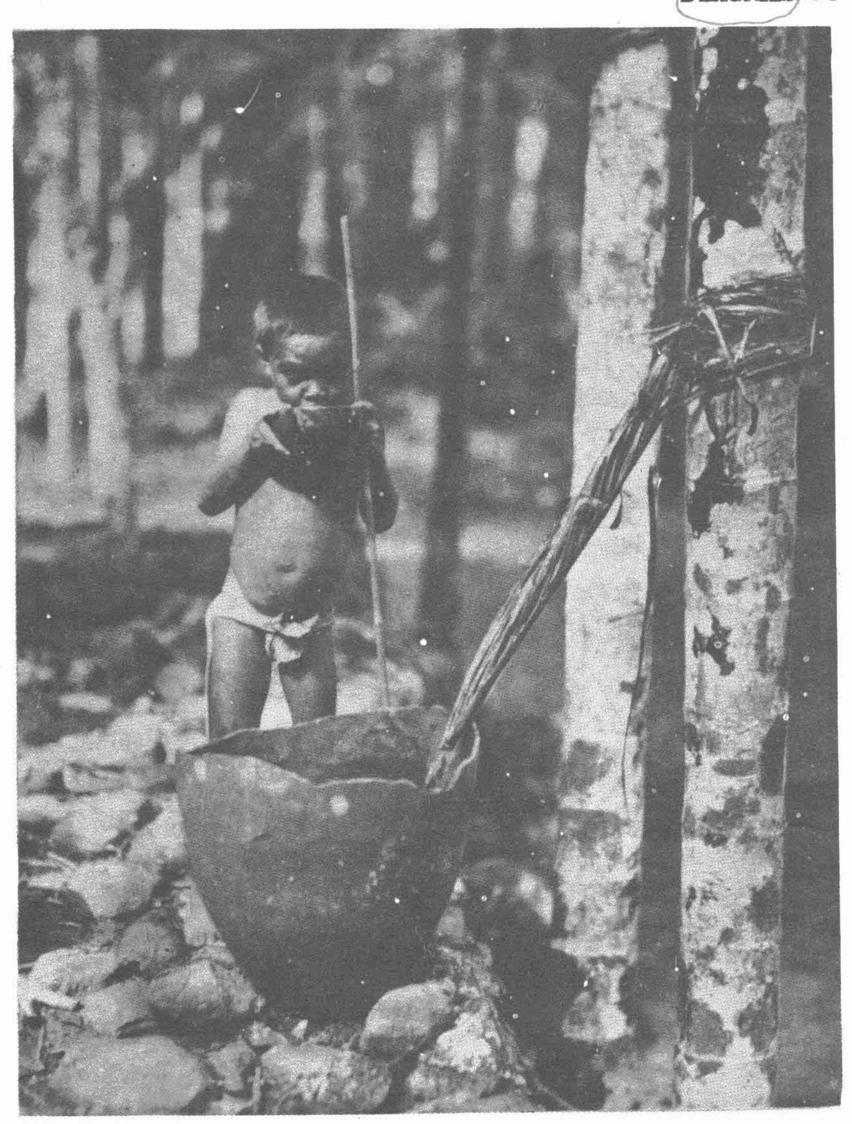


Figure D. Diagram showing infiltration galleries and relation of the salt-water and fresh-water zones during pumping. Note that the rise of the salt water is much less than when sand points are used. The shaft is sunk below the water table and galleries are driven from it. The floors of the galleries are inclined so the water can be collected in a central sump. The highest parts of the floors should be below the lowest level of the water table during the year, but the floors should not extend below sea-level. The sump may be below sea-level or even in the salt-water zone if lined with impervious material. In unconsolidated deposits or loose rock it is essential to provide adequate timbering or other support for walls and roof.

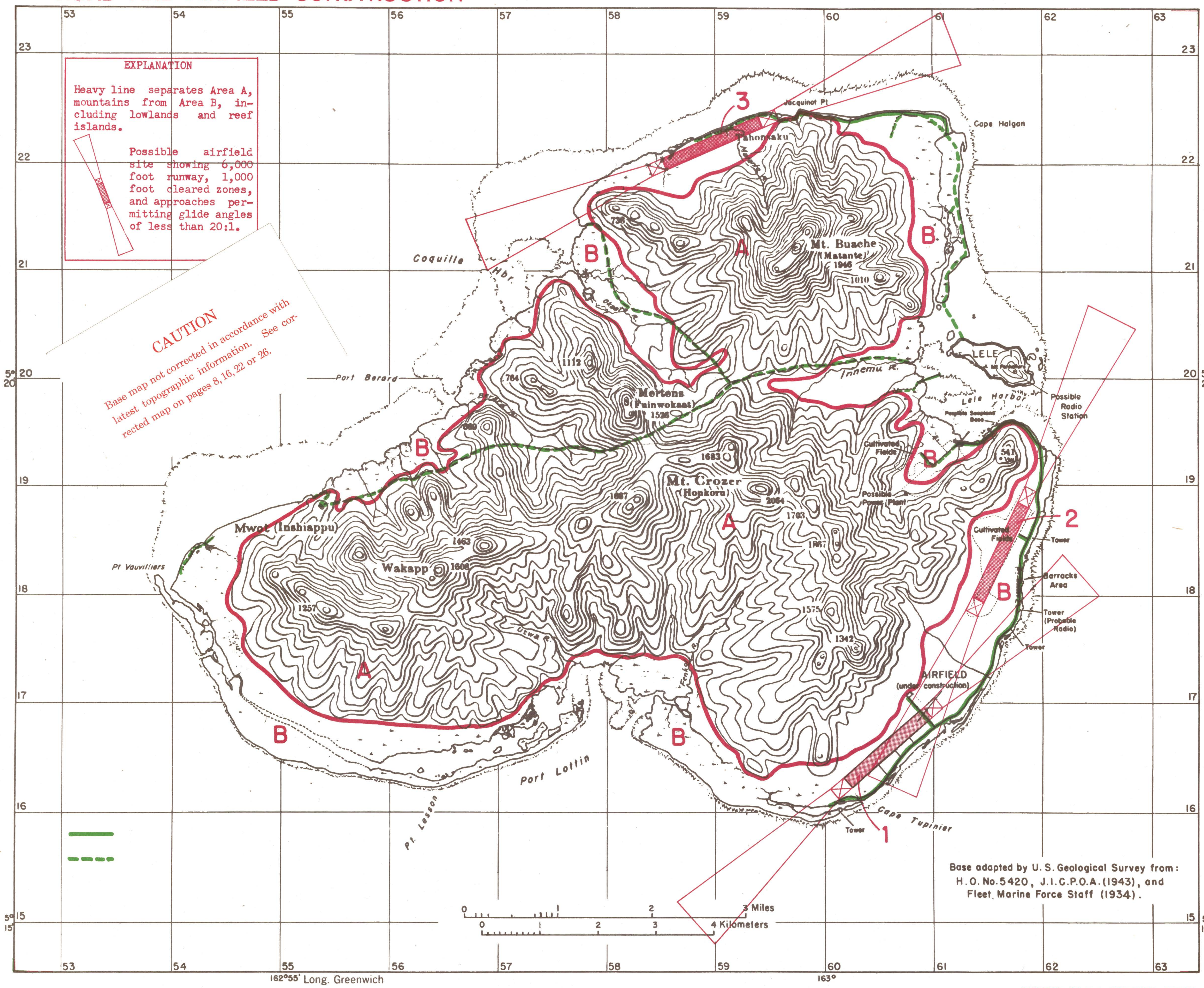
DIAGRAM 3. COLLECTING WATER FROM COCONUT TREES.



Rope, twisted grass or ropy vines can be used to intercept and lead rainwater to containers. Slanting trees will be most satisfactory. "Intercepting" rope should be tied around tree at the place where the tin spout is fastened in the picture at the right.

Prepared by U. S. Geological Survey for Chief of Engineers, U. S. Army.

ROAD AND AIRFIELD CONSTRUCTION



PREPARED BY U. S. GEOLOGICAL SURVEY FOR CHIEF OF ENGINEERS, U. S. ARMY

CONFIDENTIAL

Reliability rating: Class C

INTRODUCTION

The small, mountainous island of Kusaie consists of a rugged basaltic core surrounded by a narrow coastal lowland, with swamps, and coral reefs. Because of dense vegetation, and rugged topography of the island interior, communication between coastal settlements in recent years has been primarily by canoe. Old trails and routes of cross-island communication are reported to have been abandoned for many years. It is possible that recently trails may have been reconstructed. All routes of communication shown on the accompanying map have been taken from the map compiled by the Fleet Marine Force Staff, Quantico, Va. (1934) and compiled by J.I.C.P.O.A. Dec., 1943 from aerial photographs.

Possible airfield sites are located only on drained parts of the coastal lowland. Two good sites are on the east side of Kusaie. Airfield reported under construction (Oct. 22, 1943) on southeast coast, near Cape Tupinier (J.I.C.P.O.A. map) at site 1. Location of other airfield sites on map is inexact because of lack of complete information on terrain. Aerial photographs (1943) covering east, south and southwest coasts have been examined.

AREA A. MOUNTAINS

Topographic Setting

Most of the island is composed of rugged steep-sided mountains cut by numerous deep ravines and valleys. In the northeast part of the area, the small mountain group which culminates in Mt. Buache (1,946 feet in altitude) is nearly separated from the main mountain mass by the broad, deep Okaato-Innemu valleys and their relatively steep, narrow, headwater divide. Altitudes are generally between 1,000 and 1,600 feet; Mt. Crozer, in center of the island, reaches a maximum altitude of 2,064 feet.

Summits and ridge crests are sharp and commonly rocky. Slopes are steep, generally up to 100%; some are almost vertical.

Engineering Problems

Clearing: Area covered largely by tropical rain forest. Large trees can be removed by blasting and grubbing. Dense tangles of vines and smaller trees probably can be cleared by bulldozers.

Subgrades and Excavations: Clay loam or clay soil (commonly A-4) compacts into hard surface at optimum moisture content but during long or heavy rains rapidly forms deep slippery mud in roads and excavations. Addition of coarse gravel or aggregate needed for satisfactory mechanical or cement-stabilized surfaces. Although depth of soil is highly variable, may be 15 to 30 feet on moderate slopes. Hill side cuts are mostly in soil or soft weathered rock. Steep slopes are subject to landslides and slumping where disturbed by excavation. Drilling and blasting required for rock cuts where sound rock crops out or is near surface, as on ridge crests, very steep upper slopes, some valley bottoms and a few coastal promontories. Unweathered rock provides good bridge footings.

Materials Available: Unweathered basalt forms good crushed aggregate for base course or surfacing; rock commonly tough and hard to crush. Quarry faces can be readily established on rocky points and some steep valley walls; elsewhere overburden of soil and weathered rock is thick. In zones of weathered rock most material is unsuitable for surfacing. Gravel and boulders in stream bottoms are possible source of surfacing material. Trees furnishing good timber for bridges, culverts and other structures are found throughout the mountains of Kusaie but lack of roads and trails makes best supplies difficult to obtain. Streams and heavy rainfall furnish adequate water for all purposes.

Roads

Existing Roads and Trails: Old foot trail crossing the saddle of the Okaato-Innemu depression south of Mt. Buache was abandoned about 1880; Japanese may have reestablished it. Trail follows best alignment for cross-island road. Foot path existed at one time from Port Lottin across mountains to Lele Harbor. Route was never important and was abandoned many years before the Okaato-Innemu trail.

Alignments and Grades: Road alignments will entail numerous sharp curves with very short tangents; some hairpin turns. Deep hillside cuts commonly needed; some partly in solid rock. Grades would be moderate to steep in nearly all parts of mountains.

Streams and Crossings: Short swift streams are numerous; cascades and waterfalls are common. Streams are commonly 3 to 5 feet deep; subject to frequent floods. Most cannot be forded by wheeled vehicles; trestle bridges can be used. Numerous short bridges and culverts required to cross minor ravines and gullies. Steep narrow valleys, and rocky gorges in which stream channels commonly fill entire width of valley floor, make approaches difficult. Rock is commonly exposed on sharp jagged crests; less commonly in deep valley bottoms and in a few craggy promontories along the coast.

Airfields

No sites in Area A.

AREA B. LOWLANDS AND REEF ISLANDS

Topographic Setting

Kusaie is almost completely bordered by a narrow coastal lowland; the mountain spurs (Area A) reach the coast in only a few places. The lowland is generally only a a few hundred yards wide although it attains a maximum width of about ¾ mile in a few places. On the east and north, the lowland consists chiefly of flat alluvial plains. Mangrove swamps line the west side of Lele Harbor and extend from north side of the harbor nearly to Cape Halgan inland from a slightly higher belt of sandy lowland. Mangrove flats also dominate parts of the lowland on the west coast. The fringing reef borders most of Kusaie; the small islands that rise above are low sandy mounds. South of Kusaie, inland margins of the islands have broad mangrove flats which commonly extend almost to the Kusaie swamps.

Engineering Problems

Clearing Problems: Dense jungle on inland margin of lowland must be cleared. Stumps of large trees probably require blasting but are not deeply set; small trees and undergrowth can be cleared by bulldozers. Groves of coconut palms with little undergrowth cover most of the better drained, slightly higher parts of the lowland and the fringing islands; can be cleared by bulldozers. Mangrove swamps occupy poorly drained parts of lowland; soft marshy ground probably will not support bulldozers and other clearing equipment. Large cultivated tracts on east side present no clearing problems.

Subgrades and Excavations: Gravelly loam and friable stony clay loam (A-2, A-4, locally A-3) covering better drained parts of lowland has variable texture; commonly medium to coarse; under compaction forms stable subgrade. Coarse gravel in stream channels near inland margin of lowland. Soil suitable for cement stabilization. Ground is generally well-drained. Near coast ground water-table is locally close to surface; in rainy season, high ground water level may necessitate raised subgrades for roads and airfields. Drainage ditches and subdrains needed to carry heavy runoff. Culverts must be provided under roads and runways crossed by shallow gullies. Photographs of airfield site under construction by Japanese (1943) show close network of drainage channels. Alluvial silt loam and silty clay loam (A-5, A-7) in valley bottoms of large streams need addition of coarse fraction for stabilization.

Sandy islands on reefs provide good natural foundations. Unstable water-logged mud of mangrove flats is unsuitable for roads without addition of coarse aggregate and construction of high subgrades; corduroy roads may locally serve as expedients.

The east end of Lele island is underlain by basalt covered to a depth of 10 to 25 feet by clay loam or clay soil. West end has sandy loam or clay loam soil. Ground at western end of Lele is generally more stable and less slippery than clay soil of the rugged eastern end.

Materials Available: Coarse gravels and rock fragments for surfacing and aggregate can be obtained locally from stream channels near inland margins of the lowland; may require screening. Coarse coral sand from sand islands off shore is good material for surfacing; develops high percent of fines under heavy traffic. Blocks of coral limestone can be crushed for aggregate or can be used for rough masonry. Basalt available on Lele Island is good material for aggregate and building stone; when unweathered is tough and hard to work. Good timber can be obtained from inland margin of plain on north and west side of Kusaie. Coconut palm has soft wood which can be used only for very light construction.

Roads

Existing Roads and Trails: On Kusaie Island, good road 5 miles long and 20 feet wide extends from Lele Harbor south along the east coast to Cape Tupinier; probably suitable for military traffic. Japanese may have recently extended this road to south coast. A secondary road 2½ miles long and 8 feet wide extends along the north coast between Tahonsaku and Cape Halgan.

A few short trails and cart roads to villages and cultivated fields on the west and southwest sides of Lele Harbor, near the landing field at Cape Tupinier, and at a few other scattered points on Kusaie. A foot trail extends south from Cape Halgan to northwest corner of Lele Island; the last 700 yards crosses reefs between Lele and Kusaie and can be used only at low tide. Old foot trail following Okaato and Innemu Valleys offers best alignment for cross island road.

On Lele Island an 8-foot road in good condition parallels the coast encircling the entire island; partly surfaced by stone blocks. Several poor short roads cross island.

Alignments and Grades: Road alignments on well-drained parts of Kusaie lowland permit open curves and fairly long tangents. Where mangrove swamps occupy all or most of the lowland, as in south and west, alignments giving fewest construction problems are restricted to narrow belts of higher, better-drained ground. Cross island road could follow lower slopes of Okaato and Innemu Valleys.

Streams and Crossings: Numerous small sluggish streams cross the lowland. Most are shallow, only a few feet deep and can be easily forded; subject to rapid rises in level during sudden hard rains. The largest rivers are the Innemu, Okaato, Berard, the Utwa, the Fenkol and the Matante. The first two may be unfordable by wheeled vehicles during most of the year; easily crossed by temporary bridges. Except in southeast Kusaie, bordering mangrove and hibiscus swamps are serious obstacles to crossings. Elsewhere approaches are generally easy although stream banks are locally matted with vegetation.

Possible Airfield Site 1

Alignments and Grades: Site is on coastal lowland on the southeast side of Kusaie. Japanese airfield aligned NE. under construction in 1943 at Site 1 is 5,700 feet long and 750 feet wide. Can be extended at least 1,000 feet to NE.; mangrove swamps are an obstacle to more construction to the south. Abundant space for taxiways and dispersal bays.

Approaches: Approaches clear. Steep mountain slopes a few hundred feet to 0.5 mile northwest of site are possible hazards.

Accessibility: Good road from Lele Harbor to south end of site. Coast near site poor for landings.

Rating: Good.

Water Supply: Surface Water. Water sufficient to supply all requirements is probably available from small mountain streams if their combined runoff is utilized. Discharge will fluctuate in response to precipitation, and carry-over reservoirs may be required to assure a reliable supply between high-water flows. If pipe is available, gravity supply is possible. Water is low in mineral content, but silt load is probably high, and dissolved and suspended vegetable matter is present. Filtration and chlorination will be necessary.

Water Supply: Ground Water. Water in sufficient quantity for all needs is available at depths of less than 100 feet. Wells should be located on the plain about 1/5 the distance from the beach to foot of mountains. Moderately high yields without a large draw-down may be expected. Wells will be in alluvium or limestone. Quality of water is good, but danger exists of salt water invasion in wells drilled near seaward margin of coastal plain.

Possible Airfield Site 2

Alignments and Grades: Site 2, situated between Site 1 and Lele Harbor, is suitable for one or possible two runways oriented NNE. to northeast. Ground is flat or gently undulating; crossed by a few shallow gullies and small drainage canals. Space for hard standings and taxiways is abundant. Grades less than 2%. Altitudes between 20 and 50 feet.

Approaches: Approaches are clear. Steep hills rising to altitudes of 500 to 700 feet within ¾ mile from northwest side of site are possible hazards.

Accessibility: Near good road extending south from Lela Harbor.

Rating: Good.

Water Supply: Similer to Site 1.

Possible Airfield Site

Alignments and Grades: Coastal plain is suitable for runway oriented northeast. Ground flat or gently undulating; grades less than 1 1/2%. Channel of the Matante River cutting across east side of site is most serious objection to site; probably can be diverted or carried under site in culvert to permit construction of 6,000-foot runway.

Approaches: Ridge at northeast corner of site is 100 to 300 feet in altitude and is possible minor hazard. Steep ridge rises to 600 to 750 feet in altitude about 0.5 mile southwest of the site. Steep slopes of Mt. Buache near the southeast side are possible hazards.

Accessibility: Accessible by road and trail or canoe from Lele Harbor, the nearest good port.

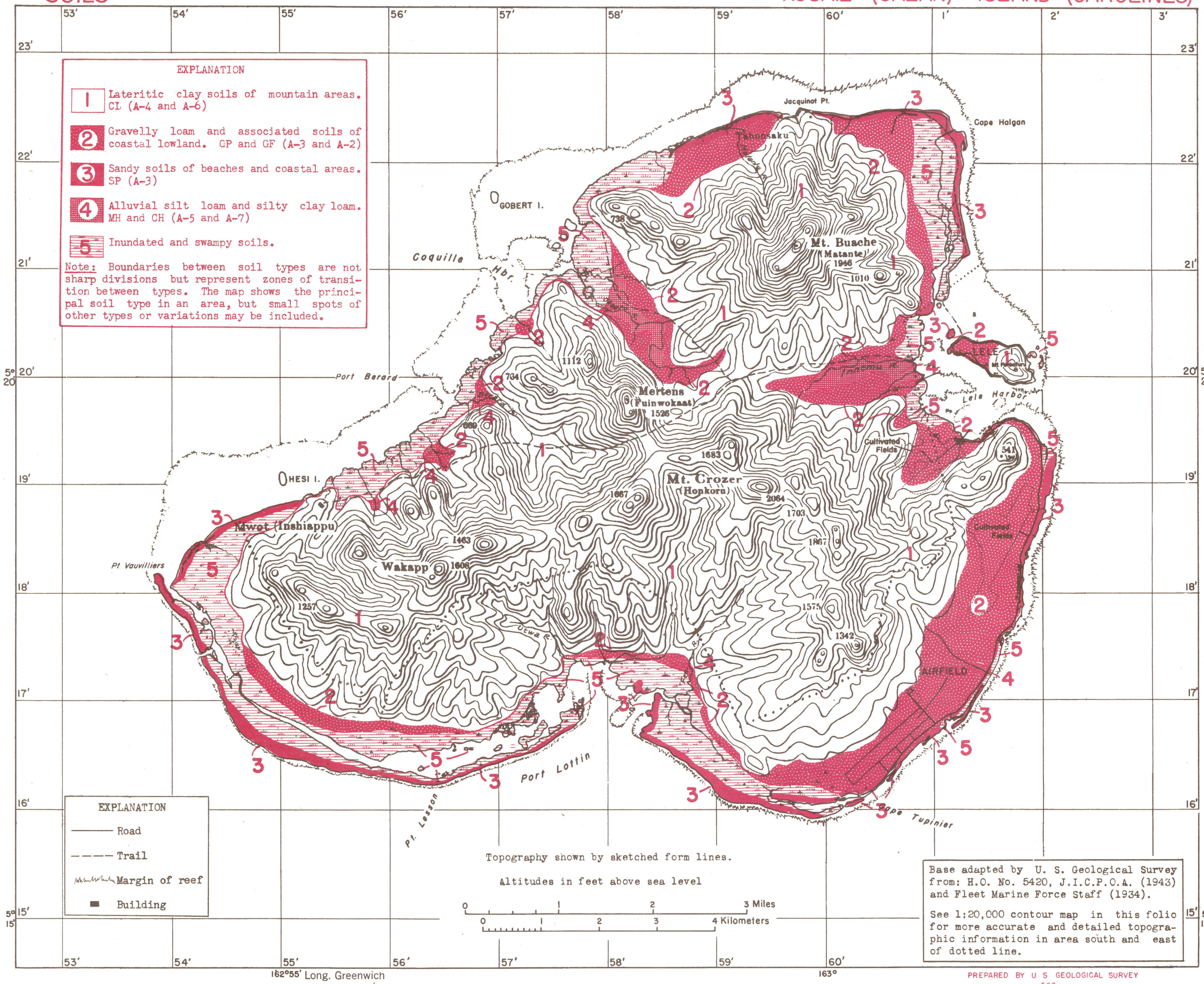
Rating: Fair.

Water Supply: Similar to Site 1 except that Matante River will probably supply all the water needed from surface sources.

Prepared by U. S. Geological Survey
for Chief of Engineers, U. S. Army.

SOILS

KUSAIE (UALAN) ISLAND (CAROLINES)



PREPARED BY U. S. GEOLOGICAL SURVEY FOR CHIEF OF ENGINEERS, U. S. ARMY

Reliability rating: C.

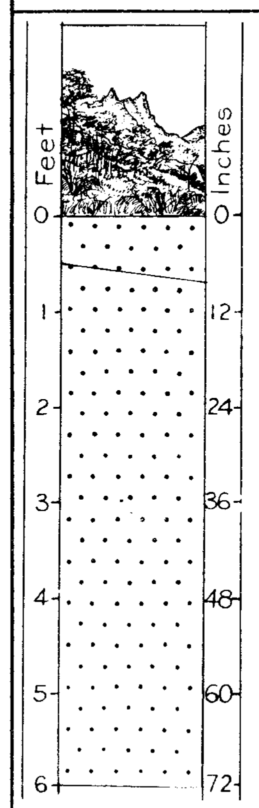
Introduction

The soils map and table were compiled from very brief descriptions of the soils on Kusaie and interpretations based on geologic data and knowledge of soil development under similar conditions elsewhere.

The climate of Kusaie is characterized by high temperature and very high, uniformly-distributed rainfall. The dominant soil-forming process is laterization and the major part of the area is covered by fine-textured red and brownish-red lateritic soils. Some true laterites may be found, particularly on flat areas of intermediate elevation. Near the coast, soils of coarser texture are present and there are also extensive areas of swamp and some silt loam and silty clay loam alluvial soils. A feature of the soil material on this island is the complete absence of primary quartz.

Tropical clay soils have some outstanding properties due to their chemical composition. Tropical weathering produces a clay which is high in iron and aluminum oxides and low in silica. Such clay has a very stable granular structure and is not easily dispersed even when very wet. Water absorption is high and water penetrates into the soil very rapidly. Such soils are often deficient in available water for plants in spite of the heavy rainfall; from the physical or engineering standpoint this behavior toward moisture is favorable, for it means that such soils may be worked or traversed soon after rain.

Soil Type 1



Lateritic clay soils of mountain areas.

0 to (6-8)": Brownish red and red fine granular clay; some concretions. In places may be overlain by thin layer of moss and humus.
(6-8)" and below. Red and brick-red clay containing abundant iron concretions. Becomes lighter with depth grading into yellowish clay, in places mottled dark red and white, with rock fragments. Depth to solid rock very variable; may be 50 feet in places, but average is probably 8 to 15 feet.

Parent Material: Olivine or nepheline basalt, fine grained, in places porous, slaggy.

Relief: Steep slopes, roughly conical mountains. Altitude range 150 to 2,000 feet. Very much dissected; gorges and spurs.

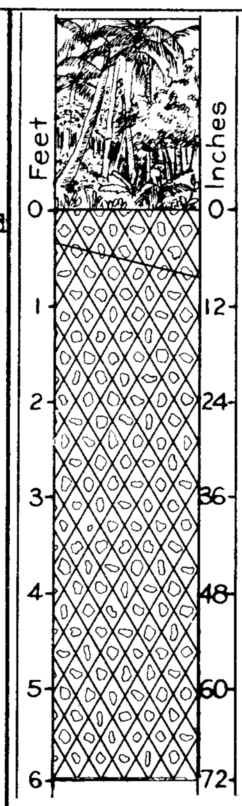
Vegetation: Dense rain forest; contains fewer species than mainland types. More open in areas bordering coastal plains. Grass and scrub growths at highest altitudes.

Physical properties: Well aggregated and stable. Water absorption and water penetration high. Fairly friable. Plasticity and cohesion low for its texture. In some flat areas, may be somewhat indurated.

Chemical properties: High in iron, low in bases; contains some organic matter, particularly at higher altitudes. Fertility low to moderate, depending on depth and organic-matter content. Acid reaction.

Engineering properties: CL (A-4 and A-6) Plasticity low. Has properties like the A-4 soils because of the stable structure. Bearing power poor to fair, somewhat elastic. Compactability relatively easy with careful moisture control. Permeability high, water retention high. Low in aggregate except for concretions and rock in deeper layers. Slippery when wet, but dries rapidly. In flat areas may have less favorable properties due to the possibility of impeded drainage.

Soil Type 2



Gravelly loam and associated soils of coastal lowland.

0 to (4-8)": Brown to brownish-red gravelly loam to silty clay loam with some humus.
(4-8)" and below: Yellow to brownish-red gravelly loam to silt loam. Texture depends on width of plain and distance from steep mountain areas. Becomes lighter in color and somewhat coarser with depth.

Parent material: Largely alluvial material eroded from basaltic upland. Quite gravelly inland with increasing amounts of finer material toward the coast, especially on wider areas. Some coral limestone material may be present near the coast.

Relief: Generally gently rolling.

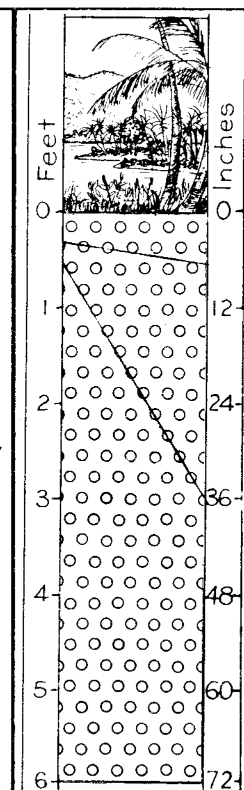
Vegetation: Largely various kinds of palms and associated species. Much of agricultural area of islands is of this type.

Physical properties: Generally well-drained and permeable; low plasticity and cohesion and fairly low water-holding capacity. Fine-textured varieties near the coast drain somewhat less rapidly and are more plastic and cohesive and have a greater water-holding capacity. Some of the area may be too flat or too close to the water table for good drainage.

Chemical properties: Fertility fairly good, especially where texture is finer.

Engineering properties: Varies from gravel with no fines, GP (A-3), near the base of mountains, to silty clay loam ML (A-4). Most of area is gravel with large amount of fines GF (A-2). In general compacts readily to fair wearing surface or excellent subgrade. Some local areas high in gravel near the inland slopes may serve as source of aggregate.

Soil Type 3



Sandy soils of beaches and coastal areas.

0 to (4-6)": Light brown to white or grayish sand with some volcanic and coral fragments and a little organic matter.
(4-6)" to (6-36)": Yellow to white or grayish sand with some darker gravel of volcanic rocks.
(6-36)" and below: Yellowish sand, more or less cemented with lime.

Parent material: Largely coral sand and coral fragments, mixed with more or less volcanic material.

Relief: Gentle slope from sea level to altitude of about 6 feet.

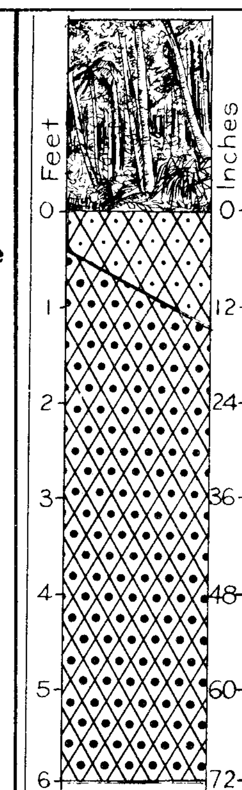
Vegetation: Largely coconut palms; some other tree species and grass.

Physical properties: Sand texture, fairly coarse; more or less volcanic and coral gravel. Good aeration and permeability; no plasticity or cohesion.

Chemical properties: Fertility very low unless amount of volcanic material is high.

Engineering properties: SP (A-3). Sand with small amount of fines. Permeable, low water-holding capacity. Easily compacted. Fair wearing surface, good subgrade. Some coarse aggregate. Some areas are rough and covered with blocks of coral rock cast up by waves.

Soil Type 4



Alluvial silt loam and silty clay loam.

0 to (5-15)": Dark brown to black silt loam or clay loam; fine crumb structure.
(5-15)" and below: Dark gray to gray silt loam. May be stratified.

Parent material: Silt, clay, and some fine sand deposited by rivers on flood plains. May include areas of rather high humus content.

Relief: Very slight. Altitude ranges from 5 to 25 feet. Largely swampy.

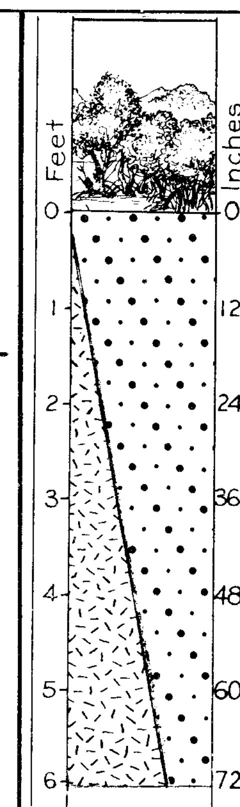
Vegetation: Swamp vegetation, very dense.

Physical properties: Poorly drained. Aeration and permeability low. Moderate to high plasticity and cohesion.

Chemical properties: Fertility and organic matter content high. Slightly acid reaction.

Engineering properties: Soil predominantly silt, MH (A-5); some CH (A-7). Poorly drained, very elastic. Sticky, slippery, and soft through a wide moisture range. May include peat or muck, OH (A-8).

Soil Type 5



Inundated and swampy soils.

Coastal swamps entirely or intermittently flooded. Grayish or dark brown to black silt and clay, generally high in organic matter. Unconsolidated material may be very shallow or lacking and the trees rooted directly on the reef rock. Vegetation is mostly mangrove but other swamp forms are present.

EXPLANATION OF PATTERNS USED IN SOIL DIAGRAMS

LOAM GRAVEL SAND SILT CLAY CORAL ROCK

Prepared by U. S. Geological Survey for Chief of Engineers, U. S. Army.

Reliability rating: Class C.

Introduction

The engineering properties of soils are dependent primarily upon their texture; so this was the chief factor considered in estimating the engineering properties given in this table. Soil structure, topography and moisture relationships were also taken into account. In using these data it should be kept in mind that the figures are estimates. Allowances have been made for the distinctive properties of tropical clays. The values given are based on the material passing a 2 mm seive. Therefore the figures for soils containing gravel will be too low for the following properties: original field dry weight, dry weight after construction treatment, and bearing ratio, and too high for moisture retention and void ratio.

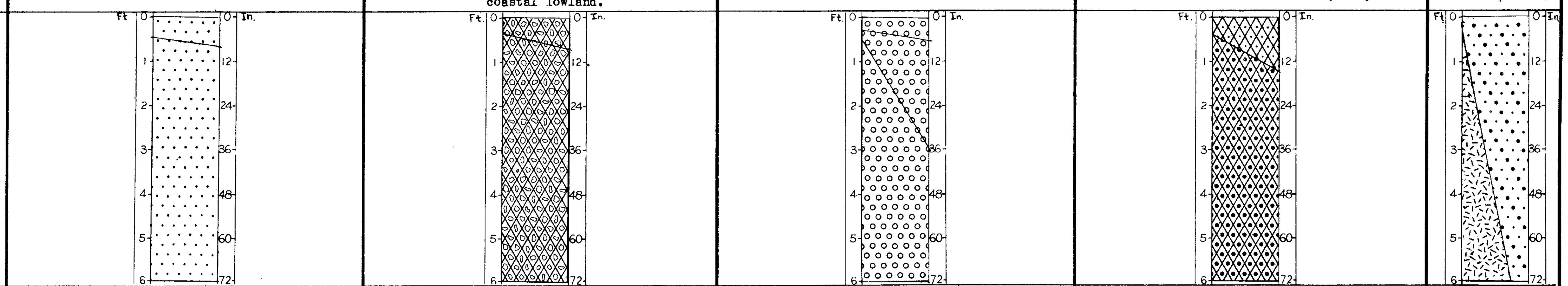
Void ratio represents the ratio of void space to volume of solid and is calculated from the original field-dry weight by the formula $\frac{1-V}{V}$ where V is volume of solid in a cubic foot of soil. The specific gravity of the solid material is assumed to be 2.65.

Moisture retention as percentage of oven-dry weight is the amount of water a soil in place will retain against gravity when thoroughly wetted and allowed to drain freely. It is the same as field capacity and close to the moisture equivalent. The magnitude depends chiefly upon the particle size distribution, pore size distribution, and organic matter content of the soil. In general, moisture retention is a function of the clay content of soils, varying from low in sandy soils to high in clay soils. Experiments have shown that roughly 5% moisture is retained in soils composed wholly of sand, 25% in silt soils, and 60% in soils composed entirely of clay. Soils of different texture when wetted to their respective moisture-retention capacities show many similarities in their physical behavior regardless of the actual percentages of water present. On the other hand, when two equal weights each of sand and clay are brought to the same water content by adding equal weights of water to each, the sand may show all the properties of a "wet" soil while the clay may remain relatively "dry" in appearance and behavior.

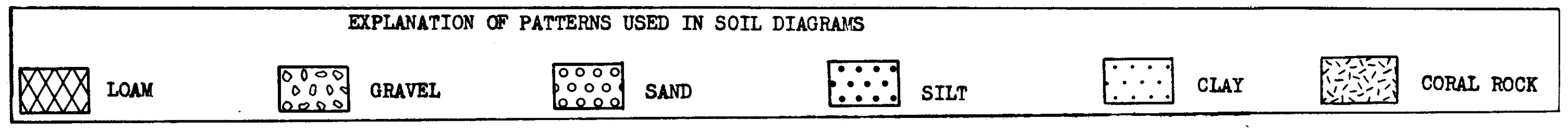
All soils containing much clay become more or less plastic when moistened sufficiently and if worked with implements in the wet state tend to compact. The so-called plastic clays become conspicuously sticky and plastic and in this state lose pore space and compact very readily. The friable clays, are much less plastic or sticky in their behavior and do not lose their pore space so readily when worked. These friable clays have a higher content of iron and aluminum and are commonly found in the humid tropics. The presence of such clay has a strong effect on the behavior of soils in construction practice.

The moisture data are also expressed as inches of water per foot of soil. In addition to giving a means of judging the proportion of fine material and pore space these moisture estimates enable the engineer to determine (1) the amount of water in a well-drained soil within one or two days after a deep-penetrating rain, and (2) the moisture content below which the soil cannot be uniformly wetted throughout by the addition of more water. That is, if the water-retention capacity is 3 inches per foot and the soil is to be uniformly wetted to a depth of two feet, at least six inches of water must be added to dry soil to accomplish this. The addition of only three inches of water would wet the top foot, but the water would penetrate no farther. The amount of water in air dry soil may also be estimated, for at an air humidity of 50% the water content of soil is one-fourth to one-fifth the moisture retention capacity.

The properties after construction treatment, or compaction, are obtained from Technical Manual 5-255. The terms have the same meaning as before except that they apply to optimum compaction conditions. Bearing ratio represents the load-supporting power of the soil in comparison with that of crushed rock.

Soil type (Map unit no.)			1. Lateritic clay soils.		2. Gravelly loam and associated soils of coastal lowland.		3. Sandy soils of beaches and coastal areas.			4. Alluvial silt loam and silty clay loam.		5. Swamp soil.
Soil profile												
Depth, in inches			0 to (6-8)"	(6-8)" and below	0 to (4-8)"	(4-8)" and below	0 to (4-6)"	(4-6) to (6-36)"	(6-36)" and below	0 to (5-15)"	(5-15)" and below	
Engineering name and group symbol[a]			Clay of low plasticity CL (A-4)	Clay of low plasticity CL (A-4, A-6)	Gravel and fines GF (A-2)	Gravel and fines GF (A-2)	Sand, small amts. gravel SP (A-3)	Sand, small amts. gravel SP (A-3)	Same as upper layers, cemented SP (A-3)	Organic silt and clay MH, CH (A-5, A-7)	Silt and clay MH, CH (A-5 to A-7)	Silt and clay, in places organic CH, MH, OH (A-7), (A-5), (A-8)
Properties before construction treatment	Cohesion in dry state		Low to medium	Medium	None to medium	None to medium	None	None	None	High	High	
	Foundation value		Poor to fair	Fair	Good	Good	Fair to good	Fair to good	Good	Very poor	Very poor	
	Expansion and shrinkage		Medium	Medium	None	Very low	None	None	None	High	High	
	Permeability		Fair to good	Poor to fair	Very good	Good	Good	Good	May be poor	Very poor	Very poor	
	Original field dry weight, lbs/ft^3		65-80	65-90	70-90	75-100	80-100	85-110	100-130	50-70	50-70	
	Original void ratio		1.2-1.4	1.0-1.4	.82-1.4	.65-1.3	.65-1.2	.45-.95	.3-.65	1.4-2.3	1.4-2.4	
	Moisture retention after free drainage at original field dry wt.	%	25-35	25-35	9-18	9-18	4-6	4-6	5-	25-35	20-30	
		ins/ft	3.5-5.5	3.5-6.0	1.2-3.4	1.4-3.6	0.6-1.2	.6-1.0	1.0-	2.5-5.0	2.0-4.2	
Properties dependent upon construction treatment	Dry weight, lbs/ft^3		100-120	100-120	115-130	115-130	110-125	110-125	110-130	100-	100-	
	Void ratio		.4-.7	.4-.7	.3-.45	.3-.45	.3-.5	.3-.5	.25-.5	.6+	.6+	
	Moisture content	%	13-16	13-16	9-14	9-14	11-17	11-17	9-17	22+	22+	
		ins/ft	2.4-3	2.4-3	2.0-3.4	2.0-3.4	2.5-3.5	2.5-3.5	2.0-3.5	4-	4-	
	Bearing ratio		6-15	4-15	25-60	20-60	10-25	10-25	15-30	3-8	3-8	
Suitability for construction			Kind of aggregate and binder: Generally low in aggregate. That present consists of very hard iron concretions, bean-sized or larger. In some places these may be concentrated due to erosion of finer material. Rock fragments may be found in the shallower soils. Binder is ferruginous clay of low plasticity. Mechanical stabilization: May be rather difficult to stabilize. Sheepsfoot roller with careful moisture control would give best results. Because of high rainfall, maintenance under wheel or heavy foot traffic will probably require addition of sand of gravel to the surface; in some places drainage necessary. Suitability for subgrade or base course: If adequately provided with drainage and properly compacted might make fair but somewhat elastic subgrade. Should have a surface layer of sand and gravel added for best results. Suitability for stabilization with bitumen or portland cement: Too high in clay for use with cements.		Kind of aggregate and binder: Aggregate consists of volcanic and some coral rock fragments and a little sand. Some of the volcanic fragments may be soft and partly decomposed but the limestone is hard and firm. Binder variable in amount; consists of moderately plastic to friable clay. Gravel accumulations may be present at the inland edge of the area and silty clay areas near the coast. Mechanical stabilization: Can be readily compacted with tractors or rollers; sheepsfoot rollers desirable in areas of finer texture. Moisture control not difficult, though some sections may require drainage, because of topography. When well drained should have good bearing power, fair wearing surface. Suitability for subgrade or base course: Generally highly suitable for subgrade and base course, if drainage is provided when necessary. Suitability for stabilization with bitumen or portland cement: Generally fairly well suited; may be necessary to add some sand in areas of fine texture.		Kind of aggregate and binder: Aggregate is largely coral sand with some limestone and volcanic rock fragments. Larger fragments are angular, but sand is rather coarse and rounded. Low in binder. In areas near mangrove swamps, may grade into finer-textured type. Mechanical stabilization: Can be compacted easily but too poorly graded and too low in binder to be adequately stabilized. Suitability for subgrade or base course: Fairly well suited for either, though addition of some gravel and binder is generally desirable. Suitability for stabilization with bitumen or portland cement: Fairly suitable, but could be improved by addition of some gravel.			Kind of aggregate and binder: No aggregate present, except minor amounts of fine sand. Binder consists of plastic silt and clay; fairly high in organic matter. Mechanical stabilization: Difficult to stabilize. Would require drainage and addition of aggregate. Suitability for subgrade or base course: Very poor for both. If necessary might be used for subgrade if thick layer of gravel and sand is laid over surface. Suitability for stabilization with bitumen or portland cement: Not suitable. Too low in aggregate and organic-matter content is probably too high.		A swamp type of soil, wholly or partly under water; unsuited for any type of engineering use.

EXPLANATION OF PATTERNS USED IN SOIL DIAGRAMS

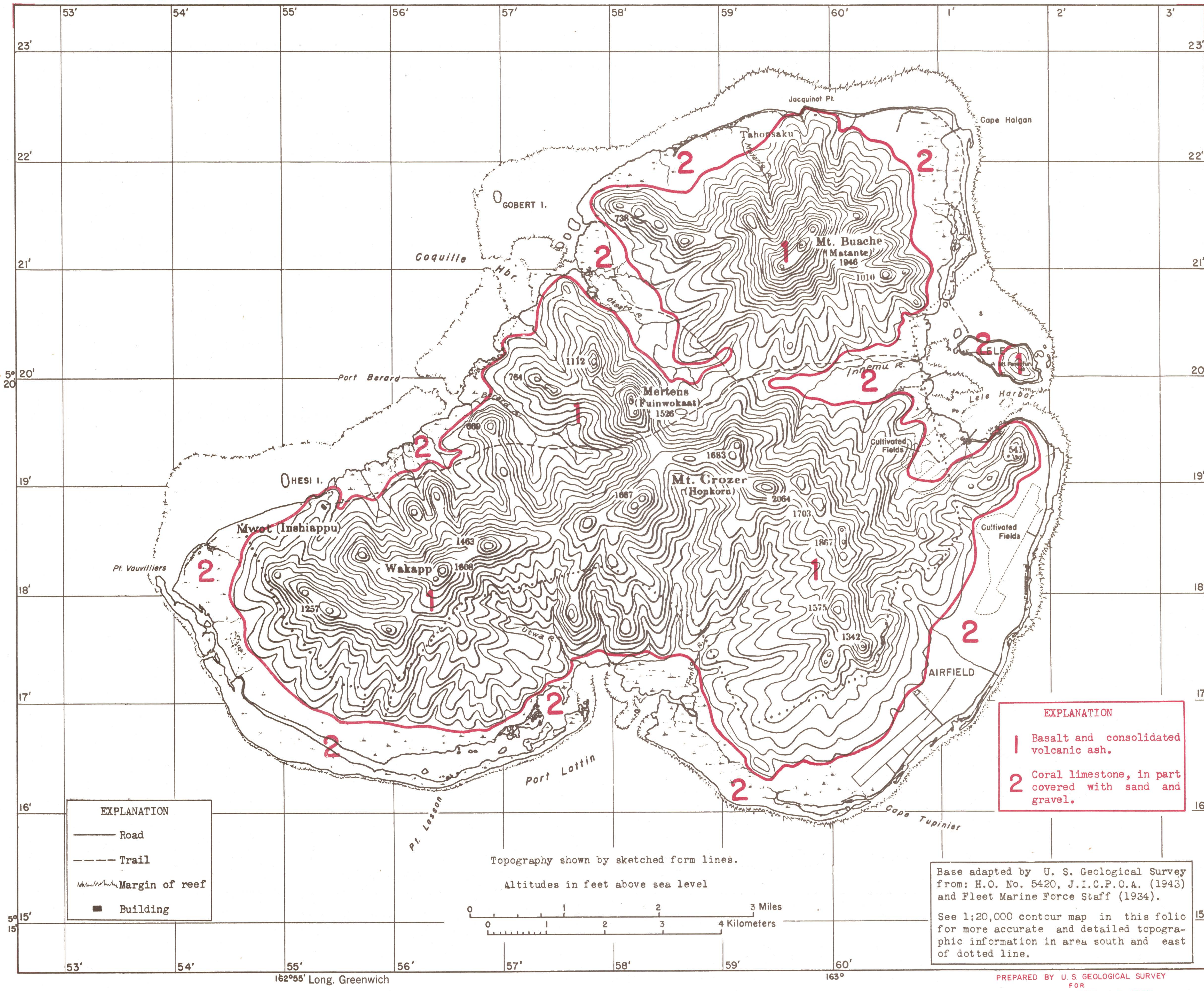


a/ Engineering group symbols have the significance given them in the War Department Technical Manual 5-255, Aviation Engineers, December, 1942 and the Principles of Highway Construction published by the Public Roads Administration, June, 1943.

Prepared by U. S. Geological Survey for Chief of Engineers, U. S. Army.

CONSTRUCTION MATERIALS

KUSAIE (UALAN) ISLAND (CAROLINES)



PREPARED BY U. S. GEOLOGICAL SURVEY FOR CHIEF OF ENGINEERS, U. S. ARMY

KUSAIE (UALAN) ISLAND (CAROLINES) | CONSTRUCTION MATERIALS

Reliability rating: Class C

Introduction

Basalt, which forms the bedrock of Kusaie, was used at an early date by natives in constructing buildings and walls, ruins of which are still standing on Lele Island. In addition to building stone, the basalt and reef rock of Kusaie offer suitable sources of lime, concrete aggregate, road metal, and riprap.

Information on the rocks is derived from American, German, and Japanese studies, published between 1903 and 1939. The different rock types are discussed briefly; several detailed descriptions of the basaltic rocks are available. There is no known published geological map of the island.

Kusaie possesses tall straight, very durable timber that is particularly suitable for marine construction because of its resistance to attack by sea water and organisms.

Geological setting

Kusaie is a small volcanic island bordered by a narrow coastal lowland surrounded by coral reefs. The bedrock consists of thin bedded basaltic lava flows, in part compact and columnar, in part very porous; with some consolidated volcanic ash beds and dike rock. At the base of mountains is an uplifted coral reef covered with a layer of alluvium (volcanic rock-debris and coral sand). On the south and east coasts, narrow islands of coral gravel and sand mixed with volcanic waste lie on the reef flat. Lele Island, off the east coast, is dominated by a low volcanic peak.

The volcanic activity is believed to have occurred in two main episodes (probably during the Tertiary). The basaltic lava, ash and volcanic blocks probably issued from several vents.

Apparent vertical movements of the island are revealed in terraces. Small benches cut in the volcanic rocks are reported at altitudes of 100 to 165 feet. They may be gravel capped. The old reef limestone in the coastal lowland is about 3 to 6 feet above sea level.

Mineral deposits

The discovery of bauxite in Kusaie was reported in 1936. No details concerning the deposit, its extent or its location are available.

Unit 1. Basalt and consolidated volcanic ash rock

Characteristic features: Thin-bedded compact basalt, in places with columnar structure; also very porous slaggy basalt and consolidated ash rock between the compact lava flows. Rock generally granular; color gray to black where unweathered. Weathers readily, forming brownish-red crumbly rock, rock waste, and deep reddish clay soil.

Distribution: Forms bedrock of Kusaie except for coastal belt; also east part of Lele Island. Exposed only in mountain spurs, peaks, and river gorges, elsewhere generally concealed by deep soil cover and dense vegetation.

River gorges are filled with basaltic sand, gravel and cobbles. Terraces, reported at 100 to 165 feet above sea level may have thin cover of basaltic gravel.

Engineering properties: In some places blasting and drilling may be required to excavate unweathered compact volcanic rock. Where columnar structure is developed, blocks can be removed by wedging out individual pillars (probably averaging 1 foot in maximum width). Porous slaggy basalt and consolidated ash rock tend to yield more readily than compact basalt.

Bearing strength of compact lava rock is high; lower in porous lava rock and consolidated ash rock.

Crushed compact basalt will furnish suitable material for concrete aggregate, road metal, and fill. Compact and columnar basalt is good source of building stone and riprap.

Unit 2. Coral limestone, coral sand and gravel; volcanic rock sand, gravel, and cobbles

Characteristic features: Coral limestone in reef masses and large broken blocks; reef rock case-hardens when exposed to air. White coral sand and gravel, in places slightly consolidated, may be mixed with basaltic rock gravel and cobbles. Volcanic rock waste ranging from sand to large boulders.

Distribution: Coral reef limestone underlies (1) reef fringe of island and (2) terrace at 3 to 6 feet above sea level in coastal lowland. Layer (few feet to possibly 80 feet thick) of alluvial sand and gravel, composed of both coral and volcanic rock fragments, covers limestone terrace of coastal lowland. Similar material forms narrow reef islands on south and east coasts. Some islets of pure, slightly consolidated coral sand are scattered on reef. Large blocks, gravel, and sand, eroded by surf from outer edge of reef, are thrown up on reef flat and beach. Volcanic rock waste distributed in large river valleys.

Engineering properties: Hand tools are probably adequate to work most unconsolidated and slightly consolidated material on reef and coastal lowland; some blasting may be necessary. Coral limestone can be trimmed into blocks or readily crushed.

Sand and gravel on coastal lowland and reef islands have low bearing strength. Reef limestone, especially when case-hardened, probably has fairly high bearing properties.

Homogeneous coral rock and unconsolidated sediment are excellent source of lime, but large quantities with required quality may not be available. Naturally cemented coral sand and limestone are suitable for light construction. Coral and basaltic gravel and boulders are source of concrete aggregate. Crushed coral rock and basaltic gravel can be used as road metal. Coral rock will disintegrate under heavy traffic; must be replaced frequently.

Prepared by U. S. Geological Survey
for Chief of Engineers, U.S. Army.

Sources:

Strategic Bulletins of Oceania, No. 7, Meteorology of the Caroline Islands: Inst. of Human Relations, Cross-Cultural Survey, Yale University, March 5, 1943.
Inter-Service Topographic Division/D30, Island of Kusaie, March 26, 1942.
Engineer Research Office Report no. 60, Caroline Islands, Military Intelligence Div., U. S. Army, January 25, 1944.
Monthly Weather Review Supplement No. 28, Climatological data for the tropical islands of the Pacific Ocean (Oceania), Weather Bureau, U. S. Dept. Agriculture, 1927.
Hydrographic Office no. 273, Naval Air Pilot, West Pacific, Caroline and Marshall Area, U. S. Navy, July 14, 1943.
For more detailed information consult other intelligence sources.

Winds, Squalls and Typhoons

Kusaie is on the southern margin of the NE trade winds. The northeast trade winds, dominant from December to April inclusive, are primarily easterly and northeasterly and have average velocities between 11 and 17 miles per hour. In June and July, when the northeast trade winds shift northward, light variable winds and calms prevail until the southeast trade winds become dominant. The winds of the southeast trade wind season are lighter and more variable than those of the northeast. In November and December the wind systems shift southward and the island has another period of doldrums. Strong offshore winds are frequent. Squalls, ordinarily with easterly but occasionally with westerly winds occur almost daily, particularly during June and July. They are of short duration but violent, with wind velocities of 15 to 35 miles per hour. December and November are also squally, but less so than June and July. Typhoons occur in the area, particularly during late summer and early fall. Two such storms have occurred since weather records were kept, one in March 1891 and another in April 1905.

Temperatures

There is little variation in temperature throughout the year; June, July, and August are the hottest months; March and April the coolest. The daily range is 5 to 12 degrees F., and the minimum temperature is 77 degrees. Temperature records were not kept at the stations on Kusaie but records at stations elsewhere in the Caroline Islands indicate that conditions are approximately as given in the following table.

Temperatures	Degrees Fahrenheit
Maximum	100±
Average Maximum	84 to 90
Average	80 to 82
Average Minimum	79 to 82
Minimum	77

Relative Humidity

Average relative humidity is about 82%. The minimum relative humidity of 62% is reached in mid-afternoon on hot sunny days following several days of clear weather. On clear cool nights the saturation point is reached occasionally and heavy dews and fog form.

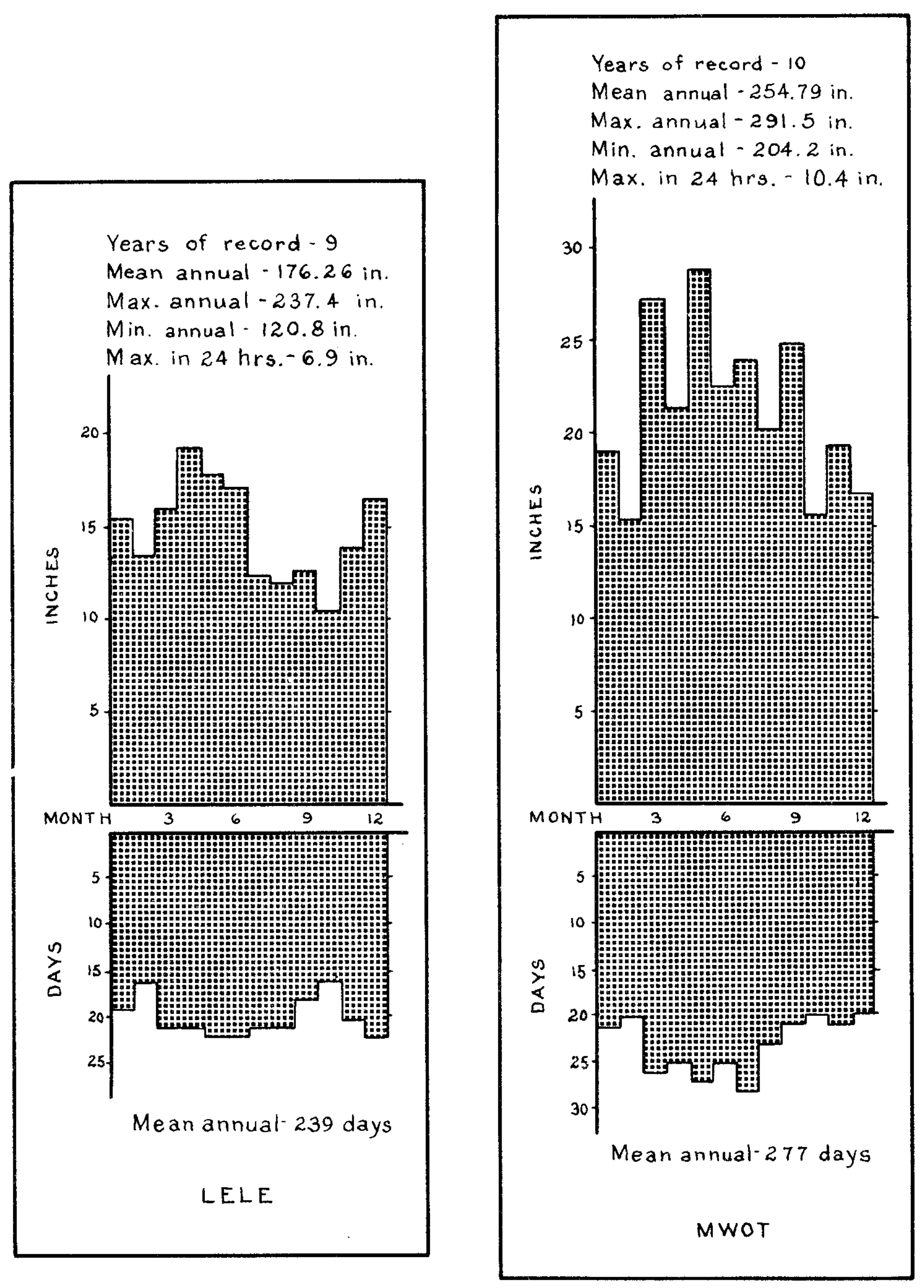
Clouds and Visibility

Higher mountain peaks are commonly hidden in clouds. At sea, cloudiness averages about 5/10 and clouds are practically always present. Altitude of the cloud base ranges from 500 to 1,500 feet, and the summits often extend to 10,000 and occasionally to 20,000 feet. Fogs lie over the rivers and swamps on the east coast in the early morning, particularly during the northeast trade wind season. They are dissipated by the sun by 9:00 A.M. The west coast is reported to be fog free, but ground views of that part of the island show fog. Ground fogs are common at higher altitudes in the mountains, particularly on the leeward sides. Visibility at sea and on the lowlands is generally good except when limited by rain.

Precipitation

The two weather stations at which records have been kept are Lele Island, at sea level off the northeast coast less than a mile from the mountains, and Mwot, on the southwest coast on the lower mountain slopes between 200 and 300 feet in altitude. Average annual precipitation at Lele is 176.3 inches and at Mwot 254.8 inches. Drought is unknown. Records show an annual rainfall range from 120.8 to 237.4 at Lele, and from 204.2 to 291.5 inches at Mwot. Precipitation is quite evenly distributed throughout the year. The rainiest months are March to June inclusive, with a secondary peak in December and January, at Lele, and March to Sept. inclusive at Mwot. Precipitation in the mountains probably is higher than that measured at either of the weather stations. Torrential showers of limited extent and short duration fall almost every day, generally in the early morning and late afternoon. Occasional storms of several days duration, with several periods of intense precipitation, take place. Periods of several successive days of clear weather may occur.

Average monthly and annual precipitation, in inches (upper graphs); average number of rainy days per month and year (lower graphs).



Source: Monthly Weather Review, Supplement No. 28, Climatological data for the tropical islands of the Pacific Ocean (Oceania), Weather Bureau, U. S. Dept. Agriculture, 1927.

OCEAN AREA 05160E. POSITION: LATITUDE 5°-10° N., LONGITUDE 160°-165° E. GREENWICH NOON OBSERVATIONS. YEARS COVERED 1881-1933

Month	Number of observations surveyed	Wind: Mean velocity (knots)	Wind, percentages of observations from—: N.	NE.	E.	SE.	S.	SW.	W.	NW	Calm	Weather, percentages of observations recording—: Haze	Mist	Fog	Drizzle	Rain	Lt. Squalls	Showers	Thunderstorms	Heavy squalls	Gales (force 8 or over)	Exceptional visibility	Mean cloud amount (0-10)	Average air temperature	Average sea surface temperature
January	54	13.5	15	70	9	0	0	2	0	2	2	2	0	0	0	2	9	6	2	2	0	0	4.0	82	82
February	64	11.6	9	63	22	0	2	4	0	0	0	0	0	0	0	7	8	5	0	0	0	0	4.5	81	81
March	27	12.0	5	82	0	13	0	0	0	0	0	7	0	0	0	14	33	11	0	0	0	4	4.3	82	83
April	33	14.5	9	73	9	6	0	0	3	0	0	0	3	0	0	15	18	12	0	0	6	0	5.5	82	82
May	18	12.5	6	55	27	0	6	0	6	0	0	0	6	0	0	6	6	12	0	0	0	0	4.4	81	81
June	15	9.7	13	33	40	7	0	7	0	0	0	0	0	0	0	7	13	13	0	0	0	0	5.6	82	82
July	17	8.9	12	32	38	0	6	6	6	0	0	0	0	0	0	6	18	0	0	0	0	0	5.1	82	82
August	15	7.6	8	17	8	42	17	0	0	0	8	0	7	0	0	13	20	7	0	0	0	13	6.2	84	83
September	21	6.8	0	19	28	10	5	23	5	0	10	0	0	0	0	18	10	0	0	0	0	5	4.7	84	82
October	39	4.6	14	11	17	8	3	8	3	11	25	0	0	0	0	6	3	5	15	8	0	8	4.7	83	84
November	49	8.4	2	36	24	10	12	2	2	7	5	4	0	0	0	16	14	16	4	8	0	0	5.1	82	83
December	30	14.0	3	56	28	6	0	7	0	0	0	0	0	0	0	3	7	13	7	0	0	0	4.4	83	82
Mean	——	10.3	8	46	21	8	4	5	2	2	4	1	1	0	0	9	13	8	2	2	0.5	2	4.9	82	82
Total	382																								

Compiled by the U. S. Weather Bureau

* Less than 0.5 percent

* 1 knot = 1.15 m.p.h.

Prepared by U. S. Geological Survey for Chief of Engineers, U. S. Army.