MILITARY GEOLOGY OF SAIPAN, MARIANA ISLANDS

(In Three Volumes)

VOLUME I

INTRODUCTION AND ENGINEERING ASPECTS

Prepared under the direction of the
Chief of Engineers, U. S. Army
by the
Intelligence Division, Office of the Engineer
Headquarters United States Army Forces Far East
and Eighth United States Army
with personnel of
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1955

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Foreword

January, 1955

Engineer Intelligence Study - Saipan, Mariana Islands

This study on Military Geology of Saipan, Mariana Islands, consists of three volumes: I, Introduction and Engineering Aspects; II, Water Resources; and III, Beach and Terrain Analysis.

Volume I, presented here, deals with the physical geography and engineering aspects of the geology and soils. It delineates and locates construction materials available, describes the soil cover, briefly describes the topography of the island, and evaluates areas relative to suitability for construction. Volumes II and III are being prepared for publication.

The study was prepared in cooperation with the U. S. Geological Survey, Department of the Interior.

Frank O. Bowman
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Major General, USA
Engineer

Preface

The Military Geology of Saipan, Mariana Islands, is one of a series of reports resulting from detailed geologic and soil surveys conducted under the Pacific Geological Mapping Program which was established as a part of the Corps of Engineers Post Hostilities Mapping Program. The purpose of these surveys is twofold. The first is to collect scientific information through field study of major islands in the Pacific; the second is to publish it in a form so that it is usable by the United States Armed Forces and Civil Administrators working on assignments in those islands.

Volume I of the Military Geology of Saipan is compiled from observations made in the field, physical testing of materials, and evaluation of the geological and soils materials in terms of their engineering properties. Mapping was done in the field on aerial photographs, scale 1:10,000, and the data were later transferred to topographic base maps, scales 1:10,000 and 1:25,000. Both the geological and soils mapping were done during the period September 1948 to July 1949.

The Saipan field party was composed of geologists of the U.S. Geological Survey and soil scientists of the U.S. Geological Survey and the U.S. Department of Agriculture assigned to the Office of the Engineer, Far East Command. Members of the party and specific responsibility of each were:

Preston E. Cloud, Jr., U.S.G.S. geologist, chief of party: Introduction, General Geology, Stratigraphy (in part), Mineral Resources (in part), Beach and Terrain Analysis.

Robert G. Schmidt, U.S.G.S. geologist: Stratigraphy (in part), Mineral Resources (in part).

Harold W. Burke, U.S.G.S. geologist: Stratigraphy (in part).

Allen H. Nicol, U.S.G.S. geologist: Engineering Geology.

Dan A. Davis, U.S.G.S. geologist: Water Resources.

Ray E. Zarza, U.S.G.S. soil scientist: Soils Mapping.

Ralph J. McCracken, U.S.D.A. soil scientist: Soils, Engineering Aspects of Soils.

In addition to the comprehensive military geology report, of which this is the first published volume, a considerable quantity of detailed source data was assembled. This material has been assembled in the form of two specialized reports. The first of these, "Geology and Mineral Resources of Saipan, Mariana Islands" was prepared by Preston E. Cloud, Jr., Robert G. Schmidt, and Harold W. Burke. The second, "Soils of Saipan, Mariana Islands" was prepared by Ralph J. McCracken. These reports contain much of the basic and detailed scientific data and large scale geologic and soils maps upon which much of the information presented in the geology report is based. These two specialized reports are not yet available in published form.

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MILITARY GEOLOGY OF SAIPAN, MARIANA ISLANDS

VOLUME I, INTRODUCTION AND ENGINEERING ASPECTS

INTRODUCTION

Physical Geography: Saipan lies at a latitude of approximately 15° north and a longitude of approximately 146° east, in the minus ten-hours time zone west from Greenwich. It is in the Mariana Island chain, which extends from 13° to about 21° north latitude and between 145° and 146° east longitude. The Mariana Island chain consists of fourteen single islands, one group (Maug) of three small islands, lesser islets, and banks or reefs. From south to north, the main islands of the Marianas are Guam, Rota, Aguijan, Tinian, Saipan, Farallon de Medinilla, Anatahan, Sarigan, Guguan (Gugan), Alamagan, Pagan, Agrihan, Asuncion (Assongsong), Maug, and Farallon de Pajaros (Urakas).

Saipan is about 13 miles long and averages 4 miles wide, altogether comprising about 48 square miles. It is second largest among the Marianas, being exceeded only by Guam which has an area of approximately 236 square miles. Guam, Rota, Tinian, and Saipan are the only members of the Mariana Islands whose areas exceed 10 square miles. Saipan is shaped like a spanner wrench, with the handle to the north and the jaws opening to the east at Bahia Laulau. A coral-algal barrier reef and narrow lagoon border Saipan on the west, and a narrow fringing reef occurs discontinuously around much of the rest of the island.

Saipan, despite its small size, is an island of considerable geographic diversity. Its dominant topographic feature is an axial ridge or highland area that extends through the northern three-fourths of the island and has a maximum elevation of 1,555 feet at Ogso Tagpochau near the center of the island. In the vicinity of Ogso Tagpochau, this highland area consists of a series of nearly flat benches and vertical scarps of limestone, but northward it becomes a true ridge of mostly volcanic rocks, culminating in Ogso Achugau at an elevation of 767 feet. North from Achugau the central highland area is again one of flat benches and scarps of limestone, terminating in the bluffs of Laderan Banadero that rise to a peak of 833 feet at Pidos Kalahe. Plate 1, a map at 1:25,000, shows the topographic features of Saipan and gives the native geographic names for these features.

The middle stretch of the axial ridge is intricately dissected into steep-sloped hills and mostly short, rugged valleys cut deeply into the volcanic foundation rocks. The north and south thirds are marked by steep-walled, slot-like valleys incising a terrain of older limestone. Valleys drain generally east or west. The longest valleys are located on the eastern slope in the volcanic terrain near the mid-length of the island. Here, also, are located the only two essentially perennial streams on the island, Sadog Talofofo and Sadog I Hasngot.

In the southern fourth of Saipan, and in the vicinity of Chacha, and Banadero, the terrain is relatively low and flat, consisting of broad limestone benches separated by low scarps. North from the rough and hilly area of Sabanan Laulau, on the north shore of Bahia Laulau, approximately the eastern third of the island consists of narrow north-northeast-extending benches with steep cliffs at their seaward margins. The benches and cliffs extend step-like from sea level to the crest of Ogso Tagpochau, itself a remnant of the highest and oldest preserved bench.

The number of recognizable surfaces varies locally, and detailed study would probably reveal an extensive and complex succession of mainly erosional benches and scarps. Casual observation indicates that these could be grouped into 10 to 13 terraces, with smaller benches and scarps between these major surfaces.

The most continuous smooth areas are along terrace surfaces or benches, but the scarps between are walls that separate them. Continuous surfaces extend from one bench to another only at places where later subaerial erosion has produced gaps in the wave-cut scarps, or where local variations in resistance to wave abrasion, or erosional history, has caused two benches to merge. The same ravines that provide passage through the scarp walls, however, commonly form natural barriers athwart the benches.

Areas of volcanic terrain have unique topographic characteristics. The jungle and cane fields of the terraced limestone reaches here give way to swordgrass-covered slopes and an intricate drainage system. The soil is no longer characteristically a thin veneer with numerous limestone pinnacles protruding from a mainly solid to cavernous substratum. It is either deep, sticky clay over largely detrital andesitic rocks or a very thin mantle over a rough and rocky substratum of dacitic rocks.

The incision of the benches east of the central highland area, by a series of deep east-trending valleys, make very rugged terrain. The flatter, more continuous surfaces, generally extend north-northeast along the bench surfaces and around the heads of ravines that extend back into them. The area of I Naftan, at the southeast end of the island, and that east from Laderan Hagman, at the northeast of Bahia Laulau, are even more rugged. The central ridge is the most difficult terrain in the island, and from it steep, swordgrass-covered spurs extend south from Ogso Tagpochau.

The west slope of the central highland area in the northern two-thirds of the island is even more precipitous than the eastern slopes. However, a narrow coastal plain, at few places over 20 feet above sea level, provides a southwestward-extending corridor from the area of Matansa to the southwest end of the island. This coastal plain widens to the south, and its soil is generally firm, except in the marshes about Hagoi Susupe.

A fringing reef occurs along much of the north, east, and south shores of Saipan. It ranges from extensive, well-developed belts to patches, and at places is separated from the island proper by a shallow moat.

Along the west coast a barrier reef lies offshore, separated from the island by a lagoon one-fourth to two miles wide; the barrier reef grades to a fringing reef at either end. Most of the lagoon is too shallow for shipping, and at many places it is too shallow even for small boats, but it can be waded only at the extreme south and north ends. A deep area (Puetton Tanapag) off the center of the west coast offers limited harbor facilities. A passage through the barrier reef at the center of Puetton Tanapag gives access to a dredged channel about one mile long and 30 feet deep. The channel leads into a protected anchorage approximately three-fourths of a mile in diameter and with depths generally in excess of 30 feet. Part of the anchorage has been dredged. Its general contour and the location of shoal waters within it are shown in detail on U. S. Navy H. O. Chart 6062.

A large bank area off the southwest coast of Saipan offers anchorage for larger ships. It is generally shallower than 20 fathoms. Bahai Laulau is too deep and treacherous to be a suitable place for anchorage, although it offers some shelter from major storm waves and ships with enough chain might anchor there. Over-all comprehension of the general hydrographic and topographic features of Saipan may be gained from study of plate 1, of this volume, and the illustrations in Volume III, Beach and Terrain Analysis.

Climate: Japanese climatic records for Saipan have been summarized in compilations by the U. S. Navy (1944) and Military Geology Section, U. S. Geological Survey (1944). Temperature and rainfall data from the latter reference are condensed in the following tabulation, based on data from 7 to 9 years of Japanese records:

LOCATION	Central Ridge	Southwest Lowlands
	Elev. 676 ft.	Elev. 10 ft. to 200 ft.
Temperature (degrees F)		
Mean annual	78	85
Maximum..............	89	102 (Sept.)
Minimum..............	67 (Jan.)	68 (Jan.)
Rainfall (inches)		
Mean annual..........	90.7	81
Maximum monthly		
mean................	15.7 (Sept.)	13.6 (Sept.)
absolute............	27 (Sept.)	25.7 (Sept.)
Months with 1 inch....	April	Feb. Mar. April
Rainest months........	July to Oct.	July to Nov.
Less rainy months.....	Nov. to June	Dec. to June

Saipan is characterized by a tropical oceanic climate with relatively high and uniform temperatures. Recorded mean annual temperature ranges from 78°F. at an elevation of about 676 feet on the central ridge east of Tanapag to about 85°F. in the southwest lowlands. Recorded deviations from the mean are as low as 67° on the central ridge and as high as 102° in the southwest lowlands. The mean annual relative himidity is about 82 percent, with a monthly average between 79 and 86 percent (U. S. Navy, 1944, p. 5). The central ridge crest and east slope of the island, being exposed to the easterly trade winds, are cooler and generally less humid than its western slope and coastal area.

Average annual rainfall, according to Japanese records, varies from 81.0 inches in the southwestern lowlands to 90.7 inches at an elevation of 676 feet on the central ridge. Ogso Tagpochau, which rises to a peak of about 1,555 feet, would doubtless show a still higher rainfall. A maximum annual precipitation of 130 inches has been recorded at an unidentified locality (U. S. Navy, 1944, p. 5). Records kept at the Tanapag Naval Air Base from September 1948 to August 1949 show only 51.4 inches of rain, the minimum yearly rainfall recorded for Saipan. It is conceivable that rainfall in this lee area would average less even than that in the southwestern lowlands.

Seasonal variation on Saipan is not marked, but in a general way one may recognize a rainy season and a dry season. Some rain is apt to fall on a majority of the days in all months of the year but rains are heaviest, and there tend to be more rainy days, from July through October or November. The dry season may be taken as extending from about late November or December through June. However, although less than an inch of rain has been recorded for each of the first four months of the year, as much as 18.4 inches has been recorded at Saipan in January. The record maximum rainfall in 24 hours was 13.1 inches, in November, with the average maximum precipitation in 24 hours being in August and amounting to approximately 5.5 inches. The dry season (approximately December through June) is the time of essentially continuous northeast trade winds and is the pleasantest climate from the point of view of the white visitor. The rainy season (approximately from July through November) is the time of shifting winds and typhoons. During this period the wind comes most frequently from the southeast or east, but it may shift so as to blow from other quarters, particularly from the south and southwest. The typhoons come generally from the south or southwest and most frequently toward the latter part of the rainy season. During typhoons the wind may rise to very high velocities and do great damage, and the combination of high wind and heavy rainfall seldom fails to do some damage.

A high degree of cloudiness prevails over Saipan, as it does over all the Mariana Islands, which usually can be located from far away by the bank of clouds above them. Over an 8-year period of observations on Saipan, the mean annual cloudiness averaged 6.7 on a scale that ranges from 0 for cloudless to 10 for completely overcast. However, records show that approximately 59 percent of the hours between 0600 and 1800 are hours of sunshine, with cloudiness greatest from July to

September and least in April. Days with clear skies, however, occur most frequently in February.

More specific climatic data than the foregoing are cited in graphic form on the Beach and Terrain Analysis map (Volume III, Plate 1).

Rocks: Saipan consists of a central core of primary and reworked volcanic rocks of Eocene age overlapped on all sides by latest Eocene, lower Miocene, and Quaternary marine limestone. Unconsolidated or poorly consolidated deposits of limestone of Pleistocene and Recent age, and mostly of a marginal nature, occur here and there on the older deposits.

The composite column of all geologic units on Saipan aggregates more than 6,200 feet. This column comprises 7 formally named formations, ranging in age from Eocene to probably Recent, and 14 informally designated, mostly unconsolidated deposits of Pleistocene and Recent age. Including 2 named members and 26 mapped facies subdivisions, a total of 43 separate geologic units have been recognized and mapped on Saipan. These units are mostly varieties of detrital limestone and volcanic rocks, but the most recent ones include several kinds of unconsolidated covering deposits, one includes the various developments of the offshore reef, and one includes marsh deposits. All are geologic deposits, even though the most recent ones are still accumulating; and, with the possible but unlikely exception of the Sankakuyama formation, all the units are of Cenozoic age.

Although the volcanic core rocks account for more than two-thirds of the total known thickness of the geologic column on Saipan, they crop out on only a little over 5 square miles, or about one-tenth, of the land surface. Limestone which accounts for only about 2,000 feet of the composite column, crops out over about 35 of Saipan's 48 square miles of land surface. The remaining 8 square miles are underlain by various unconsolidated and marginal deposits.

The broad distribution and relationships of the formations and certain of the covering deposits of Pleistocene and Recent age are shown on the generalized geologic map of Saipan (plate 2). The engineering properties of the rocks are discussed, tabulated and mapped in Part I of Engineering Aspects of this volume.

The major rock units recognized on Saipan are briefly described, in order of increasing age, as follows:

1. The Tanapag limestone (Recent ?) is a coral- and algal-rich raised reef limestone, highly porous and open in texture, containing shell material of mollusks and coral skeletons which are generally well preserved. It underlies roughly 1,050 acres along the present coast, and averages 10 to 20 feet in thickness but ranges to possibly 100 feet in thickness.

2. The Mariana limestone (Pleistocene ?) is a generally coarsely porous, nonbedded to indistinctly bedded, dirty white to brownish, fragmental limestone with abundant to scattered remains of corals and coralline algae. It contains shells of other than very massive-shelled mollusks which are ordinarily dissolved away, and coral skeletons which have been noticeably altered. Corals are much more abundant in the Mariana limestone than in older rocks. It includes five distinct but intergrading facies; crops out over roughly 7,350 acres near the coast, and averages about 400 feet thick, but ranges from a feather edge to perhaps 500 feet thick.

3. The Tagpochau limestone (lower Miocene), is a complex of varied calcareous facies that intergrade with one another and are distinguished from other fragmental limestones on Saipan mainly by the presence of large Foraminifera and other fossils of lower Miocene age. The commonest and most distinctive facies of the Tagpochau limestone is a compact, fairly pure, pink to white, inequigranular limestone. However, the formation also includes impure limestone and sandstone and conglomerate of reworked volcanic materials; includes 6 facies and two

named members (Donni sandstone member, Machegit conglomerate member). It is found over about 14,250 acres mostly in central and north Saipan and is believed to average 300 to 600 feet thick, but ranges from a feather edge to perhaps 1,000 feet or more thick.

4. The Matansa limestone (upper Eocene) is pure to impure, inequigranular, white to pink or dark red, bioclastic limestone. Three distinctive types of limestone in the Matansa are recognized as separate facies. It crops out over about 310 acres in north-central Saipan, and averages perhaps 200 to 500 feet thick, but probably does not much exceed 500 feet.

5. The Densinyama formation (upper Eocene) consists of volcanic conglomerate, tuffaceous sandstone, calcareous tuff, tuffaceous limestone, and conglomerates that contain both limestone and volcanic fragments. The sediments are mainly reworked; rock types include andesite, siliceous igneous rocks, chert, and calcium carbonate. Andesite is the most abundant rock type but quartz and quartzose rocks are more distinctive. Three facies are recognized in the Densinyama. Densinyama beds underlie about 1,200 acres in north- and east-central Saipan. They are believed to average 200 to perhaps 600 feet thick and to range from a feather edge to the neighborhood of 800 feet.

6. The Hagman formation (upper Eocene) consists of mainly andesitic rocks comprising subaerial (breccia-tuff) and marine (conglomerate-sandstone) detrital facies, massive andesite flow rock, and interbedded flows and tuffs. Parts that resemble the Densinyama can ordinarily be distinguished by the absence or extreme paucity of quartz. The Hagman formation is divided into four facies, all of which are deeply weathered except in bluff exposures. It is found over about 1,300 acres in scattered localities and is believed to range up to perhaps 1,500 feet thick.

7. The Sankakuyama formation (Eocene ?) consists of dacitic volcanic rocks; mainly breccia and massive flow-rocks, and lesser amounts of

tuffs and mixed pyroclastics. It is rich in siliceous glass and is in part conspicuously laminated and locally vesicular. Four facies are mapped over a total area of about 455 acres in north-central Saipan. Its total thickness is at least 1,800 feet.

Soils and Land Classes: Three major soil groups occur on Saipan - soils on limestone, soils on volcanic rocks, and soils on elevated beach deposits. Limestone underlies approximately 83 percent of the island, volcanic rocks about $10\frac{1}{2}$ percent, and elevated beach deposits on the coastal flats about $6\frac{1}{2}$ percent.

The distribution of the major soil groups of Saipan is shown on the generalized soils map of Saipan (plate 3) accompanying this report. The engineering properties of soils are described in Part 2 of Engineering Aspects of this volume.

Four major soil units occur on limestone. These are Rough stony land; the shallow stony Chinen soils; the brown friable Dandan soils; and the firm soils of the Chacha and Saipan series. Rough stony land is widespread over the island on limestone of all ages where soil cover is thin or absent. Chinen soils also occur on limestone of all ages except for the most recent, but their dominant occurrence is in southern Saipan on the Pleistocene(?) Mariana limestone. Dandan clay loam occurs chiefly in southern Saipan and can be roughly correlated with the massive facies of the Mariana limestone in this area. However, it occurs also in northern Saipan on various terrace levels and over other limestone units. Saipan clay and Chacha clay are both developed over the Mariana and the older Tagpochau limestone.

Correlations and relationships of soils derived from the volcanic rocks of the Hagman formation, the reworked volcanic sediments of the Densinyama formation, and the Donni sandstone member of the Tagpochau limestone are obscure and ill-defined. This is due, in part, to the convergent effects of intense weathering which tends to produce similar soils on rocks of slightly varying composition, age, and morphology.

Also, because of interbedding and intertonguing of the various rock types, a complex and intricate pattern of exposures of the various volcanic units is produced, and the relationship of a particular soil type to any given minor rock unit is not ordinarily evident.

Soils on the dacitic Sankakuyama formation are uniformly shallow to very shallow, and mainly fall into the category of Rough stony land.

The various soil types are subdivided into significant slope phases (not shown on plate 3; shown on soils map at 1:12,500 in Soils of Saipan, Mariana Islands, a separate basic data report). These slope phases are established arbitrarily according to prevailing gradient of the surface. Boundaries between individual slope phases are based in part on significant differences in agricultural management and land use and in part on minor variations in accessory characteristics of the soil profile. For instance, erodability of the soils and usability of agricultural machinery differ for each slope phase, and the depth of the soil profile or thickness of a particular horizon in the profile may differ between slope phases of any soil unit. The gently sloping phase includes those parts of the land with a prevailing gradient of less than 8 percent; the sloping phase includes areas whose prevailing gradient is 8 to 15 percent; the prevailing gradient of the hilly phase is 15 to 25 percent; and the steep phase includes all areas in which the prevailing gradient is over 25 percent.

The soils, and areas of little or no soil, on Saipan may be grouped into five major land-classes.

(1) Arable land on gentle slopes originally covered 4,960 acres or about 16 percent of the total land area on Saipan. Between 10 and 20 percent of the arable land has been rendered indefinitely unfit for agricultural use as a result of postwar construction.

(2) Marginal land suitable for limited cropland use or grazing land formerly comprised 12,620 acres or about 41 percent of the island's area. Between 10 and 15 percent of this land is estimated to have

been indefinitely withdrawn from use owing to postwar construction.

(3) Non-arable land usable as grazing land or for limited forest-growth underlies 12,660 acres or a little over 41 percent of Saipan. This land is largely rough, stony land, barren of soil, or with thin or patchy development of relatively infertile soil. It also includes marshland.

(4) Low quality grazing land not suitable for crops or forest growth covers 250 acres of north-central Saipan. This is essentially an area of outcrop of dacite breccia and flow-rock, comprising slightly less than 1 percent of the island's area.

(5) Completely barren areas, including quarries and the lake known as Hagoi Susupe, account for 230 acres or less than 1 percent of Saipan's surface.

Water Resources: (For a detailed report on the water resources of Saipan see Volume III, Water Resources report. The following abstract is given only as pertinent introductory background). Approximately 73 billion gallons of rain falls on Saipan in an average year. If the rainfall were uniformly distributed in time, which it is not, this would amount to about 200 million gallons per day. The ultimate problem of water supply on Saipan relates to how much rainfall can be recovered in usable form.

Sources of fresh water on Saipan before American occupation were Donni Springs (Bobo I Denni), flowing 80,000 to 400,000 gallons per day, about a dozen smaller springs (such as Talofofo Springs, Nicholson Spring, Achugau Springs), catchment of rainfall in cisterns, a few drilled wells, and several hundred dug wells. Slightly brackish water for industrial purposes was obtained from the Starch Factory Spring or Salt Spring, near Tanapag. This spring normally flows from 100,000 to 130,000 gallons daily, and has a chloride content of 480 to 1,200 parts per million. Hagoi Susupe, a slightly brackish and generally contaminated lake, furnished water for operation of the Japanese sugar mill at Chalan Kanoa. Dug wells in the low coastal plain along the west coast provided generally brackish water. A few drilled wells in the southern fourth of the island produced fairly large quantities of basal water of good potability at a fairly consistent flow. Cisterns provided most of the water for individual dwellings away from the villages.

After the American landing many wells were drilled, and a large number produced potable water. One Maui-type infiltration tunnel near the center of the south fourth of the island (U. S. Maui No. 1) was extended from the base of a 100-foot shaft. Another Maui-type infiltration tunnel near the center of the west side of the island (U. S. Maui No. 4) was extended from the base of a 200-foot shaft driven down from the 200-foot terrace surface. Other proposed Maui-type wells were abandoned before completion, but the two mentioned have, with local fluctuations, produced a large part of the potable water used on Saipan since their completion.

The only place on Saipan where additional water might be obtained from surface sources is the Talofofo area where the two essentially perennial streams and several small springs occur.

Taking all possible sources into consideration, development on Saipan of a daily supply of 5 million gallons of potable water at the source seems entirely possible. It should be emphasized that prevention of excessive loss of water enroute to points of demand requires excellent pumping and piping facilities and proper maintenance of them. Deterioration of such facilities in the tropics is rapid, but their maintenance is at least of equal importance with the development of original supply and a common source of difficulty in the larger islands.

Plants: The vegetation of Saipan has been so altered by burning, cultivation, and importation of foreign species that it is difficult for any but the skilled botanist to know what plants are indigenous and which introduced. S. J. M. Von Prowazek (1913, p. 104-121) listed the flora, discussed floral communities and relationships, and cited important references to the previous literature. According to the Mandated Marianas Islands, Civil Affairs Handbook (U. S. Navy, 1944, p. 16), Sigeki Kawagoe in 1915 recorded a presumably inclusive flora of 107 species grouped in 51 genera. Of these the grasses and the legumes include the largest number with 10 species each. The Useful Plants on the Island of Guam by Safford (1905) describes and discusses a flora similar to that of Saipan. The information here presented is based on the sources cited; it does not attempt inclusiveness or distinction between endemic, indigenous, and introduced.

In the past the coconut palm was important in the native economy of Saipan, but the trees were seriously afflicted by blights, the Japanese sugar-cane industry, and war. Recently there have been sporadic efforts to replant the coconut more extensively. Bananas, taro, tapioca, yams, and sweet potatoes are extensively raised, and the breadfruit, pandanus, and soursop are important food sources. Mangoes, papayas, and pineapples are grown locally, and coffee, citrus fruit, cotton, tobacco, and kapok trees have been introduced and raised in varying quantities in times past. Ifilwood (*Intsia bijuga*) and daog (*Calophyllum inophyllum*) are potentially important timber species.

Throughout Saipan dense and varied jungle vegetation characterizes the immediate vicinity of the limestone cliffs, and the pliant but vicious swordgrass (*Miscanthus floridula or M. sinensis*) is the characteristic plant of the volcanic areas or areas of limestone with much volcanic detritus. Despite a deceptively smooth appearance from a distance, areas of thick growth of swordgrass are most difficult to penetrate on foot. Second and third in order of difficulty for the hiker are jungle and second-growth cane. Under Baron Mitsui and the South Seas Development Company (*Nanyo Kohatsu Kaisha*), the Japanese evolved an extensive sugar-cane industry, and second-growth cane occurs over much of the island. The casuarina tree (*Casuarina cf. C.* equisetifolia, Australian pine, ironwood) grows extensively along the beaches, and locally it and the xerophytic fern Gleichenia compete with swordgrass on the volcanic soils and weathered volcanic rocks. The casuarina has also been planted in windbreaks.

Leguminous trees and shrubs are among the most numerous and varied on the island. The scrub, acacia (Leucaena glauca), is the commonest and most widely distributed. Another common leguminous tree, the Formosan koa (Acacia confusa), was widely introduced by the Japanese as a windbreak, wood lot, and shade tree; the locally extensive patches of this low tree are the pleasantest woodland on Saipan. Their dense shrubbery not only provides shade but so completely shuts out the sunlight as to inhibit the growth of all underbrush.

ENGINEERING ASPECTS

General Statement

Saipan is abundantly supplied with natural construction materials. Hard limestone, suitable for crushing and use for coarse aggregate for concrete, surfacing, base course, riprap, and masonry is nearly everywhere available and easily accessible. Volcanic rock, similar to trap rock, occurs sporadically in northeastern, east-central, and southwest Saipan, but is rather inaccessible. Coralline rubble, excellent for base course without the need for crushing, is readily available within short-haul distances nearly everywhere, although it is most uniformly distributed in the central and northern parts of Saipan. Medium- to fine-grained beach sand is widespread along the west coast but only in isolated spots along the east coast. Excellent binder clay is readily available nearly everywhere. Perhaps the least readily available construction material is gravel. Only fair to poor quality gravel may be obtained from small areas in north-central Saipan and isolated spots along the east coast.

Excavations in the well lithified limestones, which constitute about three-fourths of Saipan, require drilling and blasting, and stripping of the overburden is difficult because of the presence of limestone pinnacles at or immediately below the surface. When wet, the clay overburden which occurs extensively throughout the gently sloping areas of Saipan strongly adheres to excavation equipment.

Foundation conditions are good throughout most of Saipan, the major exceptions being marshy areas in the southwest, deep clay areas inland from and along the east-central coast and many individual low areas in central Saipan. Hidden subsurface caverns or openings occur in the widespread hard limestone so that detailed subsurface investigations are necessary at all sites where permanent structures are to be built.

Road construction is easy over the gently rolling coastal lowlands in northern, eastern, southern and southwestern Saipan. The need for cut and fill, fairly steep grades and curves, make road construction moderately difficult in most of the rolling interior terrain. Special road building problems arise in the marshy areas in southwest Saipan, the rugged volcanic-rock areas in northcentral Saipan and deep clays of local low areas.

The most suitable areas for airfield construction, namely the extreme northern and southern parts and on the east-central peninsula, have already been utilized, but ample room is available either for new fields or extended development of existing fields. If the need were great enough, additional sites could be developed along the west coast and in east-central Saipan but at the expense of moderately difficult construction or destruction of existing installations.

The soils of Saipan, for engineering purposes, consist of clays some of which are highly plastic or "fat", lime sands, and marsh soils. Slightly more than one-third of the island has either no soil cover or only a very shallow cover of stony lays.

About one third of island has a soil cover of "lean" clays, that is, clays with low plasticity. These are generally less than 5 feet deep and occur on slopes with gradients ranging from 1 to 15 percent although the steeper the gradient the shallower and stonier the soil. These soils have medium to rapid internal drainage, provide fair foundations for light structures but are shallow and close enough to bedrock to allow good foundations for heavy structures. They are fair to good for most engineering purposes but may be difficult to excavate because of the presence of hidden limestone pinnacles.

A little less than one fourth of Saipan has a soil cover of "fat" or highly plastic clays, much of which are 5 or more feet deep and on slopes of from 1 to 25 percent. These soils have slow internal drainage, can provide only fair foundation for light structures and are poor or unsuited for heavy structures. Their suitability for engineering purposes is good only for binder soil and only poor to fair for most others. These fat clays although easily excavated are slippery and because of their stickiness adhere strongly to equipment.

Limy beach sands which occur extensively only along the west coast have very rapid internal drainage, provide good foundation for light structures but poor for heavy, are easy to excavate and are generally good for subgrade and fill.

Small areas of marsh soils, most of which occur in the southwest part of Saipan, are saturated, provided no suitable foundations for structures, and are suitable only for binder soil.

ENGINEERING ASPECTS: PART I, ENGINEERING GEOLOGY

Introduction

The section on Engineering Geology consists of a map (plate 4), text, and three tables (tables 1, 2 and 3). It presents information for engineers on the occurrence, properties, uses, and field conditions of all earth and rock materials which occur on Saipan, excluding the top few feet of soil, and is based on field investigation, geologic mapping, and engineering testing. The field data were obtained from more than 100 exposures in quarries, borrow pits, road cuts, and outcrops, where observations were made of thickness, lateral extent, gradation, compaction, associated landforms, overburden, weathering, excavation conditions, slope stability, resistance to erosion, drainage, and foundation conditions.

Tentative engineering materials units were established during a preliminary field investigation conducted prior to completion of geologic mapping. Upon the completion of geologic mapping these tentative units became engineering geology units; from a total of 51 geologic map units 17 engineering geology units were derived by combining two or more geologic map units of similar lithology. The Geologic Map of Saipan, Mariana Islands, 1:12,500, in 4 sheets, in a separate report on the geology of Saipan, is the basic map from which the Engineering Geology map was compiled. Units shown on the Engineering Geology Map of Saipan (plate 4) are:

Unit 1. Very compact limestone
Unit 2. Firm, porous limestone
Unit 3. Coralline rubble
Unit 4. Clayey coralline rubble
Unit 5. Red clay overlying limestone
Unit 6. Brown clay
Unit 7. Mottled clay

Unit 8. Weathered andesitic conglomerate and breccia

Unit 9. Partly weathered andesitic conglomerate and breccia

Unit 10. Clayey volcanic sediments

Unit 11. Compact dacite

Unit 12. Friable dacitic breccia and tuff

Unit 13. Compact andesite

Unit 14. Indurated andesitic conglomerate and sandstone

Unit 15. Beach sand

Unit 16. Lagoon deposits

Unit 17. Marsh deposits

Artificial fill is shown on the map as Unit 18 but is not considered in the text or tables as a unit. The 17 engineering geology units, therefore, include 2 varieties of coralline limestone, 2 of coralline rubble, 4 varieties of clay, 6 volcanic materials, and one each of beach sand, lagoon, and marsh deposits.

Derivation of the engineering geology units from the geologic map units is based largely on engineering properties, the more important of which are consolidation, compaction, gradation, bedding, layering, and jointing; of secondary consideration are mineralogical composition, geologic origin, and distribution. A correlation table on the Engineering Geology Map (plate 4) shows engineering geology units and their equivalent geologic map units. The Engineering Geology Map of Saipan is, therefore, a special purpose map based largely on geology and engineering characteristics of the earth materials, with fewer map units and with different boundaries than the geologic map.

The text presents factual data for each of the 17 units shown on the Engineering Geology Map, with special emphasis on engineering application and utilization. Table 1, "Field Conditions Affecting Engineering Operations," is a summary of part of the data contained in the text; it supplies information on overburden, weathering, excavation conditions, and road and airfield construction. Table 2, "Construction Material Suitability," is a rating scale of the suitability of the dominant material in each unit for various construction uses, based on field observation and laboratory testing. Table 3, "Engineering Test Data," shows test results for 25 samples, of the various units, collected from pits, quarries, and natural exposures. All sample site locations are shown on the Engineering Geology Map by appropriate symbol.

The Saipan Engineering Geology Map, text, and tables are intended to provide a regional estimate of the general engineering properties of various earth materials for overall appraisal and planning. These data are not intended to supplant detailed engineering investigations at specific sites. The function of the map and tables in supplying basic subsurface data is limited to a depth of 100 feet, which is probably an adequate depth for most engineering work except groundwater development and deep underground construction. Data applicable to bedrock and structural conditions at a greater depth than 100 feet are given in a separate report,"Geology and Mineral Resources of Saipan, Mariana Islands." Detailed engineering data strictly applicable to surface soil within 5 feet of the surface are given in the Engineering Aspects of Soils section, (Part 2) of Engineering Aspects.

In the planning stages of various military operations, use of the data presented here should provide an understanding of the engineering problems, properties, and uses of earth materials where such operations are planned.

Description of Engineering Geology Units

UNIT NO. 1 VERY COMPACT LIMESTONE

General description: The rock is a massive, dense, fine- to coarse-grained limestone. Its colors are white, pink, pinkish-gray, cream, yellow, or variegated. It is similar in engineering properties to compact crystalline limestones of the United States. Most of this unit is a durable rock. Typical exposures are shown in plates 6A, 6B, and 7A.

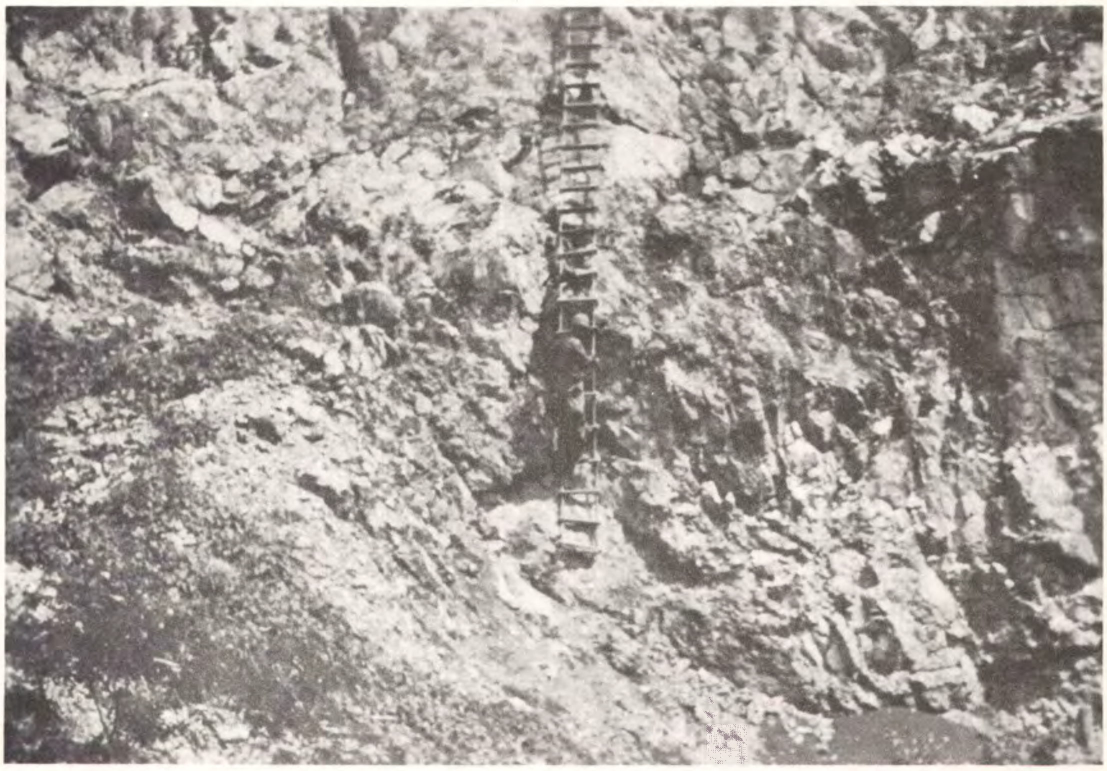
Landforms: Very compact limestone occurs on broad, flat terraces locally covered by red and brown clay, and on terrace margins separated by steep to vertical cliffs from a few tens to 600 feet high. Slump blocks are common along the coasts, and much talus has accumulated at the bases of terrace and coastal cliffs. Caverns occur locally within the unit.

Overburden and weathering: This unit has been irregularly dissolved by rainwater leaving pinnacled solution surfaces of fresh rock overlain by residual red or brown clay of fairly high plasticity. The clay thickness ranges from a few inches to more than 10 feet with generally sharp contacts with underlying bedrock.

Excavation and tunneling: Blasting is required to excavate in all areas with this rock. Drilling may be difficult because of small cavities and vugs but otherwise the hardness of this rock is much less than that of trap rock. Jointing and bedding are not distinct, and large blocks up to several feet in diameter can be quarried; proper spacing of drill holes and care in exploitation can produce blocks of sufficient size for cyclopean riprap from many parts of the unit. Because jointing, bedding, and fracturing are not well developed, fragmentation will be somewhat lower than for bedded and jointed crystalline limestones. Tunnels stand well without support except in a few fractured and sheared zones. Water drains rapidly from most excavations unless floors become clayey from puddling.

Slope stability and erosion: Quarry faces and excavation walls stand well vertically; sea cliffs have overhang. Some slumping occurs along vertical master joints and in underground caverns due to solvent action of water. Mechanically, this rock is fairly resistant to erosion, but chemically it is readily dissolved by carbonated waters, resulting in fretted and pinnacled surfaces, underground openings, caverns and

A. Unit No. 1 Very compact limestone. Quarry S-25 at Laderan Dago, south-central Saipan. Sample site No. 2.



B. Unit No. 1 Very compact limestone. Quarry S-25 at Laderan Dago, south-central Saipan. Sample site No. 2.

passages along water courses, and other solution features.

Foundation conditions: Very compact limestone has excellent bearing capacity for all structures where no large underground caverns or cavities occur near the surface. Because no rapid, economical method for detection of concealed underground caverns is presently known, sub surface conditions for proposed sites of large, permanent structures should be investigated in detail by exploratory borings. Structures should be placed away from the edge of cliffs and escarpments to avoid danger from slumping material. Elsewhere, this unit is stable without fill, and its bearing capacity is equal to that of most crystalline limestone.

Quarries: Present development is limited to a few aggregate quarries. However, many good potential sites within the unit could be developed for recovery of aggregate and riprap.

Road and airfield construction: Construction of new roads in areas of this unit would require negligible cut and fill along terrace surfaces. Deep cut and fill are required, however, in crossing scarps between terraces and in crossing ridges. All excavations require drilling and blasting; excavated rock is a useful construction material. The clay overburden above irregular, pinnacled limestone bedrock surfaces is difficult to strip. Existing roads have moderate-radius curves; along main highways grades are fairly steep only where crossing the terraces. Subgrade and drainage conditions are excellent. This unit is topographically unfavorable for major airbase construction.

UNIT NO. 2 FIRM, POROUS LIMESTONE

General description: The rock is a firm, obscurely bedded to non-bedded, generally porous limestone, grading to massive, compact limestone. It tends to grade to, and be intermixed with, rubbly, weakly consolidated limestones of the type included within unit 3 on the one hand, and to compact limestones of the type included within unit 1 on the other hand. Its color is ordinarily light gray or yellowish gray to white and its texture coarse- to fine-grained with large discrete blocks, or heads, of coral in position of growth. In general, it is somewhat similar to the poorer grades of unit 1, but inferior in quality. A typical exposure is shown in plate 7B.

Landforms: This unit occurs on broad to narrow, flat or gently sloping benches separated by steep to vertical cliffs up to several tens of feet high. Bench surfaces, especially near the sea, are highly irregular, with extremely abundant, irregular pinnacles up to 6 feet high. Slump blocks are common along the coast. Caverns are visible locally in cliff faces, and doubtless occur at many places beneath the surface.

Overburden and weathering: Solution effects of rainwater produce irregular, pinnacled, bench surfaces that are overlain by 1 to 10 feet of red clay. Locally, deep pockets of soil of complex derivation occur. The contact between soil overburden and bedrock is sharp.

Excavation and tunneling: Blasting is required to excavate the limestones of this unit. The drill should penetrate the soft limestone readily, but may be expected to encounter many small cavities and at places large caverns. Fragmentation on blasting will be somewhat low because of the porous nature of the rock. Tunnels will probably stand well without support except in fractured and sheared zones. Water will drain rapidly from excavation floors.

Slope stability and erosion: Quarry faces and excavation walls will stand vertically, except where loose material is encountered. Slumping occurs locally along the higher cliffs. Mechanically, this material is fairly resistant to erosion, but chemically it is readily dissolved by carbonated waters, resulting in pinnacled bench surfaces, underground openings, and other solution features.

Foundation conditions: Foundation conditions are generally similar to unit 1. Some thin cavern roofs, apparently stable, may collapse if mechanically overloaded; others may in time collapse through natural solution or weathering. Subsurface conditions for proposed sites of

A. Unit No. 1 Very compact limestone. Quarry S-2 at south side of Laderan Lagua, northeast Saipan.

B. Unit No. 2 Firm, porous limestone. Quarry at Laderan Dandan, southeast Saipan.

large, permanent structures should be investigated in detail by exploratory borings to locate concealed caverns. Otherwise, this unit is stable and has a bearing capacity nearly equal to most crystalline limestone.

Quarries: Although present quarry development is limited, many good potential sites could be developed within this unit for aggregate and riprap.

Road and airfield construction: Roads require negligible cut and fill along terraces, but deep cut and fill in crossing scarps between terraces. Subgrade and drainage conditions are excellent. Excavated rock is a useful construction material. Existing roads have moderate- to long- radius curves. Grades are steep only where passing through cliffs. Existing arifields are constructed on this unit and the terrain is favorable for the construction of many new sites.

UNIT NO. 3 CORALLINE RUBBLE

General description: The rock is a loose, rubbly, brecciated or fractured, clastic limestone, containing angular particles of semi-indurated to chalk-like limestone in a matrix of fine limy sand, and locally, some clay. Individual particles are commonly up to several inches in diameter; masses larger than one foot are uncommon. Its color is ordinarily white or light tan; exposed surfaces are discolored gray by algae and similar vegetation. Typical exposures are shown in plates 8A, 8B, 9A, 9B, 10A, and 10B.

Landforms: Areas of this unit occur in hilly, undulatory terrain, where slopes range from 10 to 35 degrees; steep cliffs and scarps are less common than in unit 1. On flat areas and in depressions the coralline rubble is covered by red clay soil.

Overburden and weathering: The overburden of red clay soil is less than one foot thick. The contact between soil and weathered rock is sharp, like that of unit 1.

Excavation and tunneling: This material is easily excavated by power equipment or hand tools. Blasting is not essential except in occasional hard, cemented zones and layers. In open excavations, made in 1944, this material has stood up well on nearly vertical slopes. Tunnels and underground chambers require support; stand-up time is comparable with slowly raveling ground. Seepage and drainage are rapid.

Slope stability and erosion: Most excavated slopes appear stable from $\frac{1}{2}$:1 to nearly vertical. Hillsides have slopes of 1:1 and occasionally 2$\frac{1}{2}$:1. Excavations of 50 feet or more in depth may require shoring or benching of cut slopes to prevent slumping and raveling. Most of this unit is not easily eroded. Rock mantle and soil creep are greatly accelerated on steep slopes when extremely wet.

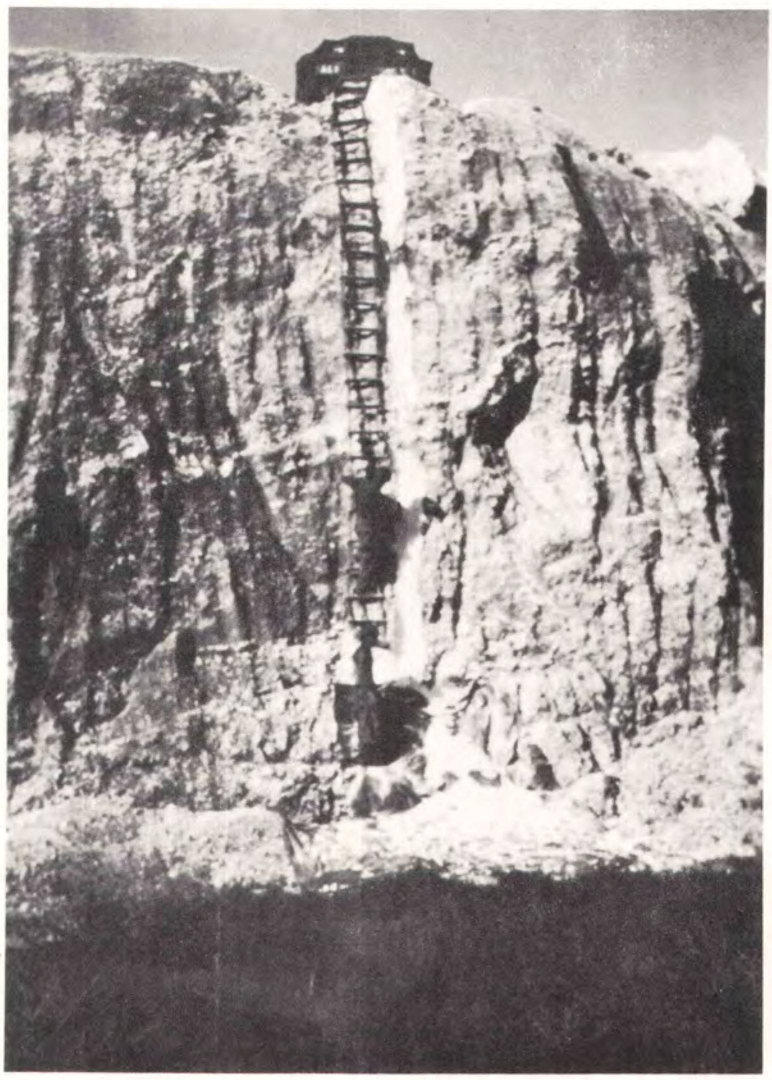
Foundation conditions: The rocks of this unit have excellent bearing capacity for all structures; unit has stability comparable with that of consolidated bedrock. Coralline rubble contains concealed underground caverns and openings, however, and the conditions described in units 1 and 2 obtain equally well for this unit except that loose, rubbly, and fractured rock conditions provide inferior roof support. Subsurface investigations by borings are required to locate possible caverns underlying proposed construction sites in order to safeguard against the hazards of subsidence and collapse of the foundations.

Quarries: Quarry development has been extensive. The material in this unit was used extensively by the military from 1944 to 1948 for base course and fill in road and airfield construction, and most large quarries on Saipan were developed for this purpose. Abundant supplies remain at all quarries; potential new quarry sites are numerous.

Road and airfield construction: Roads over most of this unit require cut and fill with numerous curves but little or no blasting is necessary. Material from cuts makes excellent embankment and fill. Subgrade and drainage conditions are generally excellent. Terrain is favorable for only a limited number of airfield sites.

Remarks: Construction material suitability for rocks of this unit is given in table 2 of this section.

A. Unit No. 3 Coralline rubble. Quarry in southern part of district of As Matuis, northern Saipan. Sample site No. 2.



B. Unit No. 3 Coralline rubble. Quarry in southern part of district of As Matuis, northern Saipan. Sample site No. 2.

A. Unit No. 3 Coralline rubble. Distant view of Quarry S-16 at Laderan Dandan, south-central Saipan. Sample site No. 1.

B. Unit No. 3 Coralline rubble. Close-up view of quarry S-16 at Laderan Dandan, south-central Saipan. Sample site No. 1.

A. Unit No. 3 Coralline rubble. Quarry S-16 at Laderan Dandan, south-central Saipan. Sample site No. 1.

B. Unit No. 3 Coralline rubble. Quarry at base of Laderan I Agag, east-central Saipan.

UNIT NO. 4 CLAYEY CORALLINE RUBBLE

General description: The rock is a loose, rubbly, clastic limestone containing clay-coated fragments commonly up to several inches in diameter in a matrix of fine sand, silt, and clay. The unit is distinguished from unit 3 by a higher clay content, ranging from 10 to 50 percent, and by impurities which impart a reddish or brownish discoloration.

Samples were taken from two sites in this unit but no engineering tests were made.

Landforms: Areas of this unit occur on gently undulating terrain with moderately steep slopes. Steep cliffs and bluffs are uncommon.

Overburden and weathering: The overburden is of clay and gravelly soil, with local coverings of slope wash, and may reach 12 to 15 feet, but commonly less than 6 or 7 feet. This unit contains more weathered products, clay, and silt than unit 3. Impurities derived by weathering extend to a considerable depth below the surface throughout much of the unit.

Excavation and tunneling: Rocks of this unit are easily excavated by hand tools or power equipment without blasting; most excavations require shoring. Tunnels driven into this material require support; stand-up time is similar to slowly raveling ground. Excavations seep water rapidly; floors puddle and hold water for long periods.

Slope stability and erosion: The amount of clay and fines in the matrix greatly affects slope stability of the material. Many road cuts of 25 feet or less in depth appear to be stable on $\frac{1}{2}$:1 or nearly vertical slopes. It is probable that cuts greater than 25 feet in depth may require 1:1 or more gentle slopes, and possible benches. Erosion of cut slopes is moderate to rapid because natural compaction is fairly low and the clay which coats the particles acts as a lubricant when wet, promoting sliding and slumping.

Foundation conditions: Material has adequate bearing capacity for all structures to be placed upon it, but borings are required to safeguard against possible collapse of underground caverns and openings. The loose, rubbly condition of this material provides poor natural roof support above such openings compared with solid rock. Foundation conditions within this unit are generally similar to those in unit 3 (see unit 3 for further details).

Quarries: Numerous potential sites could be developed into good quarries but few have been exploited. Some deposits are gradational with unit 3. Many favorable locations for sites occur on slopes of 20 to 35 degrees.

Road and airfield construction: Conditions are generally similar to those of unit 3. An optimum percent of clay binder gives this material somewhat greater stability, when properly compacted at optimum moisture content, for base course, embankment, and fill than unit 3. Some portions of the unit that contain an excessive amount of clay require blending with a non-clayey material such as unit 3 to increase the bearing capacity and improve stability. Materials of this unit are easily exploited without blasting and readily placed, rolled, and compacted. The terrain is unfavorable for the construction of airfields.

Remarks: Construction material suitability of this unit is given in table 2.

UNIT NO. 5 RED CLAY OVERLYING LIMESTONE

General description: The material is red to reddish-brown, plastic clay containing some sand, manganese concretions, and a few limestone fragments. Thickness of unit ranges from 1 to 20 feet; average thickness between 3 and 4 feet, and is underlain by limestone bedrock. A typical exposure is shown in plate 11A.

Landforms: Areas of this unit occur on slopes of 25 or more degrees, and in depressions, sinkholes, or on pinnacled surfaces of terraces.

Overburden and weathering: The unit consists only of overburden and is dominantly a residual product of limestone decay, mapped where fairly thick and extensive. The change from clay to underlying bedrock is

A. Unit No. 5 Red clay overlying limestone. At base of Laderan Kalaberan Katan, north Saipan.

B. Unit No. 6 Brown clay. Cut along west side of Cross-Island Highway, district of Papago, east-central Saipan.

sharply defined rather than gradational, and the transition zone is only a few inches thick.

Excavation and tunneling: The unit is not deep enough to tunnel. It is easily excavated by hand tools and power equipment; excavations require shoring to prevent caving. When wet, this clay adheres to excavation equipment. Pinnacles of the firm underlying limestone require blasting.

Slope stability and erosion: Natural slopes in dry material appear to be fairly stable on 3:1; when wet, slopes steeper than 4:1 may become unstable because of the low angle of internal friction and high plasticity. Excavation slopes are easily eroded, and gullies form quickly.

Foundation conditions: Foundation conditions are very unsatisfactory. Bearing capacity is poor and the material is unstable when wet. Stripping is required to permit footings of heavy structures to rest on underlying limestone bedrock. See units 1, 2, 3, and 4 for foundation conditions in limestone bedrock.

Quarries: There has been no development, although the material has been used locally for ammunition revetments.

Road and airfield construction: Roads on most of this unit require little cut and fill. Material is an unsatisfactory, poorly drained subgrade when disturbed, and necessitates considerable thickness of base course to produce stable roads. Grading and leveling is difficult; easy stripping by bulldozers will remove the clay, but blasting may be required to remove protruding limestone pinnacles. Heavy rains easily erode this red clay and form gullies; slopewash often covers the roads after storms, causing slippery, hazardous conditions. Gutters and side ditches require protective riprap to prevent undermining of shoulders. In places where slopewash accumulates swiftly, gutters become choked, causing overflow on the road surface. Terrain is unfavorable for the construction of airfields.

Remarks: This red clay unit is sporadically distributed throughout Saipan. Generally, in any given area of half a square mile or less, some bedrock limestone or pinnacles will be found projecting through the clay. The thickness of the clay overlying the bedrock is quite variable, and in some depressions is more than 10 feet.

Engineering properties are given in table 2. For further details, see Part 2, Engineering Aspects of Soils.

The sample site for this unit appears on the map in an area mapped as unit 1, the discrete area of unit 5 here being too small to map individually at the scale used.

UNIT NO. 6 BROWN CLAY

General description: This is a brown to yellowish clay, commonly containing pea-sized concretions of manganiferous and ferruginous composition, some sand, and limestone fragments. Valley deposits of the clay are gravelly. The clay is weakly to highly plastic; commonly loose when dry, but very sticky when wet. Thickness averages perhaps 5 feet or more and may reach as much as 25 feet locally. Underlying beds are not ordinarily exposed, but in most places they are limestone. A typical exposure is shown in plate 11B.

Landforms: Areas of this unit occur in closed depressions, on very gentle slopes of not more than 2 or 3 degrees, and along certain valley courses. The largest areas of the unit are in southwest-central and central Saipan, but small to large areas occur in many other parts of the island.

Overburden and weathering: The unit consists of overburden, dominantly a weathering product of underlying and adjacent limestone.

Excavation and tunneling: Brown clay is easily excavated by dozers, power shovels, or hand tools; when wet it strongly adheres to excavation equipment. Excavations require shoring and timbering to prevent caving; tunnels, if driven into the deeper parts of the unit, would require support and lining.

Slope stability and erosion: Characteristics are generally similar to unit 5. Natural slopes of 3:1 or 4:1 are fairly stable in dry material;

brown clay is easily and rapidly eroded.

Foundation conditions: Foundation conditions are generally unsatisfactory; material is unstable when wet. Conditions are generally similar to unit 5, but bearing capacity may be somewhat higher.

Quarries: No development has been made.

Road and airfield construction: Roads have long-radius curves, with negligible cut and fill. This brown clay unit is an unsatisfactory, poorly drained subgrade when disturbed, and necessitates considerable thickness of base course to produce stable roads. Grading and leveling is easily done except that, when wet, clays of the unit stick to equipment. The clay is easily eroded and gullied by rain in sloping areas. Gutters and side ditches require protective riprap to prevent undermining. The terrain is favorable to the construction of a few short airstrips.

UNIT NO. 7 MOTTLED CLAY

General description: Material is plastic clay overlying weathered volcanic rocks and impure limestones. Its color is dark red to reddish brown, at many places, a mottled yellow, orange, gray, and lavender. Relict structure of rotted volcanic rock particles is commonly well preserved. It contains up to 30 percent sand. Distinguished from unit 5 by mottling and by greater thickness. Bearing capacity, unit weight, cohesion, and angle of internal friction are lower than unit 5. (See table No. 3 for further details.) Typical exposures are shown in plates 12A and 12B.

Landforms: Occurs on gently sloping uplands, hills, some steep ridges, and narrow valleys.

Overburden and weathering: The clay composing this unit is a residual product formed by the complete weathering of volcanic rock and limestones contaminated with volcanic material. It constitutes only overburden, and is similar to unit 5, but differs from unit 5 in origin, greater thickness (average perhaps 25 feet), and engineering properties.

Excavation and tunneling: Easily excavated by dozers, power shovels, and hand tools. Excavations over 15 feet deep require shoring to prevent caving; tunnels require support; stand-up time is comparable with that of squeezing ground. Workings retain water for long periods, especially after material is disturbed and puddled. Wet material strongly adheres to equipment.

Slope stability and erosion: Cut slopes of moderately shallow depth require slopes of about 2:1 or $2\frac{1}{2}$:1 for stability. Natural slopes are flatter, some over 3:1. Deep cuts need benches and protective vegetative cover to prevent rapid gullying and erosion.

Foundation conditions: Very unsatisfactory. Customary precautions should be taken as with ordinary plastic clay foundation beds; footings require protection against erosion. Bearing capacity is lower than clay of unit 5. Material is thick, extremely unstable when wet, and difficult to strip to firm bedrock. At proposed sites for massive, permanent structures, detailed subsurface investigations are essential to establish exact thickness of clay and local variations in bearing capacity.

Quarries: No development.

Road and airfield construction: Moderate cut and fill are required for most road construction. Material is a poorly-drained, unsatisfactory subgrade. Primary roads that support heavy traffic need an adequate thickness of satisfactory base course. Cuts will require slopes of 2:1 or more for stability, and protection against erosion. Excavated material is unsatisfactory for fills. Gutters and drains require riprapping to prevent erosion. Terrain is unfavorable for airfield construction.

Remarks: The engineering properties of this clay are shown in table 2, and test data are given in table 3.

A. Unit No. 7 Mottled clay. Base of Laderan I Agag, east-central Saipan.

B. Unit No. 7 Mottled clay. About 100 feet northeast of As Perdido Road, district of Fina-sisu, southwest Saipan.

UNIT NO. 8 WEATHERED ANDESITIC CONGLOMERATE AND BRECCIA

General description: Highly weathered beds of volcanic conglomerate, sandstone, breccia, and tuff. Consists mainly of intensely rotted boulders and gravel sized fragments of andesite in a sandy clay matrix. Parts of this unit contain fragments of hard dacite and chert. About 50 percent of the matrix material is finer in grain size than a No. 200 mesh sieve. Most beds are reddish brown, but in places they are mottled and similar to unit 7. Relict structure is well preserved; the fragments appear intact but are mostly altered to soft, earthy clay materials. Typical exposures are shown in plates 13A and 13B.

Landforms: Chiefly gently sloping uplands, but part of unit underlies hilly and steep uplands with narrow ridges, deep ravines, and many gullies.

Overburden and weathering: Deeply weathered with fragments of volcanic rock decomposed to grit and clay. Firm, coherent rock forms less than 5 percent by volume. (Unit 9, however, contains a higher percent of moderately fresh or partly weathered rock.) Weathered zone extends in some places to a depth of 40 or 50 feet with little change in physical properties. Surface mantle of soil is 2 to 4 feet thick and composed chiefly of red-brown, iron-stained, plastic clay.

Excavation and tunneling: Easily excavated by dozers, power shovels, or hand tools. No drilling or blasting necessary. Shoring and timbering are essential to prevent caving, in all fairly deep excavations. Tunnels require support; stand-up time is comparable with slowly raveling ground. Workings will drain moderately well except for puddled floors; more easily drained than unit 7.

Slope stability and erosion: In moderately shallow cuts slopes of $1\frac{1}{2}$:1 or 2:1 are essential for maximum stability; benches may be required in deep cuts to prevent slumping, and adequate vegetative cover necessary to retard rapid erosion.

Foundation conditions: Bearing capacity of undisturbed material is fair; unit is more stable than units 5, 6, and 7. Stability is low in wet or disturbed material, which has properties of a plastic clay.

Unit is too deep to strip, hence footings should rest on undisturbed material wherever possible. Subsurface investigations are required at sites where permanent structures are proposed in order to determine local conditions and to evaluate them for foundation design. Footings require protection against erosion.

Quarries: Limited development. A small borrow pit is located at the south end of Ogso Talofofo.

Road and airfield construction: Road construction conditions are similar to those of unit 7. Only moderate cut and fill are required for most new construction within the unit. Material is an unsatisfactory subgrade; drainage is poor to fair. Cuts require slopes of $1\frac{1}{2}$:1 or possibly 2:1 for stability and may need protection against erosion. Excavated material is poor for embankment and fill. Ditches and gutters scour rapidly unless protected by riprap. Terrain is unfavorable for airfield construction.

Remarks: This unit is an unsatisfactory construction material. See tables 2 and 3 for further details.

UNIT NO. 9 PARTLY WEATHERED ANDESITIC CONGLOMERATE AND BRECCIA

General description: This unit has a similar geologic derivation to unit 8, but comprises less severely weathered rocks. It consists of poorly consolidated beds of volcanic conglomerate, sandstone, and breccia made up of partly weathered to relatively fresh boulders, cobbles, and gravel-sized particles of volcanic rocks mixed with sand and fines. The boulders range up to 15 feet in diameter; the average is about 1 foot. The volcanic fragments comprise various types of andesite and dacite. Chert fragments are abundant in parts of the unit. Typical exposures are shown in plates 14A, 14B, 15A, and 15B.

Landforms: Hills and steeply sloping uplands with many sharp spurs and ravines. Steep slopes to vertical cliffs at Puntan Hagman and I Naftan.

Overburden and weathering: Practically no overburden. Fresh or relatively non-weathered to severely weathered and friable. Many of

A. Unit No. 8 Weathered andesitic conglomerate and breccia. District of Talofofo, northeast Saipan.

B. Unit No. 8 Weathered andesitic conglomerate and breccia. Cut along west side of Cross-Island Highway, district of Papago, east-central Saipan.

A. Unit No. 9 Partly weathered andesitic conglomerate and sandstone. Road cut at Laderan Hagman, eastern Hagman Peninsula, east-central Saipan. Sample site No. 1

B. Unit No. 9 Partly weathered andesitic conglomerate and sandstone. Bluffs above Unai Hagman, eastern Hagman Peninsula, east-central Saipan.

A. Unit No. 9 Partly weathered andesitic conglomerate and sandstone. East slope of Laderan Hagman, eastern Hagman Peninsula, east-central Saipan.

B. Unit No. 9 Partly weathered andesitic conglomerate and sandstone. Fresh andesite boulders and cobbles on surface. East slope of Laderan Hagman, eastern Hagman Peninsula, east-central Saipan.

the large boulders are fresh; the gravel and sand sizes are partly to severely weathered at the surface. Weathering extends to depths of 25 or 30 feet below the surface; below this depth the beds are better cemented and the rock is less friable.

Excavation and tunneling: This material can be easily excavated by hand tools or power equipment to a depth of 25 or 30 feet. The large, fresh boulders, however, require shattering by explosives. Progressive hardening of the sandy matrix of the conglomerate beds below 30 feet may necessitate blasting for effective removal. Excavations require shoring. Workings will seep much water but drainage is rapid. Tunnels require support and lining to prevent loose rock from falling; stand-up time ranges from that of slowly raveling ground to running ground.

Slope stability and erosion: A cut of 30 feet in depth along abandoned railroad grade at Ogso Laulu is nearly vertical and appears stable except for rolling boulders. Slopes of 1:1 are thus considered stable for shallow cuts except for large boulders that may become loose and roll down. Very deep cuts would need benches, steel netting, or other safeguards against loose rock. Material is easily eroded.

Foundation conditions: The bearing capacity of this material is similar to common sand and gravel mixtures and is adequate for all structures. Footings require protection against erosion, and ordinary precautions against mantle creep on steep slopes.

Quarries: The south half of the large quarry at the foot of the central island ridge directly east of Puntan Flores is in this unit. Potential sites on Hagman Peninsula, at Ogso Laulau, and other areas can be developed with limited exploration.

Road and airfield construction: Road construction requires moderate to deep cut and fill. Most of this material makes an excellent, well-drained subgrade, and is fair for base course when compacted and protected. Moderately deep cuts require minimum slopes of 1:1; deep cuts may require benches. Wire nets or other protective measures are necessary in places to prevent dislodged boulders from falling onto road bed. Terrain is unfavorable for airfield construction.

Remarks: Construction material suitability of this unit is given in table 2; engineering test data in table 3.

UNIT NO. 10 CLAYEY VOLCANIC SEDIMENTS

General description: Stratified layers of silt, silty clay, sandy clay, marl, and weakly-cemented, calcareous, tuffaceous sandstone; silt and clay layers predominate. Maximum thickness of this unit is approximately 200 feet. Individual beds range from a few inches to several feet in thickness and are various shades of brown, green, gray, and red; they are inclined generally eastward at moderate angles, and in some areas are gently folded, deeply incised, and eroded. Some beds are partly bentonitic, and swell when wet. Textural and compositional differences between beds, undulations caused by folding, and erosion account for exposure of dissimilar layers at different locations within the unit. Typical exposures are shown in plates 16A and 16B.

Landforms: Part of unit comprises gently-sloping, gullied uplands and part hilly areas with sharp spurs and narrow ravines.

Overburden and weathering: Overburden soil mantle, where present, ranges from a few inches to three feet in thickness. Most beds contain highly altered volcanic materials, with a high percent of clay, and are weakly cemented.

Excavation and tunneling: Excavations can be made easily by hand tools or power equipment without blasting. Wet material is highly plastic and strongly adhesive to excavation equipment. A few short adits driven into this material are standing fairly well but portals are badly caved. Lining is probably needed in most tunnels for permanent use; stand-up time above water table varies with changing ground conditions and may be comparable with that of slowly raveling ground or even firm ground in some beds, and is comparable with squeezing ground in other beds containing plastic materials or bentonite. Most

A. Unit No. 10 Clayey volcanic sediments. Quarry at Laderan Dago, about 800 feet east of Isley Entrance Road, south-central Saipan. Sample site No. 2.

B. Unit No. 10 Clayey volcanic sediments. Cut along East Coast Highway, district of I Hasngot, northeast Saipan.

excavations to great depth will probably require shoring. Seepage and drainage are moderate to slow and water stands for long periods on puddled floors.

Slope stability and erosion: In excavations of 10 feet or less, vertical slopes may remain stable for fairly long periods. In deep excavations, slopes of $\frac{1}{2}$:1 may be required. Material is easily eroded and gullies on steep slopes become incised rapidly. Undermining of the sandstone beds is common, leaving protruding masses that slump and eventually break off to form talus deposits at the base of excavations.

Foundation conditions: The bearing capacity of most of the material in this unit is poor. Weakly-cemented sandstone beds may improve the bearing capacity somewhat. but variations in local conditions can best be determined by subsurface investigations with borings at sites where permanent structures are proposed. CBR (California Bearing Ratio) results for samples tested are poor; the clay sample shows an excessive percent of swell.

Quarries: Extremely limited development. The only observed excavation is near Isley Field, at the north end of Laderan Dago, in south central Saipan, at the site from which a test sample was taken.

Road and airfield construction: Road construction in the hilly areas require moderate to deep cut and fill with some fairly steep grades and short-radium curves; elsewhere construction conditions are less difficult, with only moderate cut and fill required. Subgrade conditions and drainage are generally poor to unsatisfactory, depending upon thickness and properties of prevailing surface beds. Most of the material is unsatisfactory for base course although the sandstone beds are somewhat better for this purpose than the silty clay and marl. Fills made of this unit should utilize as much as possible of the sandy material. In cuts where sandy beds dip at an angle toward centerline of the road, benches and protective measures on the cut slopes may be needed to prevent sliding and slumping. The wide variation of materials composing this unit results from textural and compositional differences between beds. Different beds are exposed at various localities, depending on where the outcrop lies within the succession of beds as determined by the nature and degree of folding and erosion. Borings along centerline of new construction are essential to determine thickness and properties of the underlying beds. Terrain is unfavorable for airfield construction.

Remarks: The plastic material within this unit is excellent for binder. Two samples from different beds in this unit were tested; one is a sample of tuffaceous sand, and the other is a sample of silty clay; they were taken from different locations. See table 3 for results.

UNIT NO. 11 COMPACT DACITE

General description: Fairly hard, massive, compact, glassy, porphyritic dacite rock; closely jointed and fractured. Contains extremely hard, but brittle, siliceous zones. Commonly intercalated with and overlain by unit 12. Typical exposures are shown in plates 17A, 17B, and 18A.

Landforms: Hills with many steep slopes, vertical scarps, and deep ravines; prominent sea cliffs along the coast of northeast Saipan at Unai Fanunchuluyan.

Overburden and weathering: Surface mantle of soil above this unit in most places is less than one foot thick, and is absent in many prominent outcrop areas. Locally, soil is 2 or 3 feet in thickness, developed in part upon adjacent rocks of unit 12. Most rock is unweathered, but occasionally is leached and altered. Mostly fairly hard; within siliceous zones the rock is extremely hard and brittle.

Excavation and tunneling: Excavations require blasting. Hard, siliceous zones drill with difficulty. Nearly all of this rock fractures readily with normal blasting charges; high fragmentation is expected because many seams and cracks are present. Shoring may be required occasionally for deep excavations or for tunnel portals to

A. Unit No. 11 Compact dacite in upper part. Unai Fanunchuluyan, northeast Saipan.

B. Unit No. 11 Compact dacite. In valley on southwestern flank of Ogso Achugau, northeast-central Saipan.

prevent loose blocks from falling; vehicular tunnels may require lining for the same purpose. Shallow excavations do not require shoring. There seems little danger of massive slumping or caving, and excavations will stand on a nearly vertical slope. Borings may be necessary to locate hard, siliceous zones and to establish the thickness of unit 12 with which this unit is interlayered.

Slope stability and erosion: Vertical slopes are stable but there is danger from falling rock in fracture and shear zones. Sea cliffs have overhang. Excavations and exposures are highly resistant to erosion.

Foundation conditions: Excellent. Bearing capacity is adequate for the support of heavy, permanent structures and equivalent to that of any comparable solid rock; no cavernous underground conditions occur.

Quarries: The only quarry observed in this unit is in fractured, brecciated rock near the junction of the East Coast Highway and Little Burma Road. However, numerous potential sites in better rock could be developed easily with limited prospecting.

Road and airfield construction: Road construction is very difficult and requires deep cuts and fills, possibly some bridges and tunnels. Because this unit is not extensive, however, some areas can be bypassed if necessary. Excavations require drilling and blasting; excavated rock is a fair to good construction material. Subgrade and drainage conditions are excellent. Terrain is unfavorable for airfield construction.

Remarks: See table 2 for construction material suitability.

UNIT NO. 12 FRIABLE DACITIC BRECCIA AND TUFF

General description: Porous, commonly thinly layered, fragmental volcanic rocks, mostly breccia and tuff. Color gray or grayish white. Tuff beds contain loose, medium- to fine-grained, angular fragments of glassy dacitic rocks, dacitic glass, small crystals of quartz and feldspar, and occasional large crystalline dacite fragments. Breccia beds contain angular fragments of glassy dacite and, occasionally, crystalline dacite that range up to several inches in diameter. Most of this material, except the larger fragments, is not obtainable in large, firm, coherent lumps and easily falls to pieces when removed. Occasional massive zones of glassy dacite and crystalline dacite several feet thick and 100 feet or more in lateral extent occur within and underlie part of this unit. Typical exposures are shown in plates 18A, and 18B.

Landforms: Hills with many steep slopes and deep ravines; prominent sea cliffs along the northeast coast near Unai Fanunchuluyan.

Overburden and weathering: Surface mantle of soil ranges from a few inches to about 30 inches thick, but is generally absent. Most exposed beds contain some weathered material, but depth of weathering is not known. In the road cut where a channel sample was taken for engineering tests, there appeared to be very little change in the physical properties of the material from the surface to a depth of 35 feet.

Excavation and tunneling: Most of the unit can be excavated by hand tools and power equipment except the massive and generally irregular, indurated zones that require drilling and blasting. Excavations to moderate depth will probably encounter some compact, indurated rock; deep excavations may penetrate underlying massive, compact dacite of unit 11. Shoring is not required for shallow excavations. Tunnels require support; stand-up time is comparable with slowly raveling to firm ground. Seepage occurs along contacts of permeable with impermeable beds, and at the contact with underlying rock of unit 11; drainage from excavations is fairly rapid.

Slope stability and erosion: Nearly vertical slopes appear fairly stable for excavation depths of 30 to 35 feet. Some sea cliffs have slight overhand. Unit is somewhat more resistant to erosion than other unconsolidated materials such as units 5, 7, and 10, but many gullies and deep ravines are developed locally.

Foundation conditions: Bearing capacity is excellent. Engineering properties and behavior under load are probably similar to confined

A. Units No. 11 and 12 Compact dacite, and friable dacitic breccia and tuff. Achugau district, northeast-central Saipan.

B. Unit No. 12 Friable dacitic breccia. Southeast slope of Ogso Achugau, northeast-central Saipan.

sand. CBR, on sample tested, gave 128 percent with zero percent of swell. No cavernous underground conditions occur. Unit rests on solid dacite rock, unit 11.

Quarries: A small borrow pit along the Little Burma Road was excavated by power shovel, presumably for road construction. Many other prospective sites could be developed.

Road and airfield construction: Roads over most of this unit require moderate to deep cut and fill, with short-radium curves. Although most excavation is easily accomplished by hand tools, blasting is required in zones of massive, glassy, and crystalline rock. The limited extent of this unit, like that of unit 11, permits by-passing if necessary. Material is a good subgrade, good to fair for base course, and is well-drained. Terrain is unfavorable for airfield construction.

Remarks: See table 2 for construction material suitability.

UNIT NO. 13 COMPACT ANDESITE

General description: Moderately fresh, hard, tough, compact, fine-grained volcanic rock. Color dark gray, dark green, and red. Surface generally partly vesicular, with vesicles containing calcite and zeolites. Joint spacings vary greatly but are commonly greater than 2 or 3 feet; closely spaced columnar jointing occurs locally. Non-layered and not extensively fractured. Thickness of unit ranges from 30 to 100 feet. Typical exposure is shown in plate 19.

Landforms: Hills with rolling, dissected ridges and spurs separated by short V-shaped valleys. Total outcrop area only about 80 acres.

Overburden and weathering: Surface of rock shows intense weathering, extending to depths of tens of feet in exposures in south Saipan. Exposures in central Saipan only slightly weathered, but weathering extends to a depth of several feet along joints. Spheroidal weathering is prominent along closely-spaced columnar joints. Soil overburden and slope wash thick, except over small areas, ranges from 10 to 30 or more feet deep.

Excavation and tunneling: Blasting is required to excavate this rock. Drilling is difficult because of the toughness; fragmentation is low because of toughness and moderately wide jointing. Excavation properties are generally similar to those of trap rock. Shoring is not required. Tunnels require lining and support only in shear zones and local areas having closely spaced, loose jointing.

Slope stability and erosion: Vertical slopes are stable and this rock is highly resistant to erosion and scouring.

Foundation conditions: Excellent for all permanent structures. Conditions in this unit below the weathered zone are similar to hard, solid trap rock. No cavernous underground conditions occur.

Quarries: None were observed, but good potential sites could be developed with limited prospecting and exploration.

Road and airfield construction: Roads through the few known exposures of the unit would be difficult and require moderate to deep cut and fill with short-radius curves and steep grades. Excavated rock when crushed provides good material for base course and aggregate. Ledge deposits can provide satisfactory riprap. Subgrade and drainage conditions are very good. Seepage occurs at contact with overlying limestone, and with surface mantle of soil. Terrain is unfavorable for airfield construction.

Remarks: See table 2 for construction material suitability.

UNIT NO. 14 INDURATED ANDESITIC CONGLOMERATE AND SANDSTONE

General description: Compact, moderately hard and tough volcanic conglomerate occurring in lenticular beds associated with tuffaceous sandstone. Composed of rounded to subangular andesitic fragments of pebble size up to large boulders cemented in a dense, granular matrix. Color dominantly greenish gray. Bedding and jointing poorly developed to indistinct. Some material resembles cemented gravel but the deposits are lenticular and grade laterally over short distances into beds of coarser or finer material.

Overburden and weathering: Overburden soil ranges from a few inches to

Unit No. 13   Compact andesite. About 1000 feet northeast of As Perdido Road, district of Fina-sisu, southwest Saipan.

1 or 2 feet in thickness. Most of this rock is relatively fresh; alteration extends to a very slight depth below the surface.

Landforms: Hills with rolling dissected ridges and spurs separated by short V shaped valleys, similar to unit 13.

Excavation and tunneling: Blasting is required. Drilling is less difficult than in andesite rock of unit 13; fragmentation is low to moderate. Excavation properties and tunneling conditions are generally similar to those of unit 13. Shoring is not required for excavations to moderate depth.

Slope stability and erosion: Vertical slopes are stable; material is relatively resistant to scour and erosion.

Foundation conditions: Excellent conditions prevail within this unit for all permanent structures.

Quarries: None were observed but potential sites can be easily developed.

Road and airfield construction: Road construction conditions are less difficult than those in unit 13. Excavated rock has general utility, although somewhat inferior engineering properties compared with trap rock of unit 13. Terrain is unfavorable for airfield construction.

Remarks: See table 2 for construction material suitability.

UNIT NO. 15 BEACH SAND

General description: Medium- to fine-grained, creamy-white beach sand composed chiefly of comminuted shells and coral, and calcite grains. Contains less than two percent of clay and fines. Coarse-grained sand and some gravel occur in limited amount at Bahia Laulau. Quartz-rich sands occur at Unai Nanasu and Unai Fahang. Beach sand is abundant on the west coast between Tanapag and Chalan Kanoa. Most of this unit occurs as elevated sands from the beach up to 15 feet above sea level. Thickness ranges from less than 1 foot to perhaps 30 feet; average is 5 to 6 feet. Underlain by fragmental or pinnacled limestone bedrock.

Landforms: Coastal plains and beaches.

Overburden and weathering: There is no overburden. Constituent grains are water-worn but not chemically weathered.

Excavation and tunneling: Easily excavated by hand tools and power equipment. Unit is underlain by hard limestone bedrock having pinnacled surfaces that present difficulties during excavation of shallow sand layers. This unit is so shallow that tunneling is impracticable; the stand-up time above the water table compares with running ground, and below water table with flowing ground. All excavations with vertical walls require shoring to confine the sand and prevent caving; water table will ordinarily be encountered a few feet below ground surface.

Slope stability and erosion: Unit is so shallow that no deep cuts occur. Material is easily and swiftly eroded; slopes require protective riprapping or stabilization.

Foundation conditions: Bearing capacity of the dry confined sand above water table is good, and is comparable with any beach sand having a similar composition. However, many unfavorable conditions prevail throughout most of the unit, the most important of which include shallow depth, high water table, low elevation above sea level and proximity to shore, and low resistance to erosion. Sites where massive, permanent structures are planned require a detailed subsurface investigation.

Quarries: Material was excavated along the beach in southwest Saipan and at other places. No large pits were observed but many can be developed. Recovery will involve careful, shallow stripping operations, and in many places the sand layer is too thin for practical recovery.

Road and airfield construction: Roads have long-radium curves with negligible cut and fill. Subgrade and drainage conditions are very good. Terrain is favorable to the construction of a limited number of north-south trending airfield sites, but selection will be hindered by habitation, roads, and other cultural features.

Remarks: Used locally for sand-blasting operations in buoy reclamation. Can be used for mortar sand when properly washed and graded. See table 2 for other construction material suitability.

UNIT NO. 16 LAGOON DEPOSITS

General description: (Based on examination of material dredged from the lagoon floor, Tanapag Harbor, by U. S. Navy). Material consists of a loose, unconsolidated mixture of gravel-sized coral fragments, shell fragments, shells, sand, silt, organic matter, and some clay. Color gray, but rapidly changes on exposure to a yellow or pale brown. The gravel portion constitutes about 50 percent of the mass by volume, and many varieties of coral are present. Contains a high percent of organic matter. Autogenous properties develop upon exposure to air; after 60 days of exposure the surface of a pile of this unit, dredged from the lagoon, was cemented like concrete.

Landforms: Not applicable to this unit.

Overburden and weathering: Organic matter is rapidly oxidized on exposure to air.

Excavation and tunneling: Easily removed by dredging equipment.

Slope stability and erosion: (Applicable to dredged material, and not to material in place in the lagoon.) Embankment and fill slopes will probably remain stable on 1:1 if the material is well-compacted. Freshly-placed material is easily eroded, but becomes resistant to erosion after an exposure of 60 to 90 days.

Foundation conditions: No underwater data available. Pile foundations used in the Tanapag Harbor area appear stable; a few fill approaches however, show subsidence and "boiling".

Quarries: Not applicable to this unit.

Road and airfield construction: Not applicable to this unit. See Table 2 for construction material suitability of dredged material.

Remarks: This material is not easily processed for the recovery of aggregate. Lagoon deposits have had a wide use since 1944 by the military for embankment, fill, base course, and harbor work. Lateral and vertical variations in gradation, composition, and engineering properties of lagoon deposits do not come within the scope of this report.

UNIT NO. 17 MARSH DEPOSITS

General description: Highly plastic blue-gray sandy clay, containing a high percent of colloidal and organic matter. Unit weight is quite low; moisture content very high.

Landforms: Depressional areas on coastal plains, several permanent ponds, and marshes.

Overburden and weathering: Not applicable.

Excavation and tunneling: Easily excavated above the water table by hand tools or power equipment. Excavations below water table are impeded by adhesion of clay to equipment; require shoring, caissons. Unit is too thin for tunnel construction, but stand-up time is equivalent to that of squeezing ground.

Slope stability and erosion: High water table makes ordinary excavations impracticable.

Foundation conditions: Unsatisfactory. Cohesion and angle of internal friction are very low. Bearing capacity is poor. CBR test on undisturbed sample showed 3 percent, with 28 percent of swell. Drainage and stripping of this material are required to permit footings to rest on firmer ground unless pile foundations are used. Construction on marsh should be avoided.

Quarries: None.

Road and airfield construction: Road construction is difficult; subgrade conditions are extremely unsatisfactory and drainage is a major problem because of high water table. Excavation is impeded by strong adhesion of clay to equipment. Fills placed over this unit will settle, and some "boiling" is to be expected. Excavated material is probably unsatisfactory for embankment and fill. Bearing capacity is poor and swell excessive. Unit is unsatisfactory for airfield construction.

Summary of Engineering Geology Conditions

The following is a summary of engineering geology conditions applicable to construction materials, excavations, foundations, road construction, and airfield construction which are covered in detail by the text and tables.

Construction materials: On Saipan, natural construction materials are abundant. Limestone units 1 and 2 are widespread, easily accessible, and can supply rock for coarse aggregate for concrete, surfacing, base course, riprap, masonry, and other uses. Volcanic rock of units 11, 13, and 14 is less extensive and rather inaccessible, but can also be used for aggregate, base course, riprap, and masonry. Coralline rubble, unit 3, does not require crushing, and is an excellent source of base course. Medium- to fine-grained beach sand, unit 15, is available along parts of the west coast; this material has a variety of uses but is too fine-grained for concrete aggregate. Unit 9 contains limited amounts of gravel of fair to poor quality; considerable processing is required to make satisfactory concrete aggregate. Units 5, 6, 7, and 10 provide excellent binder.

Excavations: Excavations in well lithified units 1 and 2 require drilling and blasting; overburden stripping above pinnacled bedrock surfaces is difficult. Excavations in volcanic rock units 11, 13, 14, and parts of 12 also require drilling and blasting. All other units can be excavated by hand tools or power equipment. When wet, most of the clayey materials of units 4, 5, 6, 7, 8, 10, and 17 strongly adhere to excavation equipment.

Foundations: Foundation conditions are excellent to good in all units except 5, 6, 7, 8, 10, 17, and parts of 4. Limestone units 1, 2, 3, and parts of 4 are stable from a standpoint of adequate bearing capacity but they contain caverns and other underground openings of a concealed nature that may cause subsidence or collapse; detailed subsurface investigations are necessary at all sites where permanent structures will be placed.

Road construction: Roads can be easily constructed over the large, flat areas of units 2, 15, and 17; construction conditions are moderately difficult and require some cut and fill with many curves and some fairly steep grades in units 1, 3, 4, 5, 6, 7, 8, 9, and 10; conditions are difficult in volcanic units 11, 12, 13, and 14 and require deep cut and fill, many sharp curves and steep grades, with possibly some bridges and tunnels. Bearing capacity and subgrade suitability are excellent in units 1, 2, 3, 11, 12, 13, and 14; in units 4, 9, and 15 they are good; but in the clayey materials of units 5, 6, 7, 8, 10, and 17 the bearing capacity, subgrade suitability and drainage conditions are poor to unsatisfactory.

Airfield, construction: Firm, porous limestone, unit 2, provides favorable terrain for the best sites for airfield construction, with excellent subgrade and drainage conditions. The existing fields are built on this unit and other sites could be easily developed. Unit 3 has favorable terrain for only a few sites with excellent subgrade and drainage conditions. Unit 15 has favorable terrain for sites with good subgrade and drainage conditions but site development in most of this unit would infringe upon habitation. Units 6 and 17 have favorable terrain for a limited number of sites, but subgrade and drainage conditions are poor to unsatisfactory. In all other units terrain is unfavorable for airfield site development.

ENGINEERING ASPECTS: PART II, ENGINEERING ASPECTS OF SOILS

Introduction

The section on engineering aspects of soils consists of a map, text, and a table describing the units of soil material whose aerial distribution is shown on the map. These units were synthesized from classes of soils established during a detailed basic soil survey of Saipan. In the basic, detailed soil survey, soils were separated into classes which could be mapped on the basis of differences in color, reaction (acidity or alkalinity), consistency or plasticity, structure, and particle-size distribution (texture) of the various soil "horizons" or layers; the number, relative arrangement, and thickness of these various horizons; and the type of "parent material" from which the soil is developing. These classes were mapped in the field after examination of many hundreds of auger borings to depths of nearly 5 feet, examination of soils in road cuts, quarries, and borrow pits.

Upon establishment of these basic soil classes (known as "soil series") and their delineation on maps, they were aggregated into units according to similarity of properties relevant to engineering practice. These are, in general, Corps of Engineers designations (i.e., relative particle-size distribution and plasticity), depth of soil material, and nature of material underlying the soil. It is these aggregated units which are shown on the map and described in the text and table. The combinations of basic soil units, or classes, of which the engineering aspects of soils units are composed are found in table 4. Detailed descriptions of these basic soil units are given in separate report "Soils of Saipan, Mariana Islands."

Seven bulk samples of soil material and two CBR (California Bearing Ratio) tube samples were collected and submitted for laboratory tests. Results are given in table 3 (Engineering Geology).

These results are reflected and utilized in evaluating soil units in this section.

The purpose of the text and table is to provide a qualitative description of the properties of the soil materials relevant to engineering practice. The purpose of the Engineering Aspects of Soils Map (plate 5) is to illustrate the areal distribution of these types of soil material on Saipan. It is emphasized that these data and descriptions of properties are not intended to take the place of detailed, quantitative tests - such as Proctors and in-place density.

It should be borne in mind that the Corps of Engineers designations (such as MH, fat clay) are based on ranges of Atterberg limits and of particle-size distribution found desirable for engineering practice in temperate regions and which, therefore, may not apply very well to tropical, lateritic soils with their higher accumulations of iron and aluminum oxides and greater weathering.

The soils of Saipan are more plastic and firm, contain a higher percentage of swelling-type clay minerals, and are stickier when wet than would be expected under the prevailing tropical climatic conditions, that is, they do not have many of the properties of typical lateritic soils. This is apparently due to the type of weathering resulting from the 80-inch annual rainfall without a pronounced dry season and also to the relatively high content of swelling-type clay minerals in the parent materials giving rise to these soils. These soils do not dry out as quickly after rains as typical lateritic soils, nor are they as stable (resistant to erosion) in steep cuts.

This report is intended to describe the surface 5 feet, approximately, of soil material. Unconsolidated material deeper than this is described in the Engineering Geology section of this volume.

Description of Engineering Soils Units

The essential elements of information on the engineering aspects of the soils of Saipan are given in Table 4. The following descriptions supplement that table and include a general description of the soils, their relation to the topography, general comments on the ease of movement within the unit, and recorded observations on the vegetation cover and its potential value as concealment in military operations.

It should be noted that no detailed analysis of Saipan was made for cross-country movement conditions (i.e., for tracked vehicles) or military aspects of vegetation. The comments on ease of movement, vegetation and concealment given in this section are merely the recorded observations of the party and are here presented only as a potential guide in indicating problems which would normally be encountered in any engineering operation in undeveloped areas. The comments on vegetation for example would indicate in a general way the nature of clearing which might be necessary.

UNIT NO. 1 STONY CLAY, SHALLOW, OVER LIMESTONE

General description: This is a residual, dark-brown stony-soil material, generally of lean (non-plastic) clay, about neutral in reaction, and averaging about 6 to 15 inches deep over limestone.

Topographic relations: It occurs on limestone uplands which consist generally of a series of terrace or bench levels of moderate relief, broken by steep rugged slopes and cliffs. About one-third of the total area of this unit occurs on gradients of over 15 percent, the rest on gradients from 5 to 15 percent.

Ease of movement: Smoother areas (about two-thirds of unit) are trafficable to wheeled vehicles and easily traversed by foot troops, with some limestone-outcrop obstructions. Hilly and steep areas are not trafficable by vehicles and may be nearly impassable locally for foot troops, owing to brush, rock outcrops, and cliffs.

Vegetation and concealment: Over half of the area has a cover of abandoned sugar cane, 4 to 6 feet high. This cane is tangled and provides some screen for troops from ground observation but not from aerial observation. The rest of this area has a cover of low trees and shrubs which provide fair to good concealment from ground observation.

UNIT NO. 2 CLAY, DEEP, OVER LIMESTONE

General description: The unit is a residual, red and brown, fat (highly plastic), firm clay averaging several feet in thickness over limestone. The contact of the clay with the underlying limestone is sharp but irregular. A slightly darker 6-inch surface layer has essentially the same soil engineering characteristics as the underlying soil material, though of a slightly higher humus content and probably lower clay content.

This unit includes areas of alluvial clays or clay wash which occur in sinks and valleys. Though these alluvial clays are darker in color than the predominant material of this unit, soil engineering properties are similar.

In many areas of gently sloping terrain the soil contains appreciable percentages of dark ferro-manganese nodules averaging about one-fourth inch in diameter and comprising as much as five percent of the total volume.

Topographic relations: About three-fourths of the area of this unit is gently sloping limestone uplands with some sinks and limestone outcrops. The other fourth is hilly and steep.

Ease of movement: When dry, vehicles can move with ease on gently sloping terrain. When wet, the soil tends to be slippery, rather sticky, and soft, but it dries rapidly in the sun. In places, tangled sugar cane slows foot travel.

Vegetation and concealment: A large percentage of this unit has a cover of abandoned sugar cane averaging 4 to 6 feet high. It is tangled and provides some concealment from ground observation but affords little from air observation. Second-growth bush which is gradually invading parts of these areas provides some concealment. Interspersed with these areas are small areas of rough stony land with clumps of trees which provide fair concealment.

UNIT NO. 3 CLAY MODERATELY DEEP, OVER LIMESTONE

General description: The subsoil is residual, brown, friable to firm, permeable clay two to three feet deep overlain by a dark-brown topsoil layer a few inches thick. This darker layer contains a higher percentage of organic matter and is less plastic; however, it is not necessary to treat it separately because the engineering properties are not of appreciable difference and it makes up only a small percentage of the soil.

The contact of the clay with the underlying limestone is abrupt but irregular with occasional pinnacles. Small areas of shallow soils are scattered throughout this unit. The larger part of this unit is in southern Saipan in the vicinity of Kobler and Isley Airfields.

Topographic relations: Almost all of this unit occurs on gently sloping uplands with a prevailing surface gradient of less than eight percent, generally bounded by steep limestone cliffs or slopes.

Ease of movement: Areas of this unit are excellent for foot travel and wheeled vehicles when the soils are dry; during the rainy season, the soils are slippery, sticky, and soft, however, these permeable clays dry rapidly with a few hours of sunshine.

Vegetation and concealment: The major part of the unit has a cover of tangled abandoned sugar cane, 4 to 6 feet tall. Cane affords some concealment from ground observation, but poor concealment from aerial. Minor parts of this unit have a brush cover which offers some concealment.

UNIT NO. 4 CLAY, DEEP, OVER VOLCANIC ROCKS

General description: The soils are residual, very firm and plastic, reddish clays, acid in reaction, which grade into highly altered, soft, volcanic rock at depths of 27 to 36 inches. The topsoil is generally somewhat darker than the subsoil, and contains more organic matter, but has engineering properties similar to the subsoil. The depth to unaltered and unweathered volcanic rock is about 25 to 45 feet. In scattered small areas the clay is underlain by impure, volcanically contaminated limestone at depths of about 3 to 4 feet. The principal occurrences of this unit are in east central Saipan and north of Hagoi Susupe in southern Saipan.

Topographic relations: About one-half of the total area of this unit is on gently sloping uplands, the remainder is hilly uplands with steep ridges and narrow valleys.

East of movement: When dry, the soils are good for foot travel and wheeled vehicles on gently sloping terrain; fair on hilly. In wet weather, the soils are slippery, soft, and somewhat sticky.

Vegetation and concealment: A greater part of this unit has a cover of abandoned cane or grasses that offer little to no concealment; a lesser part has cover of brush and low trees which afford fair to good concealment from air and ground observation. There are usually clumps of trees or brush scattered throughout the unit so that some type of concealment is available.

UNIT NO. 5 CLAY, SHALLOW, OVER VOLCANIC ROCKS AND IMPURE LIMESTONE

General description: The soil is residual, reddish, acid clay of varying plasticity over mottled, highly altered, soft, volcanic rocks; soft bedded sediments from volcanics; or highly impure limestones.

Topographic relations: The unit is distributed on predominantly hilly and steep uplands with narrow ridges, deep ravines, and many gullies.

Ease of movement: The soils are fair to good for foot travel, fair to poor (locally impassable) for wheeled vehicles due to steep slopes. When wet, the clay is slippery and soft.

Vegetation and concealment: The major part of this unit has a cover of brush or low trees which offer concealment from ground and aerial observation. There are some local spots of grass which offer poor concealment and a species of low tree, common on this unit, which affords excellent overhead concealment.

UNIT NO. 6 LIME SAND

General description: The unit consists of deep, light-colored sand composed of small fragments of coral and sea shells with a darker surface layer several inches in depth. The material is loose, non-plastic, and drains rapidly.

Topographic relations: This unit occurs on nearly level coastal flats, a few feet above sea level along the western coast.

Ease of movement: The sands are readily traversable by vehicles and foot troops. They are firm when moist, loose when dry.

Vegetation and concealment: The vegetation is sparse but where present consists of belts of strand vegetation, cultivated areas around villages, and brush areas inland from beach, all offering but little concealment.

UNIT NO. 7 ROCK LAND

General description: This unit includes areas of very shallow soils and rock outcrops of limestone and dacite which are usually rough and hilly to steep. The soil is so shallow that the engineering geology equivalents of this unit should be consulted for details.

Rough stony land on dacite is confined to about 250 acres in northern Saipan. Rough stony land on limestone is widespread and covers about one-third of the total area of Saipan.

Topographic relations: Rough stony land on limestone is generally hilly and steep with sharp cliffs. A few areas occur on sloping bench along coasts bounded by cliffs and scarps and in occasional steep-sided valleys and sinkholes. Rough stony land on dacite is steep to very steep with deep ravines and sharp peaks.

Ease of movement, vegetation and concealment: The limestone areas usually have a cover of rather dense trees and brush offering excellent concealment but difficult to move through; valleys and forested areas are good for bivouac and parking. The dacite areas have a cover of grasses which offer no concealment from air observation and little from ground. Both the limestone and dacite areas have many peaks and ridge tops from which observation of surrounding area is good.

UNIT NO. 8 MARSH

General description: The soils in the marshes are wet to saturated mottled dark clays of depressional areas of coastal lowlands. The clay is slightly to moderately plastic, occasionally underlain at shallow depth by marl-like material. There are several permanent ponds and one slightly brackish lake (Hagoi Susupe) in this unit.

Topographic relations: The marshes occur in level depressional areas on flats of western coast, most extensive east of Chalan Kanoa in southern Saipan.

Ease of movement: Marshes are impassable for wheeled vehicles and difficult to cross on foot although during the dry season the soil is somewhat more firm.

Vegetation and concealment: The vegetation consists of tall grasses, ferns, and open vine-covered areas which offer little, or no concealment.

Glossary of Terms

algal reef - A reef or portion of a reef composed primarily of the hard calcareous secretions of marine plants called algae.

andesite - A volcanic rock, of fine-grained texture, consisting chiefly of plagioclase feldspar and ferromagnesian minerals, without olivine.

autogenous - The property of becoming cemented after removal from original deposit. Similar to the setting characteristic of cement, only less pronounced.

basal water - Ground water in hydrostatic equilibrium with sea water. Compare with artesian (under hydrostatic pressure) and perched (trapped at higher subsurface levels by impermeable rock strata).

bedded - Applied to rocks having distinct planes of separation resulting from changes in the environment during deposition.

bench - A narrow, approximately horizontal, terrace or step-like ledge.

bentonite - A plastic, clay-like material consisting largely of the mineral montmorillonite, and formed by the weathering of volcanic ash or tuff. It swells enormously in water and forms a milky suspension.

bioclastic - Consisting of fragments of animal skeletons or plant material, most commonly calcareous.

breccia - A rock composed of moderate to large-sized angular fragments cemented together.

brecciated - Converted into, or resembling a breccia.

Cenozoic - See "geologic time."

chert - A very fine-grained dense rock consisting of opal or chalcedony, often with some quartz, and sometimes with accessory calcite, iron oxide, organic matter, sponge spicules, or other impurities. It is usually associated with limestones, either as entire beds or as isolated, included masses. It has a homogeneous texture, and a white, gray, or black color.

columnar jointing - Process of jointing where the fissures form columns polygonal in cross-section.

concretion - A spherical to disc-shaped or irregular body ranging in size from a pebble up to several feet in diameter, formed by the segregation and precipitation of some soluble material; generally in rock of a composition different from its own and from which it separates on weathering.

conglomerate - A rock made up of worn and rounded pebbles of other rocks, cemented together.

coralline algae - Marine plants which secrete hard calcareous material; not to be confused with corals, which are animals.

creep - The slow, natural movement of soil and rock waste down the slope from which these materials have been derived by weathering.

crystalline - A term commonly applied to rocks consisting of crystallized minerals and no glass, as contrasted with one made up of cemented grains of sand or other material.

dacite - A fine-grained volcanic igneous rock containing essential plagioclase and quartz, with or without hornblende and biotite or both.

detrital - Pertaining to mechanically, although naturally, formed rock debris.

endemic - Confined to a certain limited area or climate; native.

Eocene - See "geologic time."

escarpment - A generally linear cliff or relatively steep slope. Scarp and escarpment are generally synonymous although the term "scarp" commonly implies origin by faulting.

facies - A term applied to varieties within a single body of rock; thus, a single rock formation may exhibit differences in characteristics (different "facies") from area to area because of differences in the environment from area to area at the time when that specific formation of rock was deposited.

fat - Applied to clays lacking any significant amounts of silt or sand and thus are highly plastic, slippery, and sticky.

fines - As used in the Corps of Engineers, Uniform Soil Classification (based on Casagrande Classification), March 1949, the term "fines" applies to that fraction or percent of the soil which passes the No. 200 mesh sieve (0.074 mm).

firm ground - Material will stand almost vertical for some time, after being exposed, before any movement begins.

flowing ground - Material moves like viscous liquid.

flow rock - Rock solidified from moving lavas.

fragmental limestone - A rock consisting of consolidated calcareous debris generally of gravel or pebble size.

friable - Easily disintegrated or crumbling naturally; easily broken in the fingers; non-plastic.

geologic time - Geologic time as referred to in this report is expressed in eras, periods, and epochs. The largest unit is the era which is subdivided into periods which in turn are subdivided into epochs. There are four eras of geologic time; listed in order of increasing age they are Cenozoic, Mesozoic, Paleozoic, and Proterozoic. Only rocks deposited during the Cenozoic era are found on Saipan. The Cenozoic era is subdivided into 2 periods and 7 epochs as shown in the following tabulation

- Cenozoic (era)
  - Quaternary (period)
    - Recent (epoch)
    - Pleistocene (epoch)
  - Tertiary (period)
    - Pliocene (epoch)
    - Miocene (epoch)
    - Oligocene (epoch)
    - Eocene (epoch)
    - Paleocene (epoch)

grit - A coarse sand or sandstone formed mostly of angular quartz grains.

igneous - Term applied to rocks which have been formed by solidification from the molten state.

indigenous - Growing or living naturally in an area or climate; native.

indurated - Hardened; applied to rocks hardened by heat, pressure, or the addition of some ingredient not commonly contained in the rock referred to.

inequigranular - The texture of crystalline rocks in which the grains are of various sizes.

joint - A natural parting plane or gently curved crack, fissure, or fracture in rock along which it breaks with ease; a purely mechanical effect.

laminated - Containing many closely spaced, distinct planes.

lateritic - Applied to soils which develop under humid-tropical and subtropical conditions where chemical weathering is intense and continuous. Organic residues are rapidly reduced to carbon dioxide; silica is removed resulting in high concentrations of iron and alumina; color is commonly red.

lean - Applied to clays having a sufficiently high percentage of silts and sand to result in relatively low plasticity, slipperiness, and stickiness.

leguminous - Bearing fruit in pods, as peas; by implication, nitrogen-fixing plants.

lenticular - Lens-shaped.

lithify - To consolidate or become consolidated into rock, either from a molten condition, as lava, or from a state of loose aggregation, as sand or gravel.

loam - A mixture of approximately equal parts of sand, silt, and clay.

mantle - The loose, unconsolidated rock material, such as sand, gravel, and clay resting on the solid rock.

marginal (deposit) - Consisting of or pertaining to material laid down in an environment, commonly marine, closely adjacent to a land mass.

marl - An earthy, friable material consisting chiefly of clay mixed with calcium carbonate.

massive - Occurring in thick layers, if stratified at all, free from minor fractures and planes of separation.

matrix - The general mass of a rock which has isolated crystals or larger fragments; sometimes called groundmass.

Maui-type well - A water well consisting of, or including horizontal collection galleries at or slightly below the ground-water level.

Miocene - See "geologic time."

moat - A channel, generally shallow and parallel to the shoreline situated between the margin of a fringing reef and the shore.

morphology - Denoting structure, form, and shape.

non-bedded - Lacking distinct planes of separation; massive.

phase (slope) - See "slope phase."

pinnacle (hidden, subsurface) - Spire-shaped protrusion, of several feet, of bedrock extending slightly above, to, or immediately below the soil surface.

pit-run gravel - The term generally applied to the mixture of gravel, sand, and foreign materials as it occurs naturally in any deposit.

Pleistocene - See "geologic time."

primary (volcanic rocks) - In the original position and condition of deposition or placement. Compare with "reworked."

profile (soil) - The soil in vertical dimension.

pyroclastic - Consisting of fragments or ejecta from volcanoes.

quartzose - Containing quartz as a principal ingredient.

Quaternary - See "geologic time."

raised reef - Any reef which is elevated relative to the body of water in which it was formed.

raveling ground - Chunks or flakes of material begin to drop out some time after the ground has been exposed.

Recent - See "geologic time."

relict structure - Remnants and relics of completely decomposed rock in which the original texture is preserved.

reworked (volcanic rocks) - Broken up by erosional processes and redeposited. Compare with "primary."

running ground - The material flows like granulated sugar until the slope angle becomes about 35 degrees.

scarp - A linear cliff or steep slope, most commonly implies origin by faulting.

series (soil) - A group of soils having soil horizons similar in character and arrangement, and developed from a particular type of parent material.

shear zone - In geology, a zone in which shearing has occurred on a large scale, so that the rock is crushed and brecciated.

siliceous - An adjective applied to rocks containing silica, the oxide of silicon (SiO_2).

slope phase - That portion of a given soil, however distributed areally, whose surface slope is within a specific gradient range.

slope wash - The process of removal of erosional debris from sloping surfaces by natural run-off of water which is not concentrated is well-defined channels; deposits of material so removed.

slump block - Large detached, isolated masses or blocks of rock that fall, slide or roll down steep hillside slopes, sometimes for a considerable distance from the parent bed.

solution surface - A very irregular surface (in limestone) from which much soluble material has been removed by water or by scour.

structure (soil) - The shape, arrangement, size, distinctness, and durability of visible soil aggregates. Typical soil structures include platy, columnar, blocky, and granular.

subaerial - Exposed to the atmosphere; as compared with submarine and subterranean.

surficial - Characteristic of, situated at, or occurring on the earth's surface; consisting of unconsolidated residual or alluvial deposits lying on the bedrock.

spheroidal weathering - Weathering which results in the formation of residual, boulder-like masses of rock having a crude spheroidal structure.

squeezing ground - The material slowly advances without any signs of fracturing.

stand-up-time - Time that elapses between the exposure of an area and movement of exposed material.

subgrade - Soil beneath the road surface.

tuff - A rock composed of fine-grained fragmental material usually finer than 4 mm, explosively ejected from a volcano; usually indurated but may be unconsolidated.

tuffaceous - Characteristic of, pertaining to, containing, or resembling tuff.

trap rock - A general name for the dark fine-grained and dense igneous rocks composed mainly of the ferromagnesian minerals, basic feldspars, and little or no quartz. A useful field name for any dark finely crystalline igneous rock, but most commonly applied to basalt, diabase, gabbro, and occasionally andesite.

vesicular - Containing many small cavities throughout the mass.

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