Geology of Ishigaki-shima Ryūkyū-rettō

GEOLOGICAL SURVEY PROFESSIONAL PAPER 399-A

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By HELEN L. FOSTER

GEOLOGY AND PALEONTOLOGY OF ISHIGAKI-SHIMA, RYŪKYŪ-RETTŌ

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The stratigraphy, the geologic history, and the regional relations of a small island in a western Pacific island arc

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GEOLOGY OF ISHIGAKI-SHIMA, RYŪKYŪ-RETTŌ

By HELEN L. FOSTER

ABSTRACT

Ishigaki-shima, Yaeyama-guntō, an island in the southern Ryūkyū-rettō, is about 440 kilometers southwest of Okinawa-jima and 240 kilometers east of Taiwan. The island represents one of the high points on a mostly submarine ridge that extends in an arc, convex toward the east, from Kyūshū in southern Japan to northern Taiwan.

About half of the island's area is hilly or mountainous, and most of the remainder consists of slightly to considerably dissected marine-cut terraces and narrow coastal lowlands.

The oldest rocks, probably Paleozoic in age, are those of the Ishigaki Group. These rocks consist of sediments and volcanic material—now metamorphosed—that were deposited in a geosyncline. The Ishigaki Group is divided into two formations, the Tumuru and the Fu-saki. The Tumuru Formation consists principally of greenschist, quartz-mica schist, and crossite schist. It has an estimated exposed thickness of about 600 meters. The Fu-saki Formation includes chert, phyllite, greenschist, conglomerate, quartz-mica schist, hornfels, and a little marble. A thickness of about 168 meters is exposed on Ishigaki-shima. In late Paleozoic or Mesozoic time, these geosynclinal deposits were metamorphosed, folded, and faulted. They were then uplifted and subjected to erosion.

Rocks of the Ishigaki Group are overlain unconformably by the Eocene (Tertiary *b*) Miyara Formation, which consists of conglomerate, sandstone, and limestone. This formation crops out in small patches near the coasts of the island at altitudes of sea level to 100 meters. On Funakuyā-wan the conglomerate contains abundant fossil mollusks. The limestone has well-preserved calcareous algae and some Foraminifera, particularly *Pellatispira* and *Discocyclina*. The maximum exposed thickness is about 102 meters. The Miyara Formation has been faulted and tilted but not folded.

The Nosoko Formation is a succession of tuffs, volcanic breccias, and lavas. The volcanic rocks are chiefly andesitic but include small amounts of basalt, dacite, and rhyolite. Volcanism began in Eocene time and may have extended into Miocene time; most of the activity occurred after the deposition of the Miyara Formation. The volcanic rocks are tilted and faulted in places.

The Ishigaki Group has been intruded by rocks ranging in composition from granite to diorite. Some intrusive rocks may grade into extrusive rocks. Granite and granite porphyry, called the Omoto Granite, are more abundant than granodiorite or diorite, and they compose a small stock. The granodiorite occurs mostly around the margin of the granite stock or as dikes and has been named the Cha-yama Granodiorite. The Sakieda Rhyolite is a light-colored, generally prophyritic rock that appears to grade into granite in the Kabira area. The age of the intrusive activity is probably Tertiary. The granitic rocks are much jointed and have been faulted.

The Sakishima Group, consisting of the Nagura Gravel and Ryukyu Limestone, overlies rocks of the Ishigaki Group and the Miyara and Nosoko Formations and the granitic rocks. The Nagura Gravel consists mostly of rounded to angular pebbles and cobbles in a reddish- or yellowish-brown loamy matrix, but it also includes a basal fossiliferous gray clay called the Bunera Clay Member. Although the clay contains abundant fossil mollusks, Foraminifera, other invertebrates, pollen, and wood, its age cannot be determined with certainty but is probably Pleistocene. In one locality along the Todoroki-gawa, the clay contains fossil deer bones and antlers. Maximum thickness of the Nagura Gravel is not known but is at least 23 meters in terraces along the Miyara-gawa.

The Ryukyu Limestone is a reef limestone that crops out mostly around the margins of the island. It is most extensive in southern Ishigaki-shima. It has two principal facies, sandy and coralliferous. Thicknesses of as much as 20 meters have been measured.

Recent deposits include raised beach sand and gravel and raised reef-flat deposits, sand dunes, beachrock, sand and gravel of the present beaches, and alluvium. A Recent terrace deposit of stony silt along the Todoroki-gawa yielded bones of pig.

The rocks of Ishigaki-shima have been acted upon by a succession of tectonic forces throughout their geologic history, and the resulting structures are directly and indirectly responsible for many aspects of the configuration and topography of the island. Northwest-striking ridges in the schist mountains west of Hoshino are the limbs of large folds, and one or more sets of smaller folds, including drag folds, are superimposed upon them. The offsetting of the Hirakubo peninsula from the Ibaruma peninsula and the Ibaruma from the Nosoko peninsula suggests the presence of parallel strike-slip faults.

Most of the faults that cut the Tertiary and Pleistocene rocks are high-angle faults. The volcanic rocks at the southern end of the Nosoko peninsula are separated from the metamorphic rocks of the Ishigaki Group by a high-angle fault. Hills of limestone of the Miyara Formation near Hoshino probably are fault blocks. The most distinct Pleistocene or Recent fault cuts the Ryukyu Limestone on Taketomi-shima and thereby makes a northward-facing escarpment.

Earthquakes in the Ryukyu Islands are evidence of continuing tectonic activity. Strong submarine earthquakes have produced destructive tsunami in the past and are a continuing threat to the islands. No recent volcanic activity is known in the Yaeyama-guntō except a submarine eruption northeast of the island of Hatoma reported in 1924.

The island contains no metallic mineral resources of commercial value. Nonmetallic mineral resources are limited to small quantities of such materials as limestone, clay, gravel, and rock for riprap and crushing; these materials are used only locally.

Surface water is used for most domestic water supplies and irrigation. Ground water is obtained from shallow dug wells and is used for domestic purposes in some villages. Many wells near the coasts are brackish.

INTRODUCTION

LOCATION AND SIZE OF THE ISLAND

Ishigaki-shima is one of the southern islands of the Ryūkyū-rettō, an arcuate chain of islands, commonly called the Ryukyu Islands, extending from southern Japan southwestward nearly to Taiwan (Formosa) (fig. 1). Ishigaki-shima is about 1,955 kilometers (1,215 statute miles) southwest of Tokyo, Japan; 440 kilometers (275 miles) southwest of Okinawa-jima, the principal island of the Ryūkyū-rettō; and 240 kilometers (150 miles) east of Taiwan. It extends from about lat 24°19′ to 24°37′ N. and from about long 124°04′ to 124°20′ E. It is included in the group of islands called the Sakishima-guntō (Sakishima archipelago), which is further divided into two groups, the Miyako-guntō to the north and the Yaeyama-guntō, including Ishigaki-shima, to the south. Ishigaki-shima is the easternmost island in the Yaeyama-guntō (pl. 1); it has the largest population and is the seat of government for the island group. Other islands in the Yaeyama-guntō are Taketomi-shima, the nearest to Ishigaki-shima; Iriomote-jima, the largest; Yonaguni-jima, the most distant from Ishigaki-shima; Kobama-jima, Hateruma-shima, Hatoma-jima, Kuro-shima, Aragusuku-shima; Okinokami-shima; and a few islets.

Ishigaki-shima has a maximum length of about 32 kilometers and a maximum width of about 19 kilometers. Because of its irregular shape, it has an approximate area of only 223 square kilometers (86 square miles).

PURPOSE OF THE REPORT

This report describes the geology of Ishigaki-shima, a little-known island that is important to an understanding of the geology of the Ryūkyū-rettō and the neighboring Pacific areas, including Japan. The island, although small, has considerable variety in its rocks. Some of its geologic features, such as the occur-

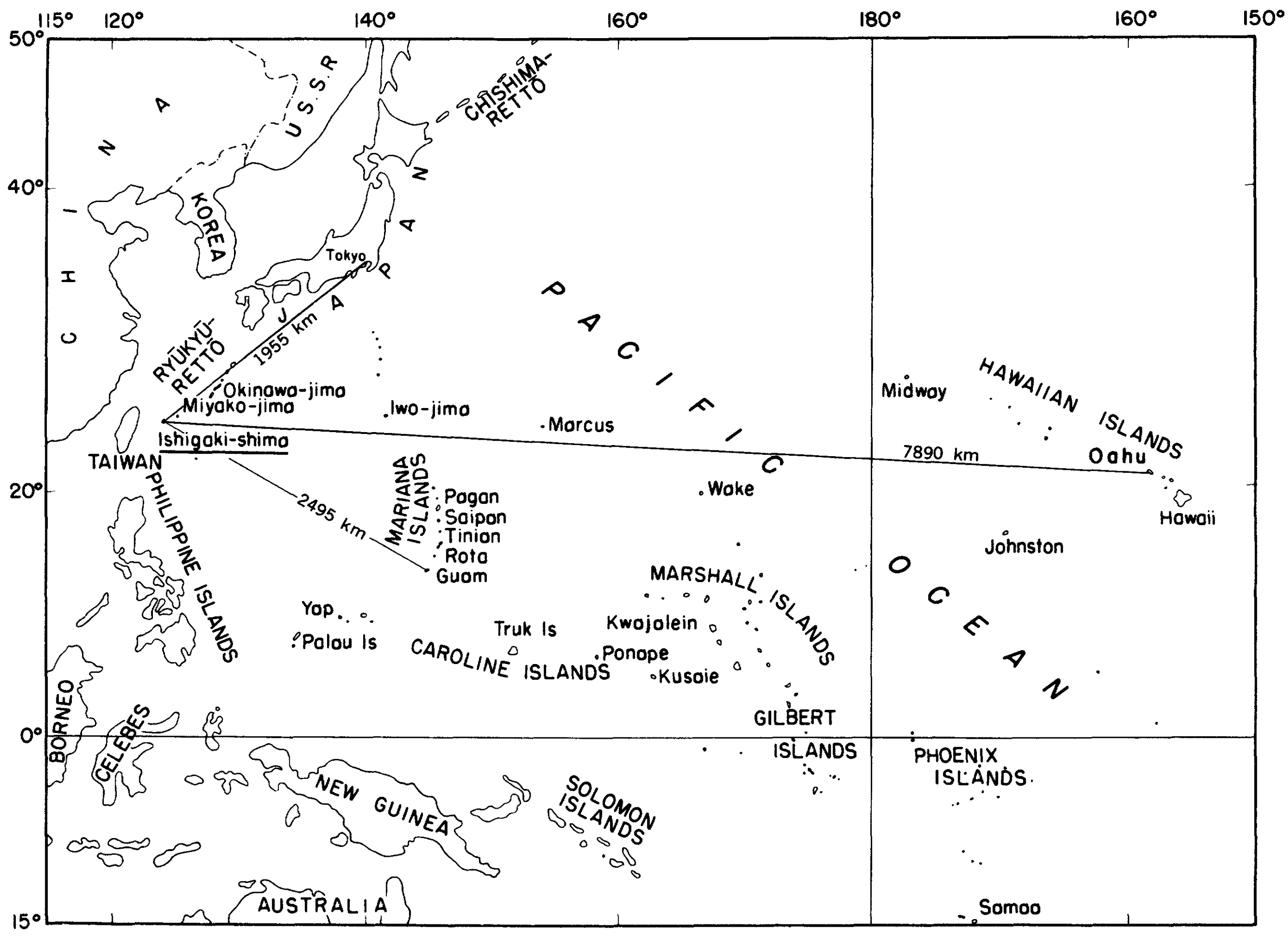


FIGURE 1.—Location of Ishigaki-shima, Ryūkyū-rettō.

rence of granite, are unique in the southern Ryukyu Islands. Glaucophane schists, fossiliferous Eocene rocks, and Pleistocene and Recent vertebrate fossils are other comparatively unusual features of the geology.

COLLECTION OF DATA

The geologic field data presented in this report were acquired from June 1955 to October 1956 when geology, soils, and vegetation were mapped by personnel of the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers. The geological investigations were made chiefly by the author, chief of the field party, and by Harold G. May. Soil scientists in the field party were Carl H. Stensland and Richard J. Alvis. F. Raymond Fosberg, botanist, studied the vegetation. Laboratory studies followed and supplemented the fieldwork. Although this report is primarily geological, information was also contributed by the soil scientists and the botanist.

The mapping of Ishigaki-shima was part of an extensive geologic and soils mapping program of about eleven western Pacific islands and island groups undertaken by the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers after World War II. Okinawa-jima and Miyako-jima in the Ryūkyū-rettō were also mapped under this program, and reconnaissance studies were made of other islands in the southern Ryukyus. The work on Okinawa-jima is reported in five volumes, "Military Geology of Okinawa-jima, Ryūkyū-rettō," published by the Office of the Engineer, Headquarters, U.S. Army Pacific. Military geology reports have also been published for Miyako-jima and Ishigaki-shima (Doan and others, 1960; Foster and others, 1960).

MAPPING METHODS AND COMPILATION

Field mapping on Ishigaki-shima was done largely on vertical aerial photographs flown in July 1955 by the U.S. Air Force, scale 1:12,000, and on Army Map Service (A.M.S.) map series L791, sheets 2920, I, II, and III, and 2919 IV, scale 1:50,000. Compilation of the geologic map was on a special one-sheet map, scale 1:40,000, compiled from the four 1:50,000 A.M.S. map sheets Compilation from the aerial photographs was done by visual methods without the aid of plotting and scale-changing instruments.

GEOGRAPHIC NAMES

The principal place names used in this report are those recommended by the U.S. Board on Geographic Names. Preliminary National Intelligence Survey Gazetteer, Japan (1953), was the primary reference. Where no decision was available for local place names, those employed by Foster and others (1960) for Ishigaki-shima were used because these names were carefully checked and authenticated by the field party while on Ishigaki-shima. If a choice of names was permitted by the Board on Geographic Names, the Japanese form was chosen in order that the names might be consistent with the other place names, most of which follow the Japanese form. Therefore, the designation Ryūkyū-rettō is generally used, but in a few places, for convenience, the also accepted anglicized form, Ryukyu Islands, is employed. Many of the place names, such as Ishigaki-shima, are of Japanese origin; but some, such as Nosoko-māpē or Bunada-baru, are words from Yaeyaman dialects.

HISTORY AND GOVERNMENT

The history of Ishigaki-shima is closely tied to that of Okinawa-jima because from earliest known times the islands of the southern Ryūkyū-rettō were ruled by native kings seated in Okinawa-jima. The kings exerted different degrees of control over local chieftains on the various islands, depending upon the power and influence of the individual king.

Chinese annals which include the Ryūkyū-rettō date from the early seventh century and record visits to the islands in A.D. 605 and 610 and a military expedition in A.D. 611 (U.S. Dept. Navy, Office of Chief of Naval Operations, 1944, p. 39). Some trade developed between Okinawa-jima and China, but no further official intercourse, diplomatic or military, is recorded for several more centuries.

The first recorded contact between the Ryūkyū-rettō and Japan was in A.D. 617 when some natives from Yaku-shima visited the Japanese court with gifts for the empress. Several other exchanges of gifts and envoys occurred between Japan and various of the Ryukyu Islands during this century, and representatives from Ishigaki-shima are reported to have visited Japan in the following century.

In 1372 the king of Okinawa-jima began to pay tribute to the Chinese court, and the influence of China became strong in the Ryūkyū-rettō and remained dominant until 1609. In 1451 the king of Okinawa-jima also began to pay tribute to Japan.

In 1609 the king of Okinawa-jima was defeated by the prince of Satsuma from Japan, and the Ryukyu Islands became virtually a protectorate of Japan; however, trade and cultural ties with China continued.

Toward the middle of the 19th century, various western powers became interested in the Ryūkyū-rettō as a possible means of opening trade with Japan. In 1844 the French landed on Okinawa-jima and were soon followed by the British. In 1853, Commodore Perry explored Okinawa-jima and concluded a treaty between the king of the Ryukyus and the United States guaranteeing good treatment for American ships. In 1854 the French obtained a similar treaty, as did the Dutch in 1858; however, because of the opening of direct relations with Japan shortly thereafter, the interest in the Ryukyu Islands decreased. In 1871 Japan began steps to incorporate the Ryūkyū-rettō as an integral part of the Japanese State. Eventually, the king of Okinawa-jima was removed to Tokyo, and Japan governed the islands until the Japanese were defeated on Okinawa-jima in 1945 in World War II. Before and during World War II, Japanese troops were garrisoned on Ishigaki-shima, but no actual fighting took place there.

At the close of World War II, the islands of the Ryūkyū-rettō were under the military government of the United States, but in 1950 the U.S. Civil Administration of the Ryukyu Islands (USCAR) was established. In 1951, a "Provisional Central Government" was organized to administer local activities and to form the basis of a permanent central government within the Ryukyu Islands. In 1952 the Government of the Ryukyu Islands (GRI) was established and now operates under supervision of the U.S. Civil Administration of the Ryukyu Islands.

The U.S. administration of the Yaeyama-guntō (Yaeyama group of islands) is supervised on Ishigaki-shima by the Yaeyama Civil Administration Team (YCAT). GRI is represented on Ishigaki-shima and other islands by various elected and appointed officials, and representatives of the people are elected to the legislature in Okinawa-jima. Major towns and villages and some small islands are governed by locally elected officials.

POPULATION AND LANGUAGE

Ishigaki-shima had a native population of approximately 33,000 in 1955 (U.S. Civil Administration of the Ryukyus, 1956, p. 165). The population has increased considerably since World War II, and it may continue to increase because of resettlement programs in which native peoples from Okinawa-jima and Miyako-jima are moved to new permanent homes on Ishigaki-shima and because of improved health conditions. Shika (Ishigaki City) is the largest population center on the island and has about 22,000 people. It is the center of trade, government, education, and other island activities. Ōhama, Miyara, Shiraho, and Kabira are the other large long-established towns or villages.

Japanese is written and spoken by most of the people on Ishigaki-shima and is taught in the schools, but several Yaeyaman dialects are still used, especially by older people in the smaller villages. Chinese is spoken by a few inhabitants.

ACKNOWLEDGMENTS

The work of the field party on Ishigaki-shima was greatly facilitated by the logistic support furnished by Maj. Russell A. Broner and members of the Yaeyama Civil Administration Team under his supervision. American military and civilian personnel, as well as native employees, gave much assistance to the field party. The efficient and varied assistance of Miss Setsuko Yamazato and the capable help of Mr. Yasuo Osoko were especially appreciated. The local inhabitants of Ishigaki-shima and neighboring islands were very cooperative and helpful. Transportation to and from Ishigaki-shima, mail service, and other assistance were provided by the U.S. Civil Administration of the Ryukyus (USCAR) from Okinawa-jima, and valuable assistance was rendered by the Office of the Post Engineer, Ryukyus Command, and the post engineers stationed on Ishigaki-shima.

Many samples and specimens collected during the course of fieldwork on Ishigaki-shima were studied by U.S. Geological Survey scientists. W. Storrs Cole identified the larger Foraminifera from the Eocene, Pleistocene, and Recent formations and contributed information on their age, ecology, and correlation. Ruth Todd identified the smaller Foraminifera and provided information on their probable habitat and age. John W. Wells identified the Pleistocene and Recent corals which were collected. Estella B. Leopold furnished age and ecological information from the study of pollen and spores. J. Harlan Johnson studied the calcareous algae; F. Stearns MacNeil, the Mollusca; and Frank C. Whitmore, Jr., the vertebrate fossils. Preliminary determinations of fossils—made while the party was still in the field—by Cole, Todd, MacNeil, and Johnson were very valuable for mapping and stratigraphic studies.

The carbon-14 dating was done by Meyer Rubin. Thomas Stern provided a lead-alpha age for the Omoto Granite. Frances Fisher identified the blue amphiboles.

Shigeo Aramaki and S. Banno, University of Tokyo, made preliminary examinations of thin sections of igneous and metamorphic rocks. Contributions by other scientists are acknowledged where discussed in the report.

PHYSICAL GEOGRAPHY

CONFIGURATION, TERRAIN, AND DRAINAGE

Ishigaki-shima is very irregular in shape and has many types of terrain (pl. 2). The main body of the island is indented by two bays, Nagura-wan on the west and Miyara-wan on the south. From the island's northeastern corner, a long strip of land extends northeastward. The extension is about 19 kilometers long and 0.6–5 kilometers wide. It is divided into three segments by two isthmuses, one south of Ibaruma and the other at Akeishi. The northernmost segment is locally known as the Hirakubo peninsula, the middle segment as the Ibaruma peninsula, and the southern segment as the Nosoko peninsula (pl. 2). Although these segments are not true peninsulas, the name peninsula is used in this report for convenience. From the northwestern corner of the main landmass, two smaller land extensions protrude. The one to the west is known as the Yarabu peninsula, and the one to the north as the Kabira peninsula.

The three northeastward-trending land segments are all mountainous. The mountains are bordered by narrow, sloping, slightly dissected, marine-cut terraces (fig. 2). In some places, narrow lowlands parallel the coast and extend short distances inland along streams. The Yarabu and Kabira peninsulas are also mountainous. The mountains of the Kabira peninsula are mostly in the southern part of the peninsula; the northwestern end is rolling or hilly terrain.

The main body of Ishigaki-shima is mountainous in the north and in one area in the southwest. Most of the remainder is hilly, or rolling, or consists of terraces that are slightly to highly dissected. Lowlands are present along coasts, near stream mouths, and inland along the three major streams. The highest mountain, Omoto-yama, which is more than 500 meters high, is in the northern section of this main part of the island. This mountain area is continuous on the east with the mountains of the Nosoko peninsula.

The mountain topography of Ishigaki-shima is physiographically young in aspect. Differences in form and erosional characteristics due to rock composition are not particularly conspicuous, although slight differences in the texture of the landscape are detectable between some mountain areas of differing rock compositions. For example, the mountains of the Nosoko peninsula which are composed of volcanic rocks have a somewhat more closely spaced pattern of dissection than the mountains to the south which are composed of metamorphic rocks.

The marine terraces range in altitude from a few meters above sea level to about 80 meters. Limestone terraces are most extensive in the southern part of the island, but they are also conspicuous along the margins of the northern mountains. Their surfaces are commonly rather rough. Sinkholes, limestone ridges (0.3–1.5 m high), pinnacles (as much as 2 m high), and pitted limestone boulders are common surface features. In places the surface is somewhat smoothed by local deposits of sand and gravel, as in the vicinity of Yoshi-

FIGURE 2.—Marine terraces flanking the mountains on the eastern coast of the Hirakubo peninsula. The terraces have been cut on schist of the Tumuru Formation and in places have a thin covering of Nagura Gravel. Photograph by Far East Air Force, June 1956.

hara. The limestone terraces generally slope seaward, without conspicuous scarps except near their coastal margin where elevated sea cliffs indicate the position of old shorelines.

Terraces composed of unconsolidated gravel are particularly evident in the drainage areas of the Nagura-gawa, Miyara-gawa, and Todoroki-gawa. Their surfaces are fairly flat or gently sloping. Streams have considerably dissected them, cutting valleys 3–8 meters deep. The edges of the terraces along the valleys tend to round off. Where dissection is severe, little of the terrace surface remains, and small rounded hills are developing (fig. 3). The largest number of gravel terraces are about 40 meters above sea level, but they range in altitude from less than 20 to 80 meters. Terraces of several different altitudes are present in the same area. For example, in places along the eastern shore of Nagura-wan, a series of five steplike benches rises from near sea level a few meters inland from the coast to about 80 meters altitude at the base of the mountains. Most of the upper terrace levels are cut into bedrock and have only a thin or irregular gravel covering. Some terraces cut on rocks of variable hardness, such as schist and chert, have remnants of the harder rock standing above the general level of the terrace. Marine terraces on different parts of the island are not definitely correlatable because of differential uplift and tilting.

FIGURE 3.—Interior marine terraces. Dissected grass-covered terraces near Kainan are composed of gravel. Little of the original terrace surface remains.

The three largest rivers, the Miyara, Nagura, and Todoroki, drain the southern part of the island (pl. 2). Many short streams that have small drainage areas flow northward from the mountains. The streams draining the peninsulas are mostly small and have limited drainage areas. The largest of these streams are the Fukidō-gawa, Nishi-hama-gawa, and Ōura-kawa, all on the Nosoko peninsula. Most of the streams originate from springs 30 meters or more beneath the summits and ridges of the mountains, except in some mountains of volcanic rock where they commonly begin in rather broad basins in weathered volcanic rocks; the basins often become mud wallows frequented by wild pigs. Overall drainage patterns are dendritic, but locally, where largely controlled by joints, they may be trellised.

Terraces occur in places along the larger streams. They range from a few to 400 meters in width. Some stream terraces are bordered in places by Ryukyu Limestone which extends upstream along the margins of the valley. The width of the limestone along the sides of the valleys is generally only a few meters. On the Yassa-gawa on the eastern side of the Hirakubo peninsula, Ryukyu Limestone is found along the sides of the valley as far inland as 1.4 kilometers. Here it ranges in width from a few to about 135 meters.

A few larger streams such as the Nagura-gawa, Fukidō-gawa, and Miyara-gawa enter the sea through estuaries. The mouths of the estuaries are sandy or silty, and water reaches the sea through small distributaries or by seepage. Conditions at the mouths of the streams change continually, and at times sufficient sand and silt accumulate to block the flow of the Nagura-gawa and some other streams at low tide. The flow at the mouths of the Miyara-gawa and Fukidō-gawa is generally great enough to keep at least a small channel open. Coral growth is unusual around the mouths of streams with estuaries. Mangrove is generally present.

COASTS

The extensive coasts of Ishigaki-shima are of many different types. In general, the northern coastal area is rocky and cliffed; the southern coastal area is low and has sand and gravel beaches (pl. 2). Low (mostly less than 4 m high) sand dunes and dune ridges are present along the northeastern coast at Akeishi, at the isthmus south of Ibaruma, on the western coast near Fu-saki, and on the Kabira peninsula. Most of the dunes are irregular mounds that have no consistent form. Other fairly large accumulations of sand occur near the mouths of streams such as the Todoroki-gawa. Along the eastern coast where sand has accumulated at the mouths of rivers, a little sand blows inland from the shore and accumulates around the base of low limestone cliffs.

The cliffed coastlines of Ishigaki-shima are mostly in limestone, volcanic rocks, or metamorphic rocks. The cliffs range in height from 1.5 to 15 meters. Limestone cliffs are extremely rough and irregular; they have pitted surfaces, jagged rock pinnacles, and projecting ridges (fig. 4). Joints and cracks are conspicuous. Some projecting headlands have formed because of erosion along joints (fig. 5). Caves are common. Nips or indentations at about high-tide level have formed in many places (fig. 6*A*). The overhang above nips may

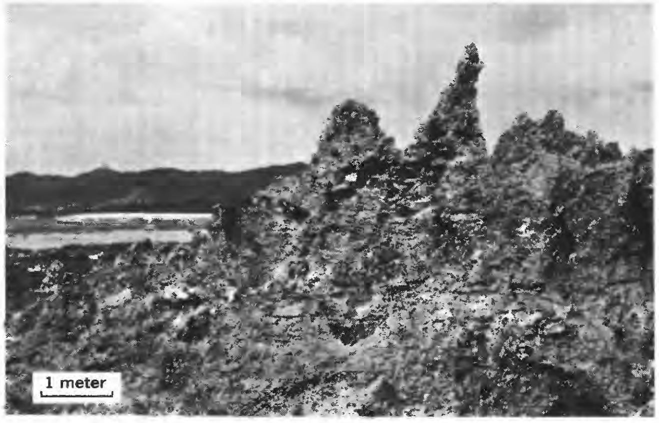


FIGURE 4.—Pinnacled coastal limestone ridge. Rough-surfaced coralliferous Ryukyu Limestone is common along coasts. It is generally massive. View north of Tomino. July 1955.

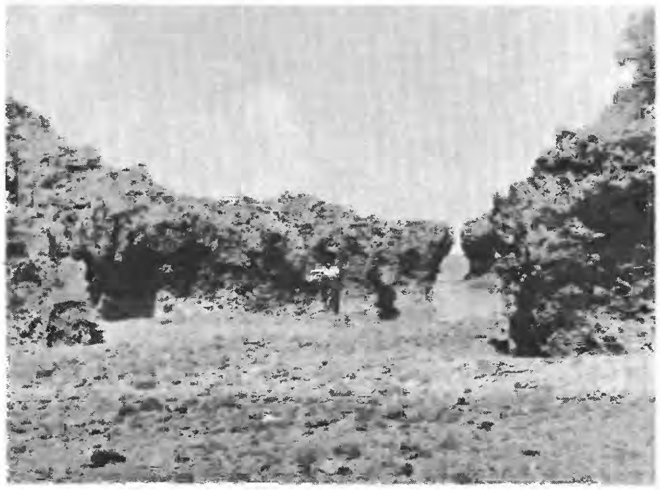
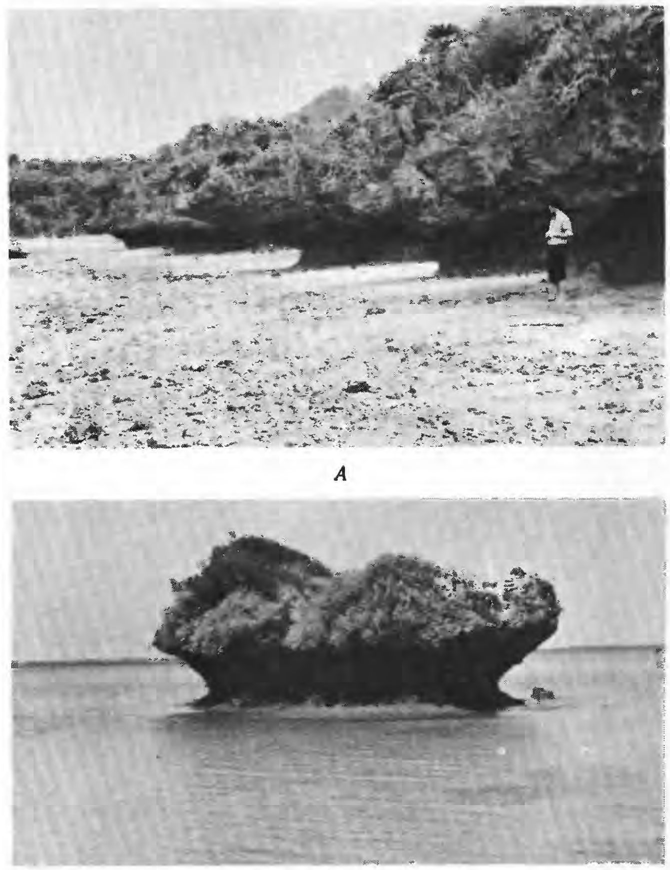


FIGURE 5.—Coastal limestone cliffs. Ryukyu Limestone commonly occurs at sea level, forming a rough, irregular coast. Indentations and jutting headlands are numerous. At high tide, sea water fills this area, which is backed by cliffs of Ryukyu Limestone. The limestone surface is jagged and solution pitted. View 1 kilometer east of Ogan-zaki. 1956.

extend out a distance of more than 1.5 meters (fig. 6*A*). Islets shaped like mushrooms because of nips on all sides stand a few meters offshore from some limestone coastlines (fig. 6*B*). At high tide the waves generally wash directly against the limestone cliffs, but at low tide a narrow band of planed-off sloping limestone or a ramp may separate the cliffs from the water.

Erosion along joints in cliffs of metamorphic and volcanic rocks has produced small islets and sea stacks at Hirakubo-zaki, Kabira-ishi-saki, and Ogan-zaki. Exceptionally hard rocks, such as chert, form projecting headlands.

Beaches on Ishigaki-shima are composed of sand, gravel, and boulders (fig. 7). They range in size from small pockets of sand only 4 meters across between projecting limestone headlands to sand and gravel beaches several kilometers long. Their width changes consid-



A

B

FIGURE 6.—Coastal features in Ryukyu Limestone. *A*, Where Ryukyu Limestone forms the coast, rugged cliffs that have irregular, rough, and pitted surfaces are common. Nips and overhangs have formed. At high tide the waves wash against these cliffs. Location is 3.5 kilometers west of Ibaruma. February 1956. *B*, Small islets of Ryukyu Limestone are commonly present along limestone coasts. Nips are formed all around the islet. This islet is located near Shimoji-dan. February 1956.

FIGURE 7.—Boulder beach near Inōda. Large boulders of volcanic rocks from the Nosoko Formation compose this beach. May 1956.

ably with the tide, but few are more than 15 meters wide at high tide (mean tidal range is a little more than 1 meter and maximum range about 2 meters). A band of dense vegatation composed of a prickly tangle of trees, shrubs, and vines a few meters to a few hundred meters wide commonly fringes the landward side of the beach.

The fringing reef gives considerable protection from waves, and most of the beach slopes are fairly well stabilized. The slope of the beaches is generally between 2 and 8 percent, but some beaches are as steep as 20 percent. Some changes were noted during and after typhoons. A typhoon in August 1956 built up the profile of the beach on the northeast side of Fu-saki from a few to 30 centimeters, though the general shape of the beach remained the same.

Longshore currents, active along some parts of the coast, distribute sand from the mouths of streams. This was particularly observed along the southeastern coast north of Shiraho and between Shika and Fu-saki.

The beaches on Ishigaki-shima were grouped into four categories for mapping purposes: sand and gravel beaches, boulder beaches or sand and gravel beaches having reef flats with many boulders, sand or gravel beaches having bedrock outcrops, and sand or gravel beaches backed by limestone benches less than 1.5 meters high. The location and extent of these various types of beaches are shown on plate 2.

CORAL REEFS

Coral reefs fringe the coasts of Ishigaki-shima; the only breaks in the reef occur at the mouths of some streams and at Ogan-zaki. The approximate outline of the reef is shown on plate 2.

The width of the reef ranges from 60 to 1,500 meters and averages about 900 meters. It is very narrow at Yarabu-zaki. In some places, particularly where the reef is wide, as at Nagura-wan, Kanama-wan, off Nosoko, and between Iha-saki and Yassa-zaki, holes of various sizes are present. The seaward margin is generally steep and irregular. Surge channels are present in some places, particularly along the east coast. They are generally 30 meters or more apart and 0.3–3 meters deep. Elsewhere true surge channels are absent, although indentations in the reef margin are generally present.

Where observed, the seaward margin of the reef does not have a well-formed ridge or rim as do many reef margins elsewhere in the Pacific. Coral and algal growth is not especially prolific.

The shoreward sides of reef flats commonly are fairly smooth but contain a few shallow pits. Gently sloping limestone platforms or ramps may extend seaward from indentations or nips at the base of limestone cliffs. Relief on the shoreward parts of reef flats averages less than 30 centimeters, except offshore from some limestone cliffs where the reef flat is very irregular and rough. Some reef flats, especially those off the eastern coast, have many cracks (2 to about 8 centimeters wide) in the reef floor, and these cracks range from 1 to more than 300 meters in length. Patches of sand, gravel, and some scattered boulders and coral heads occur on many reef flats. Patches of marine grass grow here and there on the shoreward parts of the reef flats, but marine plant and coral growth is generally sparse.

The seaward parts of the reef flats are generally more deeply pitted and rougher surfaced than the shoreward parts. Organic growth is more abundant but rarely prolific. *Acropora* and other corals grow in patches (figs. 8, 9). Moray eels, sea urchins, holothurians, and other marine life are found in the pits and other irregularities of the surface. This part of the reef is out of water only at extreme low tides.

About 0.8 kilometers north of the mouth of the Todoroki-gawa, remnants of two older reef surfaces rise above the level of the present reef flat as small islands. One surface is represented by three remnants 4–5 meters above the level of the present reef flat. The tops of these older reef surfaces are rough and uneven, and their sides are strongly undercut. Lower remnants, about 1–1.5 meters above the present reef flat, are flat-topped

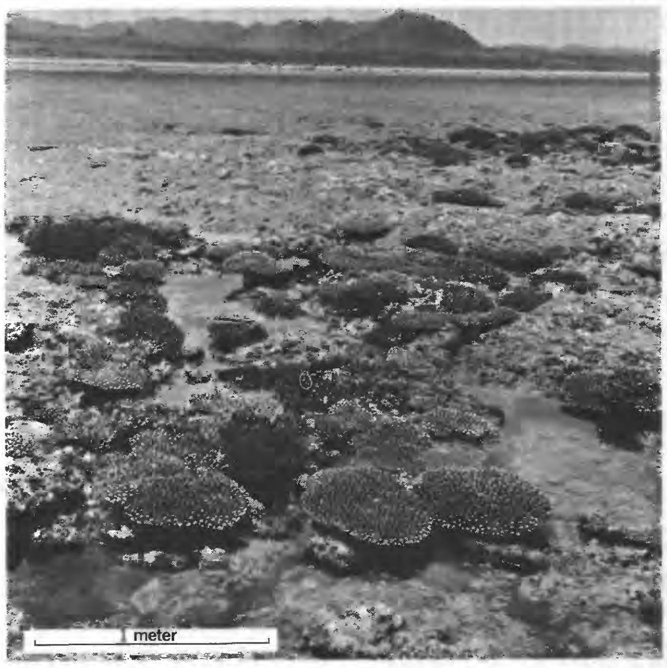


FIGURE 8.—Coral heads on reef flat. This reef flat is 0.8 kilometer north of the mouth of the Todoroki-gawa. Living coral is exposed at extreme low tide. June 1956.

and partly covered by beachrock. Also conspicuous on the reef flat between the old reef remnants and the shore are flat-bottomed, rimmed basins. The basin rims are of sandy limestone resembling beachrock and are 3–6 centimeters high. The bottoms of the basins are of hard

FIGURE 9.—Coral on reef flat south of Nagura-gawa. *Acropora* and other live coral are exposed on the reef flat about 1.6 kilometers south of the mouth of the Nagura-gawa at extreme low tide. View southeast. June 1956.

limestone. The basins range from 0.3 to more than 1 meter across and are irregular in shape.

Isolated living coral heads or groups of coral heads and small reefs are common outside the fringing reef on the west side of Ishigaki-shima. They make boat travel somewhat hazardous.

CLIMATE

Ishigaki-shima has a subtropical oceanic climate that is considerably influenced by the Kuroshio, a warm ocean current that flows generally northeastward along the Ryūkyū-rettō. As the Kuroshio has both a stabilizing and warming influence, temperatures are somewhat higher and less variable than might be expected at this latitude. The current also tends to increase the humidity because the warmed air masses gradually pick up additional moisture from the sea and carry it to the islands. Humidity on Ishigaki-shima is high throughout the year, and cloudiness and rain are frequent.

The mean summer temperature on Ishigaki-shima is about 26.5°C, and the mean winter temperature about 20.5°C. Highest air temperatures occur in June, July, August, and September. The mean maximum air temperature for these months is about 30°C. The highest air temperature ever recorded was 35.4°C on September 15, 1899 (table 1, line 6). Lowest air temperatures on Ishigaki-shima occur during the months of January and February. The mean maximum air temperatures recorded for these months were 21.1°C and 21.0°C, respectively, and the mean minimum air temperatures were 15.0°C and 14.9°C, respectively. The coldest temperature ever recorded was 5.9°C on February 19, 1918. Freezing temperatures have never been recorded, although it is possible that they may have occurred on rare occasions in the mountains.

Rainfall is fairly well distributed throughout the year. The yearly mean average is 2,183 millimeters. May, June, July, August, and September are usually the months of highest rainfall because tropical storms are frequent. If such storms do not pass near Ishigaki-shima, droughts commonly result. Rainfall varies on different parts of the island and is generally somewhat heavier in the northern part, especially in the east-west mountain range which includes Omoto-yama.

Rainfall intensities may be high for short periods of time (table 1, lines 20, 21, 22), especially in torrential downpours associated with the passage of typhoons or tropical storms. The maximum precipitation for a 10-minute period was 38.2 millimeters on March 30, 1937.

The dominant wind on Ishigaki-shima is from the northeast, except in June, July, and August, when it is from the south due to the summer monsoon. The mean surface wind velocity is 4.7 meters per second. During winter strong winds as much as 20 meters per second may blow continuously for several days. Severe tropical storms and typhoons are common from June through September. The monthly distribution (1897–1949) of tropical storms and typhoons which had wind velocities of more than 30 meters per second are shown below (Ishigaki-jima Observatory, 1953).

Month	*Frequency*
June	2
July	10
August	11
September	10
October	4
Total	37

It is rare for the eye of a typhoon to pass directly over Ishigaki-shima because the storm track seems to be east of the island. However, the typhoons follow very unpredictable paths as they approach Ishigaki-shima, and they are apt to veer suddenly.

Damage from high winds, intense rainfall, storm-generated waves, and wind-blown salt spray varies with the intensity and size of the typhoon or tropical storm, its duration, nearness, direction, and time of approach to the island. For example, if maximum wave size coincides with high tides, damage to structures such as seawalls and shore installations may be great. The fringing reef that surrounds most of the island gives considerable protection from storm-generated waves.

Twisters (high-velocity winds of short duration that have a whirling or twisting motion), or waterspouts (so-called if they are crossing water instead of land), are dangerous wind phenomena that occur on Ishigaki-shima. They strike suddenly and pass quickly but leave extensive damage along their usually narrow and very irregular paths.

Other weather data obtained over a period of more than 50 years at the Ishigaki Weather Station are summarized in table 1.

Table 1.—*Meteorological data from Ishigaki-shima Weather Station*

[Compiled from table 1, Ishigaki-jima Observatory, 1953]

Data	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Period of record
Mean atmospheric pressure............mm	764.8	764.1	762.8	760.9	758.2	755.7	755.0	755.0	757.4	760.5	762.7	764.1	760.1	1936–49
Mean atmospheric pressure (at freezing point, reduced to sea level)........do	765.5	764.7	763.4	761.3	758.7	756.5	755.8	755.1	757.5	761.1	763.5	765.0	760.7	1897–1949
Mean atmospheric temperature........°C	18.0	17.9	19.7	22.2	24.8	27.1	28.2	27.9	26.9	24.6	22.0	19.4	23.2	1897–1950
Mean maximum atmospheric temperature do	21.1	21.0	22.9	25.5	28.2	30.2	31.5	31.2	30.5	28.0	25.1	22.3	26.5	1897–1950
Mean minimum atmospheric temperature do	15.0	14.9	16.7	19.4	22.1	24.6	25.5	25.2	24.0	21.8	19.2	16.5	20.4	1897–1950
Maximum atmospheric temperature do	27.8	29.1	29.4	32.9	33.7	34.0	34.8	34.8	35.4	33.2	30.9	29.0	35.4	1897–1950
Minimum atmospheric temperature do	6.0	5.9	7.2	10.0	11.2	16.5	20.0	17.4	17.2	14.0	7.1	6.6	5.9	1897–1950
Mean number of days above 25°C	--------	.0	.3	4.5	16.5	26.9	30.9	30.9	28.3	14.0	2.4	.0	154.8	1897–1949
Mean ground temperature............°C	18.5	19.0	21.0	24.4	27.8	30.6	32.0	31.5	29.7	26.1	22.7	19.4	24.7	1897–1949
Sea-water temperature............do	19.9	19.9	21.0	23.2	25.9	27.6	28.7	28.7	28.0	25.9	23.7	21.4	24.5	1914–49
Mean water vapor pressure.....millibars	12.0	12.1	13.8	16.5	19.7	22.7	23.2	23.0	21.3	17.8	15.2	13.1	17.5	1897–1949
Mean relative humidity..........percent	77	78	79	82	84	85	82	83	81	77	76	77	80	1897–1950
Minimum relative humidity........do	39	38	30	35	28	45	46	41	39	38	41	40	28	1897–1950
Duration of sunshine..............do	99.3	96.7	121.5	156.5	189.3	229.3	276.3	258.7	228.8	186.8	130.3	103.4	2,076.7	1897–1949
Duration of sunshine (sunshine in hours, divided by hours of daylight and multiplied by 100)..............do	30	30	33	41	45	56	66	65	62	52	40	31	47	1897–1949
Mean monthly precipitation.........mm	141.0	124.8	141.2	140.9	223.6	213.9	201.5	218.2	238.4	199.4	176.6	163.6	2,183.2	1897–1949
Maximum monthly precipitation...do	339.6	343.0	390.9	394.3	671.7	583.5	673.3	534.6	655.6	732.5	637.7	378.4	732.5	1897–1950
Minimum monthly precipitation....do	39.7	17.6	8.1	4.4	35.0	16.0	14.8	25.5	34.6	41.9	24.0	51.3	4.4	1897–1950
Maximum daily precipitation.......do	136.2	157.8	165.9	169.1	194.4	210.1	378.9	231.8	349.5	245.3	266.6	243.7	378.9	1897–1949
Maximum amount of precipitation in a 4-hour period..............do	77.8	64.9	120.1	100.5	109.6	127.5	219.9	178.6	140.0	121.9	226.0	100.8	226.8	1897–1939
Maximum amount of precipitation in a 1-hour period..............do	40.6	60.5	88.7	59.2	68.2	84.7	96.3	92.5	57.3	72.2	111.8	87.5	111.8	1897–1949
Maximum amount of precipitation in a 10-minute period..............do	17.0	22.0	38.2	24.0	32.3	28.0	25.1	20.0	22.6	19.0	22.6	21.5	38.2	1897–1949
Mean daily evaporation..............do	2.8	3.0	3.5	4.3	4.7	5.4	6.4	5.9	5.6	4.9	3.9	3.0	4.5	1908–49
Mean cloud cover..............percent	80	80	77	73	72	68	57	58	56	64	72	79	70	1897–1950
Mean number of clear days (20 percent or less cloud cover)	1.3	1.2	1.7	2.1	2.3	2.5	4.9	4.7	4.9	4.0	2.5	1.4	33.8	1897–1949
Mean number of cloudy days (more than 20 percent cloud cover)	21.1	19.6	20.5	17.5	17.8	15.2	10.5	10.7	9.5	13.2	16.8	20.8	193.1	1897–1949
Mean number of rainy days	19.8	16.8	16.8	14.3	16.8	16.2	16.5	17.3	17.7	17.3	18.3	20.2	208.1	1897–1949
Mean number of days with thunderstorms	.5	.7	2.0	3.4	4.8	3.8	2.6	2.7	2.5	1.4	.5	.2	25.0	1897–1949
Mean number of foggy days	.2	.3	1.3	1.3	.6	.4	.4	.4	.2	.1	.1	.2	5.4	1897–1949
Dominant wind direction	NNE	NNE	NE	NE	NE	S	S	S	NE	NE	NE	NE	NE	1897–1950
Mean wind velocity..........m per sec	4.8	4.7	4.7	4.2	4.1	4.7	5.1	4.8	4.6	4.8	5.1	5.1	4.7	1897–1948
Maximum wind velocity..........do	S 18.6	SSE 17.9	SSE 17.6	NE 16.1	NE 16.9	SE 41.2	S 44.3	SE 46.5	S 50.3	ESE 39.6	NNE 21.8	WNW 19.0	S 50.3	1897–1948
Number of days with wind velocity of 10–15 m per sec	2.1	2.3	3.1	1.6	1.7	3.5	4.3	3.9	3.0	2.9	3.3	3.0	34.9	1897–1948
Number of days with wind velocity of 15–29 m per sec	.1	.1	.1	.0	.1	.4	1.2	1.7	1.1	.5	.2	.1	5.8	1897–1948
Number of days with wind velocity over 29 m per sec	--------	--------	--------	--------	--------	--------	.3	.3	.3	.1	--------	--------	.9	1897–1948

VEGETATION

About 65 percent of the area of Ishigaki-shima is in forest and scrub, 15 percent in grassland, and 20 percent in crops. The island lies within the general area of the temperate to subtropical broad-leaved evergreen forests of eastern Asia, and most mountain areas above 100 meters altitude are covered by such forests. On Ishigaki-shima, *Quercus* (oak) or *Ardisia* and *Diospyros* (persimmon) are the dominant forest trees. *Ardisia* is a smooth-leaved evergreen tree that sometimes grows as high as 15 meters.

Two types of oak forest are recognized on Ishigaki-shima: a wet forest growing above 200 meters in altitude and a dry one at lower altitudes. The wet forest is a broad-leaved evergreen forest; oak (*Quercus cuspidata*) is commonly predominant, but many other kinds of trees are present, including *Elaeocarpus*, *Dendropanax*, *Styra*, *Cinnamomum*, *Ficus*, *Ardisia*, and *Camellia*. The trees range in height from 5 to 20 meters, but are generally 10–12 meters tall. The canopy is complete and dense. Undergrowth is moderate to absent. Where present, it consists mostly of shrubs 1–2 meters tall. The ground is generally covered by ferns. Patches of dwarf bamboo grow on some higher peaks and slopes, principally on mountains composed of granitic rocks.

The dry oak forest is similar to the wet oak forest but somewhat less luxuriant. The canopy is locally more uneven and less dense. Undergrowth is commonly more abundant, and in places there are thickets of dwarf palm (*Argenga*). Ground cover is thin or absent.

Ardisia-Diospyros forest commonly grows at altitudes between 100 and 200 meters rather than the dry oak forest. *Ardisia*, *Diospyros*, and locally *Ficus* are the dominant trees. Fan palms (*Livistona*) are locally common. The top of the canopy is usually 10–15 meters high. Undergrowth is mostly fairly thick and may include dwarf palms.

In a few places, patches of pine (*Pinus luchuensis*) or of mixed pine and broad-leaved forest are also found between the altitudes of 100 and 200 meters.

Many parts of the coast have a littoral broad-leaved evergreen forest in which *Hernandia* or *Pandanus* is dominant and in which *Calophyllum*, *Pouteria*, *Guettarda*, *Tournefortia*, *Scaevola*, *Hibiscus tiliacous*, *Ficus retusa*, and occasionally *Casuarina* are present. Small plantations of *Casuarina*, *Calophyllum*, *Acacia*, and groves of *Livistona* grow in places.

The mountain forests have all been selectively logged for a long time, and as a result they are mostly low, scrubby, and tangled. On the lower slopes of the mountains and in the mouths of canyons, a forest type composed largely of banyans (species of *Ficus*) seems to have resulted from long-continued selective cutting of timber species—a selective cutting which has left the relatively useless banyans that now dominate the forest. Small areas have been reforested.

Some coastal areas, rocky lands, and other areas unsuited to agriculture are in scrub, that is, dominantly woody vegetation not exceeding 4 meters in height; for example, cycad scrub is found commonly on exposed rocky slopes, knobs, and flats near the sea, and *Pandanus* scrub is common along the coast, especially on rough limestone areas.

Most of the trees which grow on Ishigaki-shima are described and pictured in the book, "Important Trees of the Ryukyu Islands" (Walker, 1954).

Extensive grasslands are a conspicuous feature of Ishigaki vegetation. Grass areas occur mostly on marine-cut terraces at altitudes just a little above sea level to about 80 meters, but grass covers some steep mountain slopes (fig. 2). *Imperata* or *Miscanthus*, both harsh coarse grasses which make poor fodder, are dominant. Some of the grassy areas have stands of Ryukyu pine, either scattered and forming savannas or in forests (fig. 3). Most of the grasslands are burned once or twice a year.

Many valley bottoms, some coastal flats, and all other possible areas are planted to wet rice (fig. 3). Sugarcane and sweet potatoes are economically important crops on remaining areas suitable for agriculture. Much rocky land and some steeply sloped areas are now planted to pineapple. Wetlands containing salty or brackish water are commonly mangrove swamp. Freshwater swamps are usually dominated by broad-leaved evergreens such as *Pandanus*, *Hibiscus tiliaceus*, or *Barringtonia racemosa.*

FAUNA, PARTICULARLY THE HAZARDOUS ASPECTS

The fauna of Ishigaki-shima includes a large variety of insects and other kinds of arthropods including centipedes, spiders, ticks, and crustaceans; land and freshwater snails; a variety of snakes, lizards, geckos, and toads; numerous sea and shore birds; a few mammals such as wild pigs, bats, moles, rats, and mice, as well as such domesticated animals as dogs, cats, horses, cattle, goats, hogs, chickens, oxen, and carabao. The yamanekko or mountain cat is a rarely seen nocturnal mammal, about the size of a small fox. A few small fish were noted in fresh-water streams, and an abundant variety of fish and shellfish inhabit the sea around the island.

Because the fauna of the island includes several types of animals that are hazardous or annoying, especially for those doing fieldwork, the most commonly seen are briefly described in the following paragraphs.

The habu or Sakishima habu, a poisonous snake, probably causes the greatest concern. This snake—*Trimeresurus elegans* Gray, a pit viper of the family Crotalidae—is common and occurs in many different habitats. It comes around habitations and other buildings in search of food and may be found under piles of lumber or rubbish. It is also common in the mountains and may be encountered almost anywhere—in tree branches, hollow trees, holes in the ground, caves, rocky ledges, along streams, and on ridge tops. It is largely nocturnal but may be aggressive during the day. The adult is commonly 90–120 centimeters long but may attain a length of 150 centimeters. Although the bite of this snake is dangerous, it is generally not fatal to man; however, no antivenin has been produced that is effective against its bite (Maj. H. L. Keegan, oral commun., 1956).

Coral snakes, *Hemibungarus japonica* and *H. iwasakii*, small snakes related to the cobra, also occur on Ishigaki-shima. These snakes are much feared by the local people, but are not particularly dangerous because they are secretive and nocturnal in their habits.

Poisonous sea snakes of the genus *Laticauda* are fairly common in the sea water around the island and are frequently encountered by swimmers or are seen from small boats. They are extremely poisonous but, fortunately, rarely bite.

A small black spider with a red streak down its back, *Latodectus hasseltii* has a very poisonous bite; it is generally believed to be rare. Most of the spiders on Ishigaki-shima are not dangerous.

Yamangi (*Dendrolimus* sp.), a large ugly gray moth larva, is dreaded by the natives, but laboratory tests indicate that it may not be especially harmful. It lives on the trunks and branches of trees in heavily vegetated mountains. It is covered with hairs, which the natives report cause considerable pain to the person who touches them. These larvae blend so well with their surroundings that they are difficult to see. Numerous other larval forms which cause varying degrees of irritation, if touched, are present at certain times of the year on vegetation, especially in the mountains.

Centipedes which are reported to have somewhat poisonous bites are also very abundant in the mountain areas. They may attain a length of more than 25 centi-

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meters. Whip scorpions are ugly but comparatively harmless arachnids commonly found under logs and under the floor matting in native dwellings. Terrestrial leeches, locally called yama-biru, are annoying but not poisonous. They occur in great abundance on the ground, sporadically throughout the mountains. They puncture any exposed patch of skin that they can reach and suck the blood.

Wild pigs are common in the more remote mountain areas but are generally not dangerous if unmolested. If they have young, however, or if they are cornered, they are ferocious. Ticks and fleas are especially annoying in areas frequented by wild pigs.

Several species of malaria-transmitting mosquitos are abundant, and malaria occurs on the island, mostly in northern areas. *Anopheles minimus* is probably the most important vector on Ishigaki-shima. Numerous other insect-borne diseases such as filariasis and encephalitis are also common. Ticks and several kinds of wasps and bees are fairly abundant.

Eels are common in depressions and channels on the reef and will sometimes attack, inflicting severe wounds. As in other subtropical and tropical areas, fish that are poisonous to eat may be present in the sea. Danger from sharks is slight in the shallow lagoonal waters around Ishigaki-shima. A gastropod of the genus *Conus*, which can sometimes inflict a very dangerous wound, probably occurs in the sea around the island. Jellyfish, many of which are large, drift along the shores in great numbers at times. Contact with the stinging tentacles of the larger specimens may cause pain and a variety of allergic manifestations.

PREVIOUS GEOLOGIC STUDIES

Most early scientific information on the southern Ryūkyū-rettō concerns Okinawa-jima because it is the largest and the most heavily populated island and was the seat of government. The first geologic report originates from the visit by Commodore Perry and his American naval squadron to the island in 1853 while they were en route to Japan. The chaplain of the expedition, the Rev. George Jones (1856), observed and reported on the geology.

In 1860 some fossils from Okinawa-jima collected by the missionary Furet (Petermann, 1860, p. 156) were mentioned in an article on the Ryukyu Islands. Döderlein (1880–84) was the next to make geological observations of the islands. He described Okinawa-jima in some detail and listed the more southerly islands, including Ishigaki-shima. Suess (1888), drawing upon the observations of Jones, Döderlein, and authors who had written on Formosa, rather accurately described some of the major characteristics of the Ryukyu arc, such as the inner zone of volcanoes and "the fragments of the cordillera," which make an outer zone. He recognized the similarity of the Ryukyu arc to other island arcs.

The first specific geologic description of Ishigaki-shima, as far as is known, is by T. Kata in 1885. He included a geologic map of the Ryūkyū-rettō. In 1895 Nakayoshi published a description of the topography, soil, and climate of the Yaeyama-guntō. He described four types of "soil" on Ishigaki-shima: limestone, mica schist, gneiss, and granite.

In 1899 Kuroiwa described the geology of Ishigaki-shima; he based his description on a visit to the island and on the publications of Kata and Nakayoshi. His rock samples were studied by B. Kotō in Japan. Glaucophane schist was identified and assigned to the upper Archeozoic, along with chlorite schist and mica schist. Kuroiwa recognized the similarity of these rocks to those of the "Sambagawa series" on the island of Shikoku, Japan. He regarded the chert and quartzite as probably Paleozoic in age. He found the Eocene limestone and stated that it was Tertiary in age and that it might be Miocene. He described the Ryukyu Limestone and assigned it to the Diluvium. He also mentioned the igneous rocks.

In 1897 Kotō collected the scanty information on the Ryūkyū-rettō, including the Yaeyama-guntō and Ishigaki-shima, and presented a summary and interpretation. He described a "three fold structure in the Riu-Kiu Curve," an inner volcanic chain of islands, a middle arc to the east consisting of older geologic formations, and an outer arc of Tertiary and Quaternary formations on the Pacific side. He recognized that the inner volcanic chain is not traceable south of Tori-shima. Of the middle arc, he said, "A mountain range was raised up in this region before the Mesozoic era, and remained emerged until the early period of the Cenozoic era. Then, during the Cenozoic a crustal change of a grand scale took place, as the result of which there is only a remnant of 'the Riu-Kiu Cordillera' represented by the islands of the Riu-Kiu Curve." [1] He assigned the southern part of Okinawa-jima and of Miyako-jima to the outer Tertiary and Quaternary arc, but he recognized a disruption of the patterns between Okinawa-jima and Ishigaki-shima.

In 1899 Yoshiwara traveled extensively in the Ryukyu Islands. He described (Yoshiwara, 1901a) the geology of Ishigaki-shima and other islands of the Yaeyama-guntō in some detail. He presented a generalized geologic map of Ishigaki-shima at a scale of 1:200,000.

In 1902 Von Richthofen presented a map which di-

[1] Translation by Ichiro Hayasaka.

vided the Ryūkyū-rettō into three zones, virtually as proposed by Kotō.

Yabe and Hanzawa became interested in the stratigraphy and fossils of the Ryūkyū-rettō and published the first of several papers in 1920 and 1921. Earlier Yabe (1906) had published a study of *Nummulites* from Okinawa-jima and had discussed the geotectonics of the Ryukyu Islands (1917). Aoki (1932) also published a report during this period on the geology of Ishigaki-shima.

In 1935 Hanzawa published a comprehensive description of the geology of the Ryūkyū-rettō, including Ishigaki-shima, with colored geologic maps, scale 1:500,000. This work has served as a basis for all later geological work, as Hanzawa recognized and described the major elements of the geology of Ishigaki-shima.

After the work of Hanzawa, Japanese military operations and World War II prevented much additional fieldwork in the southern Ryukyu Islands, and the next geologists to visit the islands were Americans during and after the war. Flint and Saplis made a reconnaissance of Ishigaki-shima in 1948; Neuschel investigated manganese prospects in 1949; and Carson and Davis surveyed the water resources in 1954; but no detailed work was done until the present study.

GEOLOGIC SETTING AND THE RYUKYU ARC

The islands of the Ryūkyū-rettō compose one of several island arcs which bound the basin of the Philippine Sea (pl. 3). The Ryukyu arc or Ryukyu ridge has the typical features of island arcs—a zone of active volcanoes on the inner, concave (continental) side and a trench or foredeep on the outer, convex (sea) side. Most of the volcanoes are in the northern segment of the arc, and the trench is deepest off the southern segment of the arc. The highest altitude, about 520 meters, is in the southern part of the arc on the island of Ishigaki. The deepest known part of the trench is about 7,500 meters. Thus the known difference in altitude in this part of the arc, about 8,020 meters, is considerably smaller than that of the Japanese arc, which has a relief of about 12,180 meters.

The northern part of the Ryukyu arc and the southern part of the Japanese island arc terminate in the Japanese island of Kyūshū. The volcanic zone of the Ryukyus seems to continue into Kyūshū. Taiwan is the southern terminus of the Ryukyu arc, and the volcanic rocks of northern Taiwan may be a continuation of the Ryukyu volcanic zone. The relationship of other rocks and structures to Taiwan is uncertain, but Yen believes that the northern part of Taiwan displays many of the same structural features as the Ryukyu arc (Yen, 1958c, p. 13).

The concept of a triple arc in the Ryukyus as described by Kotō (1897), Kobayashi (1941, p. 457), and others is illustrated on plate 3. However, the writer prefers a concept of only two principal longitudinal zones in the arc, that is, an inner volcanic zone corresponding to that of Kotō, and an outer core of old rocks over which Tertiary and Quaternary deposits are present in places. On many of the islands the older rocks of the core are not exposed but nevertheless probably compose the foundation of the island. Even the concept of two zones or arcs is not very applicable in the southern Ryukyu Islands because a distinct zone of active volcanoes is absent.

The islands of the southern part of the Ryūkyū-rettō are of three general types: islands having an exposed core of old (Paleozoic (?)) folded, faulted, and metamorphosed rocks, over which Tertiary and Quaternary sediments have been deposited in places, particularly around the margins of the islands; islands whose principal body is tilted and faulted Tertiary sedimentary rocks with marginal and overlapping Quaternary deposits; and islands which expose only Quaternary (and possibly Pliocene) rocks, such as reef limestones and beach deposits. The Sakishima-guntō has islands of all three types. Ishigaki-shima, Taketomi-jima, Kobama-jima, and Iriomote-jima have cores of old Paleozoic(?) metamorphic rocks; Yonaguni, Okinokami-shima, Hatoma, and the islands of the Miyako-guntō are composed of Tertiary and Quaternary rocks; and Kuro-shima and Aragusuku-shima have only Quaternary rock exposures. Ishigaki-shima is the only island of the Sakishima-guntō which has exposed granitic rocks.

Data on submarine geology in the southern Ryukyu Islands are very limited. Hanzawa (1935, p. 9) described the islands or groups of islands as resting on insular shelves up to 100 meters in depth. The insular shelf upon which the Miyako island group rests is separated from islands of the Okinawa-guntō by waters having a depth of more than 1,000 meters (Hanzawa, 1935, p. 9). The Miyako-guntō is separated from islands of the Yaeyama-guntō by water depths of about 400 meters. All islands of the Yaeyama group except Yonaguni-shima and Okinokami-shima are on the same insular shelf. Hanzawa also recognized several submarine furrows which incise the insular shelf on the west and north sides of Iriomote-jima, and he suggested that some of these furrows might be submarine canyons.

The insular shelf upon which Yonaguni-shima is located is very narrow and is flanked by a deep or submarine platform 400 meters deep (Hanzawa, 1935, p. 10), and a submarine canyon is traceable south of the island to a depth of 500 meters.

Three ages of disturbances are discernible in the Yaeyama-guntō. The oldest disturbance represented is the folding and faulting shown by the Paleozoic(?) rocks. Next is Tertiary tilting and faulting, and the youngest is faulting of late Pleistocene or Recent age. All these disturbances affected Ishigaki-shima, but indications of the latest faulting are not as well displayed there as on some of the other islands, such as Yonaguni and Taketomi.

Several early workers postulated that the Ryukyu arc had been thrust eastward away from the mainland of Asia. Kobayashi accepted this concept and associated the Ryukyuan thrusting with the Sakawa orogenic cycle, which he postulated as a Late Cretaceous episode of major thrusting in the Japanese arc.

Cloud and others (1956, p. 18) have called attention to the similarity between the Ryukyu arc and the Mariana arc, along with certain differences between these arcs and the Indonesian arc. They suggest that the Ryukyu arc represents an older and more complex structure than the Mariana arc. Hess (1948, p. 421–422) has also suggested that the Ryukyu arc may be older because of the shallowness and limited extent of the Ryukyu trench. The Ryukyuan arc may have come into being in late Paleozoic or Mesozoic time; the Mariana arc, sometime during the Tertiary.

Benioff (1954) has suggested that originally the Ryukyuan-Japanese-Kamchatka arc was a single arc of large curvature. Later approximately 90° counterclockwise bending about a vertical axis in Manchuria resulted in the present form of the arcs and the formation of the Honshu-Mariana arc.

The rocks of the Ryukyu arc are believed to be more closely related to those of Taiwan, Japan, and the Asiatic Continent than to those of the deep Pacific basin. For example, the volcanic rocks ar chiefly andesitic rather than olivine-, picrite-, or nepheline-basalt; granitic instrusives are present; and sedimentary and metamorphic rocks are of the same general types as occur on the Asiatic Continent and its border areas. Also, fossil mammal bones and the present distribution of poisonous snakes and wild pigs are indications of actual geographic land connections between these islands and the Asiatic mainland, possibly through Taiwan, in late Tertiary or Pleistocene time. The so-called andesite line is well to the east of the Ryukyus, and Cloud and others (1956, p. 19) concluded that it is nearly located by the Palau-Yap-Mariana-Japan trench system.

STRATIGRAPHY

Ishigaki-shima has a large variety of rock types, and these rock types have a wide range in geologic age for so small an island (223 sq km in area). The general stratigraphic succession of these rocks was established by the work of Japanese geologists. The present study produced much additional information about the geologic formations and their relationships to one another, although many problems merit further investigation. The stratigraphic sequence, as presently interpreted, is shown in figure 10.

The oldest rocks exposed on the island are metamorphic rocks, the Ishigaki Group, which are probably Paleozoic in age. No Mesozoic rocks are known, although some of the metamorphic rocks or some of the intrusive igneous rocks may belong to this era.

The oldest unmetamorphosed sedimentary rocks are those of the Miyara Formation of late Eocene age. These are overlain, in places, by bedded volcanic rocks, the Nosoko Formation. The exact age of the Nosoko Formation is undetermined, except that most of it is younger than the Miyara Formation and that it is older than the Nagura Gravel.

Other sedimentary deposits are probably mostly Pleistocene or Recent in age. They include the Nagura Gravel with the Bunera Clay Member; the Ryukyu Limestone, a reef limestone; beach gravel and beach and dune sand; and alluvium.

Granite, granodiorite, and diorite of probable Tertiary age intrude the metamorphic rocks. Rhyolite and granophyre are closely associated with them.

ISHIGAKI GROUP

The metamorphic rocks of Ishigaki-shima, called the Ishigaki Group (Foster and others, 1960, p. 88) are the oldest rocks exposed, and they form the core or foundation of the island. The total area of outcrop is nearly 68 square kilometers, and this area constitutes more than 30 percent of the total land area of the island. A Paleozoic age is tentatively assigned to these rocks. They have been intensely folded and faulted and are intruded by granitic and andesitic rocks. Similar metamorphic rocks crop out on the neighboring islands of Taketomi, Kobama, and Iriomote.

The Ishigaki Group has been divided into two formations, chiefly on the basis of lithology. The Tumuru Formation comprises low-grade metamorphic schistose rocks such as greenschist, glaucophane and crossite schist, quartz-mica schist, and graphitic schist [a schistose rock containing some graphite]. The Fu-saki Formation comprises bedded chert, conglomerate, sandstone, phyllite, quartzite, graphite schist [a schist composed largely of graphite], greenschist, quartz-mica schist, hornfels, meta-andesite, and some marble.

Some metamorphic rocks of the Ishigaki Group were not separated into formations. These are shown as the undifferentiated Ishigaki Group on the geologic map (pl. 4). In the southeastern part of the island,

Era	Period	Epoch	Group	Formation or deposit	Type of rock or sediments	Thickness (in meters)
Cenozoic	Quaternary	Recent		Alluvium	Gravel, sand, silt, and clay	Commonly 1–10
				Beach deposits: Deposits on present beaches	Sand and gravel	0.3–15+
				Beach deposits: Beachrock	Conglomerate	
				Beach deposits: Elevated deposits	Sand and gravel	
		?		UNCONFORMITY		
		Pleistocene	Sakishima	Ryukyu Limestone	Sandy and coralliferous limestone	1–20+
				Nagura Gravel Bunera Clay Member	Gravel, sand, and clay Gray, fossiliferous clay	1–23+
	Tertiary	? Pliocene		UNCONFORMITY		
		Miocene(?)		Nosoko Formation	Andesite, andesitic breccia, and tuff	300±
		Oligocene(?) ?		UNCONFORMITY?		
		Eocene		Miyara Formation	Limestone, sandstone, conglomerate	1–141+
				UNCONFORMITY		
Paleozoic(?)			Ishigaki	Fu-saki Formation	Chert, schist, phyllite, marble, meta-andesite, metaconglomerate	170±
				Tumuru Formation	Schist	600±
Tertiary(?)		Igneous intrusive rocks		Sakieda Rhyolite; locally includes granophyre and mylonite Cha-yama Granodiorite Omoto Granite		

FIGURE 10.—Stratigraphy of Ishigaki-shima.

the undifferentiated Ishigaki Group includes greenschist, quartz-mica schist, and some crossite schist. A mountainous area adjoins the granitic mountains on the east. It has graphitic schist in the vicinity of Fukai and in the southwestern part of the area; bedded chert is exposed along tributaries to the Miyara-gawa and also in the southwestern part of the mountainous section; quartz-mica schists compose many of the higher mountains; and some greenschist is present, and a hornfels is found in the northeastern part of the area.

The Ishigaki Group is referred to in previous literature as simply the Paleozoic formation (Aoki, 1932; Hanzawa, 1932a, 1935, p. 43) or as the Kunchan Group (Kata, 1885), a name taken from Okinawa-jima.

TUMURU FORMATION

TYPE SECTION AND STRATIGRAPHIC RELATIONSHIPS

The Tumuru Formation was named by Foster and others (1960, p. 88) from Tumuru-saki, about 1,350 meters southeast of the village of Akeishi on the northeastern coast of the island. Because no type section was designated, the following representative partial section of the Tumuru Formation measured near Tumuru-saki (fig. 11) is here designated as the type section.

Partial section of Tumuru Formation at Tumuru-saki

[See fig. 11; index map shows location of stratigraphic section]

	Thickness (meters)
Top of section eroded.	
Mica schist, dark-gray; may contain hornblende or carbonaceous material	?
Schist, green, and gray quartz-mica schist; many veins and chunks of milky quartz	105.0
Schist, green, and blue crossite schist; interbedded with quartzitic layers; much contorted into small drag folds; lenses and chunks of milky quartz abundant; numerous vugs in the quartz	137.0
Schist, green, and covered; probably mostly greenschist	179.0±
Quartz-mica schist, light-gray; has white quartzitic layers interbedded with silvery mica layers; contains many veinlets and chunks of milky quartz	91.5
Schist, green, interbedded with light gray quartz-mica schist	6.0
Quartz-mica(?) schist, dark-gray; many quartz veinlets; much fractured and highly contorted; grades downward into graphitic schist	1.5
Graphitic schist, dark-gray; infolded quartz veinlets and 5-cm layers of greenschist; highly contorted	1.5
Quartz schist, gray to tan	2.0
Carbonaceous schist, dark-gray	0.3
Schist, green, with interbedded blue crossite schist	6.0
Base of section not exposed.	
Total exposed thickness	529.0±

Complete sections are not available because much of the formation is covered and the lower contact is not exposed. The top of the Tumuru Formation is an irregular erosional surface, in places covered by the Miyara Formation, Nagura Gravel, Ryukyu Limestone, or other deposits, all of which are in angular unconformity to the Tumuru. Younger rocks obscure the contacts of the Tumuru with the Fu-saki Formation, or faults separate the two formations.

THICKNESS AND DISTRIBUTION

The exposed thickness of the Tumuru Formation on Ishigaki-shima is estimated to be about 600 meters. The total area mapped is about 25 square kilometers, and, in addition, part of the area mapped as undifferentiated Ishigaki Group includes rocks of the Tumuru Formation. The Tumuru Formation crops out in the northern and western parts of the island, chiefly in mountainous terrain and on marine-cut terraces at the base of mountains (figs. 12, 13).

LITHOLOGY

GREENSCHIST

Greenschist is one of the most abundant lithologic types of the Tumuru Formation. It is interbedded with bluish-gray or bluish-green crossite and glaucophane schist, dark-gray carbonaceous and graphitic schist, and light-gray quartz-mica schist. Schistosity generally is well developed. Quartz veins and veinlets commonly cut the rock in many directions, and lenses and stringers of quartz are characteristic along planes of schistosity.

Greenschist is abundant on the Yarabu peninsula (fig. 14) and composes large parts of the Tumuru Formation of the Ibaruma and Hirakubo peninsulas.

Typical outcrops of greenschist are green or green and brown on weathered surfaces. Most weathered rock is fairly soft and easily dug away with a pick, but in places, especially where the amount of quartz is high, the rock is hard and forms ledges. Locally, as at Ō-saki on the Yarabu peninsula, small pyrite crystals are abundant and may cause the weathered surface to be brown and speckled.

The color of fresh greenschist surfaces is green or greenish-gray with white streaks and patches of quartz. A mottled appearance characterizes a few specimens in which albite is a principal constituent.

The principal minerals composing greenschist are epidote, chlorite, actinolite, and albite. Common minor constituents are titanite, iron oxides, iron sulfides, mica, and quartz. Grain size generally ranges from 0.05 to 0.3 millimeters. Some specimens show distinct banding, but others do not. Banding seems to be due in part to differences of mineral composition, and some bands may represent original bedding. Some types of greenschist are very dense, but others have small cavities as much as 3 centimeters long along planes of schistosity. On the axes of small folds, cavities may be larger.

GLAUCOPHANE SCHIST AND CROSSITE SCHIST

Bluish-gray and bluish-green schists are interbedded with greenschists, although they seem to be most common toward the upper part of exposed sections. Blue schists are most abundant on the Hirakubo and Yarabu peninsulas; yet they also crop out in areas where the Ishigaki Group has not yet been differentiated into formations, as along the eastern coast near Tōzato and in the Fukai area. The bluish color is due to the sodium amphiboles crossite and glaucophane, crossite being the most common.

Typical types of the crossite and glaucophane schists, along with their minor constituents, are as follows: epidote-glaucophane schist with titanite, muscovite, quartz, and rare albite; albite-chlorite-quartz-muscovite-epidote-crossite schist with iron oxides and a little titanite; epidote-muscovite-crossite schist with quartz, albite, and titanite; epidote-crossite schist with quartz, titanite, albite, muscovite, chlorite, and iron oxides; pumpellyite-glaucophane schist with quartz, albite, titanite, apatite, and iron oxides; albite-epidote-chlorite-crossite schist with titanite, iron oxides, and calcite; quartz-chlorite-epidote-crossite schist with titanite, muscovite, and iron oxides; garnet-crossite-quartz schist with iron oxides, muscovite, chlorite, apatite, and albite; and epidote-chlorite-crossite-quartz schist with titanite and muscovite.

Grain size of crossite and glaucophane schists generally ranges from 0.05 to 0.3 millimeter, but a grain size of 0.01–0.05 millimeter was observed in some samples.

Schürmann, who examined some of the Ishigaki-shima material, reported that specific gravity ranges from 3.02 to 3.18 and that the average of 13 determinations was 3.10. He stated (1958, p. 135) that this specific gravity is well known from fine-grained or dense dull glaucophane-bearing rocks in Japan, Turkey, Venezuela and Queensland.

Schürmann (1958, p. 134–135) further described the samples that he examined, 2 of which were from the Yarabu peninsula and 3 of which were from the north end of the island, as

> * * * very fine-grained, greyish-green to bluish-green coloured dull rocks without pronounced schistosity. On the cleavage planes some silky luster caused by chlorite and exceptionally by muscovite is frequent; some specimens show irregular bedding; porphyroblasts are absent. In some rocks there are concentrations of chlorite and of epidote. Needles of hornblende are only exceptionally recognized under the hand-lens * * *.

Under the microscope quite a variation in the different parts of the rocks is recognizable. Some parts show more schistosity than others and the mineral composition of the different parts varies too; some are rich in dolomite, others are not. A great variation in the chlorite content is also observed. Quartz as grains and veinlets is present. I am inclined to consider these rocks as having originated from sediments partly mixed with some tuffaceous material.

FIGURE 11.—Index map showing location of stratigraphic sections for the Ishigaki Group, Miyara Formation, and Nosoko Formation and location of samples from the Ishigaki Group. The stratigraphic sections are numbered as follows: Tumuru Formation (1); Fu-saki Formation (2); Miyara Formation (3); Miyara Formation (4); Miyara Formation (limestone) (5); Nosoko Formation (A); Nosoko Formation (B).

FIGURE 12.—Schist mountains of the Ibaruma peninsula. View northeast of the southwestern side of the Ibaruma peninsula. The mountains are composed of schist of the Tumuru Formation. The upper part of the terrace is cut on schist, but other rocks including those of the Miyara and Nosoko Formations and Sakishima Group compose parts of the terrace. June 1956.

FIGURE 13.—Sea cliffs and sea stack at Hirakubo-saki. Jointed schist of the Tumuru Formation composes the northern end of the Hirakubo peninsula, which terminates in sea cliffs more than 20 meters high. December 1955.

The material as described by Schürmann can be considered fairly representative of the glaucophane and crossite schists of Ishigaki-shima, although variations exist in color, schistosity, and mineralogy. Some of the schists of Ishigaki-shima are also bluish gray in color; many have pronounced schistosity; and carbonate may be lacking.

Schürmann (1958, p. 135) originally regarded blue amphibole in rocks from Ishigaki-shima as a variation of riebeckite tending to crocidolite. He stated that similar blue amphibole had been described from Japan by Suzuki and from California by Borg. Later Schürmann (oral commun., 1959) recognized the blue amphibole as crossite. Suzuki (1939) described an isomorphous series from glaucophane through crossite and riebeckite to crocidolite. Blue amphiboles from Ishigaki-shima seem to be more like most of the blue amphibole that Suzuki described as crossite than like the other minerals in the series. Borg (1956, p. 1569) designated the amphibole in his California material as crossite. In the terminology of Miyashiro and Banno (1958, p. 99), blue amphibole from Ishigaki-shima is probably "parallel-symmetric glaucophane" and crossite.

In the specimen from Ishigaki-shima that contains pumpellyite (IS–F–197–56)[2], the glaucophane is very pale. Banno stated (written commun., 1957) that this pale variety of glaucophane resembles that described from California but is rare in glaucophane schists in Japan.

Blue amphibole in 13 specimens from Ishigaki-shima was determined optically by Frances Fisher, U.S. Geological Survey; 11 were identified as pale- to medium-blue crossite and 2 as very pale glaucophane (fig. 15). Optical characteristics of 3 specimens as determined by Mrs. Fisher, are as follows:

Optical properties of blue amphibole from Ishigaki-shima

Glaucophane (specimen IS–F–228–56):
- $Y=b$ [optic plane parallel to (010)]
- $Z \wedge c = 6°–14°$
- $2V_z = 33°$
- Strong inclined dispersion of bisectrices, red>violet
- X=neutral or colorless
- Y=faint violet
- Z=faint blue

Crossite (specimen IS–F–270–56):
- $Z=b$ [optic plane normal to (010)]
- $Y \wedge c = 3°$
- $2V_z = 35°$
- Strong inclined dispersion of bisectrices, red<violet
- X=colorless, or pale yellowish blue
- Y=blue
- Z=violet

Crossite (specimen IS–F–149–56):
- $Z=b$
- $Y \wedge c = 12°$
- $2V_z = 54°$
- Strong dispersion of bisectrices, red<violet
- X=colorless
- Y=blue
- Z=violet

OTHER ROCK TYPES

Light-tan and light-gray schists make up a small part of the Tumuru Formation in most outcrops, particularly in the southern part of the Ibaruma peninsula. Combinations of chlorite, muscovite, sericite, albite, and quartz are the principal mineral constituents of these schists; apatite, tourmaline, and titanite, and in some places iron oxides and graphite are the usual minor constituents. Where the mica content is high, the schist is rather soft, and outcropping ledges are rare; but

[2] Most samples and sample localities have designations such as IS–F–21–56 or IS–M–122–55. "IS" indicates that the specimen is from Ishigaki-shima. "F" shows that it was collected by H. L. Foster and "M" that it was collected by H. G. May. The last number is the year of collection. In some places, this complete sample designation has been shortened, for example, F–21 or M–122.

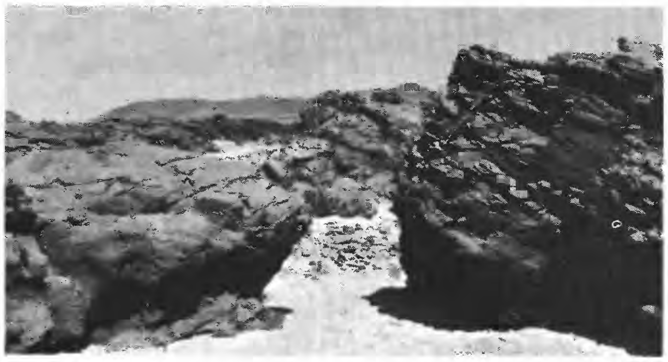

FIGURE 14.—Greenschist of the Tumuru Formation at Ō-saki, Yarabu peninsula. Note schistosity and joints. Rock on the left has been smoothed by wave action. July 1955.

schists composed principally of quartz are fairly resistant.

Very dark-gray, almost black schists—composed chiefly of graphite and quartz, with minor constituents such as albite, calcite, sericite, and iron oxides—occur in shear zones and are found interbedded with quartz-mica schists. Graphitic schists are most common near the base of the exposed sections of the Tumuru Formation; they are generally about 2–20 centimeters thick but are more than 1 meter thick in one section near Tumuru-saki.

Schist, nearly 50 percent of which is pyrite grains, crops out along the eastern coast about 1.8 kilometers southeast of Akeishi. Other principal mineral components of this rock are chlorite, muscovite, albite, and quartz. Apatite is a minor constituent. Chlorite and some pyrite have altered to a deep reddish-brown secondary mineral of high birefringence. The zone of high concentration of pyrite in the schist is less than 46 meters across. Springs emerge along cracks in the schist, and blue-green stains from secondary deposits occur here and there on the surface. The copper content of two specimens of schist collected from slightly different stratigraphic positions within approximately 1 meter of each other is 0.245 percent for one specimen and 0.0085 percent for the other. This pyritic zone in the schist could not be traced inland along the strike because of the vegetation cover and the poor outcrops. It was not found in the mountains to the west or on the western coast.

ORIGIN

The Tumuru Formation probably originated as sediments and volcanic materials deposited in a geosyncline, very likely a eugeosyncline. Because of the abundance of greenschists, it is estimated that more than 60 percent of the Tumuru Formation came from mafic volcanic materials. Crossite and glaucophane schists also seem to be derived largely from mafic igneous rocks because they are similar in chemical composition (table 2) to many basalts. The mineral assemblages are similar to those Turner (Fyfe and others, 1958, p. 227) cited as mafic assemblages. Abundance of epidote in many schists is also considered indicative of a mafic igneous origin (Williams and others, 1954, p. 228). A few glaucophane schists, however, may have been derived from several different kinds of sedimentary rocks, including tuffaceous sediments, as suggested by Schürmann (1958, p. 134–135), because there is considerable variation in the mineral compositions of specimens from different stratigraphic positions. The abundance of minerals such as chlorite, albite, quartz, and, in some specimens, micas and the minor amounts of epidote and glaucophane or crossite suggest that some parent rocks may have been pelitic and psammitic. Where epidote and glaucophane or crossite are also abundant, a pelitic parent sediment mixed with some mafic material may be indicated. For instance, the thin section of specimen IS–M–234–56 from near Tōzato, which is an epidote-muscovite-crossite schist with quartz, albite, and titanite, contains bands composed principally of muscovite and bands consisting largely of crossite. The muscovite-rich bands may indicate a parent pelitic sediment; the crossite-rich layers may indicate original mafic materials, such as mafic tuff.

TABLE 2.—*Chemical analyses of schists from the Tumuru Formation*

[Analyses 1, 2, and 4 by Dorothy F. Powers, U.S. Geol. Survey, 1959. Analysis 3 by Japan Inspection Co., Ltd., Tokyo, Japan, 1957. Analysis 5 is from Daly (1914, p. 27) and is an average of 121 basalts]

	1 IS–F–228–56 Glaucophane schist	2 IS–F–262–56 Crossite schist	3 IS–F–263–56 Crossite schist	4 IS–M–429–56 Greenschist	5 Average basalt
SiO_2	46.93	48.86	47.00	49.59	48.8
Al_2O_3	13.45	15.83	14.52	14.05	15.8
Fe_2O_3	6.74	8.18	7.28	3.55	5.4
FeO	8.05	3.51	7.67	6.70	6.3
MgO	6.04	3.86	5.09	6.83	5.4
CaO	8.65	8.80	9.22	10.44	8.2
Na_2O	3.07	4.86	1.63	3.60	3.9
K_2O	.93	.79	.55	.22	2.8
H_2O+	2.95	2.19	2.05	2.32	1.5
H_2O-	.14	.04	.58	.10	
TiO_2	2.51	1.57	3.15	1.54	1.9
P_2O_5	.24	.24	.46	.15	.5
MnO	.22	.13	.23	.16	.3
CO_2	.02	.94	nil	.62	----------
CuO	----------	----------	.05	----------	----------
Total	99.94	99.80	99.48	99.87	100.8

Graphitic schist and quartz-mica schist probably originated from pelitic and psammitic rocks because these schists have micas, chlorite, quartz, albite, and epidote as the common abundant minerals.

FIGURE 15.—Localities for crossite and glaucophane schist specimens (c, indicates crossite schist; g, indicates glaucophane schist). Determinations by Frances Fisher, U.S. Geological Survey.

FU-SAKI FORMATION

TYPE SECTION AND STRATIGRAPHIC RELATIONSHIPS

The Fu-saki Formation of the Ishigaki Group was named by Foster and others (1960, p. 88) from Fu-saki, a point on the southwestern coast of Ishigaki-shima where a part of the Fu-saki Formation is well exposed. Because no type section was named, the stratigraphic succession in the vicinity of Fu-saki and in the mountains to the west is here designated as the type section (figs. 11, 16). This section is considered the most representative available, even though it does not include all the rock types; it is partly covered, not continuous, and is folded and faulted. The top of the section is irregularly eroded, and the base is not exposed. This is true of all known exposures of the formation. The lowest part of the section consists of about 23–36 meters of conglomerate, the base of which is concealed. Above, 2.5–3 meters of dark-gray phyllite crops out locally. Bedded chert, 7.5–14 meters thick, overlies the phyllite, and dark-gray phyllite, 7.5–12 meters thick, overlies the chert. Massive sandstone about 7.5–12 meters thick lies

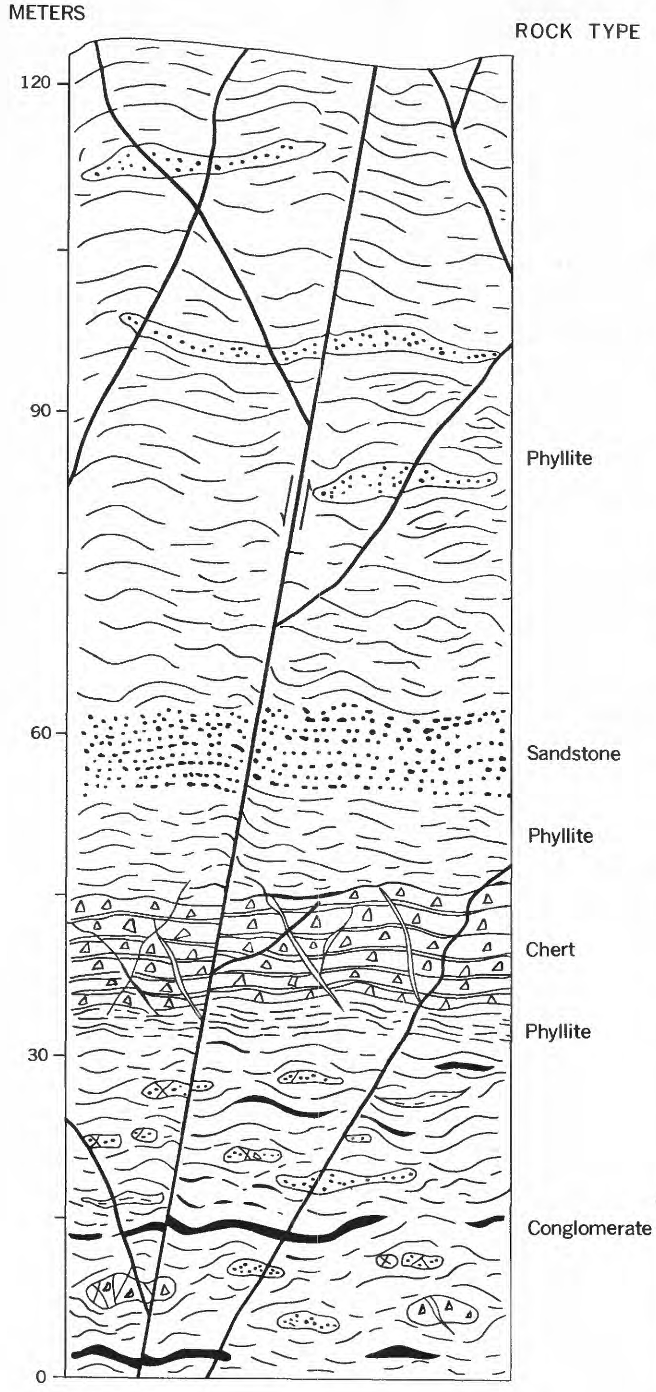

Figure 16.—Diagrammatic stratigraphic section of the Fu-saki Formation.

above the phyllite, and more than 60 meters of dark-gray phyllite and lenticular quartzitic sandstones in turn overlie the sandstone. Locally the phyllite grades into schists or is replaced in the section by schists.

The stratigraphic position of some other rock types in the Fu-saki Formation, such as marble and some phyllites and related schists, is not known.

THICKNESS AND DISTRIBUTION

The maximum observed thickness of the Fu-saki Formation is about 168 meters, but the formation is probable considerably thicker. A better knowledge of the structure of the formation is needed before more accurate determinations of thickness can be made. The Fu-saki Formation crops out chiefly in southeastern and southwestern Ishigaki-shima. It covers a mapped area of approximately 18 square kilometers.

LITHOLOGY

CONGLOMERATE

Conglomerate crops out at Fu-saki and along the coast 300 meters to the southeast, at Aka-saki, on the neck of the Yarabu peninsula, and in the mountainous area south of Nagura, as well as on the northeastern coast of the island of Taketomi. The conglomerate seems to be the lowest part of the Fu-saki Formation, but its base is concealed. It is estimated to have an exposed thickness of 23–46 meters. The conglomerate is composed chiefly of angular to subrounded fragments of light gray quartzite about 0.6–5 centimeters across embedded in a gray shaly matrix that locally has abundant black, fine-grained carbonaceous material. The matrix is somewhat sandy in places and is slightly schistose. Gray or brown shaly fragments are locally abundant. On Taketomi-shima, fragments of chert as much as 46 centimeters across were seen, but, in general, chert and white quartz are rare. No fragments of igneous rock or of greenschist were observed. The schistosity of the matrix commonly seems to flow around the larger rock fragments. Broken pebbles and rock fragments which seem to be stretched and rolled are characteristic at Fu-saki. Bedding, if formerly present, is unrecognizable. At Aka-saki, andesitic dikes or sills of at least two ages cut the conglomerate, and at least one set is infolded with conglomerate.

In the mountain area south of Nagura, the conglomerate has seams of quartz-graphite schist, and at Aka-saki, the conglomerate is interbedded with light-gray siltstone and some brown sandstone lenses. At Fu-saki, the conglomerate is overlain by 2.5 meters of weathered yellowish-brown schist which is absent in the mountains south of Nagura. This schist is in turn overlain by chert. At Taketomi-shima sandstone probably overlies the conglomerate; and chert, the sandstone. The kind of overlying rock is not certainly known in other places but is probably chert, or schist and then chert.

CHERT

Chert is one of the most characteristic and conspicuous rocks of the Fu-saki Formation (fig. 17). Because

FIGURE 17.—Chert at Fu-saki. These fractured and folded beds of chert at the type locality of the Fu-saki Formation are characteristic of the formation. 1956.

of its resistance to erosion, chert forms knobs, hills, and boulder fields which are more or less alined along the strike of the chert; examples are those eastward from Fu-saki and north and northeast of the mouth of the Nagura-gawa. Chert composes the prominent point of Fu-saki upon which a lighthouse is built, and it is an important component of the mountain area south of Nagura.

There is probably only one sequence of chert beds, 7.5–14 meters thick, but because the structure is very complex, this was not determined with certainty.

Most of the chert is light gray or white, but that along the coast 1,400 meters northeast of Fu-saki is red. In places, it is banded gray and white or mottled. In the vicinity of Fu-saki and eastward, north of the mouth of the Nagura-gawa, and in other scattered exposures, thin beds of chert range from 0.6 to 4 centimeters in thickness. Chert beds are commonly separated by paper-thin layers of shale or limonitic clay. In a few localities, as at the mountain front along the northeastern shore of Nagura-wan, the chert is massive. It may have originally been thick bedded, or massiveness may be due in part to obscuring of bedding by metamorphism and the emplacement of quartz veins and veinlets. Much of the chert in this area grades into a rock resembling true quartzite, which may be completely or partly recrystallized chert. No evidence of fossils, either megascopic or microscopic, has been found in the chert.

The chert is tightly folded and much fractured (fig. 17) and has abundant veinlets of quartz extending in many directions. Calcite veinlets also occur but are less abundant. Some of the veinlets pinch and swell, but others are uniform in width. Offsets are common. Margins of veinlets, especially the larger ones, have a narrow zone of crystals smaller than those composing the interior of the veinlet. Inclusions are common in the quartz crystals, and crystals of both the rock mass and the veinlets have pronounced undulatory extinction. Some of the chert seems to have been crushed and severely fractured; the fractures are now healed and filled by linear mosaics of fine quartz crystals.

SANDSTONE

Gray and tan massive sandstone forms persistent beds in the Fu-saki Formation, particularly along the shore near the mouth of the Nagura-gawa and in the mountainous area south of Nagura. It also crops out on the northeastern shore of Taketomi-shima. A typical sandstone is composed mainly of quartz and plagioclase grains, the plagioclase commonly being more abundant than the quartz. Grains are mostly angular or subangular; they range in size from 0.05 to 1 millimeter and average 0.5 millimeter. Quartz grains have undulatory extinction. Recrystallized muscovite, chlorite, and clay minerals are common cements, but some siliceous cement is present.

Sandstone from Mi-saki on Taketomi-shima weathers steel gray or olive brown. It is gray or tan on fresh surfaces. On the basis of microscopic examination, it is slightly metamorphosed arkosic wacke (terminology of Williams and others, 1954, p. 291). Muscovite formed during the metamorphism, and some is oriented. Plagioclase and other feldspars, quartz, and chert are the predominant mineral grains. Most quartz grains show strain effects. Some of the feldspar is microcline and perthite.

PHYLLITE, CARBONACEOUS SCHISTS, AND GRAPHITE SCHISTS

Phyllite at several different horizons in the succession of the Fu-saki Formation is of two general types. One type is dark gray; in places it resembles a shale but grades to true dark-gray phyllite, to carbonaceous schist, and in shear zones to graphite schist. In thin section, a dark-gray phyllite (IS–M–200–56) is seen to be a very fine-grained sericite phyllite that has the recognizable minor constituents chlorite, graphite, and iron oxides. The second type is a tan or light-gray phyllite that is commonly smooth, silvery, and micaceous. This phyllite grades into sericite, mica, and light-green schist. A common type of light-gray and tan banded phyllite from Nusukun-muru (6 km north of Shiraho) is a sericite-chlorite phyllite (IS–M–229–56). It is very fine grained and schistose. The gray bands include graphite. Chlorite and sericite are altered to reddish-brown secondary minerals.

The phyllite both overlies and underlies chert and in the mountainous area south of Nagura forms a thick sequence about 60 meters thick at the top of the exposed section of the Fu-saki Formation.

MARBLE

Marble has been found on Ishigaki-shima at one locality, Ishisoko, and also on the northeastern coast of Taketomi-shima. The thickness is not measurable at either locality. At Ishisoko, 2.5 kilometers north of Shika, marble composes an isolated conical knob about 21 meters high, 61 meters long, and 46 meters wide. The marble is gray and massive. It is broken by a conspicuous set of widely spaced vertical joints and a few less conspicuous oblique joints. Solution has widened the joints, and the top of the knob is pinnacled. The relation of the marble to other rocks in the vicinity is not known.

Microscopically, the rock is a mosaic composed of an aggregate of interlocking calcite crystals, which Heinrich (1956, p. 195) described as a sutured texture. The common grain size is about 0.45–0.85 millimeter across; however clusters or areas of smaller crystals are found. All clastic and organic structures have been effaced. Bent twinning planes and granulated zones and streaks are common.

Crystals of calcite both larger and smaller than those of the main mass of rock compose veinlets that extend in many directions. Minerals other than calcite are rare in the thin sections, although occasional quartz and chert grains were found.

Marble on Taketomi-shima lithologically resembles that of Ishisoko, but only a small amount of it is interbedded with or occurs as a lens in gray shale. It crops out for a distance of about 5 meters along the strike and has a maximum outcrop width of as much as 1.3 meters. Because the marble has been folded and squeezed, the width of outcrop does not represent the true thickness of the marble. The marble itself contains some dark-gray streaks. A thin section showed that the rock is coarser grained than that from Ishisoko, having calcite crystals as large as 1.6 millimeters across. The texture is somewhat granoblastic.

Lithologically, the marble of Ishigaki-shima and that of Taketomi-shima closely resemble the Motobu Formation of Okinawa-jima.

OTHER ROCK TYPES

Hornfels occurs mostly along the margins of the granitic intrusives. A typical biotite hornfels from along the western contact between the granite and the Fu-saki Formation consists of fine grains of light-reddish-brown biotite scattered among fine grains of quartz. Minor constituents are chlorite, muscovite, garnet, tourmaline, and calcite. Grain size ranges from less than 0.01 to 0.05 millimeter. The hornfels probably formed from a psammitic rock. A biotite hornfels from the contact between granitic rocks and the Fu-saki Formation along the Shiramizu-gawa has biotite crystals 0.2–0.4 millimeter in size in a groundmass of quartz and feldspar. The feldspar is partly altered to aggregates of muscovite with a small amount of chlorite. Quartz is medium grained and has an allotriomorphic texture.

Meta-andesite occurs as thin dikes offshore from the mouth of the Nagura-gawa and at Aka-saki. The dikes were emplaced before the metamorphism of the Fu-saki Formation because they were metamorphosed along with the host rocks. A few andesite dikes in the same localities were injected after the metamorphism.

Quartzite is most common in the area along the eastern side of Nagura-wan where the Fu-saki Formation borders the granitic intrusion. Most of the quartzite is white and massive. Some probably originated from contact metamorphism of sandstone, but part may be recrystallized chert. Under the microscope, quartz crystals show strain effects. Commonly the rock has closely spaced fractures which have completely healed. Quartzite (IS–M–210–56) also occurs associated with chert. For example, about 2.5 kilometers north of Shika, a reddish-brown quartzite underlies chert.

ORIGIN

The Fu-saki Formation was originally chiefly sedimentary rocks, such as arkosic sandstone, shale, and chert; the sediments were probably deposited in a geosyncline, very likely the same geosyncline in which the Tumuru Formation was deposited. However, at the time of deposition of the Fu-saki Formation, materials typical of miogeosynclinal conditions were accumulating, that is, predominantly arkosic sands and carbonaceous muds and silts. The arkosic sands containing microcline and perthite suggest a granitic source, perhaps granitic highlands bordering the geosyncline.

The origin of the bedded chert is unknown. It does not seem to be lenses in limestone. Similar bedded chert is present on Okinawa-jima and in Japan. It may have precipitated from water high in dissolved silica of volcanic origin. In cherts in Japan, lucid spots which have been interpreted as Radiolaria suggest that the silica may have been organically precipitated.

Limestone was also probably deposited in sequence with the other sediments. Marble at Ishisoko may be the erosional remnant of a lense of limestone squeezed into the crest of a fold.

WEATHERING AND SOILS

Weathering of the rocks of the Ishigaki Group varies in depth from 0 to about 8 meters because of the many different lithologic types and the variety of topographic situations. Generally, the chert, marble, crossite schist, some greenschists, some quartz schist, and hornfels are fairly resistant to weathering. Commonly, phyllites, metasandstone, some carbonaceous schists, and some mica and greenschists are deeply weathered. Weathering is generally deepest and soils are thickest in swales on ridges and hilltops composed of metasandstone, such as the swales in the mountains of southwestern Ishigaki-shima, including Maishi-take and Bannā-dake. Small areas of deep soil are commonly separated by areas of shallow soils or even areas of bedrock with no soil cover.

Shallow acid dark-grayish-brown Lithosols are the most common types developed on the Ishigaki Group in mountainous terrain. Rocky areas without a soil cover are common, and scattered areas of Red-Yellow Podzolic soils range in depth from 3 to 8 meters. In the hilly areas and on the marine-cut terraces underlain by the Ishigaki Group, Red-Yellow Podzolic soils predominate. These soils generally have a brownish loamy A horizon over a yellowish-red clay loam B horizon. Much of this soil is very stony, although there are stone-free areas. In the mountain region of southwestern Ishigaki-shima and on surrounding terraces underlain by the Fu-saki Formation, yellowish-brown, gravelly, sandy, and silty loams which are strongly acid are common.

AGE AND CORRELATION

The age of the Ishigaki Group is not definitely known as no fossils have been found in it. The group is certainly older than Eocene because it is overlain unconformably by Eocene conglomerate which contains rock fragments derived from the Ishigaki Group. It is known that rock fragments of the Ishigaki Group were eroded and incorporated in the Eocene conglomerate after the metamorphism of the rocks of that group because the Eocene conglomerate is not metamorphosed. Relative ages of the Tumuru Formation and Fu-saki Formation were not determined. No sedimentary contacts were observed between the two formations as they are separated by faults, or have their contacts covered by later deposits. Detailed studies of the undifferentiated areas of the Ishigaki Group may yield information on this problem in the future. Tentatively, the Tumuru Formation has been placed beneath the Fu-saki Formation in the geologic column because it seems to show a slightly higher degree of metamorphism, suggesting deeper burial. However, the degree of metamorphism cannot be directly compared because of differences in the original materials composing the two formations. Theories concerning the age of the Ishigaki Group are based largely on lithologic similarity between these rocks and those of neighboring areas, particularly those of Japan, Taiwan, and Okinawa-jima.

SIMILIARITY TO ROCKS IN JAPAN

Metamorphic rocks of the Ryūkyū-rettō resemble some metamorphic rocks of Japan, particularly the Paleozoic Sambagawa and Mikabu metamorphic rocks which occur in an elongate zone from the Kwanto mountain land of central Honshū southwestward to Kyūshū. The Sambagawa and Mikabu metamorphic rocks are a thick complex of crystalline schists, phyllites, chert, and crystalline limestone, mostly of the greenschist metamorphic facies. The rocks are highly deformed and their structure is extremely complex (Japan Geol. Survey, 1956, p. 118–124).

Yoshiwara, as early as 1899 (1901a), saw the resemblance of Ryukyuan metamorphic rocks to the Sambagawa and Mikabu metamorphic rocks (Chichibu System) of Japan and referred the age of the Ryukyuan rocks, including the Ishigaki Group, to the Paleozoic Era.

SIMILARITY TO ROCKS IN TAIWAN

The island of Taiwan, 240 kilometers west of Ishigaki-shima, has on its eastern side rugged mountains, the backbone range, composed of metamorphic rocks. These rocks include the Tananao Schist which "* * * on the eastern flank of the backbone range consists of graphite schist, schistose sandstone, cherty quartz schist, crystalline limestone, chlorite schist, and paragneiss derived mainly from sandstone, shale, limestone and basic pyroclastics" (Chang, 1958, p. 13). The Tananao Schist is considered by Yen (1954a, p. 50) to be of late Paleozoic age because of fusulines and corals obtained from the limestone.

Material which formed the Tananao Schist was similar to that which formed the rocks of the Ishigaki Group. Greenschists, which are an important part of the Tananao Schist, are mineralogically similar to those of the Ishigaki Group. The Tananao Schist differs from the Ishigaki Group in that it has much more crystalline limestone (marble) and graphite schist in the section and in that chert beds like those of the Ishigaki Group are missing.

The Tananao Schist may have been deposited in the southwestern part of the geosyncline in which the Ishigaki Group was deposited or in an adjoining contemporaneous geosyncline. Later, these deposits may have been affected by the same regional metamorphism, because the Tananao Schist shows the same general type and intensity of metamorphism as does the Ishigaki Group. Chang considers the Tananao Schist as belonging to the greenschist metamorphic facies (1958, p. 24). However, amphibolite schists (Yen, 1954a, p. 49), included in the Tananao Schist may indicate a slightly higher degree of metamorphism, at least locally, than is found in the Ishigaki Group. Limited personal field observations of some outcrops of the Tananao Schist also indicated that at least some of these rocks were somewhat more intensely metamorphosed than those of the Ishigaki Group.

Kobayashi (1954, p. 209–210), on the basis of structural and paleontological considerations, believes that the Tananao Schist (which he refers to as the Dainano Formation) is correlative with the metamorphic rocks of the Ryukyu Islands. Yen also considers this a likely correlation. Thus, correlatives of the Ishigaki Group may extend from central Japan as far south as northeastern Taiwan.

SIMILARITY TO ROCKS ON OKINAWA-JIMA

Okinawa-jima, 440 kilometers northeast of Ishigaki-shima, and several of the smaller islands near Okinawa-jima have outcrops of metamorphic rocks. The core of the northern part of Okinawa-jima is composed of metamorphic rocks called the Kunchan Group and Motobu Formation by Flint and others (1959, p. 19). These rocks are lithologically similar to those of Ishigaki-shima in that they include chert, sandsone, phyllite, and marble, as well as greenstones which might be equivalent to the greenschists of Ishigaki-shima. Structural deformation of the rocks is also similar in amount and kind to that of the Ishigaki Group. The rocks differ, however, in that some of the metamorphic rocks of the Ishigaki Group, particularly those of the Tumuru Formation, show a slightly higher degree of metamorphism and in that sodium amphibole schists have not been found on Okinawa-jima. Rocks of the Fu-saki Formation are most like those of Okinawa-jima in both lithology and degree of metamorphism; however, the rocks on Okinawa-jima seem to have much more marble and many more chert beds. Also, probably a much greater thickness of rock is exposed on Okinawa-jima than on Ishigaki-shima; the sections are probably thousands of meters thick rather than hundreds of meters thick.

On the Motobu peninsula (Okinawa-jima), crystalline limestone of the Motobu Formation contains the Foraminifera *Neoschwagerina* sp., *Paleofusulina* sp., and *Verbeekina doufillei* (Deprat), described by Hanzawa in 1932 (1932b, p. 672). The Foraminifera indicate a Permian age for the Motobu Formation. Unfortunately, the limestone of the Motobu does not give any definite information on the age of the other Okinawan metamorphic rocks, the Kunchan Group, as it is separated from them by a major thrust fault. The possibility that the Kunchan Group, or part of it, as well as other metamorphic rocks of the Ryūkyū-rettō are Mesozoic in age cannot be ruled out. For example, to the south a relationship with metamorphic rocks of possible Mesozoic age in the Philippine Islands could be considered. Also, in Mesozoic time, extensive geosynclines existed in Indonesian areas (Klompé, 1957, p. 57–60), in Japan, and possibly in Taiwan. Thus, Mesozoic geosynclines might have existed in the Ryukyu area.

The Ryukyu metamorphic rocks, however, are more like some of the Paleozoic rocks of Japan than like the Mesozoic rocks; and, as Irving (1952, p. 445) pointed out, "the Philippine Archipelago is more closely related to Indonesia than to Formosa (Taiwan) or to the Ryukyu and Japanese archipelagos." On the basis of present information and interpretation, therefore, the writer prefers to relate most of the Ryukyuan metamorphic rocks, including the Ishigaki Group, to the lithologically similar rocks of Taiwan and Japan rather than to those of the Philippines and Indonesia, and the writer prefers to consider them of probable Paleozoic age.

CORRELATION WITHIN THE SAKISHIMA-GUNTŌ

Metamorphic rocks similar to those of the Ishigaki Group in lithology and structure crop out on Taketomi-shima, Kohama-jima, Kayama-jima, and Iriomote-jima, neighboring islands in the Yaeyama-guntō. They crop out in localities which would be on the general east strike line, if extended westward, of the Ishigaki Group of southwestern Ishigaki-shima. Near Ishigaki-shima, Taketomi-shima, and Kayama-jima, offshore rocks are composed mostly of chert, indicating that the Ishigaki Group may be continuous beneath the comparatively shallow lagoonal waters that separate these islands. Therefore, all metamorphic rocks that crop out on islands of the Yaeyama-guntō are probably part of the Ishigaki Group or are correlative with it.

The islands of the Miyako-guntō, 177 kilometers northeast of Ishigaki-shima, have no outcrops of metamorphic rock, although pebbles and cobbles of metaquartzite, metamorphosed volcanic rocks and chlorite schist are found in a Tertiary conglomerate on Ogami-jima, a small island in the northern part of the island group (Doan and others, 1960, p. 77).

MIYARA FORMATION

The Miyara Formation is composed of conglomerate, sandstone, shale, and limestone. It overlies the rocks of the Ishigaki Group uncomformably. It is overlain by younger beds only in a few places, such as on the Yarabu peninsula where beds of the Nosoko Formation are present, and in southern Ishigaki-shima by formations of the Sakishima Group. The strata most commonly dip 15°–35° S. or SW.

The Miyara Formation crops out in small patches as far north as Kūra on the Hirakubo peninsula and as far south as Kāsunnā-saki on the western side of Miyara-wan in southern Ishigaki-shima. It occurs on the Yarabu peninsula and in several places along the eastern coast of the island. The formation most commonly crops out along the coast or on slightly hilly uplifted marine terraces, but on the Yarabu peninsula the limesone of the Miyara Formation is also present at altitudes of 100 meters as small patches on schist mountains or hills. Near Hoshino, limestone of the Miyara Formation forms three small, steep-sided hills 60–100 meters above sea level.

Terrain covered by limestone of the Miyara Formation is generally rough and difficult to traverse, owing to solution of the limestone. Patches of limestone remain as steep-sided, pinnacled, and solution-pitted blocks of differing sizes. The most extensive area of this rough, irregular limestone terrain is north of Ōno-saki on the eastern coast of the island.

The sandstone and conglomerate generally form gently rolling to hilly surfaces. The most extensive outcrops are 2 kilometers northeast of Shika and 2 kilometers northwest of Miyara. Shale is best exposed in stream valleys of the southwestern part of the Yarabu peninsula and along the southwestern coast of the Ibaruma peninsula.

ORIGIN OF NAME

Yoshiwara (1901a) observed and first described the sandstone, conglomerate, and limestone of the Miyara Formation on Ishigaki-shima, along with the volcanic rocks of the Nosoko Formation. He recognized that they were Tertiary in age but did not apply any formation names. Hanzawa (1932a) included most of these rocks in the "Eocene formation."

A few months later, Aoki (1932) published the name "Miyara group" and applied it to Hanzawa's "Eocene formation." He gave no type section. Hanzawa (1935, p. 12), in describing the stratigraphy of the southern Ryukyu Islands, used the term "Miyara beds" and described them as consisting "* * * mostly of hard compact limestones, with subordinate sandstones and conglomerates." He regarded the volcanic rocks as part of a younger formation, the Yaeyama coal-bearing beds, and not as part of the "Miyara beds." He assigned a late Eocene age to the "Miyara beds."

Hanzawa's (1935) stratigraphic divisions of the Tertiary and his application of the name Miyara to upper Eocene limestone, sandstone, and conglomerate beds are virtually the same as the usage in this paper. However, these strata will be referred to herein as the Miyara Formation, rather than the Miyara beds.

The name Miyara was probably obtained by Hanzawa and Aoki from outcrops of sandstone, conglomerate, and limestone northwest of the village of Miyara.

THICKNESS

The thickness of the exposed parts of the Miyara Formation varies at its several outcrops on the island. The original thickness was probably not uniform, and the difference in thickness has been accentuated by erosion and faulting. A section measured on the Yarabu peninsula exposes 52 meters of shale, sandstone, and limestone. The coastal section measured on the Ibaruma peninsula is about 141 meters thick. Near Miyara, only 12 meters of continuous section of sandstone and conglomerate could be measured because of poor exposures and faulting. Harold May, on the basis of scattered exposures (oral commun., 1956), however, estimated that the conglomerate and sandstone section in this area may be 75–90 meters thick. South of Ōzato, a section of sandstone and conglomerate of the Miyara Formation, bounded by faults and partly concealed, measured 44 meters. Limestone sections examined near Hoshino are estimated to be 25, 30, and 60 meters thick. No complete sections are exposed.

LITHOLOGY

The predominant rock types of the Miyara Formation are sandstone, conglomerate, and limestone. Shale and tuffaceous sandstone are minor rock types. Other volcanic rocks are present, such as a limy andesitic tuff in the Kūra area. However, most volcanic rocks associated with the Miyara Formation are considered to be younger than the sandstone-conglomerate-limestone sequence and are therefore included in the Nosoko Formation. Two sections of the Miyara Formation, one near Ibaruma and the other on the western side of the Yarabu peninsula, are most representative of the formation and are given below, although the limestone parts of the section are somewhat less typical of the formation than are the thick limestones near Hoshino (fig. 11).

Section of Miyara Formation measured west of Ibaruma

[Location of section shown in fig. 11]

	Thickness (meters)
Miyara Formation:	
Sandstone, greenish-gray; weathers buff	6.0±
Sandstone with interbedded limestone	4.5±
(Break in Section—the two sandstone beds above are believed to overlie the section given below, and a 1.5- to 6-m interval may occur between.)	
Limestone, dark-gray, shaly, with interbedded dark-gray dense limestone	3.5±
Sandstone, tan or greenish-gray, coarse- to fine-grained	7.5±
Limestone, dark-gray, shaly, thin-bedded; interval partly covered but probably includes bed of fairly coarse conglomerate and also 2.5- to 8-cm beds of dense limestone	10.0±
Limestone, gray, dense	7.5

Section of Miyara Formation measured west of Ibaruma—Continued

	Thickness (meters)
Miyara Formation—Continued	
Limestone, dark-gray, shaly, thin-bedded	0.5–1.0
Limestone, medium-gray, dense, sandy and conglomeratic; 0.7-cm pebbles	0.3±
Limestone, dark-gray, iron-stained, shaly; has nodular weathered surface; is much pointed and breaks into rectangular and triangular blocks about 30 cm in diameter	3.5
Covered; probably shaly limestone and perhaps lava or a dike	39.0
Limestone, dark-gray, shaly	1.0
Limestone, dark-gray, fairly dense; bedding irregular; beds range from 15 cm to more than 1 m thick	8.5
Covered; probably limestone and a bed of coarse conglomerate	6.0±
Limestone medium-gray, dense, somewhat nodular	0.4
Limestone, mottled	0.4
Limestone, medium-gray, slightly sandy, with thin pebbly zones	2.5
Limestone, sandy, with milky quartz and schist pebbles; most pebbles angular or subangular	5.0
Conglomerate; greenish-gray limestone matrix; most rock fragments are milky quartz, but some are schist; most fragments are somewhat angular; the fragments average 5 cm in diameter but some are as much as 15 cm in diameter	0.5
Conglomerate; limy matrix; finer than above bed as rock fragments are mostly less than 2 cm in diameter	2.0
Conglomerate; angular or subangular milky quartz and schist fragments in tan sandy matrix that composes about 25 percent of the rock; fragments average 1.5–5 cm in diameter and become coarser toward top of bed	4.0
Limestone, dark-gray, sandy; contain recrystallized fossil fragments; has poorly defined bedding, the beds 0.6 m ± thick	3.0
Limestone, gray, sandy	0.6
Covered	3.5
Conglomerate; chert, white quartz, and schist pebbles, mostly subangular; limy matrix; approximately 60 percent pebbles and 40 percent matrix	0.8
Limestone, greenish-gray, coarsely crystalline; weathers greenish-gray or black; has sandy and pebbly appearance near the base and rough, irregular surface	10.0
Covered; probably limestone	3.0
Andesite (sill?)	1.0
Conglomerate, roughly bedded; composed of angular white milky quartz fragments and a few pieces of schist averaging 0.6–5 cm in diameter but as large as 15 cm in diameter; matrix is tan or greenish-gray sandstone and makes up about 25 percent of the rock; at base, 0.6–5 cm of carbonaceous shale	6.0
Total thickness	141 ±
Unconformity.	
Schist.	

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Section of Miyara Formation measured on west end of Yarabu peninsula

[Location of section shown in fig. 11]

	Thickness (meters)
Miyara Formation:	
Sandstone, tuffaceous, greenish-brown, fine-grained, blocky; beds about 10 cm thick	0.49
Sandstone, tuffaceous, blackish-brown, conglomeratic, crumbly	.46
Limestone, greenish-gray, blocky; beds 5–10 cm thick	.92
Sandstone, tuffaceous, brown; possibly limy	.58
Sandstone, tuffaceous, brown and green	.52
Sandstone, tuffaceous, tan; blocky in places, shaly in places	2.5 ±
Covered	1.5
Tuff, tan, and limy shale and shaly limestone; blocky beds between shaly beds	6.0 ±
Covered	3.0 ±
Lava (probably a sill)	2.5 ±
Covered	6.0 ±
Shale, gray, much fractured	2.5 ±
Covered	3.0 ±
Shale, gray, much fractured; conchoidal fracture	9.0 ±
Limestone, gray, dense; contains Foraminifera, including *Pellatispira*	0.6–2.0
Shale, gray	9.0 ±
Limestone, gray, shaly; erosional remnants only	2.0 ±
Total thickness	51.97±
Unconformity.	
Schist, green.	

CONGLOMERATE AND SANDSTONE

Conglomerate and sandstone of the Miyara Formation crop out on the coast at Kāsunnā-saki near Ōhama (fig. 18), northeast of Shika, northwest of Miyara, 1.6 kilometers south of Ōzato (fig. 19), on the coast west of Ibaruma (fig. 20), and in minor amounts on the Yarabu peninsula.

The conglomerate consists of subrounded to rounded pebbles derived from the Ishigaki Group embedded in a gray, greenish-gray, reddish-brown or tan sandy, clayey, or limy matrix. A tan or gray sandy matrix is the most abundant type. The rock fragments are chiefly milky quartz, chert, greenschist, glaucophane schist, quartz-mica schist, and minor amounts of other metamorphic rocks. No granite or granodiorite was found, although Hanzawa (1935, p. 12) mentioned granitic material in the conglomerate.

The rock fragments range in diameter from 0.6 to 46 centimeters (fig. 18*A*), but beds containing fragments 1–5 centimeters across are most common (fig. 20). Fragments compose from about 25 to 75 percent of the total rock, the amount of matrix being greater in the finer conglomerate. Bedding in the conglomerate is commonly obscure and irregular, whereas lensing is a conspicuous feature. Beds of conglomerate range from 2 centimeters to about 1 meter in thick-

FIGURE 18.—Miyara Formation at Kāsunnā-saki, Ohama. Upper, Coarse conglomerate of the Miyara Formation; large boulders of schist, chert, and quartz are as much as 46 centimeters in largest diameter; matrix is tan sandstone and is not calcareous. April 1956. Lower, Concretionary material in the Miyara Formation. Weathered surfaces of sandstone and interbedded conglomerate at Kāsunnā-saki, Ōhama, have irregular protrusions and lumps produced by differential weathering and erosion of the outcrop. White specks in the lower part of the sandstone are small white quartz pebbles. Larger pebbles can be seen in conglomeratic beds at the top of the exposure. April 1956.

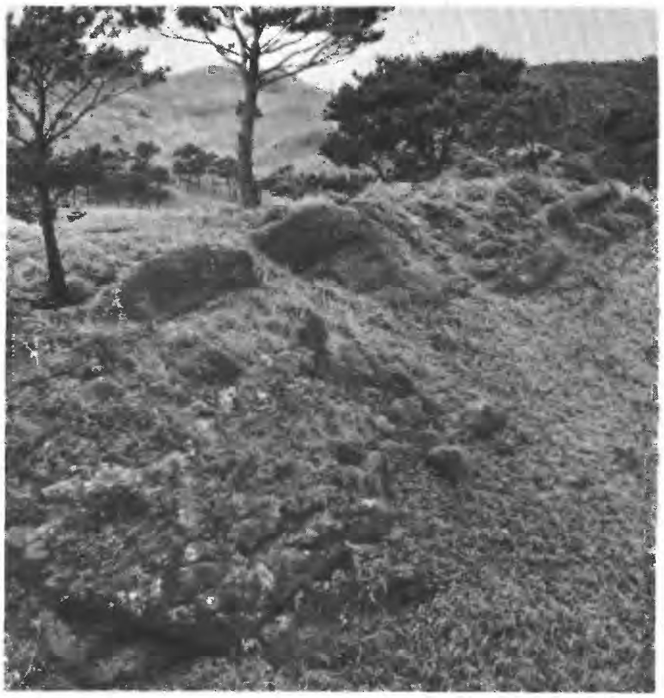


FIGURE 19.—Conglomerate of the Miyara Formation 1.6 kilometers south of Ōzato. This outcrop of typical southward-dipping beds in characteristically hilly terrain is somewhat smoothed and rounded by weathering. Some of the bedding planes are distinct. The beds are as much as 0.8 meter thick. April 1956.

ness; the thicker beds are not confined to the coarse conglomerates.

Sandstone is interbedded with conglomerate, and sandstone and conglomerate grade into each other (fig. 18*B*). Also, lenses of sandstone occur in the conglomerate. Conglomerate with a limy matrix commonly grades upward into limestone. Characteristics of the principal exposures of conglomerate are given in table 3.

The sandstone is most commonly tan or brown on weathered surfaces and tan or gray on fresh surfaces. It is composed predominantly of angular quartz grains and fragments of milky quartz and chert. Feldspar grains and small fragments of schist occur in minor amounts. Locally the sandstone is tuffaceous. The matrix most commonly contains chlorite, calcite, or both. Limonitic cementing material is present in places.

Grain size ranges from fine to very coarse, and the coarse sand grades into conglomerate. Some of the sandstone might be called pebbly sandstone because it has small (0.3–0.7 cm) chert or quartz pebbles scattered sparsely through it. Most exposed sandstone is much weathered and rather crumbly.

LIMESTONE

Kinds and distribution.—Limestone of the Miyara Formation is dominantly light-gray or tan; it is dense,

FIGURE 20.—Conglomerate of the Miyara Formation west of Ibaruma. This coastal exposure consists of slightly rounded to angular quartz and schist fragments in a tan and gray sandstone matrix. The rock fragments are mostly in a size range of 1–5 centimeters. Stratification is indistinct. November 1955.

finely crystalline and fossiliferous (fig. 21). Other, less abundant types are dark-gray limestone, brown sandy limestone, and conglomeratic limestone. These are commonly found at the base of the limestone sections and grade upward into the more typical dense light-gray or tan limestone.

On the Ibaruma peninsula and in the Miyara area, limestone, conglomerate, and conglomeratic limestone are interbedded. On the Yarabu peninsula, limestone occurs in small isolated outcrops. In the stream valley 1 kilometer southeast of Yarabu-zaki, limestone is interbedded with shale. Conglomeratic limestone grades upward into dense light-gray limestone 1 kilometer north of Ō-saki. Dark-gray shaly limestone crops out on the Ibaruma peninsula and in the Miyara area.

Large outcrops of limestone are found near Hoshino and Ōzato. Small erosional remnants occur in the vicinity of Inōda. Limestone blocks are also found near Kūra (fig. 21*B*).

Light-gray and tan limestone.—The dense light-gray and tan limestone is a bioclastic limestone and consists mainly of debris of calcareous algae, foraminiferal tests, and fragments of calcareous shells and exoskeletons. Calcareous algae contributed the most to the limestone (fig. 21*C*). Foraminifera were important contributors in places, but corals were comparatively unimportant. The other principal organisms represented, but in minor amounts, are echinoderms and bryozoans. The groundmass consists chiefly of fine organic debris and crystalline calcite. A few fine sand grains are an insignificant part of the total composition of the rock. The limestone is relatively pure. Chemical analysis of a sample (IS–M–125–56) from 0.4 kilometer west of Hoshino shows only 0.22 percent MgO, 1.82 percent SiO_2, 0.30 percent Fe_2O_3, and 0.62 percent Al_2O_3. (The complete chemical analysis is given under the section on "Economic geology," table 23.) In thin section the impurities are seen to be tiny (0.1–0.3 mm) angular grains of detrital quartz or small fragments of chert. Slides of limestone from Hoshino (IS–M–236–56, IS–M–236–56f, IS–M–239–56, IS–M–24056a), from Miyara (IS–M–244–56), and from 1 kilometer south of the Tōro-gawa (IS–M–241–56a, IS–M–241–56c) show only a very few scattered small quartz grains or chert fragments. More than 97 percent of each slide is debris of calcareous algae, tests or parts of tests of Foraminifera, calcitic fragments of other marine organisms, and crystalline calcite cement.

Solution has occurred along bedding planes and joints in the limestone. Along the coast near Ōzato, solution features are particularly well developed. Joint blocks of limestone have rough, sharp, irregular pitted and fretted surfaces (fig. 21*A*). On the Yarabu peninsula, near Kūra, and in the Miyara area, some outcrops seem to be erosional remnants of formerly larger outcrops (fig. 21*A*, *B*). In places, such as northeast of Miyara, the light-gray or tan limestone weathers so that the surface around the algae composing the rock is etched out. This produces a rough surface (fig. 21*C*).

Beds in the light-gray and tan limestone range in thickness from 7 centimeters to 2 meters, the average thickness being about 1 meter. South or southwestward dips of 15°–30° are most common. In places, cracks in the limestone have been filled by calcite, and calcite veins 6 centimeters or more across are present.

Dark-gray limestone.—The dark-gray limestone is also bioclastic. Its weathered surface is commonly scaly, and thin layers of rock can be peeled off. Near Ibaruma, algal limestone is dominant, but small echinoderms are found weathered out here and there on the surface. The dark-gray limestone occurs at the base of the three limestone hills near Hoshino; there it is characterized by an abundance of *Discocyclina*. Some specimens have a few widely scattered clusters of tiny pyrite crystals. Although the limestone commonly has a shaly appearance, thin sections of specimens from near Hoshino show it to be fairly pure. Bedding is in-

TABLE 3.—*Description and comparison of principal*

Locality	Rock types and relations	Rock fragments			Matrix
		Kind	Size	Angularity	Kind
Kāsunnā-saki (coast at Ōhama).	Conglomerate and interbedded sandstone; also conglomerate lensing into sandstone.	Quartz, chert, and schist	Pebbles to boulders 46 cm in diameter.	Slightly rounded	Sandstone ranging from fine-grained to coarse pebbly sand.
North-northwest of Shika 1.6–3 km.	Conglomerate interbedded with sandstone.	Quartz and chert predominate.	Pebbles	Angular to subangular	Sandstone and sandy, pebbly clay.
Northwest of Miyara	Conglomerate interbedded with limestone and sandstone.	Quartz and chert predominate.	Pebbles mostly less than 2 cm in diameter. Rare larger pebbles and fragments as much as 16 cm in diameter.	Slightly to fairly well-rounded.	Sandy where interbedded with sandstone; limy where interbedded with limestone; in some places limonitic.
South of Ōzato 1.6 km	Conglomerate interbedded with sandstone.	Milky quartz, gray-white chert, quartz-mica schist (75 percent quartz and chert).	Mostly 0.6–10 cm in diameter.	Angular to slightly rounded.	Argillaceous, pebbly sandstone.
Coast west of Ibaruma	Conglomerate; and conglomerate interbedded with limestone, shale, and sandstone.	Predominantly quartz but some schist.	Mostly 0.6–6 cm in diameter, but some as much as 16 cm.	Angular to slightly rounded.	Sandy, argillaceous, or limy.

distinct. Solution features are not conspicuous, but weathered surfaces are usually rough, having a relief of 1–5 millimeters.

Sandy limestone.—Brown sandy limestone occurs near the base of the exposed limestone section near Ōzato (IS–M–241–56). It contains some small pebbles and traces of fossils. Elsewhere various gradations between limestone, sandy limestone, limy sandstone, and sandstone are present, especially in the Miyara area.

Conglomeratic limestone.—Conglomeratic limestone forms the base of the Miyara Formation in places on the Yarabu peninsula and near Hoshino. On the Yarabu peninsula, it unconformably overlies schist of the Ishigaki Group. It is a dense cream-colored algal limestone containing scattered small pebbles of white quartz and greenschist. Pink areas give the limestone a mottled appearance. The conglomeratic zone is commonly only a few centimeters to a meter thick, and it grades upward into fairly pure light-gray dense limestone. The base of the northern limestone block of the Miyara at Hoshino is dark-gray limestone conglomerate. White, angular to somewhat rounded quartz pebbles as large as 2 centimeters in diameter but averaging less than 0.7 centimeter are embedded in a gray algal-limestone matrix. Gradations between limy conglomerate and conglomeratic limestone occur on the Ibaruma peninsula where conglomeratic beds are interbedded with typical tan limestone of the Miyara Formation.

Limestone section.—The thickest sections of limestone of the Miyara Formation are the small fault blocks near Hoshino (fig. 11, loc. 5), where about 60 meters of limestone are exposed. The limestone section in the northern block is as follows:

Limestone section in fault block near Hoshino

	Thickness (meters)
Limestone, dark-gray, algal. *Pellatispira provaleae* Yabe abundant at top	17.5±
Limestone, gray; beds 41–61 cm thick. Part is algal limestone with a zone of *Pellatispira* near the top	19 ±
Limestone, blue-gray, algal; slumped	10 ±
Limestone, dark-gray, appears shaly. *Discocyclina* abundant	3.5±
Limestone, dark-gray, conglomeratic. Has Eocene algal limestone cobbles 2–15 cm across in a sandy or shaly fossiliferous limestone matrix. Algae is *Lithophyllum*. Base not exposed	7.5±
Total thickness	57.5±

In the central knob, slump and talus conceal much of the section. The basal limestone exposed is dark-gray shaly-appearing limestone in which *Discocyclina* is abundant. This limestone seems to correspond with the *Discocyclina* zone in the northern limestone knob. *Pellatispira* were observed in the upper part of the limestone. The southern limestone knob also has dark-gray, shaly-appearing limestone in which *Discocyclina* is found at the base. *Pellatispira* are common in a zone about 12.5 meters above the base of the limestone. The upper part of the section is mostly algal limestone.

General correspondence between the limestone section of the three blocks suggests that they represent parts of the same section rather than different parts of a single section. All three sections have a *Discocyclina* zone near the base and abundant *Pellatispira* in a zone just below the middle of the section.

exposures of conglomerate of the Miyara Formation

Matrix—Continued		Attitude		Thickness exposed	Stratigraphic relationship	Fossils	Other characteristics
Color	Percent of total rock	Strike	Dip				
Tan	25–75	West	19° S.	4.5±m	Base not exposed. Overlain unconformably in places by Ryukyu Limestone.	None	Coarsest exposed conglomerate of the Miyara Formation. Concretionary material stands out as lumps on weathered surfaces.
Tan		West	25°–35° S.	Not known	Overlies Fu-saki Formation unconformably. Dip of contact on the north is 25°–35°. Dip decreases southward. Overlain by soil.	None	Much weathered and poorly exposed. Poorly sorted.
Tan, gray, reddish-gray or yellowish-tan.	Generally less than 25 and rarely more than 35.	West or northwest.	15°–25° S. or SW.	10±m	Base not exposed. Overlain unconformably by patches of Ryukyu Limestone.	None	Section is faulted.
Pinkish-tan	55–65	West	10°–36° S.	34 m	Unconformably overlies schist of Ishigaki Group. Exposure terminated by a fault.	None	Sorting poor.
Tan, greenish-gray and reddish-tan.	25–75	Northwest	8°–35° SW.	4.5+m	Overlies greenschist of Tumuru Formation unconformably. Overlain unconformably by patches of Ryukyu Limestone.	Mollusks and other invertebrates. Gastropods especially abundant in places.	Obscure crossbedding in places.

SHALE

Shale in the Miyara Formation is best exposed on the Yarabu peninsula, but a little is also found west of Ibaruma. It is generally light to dark gray but may be tan or brown. It is commonly limy and in places sandy or tuffaceous. In most exposures the shale is much fractured and breaks easily into small fragments. Conchoidal fracture surfaces are common. The thickest shale exposures, about 9 meters, are on the Yarabu peninsula; they are included in the section measured there.

WEATHERING AND SOILS

The sandstone of the Miyara Formation breaks down fairly easily, and bedrock is rarely exposed. Depth to bedrock may be as much as 11 meters but averages 1.5–6 meters. The conglomerate is somewhat more resistant to weathering than the sandstone and is generally covered with shallow soils. At the tops of small knolls or near terrace margins, small patches of bedrock without any soil are common. The soil surface generally has a scattering of pebbles of quartz and a few widely dispersed boulders.

The soils on the sandstone and conglomerate are mostly brown to yellowish-brown and loamy (Red-Yellow Podzolic soils). Because the areas underlain by this type of bedrock are small, the soil is commonly influenced by bedrock and soils of surrounding areas, particularly limestone areas. The fertility of the soil is medium to poor. It is fairly well drained.

Weathering of the limestone of the Miyara Formation has taken place largely by solution, especially along joint cracks. Thus the surface of the limestone is pitted and irregular, but the limestone which remains is hard and chemically unchanged. Most of the limestone areas have little or no soil on them, although pockets or patches of soil may occur between limestone blocks. The patches of soil generally are shallow; they are most commonly dark-brown to grayish-brown silt loam or a lighter colored sandy loam.

ORIGIN

The Miyara Formation is mostly if not entirely of marine origin, and the greater part of the sediments was probably deposited fairly near shore and in comparatively shallow water. Where the base of the formation was observed, it rests unconformably on rocks of the Ishigaki Group. Although the conglomerate contains marine fossils in only one area, near Ibaruma, the conglomerate near Ibaruma and north of the town of Miyara is interbedded with marine limestone. Shale on the Yarabu peninsula also has interbedded marine limestone. Thus, it seems likely that all the formation was deposited in marine waters. Possibly some conglomerate, particularly coarse conglomerate with lensing sandstone such as that at Ōhama, might have been stream deposited. However, the absence of crossbedding and the geographic proximity to definite marine deposits on the landward side suggest that this conglomerate is also a near-shore marine deposit.

Material composing the conglomerates was derived locally from the metamorphic rocks of the Ishigaki Group. No pebbles or boulders of igneous material were found, except for some andesite fragments in a basal conglomeratic phase of the limestone near Kūra.

B

A

C

FIGURE 21.—Limestone of the Miyara Formation. *A*, Light-gray dense limestone of the Miyara Formation remains as joint blocks which have been pitted and fretted by solution. Exposure is 2.5 kilometers northwest of Miyara. September 1956. *B*, Remnant of light-gray limestone near Kūra. The rock is dense and contains abundant fossil calcareous algae and Foraminifera. The surface is rough, a characteristic of such outcrops. August 1956. *C*, Rough-surfaced limestone uncovered by the removal of clay. Exposure is 1 kilometer northwest of Miyara at some clay pits. The limestone is gray, dense, and fossiliferous. The rough surface is partly due to solution around fossil algae in the limestone. September 1956.

Some tuffaceous material may occur in the sandstone or in the matrix of some conglomerates, but most beds that contain volcanic material are believed to be younger than the main conglomerate, sandstone, and limestone and are included in the Nosoko Formation.

The organisms that are fossilized in the limestones could probably have grown from the intertidal zone to a depth of about 200 meters. (Johnson, 1957, p. 211). Reef-building corals are rare, but much of the algal material is the type that commonly grows on reefs. The limestones are very free of terrigenous material except in a thin basal conglomeratic zone in some places on the Yarabu peninsula and near Hoshino.

It is suggested that the Miyara Formation was deposited as marine sediments around the margins of the then-existing island or islands on submarine shelves or floors composed of the metamorphic rocks of the Ishigaki Group. Clay may have been deposited in small marine basins.

FOSSILS AND AGE

The most abundant organic remains preserved in the Miyara Formation are those of calcareous algae. Larger Foraminifera are fairly abundant in places. Smaller Foraminifera are few. Mollusks were found in the conglomerate on the Ibaruma peninsula but are rare in the limestone. A few poorly preserved gastropods were found in the dark-gray shaly-appearing limestone near Miyara. Corals are comparatively rare, but a few, mostly small branching or encrusting types, were found in the algal limestone. Small echinoderms are fairly common in the dark-gray limestone in one locality on the Ibaruma peninsula and in the Miyara area. The larger Foraminifera from the limestone of the Miyara were studied by W. Storrs Cole, the calcareous algae by J. Harlan Johnson, and the mollusks from the conglomerate by F. Stearns MacNeil, all of the U.S. Geological Survey.

The larger Foraminifera and calcareous algae of the limestone of the Miyara indicate that it is late Eocene in age and that it is equivalent to the Tertiary *b* zone in the Indo-Pacific area. The molluscan fossils from the conglomerate near Ibaruma also indicate an Eocene age. MacNeil believes that the degree of evolution of the mollusks and their similarity to those known in formations elsewhere indicates a middle Eocene age in a threefold division of the Eocene but probably the lower part of the Tertiary *b* zone in the Indonesian twofold division of the Eocene.

LARGER FORAMINIFERA

W. Storrs Cole (written commun., 1959) identified the larger Foraminifera from the limestone of the Miyara Formation and has contributed the following information from his studies.

Thin sections from 36 stations representing 23 localities were examined. Although eight species were identified from these stations, the number of species at any one station was small as many of the suites of thin sections from individual stations contained only a single species.

As an example, locality IS-M-236-56 was represented by thin sections made from four selected stations at this locality. Two species were found: *Discocyclina javana* (Verbeek) and *Pellatispira provaleae* Yabe. However, these species did not occur together in any of the thin sections. Thus, two suites of thin sections contained *D. javana* and the other two contained *P. provaleae.*

The species which occur in the Miyara Formation are common ones found in Tertiary *b* elsewhere in the Indo-Pacific area. These species are characteristic of the Eocene limestones of Saipan Island (Cole, 1957a, p. 322), the Palau Islands (Cole, mss.) and the Eniwetok drill holes (Cole, 1957b, p. 749) with the exception of *Discocyclina javana.* This species is recorded from numerous localities in Indonesia. However, there is a distinct possibility that this species is an ecological variant of *Discocyclina omphala* (Fritsch) which occurred in abundance at certain Eocene localities on Saipan Island.

The Eocene faunas of Ishigaki are deficient both in the number of genera and species present when these faunas are compared with the known faunas elsewhere in the Indo-Pacific area. However, the genera and species present clearly demonstrate the Eocene age of the Miyara formation.

The genera and species of larger Foraminifera identified by Cole from the limestone of the Miyara are listed with locality data in table 4. The approximate geographic position of the localities is shown in figure 22. The table includes one locality on the neighboring island of Kobama, the only other island in the Yaeyama-guntō where the limestone of the Miyara is known.

TABLE 4.—*Distribution of Eocene larger Foraminifera*

[Table by W. Storrs Cole. Symbols used: A=abundant; C=common; R=rare]

Sample and stratigraphic unit	*Asterocyclina matanzensis* Cole	*Asterocyclina penuria* Cole	*Asterocyclina* sp.	*Biplanispira mirabilis* (Umbgrove)	*Camerina pengaronensis* (Verbeek)	*Discocyclina (Discocyclina) javana* (Verbeek)	*Eorupertia plecte* (Chapman)	*Fabiania saipanensis* Cole	*Pellatispira provaleae* Yabe
Miyara Formation									
IS-F- 49-55						R			
50-55	R								
80-55								R	
83-55			R		R			R	
84-55b			R						
86-55			R						C
87-55						R			
95-55								R	
145-55	R				R				
147-55					R				
163-55		R							A
231-56	R								R
273-56				R	C			R	
IS-M-125-56									A
236-56a						A			
236-56c									A
236-56d						A			
236-56f									A
239-56				R		A			
239-56b									A
239-56c									A
239-56d									A
240-56						A			
240-56a									A
240-56b									A
241-56a						R			
241-56c									A
241-56d									R
241-56e									A
243-56a							R	C	
244-56a								C	
247-56									R
247-56b								A	
247-56c								R	
248-56c								C	
KOB-F-11-56 [1]			C						
Nosoko Formation									
IS-F- 221-56			R			R			R
284-56	R	R					R	R	
302-56								R	
IS-M-253-56			R						
253-56a			R						
253-56b	R		R						
253-56c	R							R	
253-56d	R						R	R	
253-56e	R								

[1] Locality KOB-F-11-56 is on the island of Kobama.

CALCAREOUS ALGAE

Calcareous algae are unusually well preserved in the limestone of the Miyara Formation. J. Harlan Johnson has identified 9 genera and 32 species, of which 6 are new species. The algae from the Miyara Formation are all of the class Rhodophyta (Red algae) and belong to the family Corallinaceae. Both the subfamilies Melobesioideae (Crustose corallines) and Corallinoideae (articulated corallines) are represented, but the Melobesioideae are most abundant. Genera and species of calcareous algae from the limestone of the Miyara are given in table 5. The fossil algae localities are shown in figure 22. Although the localities occur on widely separated parts of the island, no significant differences in the flora at these localities were noted.

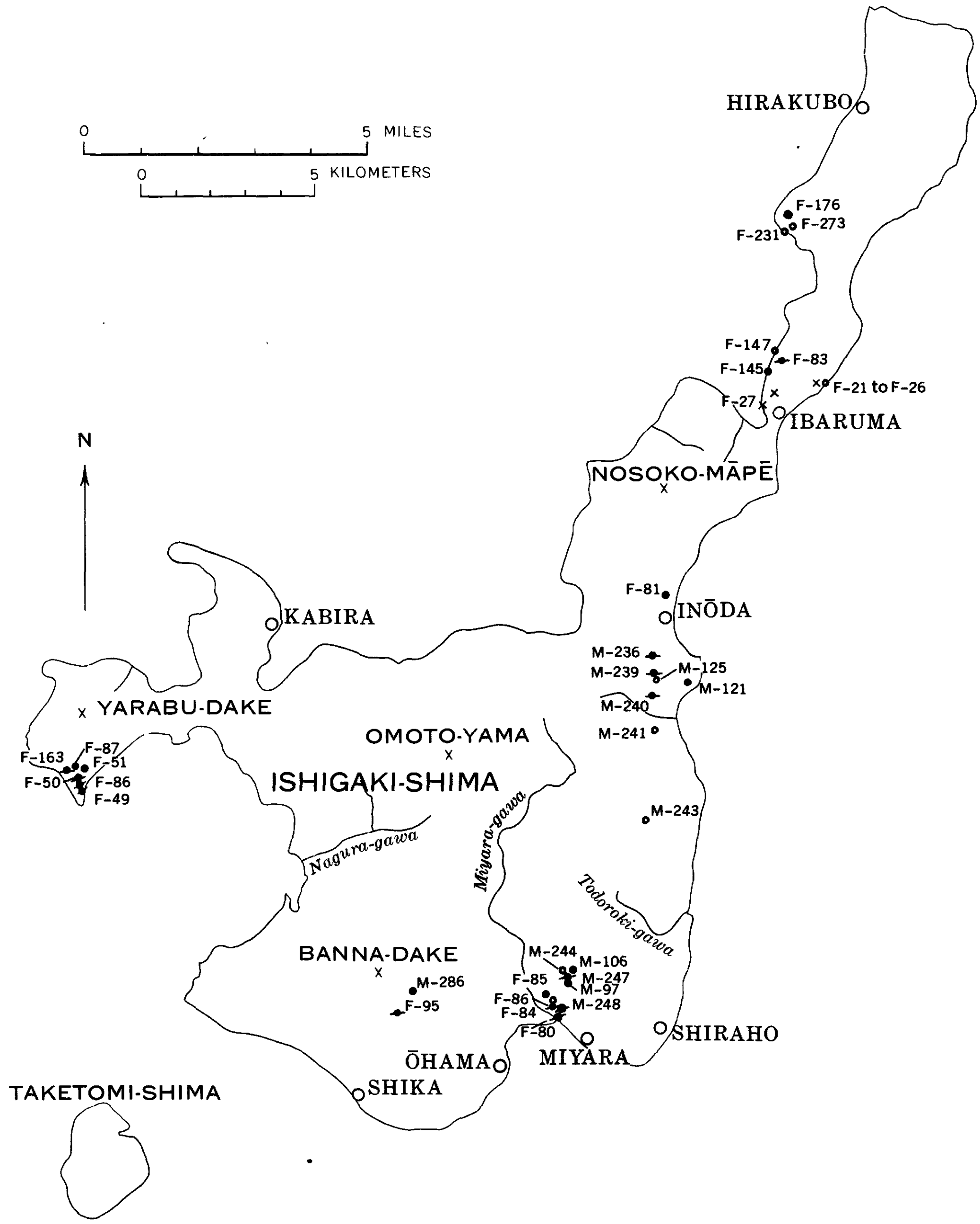


FIGURE 22.—Index map showing localities from which calcareous algae (solid circles), larger Foraminifera (open circles), and mollusks (x) of the Miyara Formation were identified. (The solid circles having a horizontal bar indicate localities from which both calcareous algae and larger Foraminifera were identified.)

Twelve of the thirty-two species were previously described by Johnson (1957) from Eocene material collected on Saipan in the Mariana Islands.

J. Harlan Johnson describes the species of calcareous algae in detail in another chapter of this Professional Paper.

MOLLUSKS

The mollusks of the Miyara Formation were all obtained from conglomerate beds along the western coast of the Ibaruma peninsula and from exposures a few hundred meters inland (fig. 22). Twelve species of gastropods, four of pelecypods, and one of echinoid were recognized by Stearns MacNeil in the collection made by the field party.

CORRELATION

In the Ryūkyū-rettō, sedimentary rocks of Eocene age have been reported only from Ishigaki-shima and the nearby island of Kobama (pl. 1) where limestone having lithology and fossils similar to that of the limestone of the Miyara Formation crops out. This

TABLE 5.—*Species of Eocene algae and their distribution*

[Identified by J. Harlan Johnson. For localities see fig. 22]

	F-49	F-50	F-51	F-80	F-81	F-83	F-84	F-85	F-95	F-163	F-176	M-97	M-106	M-121	M-236	M-239	M-240	M-247	M-248	M-286
Archaelithothamnium—																				
cf. *A. affine* Howe	×	×														×	×			
chamorrosum Johnson	×																			
fosteri Johnson	×	×		×						×						×	×			
cf. *A. liberum* Lemoine																	×			
nummuliticum (Gümbel) Rothpletz	×	×								×						×	×	×		
cf. *A. parisiense* Lemoine	×															×	×			
Lithothamnium—																				
cf. *L. abrardi* Lemoine		×																		
cf. *L. andrusovi* Lemoine																		×		
cf. *L. bofilli* Lemoine						×														
crispithallus Johnson																		×		
cymbicrusta Johnson								×		×										
faurai Lemoine	×					×														×
ishigakiensis Johnson	×	×		×		×				×										
marianae Johnson																×				
cf. *L. moreti* Lemoine	×	×		×						×										
cf. *L. tagpotchaense* Johnson							×			×										
Mesophyllum—																				
ishigakiensis Johnson	×	×																		
ryukyuensis Johnson	×	×			×	×				×										
vaughanii (Howe) Lemoine			×		×	×				×	×	×		×		×	×	×		
sp. A											×									
sp. B																×				×
Lithophyllum—																				
cf. *L. pfenderae* Lemoine						×										×	×	×		
cf. *L. ovatum* (Capeder) Lemoine	×									×								×	×	
sp. D															×					
Lithoporella melobesioides Foslie									×											
Lithoporella minus Johnson							×													
Dermana thon nitida Johnson																×				
Corallina cf. *C. cossmanni* Lemoine														×		×		×	×	
Corallina matansa Johnson												×	×	×						
Corallina prisca Johnson							×		×											
Jania mayei Johnson											×					×			×	
Amphiroa sp.																	×	×		

limestone is correlated with the Miyara of Ishigaki-shima.

Chang (1958) correlated the Miyara Formation with the Nishimura Formation and the Yonryo Sandstone of the Urai Group and with the lower part of the Suo Group of Taiwan. Some lithologic similarity exists between the Miyara Formation and these Taiwan rocks, and fossils indicate that both are of Eocene age. The Taiwan rocks contain but few genera of fossils common to the limestone of the Miyara, and the Eocene section of Taiwan is much thicker than that of Ishigaki-shima. The thickest exposure of the Yonryo Sandstone is reported to be about 1,000 meters (Chang, 1958, p. 16).

NOSOKO FORMATION

The Nosoko Formation comprises about 300 meters of bedded tuff, volcanic sandstone, volcanic breccia, and intercalated lava flows, along with dikes, sills, and small intrusive masses. The pyroclastic materials have a significantly greater volume than the lava. The volcanic material is mostly andesitic, but some is dacitic or rhyolitic. The lava is slightly to highly weathered. Most of the material was deposited in sea water after it was ejected from several different volcanic centers. The Nosoko Formation is Tertiary in age, probably late Eocene to Miocene.

The Nosoko Formation is most extensive in the northern part of the island, and the largest areas of exposure are in the mountainous Nosoko peninsula. The westernmost exposures are also extensive and compose the northwest half of the Yarabu peninsula. Cliffs of volcanic rock, such as the cliffs and sea stacks at scenic Ogan-zaki (fig. 23), are common along the western coast of the peninsula. On the western side of the Kabira peninsula, the Nosoko Formation occurs in mountainous terrain, and a marine terrace carved on volcanic rocks separates the mountains from the sea. Outcrops at the tip of the peninsula are in hilly terrain. The hills are steep sided (24°–38° slopes) and somewhat conical in shape (fig. 24).

Small exposures of lava and breccia occur in several places on the marine terraces of southern Ishigaki-shima northwest of Miyara. Scattered small exposures crop out along the eastern coast at Nobaru-zaki and inland from Nobaru-zaki, on the western side of the Ibaruma peninsula, and along the southwest coast of the Hirakubo peninsula. These areas are mostly hilly.

The total mapped area of the Nosoko Formation is about 22 square kilometers, of which more than 13 square kilometers is on the Nosoko peninsula.

ORIGIN OF NAME AND STRATIGRAPHIC RELATIONSHIPS

The Nosoko Formation was named by Foster and others (1960, p. 109) for Nosoko-māpē, a conspicuous and widely known pinnaclelike peak on the Nosoko

FIGURE 23.—Sea stack at Ogan-zaki. This stack is eroded in the tuff-breccia of the Nosoko Formation. The point, Ogan-zaki, is unprotected by coral reefs and is exposed to severe wave action. September 1955.

FIGURE 24.—Hill composed of lava on the Kabira peninsula. This steep-sided conical hill is one of several at the north end of the Kabira peninsula. It is composed of light-gray altered andesite of the Nosoko Formation. September 1955.

peninsula composed of vocanic breccia and lava flows which are characteristic of the Nosoko Formation (fig. 25). Because the heavy cover of vegetation and the resulting poor exposures prevent the measuring of good continuous sections, no type section is designated. However, because these volcanic rocks are considered as representative of the Nosoko Formation, the Nosoko peninsula is considered the type area. The most representative lithologies are bedded green tuff, volcanic sandstone, and volcanic breccia with intercalated dark-colored glassy lava, porphyritic lava, and vesicular lava. Coarse thick-bedded greenish-gray breccia which is commonly limy is conspicuous in the upper part of the section.

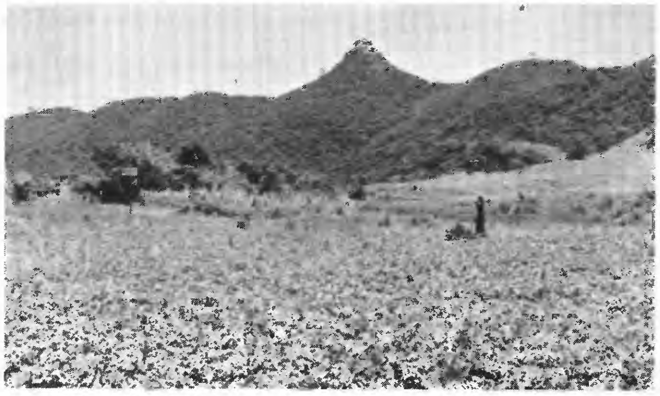


FIGURE 25.—Nosoko-māpē, Nosoko peninsula. Nosoko-māpē, the steep-sided peak from which the Nosoko Formation is named, is composed of lava and breccia. It is 282.4 meters high and is covered by broad-leaved evergreen forest. The surrounding forested mountains are also composed of similar lava and breccia. June 1956.

The volcanic rocks of the Nosoko Formation intrude or lie unconformably on metamorphic rocks of the Ishigaki Group. Their relation with strata of the Miyara Formation is conformable in some places and unconformable in others. Rocks of the Nosoko Formation are overlain in places by the Nagura Gravel or Ryukyu Limestone.

Hanzawa (1935, p. 43) correlated the volcanic rocks of the Nosoko Formation with the Yaeyama coal-bearing beds of Iriomote-jima, but because sediments typical of the Yaeyama coal-bearing beds are absent on Ishigaki-shima, he was unable to demonstrate the correlation conclusively. Fieldwork for this report did not resolve the problem, and so the new name, Nosoko Formation, was applied.

THICKNESS

The thickness of the Nosoko Formation is difficult to determine because of faulting and lack of continuous exposures. The base of the formation is exposed in only a few places. A measured partial section of the formation is 183 meters thick, and the formation is probably 300 meters or more thick in places on both the Yarabu and Nosoko peninsulas. Original thickness varied from place to place, and erosion and faulting have increased the variation. In the vicinity of Inōda and in the mountains at the southern end of the Hirakubo peninsula, only scattered boulders and erosional remnants of the formation remain.

LAVAS

Most lava of the Nosoko Formation is pyroxene andesite, but the lava ranges in composition from basalt or basaltic andesite to dacite or, possibly, rhyolite. The andesite is glassy, uniformly fine grained, or porphyritic. Phenocrysts are most commonly plagioclase, augite, and hypersthene. Olivine has not been recognized with certainty, but outlines in some rocks suggest its former presence.

The most mafic lava crops out in southern Ishigaki-shima, where it is associated with the Miyara Formation, and in the northern part of the island. In both areas, it seems to have intrusive relationships with surrounding rocks. In southern Ishigaki-shima, it composes dikes and sills which intrude the Miyara Formation. In northern Ishigaki-shima, it composes dikes cutting other volcanic rocks or composes small masses intrusive into schist. The masses in the schist may be remnants of lava in the throats and feeder channels of Tertiary volcanoes.

Dacite or rhyolite flows occur on the Kabira peninsula, and some dacite(?) may be exposed on the coast west of Ibaruma. Exposures on the Kabira peninsula are not continuous with the more typical andesite of the Yarabu peninsula; so, their exact relationship is not known. The dacite is much altered.

Average thickness of the lava flows is probably about 4 meters, but a few are as thick as 8 meters. Many flows are so poorly exposed that a reliable thickness cannot be ascertained. Most dikes and sills range from 1.5 to 3 meters, but a few are thicker.

Samples of two of the freshest lavas, one from the Nosoko peninsula (IS–M–426–56) and one from southern Ishigaki-shima (IS–M–246–56), have been analyzed chemically (table 6). Both of these lavas are augite andesite.

The andesite of the Nosoko Formation is the type characteristic of continental orogenic regions, according to the distinctions recognized by Macdonald (1960, p. 173, 175)—that is, the lava is dominantly augite andesite or hypersthene-augite andesite rather than hawaiite or mugearite. The continental affinities of the lava are in harmony with other geological observations which indicate continental rather than oceanic affinities for the Ryukyu Islands. The foundation of metamorphic rocks is similar to that on the continents; the granitic intrusions and the orogenic movements are of the same types as those which have occurred along the continental margins.

Much of the andesite on Ishigaki-shima is too greatly altered to be classified in detail and to be compared with classifications made in Japan and elsewhere, but probably andesite similar to both Kuno's pigeonitic and hypersthenic rock series is present (Kuno, 1950, p. 993). Some of the magma was probably contaminated by granitic material, as Kuno postulated for Japan, resulting in rocks of Kuno's hypersthenic rock series. Other lava may have erupted without such contamination and would correspond to Kuno's pigeonitic rock series.

The chemical composition of andesite from Ishigaki-shima is compared with that from Hawaii, Japan, Ogasawara-guntō, and Taiwan in table 6.

YARABU PENINSULA

Lava occurs on the Yarabu peninsula as dikes and sills in the Miyara Formation, as scattered boulders lying on the Miyara Formation, and interbedded with green volcanic tuff and breccia. Flows are not especially abundant in the exposed sections of tuff and breccia.

The lava is porphyritic andesite. It is much weathered and, in most places, considerably altered. The lava is tan, gray, reddish-gray, or greenish-gray on weathered surfaces and is commonly gray on freshly broken surfaces. Most of it is vesicular and much of it is jointed. Locally joints and vesicles have been filled with chalcedony, calcite, or both. Some joints have been filled with quartz sand which has become firmly cemented. Banded bluish-gray and white chalcedony also occurs as nodules. Some nodules are several inches in diameter, the chalcedony surrounding an interior filling of calcite or clear quartz crystals.

A typical occurrence of lava veined with banded gray and white chalcedony crops out on the wave-cut bench a few hundred meters south of Ogan-zaki. The veins of chalcedony cut across a lava surface which has been smoothed by wave erosion. Groups of concentric fractures are also plainly visible on the surface of this lava. The fractures may represent lobes in the forward movement of the lava flow, or they may be pillow-like structures that have been planed off. At this locality the lava is overlain unconformably by Ryuku Limestone. The lava itself is deeply weathered and is less resistant to erosion than the sand which has filled cracks in it. Thus the sand stands as low ridges, 0.3–2 centimeters high on the surface, and make rectilinear patterns.

NOSOKO PENINSULA

Most of the lava on the Nosoko peninsula is interbedded with green tuff and breccia, but some of it composes low hills which are probably remnants of flows. Most of the lava—such as that interbedded in the breccia which composes Nosoko-māpē—is much weathered and considerably altered. Some of the lava, such as that in small dikes exposed in roadcuts northeast of the Ōura-kawa, is completely changed to saprolite. However, southwest of Nosoko-zaki a very fresh, glassy andesite crops out, the freshest lava found anywhere on the island (fig. 26).

The fresh lava is andesite, generally dark gray or greenish gray. Most of it is porphyritic, but some fine-grained and glassy lava occurs, such as that south of Nosoko-zaki. Much of the lava is vesicular or amyg-

Table 6.—*Chemical composition and norms of andesite from Ishigaki-shima, and comparative analyses and norms*

	1 Andesite from Ishigaki-shima IS-M-426-56	2 Andesite from Ishigaki-shima IS-M-246-56	3 Average hawaiite (Hawaii)	4 Average "alkali" andesite	5 Average andesite	6 Average augite andesite	7 Average hyper-sthene andesite	8 Augite-hyper-sthene andesite (Japan)	9 Olivine-bearing hyper-sthene-augite andesite (Japan)	10 Augite-hyper-sthene andesite (Bonin Islands)	11 Average augite-hyper-sthene andesite (Taiwan)
Analyses											
SiO_2	54.35	59.54	48.76	47.63	54.20	57.50	59.48	59.77	57.07	58.47	53.43
Al_2O_3	17.95	17.05	15.82	14.57	17.17	17.33	17.38	17.00	17.53	16.47	19.83
Fe_2O_3	.89	1.33	4.10	3.97	3.48	3.78	2.96	2.49	2.59	2.08	3.88
FeO	6.41	3.78	7.53	7.83	5.49	3.62	3.67	5.59	5.44	5.46	3.69
MgO	3.56	3.58	4.74	7.25	4.36	2.86	3.28	2.24	3.87	3.90	3.48
CaO	8.01	6.99	7.99	9.48	7.92	5.83	6.61	7.05	8.77	7.68	9.37
Na_2O	3.91	3.27	4.50	3.75	3.67	3.53	3.41	3.29	2.80	3.16	2.35
K_2O	.66	1.22	1.58	1.20	1.11	2.36	1.64	.62	.52	.91	1.57
H_2O+	2.99	1.82		.78	.86	1.88	.74	.41	.27	.75	1.23
H_2O-	.79	.36						.51	.12	.33	
TiO_2	.45	.69	3.29	2.84	1.31	.79	.48	.63	.77	.80	.81
P_2O_5	.20	.12	.72	.52	.28	.22	.20	.10	.08	.06	.44
MnO	.18	.11	.17	.18	.15	.30	.15	.16	.14	.18	.12
CO_2	Tr	.02									
Total	100.35	99.88						99.86	99.97	100.25	
Norms											
Q	4.20	14.59			5.76	11.40	13.98	17.94	13.68	12.85	
or	3.90	7.24	9.45	7.23	6.67	13.90	9.45	3.34	2.78	5.57	
ab	33.03	27.79	30.39	27.25	30.92	29.87	28.82	27.77	23.85	26.74	
an	29.76	28.09	18.07	20.02	27.24	24.46	27.52	30.02	33.92	28.09	
ne			4.26	2.27							
di wo	3.83	2.79	9.51	10.09	4.18	1.04	2.09	1.74	3.60	4.18	
di en	8.83	8.93	6.20	6.80	2.60	.70	1.40	5.60	9.70	9.74	
di fs	10.55	4.88	2.64	2.51	1.32	.26	.63	7.39	6.73	7.39	
hy en					8.30	6.50	6.80				
hy fs					3.96	2.24	3.17				
ol fo			3.92	7.91							
ol fa			2.04	3.36							
mt	1.39	1.85	6.03	5.80	5.10	5.57	4.41	3.71	3.71	3.01	
il	.91	1.37	6.23	5.32	2.43	1.52	.91	1.22	1.52	1.52	
ap	.34		1.68	1.34	.67	.67	.34	.34	.34	Tr	

1. Sample from Ishigaki-shima (for locality see fig. 33). Analysis by Japan Inspection Co., Ltd., Tokyo, Japan, May 7, 1957.
2. Sample from Ishigaki-shima (for locality see fig. 33). Analysis by Dorothy F. Powers, U.S. Geological Survey, June 15, 1959.
3. Average hawaiite of the Hawaiian Islands (Macdonald, 1960, p. 174). Average of 21 samples.
4. Average "alkali" andesite (Nockolds, 1954, p. 1019). Average of 37 samples. Norms from Macdonald (1960, p. 174).
5. Average andesite (Nockolds, 1954, p. 1019). Average of 49 samples. Norms from Macdonald (1960, p. 174).
6. Average augite andesite (Daly, 1933, p. 16). Average of 33 samples. Norms from Macdonald (1960, p. 174).
7. Average hypersthene andesite (Daly, 1933, p. 16). Average of 20 samples. Norms from Macdonald (1960, p. 174).
8. Augite-hypersthene andesite (pigeonitic rock series). A lava of the old somma of Hakone Volcano, Japan (Kuno, 1950, p. 1001–1002).
9. Olivine-bearing hypersthene-augite andesite (hypersthenic rock series). The lava of Simohutago-yama, one of the central cones of Hakone Volcano (Kuno, 1950, p. 1001–1002).
10. Sample from Okimura, Haha-shima, Ogasawara-guntō. Analysis by S. Tanaka (Tsuya, 1937, p. 224).
11. Average of 5 samples of augite-hypersthene andesite from the Tatun Volcano group, Taiwan (Yen, 1958b, p. 26).

Figure 26.—Andesite on the Nosoko peninsula. This dark-gray fine-grained andesite crops out about 1 kilometer south of Nosoko-zaki. It is much jointed, but many of the cracks seen in the picture do not extend completely through the lava. March 1956.

daloidal, the amygdules being composed of quartz, chalcedony, or calcite. Banded blue-gray and white chalcedony similar to that in lava on the Yarabu peninsula is present in nodules in the saprolites northeast of the Ōura-kawa, in lava south of Nosoko-zaki, and in lava on the east side of the peninsula. Much of the lava has been strongly albitized, chloritized, and carbonitized.

Phenocrysts are most commonly plagioclase (andesine to labradorite), augite, and hypersthene. The plagioclase is commonly altered to albite or sericite, and augite and hypersthene have been altered to chlorite. Grains of iron oxide minerals are common. Phenocrysts range in size from 5 millimeters to less than a millimeter. The groundmass generally consists of plagioclase, chlorite, calcite, opaque iron oxide and iron sulfide minerals, and, in some lava, glass.

IBARUMA PENINSULA

Lava crops out along the isthmus on Funakuyā-wan, in hills 1 kilometer northwest of Ibaruma, and along the south side of the Fukuida-gawa. Most of the volcanic rocks at the southernmost outcrop are highly weathered, and their original composition is not certain, but they are presumed to have been andesite. A few, fairly fresh, dark greenish-gray dikes cut these weathered volcanic rocks. Megascopically the rock in the dikes resembles gabbro. Microscopically, phenocrysts of labradorite 1–3 milimeters long, augite, and hypersthene are recognized. Olivine may have been present, as indicated by mineral outlines, but, if so, it has been completely altered to carbonate. The groundmass has laths of andesine and grains of augite, hypersthene, and iron oxide minerals. Alteration products are carbonate, chlorite, saponite, and sericite (IS–F–192–56). Light-gray altered pyroxene andesite crops out in a small hill on the south side of the Fukuida-gawa. Phenocrysts are plagioclase (andesine to labradorite, 0.5–3 mm long) and augite, with hypersthene completely altered to chlorite. The groundmass consists of plagioclase laths, pyroxene prisms, grains of iron oxide minerals, and alteration products. Plagioclase is altered to a gibbsitelike mineral along cleavages and partings.

The lava one kilometer north of Ibaruma is dark-gray or bluish-gray fine-grained pyroxene andesite. It is closely associated with conglomerate, sandstone, and shale of the Miyara Formation and may have come up through or along the contact of the formation. A typical specimen (IS–F–234–56) has zoned, subhedral labradorite as plagioclase phenocrysts. Hypersthene phenocrysts are mostly altered to chlorite or carbonate. Olivine and augite may have been present, but their presence cannot be determined with certainty. The groundmass is intergranular. Andesine laths are 0.4 millimeter long, and the mafic materials have been completely altered to carbonate and chlorite. Poikilitic quartz 0.8 millimeter across, magnetite cubes 0.6 millimeter across, tabular ilmenite 0.01 millimeter across, and dust are also present.

Altered augite andesite boulders occur on small hills 0.6 kilometer south of the Fukuida-gawa. The lava is dark bluish gray and contains plagioclase (andesine to labradorite phenocrysts 0.5–0.1 mm long) and augite phenocrysts. The groundmass is fine grained and consists of plagioclase, quartz, dusty iron oxide minerals, chlorite, epidote, and calcite.

HIRAKUBO PENINSULA

Andesite crops out along the coast on the west side of the isthmus west of Akeishi and in a hilly area southeast of Dachō-zaki. The outcrops at the isthmus are light-greenish-gray altered andesite, probably the remains of a thin lava flow. The andesite has a few altered plagioclase phenocrysts and grains of iron oxide minerals. The groundmass is fine grained and felsitic. Some sericitization of the phenocrysts and of the groundmass has occurred. The outcrop is in an area of granophyre exposures, but the relationship of the andesite to the granophyre is not clear.

Andesite of the Dachō-zaki area is at least partly intrusive into schist of the Tumuru Formation. The contact seems to be nearly vertical, and the schist has a reddish-brown border zone indicating oxidizing effects from the hot lava. The lava is an altered andesite (IS–F–229–56) containing euhedral plagioclase phenocrysts as much as 3 millimeters long. Some phenocrysts are albitized, partly carbonitized and chloritized. Pyroxene phenocrysts are completely altered to chlorite, carbonate, and epidote. The groundmass texture is intersertal and has faint flow structure. Plagioclase laths are about 0.03 millimeter long. Chlorite, magnetite, carbonate, and poikilitic quartz are present. Lapilli tuff crops out a meter or so south of the lava contact, but its relationship to the lava is not clear.

The hilly area to the south consists of a dark-greenish-gray andesite that has a texture intermediate between that of an intrusive and extrusive rock. Bordering on a basalt in composition, it is one of the most mafic rocks in the Nosoko Formation. Phenocrysts consist of labradorite averaging 3 millimeters long and augite from 2 to 10 millimeters long; the groundmass consists of andesine (0.2–0.3 millimeter long), augite, and opaque iron oxides. The plagioclase and augite are fresh and unaltered in some specimens; but in others the plagioclase is partly albitized, and the augite has altered to chlorite and carbonate. The rock also contains brown carbonate pseudomorphs with and without chlorite. The original mineral may have been hypersthene. Olivine also may have been present originally. The dike rock at the isthmus, the lava 1 kilometer north of Ibaruma, and that south of Dachō-zaki are similar and are the most mafic lavas on the island.

KABIRA PENINSULA

The lavas of the Kabira peninsula are all so altered that their original composition is difficult to determine. Some of them are more silicic than the andesite typical of the Nosoko Formation. They are mostly light gray, pinkish gray, or greenish gray. Some have banding indicative of flow structure. They crop out along the coast at the tip of the Kabira peninsula, in small conical hills near the end of the peninsula, and at Azana-zaki and vicinity on the southwest side of Sokoji-wan. On the tip of the peninsula, they are associated with considerably altered volcanic breccia, probably andesitic; and near Azana-zaki, they occur near hard dense andesitic tuff-breccia and breccia.

A fairly representative lava (IS–F–93–55) exposed on one of the conical hills near the end of the peninsula is a light-gray porphyritic altered andesite—dacite(?)—(fig. 24). It has phenocrysts of albitized plagioclase 2 millimeters long. Pyroxene(?) phenocrysts have altered to iron saponite. The groundmass is oligoclase, quartz, and iron saponite.

A dacitic(?) lava (IS–F–73–55) exposed on the coast south of Azana-zaki is grayish green on weathered surfaces and pinkish gray on fresh surfaces. The fracture is blocky. Faint banding suggests flow structure. The phenocrysts are white, albitized, and partly carbonitized plagioclase mostly 2–5 millimeters long. The groundmass is a mosaic of poikilitic-textured quartz grains that contain feldspar crystallites(?). Dust of opaque iron oxides and interstitial chlorite are present.

SOUTHERN ISHIGAKI-SHIMA

A few outcrops of lava in southern Ishigaki-shima seem to be dikes and sills in the Miyara Formation. The lava is mostly very dark-gray or black fine-grained pyroxene andesite. One specimen (IS–M–99–56) resembles megascopically the mafic andesite of northern Ishigaki-shima. In this lava the plagioclase is euhedral and zoned and has glass inclusions. Aggregates of iron saponite(?) seem to be pseudomorphs after olivine or hypersthene. The groundmass is intergranular; plagioclase laths are less than 0.1 millimeter long, and augite and magnetite grains are less than 0.2 millimeter across. Interstitial iron saponite and chlorite are present as alteration products. A bronzite andesite flow or sill occurs within the Miyara Formation 1.6 kilometers northeast of Miyara.

VOLCANIC BRECCIAS AND TUFFS

Bedded volcanic breccia and tuff compose the largest part of the Nosoko Formation. They are mostly green or greenish gray, but some are tan, brown, or gray. Pyroclastic components range from silt size through sand size to lava fragments more than 1 meter in diameter. The lava fragments are andesite and dacite, but they generally are gray pyroxene andesite similar to that in the lava flows, dikes, and sills. The tuff and the tuffaceous matrix of the breccia are largely derived from andesitic volcanic ash. Some of the breccia, and some of the tuff, contain carbonate. Most breccia consists entirely of volcanic material, but some on the Nosoko peninsula contain fragments of limestone, and one in the northern part of the island contains fragments of schist.

The lava fragments are of many different textures and include glassy lava, porphyritic lava, vesicular lava, and amygdaloidal lava. Some of the fragments are probably volcanic bombs. The proportion of matrix to lava fragments ranges from about 5 percent matrix to about 75 percent matrix. In general, the coarse breccia is about 10–25 percent matrix, the larger portion of the rock consisting of lava fragments.

The thickness of tuff beds ranges from 1 centimeter to more than 300 centimeters. Most breccia beds are 1–5 meters thick, but some beds of coarse breccia are thicker. Bedding is well formed and distinct in most of the tuff, lapilli tuff, and fine- or medium-textured breccia. In coarse breccia, bedding is commonly poorly formed and obscure. Attitude of the beds ranges from nearly vertical to horizontal. Many of the beds are believed to show initial or nearly initial dips as high as 15°. Some high dips are attributed to submarine slumping.

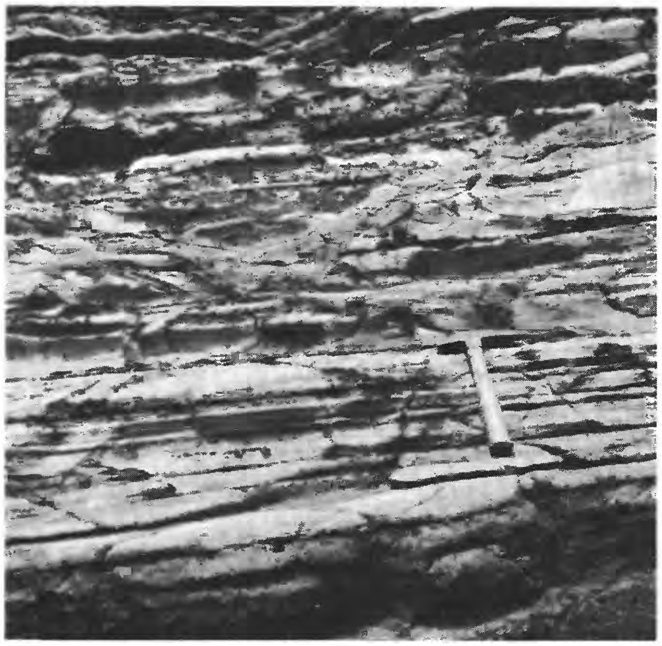
YARABU PENINSULA

Some of the best exposures of the tuff and breccia of the Nosoko Formation are along the northwest coast of the Yarabu peninsula, especially in the vicinity of Yarabu-zaki and Ogan-zaki (figs. 27 and 28). Beds of volcanic tuff, breccia, and tuff-breccia, mostly green or tan, are interbedded in layers which range in thickness from a centimeter to more than a meter. Coarse-textured breccia[3] generally composes the thickest beds. Most beds dip in a westerly direction at angles of 15°–25°. At Ogan-zaki, some of the beds are broken and jumbled, probably a result of submarine slumping (fig. 29).

Along the northwest bank of the stream 1 kilometer southeast of Yarabu-zaki, the tuff and the breccia of the Nosoko Formation seem to rest conformably on the Miyara Formation. At other places in this vicinity, the Nosoko and Miyara Formations are in fault contact. The northeast contact of the Nosoko Formation is with the metamorphic rocks, and volcanic materials rest unconformably on the Tumuru Formation or are in fault contact with it. Throughout most of the northwestern part of the Yarabu peninsula, the contact is covered. In the valleys and along the coast where the best outcrops are present, the base of the formation is not exposed.

[3] Coarse-textured breccia—many rock fragments greater than 12 cm in diameter. Medium-textured breccia—most rock fragments 5–12 cm in diameter. Fine-textured breccia—most rock fragments less than 5 cm in diameter.

A



B

FIGURE 27.—Beds of volcanic tuff near Ogan-zaki. *A*, Well-stratified beds of tan and brown volcanic tuff of the Nosoko Formation dip about 13° W. Beds of andesitic breccia are interbedded. August 1955. *B*, Close view of the beds of volcanic tuff shown in A. Bedding, jointing, and the effects of differential wave erosion can be seen. August 1955.

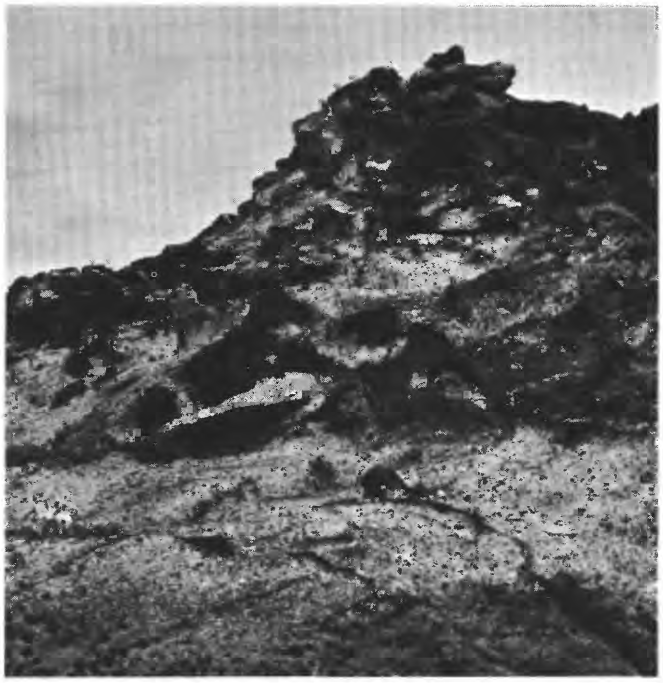


FIGURE 28.—Tuff-breccia at Ogan-zaki. Green tuff-breccia typical of the Nosoko Formation on the Yarabu and Nosoko peninsulas. The dip is about 15° SW. (to the left). The dark areas near the top are places where a resistant case-hardened outer shell is present on the rock. September 1955.

In some places on the Yarabu peninsula, as near Yarabu-zaki, greenish-gray shale occurs at the base of exposures. The shale may be part either of the Miyara Formation or of the Nosoko Formation; it is treated here as part of the Nosoko Formation because it resembles shale observed elsewhere within this formation. Several outcrops of conglomerate in the interior of the peninsula and some outcrops of tuffaceous sandstone near Ogan-zaki have uncertain affiliations. The conglomerate, although resembling the conglomerate in the Miyara Formation, is believed to be the base of the Nosoko Formation because no other rocks resembling the Miyara Formation were found in association with it. The conglomerate seems to be overlain by typical volcanic rocks of the Nosoko Formation rather than by limestone of the Miyara Formation.

Brown tuffaceous sandstone near Ogan-zaki closely resembles sandstone mapped as part of the Miyara Formation elsewhere on the island. Hanzawa (1935, p. 43) pointed out the difficulty of distinguishing some of the sandstone of the Miyara Formation from that of the Nosoko Formation (Hanzawa's Yaeyama coal-bearing beds). The Nosoko beds were said to be nearly horizontal compared with the more steeply dipping Miyara beds, and the Nosoko beds were said to contain carbonaceous material, whereas the sandstone of the Miyara did not. These differences could not be distinguished by the writer on Ishigaki-shima.

Two incomplete but representative sections of the Nosoko Formation on the Yarabu peninsula (fig. 11) are given to illustrate typical lithologies.

Partial sections of Nosoko Formation measured on west end of Yarabu peninsula

Section A

[Stratigraphic position of this section within the Nosoko Formation is unknown. For location of section see fig. 11]

	Thickness (meters)
Breccia, green, coarse-textured	15.3
Lava, greenish-gray; dark-green phenocrysts	?
Breccia, greenish-gray; conglomeratic in places; limestone nodules near base; grades into tuffaceous sandstone	4.5
Tuff and lapilli tuff, green; rough pebbly appearing weathered surface; light-colored spots evident on fresh surfaces	8.5
Lapilli tuff, green	1.2
Tuff, green; sandy and crossbedded near base, some small pebbles; includes gray shaly layers	7.5
Tuff, green; some weathers tan; mostly fine-grained but includes lapilli tuff	4.8
Breccia, green; weathers brown; has green tuff matrix; most lava fragments less than 3 cm across	6.8
Sandstone and breccia, green; includes some beds of tan fine-grained tuff and sandy tuff; 0.8 m below top is conglomeratic bed that has small fragments of sandstone and shale	5.8
Base of formation not exposed.	

Section B

[Section B was measured a few meters north of section A. Stratigraphic position of this section within the Nosoko Formation is unknown. For location of section see fig. 11]

	Thickness (meters)
Lava, gray or greenish-gray; some contains nodules of quartz and opal(?)	12
Covered	6
Lava, gray, much jointed	2.8
Fault(?).	
Breccia, greenish-gray; gray lava, reddish lava, and green shale fragments as much as 30 cm across in green tuffaceous matrix; fragments average 2–8 cm across	9
Tuff, green, sandy	3.8
Covered.	
Tuff-breccia, green; fragments mostly 0.6–1.2 cm across	13
Shale, gray, contorted; some conglomeratic tuff and lava fragments included; seems to be zone of submarine slumping	2–3
Lava, gray, vesicular; vertical joints closely and irregularly spaced; many vesicles filled with calcite, quartz, or opal(?); some of space between joints has also been filled, and filling now stands out as ridges	4
Shale (fine-grained tuff(?)), gray or green, limy, well-bedded; beds 5–8 cm thick	3.2
Tuff, green, limy	2
Covered	5.8
Breccia, green; fragments are gray lava mostly about 3 cm across	11.5
Lapilli tuff, green, limy, well-bedded; most beds 5–8 cm thick; degree of weathering varies because the beds differ in hardness	1.7
Shale (fine-grained tuff(?)), green, limy	0.2
Base of formation not exposed.	

FIGURE 29.—Submarine slumping at Ogan-zaki. This volcanic tuff and breccia is a jumble of blocks of the Nosoko Formation. Bedded volcanic materials resting on a slope apparently slid down and were broken and jumbled before they became completely indurated. Their original bedding was not completely destroyed. Adjacent undisturbed beds can be seen in the background. September 1955.

Breccia.—Pyroclastic breccia is probably the most abundant rock type. The highest point on the peninsula, Yarabu-dake, is composed of medium- to coarse-textured green breccia. The breccia is green due to its green tuffaceous ash and volcanic sand matrix. The rock fragments are commonly gray to black andesite, but in some places the breccia also has fragments of dacite. Some fragments of andesite, for example, at Yarabu-zaki and Ogan-zaki, have the shape of volcanic bombs. In some places the breccia has distinct bedding, but in other places, it—particularly the thick-bedded and coarse-textured breccia—has obscure bedding. Coarse-textured breccia beds tend to be thickest and are commonly as much as 5 meters thick; medium-textured breccia beds are commonly 1–2 meters thick; and fine-textured breccias may be only 0.3–1 meter thick.

A representative rock fragment (IS–F–32–55–1) in a sequence of bedded tuff and breccia at Ogan-zaki was examined microscopically. It is altered pyroxene andesite. The phenocrysts, which are less than 3 millimeters long, are plagioclase—mostly albitized, but partly sericitized—and partly chloritized augite. Calcite occurs as pseudomorphs after hypersthene(?). Opaque grains of iron oxide minerals less than 0.5 millimeter in diameter are present. The groundmass is hyalopilitic.

There are fine laths of feldspar, poikilitic quartz (0.2 mm across), and dust of opaque iron oxide minerals. Green tuff-breccia from Yarabu-dake has, at least partly, dacite fragments, but sampling was incomplete. Some of the dark-gray lithic fragments in the breccia resemble andesite from other localities but were not checked microscopically. The lithic fragments in the thin section examined (IS–F–100–55) are dacite that has phenocrysts of partly altered plagioclase, quartz, and carbonitized mafic phenocrysts. The groundmass is fine grained and consists of plagioclase, quartz, sericite, chlorite, unidentified brown materials, and opaque iron oxides. Threads of sericite in the matrix are characteristic.

The size of rock fragments composing the breccia ranges from less than 1 centimeter to more than 30 centimeters, and the common range in size is 2–15 centimeters. The proportion of rock fragments to matrix is different in different beds. In general, the proportion ranges from about 25–60 percent rock fragments. The matrix of the breccia consists of particles which range in grain size from clay to coarse sand. The matrix was derived mainly from andesitic ash and volcanic sand, but in places it has mineral grains, such as quartz and mica, probably derived from local sediments. Secondary calcite is a major constituent of the matrix in many places. Original minerals in the breccia are commonly altered to chlorite and sericite.

Tuff.—The tuff of the Nosoko Formation on the Yarabu peninsula is commonly green, greenish-gray, tan, or brown; its composition is andesitic. The grain size ranges from clay to sand size. Lapilli tuff is common. Sorting is poor in many beds. Some beds show laminations caused by thin layers of different dominant grain sizes. Bedding is graded in places. The tuff is well bedded, the beds ranging in thickness from about 1 centimeter to 1.5 meters (fig. 27). Most beds are 0.3–1 meter thick. Some of the tuff contains rare, poorly preserved Foraminifera that are discussed in the section "Age."

A representative tan, somewhat mottled tuff (IS–F–34–55) from a well-bedded tuff and breccia sequence at Ogan-zaki is andesitic (fig. 27*B*). Plagioclase grains as much as 1 millimeter in size, tiny fragments of altered volcanic rock, and opaque grains of iron oxide minerals compose the coarser material which is scattered throughout a matrix of brown material, possibly altered volcanic glass. Plagioclase and alteration products such as chlorite and sericite also compose some of the finer grained part.

A typical green tuff (IS–F–97–55B) from Ogan-zaki is an andesitic lapilli tuff that contains fragments of pyroxene andesite as much as 3 millimeters across. The andesite varies in grain size and is altered to different degrees. Devitrification, albitization, chloritization, and carbonitization have affected the components of the tuff.

NOSOKO PENINSULA

The Nosoko peninsula has the most extensive exposures of pyroclastic material on the island. Its prominent peak, Nosoko-māpē, is largely composed of volcanic breccia and is capped by a fairly coarse breccia (fig. 25). Breccia seems to compose more than 50 percent of the exposed volcanic rock of the peninsula. Bedded tuff and tuff-breccia similar to those of the Yarabu peninsula are also abundant. The breccia and tuff are all andesitic.

The tuff and breccia of the Nosoko peninsula closely resemble those of the Yarabu peninsula. Green is the dominant color, tan and brown being less common than on the Yarabu peninsula. The amount of coarse-textured breccia is greater, and breccia composed of rock fragments 1 meter or more in diameter is present. A large proportion of the tuff and the breccia is calcareous; in some places the breccia has limestone fragments and even large blocks of limestone incorporated in it. Breccia containing limestone fragments and large cavities from which the limestone has been dissolved is exposed about 1.6 kilometers southwest of Ibaruma and at Tamatori-saki.

In places, as along the courses of small streams tributary to the Ōura-kawa, calcium carbonate is being precipitated; it is derived from ground water seeping through very limy tuffs and breccias. The calcium carbonate precipitate covers the rocks and pebbles of the stream bottom and makes them gray. Some cliff faces of tuff and breccia are covered by a light-gray limy precipitate deposited from ground-water seepage.

In a few places the breccia in the interior and along the northeast coast contains scattered quartz pebbles. On the coast a few hundred yards south of Nosoko-zaki some white quartz, and bluish-gray banded chalcedony similar to that found in some lavas, is present in the breccia as nodules and as matrix between rock fragments.

On the coast 1 kilometer northeast of Inōda, the volcanic breccia contains rounded calcite pebbles and irregular calcite nodules and chunks which are orange-brown on the weathered surface. Some of the calcite nodules and pebbles have quartz crystals at the center. Typical limestone fragments of the Miyara are not found in the breccia at this locality.

The attitude of the beds ranges from nearly horizontal to vertical. The vertical beds are found along faults or where submarine slumping occurred. Most beds have dips of 5°–30°.

745–104 O—65——4

The base of the Nosoko Formation is not exposed on the north and west sides of the peninsula. On the south the boundary is a fault contact. On the southeast side of the peninsula, the Nosoko Formation unconformably rests on rocks of the Ishigaki Group. In places, an impure limestone or limy conglomerate 0.3–1.2 meters thick is the basal bed. It is overlain by bedded greenish-gray and brownish-gray tuffs and tuffaceous sandstone. Greenish-gray breccias occur still higher in the section. Near Inōda, patches of limestone of the Miyara crop out near volcanic rocks, but, as contacts are covered, the relation of the limestone to the volcanic rocks is not revealed.

The Nosoko Formation is overlain in scattered localities along the coasts by the Nagura Gravel, the Ryukyu Limestone, or by raised beach sands and gravels (fig. 30). However, throughout most of the peninsula, it is the outcropping surface formation.

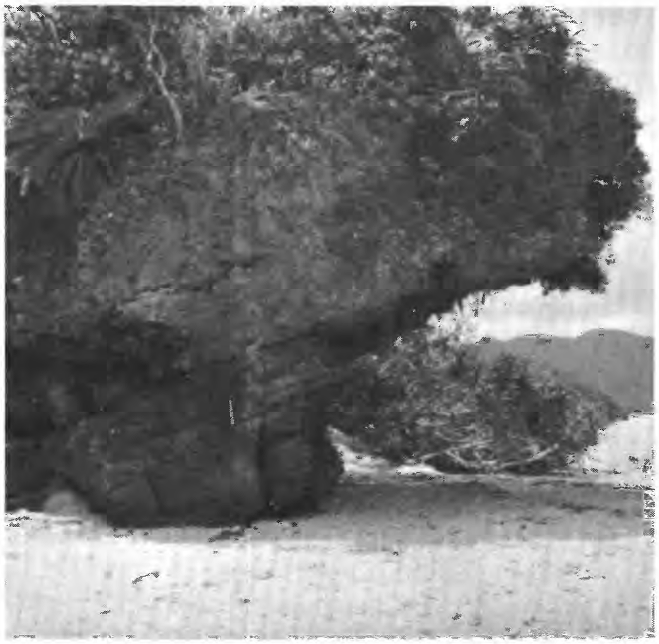


FIGURE 30.—Nosoko Formation overlain by Ryukyu Limestone. The stratified rock in the lower part of the picture is tuff of the Nosoko Formation, and the massive rock overlying it is the Ryukyu Limestone. Locality is on the northwest coast of the Nosoko peninsula. March 1956.

KABIRA PENINSULA

The pyroclastic rocks of the Kabira peninsula differ in appearance from the typical pyroclastic rocks of the Nosoko Formation which crop out elsewhere on Ishigaki-shima. Most of the pyroclastic material exposed is breccia, tuff-breccia, or lapilli tuff; only a few fine-grained tuff beds crop out on the north tip of the peninsula. The breccia is largely composed of lava fragments 0.5–8 centimeters across. On the north end of the peninsula, breccia, which is tan or brown, is mostly much altered and weathered. However, dark-gray or greenish-gray breccia exposed on the steep mountainside along the southwest side of the peninsula south of Sokoji-wan is fine grained and very hard and dense. In the field, it gives the impression of having been silicified, but microscopically there is little evidence of this. Some of the breccia is so firmly indurated that the rock breaks across lava fragments and matrix rather than around lava fragments. Microscopic examination indicates that the characteristics of the breccia must be due to a considerable amount of glass present in the original material but since devitrified.

Microscopic examination of typical hard, dense tuff-breccia (IS–F–285–56) indicates that it consists mostly of fragments of augite andesite, whose grain size varies, and that it contains some fragments of devitrified glass. The matrix consists of fairly large (1.5 mm long) crystals of feldspar and augite in a material which includes glass scattered among finer feldspar and chlorite crystals.

Another specimen (IS–F–167–55) is dark-gray andesitic tuff-breccia that has fragments of altered andesite in a matrix of devitrified glass, crystal fragments of plagioclase (andesine), augite, opaque iron oxide minerals, and alteration products.

OTHER LOCALITIES

Scattered areas of tuff and breccia occur in places along the east side of the Ibaruma peninsula, the south part of the Hirakubo peninsula, Nobaru-zaki on the east coast, and north of Miyara in southeastern Ishigaki-shima.

The breccia on the Ibaruma peninsula occurs in several scattered outcrops, mostly as large green boulders. The breccia is similar to that found on the Nosoko peninsula and is associated with dark-gray or dark-greenish-gray andesite.

Along with a limited amount of lava, small remnants of volcanic breccia occur 1 kilometer northwest of Akeishi on the schist ridge and south of Kūra. In general, the breccia is a fairly typical greenish-gray volcanic rock, but some of it contains quartz chunks and pebbles. Schist fragments also occur, in places more abundantly than lava fragments.

The breccia in southern Ishigaki-shima is poorly exposed in several scattered localities near conglomerate, sandstone, and limestone of the Miyara Formation and is associated with andesite dikes and sills previously described as part of the Nosoko Formation. The breccia may represent erosional remnants of former more extensive volcanic deposits that were closely associated with the deposition of the Miyara Formation.

WEATHERING AND SOILS

Weathering and secondary alteration have affected the rocks of the Nosoko Formation differentially. A few andesite lava flows are very fresh and little changed, but much of the Nosoko Formation is deeply weathered and considerably altered. In places, the lavas and the breccias have become saprolite (fig. 31). The saprolite is generally yellow to reddish brown. Its thickness ranges from 0.3 to 8 meters.

A minor, but unusual, feature is a pitted surface in volcanic tuff and breccia observable between high- and low-tide levels on the rock face at Ogan-zaki (fig. 32). This feature is attributed to the effect of marine animals such as spiny sea urchins, chitins, or limpets. Spiny sea urchins were found in many of the cavities, but it is not known whether the sea urchins produced the cavities or are simply later occupants.

FIGURE 31.—Saprolite formed from rocks of the Nosoko Formation. Volcanic rock of the Nosoko Formation has completely changed to soft clayey material, but it still retains the structures of the original hard rock. The beds in the lower part of the picture were originally tuff. The large masses above were probably boulders in talus or slumped material that accumulated after the deposition of the tuff beds. This exposure is in a roadcut 1 kilometer southeast of Nosoko-ishi-zaki in the north part of the Nosoko peninsula. March 1956.

In the mountainous areas, deep weathering has produced fairly thick Red-Yellow Podzolic soils. These soils have large and small breccia and lava boulders scattered on the surface and are interspersed with areas of fairly hard rock or thin soils. The soils are dark-brown to dark-reddish-brown silt loam in the upper horizon. Fairly deep Latosols and Red-Yellow Podzolic soils cover most of the terraces.

ORIGIN

The volcanic materials which composed the Nosoko Formation are, to a large extent, submarine deposits derived from Tertiary volcanoes. Many of the rocks are believed to be marine because of the fine, graded bedding, a few marine fossils, the absence of pumice, and the large amount of calcium carbonate in the matrix. Structures such as small local folds and broken segments of beds which have been recemented are best explained by submarine slumping. Most of the volcanoes probably started as submarine volcanoes, some of which later grew into small island groups or clusters. Eventually some of these groups may have become joined to the previously existing land.

Several volcanic centers are postulated to explain present distribution of the Nosoko Formation. They extended from the south part of the Hirakubo peninsula southwestward to southern Ishigaki-shima and westward to the Yarabu peninsula. Their locations are indicated in figure 33. These locations were chosen on the basis of the distribution and characteristics of the volcanic deposits. Little indication of the original volcanic topography remains.

A northernmost center of eruption is postulated in the vicinity of Kūra in the southwest part of the Hirakubo peninsula. Lava which has intrusive relationships to the schist of the Tumuru Formation indicates that this may have been an eruptive center. Few pyroclastic materials produced by this center are preserved, but small patches of breccia are found on the ridge south of Kūra-dake and elsewhere in the Kūra area. The intrusive lava may be the remains of lava which solidified in the throat of the volcano or which formed feeder dikes.

The source of the scattered lava and volcanic breccia of the Ibaruma area is not clear. Volcanic activity may have occurred along a fissure extending from Kūra to the Nosoko peninsula. Alternatively, volcanic material in the Ibaruma area may have been derived from the Kūra center and from centers in the Nosoko peninsula. A third possibility is that some of the lavas could be remnants of feeder dikes or of small local vents.

The Nosoko peninsula seems to have been the site of the greatest concentration of activity. The largest

A

B

FIGURE 32.—Pitted surface in volcanic rocks. *A*, Pits in volcanic tuff and breccia at Ogan-zaki occur between the high- and low-tide levels. Perhaps they are formed by spiny sea urchins, chitins, or limpets. *B*, Close view of pits in volcanic tuff and breccia at Ogan-zaki. Spiny sea urchins were found in some of these pits.

mass of volcanic rocks crops out here, and much of the material is coarse breccia, which probably fell very near the vents. Because of its shape (fig. 25), Nosoko-māpē has been considered a plug by many geologists who have viewed it from a distance. Close examination did not produce conclusive information as to its origin. The breccia and lava composing it are virtually the same as those in neighboring hills and ridges. No structures could be found which gave any definite evidence that the peak is a plug. Its resistance to erosion might be due to firm welding of the breccia in a vent, but it is somewhat unlikely that the topographic form would have been preserved through most of Tertiary time and through the Quaternary to the present. The peak may have resulted from fortuitous weathering along major joint cracks; however, the coarseness of the breccia near Nosoko-māpē and in the ridge to the southwest of it suggests the presence of a vent or vents in this vicinity. Nosoko-zaki and Tamatori-saki may also have been vent areas as indicated by coarseness of breccia, many lava flows nearby, structures which may be high initial depositional dips, and, in the Tamatori-saki area, considerable submarine slumping on steep slopes.

In southern Ishigaki-shima the areas north of Miyara and northwest of Ōhama, in which volcanic rocks crop out, might have been centers of eruption as numerous dikes, sills, and remnants of volcanic breccia occur in each area. If so, these were small areas of eruption probably never built up above sea level. The volcanic rocks of southern Ishigaki-shima, if more extensive than the present outcrops, are beneath the Ryukyu Limestone, which covers the southern part of the island extensively. However, exposures in stream valleys show that the Ryukyu Limestone probably does not overlie many such volcanic deposits but that it rests on older Pleistocene materials or on metamorphic rocks.

The volcanic rocks of the Yarabu and Kabira peninsulas are probably close to the vents from which they were derived. A vent is postulated in the vicinity of Yarabu-zaki because of volcanic bombs found in breccia there. The variety and the thickness of deposits at Ogan-zaki, along with steep initial(?) dips, suggest a vent in this area. Submarine slumping, which may have resulted from an abundance of material on steep submarine volcanic slopes, is seen in the beds (fig. 29).

The vent through which slightly more silicic breccia was erupted may have been in the interior of the peninsula near Yarabu-dake. Most silicic breccia was found in this vicinity.

The concentration of volcanic deposits near the end of the Kabira peninsula suggests a center of eruption there. A center in Sokoji-wan may have been the

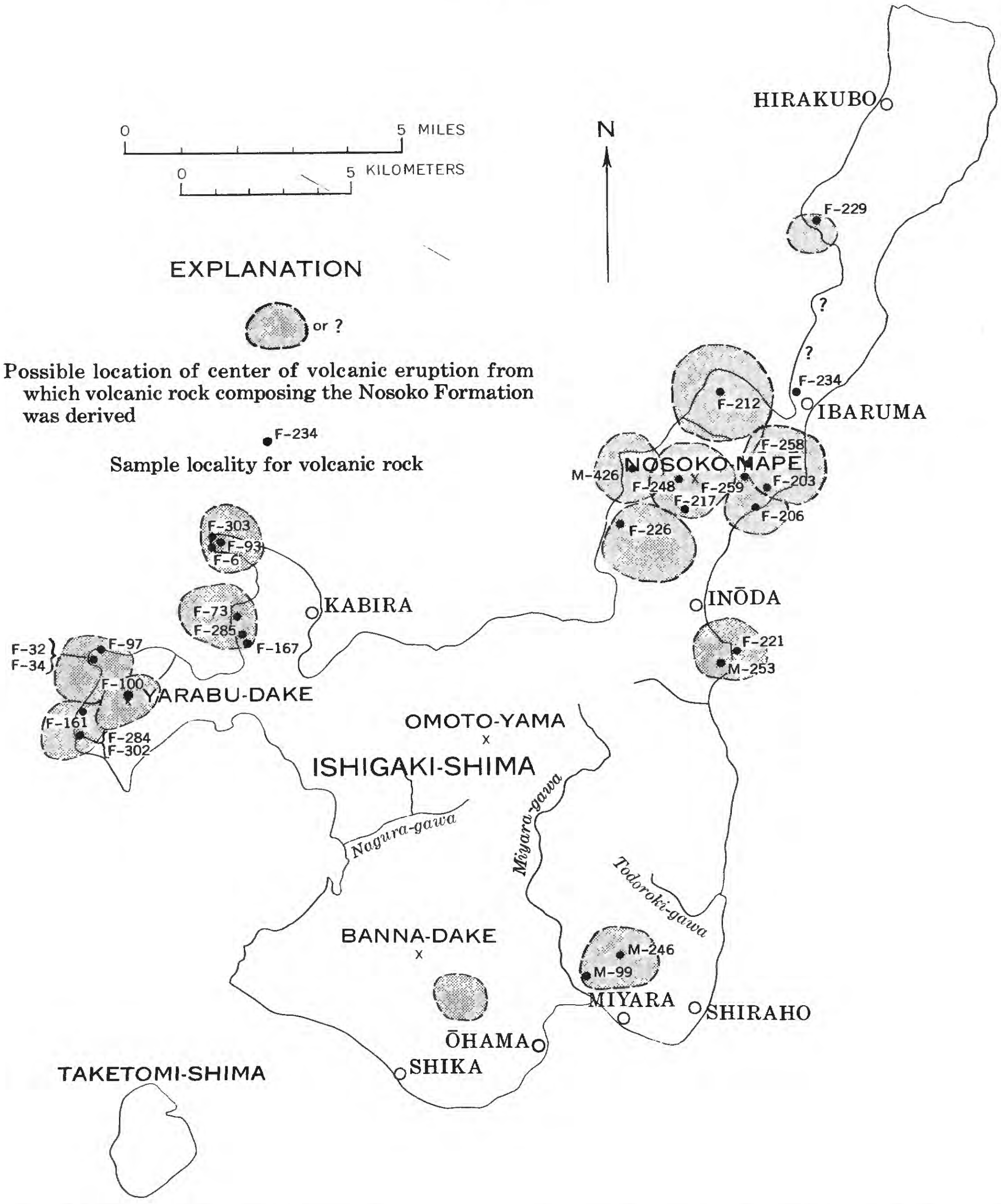


FIGURE 33.—Postulated centers of Tertiary volcanic eruptions on Ishigaki-shima and sample localities for volcanic rocks of the Nosoko Formation.

source of the tuff-breccias on the southwest side of the peninsula.

The slightly more silicic lava and breccia of the Kabira peninsula and some of that of the Yarabu peninsula seem to be from the vents which were closest to the granitic and granodioritic rocks. The andesite of the type which composes most of the Nosoko Formation may have been slightly contaminated either by silicic rocks already emplaced, through which the lava moved, or by silicic magmas. The most mafic components of the Nosoko Formation are farthest in distance from the granitic rocks.

AGE

The oldest beds of the Nosoko Formation are not older than Eocene, and the younger parts of the formation could be Oligocene or even Miocene.

Hanzawa (1935, p. 43), suggested that the volcanic rocks might be a part of the Yaeyama coal-bearing formation which he described from the neighboring island of Iriomote. On Iriomote-jima, lava, tuff, and "agglomerate" of andesitic composition (Hanzawa, 1935, p. 3) grade upward into gray and buff sandstone, gray thin-bedded shale, and conglomerate. Coal seams are present in the upper part of this sequence. Hanzawa considered both the lower volcanic beds and the conformable sandstone and shale beds as Miocene in age on the basis of fossils found on Iriomote-jima and Yonaguni-jima.

FOSSIL DATA

W. Storrs Cole, U.S. Geological Survey, studied six species of poorly preserved Foraminifera from four localities of the Nosoko Formation of Ishigaki-shima. The broken condition of the specimens suggested that they may have been reworked. The species are all known Eocene species, and Cole suggested (written commun., 1957) that the Nosoko Formation represents either a part of the Tertiary *b* (Eocene), or deposits which accumulated soon after the close of the Eocene. Table 4 lists the species of Foraminifera from the Nosoko Formation, and figure 33 shows the localities from which these specimens were obtained. Some of the specimens (IS–M–253–56) came from limestone in or on volcanic rocks of the Nosoko Formation and may be from limestone of the Miyara rather than from limestone of the Nosoko.

A few fragments of corals were found at the locality shown on the map (fig. 33) as IS–F–284–56 and IS–F–302–56. This locality is on the west coast of the Yarabu peninsula. The fossils are from the base of a green tuff-breccia which, in its lower part, is somewhat conglomeratic and contains calcareous nodules. The breccia bed is underlain by andesite and is overlain by tuff and lapilli tuff.

The corals were identified by J. W. Wells as follows:

> *Actinastrea* ("*Astrocoenia*") cf. *A. nana* (Duncan), Paleocene of India, and Eocene of Java; and cf. *A. immersa* (Von Fritsche), Eocene of Borneo.
> *Porites* sp. undet.
> *Montipora* sp. undet.
> *Elasmophyllia*? sp. undet.

Elasmophyllia ranges from Cretaceous to Eocene. *Actinastrea* ranges from Triassic to Oligocene in the Indo-Pacific area. The form represented by these fossil fragments is related to forms found in the Paleocene and Eocene of India and the East Indies (Wells, written commun., 1957).

This material was very fragmental and could also have been reworked.

A fragment of a pectinid pelecypod was collected in green tuff near Nobaru-zaki on the east coast. F. Stearns MacNeil (written commun., 1962) makes the following remarks concerning it:

> The partial mold of a pectinid in this rock is too fragmental and too poorly preserved for identification. It has some resemblance to juveniles of *Chlamys satoi* (Yokoyama), a species described from the "upper Byoritzu beds" of Formosa. Small specimens comparing with juveniles of *C. satoi* have been found in beds as old as late Miocene on Okinawa. It also resembles *Chlamys sakitoensis* (Nagao), a species described from the Maze Formation (early Oligocene) of Kyūshū. Nothing like this has been described from the Eocene of eastern Asia, to my knowledge.
>
> The possibility that the pectinid is at least closely related to an early Oligocene species does not preclude the possibility that it could be Eocene, but the supposed Eocene Foraminifera and corals in the Nosoko Formation could also be reworked from an older stratigraphic unit.

STRATIGRAPHIC DATA

The Nosoko Formation generally occurs in association with the Miyara Formation. On the Yarabu peninsula, it seems to rest conformably on beds of the Miyara Formation. In southern Ishigaki-shima, lava of the Nosoko Formation seems to intrude the Miyara Formation. Some scattered outcrops of breccia and lava may rest on the Miyara Formation or be interbedded with it, but the relation is not clear.

No Miyara beds are known on the north and west sides of the Nosoko peninsula, but on the southeast side near Inōda and in the vicinity of Nubarē-daki and Hoshino, patches of limestone of the Miyara occur both near and adjacent to volcanic rocks. Near Nubarē-daki, large irregular blocks of limestone of the Miyara seem to lie unconformably on volcanic tuff and breccia. They may, however, be blocks of limestone which were incorporated in the breccia, as were smaller pieces of limestone at Tamatori-saki, nearby Nobaru-zaki, and elsewhere.

Near Ibaruma the Miyara Formation and the Nosoko Formation crop out adjacently, but, except for a sill (or dike) in the Miyara beds, their stratigraphic relationship cannot be determined. Near Kūra, on the Hirakubo peninsula, some of the volcanic rocks seem to grade upward into calcareous beds of the Miyara Formation. The outcrop relationships suggest that here some Miyara beds might be contemporaneous or even a little younger than the lava and some breccia.

The stratigraphic relationship of the rocks of the Miyara and Nosoko Formations indicates that in places the formations were in part contemporaneous but that in most places the Nosoko Formation closely postdates the Miyara.

There is good evidence that volcanic activity occurred in the northwestern part of the Pacific Ocean in early as well as middle Tertiary time. Basaltic and andesitic rocks of Eocene and Oligocene age are present on the west flank of the Central Range of Taiwan; other volcanic rocks indicate that the Miocene was a time of greater and more widespread volcanic activity. Evidence of Eocene volcanic activity has also been found in the Ogasawara-guntō (Bonin Islands), 2,100 kilometers northeast of Ishigaki-shima and in the Mariana Islands, 2,500 kilometers southeast. Tertiary volcanic activity commenced and was extensive in the Miocene Epoch in Japan.

Volcanic deposits of the Nosoko Formation probably began to accumulate on Ishigaki-shima in Eocene time; some volcanic activity continued (probably intermittently) into Oligocene or possibly Miocene time; but most of the activity ended shortly after the close of the Eocene.

SAKISHIMA GROUP

The Sakishima Group consists of two formations, the Nagura Gravel and the Ryukyu Limestone. The name Sakishima was taken from Sakishima-guntō, the group of islands which includes Ishigaki-shima, other islands of the Yaeyama-guntō, and the Miyako-guntō. The name was first used by Foster and others (1960, p. 125). The Nagura Gravel and the Ryukyu Limestone were grouped together because of their close stratigraphic relationship. Commonly the two formations crop out in the same general area but at different altitudes. In other places, they seem to interfinger or the Ryukyu Limestone overlies the Nagura Gravel.

Although the age of the Sakishima Group is probably Pleistocene, part of the Nagura Gravel may be late Pliocene, and some of the Ryukyu Limestone may be Recent.

NAGURA GRAVEL

The Nagura Gravel consists of unconsolidated, poorly bedded deposits of angular to somewhat rounded rock fragments in a reddish-brown or yellowish-brown loamy matrix. In some localities, gray clay lies beneath the gravelly material, and this clay is included in the Nagura Gravel as the Bunera Clay Member. The Nagura Gravel unconformably overlies the older rocks of Ishigaki-shima. The contact between the gravel and underlying bedrock commonly has a steep dip (20°–30°), especially along mountain fronts.

The rock fragments of the gravelly material are predominantly milky quartz, chert, and schist, in order of abundance, but fragments of volcanic rocks, granite, granodiorite, or diorite abound locally. The composition of the gravel is closely related to the type of bedrock in the vicinity of a given exposure.

Large boulders may compose the base of the formation, except where the Bunera Clay Member is present. Stratification is indistinct in most places, and sorting is generally poor. The pebbles and cobbles show a different degree of rounding in different exposures, but slightly rounded rock fragments are most abundant. The gravel is unfossiliferous.

The matrix in the few well-stratified gravel layers is usually sandy and generally constitutes less than 40 percent of the gravel. In the poorly stratified material, it is clayey or silty. The proportion of pebbles to matrix is commonly low, the matrix generally composing 60–90 percent of the gravel. In places, the pebbles are widely scattered throughout the loamy matrix.

At the neck of the Yarabu Peninsula near Kabira-wan and in a few other places along the north coast of Ishigaki-shima, a quartz or arkosic sand occurs beneath a thin layer of gravel or in place of the gravel.

In parts of the drainage areas of the Nagura-gawa, Miyara-gawa, and Todoroki-gawa, the Bunera Clay Member, a highly fossiliferous gray clay, is present below gravel. The base of the clay is exposed only in one unfossiliferous outcrop in the northern part of the Miyara-gawa area. Here clay rests unconformably on schist.

The Nagura Gravel forms the surface of dissected terraces that occur around the coasts of the island and in the interior of it south of the mountains of granite and schist (figs. 3, 34). The coastal terraces are mostly gravel-covered shelves, cut on schist and other types of bedrock, the patchy covering of gravel being thin. Gravel lies at altitudes of 80 meters or more at the base of some mountain slopes. In the interior, Nagura Gravel is 15–22 meters or more in thickness and composes terraces which have been dissected by later erosion. These terrace surfaces range in altitude from 6 to 60 meters. Terraces along the Miyara-gawa are commonly about 40 meters above sea level (figs. 3, 34).

The most extensive areas of the Nagura Gravel are in the drainage areas of the Nagura-gawa, Miyara-gawa,

FIGURE 34.—Terraces composed of Nagura Gravel. Nagura Gravel composes these dissected terraces 1.6 kilometer southwest of Kainan. Recent alluvium floors the small valley. The terraces are not farmed but are covered with coarse grass. The scattered trees are Ryukyuan pine and *Casuarina*. View northeast. October 1956.

and Todoroki-gawa. The total area of outcrop is about 28 square kilometers.

ORIGIN OF NAME AND STRATIGRAPHIC RELATIONSHIPS

Most of the gravel deposits here called the Nagura Gravel were previously referred to by Hanzawa (1935, p. 15, 44) as Kunigami Gravel. Hanzawa wrote as follows: "Throughout the extent of the Riukiu Islands, high successive terraces, strewn in places by gravel beds a few meters thick, are extensively developed along the coasts, beveling all preceding formations * * *. The gravel beds that cover the terraces are called Kunigami gravel." Hanzawa considered that the deposition of the Kunigami Gravel took place after the deposition and beveling of the Ryukyu Limestone. The stratigraphic relationship of most of the gravel deposits on Ishigaki-shima, however, is here interpreted differently. On Ishigaki-shima, most gravel deposits are believed to be older than the Ryukyu Limestone, although some are equivalent to it in age because they are interbedded with it. Only a few gravel and sand deposits postdate the Ryukyu Limestone, and they are not the principal deposits mapped as Kunigami Gravel by Hanzawa. Because correlation of the gravel deposits on Ishigaki-shima with those on the other Ryukyu Islands has not been restudied, a separate name seemed appropriate. The name Nagura Gravel, along with the name Bunera Clay Member, was adopted (Foster and others, 1960, p. 126). The type area is the Nagura district where typical deposits of the gravel are abundant.

THICKNESS

The thickness of the Nagura Gravel, excluding the Bunera Clay Member, is less than 10 meters in most places but may be as much as 22 meters. The thickest depoists known are those in the drainage area of the upper Miyara-gawa in the vicinity of Suku-baru. The thickness of the Bunera Clay Member of the Nagura Gravel is unknown. The maximum exposed thickness is about 3 meters, but at least 5 or 6 meters is suggested from an auger boring. The clay is not present beneath the gravel in many localities, particularly where terraces join the mountain fronts. Terraces in the Suku-baru area do have the Bunera Clay Member beneath the gravel, so total thickness of the formation in at least parts of this area may be as great as 25 or 30 meters.

NAGURA AREA

Representative exposures of the Nagura Gravel are present both to the north and south of the Nagura-gawa and in terraces along the coast of Nagura-wan north of the Nagura-gawa (fig. 35). The thickness

FIGURE 35.—Typical exposure of Nagura Gravel 6 kilometers north of Shika in the type area (locality F–825). The deposit is unstratified. The Ozato soil is seen above the gravel. August 1956.

ranges from about 1.5 meters to more than 18 meters but averages about 4–7 meters. The rock fragments in the gravel of this area are predominantly chert, but a considerable number are white quartzite and milky quartz. Schist fragments occur in minor amounts. Volcanic rocks of the Nosoko Formation were not found. Granodiorite or diorite fragments are present locally.

Exposures of Nagura Gravel in the coastal terraces north of the Nagura-gawa are exemplified by an exposure 1 kilometer north-northeast of the mouth of the Nagura-gawa (locality F–1g, fig. 36). The surface layer, 0.3–0.6 meter thick, consists mostly of angular fragments and boulders of chert. Below is 0.8–1.5 meters of reddish-brown loamy material that has no large rock fragments. The lowest exposed part of the terrace is 2–3 meters of gravel consisting predominantly of well-rounded chert pebbles and a few pebbles of greenish-gray sandstone and schist. The matrix is yellowish-brown sandy clay showing red patches and streaks. In some places along Nagura-wan in this vicinity, the contact between the gravel and the underlying metamorphic rocks of the Ishigaki Group can be seen. Seeps are common at the contact.

Quartz sand without large rock fragments underlies gravel similar to that just described at a depth of 3.5 meters, 1.8 kilometers north of the mouth of the Nagura-gawa. Gray and red-brown or yellow-brown clay is exposed beneath about 4.5 meters of gravel nearby. The Bunera Clay Member is definitely known

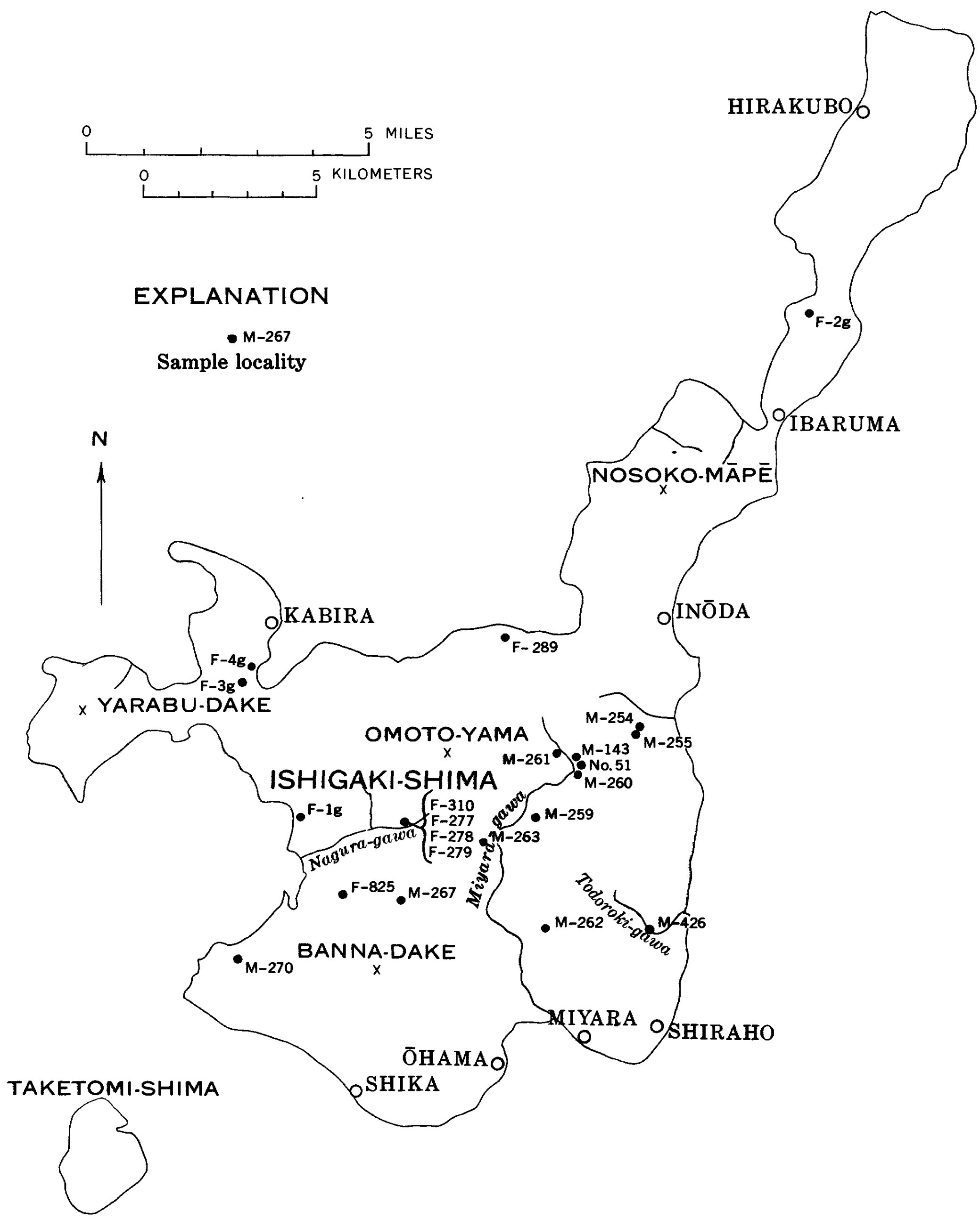


FIGURE 36.—Index map of Nagura Gravel localities including the Bunera Clay Member.

in the Nagura drainage area only in the type locality along the Bunēra-gawa, the easternmost extension of the Nagura-gawa.

A roadcut 1.8 kilometers west-northwest of the Central Agricultural Research Institute exemplifies the Nagura Gravel in the area of the drainage divide between the Nagura-gawa and Miyara-gawa (locality M–267, fig. 36). The Nagura Gravel at this locality consists of a heterogeneous mixture of chert, milky quartz, quartzite, and rare schist boulders, cobbles, and pebbles in a brown, sandy and clayey matrix. Rock fragments compose about 50 percent of the total material. Bedding is crude to indistinguishable.

Three zones can be distinguished in the exposure. The upper zone, 0.6 meter thick, consists of small boulders and pebbles. Below in a zone 0.9 meter thick are found cobbles, pebbles, and rare small boulders. The lower 0.5 meter of the exposure is sandy clay containing small (0.6–2 cm) chert and quartz pebbles. The base of the gravel is not exposed.

A pebble count of 1 square foot (0.09 sq m) in the middle zone showed that about 70 percent of the cobbles and pebbles are chert and that the remainder are mostly quartz. Sixty-seven percent of the rock fragments are between 0.6 and 1.3 centimeters in diameter, 16 percent between 1.3 and 2.5 centimeters, 15 percent between 2.5 and 5 centimeters, and only 2 percent larger than 5 centimeters. They range from angular to rounded, and the majority are slightly rounded. Shapes are mostly irregular or slightly elliptical.

One of the thickest exposures of the Nagura Gravel in the Nagura area is along an abandoned road 2 kilometers northeast of Fu-saki (loc. M-270, fig. 36). There the Nagura Gravel is a heterogeneous mixture of cobbles, pebbles, sand, and sandy clay. Crude bedding and possibly crossbedding is present. The base of the gravel is not exposed. The following section was measured:

Section of Nagura Gravel measured in Nagura area 2 km northeast of Fu-saki

	Thickness (meters)
Soil, sandy clay, with pebbles and cobbles	0.3-0.6
Cobble and pebble zone; slightly rounded to angular chert, quartzite, quartz and schist pebbles and cobbles	1.2
Gravel, sandy, clayey, with a pebble zone	1.2
Cobbles interbedded with sandy gravel consisting of pebbles 1.3-5 cm across; includes cobble lens 15 cm thick composed of fairly rounded to fairly angular cobbles of chert and quartzite 10-15 cm in diameter	1.8
Gravel, cobbly with 15- to 25-cm cobbles; slightly rounded to fairly angular chert, milky quartz, and quartzite pebbles and cobbles	1.8
Gravel, pebbly, sandy, with some cobbles. About 60 percent is sand matrix	1.8
Gravel, pebble, and cobble interbedded; composed of slightly rounded to fairly angular fragments of chert, quartzite, and quartz in a sandy matrix. Matrix composes about 40 percent of the gravel	4.3
Gravel, pebble; composed of slightly rounded to angular chert, quartz, and quartzite pebbles and scattered small cobbles 5-12 cm across in a sandy matrix	1.8
Gravel, cobbly pebble; composed of slightly rounded to fairly angular chert, quartz, and quartzite cobbles and pebbles, 1.3-10 cm across, in a sandy matrix	4.9
Total thickness	19.4

A pebble count made about 14.5 meters above the base of the exposure showed that the rock fragments are about half chert and half quartzite. The matrix of sandy clay composes about 40 percent of the total material. Nearly 80 percent of the rock fragments ranged from 0.6 to 1.3 centimeters in diameter.

MIYARA-GAWA AREA

The thickest deposits of the Nagura Gravel compose terraces in the drainage area of the Miyara-gawa in the central part of the island. There the deposits range in thickness from 4 to 22 meters or more and probably average about 11 meters. Most of the gravel deposits are underlain by gray marine clay, the Bunera Clay Member of the Nagura Gravel.

The pebbles, cobbles, and boulders in the gravel are mostly derived from the metamorphic rocks of the Ishigaki Group. They consist of chert, white quartz, and some schist, but in places granodiorite, granophyre, granite, and andesite are important components. The composition and the thickness of the gravel varies considerably from one exposure to another, and the proportion of rock fragments to matrix also has a wide range. In some places, few rock fragments are larger than 0.3 centimeter in diameter, but in others 70 percent or more of the material may be rock fragments—including large boulders. The fine material ranges from clay to sand and occurs in many different admixtures

The greatest known thickness of the Nagura Gravel which definitely includes the Bunera Clay Member is in the terrace about 3.4 kilometers north-northeast of Kawahara where an auger hold (No. 51, fig. 36) was put down to a depth of 21.3 meters. Although the base of the formation was not reached, the Bunera Clay Member was found below a depth of 15 meters. Little information was obtained on the size and the proportional amount of rock fragments, but no large boulders were found. The matrix was brown or yellowish-brown silty clay loam, silty clay, gritty clay, or sandy loam.

The following section, fairly typical of the Nagura Gravel in the Miyara area, was measured 1.6 kilometers north-northeast of Kawahara (loc. M-259, fig. 36):

Section of Nagura Gravel measured in Miyara area 1.6 km. north-northeast of Kawahara

	Thickness (meters)
Boulders, cobbles, and pebbles of weathered diorite(?), quartzite, quartz, and some schist in a brown silty clay matrix; coarse fragments are subangular to subrounded and may be as much as 30 cm in diameter; fragments larger than 0.6 cm in diameter compose about 40 percent of the total material	0.6
Clay, brown, silty; containing pebbles and cobbles as much as 10 cm in diameter; pebbles and cobbles are subangular to subrounded, and most are much weathered and partly altered to clay; silty clay matrix composes about 70 percent of the total material	0.9
Clay, brown, silty	2.9
Boulders, cobbles, and pebbles of quartzite, quartz, and much weathered schist in a silty clay and clay matrix; subrounded to subangular rock fragments compose about 50 percent of the total material; some angular schist boulders are as much as 46 cm in diameter	2.0
Base is not exposed.	

About 2.5 meters of interbedded sandy gravel and sandy clays are exposed approximately 3.2 kilometers north-northeast of Kawahara village (loc. M–260, fig. 36). Pebbles and cobbles in the gravel are slightly rounded to angular fragments of schist, quartz, and chert. They range in size from 0.6 to 15 centimeters in diameter. The schist fragments are much weathered. The clays are brown or brown mottled with gray, and they have gray streaks or veins 1.3 centimeters across. Bouldery gravel is present 183 meters to the north. In places between these outcrops, there are boulder and cobble lenses in the sandy clay. The distribution of large boulders in the gravel suggests that they may have been derived from local bedrock hills, now so buried and weathered that their presence is not determinable. A pebble count in the gravel indicates that about 25 percent of the rock fragments are schist and that the rest are mostly quartz. A sandy clay matrix composes about 70 percent of the total material.

About 3.6 kilometers north-northeast from Kawahara (loc. M–261, fig. 36), a thickness of 1.8 meters of cobbly, pebbly gravel rests on reddish-brown mottled clay. The gravel is a heterogeneous mixture of slightly rounded to angular schist and quartzitic rock fragments in a reddish-brown sandy clay matrix. The fragments range from 0.6 to 30.5 centimeters across, and a pebble count indicates that more than 80 percent are schist. About 50 percent of the total material is sandy clay matrix.

Another exposure of the Nagura Gravel 100–125 meters south of the one above displays gravel composed of a larger variety of rock fragments. The fragments, mostly pebble and cobble size, are slightly rounded to subangular pieces of weathered granite, granophyre, andesite, quartz schist, quartz-mica schist, chlorite schist, quartz, and quartzite.

Figure 37 is a schematic diagram which suggests the probable relationship of some of the gravel exposures in this general vicinity.

Several atypical deposits of Nagura Gravel also were found in the Miyara area. About 3 kilometers north-northwest from Miyara (loc. M–262, fig. 36), gravel and sand underlies Ryukyu Limestone. This gravel is unusual in that it is gray rather than reddish- or yellowish-brown in overall color and in that it contains well-rounded pebbles, is well sorted, and is somewhat stratified. No clayey material is included. Fossils were not found, although the characteristics mentioned above indicate that the gravel was fairly well washed and probably marine in origin.

Another unusual deposit included in the Nagura Gravel is an exposure of impure quartz sand 0.4 kilometers northeast of Kainan village (loc. M–263, fig. 36). The deposit rests on much-weathered rock of the Ishigaki Group and underlies Ryukyu Limestone. Pebbly sand beds occur both near the base of the exposure and near the top. The total section is about 15.5 meters in thickness.

Further variation in the gravel deposits of the Miyara area is illustrated by the gravel 0.4 kilometer south of Kainan. There the rock fragments are entirely chert, but they are found in the characteristic yellowish-brown loamy matrix.

TŌRO-GAWA AREA

In the Tōro-gawa area the gravel is characteristically coarse and bouldery where it flanks the mountains. It has been derived almost entirely from the metamorphic rocks of the Ishigaki Group. Rock fragments are mostly schist and white quartz that occur as pods and veinlets in the schist. Where the contact is visible, the gravel directly overlies metamorphic rocks, and the Bunera Clay Member is absent. The contact generally has a steep dip.

A lateral change in the texture of the Nagura Gravel is evident in this area. Near schist hills, large schist boulders (fig. 38) are abundant at the base of the gravel. As distance from the bedrock hills increases, the size and amount of large rock fragments decrease. In the middle of valleys or basins of gravel accumulation, silty and sandy clays containing few rock fragments are common.

A narrow valley about 1.1 kilometers southwest of

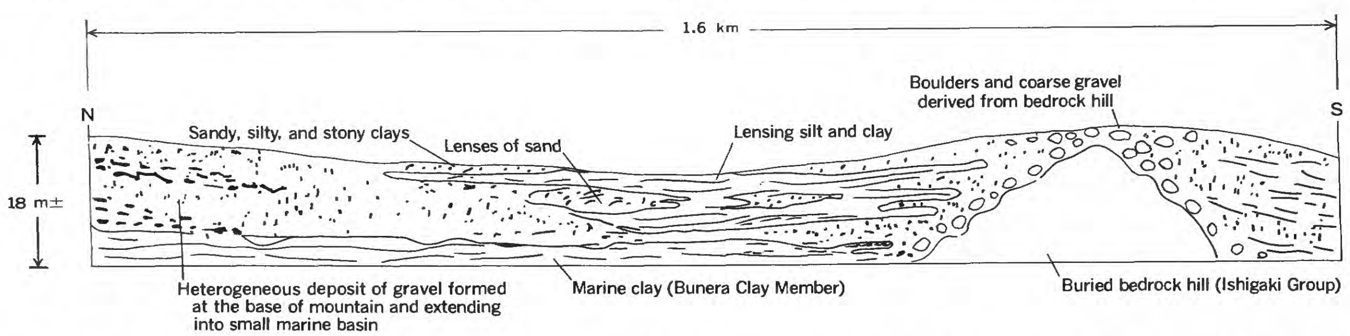


FIGURE 37.—Schematic cross section illustrating lateral changes in Nagura Gravel. Section from 3.6 kilometers north-northeast from Kawahara southward about 1.6 kilometers (after field notes by Harold G. May).

Hoshino (loc. M–254, fig. 36) exposes a section of gravel characteristic of the area. The contact of the gravel with the underlying bedrock is not exposed. The rock fragments seem to be locally derived. The section is as follows:

Section of Nagura Gravel measured 1.1 km southwest of Hoshino

	Thickness (meters)
Boulders and cobbles of weathered greenschist and micaceous schist in a brown pebbly, sandy clay matrix; fragments are slightly rounded to fairly angular. Parts of the exposure which are nearest to the mountain front have a greater abundance of boulders	1.5–2.4
Gravel, pebbly; consists of weathered, slightly rounded pebbles of schist and fairly angular pebbles of quartz with a few rock fragments of cobble size; fragments range from about 0.6 to 10 cm in size and compose 30–40 percent of the total material; matrix is brown sandy clay	1.5–1.8
Cobbles and pebbles (15–1.3 cm) of weathered schist and quartz pebbles (2.5–1.3 cm) in brown sandy clay matrix; fragments are slightly rounded to angular—oblong, circular, or elliptical in shape—and compose 40–60 percent of the material	3.0±
Clay, brown, silty; has some quartz and sand grains	1.5–1.8
Clay, brown, pebbly, sandy, and silty; pebbles mostly somewhat square, angular fragments of schist and quartz, composing 10–20 percent of the total volume of this part of the deposit	3–3.6
Boulders, cobbles, and pebbles of micaceous and chloritic schist with some white quartz pebbles and rare glaucophane schist fragments in a matrix of sandy brown clay; most fragments are slightly rounded to somewhat angular and rather flattened, are weathered, and are in the size range of 1–20 cm in diameter	2.4–3

About 90 meters south of the above section, a pebble count was taken in a roadcut in the gravel. The rock fragments are about 70 percent quartz and 30 percent schist, and the schist is much weathered. The fragments are angular to slightly rounded and are as much as 13 centimeters in diameter. Most, however, are smaller than 3 centimeters in diameter. The matrix is sandy clay and composes about 40 percent of the total material. The deposit rests unconformably on schist, and the contact dips about 3° or 4° W.

A pebble count was made in the zone of a steep contact between the Nagura Gravel and the schist in a nearby exposure. About 90 percent of the rock fragments are schist, and these schist fragments are as much as 76 centimeters in diameter (fig. 38). About 70 percent of the material is composed of rock fragments larger than 2.5 centimeters in diameter. The matrix consists of pebbles less than 2.5 centimeters in diameter and of sandy clay. The large boulders are heterogeneously scattered throughout the rest of the gravel. The material in the deposit is rather closely packed. About 90 meters west, an exposure in the same terrace shows only brown silty friable clay. The clay is apparently interbedded with pebble and cobble gravel as indicated by other exposures nearby.

FIGURE 38.—Coarse Nagura Gravel. Large boulders are abundant in some exposures of Nagura Gravel which are near bedrock hills. This exposure is at the base of the gravel near the contact with schist about 1.2 kilometers southwest of Hoshino. The tape in the picture outlines a 3-foot square (0.9 m). The large boulder is schist and is about 76 centimeters long. About 90 percent of the rock fragments in the square are schist. August 1956.

A small valley cut in gravel terraces 1.5 kilometers southwest of Hoshino exposes a heterogeneous mixture of cobbles and pebbles in a yellowish-brown sandy clay matrix (loc. M–255). The cobble-sized rock fragments are mostly angular, slabby pieces of schist; and the pebble-sized, angular, cubical pieces of quartz. The exposure is about 90 meters east of the contact between the Nagura Gravel and the schist.

No complete uninterrupted gravel section is exposed in this area, but on the basis of a study of several exposures, the following section was reconstructed:

Compiled section of Nagura Gravel southwest of Hoshino

	Thickness (meters)
Gravel; composed of slightly rounded to angular pieces of schist and quartz; unstratified	8.0
Clay; some contains pebbles of schist and quartz	1.8
Cobble and pebble gravels that have a sandy or sandy clay matrix and sandy clay interbedded; somewhat stratified; fragments are schist and quartz	1.5
Boulders of angular weathered schist (6–20 cm) in a matrix of sandy clay mixed with pebbles and cobbles	1.8
Total thickness	13.1

Figure 39 shows schematically an interpretation of the relationships of the Nagura Gravel in this area.

NORTHERN DEPOSITS

The Nagura Gravel occurs in small scattered patches on coastal terraces at the base of the mountains in northern Ishigaki-shima. Most deposits are thin and directly overlie the metamorphic rocks. The Bunera Clay Member is not present as far as is known. The deposits are unstratified or have only a very crude stratification. The rock fragments composing the gravel all seem to be of very local derivation and are mostly angular schist fragments and white quartz. Locally some pieces of volcanic rock occur. The matrix is mostly a yellow or reddish-brown silty or sandy clay. Most of the rock fragments are less than 10 centimeters in diameter, but boulders 30 centimeters or more in diameter are scattered throughout the deposits and in places occur in concentrations. The thickest deposits in the north are 1 kilometer southwest of Akeishi (loc. F–2g, fig. 36) and 1 kilometer northeast of Hirakubo.

Near Akeishi, about 6 meters of gravel are exposed at the head of a small gully. The uppermost 1.8 meters is a red-brown to orange-brown clay that contains scattered small pebbles. The number of pebbles increases with depth, and below 3 meters, scattered boulders occur. Near the base of the exposure is a concentration of andesite and schist boulders. The rock fragments consist of andesite, schist, and quartz derived from the weathering of the schist. They range from well rounded to slightly rounded. The andesite and schist fragments have weathered to a soft, clayey material easily crushed between the fingers.

KABIRA-WAN AREA AND SAND DEPOSITS

The Nagura Gravel in the vicinity of Kabira-wan and in some places westward along the north side of the island is considerably different from that previously described. Most of the material has been derived from granitic rocks, and a large part of it is sand (fig. 40). The Nagura Gravel about 1.6 kilometers southwest of Kabira at the base of the Kabira peninsula between Kamana-wan and Kabira-wan is exemplified by the following section (loc. F–3g, fig. 36):

Section of Nagura Gravel 1.6 km southwest of Kabira

	Thickness (meters)
Gravel; well-rounded pebbles mostly 1–3 cm in diameter	0.4
Cobble and boulder layer; boulders are mostly granite but a few are granophyre or diorite; are much weathered, having a soft outer shell, some being soft and friable throughout; are between 15 and 30 cm in diameter; are mostly well rounded, and elliptical in shape, although many are rather flat. Matrix is arkosic sand	0.6±
Sand, arkosic, brown or yellow-brown; resembles weathered granite	0.6–0.9

In exposures 0.4 kilometer northeast, the boulders are more angular, but they also are mostly granite. Adjacent exposures to the southeast have numerous cobbles and pebbles of chert and quartz from rocks of the Ishigaki Group and possibly some schist fragments as well as granite.

Near the junction with Ogden Road, 1.6 kilometers southwest of Kabira, more than 6 meters of unstratified sand is exposed (loc. F–4g, fig. 36). The base of the sand was not seen. In places, the sand is overlain by gravel and red-brown gravelly soil. Gravel overlying the sand contains rocks of the Ishigaki Group as well as granite. Most of the rocks are considerably weathered. The sand is coarse grained in the upper 0.6 meter but grades downward to fine-grained sand. It is mostly a quartz or arkosic sand. No shell material was discovered.

A roadcut about 600 meters west of the village of Tomino exposes poorly stratified sand and gravel (loc. F–289, fig. 36). The pebbles are mostly less than 2.5 centimeters in diameter and are derived from the metamorphic rocks of the Ishigaki Group. White

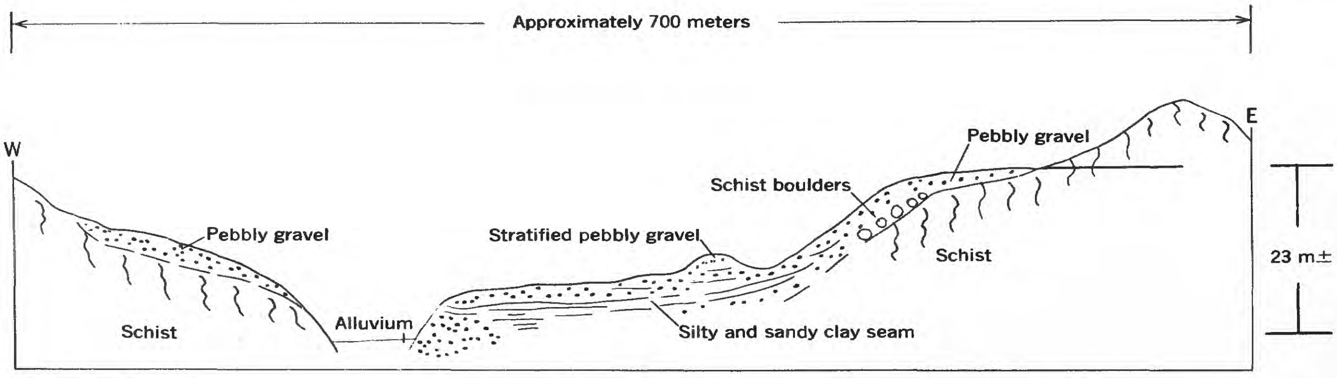


FIGURE 39.—Schematic cross section illustrating relations of Nagura Gravel as interpreted from several small exposures, 1.5 kilometers southwest of Hoshino (loc. M–255). (After field notes of Harold G. May.)

FIGURE 40.—Nagura Gravel near Kabira-wan. The Nagura Gravel in the vicinity of Kabira-wan has well-rounded granitic pebbles, cobbles, and boulders in a sandy matrix. The lower part of this exposure is arkosic sand. This exposure is in a roadcut 1.8 kilometers south-southwest of Kabira (loc. F–3g). August 1956.

quartz predominates. The base of the sand was not seen.

Other exposures of sand are beneath the Ryukyu Limestone near Goeku-dan on the Nosoko peninsula and 0.8 kilometer northwest of Akeishi on the southern end of the Hirakubo peninsula.

BUNERA CLAY MEMBER

The Bunera Clay Member of the Nagura Gravel is named (Foster and others, 1960, p. 126) from outcrops along the banks of the Bunēra-gawa. It is also known in the drainage area of the Miyara-gawa, from both outcrops and auger holes, and it is present beneath gravels in the drainage area of the Todoroki-gawa. It is generally overlain by the gravel deposits. Gravel deposits beneath the clay have not been found.

The known clay occurrences range in altitude from about 12 or 14 meters to 55 meters. The highest clay outcrop is in the upper drainage area of the Miyara-gawa near the base of the mountains, 1.5 kilometers north of borehole 51. At this locality the base of the clay rests unconformably on schist, but because no fossils occur in the clay, it is not certain that this is the Bunera Clay Member. The lowest known occurrence is also in the Miyara-gawa drainage in borehole 51 in the main part of the depositional basin. The top of most of the outcrop at the type locality has an altitude of about 20 meters, which is approximately the same altitude as some of the outcrops in the Miyara-gawa drainage. The top of the gray clay may have been eroded and reworked in places, for instance, in the Todoroki-gawa area where sand is mixed with clay near the contact with overlying gravel.

The type exposures are in the banks of the Bunēra-gawa about 4.2 kilometers east of the mouth of the Nagura-gawa (fig. 41). A maximum of about 4.5 meters of clay is exposed beneath coarse stream terrace deposits of probable Recent age. The base of the clay is not exposed, and so, the total thickness is unknown.

In the type locality (F–278, fig. 36) the Bunera Clay Member is medium to dark gray or bluish gray if wet and light gray if dry. It is silty or sandy in places and somewhat calcareous. Jointing is conspicuous, and erosion occurs along these joints (fig 41*A*). At the type locality the entire clay section is fossiliferous.

Limy concretions occur here and there near the top of the deposit. About 35 centimeters below the top of the clay at the type locality, an irregular lensing layer contains wood fragments, coral, and some shells. About 50 centimeters below this layer is a similar irregular layer, 8 centimeters to a little more than 50 centimeters thick, also containing fragments of wood, coral, and shells. Shells are scattered throughout the clay but tend to cluster locally. The wood-bearing layers were laterally continuous for only a few meters, and other stratification was not noticed except that the shells show a slight tendency to accumulate in layers or lenses.

Type section of Bunera Clay Member

	Thickness (meters)
Stream-terrace deposits: heterogeneous mixture of boulders, cobbles, and pebbles of granite, diorite or granodiorite, and chert in a matrix of yellowish sandy clay.	
Unconformity.	
Clay, gray, sandy and silty with limy concretions in places (F–279c, fig. 36); corals common locally, and fossil shells scattered throughout	0. 3–0. 9
Clay, gray; contains wood fragments, corals, and an abundance of fossil shells (F–279a; F–279d is same layer 15 m upstream)	0. 08
Clay, gray; scattered white fossil shells	0. 5–0. 6
Clay, gray; wood fragments and concentrations of white fossil shells (F–279b)	0. 08–0. 5
Clay, gray; scattered white fossil shells	0. 6–1. 5
Base not exposed.	

The gray clay in the Miyara-gawa drainage area could be identified as the Bunera Clay Member because its foraminiferal fauna and that from auger hole 51 (pl. 4, fig. 36) were similar to that of the type area. Exposures in the Todoroki-gawa drainage area were also correlated with those in the Nagura-gawa area.

A

B

C

FIGURE 41.—Bunera Clay Member of the Nagura Gravel. *A,* Exposure of Bunera Clay Member in the type locality along the upper part of the Bunēra-gawa. Vertical jointing is conspicuous. The clay is overlain by coarse stream gravels and boulders which are slowly sliding toward the stream on the upper surface of the clay. August 1956. *B,* Bunera Clay Member in the type locality on the upper part of the Bunēra-gawa. Fossil shells (the white specks) are scattered throughout the clay. August 1956. *C,* Fossil wood is exposed at two horizons in the Bunera Clay Member in the type locality on the upper part of the Bunēra-gawa. August 1956.

However, some clay exposed in the downstream part of the Todoroki-gawa drainage area is reworked Bunera clay or later sediments deposited in a brackish- or freshwater environment.

Fossil deer bones were found below Nagura Gravel in a sandy clay along the banks of the Todoroki-gawa (loc. M–426, fig. 36). The fossil bones are believed to be at the top of the Bunera Clay Member. However, the upper part of the clay is somewhat mixed with tan or brown sand, indicating that it may have been weathered and slightly reworked before or during the time of the deposition of the bones. The sandy clay grades upward into brown sand and sandy clay and then into typical Nagura Gravel through an interval of 30–90 centimeters.

FOSSILS OF THE BUNERA CLAY MEMBER

Fossils are abundant in several outcrops of the Bunera Clay Member. They are most abundant and occur in the greatest variety in the type locality. Fossils include larger and smaller Foraminifera, ostracods, gastropods, pelecypods, bryozoans, corals, and plant remains. Vertebrate fossils, mostly deer bones (*Metacervulus astylodon* Matsumoto), may also be found in the Bunera Clay Member.

The fossils are very well preserved and are easily collected because the clay is soft and can be washed away. The vertebrate fossils are discussed by Frank C. Whitmore, Jr., U.S. Geological Survey, in another chapter of this Professional Paper.

Foraminifera.—Foraminifera from three localities—the type locality (F–278, fig. 36), an exposure in the Miyara-gawa area (M–143, fig. 36), and the deep auger hole 51 (fig. 36)—were studied by Ruth Todd and W. Storrs Cole, U.S. Geological Survey. Ruth Todd reported that the major constituents of the fauna are the large planispiral forms *Operculina ammonoides* (Gronovius) and *Operculinella venosa* (Fichtel and Moll). One hundred and forty other species also occur, most of which are rare. Table 7 lists the abundance and distribution of the species, and figure 36 shows the location of the sample sites.

According to Ruth Todd, the fauna is marine and is typical of modern faunas from the tropical Pacific. The predominance of the two operculine species indicates moderate depths of water (30–100 fathoms). The presence of planktonic species (Globigerinidae) shows that water from the open ocean had access to the area. A comparison of the faunas with a list of species reported by Yabe and Hanzawa (1925b) from *Globigerina* ooze collected from the sea bottom south of Okinawa-jima showed that of 121 species listed by Yabe and Hanzawa about 18 percent were also found in the Bunera Clay Member (table 7).

TABLE 7.—*Abundance and distribution of smaller Foraminifera from the Bunera Clay Member of the Nagura Gravel*

[Identifications by Ruth Todd. Symbols used: A, abundant; C, common; R, rare. Localities are shown in fig. 36. Samples F-277, F-278, and F-279 were taken along the Bunĕra-gawa in the type locality of the Bunera Clay Member. F-277a is from the clay exposure farthest downstream at the type locality and was taken about 1.2 m below the top of the clay. F-277b was collected at the top of the clay, and F-277c from 0.8-1.5 m below the top. F-278b was collected a few tens of meters upstream from F-277 about 0.8-1.1 m below the top of the clay. F-278c came from a few tens of meters upstream from F-278b. F-279 was taken a few meters farther upstream; this is the sample site that has considerable wood. F-279a was from a bed containing wood, about 7-66 cm thick, about 0.8 m below the top of the clay. F-279b was taken 0.5-0.7 m below from another clay bed containing wood. F-279c was collected near the top of the clay above the beds containing wood]

	M-143	Hole 51	F-277a	F-277c	F-278b	F-278c	F-279a	F-279b	F-279c	Yabe and Hanzawa [1]
Ammodiscidae:										
Ammodiscus sp.	R									
Textulariidae:										
Textularia agglutinans d'Orbigny		R	R	R	R	R			R	R
aff. *T. australis* Parr			R	R	C					
candeiana d'Orbigny	R		R		R					
conica d'Orbigny		R	R	R	C	R		R	R	
foliacea Heron-Allen and Earland var. *oceanica* Cushman.	A		R	R	C	R		R	R	
Siphotextularia sp.			R	R	R	R				
Verneuilinidae:										
Gaudryina triangularis var. *angulata* Cushman					R					
Pseudoclavulina sp.				C	R					
Miliolidae:										
Quinqueloculina agglutinans d'Orbigny				R	R					
akneriana d'Orbigny	R	R	R	R	A	C		R	R	
anguina Terquem var. *arenata* Said					R	R				
berthelotiana d'Orbigny	R									
kerimbatica Heron-Allen and Earland *philippinensis* Cushman.	R			R	R				R	
neostriatula Thalmann		R	R		R				R	
cf. *Q. parkeri* (Brady)		R				R				
polygona d'Orbigny	C									
sulcata d'Orbigny		R			R	R				
sp. [flaring aperture]		R						R	R	
Cribrolinoides curta (Cushman)			R	R	R	R				
Triloculina oblonga (Montagu)	R	R	R	R	C	R		R		R
tricarinata d'Orbigny				R	C			R	R	R
trigonula (Lamarck)	C	R	R	R	R				R	R
Massilina crenata (Karrer)	R		R			R				
planata Cushman	R	R	R	R	R			R	R	
Spiroloculina aequa Cushman and Todd	C									
aperta Cushman and Todd					R					
communis Cushman and Todd	R	C	R	R	C	R			R	
corrugata Cushman and Todd		R								
disparilis Terquem	R				R			R		
Articulina sp. [smooth form]	R									
Miliolinella labiosa d'Orbigny	R		R	R	R					
Pyrgo denticulata (Brady)	C	R							R	
milletti (Cushman)	C			R					R	
subsphaerica (d'Orbigny)	C			R	R				R	
Pyrgoella sphaera (d'Orbigny)				R	R	R				
Hauerina bradyi Cushman	R	R							R	
diversa Cushman		R								
involuta Cushman		R								
Schlumbergerina alveoliniformis (Brady)		R							R	
Nubeculina divaricata (Brady)	R			R	R	R			R	

See footnote at end of table.

TABLE 7.—*Abundance and distribution of smaller Foraminifera from the Bunera Clay Member of the Nagura Gravel*—Continued

	M-143	Hole 51	F-277a	F-277c	F-278b	F-278c	F-279a	F-279b	F-279c	Yabe and Hanzawa [1]
Ophthalmidiidae:										
Cornuspira planorbis Schultze				R		R				
Cornuspiroides foliacea (Philippi)									R	
Nodophthalmidium antillarum (Cushman)	R									
milletti (Cushman)	R									
Nodobaculariella sp	R					R				
Planispirinella exigua (Brady)		R								
Placopsilinidae:										
Haddonia torresiensis Chapman		R	R	R		R				
Lagenidae:										
Robulus sp									R	
Polymorphinidae:										
Glandulina laevigata d'Orbigny	C	R	R	R		R			R	R
Nonionidae:										
Nonion japonicum Asano	A	R	R	R	C	C	R	R	R	
subturgidum (Cushman)	R				R	C	R	R	R	
Astrononion aff. *A. italicum* Cushman and Edwards.	C	R	R	C	C	R		R		
Camerinidae:										
Operculina ammonoides (Gronovius)	R	A	A	A	A	A	A	A	A	
Operculinella venosa (Fichtel and Moll)	A	A	A	A	A	A	A	A	A	
Heterostegina suborbicularis d'Orbigny	R	C		R	R	R			R	
Peneroplidae:										
Peneroplis aff. *P. carinatus* d'Orbigny								R	C	
Spirolina arietina (Batsch)			R	R	R	R				
Marginopora vertebralis Blainville		C	R	R	R					
Alveolinellidae:										
Alveolinella quoyi (d'Orbigny)	R									
Heterohelicidae:										
Bolivinella folium (Parker and Jones)			R	R						
Buliminidae:										
Buliminella madagascariensis (d'Orbigny) var. *spicata* Cushman and Parker.					R		R			
Oolina sulcata (Walker and Jacob) var. *spicata* (Cushman and McCulloch).						R				
Bolivina cf. *B. arta* Macfadyen	R	R	R	C	R	C		R	R	
catanensis Seguenza	R		R		R	R	R		R	
robusta Brady	R	C	R	R	C	R			R	R
semicostata Cushman	R	R	R	R	C	A			R	
subadvena Cushman	R				R	R				
subangularis Brady	R	R		R	R	R		R		
tortuosa Brady		R	R	R	R	R			R	R
(*Loxostomum*) *amygdalaeformis* Brady			R	R	R					
convallaria Millett	R	R								
limbata Brady						R			R	
mayori Cushman	C			R	R	R		R		
Bifarina sp	R		R		R	R				
Reussella miocenica Cushman	R				R	R				
simplex (Cushman)	R		R	R	R				R	
Trimosina sp	R				R					
Siphogenerina raphana (Parker and Jones)	R	R		R	R	C			R	R
Uvigerina proboscidea Schwager	R	R	R	R		R			R	
Angulogerina sp					R					
Siphonodosaria sp	C	R	R	R	R	R				
Spirillinidae:										
Spirillina decorata Brady			R							
vivipara Ehrenberg	R	R				R			R	
Discorbidae:										
Patellina corrugata (Williamson)					R					
Patellinella sp	R									
Rosalina concinna (Brady)		R	R		R				R	
floridana (Cushman)	R	R	R	R	R	R		R		
Neoconorbina? *tabernacularis* (Brady)			R	R				R		
Discopulvinulina bradyi (Cushman)		R			R	R				

See footnote at end of table.

TABLE 7.—*Abundance and distribution of smaller Foraminifera from the Bunera Clay Member of the Nagura Gravel*—Continued

	M-143	Hole 51	F-277a	F-277c	F-278b	F-278c	F-279a	F-279b	F-279c	Yabe and Hanzawa [1]
Discorbidae—Continued										
Pseudoeponides japonicus Uchio	R				R	R				
Poroeponides cribrorepandus Asano and Uchio		C	R		R	R	R		R	
lateralis (Terquem)	A				R				R	
Eponides subornatus (Cushman)			R	A		R	R			
Buccella sp	C		R			C		R		
Siphoninoides glabrus (Heron-Allen and Earland)			R							
Cancris auriculus (Fichtel and Moll)		R		R	R				R	
Rotaliidae:										
Streblus beccarii (Linné) *tepida* (Cushman)	C	R			R	R	R	C	C	
papillosus (Brady)				R	R					
Amphisteginidae:										
Amphistegina madagascariensis d'Orbigny	R	C	R	R	C				R	
radiata (Fichtel and Moll)		R			R	R			R	
Calcarinidae:										
Calcarina hispida Brady	C	C	C	C	C	R		R	R	R
Baculogypsinoides spinosus Yabe and Hanzawa	C	C		R	R			R	R	
Cymbaloporidae:										
Cymbaloporetta bradyi (Cushman)	R			R	R	R	R			
Pyropilus rotundatus Cushman	R									
Tretomphalus bulloides (d'Orbigny)	R			R					R	
Elphidiidae:										
Elphidium advenum (Cushman)	C	R	R	R	R	R	R	R	R	
craticulatum (Fichtel and Moll)		R			R	C	R	R	R	
indicum Cushman	C	C								
? *milletti* (Heron-Allen and Earland)		R								
Cassidulinidae:										
Cassidulina sp					R					
Epistominella pulchra (Cushman)			R	R	R	R		R		
tubulifera (Heron-Allen and Earland)									R	
Ceratobuliminidae:										
Alliatina translucens (Cushman)	R					R		R		
Pseudobulimina convoluta (Williamson)					R					
Globigerinidae:										
Globigerina bulloides d'Orbigny	R		R		R					C
eggeri Rhumbler	R		R		R		R		R	C
inflata d'Orbigny	R	R		R	R		R			C
Globigerinita glutinata (Egger)	R	R	R	R	R	R	R		R	
Globigerinoides conglobatus (Brady)			R		R					A
ruber (d'Orbigny)	R				R	R		R		R
sacculifer (Brady)		R	R	R	R	R	R		R	C
trilobus (Reuss)	R								R	C
Globigerinella aequilateralis (Brady)			R		R				R	C
Globorotaliidae:										
Globorotalia menardii (d'Orbigny)		R	R	R	R	R				C
punctulata (d'Orbigny)				R	R					
Anomalinidae:										
Anomalina glabrata Cushman			R		R	R		R		
Anomalinella rostrata (Brady)	R	A		R	R	R			R	
Planulina aff. *P. wuellerstorfi* (Schwager)				R	R					R
Cibicides lobatulus (Walker and Jacob)		R			R	R	R		R	R
mayori (Cushman)					R				R	
praecinctus (Karrer)		R	C	C	C	R	R	R	R	
pseudoungerianus (Cushman)	R	R	R		C	C		R	R	
refulgens Montfort		R			R	R	R		R	
Hanzawaia bertheloti (d'Orbigny)				R	R	R	R		R	C
Planorbulinidae:										
Planorbulina acervalis Brady					R					
Planorbulinella larvata (Parker and Jones)		R								
Acervulina inhaerens Schultze	R								R	
Gypsina globula (Reuss)	R	C	R		R	R				

[1] Indicated species were found by Yabe and Hanzawa (1925b, p. 50-52) in *Globigerina* ooze deposited on the sea floor south of Okinawa-jima.

Mollusca.—Mollusca were collected in the Bunera Clay Member only from the exposures along the Bunēra-gawa and from an exposure in the Miyara area. Those from the Bunēra-gawa exposures were identified by F. Stearns MacNeil, U.S. Geological Survey, and are given in tables 8 and 9. The Mollusca were collected from clay exposed along the stream over a distance of several hundred meters and from different stratigraphic positions in the clay section. Distribution of the species at the different sample sites is not considered significant because complete collections may not have been obtained at each site, and the true relationship of the various stratigraphic positions to each other is not known. The species from each site are listed separately to give some indication of relative frequency of occurrence of genera and species.

Mollusks from the Miyara area (loc. M–143, fig. 36) were identified by J. P. E. Morrison, of the U.S. National Museum, as follows:

Gastropoda
- *Cerithiopsis* sp.
- *Odostomia* sp.

Scaphopoda
- *Gadila* sp.

Pelecypoda
- *Corbula* cf. *C. scaphoides* Hinds
- *Abra* sp.
- "*Lucina*" sp.
- Veneridae young, undet.

Morrison suggested an offshore marine habitat on a muddy bottom of moderate depth.

H. S. Ladd, U.S. Geological Survey (written commun., 1956), stated that he has not found any close relatives of the species examined by Morrison in the collections of fossil mollusks from other Pacific Islands.

TABLE 8.—*Gastropoda from the type locality of the Bunera Clay Member of the Nagura Gravel*

[Identifications by F. Stearns MacNeil. Localities are shown in fig. 36. All samples were collected at the type locality along the Bunēra-gawa from clay exposed along the stream over a distance of several hundred meters and from different stratigraphic positions in the clay section]

Species	Sample No.							
	277a	277c	278a	278b	278c	279b	279c	279d
Anachis (*Costoanachis*) sp		X					X	
sp	X							
Architectonica sp. [juvenile]		X						
Astele (*Callistele*) sp	X							
Bittium sp				X	X		X	X
Calcar sp. [fragment]								X
Calliostomid? or trochid? [juvenile]							X	
Canarium (*Labiostrombus*) cf. *C.* (*L.*) *niasense* Wissema		X						
Clavus sp. [juvenile]		X						
Clypeomorus cf. *C. coralium* (Kiener)	X	X	X	X	X		X	X
Crassispira cf. *C. pseudoprincipalis* (Yokoyama)				X				
Cymatium gutturnium (Roeding)				X				
Cymatium? [juvenile]								X
(*Lampusia*) cf. *C.* (*L.*) *pileare* (Linné)		X		X				
sinense Reeve								X
Fusinus cf. *F. colus* Linné		X						
cf. *F. colus* Linné and *F. gracillinus* (Adams and Reeve)								X
Heliacus cf. *H. dorsuosus* (Hinds)								X
Mangelia sp	?	X						
Micantapex? sp. [juvenile]		X						
Murex cf. *M. ternispina* Lamarck (close to *M. troscheli* Lischke, Kira)	X	X				X		
Nassarius (*Niotha*) *clathratus* (Lamarck)		X						
cf. *N. picta* (Dunker)			X					
(*Zeuxis*) cf. *N.* (*Z.*) *kiiensis* Kuroda)		X						
cf. *N. dorsatus* (Roeding)				X				X
Natica stellatus (Hedley)		X						X
Pseudoraphiotoma aff. *P. crudelis* Hedley								X
Staphylaea cf. *S. limacina* (Lamarck)		X						
Streptochetus paetelianus Kobelt		X						
Tibia aff. *T. fusus* (Linné)		X						
Triphora sp							X	
Turritella cf. *T. cingulifera* Sowerby	X	X	X	X	X		X	
cf. *T. fascialis* Mencke					X			
Turris crispa (Lamarck)								X

Pollen and spores.—Material from the type locality of the Bunēra-gawa was examined for pollen and spores by Estelle B. Leopold, U.S. Geological Survey. She reported the following microspores (USGS Paleobot. loc. D1237):

Alnus
Pinus
Members of Sapindaceae, Euphorbiaceae, Chenopodiaceae, and Compositae
Podocarpus
Lycopodium
Engelhardtia
Taxodiaceae (*Glyptostropus*, *Sequoia*, or *Cunninghamia*)
Quercus
Trema
Myrica
Smilax
Picea
Trochodendron?
Lycopodium cernuum
Castanopsis
Ilex
Nymphaeaceae cf. *Nuphar*
Hystrichosphaera

Spores of the Opioglossaceae and Polypodiaceae (ferns) and fern spores of the *Cyathea* type are also present.

Except for the occurrence of *Picea*, the genera are much the same as in the present flora of the island. Unfortunately, little material of this kind from Asiatic Pacific areas is available for comparison.

SOILS

Soils developed on the Nagura Gravel are principally of two types, the Ozato soils and the Kawahara soils. They are Red-Yellow Podzolic soils strongly intergrading toward Brown Forest soils (Foster and others, 1960, p. 186, 203).

The Ozato soils have a thin dark-grayish-brown loamy upper 2.5–15 centimeters (A horizon) and a strongly acid, firm yellowish-red clay loam at depths of 15–122 centimeters (B and upper C horizons). Below is mostly coarse to fine gravel, sand, silt, and clay terrace materials. These soils are litle used for agriculture because of their acidity and the poor soil-

TABLE 9.—*Pelecypoda from the type locality of the Bunera Clay Member of the Nagura Gravel*

[Identifications by F. Stearns MacNeil. Symbols used: ×, present; F, fragment(s); J, juvenile(s). Locality numbers given are shown in fig. 36]

	277a	277c	278a	278b	278c	279b	279c	279d
Amusium sp		F						
Anadara scapha (Meuschen)					×		×	
Cardita (*Cyclocardia*) sp	J							
Cardium sp							J	
Chlamys cf. *C. gracilisquamosa* (Fischer) [possibly a juvenile of *C. satoi* Yokoyama]				×				
cf. *C. gracilisquamosa* (Fischer)		×						
nobilis (Reeve)			×					
pallium (Linné)		×						
cf. *C. squamata* (Gmelin)		×						
Chama cf. *C. dunkeri* Lischke		×						
Circe (*Redicirce*) sp		×						
Circe sp. [juveniles]	×							×
Discors sp. aff. *D. lyrata* (Sowerby)				×				
Discors sp				×				
Dosinia amphidesmoides (Reeve)	×	×	×			×		
sp. aff. *D. steinmanni* Fischer		×						
Dosinia?				F				
Fragum aff. *F. alfuricum* (Fischer)			×					
Kuphus sp		×						
Laevicardium sp	J		F		×			
cf. *L. biradiatum* (Brugière)				×		×		
cf. *L. elongatum* Dickerson, not Brugière								×
Leucoma sp. [juveniles]	×	×						
Lioconcha lorenziana (Dillwyn)					×			
Lucinoma cf. *L. annulata* (Reeve)				×				
Musculus (*Modiolarca*) *neglecta* Kuroda					×			
Mytilus sp				×				
Nuculana radiatelirata (Fischer)	×		×				×	
Ostrea hyotis Linné		×						
Ostrea sp				J	J			
Paphia aurabilis (Philippi)	×							×
Pecten sp. aff. *P. inaequivalvis* (Sowerby)	×							
Pitar cf. *P. subpellucidum* (Sowerby)				×				
Pitar sp					F	J	J	
Solecurtus cf. *S. divaricatus* (Lischke)		×						
Soletellina?			J	J				
Spondylus regius Linné				×				
Striarca interplicata (Grabau and King)	×							
Striarca sp		J						
Tellina sp	×	×					×	
Vulsella sp				F				

moisture conditions. They are most common on the high terrace levels next to the mountain fronts.

The Kawahara soils are brownish silty to loamy well-drained soils. The soil is relatively fertile and is cultivated. These soils are most common on the low, seaward ends of terraces and inland at slightly lower altitudes than are adjacent Ozato soils. Stensland (oral commun., 1959; Foster and others, 1960, p. 188), a soil scientist, has suggested that these soils are more influenced by limestone than are the Ozato soils, possibly because of the proximity of present or former outcrops of Ryukyu Limestone. For instance, the Kawahara soils have dark colloidal coatings on many soil particles, a feature characteristic of the Ryukyu Limestone terrace soils on Ishigaki-shima.

ORIGIN

The sediments composing the Nagura Gravel were largely locally derived and deposited in a marine environment. The Bunera Clay Member was probably deposited when land areas were low and not subject to rapid erosion. The loamy gravel may have been derived from deeply weathered rocks after they were uplifted, as suggested by the large amount of fine clayey material in the gravel and the fact that the somewhat poorly rounded pebbles are dominantly resistant materials such as quartz and chert. Accumulation of the gravel may have been rapid, so that sorting and rounding were limited. Toward the end of the period of gravel accumulation, limestone began to be deposited as fringing reefs around the margins of the gravel and locally on it. In a few places, gravel deposition graded into limestone deposition, causing interbedding.

In the northern part of the island, including deposits north of the Nagura-gawa on the western side, gravel deposits are generally less than 8 meters thick. Most are veneers of gravel on marine terraces cut on bedrock, chiefly schists of the Ishigaki Group. Near the coast the gravel may be only 1.5–3 meters thick. Springs or seeps commonly emerge at the contact between the schist and the gravel (fig. 42*A*). The Bunera Clay Member is absent. An example of this situation is seen along the shore of Nagura-wan 0.4 kilometers north of the mouth of the Nagura-gawa. In some places the gravel thickens toward the coast as though deposits on the cut terrace merge into deposits of a constructional marine terrace or platform. This occurs along the shore of Nagura-wan between Kēra-zaki and Mizunu-zaki (fig. 42*B*). At places on the bedrock terraces, thicker pockets or patches of gravel—probably fillings of old valleys or depressions in the bedrock surface—have been detected (fig. 42*C*).

In most places in the northern part of the island, the sea probably washed the base of the schist mountains which furnished the material for the gravel. Much of the material may have accumulated as talus along the shore; some may have been carried to the shore by streams; and some may have been derived from previously formed alluvial fans. The material was then briefly reworked by the sea at a time when sea level was higher than it is at present. The fact that the Nagura Gravel is not well rounded and that much fine matter is present suggests that it was probably not worked over for long by the waves; it was primarily redistributed, and its surface was smoothed during a period of rapid accumulation.

In southern Ishigaki-shima the fine sediments of the Bunera Clay Member accumulated in low areas invaded by the sea. Cole (written commun., 1959), on the basis of Foraminifera, concluded that the Bunera Clay Member probably was deposited in water with depths somewhere between 10 and 62 fathoms and in the open sea. The Bunera Clay Member in the Miyara-gawa drainage area is not difficult to account for in such an environment, as the whole southern part of Ishigaki-shima was probably open to the ocean. However, the deposits along the Bunēra-gawa seem to have been shut off from the open ocean to the south by a granodiorite ridge (fig. 43). Although there could have been a broad opening to the ocean to the west through Nagura-wan, fresh water from the higher area to the north, south, and east might have entered this arm of the sea in amounts too great for the operculine species to thrive. Thus, one is led to speculate whether the now mountainous areas were low and were uplifted to their present altitudes after the deposition of the Bunera Clay Member or whether *Operculina* could have thrived in a fairly deep arm of the sea that opened westward to the ocean.

Gravel began to accumulate after the uplift of the land areas. The largest part of the Nagura Gravel in southern Ishigaki-shima seems to have been rapidly deposited in basins where it was not reworked to any extent by waves. Most of it does not have the characteristics of typical deltaic deposits. Local variations in the gravel indicate that some deposits originated somewhat differently from the rest. Very coarse deposits near the base of the mountains, as in the Tōro-gawa area, may be largely talus accumulations. Some deposits in the upper Miyara-gawa might have formed as alluvial fans or stream deposits. Sand deposits, mostly in areas where weathered granite was the principal source material, may be deltaic in origin. Clean, stratified, well-rounded gravel beneath Ryukyu Limestone southeast of Kawahara indicates near-shore or

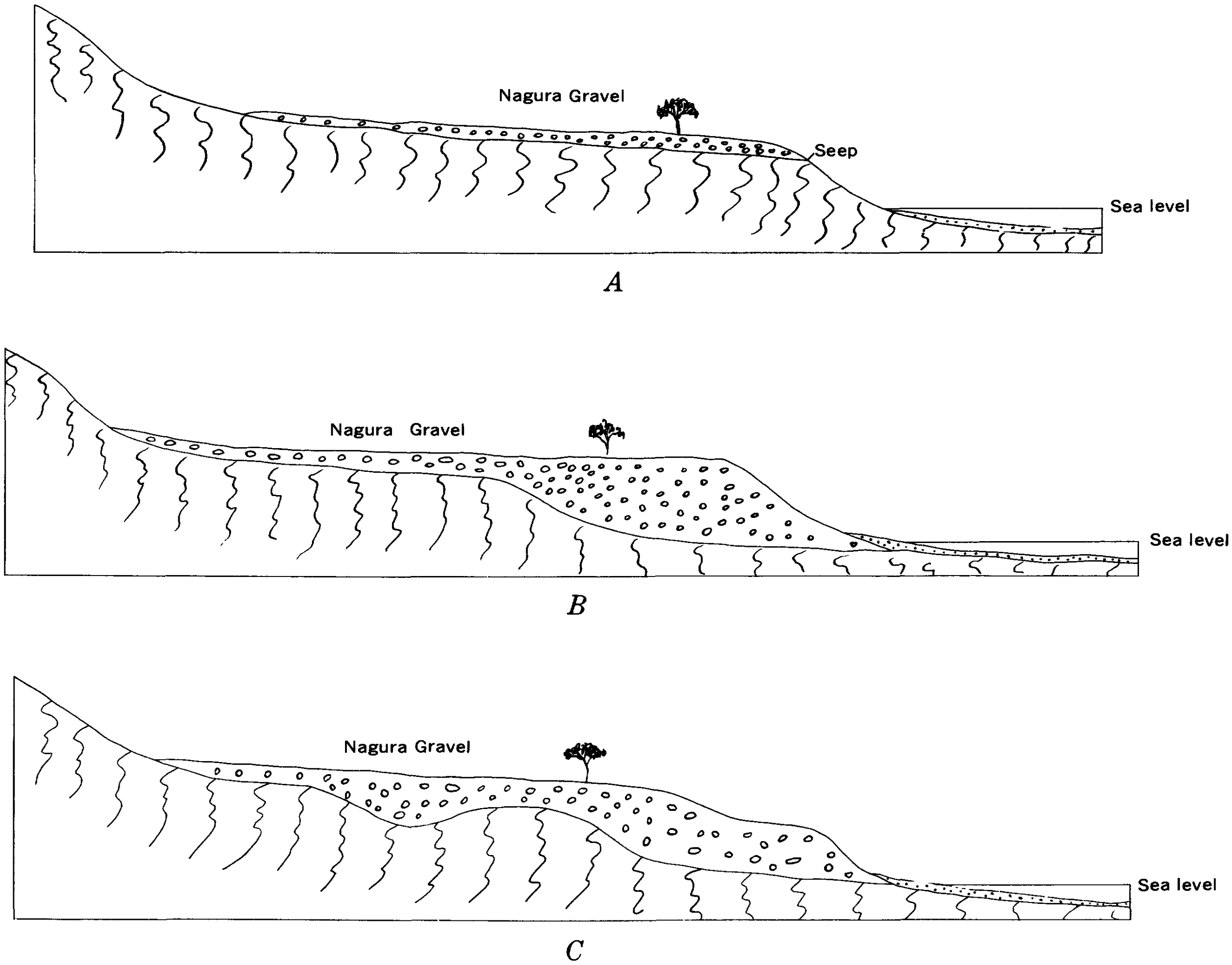


FIGURE 42.—Diagrammatic representations of Nagura Gravel relationships to bedrock and marine terraces in northern Ishigaki-shima. *A*, Thin veneer of Nagura Gravel on marine terrace cut in rock of the Ishigaki Group. *B*, Thin veneer of Nagura Gravel on marine terrace which merges with thicker gravel deposits resembling a constructional terrace. *C*, Thick patch in Nagura Gravel due to filling of an irregularity in the bedrock terrace.

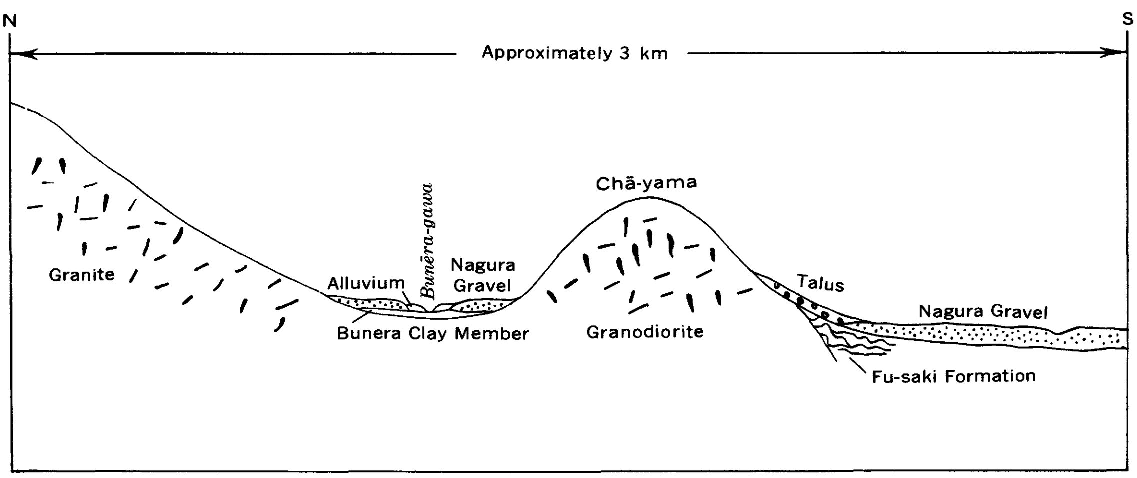


FIGURE 43.—Schematic cross section showing general relations of Bunera Clay Member and the Nagura Gravel from north to south across type locality of Bunera Clay Member and across Chā-yama.

beach deposits, probably slightly younger than the main gravel accumulation.

AGE AND CORRELATION OF NAGURA GRAVEL

Three principal lines of evidence have been used in attempting to determine the age of the Nagura Gravel: fossils in the Bunera Clay Member, a carbon-14 determination on wood from the Bunera Clay Member, and physiographic and other geologic and soils relationships.

Fossils have been helpful in only a general way because they occur only in the Bunera Clay Member and even there are not diagnostic. They demonstrate only that a range in age from late Pliocene to Recent is possible for the Bunera Clay Member, and they seem to indicate that a Pleistocene age is most probable.

F. Stearns MacNeil (written commun., 1959) examined the molluscan fauna from the Bunera Clay Member at the type locality and reached the following conclusions as to its age and correlation:

> This material was compared with fossils from Okinawa and from the Tusyo Sandstone (the upper Byoritzu beds of early authors) of Formosa. It is my opinion that the beds on Ishigaki are younger than the Tusyo Sandstone which I regard as late Pliocene. The Tusyo probably correlates with the reef facies which on Okinawa we are calling the Naha Limestone, and it is younger than the Nakoshi Sand of Okinawa (which underlies the Naha Limestone) from which the "Simaziri" fauna of Nomura and Zimbo was obtained.
>
> The Nakoshi ("Simaziri") has been correlated with the Byoritzu by most authors, but I believe this to be an error. I regard the Nakoshi as lower Pliocene.
>
> The beds on Nagura-gawa contain many more Recent species than the Nakoshi and Tusyo. *Chlamys pallium*, for instance, is a characteristic fossil of the Pleistocene Yontan Limestone of Okinawa, but it is not known in either the Tusyo, Naha, or Nakoshi.
>
> I believe at present that the beds on Nagura-gawa should be assigned to the Pleistocene.

W. Storrs Cole (written commun., 1959) pointed out that all species of Foraminifera ocurring in the Bunera Clay Member are still living. *Operculina ammonoides* (Gronovius) is the most abundant species. This species has been reported in present-day faunas from several localities in the Indo-Pacific (Cole, 1959, p. 350–351). Foraminifera are generally not conclusive for determining age from late Pliocene to Recent.

Microspores from the Bunera Clay Member were examined by Estella B. Leopold (written commun., 1959), but no conclusions on age of the flora could be reached. She writes as follows:

> The modern 'shiietum' association that grows on mountains of this region is represented here by the genera *Quercus*, cf. *Castanopsis* or 'Shiia', *Trema*, and a probable tree fern or *Cyathea*, while *Myrica* and *Ilex* are associated shrubs and *Lycopodium cernuum* and other fern types may be marginal marsh forms or forest floor types. Since this association (with pine growing in more open places) exists in the Ryukyu and Amami Islands today, the fossil assemblage would seem to have a rather modern aspect. The presence of members of the family Compositae (which evolved in Miocene time) definitely indicates a late Tertiary or younger age.

It was also pointed out that the assemblage has nothing in common with Miocene pollen of Eniwetok (material obtained from H. S. Ladd). It was concluded that the pollen assemblage suggested a Pliocene and Pleistocene age for the Bunera Clay Member.

A few ostracodes from the Miyara-gawa area were examined by I. G. Sohn. Though he was unable to give specific age determinations because of the lack of material for comparison and the scarcity of literature on the subject, he did suggest that the material could be as old as early Pliocene or even late Miocene.

The carbon-14 age determination made of a sample of wood from the type locality of the Bunera Clay Member by the U.S. Geological Survey gave no helpful age data. The wood (Lab. No. W–643) was too old for age determination by this method, and it could only be stated that the age was greater than 38,000 years.

Physiography suggests a Pleistocene age for the Nagura Gravel. The rather high altitude of the gravel in many parts of the island makes a Recent age unlikely. Known Recent deposits on Ishigaki-shima, including raised beach sands and gravels, do not occur at altitudes as high as 60 and 80 meters, as do deposits of the Nagura Gravel. Valleys as deep as 20 meters have been cut in Nagura terraces and are floored by Recent alluvium, which indicates that the Nagura Gravel is considerably older than the valleys and alluvium. In places, Ryukyu Limestone, also probably Pleistocene in age, rests on Nagura Gravel. However, surfaces of many Nagura terraces are young in physiographic appearance, and geologists accustomed to judging the age of Pleistocene surfaces in other areas consider that they resemble late, rather than early, Pleistocene terraces from other comparable areas.

Not enough data are available to attempt any kind of direct correlation of the terraces with Pleistocene sea-level changes, but several different terrace levels at fairly high altitudes (above 20 m) can be recognized. The levels are separated by scarps 1–4 meters high. These terraces may indicate Pleistocene sea-level changes; they may also be related to epeirogenic land movements.

Carl H. Stensland (oral commun., 1956), who studied the soils on the Nagura Gravel, noted characteristic differences between soils on the higher and lower terraces. The Ozato soils on the higher terraces show a longer period of soil development, are more acid, and are somewhat more gravelly than the Kawahara soils on the lower terraces. The higher terrace soils are reddish- and yellowish-brown, whereas the lower terrace soils are brown. Limestone influence, such as colloidal coatings on soil aggregates, is not evident in the higher level soils, but such coatings are present in soils on the lower terraces. In general, these soil differences support the interpretation that the higher terraces are a little older than the lower ones and that the limestone deposition began toward the end of the period of gravel deposition. Ryukyu Limestone was not found on the Ozato soils, although limestone occurs abutting against terraces composed of Ozato soils. Also, the soil scientists noted "pinnacles" of Ozato soils protruding up through surrounding Kawahara soils, and, in a few places, Kawahara soils were found resting on the eroded surface of Ozato soils. A detailed joint study of the Nagura Gravel by geologists and soil scientists would probably make it possible to separate the Nagura Gravel into two parts, an older part related to the higher terraces and Ozato soils and a younger part related to the younger terraces, the beginning of Ryukyu Limestone deposition, and the Kawahara soils.

An equivalent of the Pliocene Naha Formation of Okinawa-jima has not been recognized on Ishigaki-shima, but it is possible that some Nagura Gravel could be equivalent to the Naha Formation in age (fig. 50). If such equivalence exists, the age of the Nagura Gravel could extend back into late Pliocene time. MacNeil's observations (written commun., 1956) on the molluscan fauna of the Bunera Clay Member, however, discourage this interpretation.

Thus it can only be concluded that the age of the Nagura Gravel is probably Pleistocene.

Gravels similar to the Nagura Gravel were described by Hanzawa from other Ryukyu islands and named the Kunigami Gravel. Gravels of this description were not found by Doan on Miyako-jima, but Flint and others (1959, p. 46) described similar gravels on northern Okinawa-jima and called them by Hanzawa's original name, Kunigami Gravel. They considered the Kunigami Gravel to be partly equivalent to the Naha Formation of Pliocene age and partly Pleistocene in age (1959, p. 46).

The Guga Gravel of the neck of the Motobu-hantō on Okinawa-jima also bears some resemblance to the Nagura Gravel in its composition, its structure, and its relation to the Paleozoic(?) rocks, but it is regarded as Pliocene or older (Flint and others, 1959, p. 34). Gravels also occur in southern Okinawa-jima in the Naha Formation, some of which are similar in their stratigraphic relations and appearance to the Nagura Gravel. The gravels on Okinawa-jima are also barren of fossils; therefore, the age has been determined largely by stratigraphic and physiographic relations.

Extensive gravel deposits of both Pliocene and Pleistocene age occur on Taiwan, the best known being the Pleistocene Tableland Gravel or Tensiko Formation of northwestern Taiwan (fig. 50). The Tableland Gravel has two parts: a lower gravel sequence about 30 meters thick composed chiefly of rounded cobbles and boulders of whitish-gray and dark-gray siliceous sandstone, calcareous sandstone, andesite, dolerite, and porphyrite; and an upper part which is an earthy lateritic material generally less than 5 meters thick. The formation occurs at altitudes of 250 meters and in central Taiwan is reported at 760 meters. It is nearly horizontal in most places. In the southern part of Taiwan, the Garanbi Gravel which overlies the "Riukiu limestone" is correlated with the Tableland Gravel (Chang, 1958, p. 22–23).

The Tokazan Formation and the Koshun Formation are Pliocene and Pleistocene formations on Taiwan which have considerable conglomerate. The Koshun Formation also includes limestone similar to the so-called "Riukiu limestone" of Taiwan (Chang, 1958, p. 21).

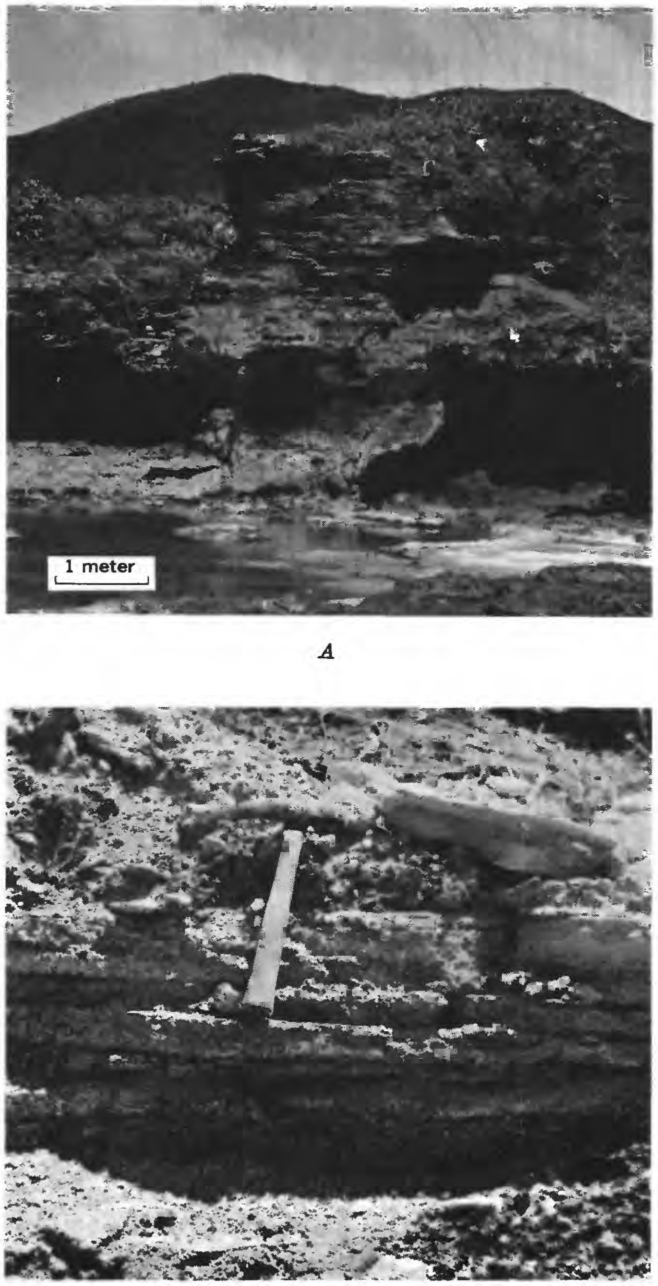
Direct correlations cannot be made between the Nagura Gravel and the conglomerate and gravel of Taiwan, but since conditions favored gravel formation on Taiwan during part of the Pliocene and Pleistocene, some of the events which produced these conditions may have been related to gravel deposition on Ishigaki-shima.

RYUKYU LIMESTONE

Ryukyu Limestone is the name applied to all post-Miocene limestone mapped on Ishigaki-shima. It was first named by Yabe and Hanzawa (1930, p. 9) in connection with their studies of the so-called "Raised-reef limestones" of Taiwan. The name (Riukiu) was later widely applied by Hanzawa to post-Miocene limestone throughout the Ryūkyū-rettō, including Ishigaki-shima. The name is used in this report in virtually the same way as Hanzawa used it in reference to Ishigaki-shima (1935, p. 44).

The Ryukyu Limestone unconformably overlies rocks of the Ishigaki Group, the Miyara Formation, the Nosoko Formation, and the Omoto Granite. In southern Ishigaki-shima, it also rests upon the Nagura Gravel, and the relationship is both conformable and unconformable. In a few places, Nagura Gravel is interbedded with Ryukyu Limestone. The Ryukyu Limestone ranges in altitude from sea level (fig. 5) to more than 80 meters above sea level. It crops out over an area of more than 46 square kilometers.

Two principal types or facies of Ryukyu Limestone occur on Ishigaki-shima—a stratified sandy foraminiferal limestone (fig. 44) and a massive coralliferous limestone (fig. 4). Conglomeratic limestone is common



A

B

FIGURE 44.—Sandy Ryukyu Limestone. *A*, Nearly horizontal thin beds of sandy Ryukyu Limestone crop out along the northern coast of Ishigaki-shima. The limestone is case-hardened. View 0.3 kilometer west of the mouth of the Ara-kawa. September 1956. *B*, Close view of sandy Ryukyu Limestone shows the coarse texture, thin bedding, and tendency of the limestone to crumble in fresh exposures. The limestone contains Foraminifera and a few megafossils. Exposure is in a quarry 1.6 kilometers southwest of Ibaruma. September 1956.

near the base of the formation. A rubbly limestone was found in one locality near Goeku-dan. No significant differences in the fauna and flora of the limestones were noted.

Ryukyu Limestone covers an area of several square kilometers in southernmost Ishigaki-shima near Shika, Ōhama, Miyara, and Shiraho. It extends 3–5 kilometers inland. Topographically this is an area of slightly seaward sloping terraces that range in altitude from a meter near the coast to 60 meters or more inland. The terrain is rough in places because of solution of the limestone (fig. 45). Drainage is mostly subsurface.

FIGURE 45.—Ryukyu Limestone terrain. Rough terrain, such as this about 2 kilometers north of Miyara, is common on the Ryukyu Limestone. The roughest terrain generally has a dense covering of low vegetation, but in places, farming—such as the growing of pineapple, as in this picture—is carried on in pockets of soil between limestone outcrops. October 1956.

Elsewhere on the island the Ryukyu Limestone occurs mostly as patches and strips bordering the coast. The largest occurrences are on the northern shore of the Yarabu peninsula along the western shore of Kanama-wan, on the Kabira peninsula, and from the eastern shore of Kabira-wan eastward to Urasoko-wan. On the Nosoko peninsula from the northern side of Urasoko-wan nearly to Nosoko-ishi-zaki, nearly continuous exposures parallel the coast. A large outcrop of the sandy limestone on a seaward-sloping terrace occurs on the southeast side of the lower course of the Ōura-kawa.

Fairly continuous outcrops of Ryukyu Limestone occur on the western sides of the Ibaruma and Hirakubo peninsulas, but outcrops on the eastern sides are limited to small discontinuous patches. Except for remnants and irregular patches, most of this limestone composes, or partly composes, seaward-sloping terraces. The surface is generally very rough because of pinnacles and other solution features.

Sinkholes and caves are in the Ryukyu Limestone on the Kabira peninsula, near Goeku-dan and elsewhere along the northern coast, along the coast of the Hirakubo peninsula, and in southern Ishigaki-shima. Some caves are coastal caves eroded largely by the sea, but others are extensive caverns consisting of hundreds of meters of underground passages. Many caves have considerable dripstone including stalactites, stalagmites, large columns, and ribbons. Some large caverns were used during World War II by the Japanese Army.

Ryukyu Limestone covers almost all Taketomi-shima. Relief is low but the terrain is locally rough. Drainage is subsurface.

Most of the coastal Ryukyu Limestone ranges in altitude from sea level to 40 meters above sea level, but between Kabira-wan and Urasoko-wan, limestone at an altitude of 60 meters or more is common, and some is found above 80 meters. Isolated small patches or remnants of limestone occur inland along river valleys as along the Nagura-gawa and the Yassa-gawa on the Hirakubo peninsula.

THICKNESS

The thickness of the Ryukyu Limestone ranges from less than 1 meter to more than 20 meters. A water well at Kainan penetrates about 20 meters of limestone, the greatest thickness known on Ishigaki-shima. A similar thickness is exposed in a scarp about 0.8 kilometer north of Ōhama. Neither the well nor the cliff exposes the base of the limestone. At several places in southern Ishigaki-shima, limestone is about 18 meters thick. Similar thicknesses are exposed 0.8 kilometer east of Yoshihara on the northern side of the island. Over much of the island the limestone is very irregular in thickness. Only in the southern part are there large areas more than 8 meters thick.

SANDY LIMESTONE

The sandy foraminiferal limestone consists of sand-sized particles loosely to firmly cemented together by calcium carbonate. It is white, light tan, or cream. Most particles are foraminiferal tests, other calcareous organic debris, and occasional quartz or chert grains or small pebbles. The amount of noncalcareous rock fragments is generally less than 5 percent of the rock and rarely more than 10 percent. The amount of quartz sand in the sandy limestone is generally a little greater in the northern part of the island than in the southern part. In a few exposures the base of the sandy limestone is conglomeratic for a thickness of a few to 60 centimeters. Thin pebbly zones occur at various horizons in the sections.

The rock is porous, but most openings are 0.6 centimeters or less across and are much smaller than many of the cavities in the coralliferous limestone. Viewed microscopically, the rock pores constitute 10–20 percent of the rock surface.

The sandy limestone is well stratified and locally thin bedded, especially in northern parts of the island (fig. 44). Beds range in thickness from 1 centimeter to more than 1 meter. Bedding planes are generally distinct in thin-bedded limestone but commonly indistinct in massive limestone (figs. 5, 44). In places, beds are distinguishable chiefly by differences in porosity. Locally, a layering is evident in the limestone; it is caused by differences in the dominant sizes of grains composing each layer. The layers are generally not separated by distinct bedding planes but grade vertically into one another. The thin-bedded limestone breaks into slabs (fig. 44*B*). The limestone varies from well indurated to crumbly and from well cemented to loosely cemented. On exposure to air, the surface of the weakly cemented material hardens considerably. Where not too thin bedded, the sandy limestone is quarried for building stone in parts of southern Ishigaki-shima (figs. 46, 47).

Typically the sandy limestone is almost horizontal. In a few places, it has gentle dips averaging about 3°, the maximum being about 8°. The dips are generally but not invariably seaward. Most gentle seaward dips are initial, but the steeper and anomalous dips are due to tilting and faulting.

The sandy limestone generally contains few corals; mollusks are abundant in places.

The following section illustrates the lithology of the sandy limestone:

Section exposed in limestone cliff in south bluff of Miyara-gawa 4.4 km north of Ōhama

[Loc. M–296 shown in fig. 48]

	Meters (above base)
Limestone, light-tan, porous, indistinctly stratified; scattered grains of chert and quartz in a fine-grained calcite matrix	15–19
Limestone, light-tan, detrital, porous, obscurely stratified; coarse parts containing slightly rounded to angular quartz and chert pebbles as much as 2 cm across; pebbles may compose 5–10 percent of the rock	11.5
Limestone, light-tan and cream, fine-grained, stratified, slightly porous to very porous; greatest porosity along planes of stratification; scattered quartz and chert grains	8.5

Section exposed in limestone cliff in south bluff of Miyara-gawa, 4.4 km north of Ōhama—Continued

	Thickness (meters)
Limestone, light-tan and grayish-white; composed of sand-sized Foraminifera and other organic debris cemented together by calcium carbonate; grains average about 1 mm in diameter, and may be loosely packed resulting in a very porous rock or somewhat more densely packed resulting in a fairly porous rock; chert and quartz grains are scattered throughout the rock, but compose less than 3 percent	6
Limestone, light-tan, detrital, porous, fairly soft and somewhat crumbly, massive; has Foraminifera, Bryozoa, and fragments of mollusk shells; has rare microscopic angular grains of chert, and much finely divided quartz and calcitic debris which becomes powdery between the larger calcitic organic debris and calcite grains	Base of exposure

Base not exposed.

FIGURE 46.—Quarry in Ryukyu Limestone. This is a typical quarry in sandy Ryukyu Limestone about 2.7 kilometers north of Ōhama. Quarrying is done entirely by hand tools. 1956.

FIGURE 47.—Construction with Ryukyu Limestone. Sandy Ryukyu Limestone is quarried, allowed to harden, and used in the construction of native tombs, walls of buildings, and retaining walls. The tomb in the picture is being constructed of blocks of sandy Ryukyu Limestone locally called awaishi. October 1956.

CORALLIFEROUS LIMESTONE

The coralliferous limestone is mostly a well-lithified, bioclastic, recrystallized limestone composed of tests or fragments of Foraminifera, pieces of coral, pieces of algae, and other types of fossils in a groundmass of fine calcareous organic debris and crystalline calcite. Some is constructional limestone formed largely of corals and calcareous algae which are in their position of growth. Both types are fairly free from terrigenous sediment and are pure chemically. Some zones of the limestone are argillaceous or slightly arenaceous, but clay, silt, or quartz sand generally constitutes less than 10 percent; for it to constitute as much as 20 percent is rare. Clayey material may be present in voids. Basal conglomeratic zones commonly occur where limestone directly overlies rocks of the Ishigaki Group or the Miyara, or the Nosoko Formation. Large boulders of schist and volcanic rock a meter in diameter are concentrated at the base of the limestone near Ogan-zaki. However, the conglomeratic limestone grades within a meter or so to fairly pure limestone.

A chemical analysis of coralliferous limestone from a terrace about 1.2 kilometers northeast of the village of Miyara is given in table 23 (sample B). In general, the bioclastic coralliferous limestone is similar throughout the island. It is mostly light gray on weathered surfaces and white, cream, or tan on fresh surfaces. Color may change slightly laterally or vertically in an outcrop. In places where fossils, or fossils and groundmass, are slightly different in color, a somewhat mottled effect results. Bedding is characteristically obscure and the limestone is massive. The beds are nearly flat in most places but locally dip 3°–10°.

The limestone is porous, and irregular cavities are scattered throughout the rock. The inside surfaces of cavities are commonly yellowish-brown owing to a thin coating of clayey material. Solution tends to enlarge the cavities and produces rough irregular surfaces on the limestone. Caves and sinkholes have formed in some areas that have comparatively thick limestone.

The fossils, particularly megafossils, are poorly preserved; many are partly recrystallized. Although the various types of organisms are well distributed throughout, in some places a single group is particularly abundant.

The coralliferous limestone is commonly about 8 meters thick, but it ranges from less than 0.3 to 20 meters. North of Shika, about 0.8 kilometer, it overlies sandy limestone, but elsewhere it commonly rests unconformably on the older rocks of the Ishigaki Group or Nosoko Formation (fig. 30). Near Ogan-zaki the limestone extends irregularly down into large joints in the underlying rocks of the Nosoko Formation.

FIGURE 48.—Index map showing the location of sections and sample localities for the Ryukyu Limestone. Dashed line indicates possible boundary between a reef flat and the deeper outer reef slope. *Cycloclypeus* is found south of the line, and *Calcarina* is abundant to the north of it in the Ryukyu Limestone.

The following descriptions of coralliferous limestone are representative of the outcrops on Ishigaki-shima.

Section of coralliferous limestone of Ryukyu Limestone in cave 3.2 kilometers north-northeast of Shika

[Loc. M-288 in fig. 48]

	Thickness (meters)
Limestone, sandy, stratified; beds about 2.5 cm thick	1.8–3
Limestone, detrital, massive, argillaceous, and coralliferous. Corals poorly preserved and recrystallized; some have encrusting algae	7.8–9
Limestone, conglomeratic and argillaceous	0.5–1.2
Rests unconformably on schist of the Ishigaki Group.	

Cliff on east side Pyūtsuta-gawa 0.5 kilometer east of Yoshihara

[Locality M-400 in fig. 48. Sandy limestone predominates in this area, but patches of coralline limestone occur along the streams and near the coast. The rock is massive without distinct bedding. Limestone at three different horizons in the cliff is described]

Limestone, white to light-gray; microcrystalline calcium carbonate matrix with some rock fragments and quartz grains; many irregular cavities. Corals recrystallized and encrusted with layers of algae	Top of section.
Limestone, white and tan, detrital; granitic rock fragments and quartz grains of microscopic size common in the matrix. Recrystallized corals embedded in microcrystalline calcium carbonate matrix	6 m above base of cliff.
Limestone, light-tan, massive, detrital, coralline, recrystallized; surface pitted with small solution cavities; calcium carbonate matrix very fine grained and includes as much as 15 percent microscopic-sized rock fragments and quartz grains	Bottom of cliff.

RUBBLY LIMESTONE

Although most Ryukyu Limestone is like the sandy or coralliferous limestone just described or varies only slightly from it, there is one occurrence of what may be called rubbly limestone. The rubbly limestone crops out on the northwestern side of the Nosoko peninsula in the vicinity of Goeku-dan (F-291, fig. 48). It underlies about 3 or 4 meters of typical coralliferous limestone and consists of loose irregularly shaped chunks of white or cream dense limestone coated with a reddish-brown clayey material. The contact with the overlying coralliferous limestone is sharp. The rubbly limestone is about 4.5 meters thick. It is underlain by brown quartz sand.

The rubbly appearance and clayey coatings are probably at least partly the result of secondary processes. For example, slowly percolating ground water might have dissolved some of the limestone and left behind the clayey residues. Corals collected from the limestone were identified as a normal reef fauna by John Wells, U.S. Geological Survey. Similar limestone has been reported on Guam (H. G. May, oral commun., 1956).

FOSSILS

Fossils in the Ryukyu Limestone are mostly modern forms, in general poorly preserved. Many have been partly or wholly recrystallized. They rarely separate easily from the matrix. As Hanzawa stated (1948, p. 77), "The organic content of this limestone varies in different localities, Foraminifera preponderating in some places and reef-building corals in others." Hanzawa also observed that the content of reef-building corals in the Ryukyu Limestone of Ishigaki-shima is small compared to the extent of the limestone and that Foraminifera are abundant nearly everywhere.

Reef corals collected from the Ryukyu Limestone were identified by J. W. Wells. Many of the specimens are in poor condition because of wear and recrystallization. The habitats indicated by the genera and species range from surface reef to the deeper part of the reef tract and from the turbulent water of the windward side to the quiet water of the leeward side.

Corals from the Ryukyu Limestone are listed in table 10.

TABLE 10.—*Corals in Ryukyu Limestone*

[Identified by John W. Wells]

	F-114	F-264	F-265	F-291	F-292	F-293	M-449
Acropora sp	----	----	----	----	×	×	×
Alveopora daedalea (Forskål)	----	----	----	----	----	----	×
viridis Quoy and Gaimard	----	----	----	----	----	----	×
Astreopora sp	----	----	----	----	----	----	×
Caulastrea furcata Dana	----	----	----	----	----	×	----
sp. cf. *C. tumida* Matthai	----	----	----	----	----	----	×
Cycloseris cyclolites (Lamarck)	----	----	----	----	----	----	×
fragilis (Alcock)	----	----	----	----	----	----	×
Cyphastrea microphthalma (Lamarck)	----	×	----	----	----	----	----
sp	----	----	----	----	----	×	×
Diploastrea heliopora (Lamarck)	----	----	----	----	----	×	×
Echinophyllia sp	----	----	----	----	×	----	----
Favia pallida (Dana)	----	×	×	----	×	----	×
speciosa (Dana)	----	----	----	----	----	----	×
stelligera (Dana)	----	----	----	----	----	----	×
Favites abdita (Ellis and Solander)	----	----	×	----	----	----	×
flexuosa (Dana)	----	----	----	----	----	----	×
Fungia fungites (Linnaeus)	----	----	----	----	×	----	----
sp	×	×	----	----	----	×	×
Galaxea clavus (Dana)	----	----	----	----	----	×	----
Goniastrea pectinata (Ehrenberg)	----	×	×	----	----	----	×
retiformis (Lamarck)	----	×	----	----	×	----	----
Goniopora sp	----	----	----	----	----	----	×
Herpolitha limax (Esper)	----	----	----	----	----	----	×
Leptastrea purpurea (Dana)	----	----	----	----	----	----	×
sp	----	----	----	----	----	----	×
Leptoria phrygia (Ellis and Solander)	----	----	----	×	----	----	×
Lobophyllia corymbosa (Forskål)	----	----	----	----	----	×	×
sp	----	×	----	----	×	----	----
Merulina ampliata (Ellis and Solander)	----	----	----	----	----	----	×
Millepora platyphylla (Haime and Milne-Edwards)	----	----	----	----	----	----	×
Platygyra lamellina (Ehrenberg) forma *sinensis*	----	----	----	----	----	----	×
lamellina (Ehrenberg) forma *stricta*	----	×	----	----	----	----	×
Pocillopora damicornis (Linnaeus)	----	----	----	----	----	----	×
ligulata (Dana)	----	----	----	----	----	----	×
sp	----	----	----	----	----	----	×
Porites sp	×	----	----	----	----	×	×
Protolopophyllia japonica Yabe and Sugiyama	----	----	----	----	----	----	×
Seriatopora hystrix (Dana)	----	----	----	----	----	×	----
Stylophora pistillata (Esper)	----	----	----	----	----	----	×
Trachyphyllia geoffroyi (Audoium)	----	----	----	----	----	×	×

Mollusca from the Ryukyu Limestone were identified by F. Stearns MacNeil and were compared with collections from Okinawa-jima. The gastropods and pelecypods were collected mostly from the sandy limestone. They are given in tables 11 and 12.

TABLE 11.—*Gastropoda from Ryukyu Limestone*

[Identified by F. Stearns MacNeil]

	F-114	F-293	M-449
Calcar cf. *C. haematragus* (Menke)			×
Cantharus cf. *C. fumosus* (Dillwyn)			×
Cassis cf. *C. cornuta* Linné			×
(*Casmaria*) aff. *C.* (*C.*) *erinacea* (Linné)			×
Cerithium aluco (Linné)			×
echinatum Lamarck		×	
Contumax citrinus (Sowerby)			×
Conus (*Tuliparia*) *tulipa* (Linné)	×		
sp			×
cf. *C. ebraeus* Linné			×
sp. cf. *C. magus* Linné		×	
cf. *C. generalis* Linné			×
cf. *C. litteratus* Linné			×
cf. *C. lividus* Hwass			×
cf. *C. marmoreus* (Linné)			×
Coralliophila cf. *C. costularis* Lamarck			×
Cymatium sp. [fragment]			×
Cypraea sp		×	×
Eustrombus thersites (Swainson)			×
Fasciolaria cf. *F. trapezium* (Linné)			×
Kelletia or *Latirus* sp. [fragment]			×
Latirus cf. *L. polygonus* (Gmelin)			×
Mammilla aff. *M. melanostoma* (Gmelin)			×
Marmorostoma argyrostoma (Linné)			×
sp			×
(*Battillus*) cf. *M.* (*B.*) *cornuta* (Humphrey)			×
Mitra puncticulata Lamarck			×
Monilea belcheri (Philippi)			×
Murex (*Chicoreus*) cf. *M.* (*C.*) *microphyllus* Lamarck			×
Nassarius sp			×
Naticarius cf. *N. marochiensis* (Gmelin) s. l.			×
sp			×
Oliva sp			×
Peristernia wagneri (Anton)			×
Polynices cf. *P. flemingianus* (Recluz)		×	
Strombus cf. *S. tridentatus* Gmelin			×
(*Euprotomus*) cf. *S.* (*E.*) *vomer* (Roeding)			×
Terebra cf. *T. straminea* Gray			×
sp. aff. *T. formosana* Yokoyama			×
Tosatrochus attenuatus (Jonas)			×
Trochus calcaratus Souverbie			×
sp			×
Turbo marmoratus Linné			×
petholatus Linné			×
Vasum sp			×

TABLE 12.—*Pelecypoda from Ryukyu Limestone*

[Identified by F. Stearns MacNeil]

	F-114	F-265	F-293	M-449
Acar plicata (Dillwyn)				×
Amusium sp	×			
Arca arabica Philippi				×
ventricosa Lamarck				×
Barbatia bicolorata (Dillwyn)				×
Cardita cf. *C. variegata* Bruguière				×
Cardium (*Fragum*) sp			×	
(*Trachycardium*) sp				×
Chama sp				×
Chlamys sp. [worn]				×
cf. *C. leopardus* (Reeve)	×			
sp. cf. *C. vesiculosa* (Dunker) and *C. radula* (Linné)	×			
Contumax nodulosus (Bruguière)		×		×
Decatopecten cf. *D. striatus* (Schumacher)	×			
Discors cf. *D. lyrata* (Sowerby)				×
Glycymeris rotunda (Dunker)				×
sp	×			×
sp. cf. *G. vestita* Dunker				×
(*Tucetona*) *auriflua* Reeve				×
(*Tucetona*) aff. *G.* (*T.*) *nodosa* (Reeve)				×
Lima sowerbyi Deshayes				×
Lioconcha? sp. [fragment]				×
Lucina? sp. [fragment]				×
Ostrea sp				×
Periglypta cf. *P. reticulata* (Linné)				×
?*Periglypta* sp. [fragment]				×
Spondylus sp. [worn]				×
Tridacna cf. *T. noae* (Roeding)				×
?*Venus* (*Ventricola*) sp. [fragment]				×

Fossil algae from the Ryukyu Limestone were identified by J. Harlan Johnson as follows:

Amphiroa foliaceae Lamouroux
  fragilissima (Linnaeus) Lamouroux
Halimeda sp.
Lithophyllum fosliei Heyrich
  hanzaur Johnson
  megacrustum Johnson and Ferris
  stefanini Airoldi
Lithoporella melobesioides Foslie
Lithothamnium cf. *L. funafutiense* Foslie
Porolithon onkodes (Heydrich) Foslie

The larger Foraminifera from the Ryukyu Limestone were identified by W. Storrs Cole. He examined thin sections from 48 stations at 36 localities. Six species occurred at certain localities either commonly or abundantly. They are *Alveolinella quoii* d' Orbigny, *Amphistegina radiata* (Fichtel and Moll), *Calcarina spengleri* (Gmelin), *Camerina complanata* (Defrance) *Cycloclypeus carpenteri* Brady, and *Heterostegina suborbicularis* d' Orbigny. These species, as well as other species which occur rarely, are still living.

For distribution of the larger Foraminifera from the Ryukyu Limestone see table 13.

SOILS

The soils on the coralliferous Ryukyu Limestone of southern Ishigaki-shima and the Yarabu and Kabira peninsulas range from shallow, rocky soils to moderately deep to deep loam. Considerable limestone rock land has little or no soil cover. The surface soils are mostly dark brown to dark grayish brown, and the subsoil is brown. The moderately deep to deep soils are intergraded Brown Forest-Reddish Brown Lateritic soils. The shallower soils are intergraded Brown Forest-Lithosols (Foster and others, 1960, p. 167, 170). Most are clay loams, but some are loams and silty clay loams.

The soils on the sandy limestone of southern Ishigaki-shima consist of fairly thick dark-grayish-brown to brown sandy loam over material which ranges from brown to dark-yellowish-brown sandy clay loam to sandy clay (intergraded Rubrozem-Brown Forest soils) (Foster and others, 1960, p. 178).

In the limestone areas east from Kabira-wan to the Sakudāra, the soils are generally brown loamy sand over material which ranges from sandy loam to sandy clay. The Ryukyu Limestone areas west of the Sakudāra, on the Ibaruma peninsula, and on the Hirakubo peninsula are limestone rock land, shallow rocky soils, or brown silty or loamy somewhat stony soils, chiefly Lithosols (Foster and others, 1960, p. 183).

TABLE 13.—*Distribution of Pleistocene to Recent larger Foraminifera*

[Table by W. Storrs Cole. Symbols used: A, abundant; C, common; R, rare]

Samples and stratigraphic unit	*Alveolinella quoii* (d'Orbigny)	*Amphistegina radiata* (Fichtel and Moll)	*Baculogypsina sphaerulata* (Parker and Jones)	*Baculogypsinoides spinosa* Yabe and Hanzawa	*Calcarina spengleri* (Gmelin)	*Camerina ammonoides* (Gronovius)	*C. complanata* (Defrance)	*Cycloclypeus carpenteri* Brady	*Heterostegina suborbicularis* d'Orbigny	*Marginopora vertebralis* Quoy and Gaimard	*Sorites Marginalis* (Lamarck)
Bunera Clay Member											
IS-F-310-56a	----	----	----	R	R	A	----	----	R	----	----
IS-M-143-56	----	----	----	----	----	A	----	----	----	----	----
Ryukyu Limestone											
IS-F- 55-55	R	R	----	----	A	----	----	----	R	R	----
89-55	----	R	R	----	C	----	----	----	----	----	----
189-56	----	C	R	----	A	----	----	R	R	----	----
236-56	----	----	----	----	A	----	----	----	----	R	----
276-56	----	----	R	----	A	----	----	R	----	----	----
280-56	----	C	----	----	C	----	----	----	C	R	R
291-56	----	----	----	----	R	----	----	----	----	----	R
292-56	----	----	----	----	----	----	----	----	R	----	----
IS-M- 72-55	----	C	----	----	R	----	----	A	R	----	----
75-56	----	R	R	----	A	----	----	----	R	----	----
105-56	----	C	----	----	----	----	----	A	C	----	----
117-56	----	----	----	----	R	----	----	----	----	----	----
149-56	----	R	----	R	----	----	A	----	----	----	----
167-56	----	R	----	----	C	----	----	----	----	R	R
167-56a	----	R	----	----	C	----	----	----	----	----	----
167-56b	----	R	----	----	R	----	----	----	----	----	----
167-56c	----	R	----	----	R	----	----	----	----	----	----
269-56	R	A	----	----	C	----	----	----	----	R	----
271-56	----	C	----	----	C	----	----	----	----	C	----
273-56	R	A	----	----	C	----	----	----	----	----	----
274-56	----	C	----	----	----	----	----	A	----	----	----
275-56	----	C	----	----	R	----	----	R	R	----	R
276-56	----	C	----	----	R	----	----	----	----	----	----
277-56	A	C	----	R	R	----	----	----	----	----	----
280-56	----	R	----	----	A	----	----	----	----	----	----
280-56a	----	R	----	----	----	----	----	A	----	----	----
280-56b	----	----	----	----	R	----	----	----	----	----	----
281-56	----	R	----	----	C	----	----	----	----	R	----
283-56	----	R	----	----	----	----	----	----	R	----	----
283-56a	----	R	----	----	R	----	----	----	R	R	----
284-56	R	----	----	----	R	----	----	----	----	----	----
285-56	----	R	----	----	R	----	----	----	----	----	----
287-56	R	C	----	----	----	R	----	----	----	R	----
289-56	----	A	----	----	C	----	----	----	R	----	----
292-56	----	----	----	----	R	----	----	----	----	----	----
293-56	----	R	----	----	R	----	----	----	----	----	R
294-56	----	C	----	----	R	C	----	A	----	----	R
295-56	----	R	----	----	----	----	----	----	----	----	----
296-56	----	A	----	R	----	----	----	----	C	----	----
296-56a	----	C	----	----	R	----	----	----	----	----	----
296-56b	----	----	----	----	R	----	----	----	----	R	C
296-56c	----	C	----	----	C	----	----	----	R	----	----
296-56d	----	C	R	----	R	----	----	----	R	----	----
400-56	----	R	----	----	R	----	----	----	----	----	----
400-56a	R	----	R	----	R	----	----	----	R	R	R
400-56b	----	----	----	----	R	----	----	----	----	----	----
410-56	----	C	R	----	R	----	----	R	C	C	----
KOB-F-8-56 [1]	----	----	R	----	R	----	----	----	R	----	----
Recent											
IS-F-192-56	----	----	----	----	A	----	----	----	----	----	----

[1] Loc. KOB-F-8-56 is on the island of Kobama.

ORIGIN

Most of the Ryukyu Limestone originated as fringing reefs like those that border the island at the present time. According to Hanzawa (1948, p. 77), some of the limestone accumulated as calcareous sediment in a neritic zone. The rubbly limestone is considered to have formed in the same manner as the more common types of Ryukyu Limestone. Climatic conditions were probably fairly similar to those at present. Hanzawa (1948, p. 77–86) has shown that the fossil foraminiferal fauna of the Ryukyu Limestone is similar to the Recent fauna found in the region of the southern Ryukyu Islands.

During Ryukyu time the reefs were widest on the southern side of the island. They commonly grew on bedrock shelves of metamorphic or volcanic rocks and in places extended over gravels that had accumulated, or were accumulating, along the margins of the then-existing island or islands. The distribution of *Cycloclypeus* and *Calcarina* in the limestone suggests that the boundary between a reef-flat environment and the deeper outer slope of a reef may have extended approximately as shown in figure 48. *Cycloclypeus*, a deeper water form, is found south of this boundary, and *Calcarina*, a shallow reef-flat inhabitant, is most abundant north of it.

Changes in sea level may have taken place several times during the formation of the Ryukyu Limestone. Some fluctuations probably accelerated growth of reefs, whereas others decreased it. Temporary cessations in growth may have occurred, but disconformities are not evident. The overall trend was for the southern reef to become wider by growing southward (fig. 49). In general, the younger parts of the reef limestone are those lowest in altitude and nearest the coast.

AGE AND CORRELATION

Fossils alone are inconclusive in determining the age of both the sandy and coralliferous facies of the Ryukyu Limestone, as, in general, they are Recent species. Many have a range in age from Pliocene to the present, indicating only that Pliocene is the oldest age that they can possibly be. However, the large amount of limestone, the high altitude of some of it, its degree of recrystallization, the extensive solution of it in some areas, and the relation of it to other deposits, such as raised beach sands and Recent alluvium, lead to the conclusion that most of the Ryukyu Limestone is Pleistocene in age.

The possibility that some of the limestone is as old as late Pliocene and possibly the equivalent of the Naha Formation of Okinawa-jima was considered. However, the molluscan fauna from limestone on Ishigaki-shima does not appear equivalent to that of the Naha Formation. The fauna does not contain the species which F. Stearns MacNeil, who has studied the Naha Formation in some detail, considered characteristic of it. In general, the species in the limestone on Ishigaki-shima are similar to those in the Yontan Limestone of Okinawa-jima, which is younger than the Naha Formation and which is considered Pleistocene in age. Although some limestone along the coasts at low altitudes may be younger than most of the Ryukyu Limestone, this could

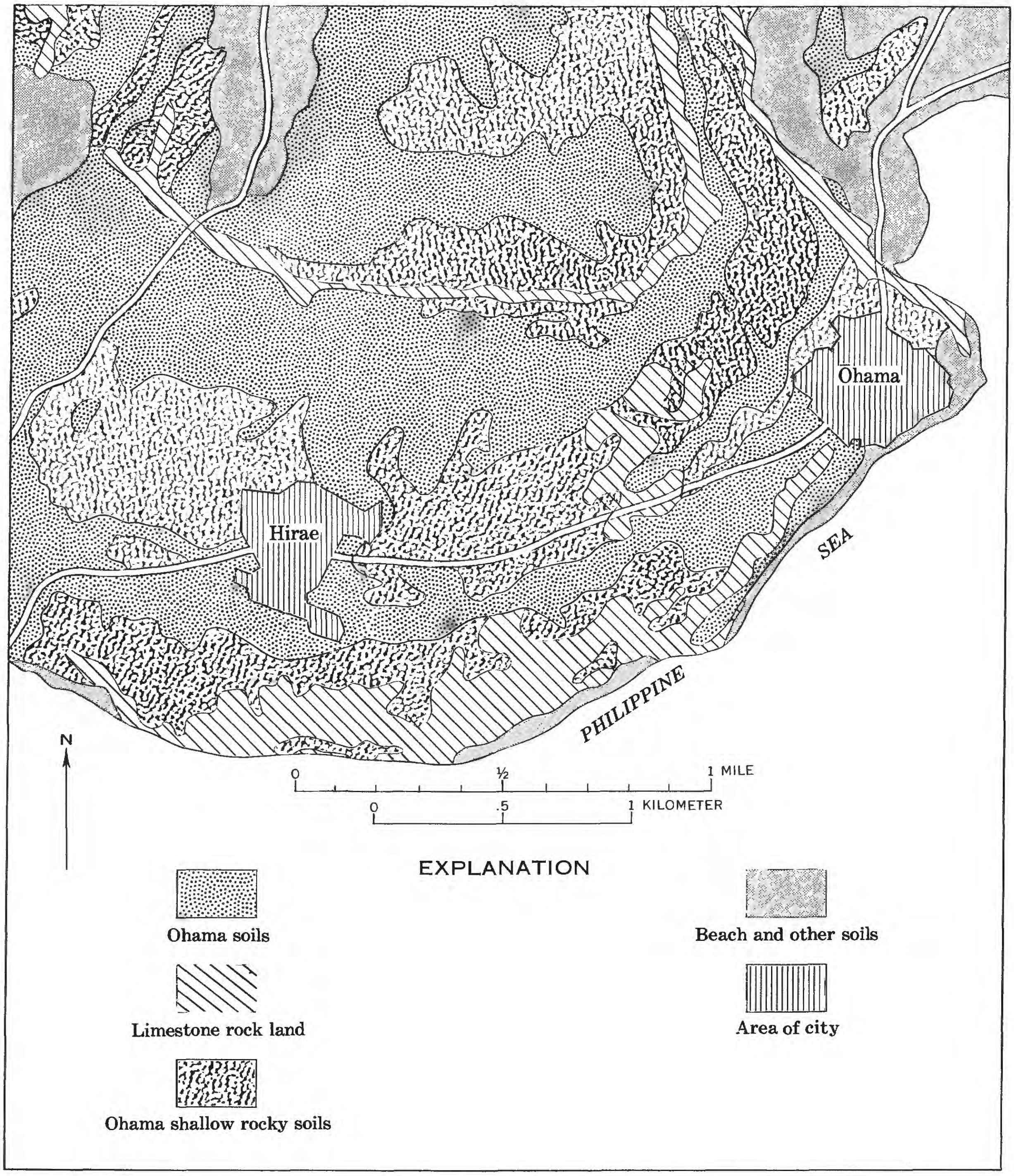


FIGURE 49.—Soils map of part of southern Ishigaki-shima, showing seaward concentric growth of Ryukyu Limestone. The distribution of the soils of southern Ishigaki-shima in concentric bands approximately parallel to the coast illustrates the successive stages of seaward growth of the Ryukyu Limestone. The reef margins of different ages are indicated by concentric belts of limestone rock land. The Ohama shallow rocky soils, which contain limestone fragments and which are generally 0.6 meter thick or less, lie in bands inland from the limestone rock land. These soils probably represent the positions of the reef flats or outer margins of the reef flats. The Ohama soils in the third concentric band are moderately deep to deep soils. They formed on older limestone flats, most of which were probably above tide level when the limestone rock land with which they are associated was being formed. The youngest concentric series is the southernmost. This may is taken from a part of plate 4 (South), Soils of Ishigaki-shima Ryūkyū-rettō (Foster and others, 1960).

not be definitely determined as no separations or unconformities were found. No faunal equivalent of the late Pleistocene Machinato Limestone of Okinawa-jima was recognized on Ishigaki-shima. Cole (written commun., 1959) found no indication of more than one Pleistocene or Recent limestone formation from his study of the larger Foraminifera.

The Foraminifera and other fossils do not provide conclusive evidence, but they tend to point to an age for the Ryukyu Limestone nearer the Recent rather than near the Pliocene. For example, according to Wells, the corals from the limestone are all Recent species, but they could be Pleistocene in age.

No definite age distinctions can be made between the sandy limestone and coralliferous limestone. In southern Ishigaki-shima, some coralliferous limestone rests on sandy limestone and is therefore younger. However, this relationship is not invariable, and these two types of limestones are virtually age equivalents in many places. Normally they represent different parts of the reef and therefore different depositional conditions. Some of the sandy limestone in northern Ishigaki-shima is probably the age equivalent of much of the coralliferous limestone elsewhere, as indicated by its altitude and other geologic relationships.

The Shimoji Limestone of Miyako-jima (Doan and others, 1960, p. 89–97) probably correlates with the Ryukyu Limestone of Ishigaki-shima, although at present, data are insufficient for definite correlation. The two distinct stages of Pleistocene limestone deposition that Doan described on Miyako-jima were not recognized on Ishigaki-shima.

Limestone which closely resembles the Ryukyu Limestone of Ishigaki-shima crops out in southern Taiwan. Differences of opinion on the stratigraphic position of this limestone have not yet been resolved, but at least some of the limestone might be equivalent in age to that of Ishigaki-shima.

Similar reef limestones on other islands of the Yaeyama-guntō are probably partly correlative with the Ryukyu Limestone of Ishigaki-shima, but they were not studied.

Figure 50 shows the stratigraphic relations of Pliocene and Pleistocene formations of the southern Ryukyu Islands and Taiwan. The Pliocene and Pleistocene formations of Ishigaki-shima are considerably thinner than those of Miyako-jima and Okinawa-jima to the northeast and Taiwan to the west.

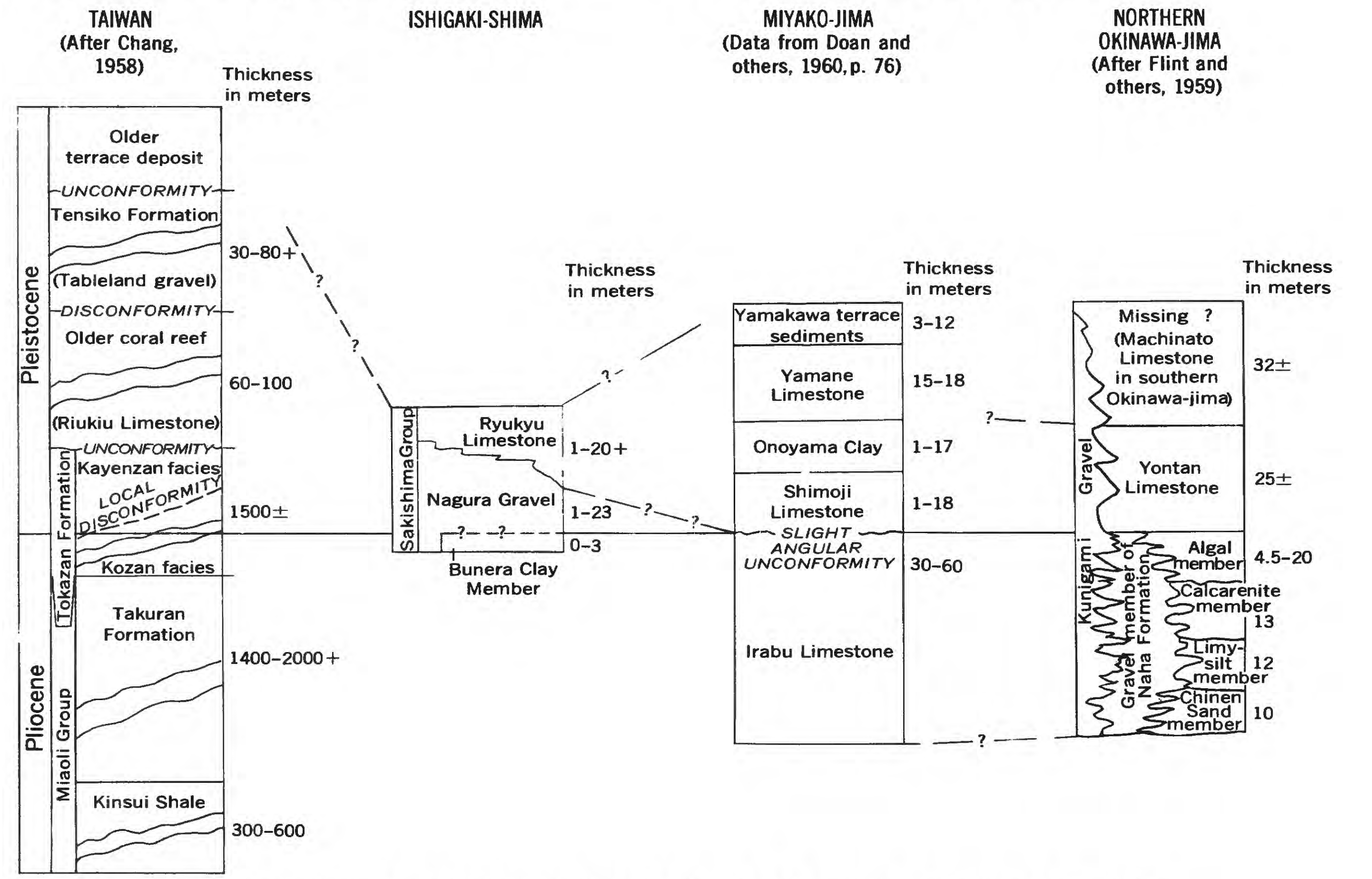


Figure 50.—Pliocene and Pleistocene stratigraphic relations of the southern Ryukyu Islands and Taiwan.

Of the three sections, that of northern Okinawa-jima has more resemblance to that of Ishigaki-shima than do the other two. Geologic relationships of the Kunigami Gravel are similar to those of the Nagura Gravel, and the Yontan Limestone has a molluscan fauna with species similar to those of the Ryukyu Limestone of Ishigaki-shima. The resemblance of the gravels, especially, may be due to similar conditions on the islands during this stage of the Pliocene and Pleistocene, and to the fact that both islands have foundations of metamorphic rocks which could produce such a gravel. Miyako-jima was much lower in altitude and probably had no exposed core of older metamorphic rocks. The overall geology of Taiwan is considerably different from that of the Ryukyu Islands, but there is some similarity. Some parts of Taiwan may have had a Pliocene and Pleistocene sequence of events comparable to that of the southern Ryukyu Islands.

RECENT DEPOSITS

Deposits of post-Pleistocene age include raised beach and reef-flat deposits; sand and gravel of the present-day beaches; sand dunes and beach and dune ridges; beachrock; thin patches of gravel mostly as a veneer on older deposits near the coasts; and alluvium composing river terraces and flooring river valleys. Several valleys also contain accumulations of peat, and there are small areas of estuarine deposits at the mouths of some large streams.

Although some of these deposits could be as old as late Pleistocene, few are probably older than 8,000 or 9,000 years, and most are younger.

RAISED BEACH-SAND AND REEF-FLAT DEPOSITS

Fossiliferous calcareous beach sand and sand and gravel were deposited between the margin of a fringing reef and the shore; these deposits occur at altitudes of about 3–24 meters above sea level at several localities on Ishigaki-shima, particularly on the southern and eastern sides of the island. Most deposits are 0.6–5 meters thick, but some are as much as 11 meters thick. Stratification is poor to good; beds of brown pumice are commonly interlayered with the calcareous sands (fig. 51). The material is loose and porous. Except for the upper few centimeters, which are commonly dark brown or gray from accumulated organic matter, most of the material is changed little, if at all, by soil-forming processes. The numerous fossils consist entirely of modern genera and species, practically the same as those found on present-day beaches and reef flats. *Acropora* is the most conspicuous fossil. The fossils are bleached white, most are water worn, and they are not recrystallized.

Unfossiliferous sand or sparsely fossiliferous sand overlies Ryukyu Limestone in the vicinity of Kabira-wan. This sand contains much quartz and some feldspar. The grains are well rounded. The deposits range in altitude from 2 to 40 meters above sea level.

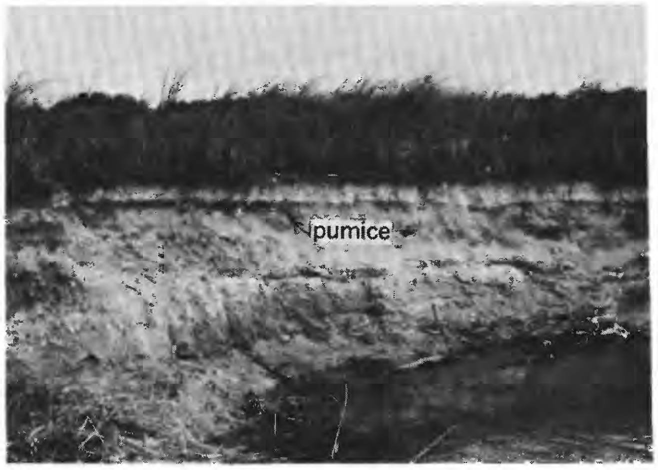


FIGURE 51.—Raised beach deposits. These beach deposits were laid down along and near the shore and then raised to their present position 3–6 meters above sea level. They consist of fossiliferous beach-sand with interbedded layers of brown pumice. Near Inōda. Top of exposure is about 1.8 meters above water. 1956.

Raised calcareous beach sand and reef flats border most of the southern coast of Ishigaki-shima at altitudes of about 1–9 meters. North from Miyara-wan, reef-flat deposits extend inland more than 1.5 kilometers and to altitudes of more than 20 meters. They occupy an area of about 2.6 square kilometers. On the eastern coast, patches of raised calcareous beach-sand and some reef-flat deposits extend from Shiraho in the south as far north as Ibaruma. The largest areas of these deposits are along Miyara-wan, near the mouth of the Todoroki-gawa, in the vicinity of Inōda, and at the isthmus south of Ibaruma. Other fairly large patches occur on the Yarabu peninsula at Akeishi, Nosoko, Yonehara, and Fumidahama and also near the mouth of the Nagura-gawa. The highest raised calcareous beach sands are in the vicinity of Inōda and 3.2 kilometers to the northeast, where they are more than 24 meters above sea level. In the vicinity of Kabira-wan, including the island of Ko-jima, patches of quartz sand overlie Ryukyu Limestone. The location of these patches is shown as Qs on the map (pl. 4).

The surface of the raised beach-sand and reef-flat deposits is generally fairly flat, has little relief, and commonly slopes gently seaward. Borrow pits are common, especially where the sands are along or near a road.

LITHOLOGY

The composition of the raised calcareous beach-sand and reef-flat deposits is fairly similar in different parts of the island. Principal differences in composition are due to beds of pumice and to a larger amount of organic material in the higher deposits. Deposits on the northeastern and northern coasts contain the most pumice (fig. 51). This distribution suggests a local source for much of the pumice, perhaps the submarine volcano near Hatoma-jima, because the pumice probably would not drift much against the northeast-flowing Kuroshio. Raised beach deposits at higher altitudes commonly have a higher content of organic material near the surface than do those at lower altitudes. Presumably, higher deposits are slightly older than lower ones; therefore, there has been more time for organic material to accumulate.

The predominant constituents of the deposits are calcareous sand and gravel, except that patches of sand around Kabira-wan (indicated on pl. 4) contain much quartz and some feldspar. Sand at high altitudes which is high in quartz has been considered as part of the Nagura Gravel.

The following sections illustrate the characteristics of the calcareous raised beach-sand and reef-flat deposits:

Section from auger hole on the shore of Miyara-wan at soil investigation site 38

[Location shown in fig. 52]

	Thickness (meters)
Sand, grayish-brown, loamy, fine to coarse, calcareous; surface has a concentration of limestone pebbles and coral and shell fragments averaging about 2.5 cm across	0.15
Sand, pale-brown, well-graded (fine to coarse), calcareous	.30
Sand, light-yellowish-brown; fine to coarse, but grain size predominantly less than 1 mm; calcareous, having less than 2 percent quartz, feldspar, and other noncalcareous material; includes fragments of coral as much as 5 cm in diameter	5.0
Water table.	
Sand and gravel; light-yellowish-brown sand and fine gravel; has grayish-brown coatings of fine sediment; shell fragments common	3.6
Clayey sand, gray, calcareous; contains angular pieces of white to light-yellowish-brown sandy limestone	3.0
(Bottom not reached).	

Section on east side of coastal road 0.8 kilometer northeast of mouth of the Inōda-gawa

[Loc. F-191a shown in fig. 52]

	Thickness (centimeters)
Sand, dark-gray grading downward to light-gray; mostly calcareous	15.2
Sand; white fragments of *Acropora*, a few small mollusk shells and echinoid spines; calcareous	15.2

Section on east side of coastal road 0.8 kilometer northeast of mouth of the Inōda-gawa—Continued

	Thickness (centimeters)
Sand, gray (former surface layer); mostly calcareous	7.6
Sand, light-gray, grading downward into tan sand; mostly calcareous	7.6
Sand and pumice; sand mostly calcareous; pumice brown; pieces range from 0.6 to 5 cm in diameter but most are 1.2–2.5 cm	7.6–20.3
Sand and gravel; sand mostly calcareous; gravel includes white *Acropora* and shells; poorly stratified	122.0
Water table.	

FOSSILS

Fossils were collected from some typical raised beach and reef-flat deposits. They are all Recent species. The specimens are not recrystallized but show considerable wear. The corals were identified by J. W. Wells and are given in table 14. The mollusks were identified by F. Stearns MacNeil and are given in tables 15 and 16. The localities are shown in figure 52.

BEACH DEPOSITS

The sediments composing the present beaches range in size from fine sand to accumulations of large boulders (fig. 7). Beachrock is present in places, particularly along shores bordered by Ryukyu Limestone (fig. 53).

From the inner margin of the fringing reef, beach deposits extend inland as much as 122 meters, although most deposits extend inland less than 30 meters.

The most abundant deposits are sand and gravel. These deposits are typically fine to coarse sand consisting largely of calcareous debris including many pieces of coral and fragments of marine shells (fig. 54). Tests of Foraminifera are numerous in some of the deposits.

Quartz and other noncalcareous mineral and rock fragments are present in varying amounts. Northern beaches, because of detritus from the mountains, generally have a higher proportion of noncalcareous material than do southern beaches. Where headlands are composed of metamorphic or volcanic rock, boulders from the local bedrock commonly have accumulated (fig. 7), as near Inōda. On some beaches, large coral heads are scattered about. Chunks of brown pumice from less than 2.5 centimeters to more than 30 centimeters across are abundant on many beaches. Slight variations in the color, texture, and degree of wear of the pumice suggest that it is not all from the same source or of the same age. Much of it may be reworked from eroded raised beach deposits.

FIGURE 52.—Index map showing the location of samples from Recent deposits and described sections.

TABLE 14.—*Corals from raised beach-sand and reef-flat deposits*

[Identifications by John W. Wells. Sample sites are shown in fig. 52]

	F–191a	F–193	F–195	M–297	M–298	M–299	M–408	M–445	M–446
Acropora sp.	×	×	×	×	×	×	×	×	×
Alveopora sp. cf. *A. excelsa* Verrill								×	
viridis (Quoy and Gaimard)							×		
Caulastrea furcata Dana					×				
Cyphastrea sp.									×
Favia sp.	×						×		
Fungia echinata (Pallas)									×
fungites (Linnaeus)						×			×
sp.	×	×	×	×	×		×	×	
Galaxea clavus (Dana)			×					×	×
Gonistrea parvistella (Dana)									×
pectinata (Ehrenberg)	×								
sp.									×
Heliopora coerulea (Pallas) [Alcyonarian]							×		
Isis sp. [Alcyonarian]							×		
Leptoseris? mycetoseroides Wells				×					
Lobophyllia corymbosa (Forskål)			×			×			×
Millepora intricata Milne-Edwards and Haime							×		
Montipora sp.	×	×	×	×	×	×			×
Pachyseris sp.				×	×				
Pavona minor Brueggemann					×	×		×	
sp.			×	×					
Pocillopora ligulata (Dana)							×		
Porites andrewsi Vaughan							×	×	
lutea Milne-Edwards and Haime									×
cf. *P. lutea* Milne-Edwards and Haime				×					
sp.						×	×		×
Seriatopora hystrix (Dana)	×	×	×						
Sinularia sp. [Alcyonarian]		×							
Stylophora pistillata (Esper)	×								
Tubipora musica (Linnaeus) [Alcyonarian]									×

In many places the beach deposits are only a few centimeters thick, as along the northeastern coast where schist extends to the shore. Elsewhere they are probably 15 meters or more thick, as near the mouth of the Todoroki-gawa. Corals from two typical beaches (loc. M–407 and M–292, fig. 52), identified by J. W. Wells, U.S. Geological Survey, are listed below:

Porites andrewsi Vaughn
  lutea
  sp.
Acropora 2 spp.
Montipora 2 spp.
Fungia sp.
Pachyseris sp.
Coeloseris mayeri Vaughn
Favia pallida (Dana)
  speciosa (Dana)
Platygyra lamellina (Ehrenberg) forma *astreiformis*
  lamellina (Ehrenberg) forma *stricta*
  lamellina (Ehrenberg) forma *typica*
Plesiastrea versipora (Lamarck)
Cyphastrea sp.
Leptastrea transversa (Klunzinger)
Lobophyllia corymbosa (Forskål)
  sp.
Symphyllia sp.

SAND DUNES

Sand from the beaches has been blown inland to form sand dunes and dune ridges at Akeishi and at Nāta-hama south of Ibaruma. The sand is largely calcareous and includes Foraminifera, coral, and shell fragments. Light tan is the predominant color; grains range from fine to coarse, but medium grains are most abundant. The sand is fairly well anchored by grass and other vegetation. Some of the ridges nearest to and parallel to the shore might be termed beach ridges because they consist largely of sand and gravel thrown up by storm waves; this sand and gravel has had only a small amount of transport by the wind. Ridges behind the beach ridges are composed mostly of sand. These ridges were moved to their present position largely by wind.

Most of the dunes and ridges are less than 4 meters high. Dune deposits showed no distinct differences in age, and they are probably all fairly recent in origin. No soil profiles were noted on them.

TABLE 15.—*Gastropods from raised beach-sand and reef-flat deposits*

[Identifications by F. Stearns MacNeil. Sample sites are shown in fig. 52]

	F–191a	F–193	F–195	M–297	M–298	M–299	M–408	M–445	M–446
Acteon flammeus (Gmelin)							×		
Angaria delphinus (Linné)								×	×
Bulla vernicosa Gould						×			
Canarium dentatum (Linné)	×								
gibberulum (Linné)		×				×	×	×	×
Cantharus fumosus (Dillwyn)		×	×			×		×	
cf. *C. undosus* (Linné)							×		
Cerithidea mörchi A. Adams									×
Cerithium sinense (Gmelin)						×	×	×	
cf. *C. sinense* (Gmelin)			×						
Clypeomorus bifasciatus (Sowerby)	×								×
Columbella cf. *C. versicolor* Sowerby								×	
Contumax nobulosus (Bruguière)				×			×		
Conus (*Puncticulis*) *arenatus* Bruguière					×				
eraeus Linné							×		
fulgetrum Sowerby								×	
cf. *C. fulgetrum* (Sowerby)		×	×						
marmoreus Linné							×		
pennaceus Born								×	
Cypraea (*Erronea*) *cylindrica* (Born)							×		
(*Mauritia*) *elegantina couturieri* Vayssière						×			
(*Erosaria*) *erosa* Linné			×				×	×	
(*Monetaria*) *moneta* Linné							×	×	×
Fasciolaria cf. *F. trapezium* (Linné)					×				
Lambis crocata (Link)				×					
cf. *L. crocata* (Link) frag			×						
lambis (Linné)					×	×			×
Mammilla melanostoma (Gmelin)		×	×						
Nassarius albescens (Dunker)							×	×	
Naticarius livida (Pfeiffer) = *N. rufilabris*						×			
Nerita albicilla Linné			×						
polita Linné							×		
cf. *N. exuvia* Linné						×			
cf. *N. laevilirata* Sowerby						×			
squamulata Recluz	×								
Neritina turrita (Gmelin)		×							
Polynices flemingianus (Recluz)						×			
Puperita japonica (Dunker)	×								
Purpura cf. *P. clavigera* Küster	×								
Pusia cf. *P. exasperata* (Gmelin)								×	
Pyrene punctata (Bruguière)									×
Pythia pachydon Pilsbry and Hirase	×								
Strombus (*Conomurex*) *luhuanus* (Linné)			×		×		×		
Terebra monilis Quoy and Gaimard							×		
Trochus maculatus Linné								×	
niloticus Linné			×			×			
cf. *T. niloticus* Linné (juvenile)								×	
cf. *T. stellatus* Gmelin						×			
Turbo (*Marmorostoma*) *argyrostomus* Linné									×
marmoratus Linné									×
Vasum turbinellus (Linné)				×					
Vexillum exasperatum (Gmelin)			×						

TABLE 16.—*Pelecypods from raised beach-sand and reef-flat deposits*

[Identifications by F. Stearns MacNeil. Sample sites are shown in fig. 52]

	F–191a	F–193	F–195	M–297	M–298	M–299	M–408	M–445	M–446
Anadara scapha (Meuschen)			×	×	×	×		×	×
Arca ventricosa Lamarck					×			×	
Asaphis deflorata (Linné)						×			
dichotoma (Anton)	×							×	×
Atactodea striata (Gmelin)	×	×	×	×	×		×	×	
Barbatia bicolorata (Dillwyn)	×		×	×	×		×	×	
lima (Reeve)						×		×	
Cardita leana Dunker			×						
Cardium flavum Linné					×				
(*Vasticardium*) *flavum* (Linné)									×
(*Fragum*) *unedo* (Linné)	×	×	×			×	×	×	
Chlamys pallium (Linné)								×	
Codakia punctata (Linné)							×	×	
tigerina (Linné)			×			×			
Corbicula luchuana Pilsbry									×
Ctena divergens Philippi					×	×			
Cyclotellina cf. *C. remies* (Linné)						×		×	
Gafrarium pectinatum (Linné)	×	×	×	×	×	×		×	×
turnidum Roeding					×	×			
Glycymeris reevei (Mayer)			×						
Hippopus hippopus (Linné)				×					
Katelysia japonica (Gmelin)								×	×
Leukoma marica (Linné)								×	
Lima sowerbyi Deshayes		×							
Lioconcha castrensis (Linné)							×		
Lucina eaentula (Linné)						×		×	
Mactra antiquata Spengler			×						
Periglypta clathrata (Deshayes)						×			
Quidnipagus palatam Iredale	×	×	×			×			
Sanguinolaria elongata (Lamarck)				×					
Scutarcopagia scobinata (Linné)			×				×		
Spondylus candidus Lamarck									×
Tellina staurella Lamarck								×	
Tridacna cf. *T. noae* (Roeding)							×		×

BEACHROCK

Beachrock—cemented layers of sand and gravel—forms a cover a few centimeters to about a meter thick over the beach between the high and low tide levels on some shores, particularly those bordered by Ryukyu Limestone. (The maximum tidal fluctuation is about 2 m, but the average is a little more than 1 m.) The beachrock generally slopes seaward at angles of 3°–6°, at about the slope of the beach. Near headlands or in other places where coarse material is abundant (fig. 53), large boulders are incorporated into and cemented together with the finer material. Recent shells, shell fragments, and corals are also a common constituent of the beachrock.

The distribution of beachrock is patchy, and most patches cover only a few square meters. Much of the beachrock is broken, and some has been displaced by strong wave action. Some margins of the beachrock give the appearance of being eroded and undermined (fig. 53), suggesting that much of the beachrock may now be eroding rather than forming. No significant relationships to streams, springs, or cliffs were noted.

Beachrock is also present along the shores of Taketomi-shima, particularly on the northwestern side.

VENEERING GRAVEL

Patches of gravel of Recent age, too small and thin to be shown on the geologic map, occur in a few places near the coasts, for example, near Hirakubo, along the south side of the Kāra-gawa, and east of the Ōura-kawa. The gravels are generally gray and consist of fairly well-rounded pebbles of metamorphic or volcanic rocks. They form thin veneers at altitudes 1 meter to a few meters above sea level. They can be distinguished from the Nagura Gravel by their gray color, by their better rounded pebbles, and by their occurrence at low altitudes. In places, they grade into Nagura Gravel, and they cannot everywhere be distinguished from it. They are unfossiliferous.

ALLUVIAL DEPOSITS

Composition of the Recent alluvial deposits of Ishigaki-shima is heterogeneous. Deposits range from accumulations of large boulders of granite, diorite, metamorphic rocks, and volcanic rocks to quartz sand, silt, and clay. Few stream terraces of any extent have developed, except along the three largest streams, the Miyara-gawa, Nagura-gawa, and Todoroki-gawa. Alluvial flats occur along the Jība-gawa on the Hirakubo

FIGURE 53.—Beachrock along the western coast of the Kabira peninsula about 3 kilometers southwest of Kabira is composed of lithified layers of sand and gravel with some large boulders incorporated. The dip is seaward about 3°. Along its margins the beachrock gives the appearance of being eroded and undermined. August 1956.

peninsula, along the Fukidō-gawa on the Nosoko peninsula, and in an area just north of Shika, now drained by a ditch. These areas are mostly low valley flats along the streams; they are bordered by terraces of Nagura Gravel. The stream channels are incised to depths of 1–6 meters into the valley flats. In places, more than one terrace level is found, and the scarps are 0.3–2 meters high between levels. The stream terraces and valley flats are at altitudes of 1 meter to at least 60 meters above sea level.

Composition of the alluvium depends largely on the type of rock in the drainage area of the streams. Terraces along the east branch of the Nagura-gawa (the Bunēra-gawa) are composed mostly of granodiorite boulders in a yellow-brown sand and silt matrix. The

FIGURE 54.—Coral gravel is a principal component of much beach material. This deposit is near Yonehara. The base of the hammer is only a few centimeters above normal high-tide level. 1956.

deposits are 3–5 meters thick. The terraces along the north branch of the Nagura-gawa (the Shiramizu-gawa) are accumulations of granitic boulders in a sand matrix. Downstream the alluvial terraces are composed mostly of granitic sand. Near the mouth of the Nagura-gawa, silt and sand are the perdominant deposits.

The alluvium of the Miyara-gawa is also coarse in the upstream parts of the northern tributaries. Boulders of metamorphic rocks of the Ishigaki Group predominate in the coarse material, but boulders of granodiorite and granite also occur. The finer grained alluvium tends to be more silty and clayey than does that of the Nagura-gawa, probably because of less granitic bedrock in the drainage basin. The alluvium of the east branch is much finer grained than that of the northern branches. An example is given in the section below, which is soil investigation site 48 along a tributary to the Miyara-gawa, 0.5 kilometer southwest of the village of Ōzato (fig. 52).

Section of alluvium at soil investigation site 48

[Location shown in fig. 52]

	Thickness (meters)
Silty clay loam, dark-grayish-brown	0.02
Silty clay loam, brown to yellowish-red; contains some angular to slightly rounded pebbles of quartz and mica schist	1.4

Section of alluvium at soil investigation site 48—Continued

	Thickness (meters)
Clay, silty and gritty, dark-yellowish-brown; slightly sticky and slightly plastic; contains some pebbles of quartz and schist	1.5
Water table.	
Silty clay loam with some fine sand, olive-gray	1.5
Silt loam, with some clay and sand, olive-gray; contains some coarse sand and angular to slightly rounded pebbles of quartz	3.0
Silt loam, olive-brown	1.5
Clay, silty, olive-gray	12.2
Clay, light-gray to white, calcareous. Base not reached.	

The alluvial terraces of the Todoroki-gawa are dominantly silts and clays, although there are some coarser materials, probably dervied largely from reworking of the Nagura Gravel.

The thickness of the alluvial deposits in the upstream parts of the main valleys ranges from 1.5 to 21 meters. Maximum depth of alluvium in the lower parts of the large valleys probably exceeds 30 meters in places.

Deposits at the mouths of some larger streams might be termed estuarine because they are influenced by tidal waters. For the most part, these deposits seem to be sand and silty sand. They are under water at high tide but are exposed at low tide. Mangrove swamp occupies some of the flats, as at the mouth of the Miyara-gawa and the Fukidō-gawa, and probably helps trap some finer sediments. The sediments are loose, and water saturated to some depth, and commonly muddy.

TODOROKI-GAWA TERRACE SITE

One of the higher and older terrace deposits along the Todoroki-gawa has special significance because it contains fossil pig bones. The terrace deposits form a bench of stony silt about 11.5 meters long and 2–3 meters wide, abutting against and overhung by a cliff of Ryukyu Limestone (loc. M–112, fig. 52). The top of the bench is at an altitude of about 12 meters above sea level. In places the silt has been hardened and cemented, probably by calcareous drippings from the limestone. The silt contains a few stones, mostly slightly rounded fragments of quartz, chert, and, more rarely, schist; fragile and fragmentary bones of pig; a few dense and somewhat lithified bones of deer (*Metacervulus astylodon* Matsumoto); and a few sea shells, some of which still retain color. No artifacts were found, although there are some bits of charcoal and some tiny, hard reddish-gray clay(?) fragments.

The pig bones are present in the terrace deposit itself and also plastered against the limestone cliff just above the bench. A carbon-14 age (sample W–588, U.S. Geol. Survey) on the pig bone gives 8,500±500 years, but determinations on bone of this type are not always reliable.

Other fossils from the site as identified by F. Stearns MacNeil are as follows:

Nerita ocellata Le Guillou
  cf. *N. polita* Linné
Neritina cf. *N. variegata* Lesson
  pulligera (Linné)
Asaphis dichotoma (Anton)
Plotiopsis scabra (Müller)
Cyclophorus sp.
Melanoides cf. *M. obliquigranosa* (Smith)
  cf. *M. hahajimana* (Pilsbry and Hirase)
2 land snails (*Trochomorpha*?)
Turbo (operculum)
Semisulcospira? sp.
Crab fragments

MacNeil (written commun., 1956) stated that these specimens are a mixture of littoral marine, brackish water, and land species and probably represent tidal flat deposition. All those identified are living species and the preservation suggests late age.

A lower terrace a few meters downstream from the one just described is composed of about 1 meter of yellowish-brown clay underlain by a 1.5 meters exposure of gray clay. The gray clay is fossiliferous, containing mollusks, a few foraminifers, and ostracodes. The ostracodes are the nonmarine forms *Darwinula* sp., *Cyclocypris*? sp., and "*Candona*"? sp.

J. P. E. Morrison (written commun., 1956) reported that the molluscan fauna is completely fresh water and that it was probably deposited in a small lake, a flood-plain (cutoff) pond, or a quiet stream. He identified the gastropods *Melanoides* cf. *hahajimana* (Pilsbry), *Thiara* cf. *scabra* (Müller), *Radix* cf. *plicatula* (Benson), *Gyraulus spirillus* (Gould), and the pelecypod *Pisidium* (*Meopisidium*) sp.

Charophyta are also present. They were identified by R. E. Peck as *Chara* cf. *C. hispida* and other species. They indicate that the environment was a fresh-water lake or pond, or possibly a brackish-water estuary. The fresh-water deposits are considered younger than the deposits containing the pig bones because of their lower altitude, only 2–3 meters higher than the present valley flat.

PEAT

Peat has accumulated in depressions, chiefly in the valley flats of the Nagura-gawa, Miyara-gawa, and Todoroki-gawa. Other small areas include two on the Hirakubo peninsula, one along the Tōro-gawa, and one on the southern side of the Yarabu peninsula. In all, there are about 700 acres of peat on Ishigaki-shima.

A carbon-14 age of 990 ± 180 years was obtained from the peat near the head of the Miyara-gawa. The sample was taken from the bottom of the deposit at about 3.5 meters below the surface (sample W–760, U.S. Geological Survey). The location (56) of this sample is shown in figure 52, and a detailed section of the peat follows:

Miyara-gawa peat section at sample site 56 about 2.4 kilometers west of Ōzato, in low marshy headwaters of Miyara-gawa

[Loc. 56 shown in fig. 52]	*Depth (meters)*
Surface contains matted growing grass, 0.6 or 0.9 m tall, a few scattered reeds	0
Grass, yellowish-brown, dead (15 percent), roots and root hairs (75 percent volume), and some very dark-grayish-brown muck; pH 6.0	0.3
Grass stems and roots, yellowish-brown to pale yellow, and muck (5–10 percent volume); pH 6.0	0.6
Peat (old grass stems, stem sheaths), dark-yellowish-brown; composed mostly of fine roots; very little muck; pH 6.5	0.9
Similar to sample just above, but made up of very few pale-brown grass stems (many are black or carbonaceous); pH 6.5	1.2
Muck (25 percent volume), very dark-grayish-brown, and peat consisting of root fibers and very pale-brown grass stems (very few carbonaceous stems); pH 6.0	1.5
Muck and peat, very dark-grayish-brown, similar to layer above; pH 6.5	1.8
Peat, mucky, dark-grayish-brown, and light-gray (as in Rock Color Chart, 7.5 *YR* 6/0, wet) silty clay (10–15 percent volume); pH 6.5	2.1
Similar to layer above, but with about 50 percent each of mucky peat and light-gray clay; pH 6.5	2.4
Muck, dark-gray (10 *YR* 4/1, wet); small amount of dark-brown clay and some fine grains (or seeds?); pH 6.0	2.7
Muck and clay or silty clay, mixed dark-gray (10 *YR* 4/1, wet), slightly sticky; pH 6.5	3.0
Muck, dark-gray; small amount of silty clay; contains seeds, few plant fibers; has flakes of carbonaceous material (one piece about 2.5 by 0.6 cm); pH 7.0	3.3
Muck, dark-gray, about 50 percent, and about 50 percent light-gray clay; several fragments of rotten wood; pH of clay-muck 7.5	3.6
Muck, sand, silt, and clay, dark-grayish-brown; contains wood fibers and broken shells (marine?); pH 7.5	3.9

OMOTO GRANITE AND RELATED ROCKS

Granitic rocks are exposed over an area of about 21 square kilometers on Ishigaki-shima. The main intrusive rock is granite, but its margins are bordered in places by dark-colored intrusive rock which ranges from diorite to grandodiorite in composition. Elsewhere granite is in contact with and seems to grade into porphyritic rhyolite. The main mass of granite is a small stock which intrudes rocks of the Ishigaki Group. The stock may be a part of a larger intrusive mass, the greater part of which is not exposed. Contact metamorphism of the country rock is not manifest.

The granite has been named the Omoto Granite from the highest mountain on Ishigaki-shima, Omoto-yama (Foster and others, 1960, p. 119). Most of it is a light-gray or pink fine- to medium-grained biotite granite. The texture, grain size, color, and mineralogy differ slightly in various parts of the exposed mass. Much of the rock is porphyritic. It is commonly soft and crumbly near the surface because of weathering. Jointing is conspicuous. Extensive exposures are rare because the vegetation cover is heavy.

The border zone of dark-colored rock has been named (Foster and others, 1960, p. 119) the Cha-yama Granodiorite. It is commonly a greenish-gray porphyritic strongly altered hornblende-biotite granodiorite. Texture, grain size, and mineralogy differ slightly from place to place.

Rhyolite, named the Sakieda Rhyolite in this paper, is present as small masses, dikes, and sills. The rock is mostly white or cream colored. It ranges in texture from fine grained to porphyritic and consists mostly of quartz and feldspar. The rock is considerably altered and deeply weathered. The Sakieda Rhyolite is described with the Omoto Granite, as it seems to be more closely related to it genetically than to the volcanic rocks of the Nosoko Formation.

The main body of Omoto Granite composes the mountains that extend about 7 kilometers eastward from the neck of the Yarabu peninsula and that include Omoto-yama and Fukai-omoto. Some granite is also present in the mountains of the Kabira peninsula and the hills to the north. The highest altitude, Omoto-yama, is a little over 520 meters, and several granite summits are more than 400 meters in altitude. Most of the summits are rather flat and somewhat rounded, although Fukai-omoto has a pyramidal appearance from a distance. Outcrops on the summits and upper slopes are rare, but huge rounded boulders of weathered granite are scattered about (fig. 55). Deep valleys, which are choked with large boulders, cut the intermediate and lower slopes and expose weathered, jointed granite. Many steep-sided valleys have been eroded along joints in the granite. Waterfalls are numerous.

FIGURE 55.—Boulder of Omoto Granite. This weathered boulder of Omoto Granite is typical of those common on the summits of the granite mountains. The small dark specks on the surface of the rock are vugs. Summit west of Fukai-omoto. January 1956.

The largest exposure of granodiorite is a ridge on the southeast side of the granite mass. The Bunēra-gawa flows in a valley along the approximate contact between the granite and the granodiorite. The ridge is somewhat rounded and flat topped. The slopes have accumulations of granodiorite and diorite boulders.

White granophyre and rhyolite crop out in low but rugged mountains on the Kabira peninsula and in low hills and on terraces on and around the neck of the Yarabu peninsula and to the east of it. On the Hirakubo peninsula, rhyolite crops out in dikes and sills which intrude schist in the mountains and on the terraces (fig. 56).

FIGURE 56.—Rhyolite dike. The rock outcrop in the foreground, about 2 meters high, is part of a rhyolite dike which cuts the Tumuru Formation on the eastern side of the Hirakubo peninsula. The hills in the background are composed of schist of the Tumuru Formation. View slightly west of north. 1956.

LITHOLOGY

OMOTO GRANITE

Specimens from Omoto-yama had to be obtained from large remnant boulders. Differences in texture, grain size, mineralogy, and color were noted in different boulders and also at exposures of the granite in other areas, but the heavy cover of vegetation prevented mapping these somewhat diverse rock types. Granite on the summit of Omoto-yama has white feldspar, giving the rock an overall gray color; that which crops out 1 kilometer south of Kabira and along the Ara-kawa has pink feldspar, giving the rock a pinkish color. In places along the mountain ridge eastward from Omoto-yama, boulders of comparatively dark-colored fine-grained rock were found, possibly granodiorite or diorite. In some valleys tributary to the Nagura-gawa north of Chā-yama, in the mountains of the Kabira peninsula, and in stringers and dikelike penetrations on the east side of the stock, the rock is white, contains little or no biotite or other mafic minerals, and has a granophyric texture. The rock is massive, showing no preferred orientation of the minerals. Neither primary nor secondary foliation was observed in the field, and no preferred orientation of mineral grains could be seen in the thin sections.

The most common type of granite observed was biotite granite, such as that from Omoto-yama and from the headwaters of the Shiramizu-gawa (fig. 57). This granite is gray but has yellow blotches and black specks and patches of biotite. In some fairly fresh specimens the feldspar has a pink tinge. The rock has a granitic or slightly porphyritic texture. It is composed mostly of grains of quartz, kaolinized potassium feldspar, plagioclase, perthite, and brown biotite. Most of the mineral grains range from 0.1 to 0.3 millimeter in size, but occasional quartz and potassium feldspar grains are as long as 1 millimeter. Porphyritic granite has phenocrysts of quartz and feldspar as much as 4 millimeters in length. Lath-shaped idiomorphic crystals of plagioclase (0.3–0.5 mm) are included in grains of quartz and potassium feldspar. Zoning is common in the feldspars. Some specimens have graphic intergrowths of quartz and feldspar. Accessory minerals are apatite, opaque iron oxide minerals, zircon, and allanite.

Granite that has pink feldspar is fairly similar in texture and mineral composition to that just described from Omoto-yama (table 17). Miarolitic cavities are common in the pink granite in the vicinity of the waterfall near the mouth of the Ara-kawa, on the Kabira peninsula, and on the summit and slopes of Fukai-omoto.

Good examples of the white granophyric quartz-feldspar rock are found in places in the granitic mountains of the Kabira peninsula. The rock appears to grade into pink or gray biotite granite. The texture is generally granophyric or porphyritic. Quartz, potassium feldspar, and plagioclase are the principal minerals. Biotite, muscovite, and opaque iron oxide minerals are common in small amounts. Grain size ranges from 0.3 to 4 millimeters. Large (2 mm) embayed quartz crystals occur locally. Graphic intergrowths of quartz and potassium feldspar are characteristic. Aggregates of sericite and muscovite scales have formed from the alteration of plagioclase.

Examples of Omoto Granite and granophyre are described and can be compared in table 17. The sample localities are shown in figure 57.

FIGURE 57.—Specimen localities of Omoto Granite and related rocks.

Chemical analyses of the Omoto Granite were first published and discussed by J. Suzuki (1937). Later, Y. Suzuki (1954) republished the same chemical analyses along with comparative data. These analyses are given in table 18. Additional analyses of samples collected by the writer in 1955 and 1956 are also given in table 18. J. Suzuki compared analyses of the granite from Ishigaki-shima with analyses of granite from both sides of the Median Tectonic line—a major northeast-trending fault zone in Japan—and from northern Ryukyuan islands. He noted that compared to the granitic rocks from the other areas, those from Ishigaki-shima differed in that they contained a higher proportion of Na_2O and comparatively smaller amounts of CaO and MgO. He concluded that the plagioclase of the Ishigaki rocks was relatively rich in albite molecules and that the mafic minerals were high in iron as compared to magnesium. Suzuki's analyses of rocks of the northern Ryukyu Islands are also given for comparison in table 19.

TABLE 17.—*Characteristics of typical specimens of Omoto Granite*

Rock name	Field No.	Locality	Color	Grain size	Texture	Principal minerals	Accessory minerals	Alteration	Special features
Porphyritic biotite granite.	IS-F-122-55	Summit of Omoto-yama.	Gray	Mostly 0.1–0.3 mm; rare phenocrysts of quartz and andesine as much as 4 mm long.	Porphyritic	Quartz, potassium feldspar, plagioclase, brown biotite.	Apatite, allanite, opaque iron oxides.	Potassium feldspar kaolinized.	Faint zoning in some feldspars.
Biotite granite	IS-F-305 and IS-M-420-56.	Along water pipeline in Shiramizu area.	Gray	Maximum 4 mm but most 0.5–1.5 mm.	Granitic	Quartz, feldspars (perthite, oligoclase, microcline?), brown biotite.	Zircon	Biotite altered to chlorite; carbonate?; feldspars are slightly sericitized.	Quartz has many dust inclusions. Rare small areas of graphic intergrowth.
Porphyritic biotite granite	IS-M-416-56	Roadcut 1 km South of Kabira.	Pink	Quartz phenocrysts more than 3 mm in width; plagioclase phenocrysts 4 mm in length; biotite 2+ mm long.	Porphyritic	Quartz, plagioclase and brownish-green biotite phenocrysts; quartz, perthite, biotite and oligoclase-albite in groundmass.	Opaque iron oxide minerals.	Plagioclase partly albitized and sericitized. Some biotite to aggregates of chlorite; calcite.	Groundmass has allotrimorphic, coarse-grained (larger than 1 mm) quartz with many minute inclusions; quartz phenocrysts rounded and continuous to ground mass; perthite has lamellar structure because of dusty inclusions. Biotite phenocryst has graphic intergrowths of quartz.
Biotite granite	IS-M-430-56	Along the Ara-kawa about 0.1 km south from the mouth of the stream.	Gray	Average 0.5–1.5 mm	Granitic	Quartz, potassium feldspar, oligoclase, perthite and biotite.	Apatite	Sericite and chlorite	Graphic intergrowth of quartz and feldspar.
Porphyritic biotite granite.	IS-F-244-56	Boulder along Ara-kawa 0.2 km from mouth.	Pink	Feldspar phenocrysts as much as 4 mm long.	Porphyritic	Quartz, biotite, oligoclase, potassium feldspar, albite.	Zircon, iron oxide minerals.	Kaolin	Graphic intergrowth of quartz and perthite? in groundmass.
Porphyritic biotite granite.	IS-F-315-56	2 km east-southeast of Yoshihara.	Gray	Phenocrysts 1–2 mm. Groundmass mostly less than 0.4 mm.	Porphyritic	Quartz, feldspar, biotite.	Allanite, zircon, apatite.	Biotite to chlorite. Brown uniaxial mineral from biotite(?).	Quartz phenocrysts enclose idiomorphic plagioclase crystals and biotite. Graphic granite penetrates embayments in the margins of some quartz crystals which it surrounds. Some quartz crystals have slightly undulating extinction.
Graphic granite	IS-F-186-56	2.4 km south-southeast of Kabira.	Gray	Quartz and feldspar grains as much as 3 mm across.	Graphic intergrowths.	Quartz, microcline, perthite, oligoclase, biotite.		Sericite; brown-colored material from biotite.	Graphic intergrowth of quartz in potassium feldspar.
Biotite granite	IS-F-123-55 and IS-F-125-55	Omoto-yama 0.3 and 0.5 km south of summit.	Gray	Fine grained mostly 0.1–1 mm.	Granitic	Quartz, potassium feldspar, biotite.	Apatite	Sericite and chlorite	Lath-shaped idiomorphic crystals (0.3–0.5 mm) of plagioclase are included in anhedral grains of quartz and potassium feldspar. Zoning in some feldspars.
Graphic granite	IS-F-141-55	3.4 km southwest of Kabira.	White	1–4 mm	Graphic intergrowths.	Quartz, potassium feldspar, oligoclase, muscovite.	Iron oxide minerals.	Sericite	
Granophyre	IS-F-76-55	Kabira peninsula	White	0.3–1.5 mm	Granophyric	Quartz, potassium feldspar, oligoclase.	Muscovite	Sericite	Graphic intergrowths of quartz and potassium feldspar.
Granophyre	IS-F-78-55	1.2 km west of Kabira.	White	As much as 2 mm	Porphyritic	Quartz, potassium feldspar, plagioclase, biotite	Opaque iron oxide minerals.	Plagioclase, albitized and sericitized.	Embayed quartz crystals with dusty inclusions; graphic intergrowths of quartz and potassium feldspar.

TABLE 18.—*Chemical analyses and norms of Omoto Granite from Ishigaki-shima*

[Analyses 1-4 from J. Suzuki (1937)]

	1	2	3	4	5	6	7
Analyses							
SiO_2	73.90	75.67	74.82	69.53	75.44	74.27	75.34
Al_2O_3	12.54	13.77	13.96	14.85	12.90	12.04	13.22
Fe_2O_3	.32	.47	.08	1.12	.30	.28	.68
FeO	2.15	1.00	1.30	2.87	1.17	1.06	.40
MgO	.42	.15	.26	.51	.22	.04	.021
CaO	.84	.56	.73	1.37	1.00	.81	.74
Na_2O	3.93	4.13	3.94	5.16	3.77	5.19	3.26
K_2O	4.44	3.63	4.56	2.77	4.24	6.14	4.30
H_2O+	----	----	----	----	.29	.35	1.70
H_2O-	----	----	----	----	.08	.17	.26
TiO_2	.12	.13	.12	.31	.15	.10	.041
P_2O_5	----	----	----	----	.02	Tr.	.007
MnO	.03	.03	.03	.06	.04	.05	.022
CO_2	----	----	----	----	.01	None	None
Ignition loss	1.15	.69	.50	1.42	----	----	----
Total	99.84	100.23	100.30	99.97	99.63	100.50	99.99
Norms							
Q	30.39	35.50	31.53	23.78	33.99	27.81	37.96
or	26.16	21.70	26.71	16.14	25.04	36.17	25.60
ab	33.03	35.13	33.56	43.52	31.98	27.79	27.79
an	3.62	2.78	3.62	6.68	5.01	----	3.62
C	----	1.94	1.22	1.02	.31	----	1.84
wo	.23	----	----	----	----	1.63	----
en	1.00	.40	.70	1.31	.60	.10	----
fs	3.43	1.19	2.11	3.83	1.58	1.85	.26
mt	.46	.70	----	1.62	.46	----	.93
il	.30	.30	.30	.61	.30	.15	----

1. Biotite-quartz monzonite from Ishigaki-shima. Analysis by Kiyoshi Isono.
2. Biotite-quartz monzonite from Omoto-yama, Ishigaki-shima. Analysis by Morinosuke Sekine.
3. Biotite-quartz monzonite from Omoto-yama, Ishigaki-shima. Analysis by Kiyoshi Isono.
4. Hornblende-bearing biotite-quartz monzonite from Omoto-yama. Analysis by Ryuji Hiratsuka.
5. IS–F–315–56. Biotite granite from mountains 2 km east-southeast from Yoshihara. Analysis by D. F. Powers, U.S. Geological Survey, 1959.
6. IS–M–430–56. Biotite granite in place along the Ara-kawa about 0.1 km south from the mouth of the stream. Analysis by Japan Inspection Co., Ltd., Tokyo, Japan, 1956.
7. GCI–1. Biotite granite from boulder on east bank of Ara-kawa 0.1 km south from the mouth of the stream. Analysis by Japan Inspection Co., Ltd., 1956.

TABLE 19.—*Chemical analyses and norms of granitic rocks from southern Japan and the northern Ryukyu Islands*

[From Y. Suzuki, 1954, p. 435–437]

	1	2	3	4	5	6	7	8
Analyses								
SiO_2	65.96	74.52	67.20	75.24	68.60	62.18	68.14	61.97
Al_2O_3	15.82	14.12	15.52	12.71	16.02	16.80	16.79	17.75
Fe_2O_3	.72	.24	.48	.70	.16	.32	.40	.80
FeO	3.95	2.66	4.32	1.19	3.74	4.46	4.03	4.20
MgO	1.81	.60	1.70	.40	1.10	2.90	1.39	2.52
CaO	3.35	.84	2.80	1.33	2.86	4.51	2.86	4.69
Na_2O	3.05	2.96	3.79	2.19	3.43	2.94	2.79	3.94
K_2O	3.22	3.89	3.44	4.63	3.84	3.50	2.62	2.14
H_2O+	----	----	----	.51	----	----	----	----
H_2O-	----	----	----	.20	----	----	----	----
TiO_2	.51	.16	.25	.36	.22	.31	.57	.85
P_2O_5	----	----	----	.07	----	----	----	----
MnO	.04	.03	.07	.03	.08	.08	.08	.09
Ignition loss	1.50	.40	.81	----	.50	1.69	.38	.76
Total	99.93	100.42	100.38	99.56	100.55	99.69	100.05	99.71
Norms								
Q	23.1	37.4	19.9	40.8	23.0	14.1	30.6	14.2
or	19.0	23.0	20.3	27.3	22.7	20.6	15.5	12.7
ab	25.8	25.0	32.0	18.5	29.0	24.9	23.6	33.3
an	16.6	4.2	13.9	6.2	14.2	22.2	14.2	23.3
C	1.2	3.5	.5	1.8	1.0	----	4.1	.4
wo	----	----	----	----	----	.1	----	----
en	4.5	1.5	4.2	1.0	2.7	7.2	3.5	6.3
fs	5.9	4.5	7.3	1.1	6.5	7.6	6.3	5.8
mt	1.0	.4	.7	1.0	.2	.5	.6	1.2
il	1.0	.3	.5	.7	.4	.6	1.1	1.6
ap	----	----	----	.2	----	----	----	----

1. Onigashiro-yama, Uwajima, Ehime Prefecture, Japan. Analysis by R. Hiratsuka.
2. Kashiwajima, Hada-gun, Kochi Prefecture, Japan. Analysis by R. Hiratsuka.
3. Mt. Tsuji, Kimotsuki, Kagoshima Prefecture, Japan. Analysis by M. Sekine.
4. Tarumizu, Kimotsuki-gun, Kagoshima Prefecture, Japan. Analysis by K. Yamaguchi.
5. Sentozan, Yakushima, Kagoshima Prefecture, Japan. Analysis by M. Sekine.
6. Ishizaki, Amamioshima, Kagoshima Prefecture. Analysis by M. Sekine.
7. Todoroki, Higashianmagi-mura, Tokunoshima, Kagoshima Prefecture. Analysis by M. Sekine.
8. Koshiyama, Okinoerabushima, Oshima-gun, Kagoshima Prefecture. Analysis by K. Isono.

Note: Spelling of place names as given in original reference.

Y. Suzuki (1954, p, 433) considered that the granitic intrusions of the Osumi peninsula of southwestern Kyūshū (Japan), Koshiki-jima south of Kyūshū, and several islands of the northern Ryukyus are closely related small intrusive masses probably of late or post-Cretaceous age. Because the nearest granitic rocks to the southwest are on Ishigaki-shima, he has also discussed their probable relationship to the northerly granitic rocks. He stated that most of the rocks from Kyūshū and the northern Ryukyus are granodioritic—composed principally of quartz, potassium feldspar, and plagioclase, with either biotite and (or) hornblende as an additional constituent—and that the granitic rocks of Ishigaki-shima are somewhat different in their chemical composition and in the microscopic characteristics of the constituent minerals. He also noted that the rocks on Ishigaki-shima are more leucocratic than those to the north and that they have abundant miarolitic cavities.

The differences and the similarities of granites from Japan, the northern Ryukyus, and Ishigaki-shima can be seen by comparing the chemical analyses and norms (tables 18, 19). The granodiorites of these tables can also be compared with the granodiorites from Ishigaki-shima which are listed in table 21. Neither J. nor Y. Suzuki compared samples of granodiorite or diorite from Ishigaki-shima with granitic rocks from the more northerly localities, but the writer finds that the granodiorites from Ishigaki-shima do not closely resemble the granodiorites from Kyūshū and the northern Ryukyu Islands used in the Suzukis' studies. However, as Y. Suzuki (1954, p. 434) noted, the supposedly related granitic masses of southwestern Japan have fairly large differences in their mineral composition within single intrusions. Thus the significance of the differences between the Ishigaki-shima granitic rocks and those from areas to the north is questionable. H. Kuno (oral commun., 1956) has stated that mineralogically the granite from Ishigaki-shima resembles some Tertiary granites from Japan.

CHA-YAMA GRANODIORITE

The principal area of granodiorite is a ridge that borders the southeastern margin of the granitic stock. The western part of the ridge is known locally as Chā-yama. Other exposures, mostly small, of granodiorite or rocks that closely resemble granodiorite are found on the western margin of the stock 3.5 kilometers south of Kabira, 1.5 kilometers west of Kabira, and in the mountains on the eastern side of the stock. A few granodiorite dikes cut the metamorphic rocks in the vicinity of the main intrusion and on the Kabira peninsula.

The rock is dark gray and ranges from fine to medium grained. Some rocks have porphyritic and granophyric textures, granophyric textures being especially common in the dike rocks. The composition ranges from granodiorite to diorite. Fresh rock is generally surrounded by a rim or border zone of brown weathered rock 0.6–1.2 centimeters thick. Plagioclase and ferromagnesian minerals have crystals as much as 3 millimeters long. The plagioclase crystals are generally strongly zoned and range from andesine to oligoclase. Graphic intergrowth of quartz with feldspar is common. Hornblende and biotite or augite and hornblende with or without hypersthene are the common ferromagnesian minerals. Feldspars are altered or partly altered to kaolin or sericite. Biotite has altered to chlorite. Opaque iron oxide minerals and apatite are common accessory minerals. Table 20 gives descriptions of some typical specimens of Cha-yama Granodiorite.

In the Kabira area, granodiorite is bordered on the west by andesitic breccia and on the east by granite and white granophyre. It crops out along the western coast of the Kabira peninsula in dikes which are exposed beneath a capping of Ryukyu Limestone. Although the shape of the granodiorite mass in the Kabira mountains is difficult to ascertain because of the heavy vegetation, the mass seems to form a narrow border along the granite and to be faulted and broken by joints.

A representative specimen from the mountains (IS–F–62–55) is porphyritic pyroxene granodiorite. The phenocrysts are strongly zoned idiomorphic plagioclase crystals, 2 millimeters long; hypersthene(?) crystals, less than 1 millimeter long, that have been completely chloritized; and partly chloritized augite, as much as 0.5 millimeter long. The groundmass is composed of ophitic plagioclase laths, 0.8 millimeter long; micropegmatitic patches of feldspar and quartz; pyroxene (0.02 mm) altered to chlorite; and pale-brown biotite which appears continuous to chlorite. Opaque iron oxide mineral grains (magnetite?) 0.02 millimeter across are present, as well as some xenomorphic quartz about 0.1 millimeter across.

The Cha-yama Granodiorite was named on the basis of examination of thin sections. Later, two chemical analyses were made of representative fresh rocks from Chā-yama and vicinity. These two analyses (table 21) indicate rock compositions that are less silicic than granodiorite. An analysis of a rock from another locality to the northwest (table 21) indicates that the rock there is somewhat more silicic than the other two samples analyzed.

SAKIEDA RHYOLITE AND MEGASCOPICALLY SIMILAR ROCKS

White or cream-colored rocks that appear to be mostly porphyritic rhyolites crop out at several widely separated localities on Ishigaki-shima. Nearly everywhere these rocks are much weathered and considerably altered. On the Hirakubo peninsula, they are intrusive into the metamorphic rocks of the Ishigaki Group. Elsewhere on the island, they are probably partly intrusive and partly extrusive. Some are very similar in megascopic appearance to the white granophyric rocks which occur with the Omoto Granite and as dikes or other intrusions along the margins of the granite stock. In the field, these and other similar-appearing white rocks were grouped together. However, microscopic examination indicates differences. Some have definite granophyric texture, some are porphyritic both with and without granophyric texture, and others have banding that resembles flow structure. Some are mylonitic. Others are highly siliceous rocks, possibly altered cherts and silicified andesites. Some have been brecciated and recemented by siliceous material.

The mylonitic rocks, which probably include granite, metamorphic, and volcanic rocks, are discussed later. The rocks described next are those which are thought to be rhyolite, mostly porphyritic rhyolite. They occur where the Yarabu and Kabira peninsulas join the main mass of the island and in the northern part of the island. Some similar-appearing rock also occurs on the northern part of the Nosoko peninsula and among the volcanic rocks of the Yarabu peninsula. The rhyolite is here named the Sakieda Rhyolite, and the type locality is cited as the Sakieda district, 3.5 kilometers south-southwest of Kabira.

The largest area of outcrop of the porphyritic Sakieda Rhyolite is in the vicinity of Tsuzutunu-muru. It comprises three small conical hills and some of the area surrounding them. The hills are covered with such a dense growth of cane and other concealing vegetation that no details of their structure were learned. The contact of the rhyolite on the east with the granite is concealed. The rhyolite is dense white, grayish-white, or cream-colored, and porphyritic. The surface has a sugary appearance when weathered, and brown stains are common on weathered surfaces. The rock is broken by many closely spaced fractures. In an adjoining area of outcrop to the west, in the neck of land between

TABLE 20.—*Characteristics of typical specimens of Cha-yama Granodiorite and related dike rocks*

Rock name	Field No.	Locality	Color	Maximum grain size (millimeters)	Texture	Phenocrysts	Groundmass	Alteration	Special features
Hornblende-biotite granodiorite.	IS-F-116-55	Kādō, a 212-m summit on Chā-yama.	Dark gray	4	Porphyritic	Plagioclase, hornblende, biotite, microcline, quartz.	Opaque iron oxides, apatite.	Feldspar partly sericitized; biotite partly chloritized.	Some graphic intergrowth of quartz and feldspar. Plagioclase strongly zoned ranging in composition from andesine to oligoclase. Hornblende prismatic.
Pyroxene porphyrite	IS-F-115-55	Few tens of meters east of Kādō.	Dark gray	3	Porphyritic	Augite, hornblende	Andesine, quartz, idiomorphic long prismatic augite, opaque iron oxides, biotite.	Augite partly to chlorite and uralite.	Intergrowths of quartz and feldspar. Hypersthene may have been present, but, if so, now completely altered.
Diorite	IS-M-421-56	South slope of Chā-yama.	Dark gray	3	Coarse	Augite, andesine	Quartz, potassium feldspar, hypersthene, apatite, opaque iron oxides.	Chlorite	Graphic intergrowths of quartz and feldspar.
Porphyritic pyroxene granodiorite.	IS-F-62-55	Southern part of Kabira peninsula.	Dark gray	2	Porphyritic	Plagioclase, hypersthene?, augite.	Ophitic plagioclase laths, micropegmatitic patches of quartz and feldspar, pyroxene, biotite, opaque iron oxides, xenomorphic quartz.	Hypersthene to chlorite; augite to chlorite.	Zoned idiomorphic plagioclase. Ground mass has ophitic plagioclase.
Porphyritic biotite-hornblende-pyroxene granodiorite.	IS-F-61-55	Southern part of Kabira peninsula.	Dark gray	1.5	Porphyritic	Plagioclase (andesine), augite, hypersthene?, brownish-green hornblende, opaque iron oxides.	Laths of plagioclase, quartz, opaque iron oxides, interstitial green amphibole, zircon.	Chlorite, sericite, green amphibole.	Andesine phenocrysts strongly zoned. Groundmass ophitic with micrographic intergrowths of quartz and potassium feldspar. Plagioclase laths as much as 0.7 mm long in a mesostasis of quartz and potassium feldspar.
Granophyre	IS-F-16-55	Dike on west coast of Kabira peninsula.	Gray	3.5	Porphyritic	Zoned plagioclase, hypersthene?, rounded quartz microphenocryst 0.3 mm across.	Poikilitic quartz, prismatic and xenomorphic potassium feldspar, plagioclase, opaque iron oxide grains, interstititial chlorite and calcite.	Hypersthene?, chloritized and carbonitized; plagioclase albitized and carbonitized.	Idiomoprhic plagioclase phenocrysts as much as 3.5 mm long strongly zoned.

Granophyre	IS-F-18-55	West coast of Kabira peninsula.	Dark gray	2	Porphyritic	Plagioclase, aggregates of chlorite and opaque iron oxides, biotite.	Prismatic plagioclase, spherulitic aggregates of quartz and potassium feldspar, fine granular aggregates of quartz and potassium feldspar, opaque iron oxide mineral grains, interstitial chlorite, carbonate.	Plagioclase albitized and partly sericitized; biotite altered to iron saponite.	
Pyroxene porphyrite	IS-F-29-55	South of Kabira 3.5 km.	Dark gray	5	Porphyritic	Strongly zoned plagioclase, hypersthene?, augite, opaque iron oxides.	Zoned plagioclase, micrographic intergrowths of quartz and alkalic feldspar, scaly blue-brown amphibole, epidote, opaque iron oxides.	Plagioclase is sericitized; hypersthene and augite uralitized.	
Pyroxene granophyre	IS-F-30-55	South of Kabira 3.5 km.	Dark gray	1.5	Porphyritic	Zoned plagioclase, augite, hypersthene?, opaque iron oxides.	Graphic intergrowths of quartz and potassium feldspar; fine granular aggregates of quartz and potassium feldspar, epidote, interstitial chlorite, altered biotite, opaque iron oxide grains.	Plagioclase albitized; augite uralitized; hypersthene?, completely altered to chlorite, iron saponite, and carbonate.	
Hornblende-augite porphyrite.	IS-F-195-56	Dike southeast of Yonehara.	Dark gray	3	Porphyritic; groundmass granophyric.	Andesine, augite, pale-green hornblende.	Plagioclase, spherulitic quartz and granular quartz, biotite, actinolitic amphibole, opaque iron oxides.	Uralite pseudomorph of augite?.	
Hornblende-quartz porphyrite.	IS-F-198-56	East margin of granite stock.	Dark gray	2	Porphyritic	Andesine, embayed quartz, pale-brown amphibole.	Plagioclase laths, spherulitic quartz, biotite, hornblende, and iron oxide minerals.		Feldspars zoned.
Pyroxene granophyre	IS-M-76-56	Southwest of Kabira 3.5 km.	Dark gray	3	Porphyritic and granophyric.	Plagioclase, augite, hypersthene?, magnetite.	Plagioclase laths 0.2 mm long. Micrographic intergrowths of quartz and potassium feldspar, interstitial chlorite and epidote.	Plagioclase albitized, sericitized, chloritized, and carbonitized; augite and hypersthene?, uralitized and chloritized.	

Nagura-wan and Kanama-wan, the rock ranges from white to gray to greenish-gray. Some resembles altered andesite. Because of extensive alteration the composition of the rock is so uncertain that it is questionable whether or not all of it should be mapped with the rhyolite, as has been done in this report. The differences in appearance of the rock may be due to differences in hydrothermal alteration and weathering, although original compositional differences may also be present.

TABLE 21.—*Chemical analyses and norms of Cha-yama Granodiorite from Ishigaki-shima*

	IS-M-421-56	IS-M-423-56	IS-M-76-55
Analyses			
SiO_2	55.07	54.02	66.00
Al_2O_3	19.68	20.52	15.43
Fe_2O_3	.53	.71	1.45
FeO	5.11	4.77	3.62
MgO	3.65	3.70	.85
CaO	9.54	9.84	2.80
Na_2O	2.85	2.80	3.24
K_2O	.75	.92	2.20
H_2O+	1.36	1.48	2.45
H_2O-	.25	.19	.35
TiO_2	.73	.58	.58
P_2O_5	.15	.12	.16
MnO	.12	.13	.14
CO_2	.02	.08	Tr.
Total	99.81	99.86	99.27
Norms			
Q	8.11	5.95	29.91
or	4.45	5.57	12.80
ab	24.12	23.59	27.26
an	38.66	40.61	13.07
C			2.96
wo	3.25	3.48	
en	9.14	9.24	2.11
fs	8.05	7.39	4.75
mt	.70	1.16	2.08
il	1.37	1.06	1.06
ap	.34		.34

IS-M-421-56. Diorite from south slope of Chā-yama 2 km west of Kainan. Analysis by D. F. Powers, U.S. Geol. Survey, 1959.
IS-M-423-56. Diorite from 1.2 km northeast of Kainan. Analysis by D. F. Powers, U.S. Geol. Survey, 1959.
IS-M- 76-55. Pyroxene granophyre from 0.6 km northeast of Aka-saki. Analysis by Japan Inspection Co., Ltd., Tokyo, Japan, 1956.

The freshest fairly representative sample of the rhyolite (IS-F-44-55) was obtained on the southeast side of an exposure in a low ridge extending from the easternmost hill. The rhyolite is composed of quartz and plagioclase phenocrysts in an allotriomorphic granular groundmass that has grains less than 0.07 millimeter across. The plagioclase phenocrysts are idiomorphic, completely albitized, and partly sericitized. They are as much as 4 millimeters long. The quartz phenocrysts, as much as 2 millimeters long, are embayed. The groundmass consists of quartz and micrographic intergrowths of quartz and alkalic feldspar. Scaly aggregates of sericite, as much as 0.04 millimeter in width, occur.

A specimen (IS-F-54-55) from the north side of the westernmost hill has phenocrysts of embayed quartz as large as 0.6 millimeter across in a mosaic aggregate of quartz. Aggregates of sericite as much as 0.5 millimeter across have formed as alteration products of phenocrysts. Scales of muscovite are scattered uniformly throughout the groundmass.

Light gray rock farther west (IS-F-36-55) has phenocrysts of embayed quartz, as much as 3 millimeters across, and idiomorphic feldspar, as much as 4.5 millimeters long, that has been completely sericitized. The groundmass consists of mosaic aggregates of quartz, 0.4 millimeter across, charged with sericite scales. There are radial aggregates of sericite in patches 0.2 millimeter across. Clear quartz and limonite(?) occur in druses.

On the Kabira peninsula at the south end of the mountains and on the northern slope of the mountains 0.8 kilometer east-southeast of Azana-zaki are areas in which white rhyolitic rocks crop out. They may be partly bounded by faults. Also, along the western coast of Kanama-wan, rhyolite flows or dikes crop out in several places, some in the vicinity of granophyric granodiorite dikes. Rhyolitic or dacitic(?) lava also crops out in cliffs along the sea at the northern tip of the peninsula, but the lava differs from the rhyolite just described in color and structure. Some of this lava is pinkish-gray or gray rather than white, and it has flow banding.

White, weathered, fine-grained and porphyritic rocks occur as sills, dikes, and possibly small intrusive masses in the metamorphic rocks of the Ishigaki Group on the Hirakubo and Ibaruma peninsulas. These rocks resemble those of the Yarabu-Kabira area in appearance and mineralogy.

A representative specimen (IS-F-159-55) from the northwestern coast of the Ibaruma peninsula is a white altered rhyolite. The presence of vesicles suggests that the rhyolite might have been a lava flow. The rock has quartz phenocrysts, 1.5-3 millimeters across, which have the high-temperature form of quartz. Feldspar crystals have been completely sericitized. Altered mica is scattered irregularly through the thin section. The groundmass is felsitic and has been sericitized.

White altered rhyolite crops out as a sill within the schist of the Ishigaki Group in the mountainside about 0.8 kilometer north of Akeishi. The rock (IS-F-250-56) shows distinct banding. It has been silicified and sericitized. Phenocrysts of quartz have the high-temperature form and are surrounded by dusty rims. The groundmass consists of mosaic aggregates of quartz grains and sericite flakes. Magnetite phenocrysts are altered to hematite.

Similar rock composes dikes (fig. 56) which cut the schist of the Ishigaki Group in the vicinity of the Yassa-gawa and elsewhere on the Hirakubo peninsula. However, some of the rock in the dikes is mylonitic and will be described later.

White rock that resembles Sakieda Rhyolite occurs among the Nosoko volcanic rocks of the Nosoko peninsula. In a few places, as along the Ōura-kawa, the rock appears to be in dikes bounded by faults. At other places, patches of the white rock occur on ridges and elsewhere among the dark andesitic volcanic rocks, and the relation of the two types of rock was not evident. Similar patches of white rock were found on the Yarabu peninsula in the midst of the Nosoko volcanic rocks. About 0.8 kilometer south of Nosoko-ishi-zaki is a fairly large patch of white and gray rock, some of which resembles rhyolite, but part of which may be mylonite or breccia. Some of it contains numerous small grains of pyrite and (or) some other metallic mineral. One specimen, brecciated quartz rock, has radiating columnar aggregates of tourmaline.

MYLONITIC ROCKS

White rocks in several small areas show clastic structures. These are included with the Sakieda Rhyolite on the geologic map (pl. 4). One such area occurs where the Yarabu and Kabira peninsulas are joined to the main part of Ishigaki-shima. Here faulting has occurred, and rhyolite seems to have intruded the shear zone. Mylonitized chert or rhyolite, chert breccia, or silicified tuff-breccia also occur in the fault zone. Most of the faulting and accompanying brecciation and mylonitization appear to have occurred before most of the rhyolite was in place, because the rhyolite locally obliterates the fractures of the fault zone. The mylonite and breccia probably formed largely from chert or other rocks of the Ishigaki Group. Slight movement after emplacement of the rhyolite is indicated by some small fault scarps and fracturing and possibly by brecciation in the rhyolite. Some mineralization has occurred in this zone. Small metallic crystals are scattered throughout much of the rock. Limonite is common in cavities and along cracks; and, in places, manganese coats the fracture surfaces of the rocks and fills cracks.

One or more fracture zones may be associated with some of the dikes and sills of the Hirakubo peninsula, because breccia and mylonite have been found in the vicinity of the Yassa-gawa and in a zone cutting across the peninsula in the vicinity of Hattsua-yama. Some mineralization has also occurred. Considerable pyrite has been found along the contact between the white dike rock and the schist country rock in the vicinity of the Yassa-gawa. Pyrite, other iron minerals, and a little manganese are found in the brecciated zone in the vicinity of Hattsua-yama.

An example (IS–F–233–56) from the Yassa-gawa area near Iha-saki appears to the naked eye to be a white quartzitic breccia. Microscopically it is a mylonitized hematite-quartz rock. Some of the quartz has wavy extinction. Hematite, other iron minerals, and a reddish-brown alteration product are present. The brecciated zone is traceable only for a few tens of meters although white dike rock extends much farther (pl. 4).

The Hattsua-yama brecciated zone appears to extend across the schist mountain range in roughly an east west direction, but observations are limited because the rugged land surface is thickly covered by vegetation Breccia is common in this zone and appears to be mostly white, gray, or reddish-brown quartz rock. Pyrite in small grains is widely disseminated in the rock. Cavities, partly filled with secondary minerals, particularly by iron and manganese oxides, are common. The surface of the rock is generally covered with yellow, green, brown, and red stains. Thin sections of random specimens are mostly a quartz rock. The quartz grains show strain, and some are fragmented. Large grains are much fractured. Opaque minerals are abundant. Old Japanese prospect pits are found in this zone.

WEATHERING AND SOILS

The granite, granodiorite, and rhyolite are weathered to depths of at least 1 meter in nearly all localities and to a depth of 15 meters or more in some places. Bedrock exposed in cuts is generally crumbly and easily dug away with a pick. The ferromagnesian minerals and feldspars are mostly altered to chlorite, sericite, and other secondary minerals. Rounded, weathered boulders are scattered about on the surface in many areas. Soil developed on the granite is generally composed of a thin layer of brownish-yellow sandy loam over brownish-yellow or yellowish-red clay loam (Red-Yellow Podzolic soils and some sandy Lithosols). The clay loam grades, at depths of 0.6–1.5 meters, into coarse angular clayey sand composed of quartz and feldspar grains derived directly from the weathering granite. The depth of soil and weathering is difficult to determine in most places because of the numerous large boulders. The soils developed from the granodiorite and diorite are similar to those from the granite except that the surface soils are generally silt loam rather than sandy loam.

ORIGIN AND AGE

The Omoto Granite, Cha-yama Granodiorite, and Sakieda Rhyolite are closely related in space and mineralogy. They probably represent different phases of a single cycle of igneous activity. The main granite stock, the Omoto Granite, has discordant relations with the country rock—that is, the metamorphic rocks of the Ishigaki Group. The intrusion caused steep upturning and fracturing of the country rock, probably with ensuing penetration of many fractures by late magmatic fluids that formed granophyric granodiorite dikes and more siliceous rhyolite and white granophyre dikes. Locally, as in the Shiramizu area, there are narrow zones of hornfels, a meter to a few meters in width, but contact-metamorphic effects are minor.

The Cha-yama Granodiorite is believed to be closely related to the main granite mass. The only observed contacts between granodiorite and granite were in the Kabira area and in the mountains on the east side of the stock. In the Kabira area the contacts are sharp and are probably fault contacts, but those on the eastern side of the stock may be intrusive contacts. On the east side of Omoto-yama, the granodiorite and granite seem to interfinger in some places. On the northern side of the stock, a granodiorite dike penetrates the granite. Thus, at least some of the granodiorite was intruded after the main granite mass. Within the granite mass, granodiorite and diorite appear to be merely areas of segregation of more mafic minerals, and these segregated areas seem to be a part of the main stock itself.

The rhyolite on the west side of the stock and in the Kabira area occurs next to the granite in several places, but its relation to the granite is not indicated definitely. The location of some porphyritic rhyolite which penetrates the Ishigaki Group in the mountains on the east side of Nagura-gawa suggests that it emerges from the granite mass, but no rhyolite was traced directly into the granite. The rhyolite of the Yarabu and Kabira areas is sufficiently similar to that of the Nosoko, Ibaruma, and Hirakubo peninsulas to suggest that these rhyolites are the same age and have the same origin.

The characteristics of the Ishigaki intrusive rocks can be compared with the criteria given by Buddington (1959, p. 677–695) for classifying plutons according to emplacement in the epizone, mesozone, or catazone of the earth's crust. The Ishigaki-shima rocks have many of the described characteristics of plutons of the epizone, particularly of Tertiary plutons. Among these characteristics are the discordance of the Omoto Granite and Cha-yama Granodiorite with the country rock, the range in composition from diorite to granite, and the apparently homophanous structure that has no lineation or foliation. Miarolitic cavities are common in the Omoto Granite. Granophyre is present. Tertiary orogenic events accompanied by emplacement of igneous bodies are known both in Japan and Taiwan; probably the Ryukyu Islands were also involved in this igneous activity.

Some of the volcanic rocks may be associated with the intrusive rocks, but present information is not sufficient to determine this with certainty. The rhyolite and the flows and the breccias of the Kabira peninsula are particularly likely to be closely associated with the granite and granodiorite. Breccia which might be related to the intrusions is present on the northern and western sides of the Kabira peninsula; however, the Kabira breccia does not, as far as observed, include rocks of the Ishigaki Group, rocks which might be expected if the breccia were closely associated with the intrusion. Many plutons of the epizone are associated with ring dikes and cauldron subsidence. No good evidence of such a relationship exists on Ishigaki-shima.

The geologic relationships of the intrusive rocks indicate with certainty only that they are younger than the rocks of the Ishigaki Group and older than the Nagura Gravel. No definite relationship to the Eocene rocks could be established because the intrusive rocks are not in contact with them. No granite, granodiorite, or rhyolite pebbles were found in the Eocene conglomerate although an intensive search was made. The intrusions could have been emplaced but not uncovered, or sufficiently uncovered, to supply material for the formation of the Eocene conglomerates.

Close association of the volcanic rocks on the Kabira peninsula with the intrusives may indicate a genetic relationship. These volcanic rocks are slightly different from the typical volcanic rocks of the Nosoko Formation, and the granite intrusions might have effected these differences. Breccias on the end of the peninsula are generally more altered than those in the rest of the Nosoko Formation, and some of the lavas are more silicic. The breccias that are adjacent to granodiorite outcrops along the western side of the peninsula are more dense and harder than most of the breccias of the Nosoko Formation. Although they are in contact with granodiorite and Sakieda Rhyolite, the type of contact is uncertain.

In places on both the Yarabu and the Nosoko peninsulas, the Sakieda Rhyolite seems to be intrusive into the Nosoko Formation. Thus, if all the Sakieda Rhyolite is the same age, it must be younger than the Nosoko Formation. However, rhyolite of more than one age may occur. For example, the rhyolite of the Hirakubo peninsula and at Tsuzutunu-muru might be different in age from that which intrudes the volcanic rocks of the Nosoko and Yarabu peninsulas.

Lead-alpha age determination of zircon from the Omoto Granite and the Cha-yama Granodiorite was attempted. The amount of zircon obtained from the granodiorite was insufficient for analysis, and, owing to technical difficulties, only one analysis of granite was possible. This analysis was made from a specimen of pink granite found near the bridge over the Ara-kawa on the north side of the mountains. The sample (WA-89) gave a Tertiary age, 40±20 million years. This is considered a preliminary age determination.

Although a late Paleozoic or, particularly, a late Mesozoic age cannot be ruled out, a Tertiary age for the intrusive rocks is suggested by (1) the single lead-alpha age determination; (2) the resemblance of the intrusion to Tertiary epizonal intrusions elsewhere in the world; (3) the lack of granite or granodiorite in the Eocene Miyara Formation; and (4) the intrusion of rhyolite into the Nosoko Formation.

STRUCTURAL GEOLOGY

Ishigaki-shima surmounts a low structural swell, one of several on the largely submarine Ryukyu ridge or arc. Iriomote-jima and the other islands of the Yaeyama-guntō, except Yonaguni-jima, are on the same structural swell. Islands of the Miyako group and the Okinawa group occupy other structural swells to the northeast (pl. 3). The Ishigaki swell is separated from that of Miyako by water more than 300 meters deep, and the Miyako swell, from that of Okinawa by water more than 1,000 meters deep.

The rocks of Ishigaki-shima have been acted upon by a succession of tectonic forces which have produced folds, faults, and joints. Some of the younger rocks have been faulted and tilted but not folded. Abundant fractures in the Quaternary rocks are indicative of recent movements and strains. The character of the folding and fracturing in the rocks is comparable to that of Taiwan and Japan, areas of great past tectonic activity and among the most active tectonic areas of today.

TECTONIC STRUCTURES

FOLDS

Folds caused by a major orogenic disturbance occur only in rocks of the Ishigaki Group. They range in amplitude from a few centimeters to tens or hundreds of meters. The large folds have been partly eroded, faulted, or concealed by later rocks so that only parts of them can be seen. Strike ridges, such as those in the schist mountains west of Hoshino, are limbs of large folds. These limbs have been crumpled into one or more series of smaller folds, including drag folds. The size of these folds and the tightness of folding varies from place to place and in different types of rock. For instance, in the chert, folds a meter or so across are sharp and angular at the crest (fig. 17). Overturned folds two to a few centimeters across are common in the schists.

The dominant strike of beds in the Fu-saki Formation is approximately east. This trend continues west from Ishigaki-shima to the islands of Taketomi and Kobama, and, according to Hanzawa (1935, p. 39), also to Iriomote. However, the strike of the Fu-saki Formation differs from this general trend in some localities on Ishigaki-shima. Such divergent strikes suggest crossfolding, especially in the vicinity of Fu-saki. At Fu-saki the axial traces of small folds trend about N. 70° E. On the coast 1.8 kilometers to the northeast, the axial trace of a fold in chert also trends about N. 70° E. Divergent strikes are abundant in small chert outcrops east of Fu-saki, but the outcrops are so broken and disturbed that no structural trends other than the general east-west trend are certain. Isolated remnants of small truncated folds in chert, including both synclines and anticlines and single limbs of folds, stand out as knobs 4–11 meters high. Expected extensions of the folds generally cannot be found. Crests of truncated folds are composed of crushed and fractured massive white quartz. On the south slopes of Taramani 3 kilometers north of Shika, remnants of broken folds in chert, obliquely truncated across axial planes, stand out in bold relief. Limbs of adjacent folds in chert display widely divergent strikes that have little relationship to each other. Limbs of broken folds in chert in adjacent ravines also have heterogeneous strikes.

In the Tumuru Formation on the Yarabu and Hirakubo peninsulas, the most common strike of the schistosity is northeast, but on the Ibaruma peninsula it is northwest. The strike, however, deviates from this general direction in many places, especially on the Hirakubo peninsula. In rocks of the undifferentiated parts of the Ishigaki Group, the dominant strike is northwest.

The strikes for the Fu-saki Formation are mostly those of bedding, as is clearly shown by chert beds in which the original bedding has not been obscured or destroyed by metamorphism. The strike of the schistosity of the schists of the Fu-saki Formation seems to correspond with that of the bedding, as indicated by the parallelism of the schists to the chert and other rocks with which they are interbedded.

In the Tumuru Formation, it is more difficult to determine the trend of the original beds. Generally, compositional differences in the schist have probably resulted from differing lithologies in the original rocks. In most places, schistosity seems to follow the same trend as the compositional layering, suggesting that schistosity is approximately parallel to the original bedding.

FAULTS

Large thrust faults and tear faults are postulated on Ishigaki-shima, and high-angle and strike-slip faults were seen. Thrust faulting probably took place contemporaneously or almost contemporaneously with the folding of the rocks of the Ishigaki Group, but traces of the thrust faults are now obscure.

Faults are more abundant on Ishigaki-shima than the geologic map indicates. Many observed faults are not shown because the scale of the map does not permit it. Vegetation prevented the tracing of many suspected faults, and many faults suggested by the topography as viewed on the aerial photographs could not be proved on the ground.

FAULTS AFFECTING THE ISHIGAKI GROUP

The offsetting of the Hirakubo peninsula from the Ibaruma peninsula and the straight southwest shore of the Hirakubo peninsula and northeastern shore of the Ibaruma peninsula suggests a northwest-trending fault with strike-slip movement. However, the fault itself was not found in the area where the two peninsulas join. A parallel fault between the Ibaruma and Nosoko peninsulas is also postulated on the basis of the straight steep south shoreline of Funakuya-wan and the abrupt termination of the rock of the Ishigaki Group south of Ibaruma. Benioff (1954, p. 385), in explanation of island arcs, proposes major thrusts along the convex side of the arcs. The eastern side of Ishigaki-shima might be such a thrust front. The two postulated northwest-trending faults could then be tear faults perpendicular to the thrust.

The Tertiary volcanic rocks of the Nosoko peninsula are separated from rocks of the Ishigaki Group on the south by a high-angle fault that can be observed at several places in a small stream valley in the mountains about 1.3 kilometers west of Inōda. At one place the fault is nearly vertical and strikes N. 40° W. Carbonaceous schist and greenschist are in contact with weathered tuffs and breccias. To the east the fault may have two branches, one extending east and the other southeast (pl. 4).

No known exposures of rocks of the Ishigaki Group occur on the Nosoko peninsula north of the fault. The Nosoko volcanism may have occurred in a down-dropped faulted or sheared zone through which magma rose, forming submarine volcanoes. Later, in Tertiary time, movement along faults uplifted the volcanic rocks.

A northeast-trending fault zone is postulated in the area where the Yarabu and Kabira peninsulas join the main body of the island. The fault separates rocks of the Fu-saki Formation to the south from those of the Tumuru Formation to the north. The formation of Kabira-wan may be related to this fracture zone, and in the schist at Ō-saki a fault which has the same strike could also be an extension of it. The Sakieda Rhyolite is believed to have risen in the fracture zone, largely obscuring the faults and fractures. In the fault zone on the east side of the road, 0.6 kilometer north of Kūra-hama, breccia and mylonite are found along with the Sakieda Rhyolite. A fault scarp or faultline scarp as much as 1 meter in height also occurs there. The scarp is believed to represent late faulting after emplacement of the rhyolite. The rhyolite dikes and sills of the Hirakubo peninsula have a similar northeastward strike and might have been emplaced along an extension of this fault zone along with the rhyolite at the northeastern end of the Ibaruma peninsula.

A fault 0.5 kilometer north of Ō-saki separates rocks of the Tumuru Formation from those of the Miyara Formation. Strike of the fault is east-west, and the south side is upthrown.

Other faults in rocks of the Ishigaki Group are found in a complex mountain area in the southwestern part of the island to the east of Fu-saki; this area includes Maishi-take on the west and Bannā-dake on the east. The rocks are so weathered, and the vegetation is so heavy that most structures are not clear or can be seen in only a single exposure. Only two faults are described, but many others are probably present. Some geologists (Aoki, 1932) have postulated on the basis of topography that the south front of the mountain range is a scarp along an east-west fault. A northwest-trending fault can be observed at the south end of the pass between the two mountain groups. The movement, as indicated by slickensides in chert, was vertical, and the northeast side of the fault is upthrown. The amount of displacement exceeded the thickness of the chert, and it was probably between 15 and 60 meters. The other fault trends northeast. Its extension would meet the northwest-trending fault where the road crosses the mountains through a pass, but the relationship of the two faults is not evident. The southeast side of the northeast-striking fault is downthrown. Vertical displacement is probably about 15–30 meters, as estimated by displaced beds. Slickensides indicate some horizontal movement, the southeast side moving northeast.

Topographic evidence indicates a large fracture or fault extending from the northeastern boundary of the granite in the vicinity of Bōbura-yama east-southeast through schists of the Ishigaki Group. It was not recognized in the field or on aerial photographs in the vicinity of a northwest-striking schist ridge to the east of Suku-baru. However, in the schist southeast of the ridge is a fracture or fault zone on the same trend, a zone in which there has been a little mineralization. Japanese prospectors dug for maganese there, and the diggings have been referred to as the Kamiyama manganese "mine." (See section on "Economic geology.")

FAULTING OF THE MIYARA AND NOSOKO FORMATIONS

The Miyara and Nosoko Formations in the interior of Yarabu peninsula are broken by many small faults. Almost all have vertical or nearly vertical fault planes. The displacement is generally less than 15 meters and usually 1.5–8 meters. Drag is common in beds along the faults. Several small high-angle faults can be seen in the volcanic rocks on Ogan-zaki, and one fault can be traced for more than 1 kilometer inland. The Miyara Formation in the near-sea-level valley 0.5 kilometer north of Ō-saki is believed to have been deposited unconformably on schist of the Ishigaki Group and then downfaulted along high-angle faults. Nearby patches of the same limestone at altitudes of about 100 meters are limestone remnants on high-standing fault blocks.

Northwest of the village of Miyara, the Miyara Formation is displaced by a northwest-trending fault. The fault plane, with slickensides, is exposed in several clay pits about 1.7 kilometers northwest of Miyara. Limestone sinks 7–9 meters deep also occur along the faultline. The northeast side of the fault is upthrown and consists of highly weathered Nosoko volcanic rocks (exposures too small to show on the geologic map) and conglomerate of the Miyara Formation. On the southwest side of the fault, limestone and conglomerate of the Miyara are exposed. The displacement could not be measured because the thickness of the conglomerate of the Miyara in this area is not known, but the displacement is not more than 30 meters and is estimated to be 7–15 meters.

Other faults in the area northwest of Miyara are less distinct, but the erratically distributed and complexly broken limestone blocks, sections of conglomerate which seem too thick, slickensides, abrupt changes in lithology from limestone to conglomerate or to volcanic rocks, and topographic breaks have been the basis for showing several other faults on the geologic map (pl. 4). Many small faults not shown are also postulated. Some of the disruption in this area may have resulted from the intrusion and extrusion of lava in Nosoko time.

Faults are suggested to separate three large blocks of limestone of the Miyara Formation which occur along a north-south line in the vicinity of Hoshino (pl. 4, cross section *B–C*). Each block forms a separate, steep-sided hill in which the beds strike nearly east and dip about 35° S. Each block seems to consist of limestone from approximately the same part of the stratigraphic section, as indicated by lithology and fossil content. From south to north the hills range in altitude from a little more than 60 meters to more than 100 meters. The blocks are probably remnants of a limestone reef that approximately paralleled the shoreline in Eocene time but that was later tilted and broken by faults. The principal evidence for the faults is the tilting of the limestone blocks and the repetition of the same part of the stratigraphic section in each block. Fault planes in the vicinity of the limestone are covered, but topographic breaks in the schist hills to the west suggest that most of the faults probably have a northwest trend. The scarps on the limestone blocks and the postulated generally straight trend of the faults indicate that the faults are high angle. Some disturbance, including brecciation, was noted in nearby schist beds.

About 0.8 kilometer north of the village of Ōzato, two faults in the limestone of the Miyara Formation were observed. One strikes north, is nearly vertical, and brings up basal conglomerate of the Miyara and schist on its west side. Displacement is probably between 15 and 60 meters. The other fault cuts northeast across limestone of the Miyara. The southeast side is upthrown. Displacement is probably less than 30 meters.

Conglomerate of the Miyara is faulted in the vicinity of Nusukun-muru. Two east-trending faults are necessary to explain the abrupt termination of the conglomerate beds against schist on the southern margin of their outcrops, as the beds are dipping about 35° S. North- and northeast-trending faults are postulated because of brecciation and disruption of the schist beds.

Many small high-angle faults were recognized in the Nosoko Formation in the interior of the Nosoko peninsula, mostly near rhyolite dikes. Amount of throw is unknown but is probably less than 30 meters in each fault. The faults cannot be traced in the field along their strike because they are generally exposed only in a single outcrop in small stream valleys. They may be direclty related in emplacement of the dikes.

A northeast-trending fault probably extends along the valley of the Ōura-kawa. It may explain the straight lower course of the river and the abrupt rise of volcanic cliffs near the coast on the northwest side of the stream.

FAULTS AFFECTING THE RYUKYU LIMESTONE

Faults that cut the Pleistocene limestone and scarps in the limestone are not conspicuous on Ishigaki-shima; however, an east-northeast-trending fault scarp, as high as 10 meters in places, occurs in the Ryukyu Limestone on Taketomi-shima. Tilted Ryukyu Limestone on the northwest shore of the Nosoko peninsula (fig. 30) and a northeast-trending fault in the Ryukyu Limestone 1.2 kilometers west of Shiraho are two indications that the Ryukyu Limestone was faulted after its deposition on Ishigaki-shima. The Shiraho fault is indicated by a long, low, particularly well-lithified ridge that has several sinks along its course.

FAULTS IN GRANITIC ROCKS

Fractures are abundant in the granitic rocks, but in most places it is difficult to discern whether or not differential movement has taken place along them. One nearly east-trending fault on the south side of Omoto-yama is postulated on the basis of topography, irregular contact with the Ishigaki Group, and local slickensides (pl. 4). Many of the straight stream valleys, especially those which begin opposite each other on a divide and then follow the same trend, are suggestive of faults. However, those investigated in the field (a prominent example is the northwest branch of the Shiramizu-gawa) appear to owe their trend to long straight joints. The granodiorite ridge which includes Chā-yama changes trend from northeast to east between Kādō and Takeda-yama. This change in trend has been attributed to faulting, but no conclusive field evidence was found to support a postulated fault. The trend of this fault would be northwest and could logically be extended across the valley of the Bunēra-gawa into the northwest-trending branch valley of the Shiramizu-gawa.

A complex of small high-angle faults is postulated in the Mae-take area of the Kabira peninsula on the basis of outcrop pattern and topography. These faults may be related to the igneous activity.

JOINTS

Joints are abundant in all rocks of Ishigaki-shima, but there is a wide range in their orientation, spacing, and influence on topography.

Rocks of the Ishigaki Group are severely jointed in most areas. In the schists of the Tumuru Formation, fairly regular sets of joints are present; but in much of the Fu-saki Formation, especially in chert, fractures are closely spaced and in many localities extend in many directions but do not show a particular pattern. In the area east of Fu-saki, this has resulted in jumbles of randomly oriented chert blocks. Many cracks, especially in the chert, have been filled with calcite or quartz, making intricate networks of white veins and veinlets. This network can be seen at Kēra-zaki on Nagura-wan and at Fu-saki.

In the Tumuru Formation at Hirakubo-zaki and Ura-saki on the northern end of the Hirakubo peninsula, small islets have resulted from erosion along joints. At Ura-saki, a conspicuous set of nearly vertical joints strikes N. 45° W., and another less conspicuous set strikes N. 10° W. Sea stacks formed by erosion along joints (fig. 13) are present at Hirakubo-zaki. The large joints are 1–5 meters apart. The small schist hills inland from Hirakubo-zaki may have formed from erosion along joints when sea level was higher than it is at present.

At Tumuru-saki at the northeastern corner of the Ibaruma peninsula, the most conspicuous joints in the Tumuru Formation strike N. 70° E. The most conspicuous set of joints on the Hirakubo peninsula generally strikes northwest. In each case, the joints are approximately at right angles to the strike of the schistosity.

Joints in the Miyara Formation are most conspicuous in the limestone because solution has taken place along them. In the limestone hills near Hoshino, two well-developed sets of joints occur in the southward-dipping rocks. One set strikes approximately west and dips steeply north; the other strikes north and is nearly vertical. Solution along rectangular joints in limestone of the Miyara Formation in the areas north of Miyara has resulted in remnant limestone blocks more than 1 meter across. Some of the limestone of the Miyara Formation of the Yarabu peninsula and of the areas near Miyara is irregularly broken and does not show particularly dominant trends in the joints. Spacing of joints in the limestone ranges from less than 0.3 to about 3 meters. Joint blocks more than 1 meter across are common.

Vertical joints perpendicular to the strike of the beds are present in the conglomerate of the Miyara Formation at places such as the Nusukun-muru area, but in most exposures joint sets are not conspicuous.

The volcanic rocks of the Nosoko Formation are considerably jointed. Joints in the coarse breccias are commonly widely spaced and result in the formation of large breccia blocks 3–8 meters across. In fine-grained tuff, some joints are only a few centimeters apart. These joints generally are only a few centimeters to a meter or so long and are rarely continuous through overlying and underlying thicker or coarser beds (fig. 27).

At Ogan-zaki, erosion along large joints in the Nosoko Formation has produced sea stacks (fig. 23) The hills at the northern end of the Kabira peninsula may have resulted from marine erosion along joints in the volcanic breccia when sea level was higher than it is at present.

The Nagura Gravel is not sufficiently compacted to show much jointing, but vertical joints are conspicuous in the outcrop of the Bunera Clay Member on the Bunēra-gawa (fig. 41*A*). These joints are 0.3–2.5 meters apart.

In the Ryukyu Limestone, joints are mostly a meter or more apart, and solution has occurred along them. This solution is particularly evident along the coasts. For example, near Tomino on the northern coast, isolated islets have been formed by the separation of limestone blocks dissolved largely along joints. Joints are more conspicuous in the coralliferous limestone than in the sandy limestone. The joint planes are commonly very irregular, and the joints have many different trends.

Ridges in Ryukyu Limestone which average about 1 meter high radiate outward from Miyara-makinaka to the east-southeast, southeast, and south-southeast. They are tentatively attributed to the effects of solution along radial joints in the limestone. Uplift, a small igneous intrusion, or volume loss in a dome-shaped limestone mass in the vicinity of Miyara-makinaka could have produced this radial pattern.

The granite and granodiorite have conspicuous rectangular joint sets, commonly 1–4 meters apart. Weathering along joints produces large, loose boulders. A very conspicuous set of joints in the granite strikes N. 50° W. Stream valleys usually follow these joints. Right-angle bends in stream courses are often controlled by joints.

STRUCTURES RELATED TO IGNEOUS ACTIVITY

The granite stock which covers a mountainous area of about 19 square kilometers in the northwestern part of the island is the only pluton known in the southern Ryukyu Islands. Wherever its contacts have been seen, they are discordant. The stock is posttectonic in relation to the major folds in rocks of the Ishigaki Group. It is undeformed, and associated dikes do not appear to be folded. The granitic rocks are not granulated, and they do not have a secondary foliation.

The intrusion caused upturning of beds of the Ishigaki Group on the western side of the stock. Some steep dips in chert and other rocks of the Ishigaki Group on the southeastern and northeastern margins of the intrusion were probably also caused by the intrusion.

Faults and fractures, which may have been caused by the rise of granitic magma, occur along the margins of the granitic stock. They were particularly observed along the contact between the Ishigaki Group and the granite on the western side of the stock. Most of the faults are small and are not shown on the map, but several larger ones, postulated on the basis of topography and outcrop pattern, are indicated as inferred faults. They are believed to have nearly vertical fault planes. Granophyre appears to have risen along some marginal faults and fractures, making dikes and veins.

Topography in the vicinity of Minanosoko-mori suggests that slight doming of the metamorphic rocks has occurred. This may have been caused by an unexposed igneous intrusion.

Little remains of the original volcanic forms associated with Nosoko volcanism. No collapse or other large volcanic structures have been recognized. Some of the volcanic materials may have come up through shear zones and along faults, particularly in the Hirakubo peninsula and in the neck of the Yarabu peninsula. The rhyolite hills at Tsuzutunu-muru may be remnants of small extrusions or shallow domelike intrusions.

The presence on the Nosoko peninsula of a continuous mass of volcanic rocks is significant because they mark a major break in the continuity of the metamorphic foundation rocks. If present beneath the volcanic materials, the metamorphic rocks are considerably lower in altitude than those to the north and south. It is possible that volcanoes did not rise through or do not rest upon rocks of the Ishigaki Group but that they were built up on other basement materials. Rocks of the Ishigaki Group in this area may have been displaced laterally to the southeast (or northwest). Unfortunately, no direct indication of the structural relationship of the metamorphic and volcanic rocks in this area was discovered.

STRUCTURES DUE TO SUBMARINE SLUMPING

Structures attributed to submarine slumping are best exhibited at Ogan-zaki. Beds of tuff, tuff-breccia, and breccia have a general dip of 15°–26° SW., but in places, small segments of these beds dip in many divergent directions. Probably the segments broke off, slid downslope, and were cemented together. The beds were at least partially consolidated when the slumping occurred, because the original bedding is visible in each diversely oriented slump block (fig. 29). Slumping was submarine rather than subaerial because the slumped beds change laterally into undisturbed marine beds, and they overlie undisturbed marine beds without evidence of an unconformity.

Folds believed to be caused by contemporaneous deformation, probably submarine sliding of unconsolidated sediments, are present in the Nosoko Formation at Tamatori-saki along the eastern coast of the Nosoko peninsula. The folds are about 1.3 meters across, and their axes can be traced only a few meters. Their axial planes are vertical. Nearby rocks of the same formation are not folded.

RELATION OF STRUCTURE TO ISLAND CONFIGURATION AND THE RYUKYU ARC

The irregular shape of Ishigaki-shima is probably due, in large part, to events in the structural history of the southern Ryukyu arc, as well as to relatively local structural events. The general trend of the present island is probably controlled, at least in part, by the position and shape of the trough in which the materials composing the Ishigaki Group were deposited. These materials became the foundation of the island. Although later thrusting of the Ryukyu arc may have displaced these rocks eastward or southeastward to some extent, they are probably not far removed from their place of deposition. As suggested previously, irregularities in the thrust front and tear faults along which lateral movement was differential may account for the abrupt breaks in the alinement of parts of the island.

Structural trends clearly related to the trend of the Ryukyu arc and relevant to its structure and history are not particularly evident on Ishigaki-shima except that the island itself, along with Taketomi, Kobama, and Iriomote, is along the axis of the Ryukyu ridge (pl. 3). The pattern of outcrop of the Tumuru Formation may result, at least partly, from the main northeast trend of the Ryukyu ridge, but the relationship, if any, between the trend, the strike of the folds, and the strike of the schistosity is not clear. The increased width of southern Ishigaki-shima compared with the northern part of the island may be due partly to the change in trend of the ridge. On Ishigaki-shima, the east-northeast trend to the north changes to an almost east trend toward Taiwan. The east strike of the Fu-saki Formation in the southern part of the island and its outcrop on islets on an approximately east-west line to the west of Ishigaki-shima are representative of this general east-west trend. Submarine contours to the south of Ishigaki-shima and Iriomote-jima have an east-west parallelism (pl. 3).

The submarine topography around Ishigaki-shima is known in too little detail to determine whether or not any of the faults on the island can be traced on the sea floor. Trends parallel to the so-called Miyako structural trend (Doan and others, 1960, fig. 6) may exist but are uncertain. A structural break striking northwest between Miyako and Ishigaki-shima is suggested by the submarine topography.

METAMORPHISM

Regional metamorphism of the sedimentary and volcanic materials composing the Ishigaki Group probably occurred either in the Paleozoic or Mesozoic Era. The metamorphism is similar to that occurring in zones of low-grade regional metamorphism in other former geosynclinal areas, for example, California, Corsica, and Japan. The physical conditions that would produce such rocks seem to be a low temperature and high water and load pressure, according to many authors, including Fyfe and Turner (Fyfe and others, 1958, p. 177; Turner and Verhoogen, 1960, p. 544). The Tumuru and Fu-saki Formations were probably metamorphosed together, but because of different original compositions the resulting metamorphic rocks differ. Possibly the rocks of the Tumuru Formation were subjected to slightly higher load pressure than those of the Fu-saki Formation because of deeper burial.

In terms of their metamorphic history, the rocks of the Ishigaki Group, especially those of the Tumuru Formation, seem to be most closely associated with rocks which Fyfe and others (1958, p. 228) and Turner and Verhoogen (1960, p. 543) regarded as representing a transition between the greenschist and glaucophane schist facies. These authors suggested that the glaucophane schist facies should be restricted to cover glaucophane schists associated in the field with lawsonite, jadeite-aegerine- or pumpellyite-bearing assemblages, in which albite is absent and epidote is rare. This is the general association in California, the Celebes, and elsewhere.

On Ishigaki-shima, no association of glaucophane with lawsonite or jadeite-aegerine is known, and only one specimen containing a small amount of pumpellyite has been found. Albite is common, and epidote, abundant. Except for the additional occurrence of sodium amphibole in the rock in place of actinolite, the mineral assemblage is virtually the same as that typical of the greenschist facies as defined by many authors for other regions. As in some other regions, such as in Japan, the glaucophane schists of Ishigaki-shima are interstratified with and grade into greenschists.

The reason for the blue amphiboles and the source of sodium which they contain is undetermined on Ishigaki-shima, as in other localities. The supposition that the agent of metasomatism is a sodic aqueous solution expelled from ultramafic magma now represented by serpentine rock does not seem applicable to Ishigaki-shima as no serpentinite bodies have been found on Ishigaki-shima or any of the neighboring Ryukyu Islands.

Other sources of sodium have been suggested for glaucophane schists, such as water rising from depth along fractures and zones of crushing (Williams and others, 1954, p. 225). Fyfe and others (1958, p. 227) suggested that glaucophane may have originated through the role of a pore fluid particularly rich in dissolved salts, derived from trapped sea water. However, Brouwer and Egeler (1952, p. 69) concluded that for glaucophane-bearing rocks of Corsica an addition of sodium was not essential for formation of the sodium amphibole and that it was not necessary to assume an initially high alkali content for the parent rock. More recently, Seki (1958, p. 256) also concluded after studying glaucophane-bearing rocks in the Kanto Mountains, Japan, "* * * most of the glaucophane bearing schists do not show any direct relation to the serpentine intrusives. Some amount of soda must be present for the formation of glaucophane, but neither the specially high contents nor the introduction of soda is necessary. Probably glaucophane schists are formed under low temperatures combined with high rock pressures, and no peculiar chemical conditions are necessary." Miyashiro and Banno (1958, p. 103) reached similar conclusions.

Although chemical data for Ishigaki-shima is limited, the conclusions of Brouwer and Egeler, Seki, and Miyashiro and Banno may be applicable. Chemical analysis of glaucophane and crossite schists of Ishigaki-shima shows a Na_2O content ranging from only 1.63 percent to 4.86 percent (table 2), which is in the range of that of many basalts. The Na_2O content of a fairly fresh rather mafic Tertiary andesite on Ishigaki-shima is 3.91 percent (table 6). Thus, because glaucophane rocks of Ishigaki-shima probably have originated largely from mafic parent materials, no additional source of sodium seems to be required.

Physical condition or conditions only slightly different from those which produce a normal greenschist facies, such as higher pressures, may be responsible for the formation of the glaucophane and crossite. Fyfe and others (1958, p. 173) stated that geological observations and experimental data suggest temperatures around 300°C and load pressure around 3,000 bars as conditions at the low-grade limit of the greenschist facies. Water pressures are assumed to approximate load pressures. For the true glaucophane schist facies, in which minerals such as jadeite-aegerine, lawsonite, and pumpellyite are present, Fyfe and others (1958, p. 177) postulated temperatures of the order of 300°C but water and load pressures considerably higher than those required for the formation of greenschist. They stated that such high pressure might obtain in localized shear zones or in deeply buried, water-saturated sediments in a region of exceptionally low thermal gradient connected in some way with geosynclincal conditions. Glaucophane schists of Ishigaki-shima, which lack minerals such as jadeite and lawsonite, are similar mineralogically to greenschists; they occur interbedded with greenschists and may have been formed under pressures intermediate between those producing the normal greenschist facies and those producing the true glaucophane schist facies (as defined by Fyfe and others, 1958, p. 227). As Turner said (Fyfe and others, 1958, p. 218), "Where temperatures are relatively low even at considerable depth (high pressure) the greenschist facies might grade, with decreasing temperature or increasing pressure, into the glaucophane schist facies."

A tentative pressure-temperature diagram—from a paper by Shido (1958, p. 213)—that illustrates these relationships is reproduced as figure 58.

Yossii (1935, p. 226) suggested, on the basis of the few specimens that he studied from Kobama-jima and Iriomote-jima that degree of metamorphism increases from east to west. Such a hypothesis does not seem justified on the basis of Yossii's few specimens. The writer's observations indicate that schists of the Yaeyama-guntō, at least those of the Tumuru Formation, have a similar metamorphic history, although slight variations in schistosity will be found at different localities within the islands. However, if any of the greenstones and phyllites of Okinawa-jima are correlative with the Tumuru Formation, Yossii's conclusion might be justified. In general, metamorphic rocks of Okinawa-jima seem to have had a somewhat lower degree of metamorphism than those of the Tumuru Formation of Ishigaki-shima. Also, no glaucophane schists have been reported from Okinawa-jima. Some metamorphic rocks of the Central Range of Taiwan are more highly metamorphosed than rocks of the Yaeyama-guntō, but their correlation with those of the Yaeyama-guntō is uncertain.

EARTHQUAKES AND TSUNAMI

EARTHQUAKES

The Ryūkyū-rettō is an active seismic zone (pl. 3). From 1885 to 1956 more than 223 recorded earthquakes having epicenters in its vicinity were strong enough to be felt throughout an area with a radius of at least 100 kilometers. Most of the earthquakes originated at shallow depths; deep-focus earthquakes are not characteristic. The zone in which large earthquakes most frequently occur lies somewhat to the east of the land areas.

Data about earthquakes on Ishigaki-shima and the rest of the Yaeyama-guntō are scarce because no seismographs have been in continuous operation there. The Ishigaki-shima Weather Station has recorded "felt" earthquake shocks since about 1897. They report that an average of about 12 earthquakes per year are felt on Ishigaki-shima. These are generally very light and cause no damage (Ishigaki-jima Observatory, 1953). Occasionally an earthquake is sufficiently strong to damage stone walls and houses and cause landslides.

The largest earthquakes to affect Ishigaki-shima in recent years occurred on September 27, 1947, and March 11, 1958 (Ishigaki-shima Weather Station, 1948; Ishigaki-jima Weather Station, 1958). In 1947 stone walls were heavily damaged, but no houses were demolished. Ground fissures opened in several places,

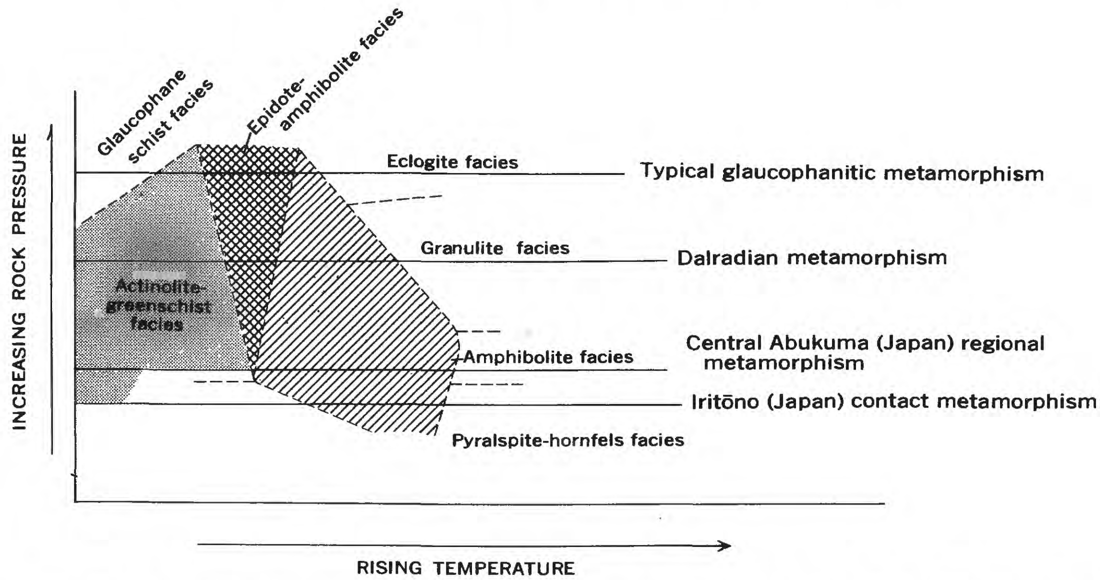


FIGURE 58.—Tentative pressure-temperature diagram for glaucophane schist. (Modified from Shido, 1958, fig. 31, p. 213)

and two landslides occurred (Ishigaki-shima Weather Station, 1948). The epicenter of the March 11, 1958, earthquake was about 100–130 kilometers southeast of Ishikagi-shima at lat 23°30′N. and long 125°E. Elderly inhabitants stated that this was the strongest earthquake felt on the island since 1898. The Ishigaki-shima Weather Station (Ishigaki-jima Weather Station, 1958) estimated that about 50 percent of the stone walls in Shika collapsed. These walls are mostly loosely piled boulders of unbonded Ryukyu Limestone. Fissures in the ground in Shika were as much as 5 centimeters wide. The concrete pier at Shika sustained a crack about 150 meters long and 14 centimeters wide. Reclaimed land near the pier was fissured and subsided 15 to 20 centimeters. About 20 percent of the roofs of the houses in Shika (mostly tile) were somewhat damaged, and the walls of many houses cracked. Many roads on various parts of the island were fissured. Several bridges and their foundations were damaged. Some rice fields were also damaged because the rice plants were buried and because parts of the fields subsided.

The intensity of this earthquake was given as V on the Japanese scale of VII—that is, very strong (estimated acceleration of 128–512 gals). Rumblings resembling distant thunder were reported to have accompanied the shocks. The direction of motion was undetermined. The seismograph of the Ishigaki-shima Weather Station was not in operation at the time of the earthquake. Duration of the earthquake motion was about 3 minutes, according to observers. No tsunami and no luminous phenomena were associated with the earthquake.

Hashimoto (1941) studied swarms of earthquakes which affected the Sakishima-guntō in 1938, 1939, and 1940. He found that fewer earthquakes occurred in the vicinity of Ishigaki-shima and Yonaguni-jima than near Miyako-jima. In 1938 he recorded 76 earthquakes in the vicinity of Ishigaki-shima which were too small to be felt and noted 2 which could be felt. In 1939 there were 37 earthquakes which were not felt and 4 which were felt; for the first 5 months of 1940, 5 were noted which were not felt. A total of 118 earthquakes which were not felt and 6 which were felt occurred during the period of study. During this same period, Miyako-jima had swarms of earthquakes of which 954 were not felt and 77 were felt.

TSUNAMI

Tsunami which result from submarine earthquakes are probably a source of greater potential danger than the earthquake shocks themselves. The largest part of the population of Ishigaki-shima live in villages along the coasts less than 20 meters above sea level and so are vulnerable.

One of the most destructive tsunami of historic times occurred on April 24, 1771. It resulted from a large earthquake which probably originated somewhere between the islands of Ishigaki and Miyako. The earthquake was felt on Ishigaki-shima about 8 a.m. but was apparently not severe enough to frighten the people. Shortly thereafter the water receded from the seashore and exposed the fringing coral reefs. Many people were attracted to the shore by this unusual phenomenon and were engulfed when enormous masses of water rushed shoreward moments later. Available information indicates that three large waves struck the shore within 2 hours (Imamura, 1938). More than 8,400 people were killed on Ishigaki-shima and Taketomi-shima.

No large disastrous tsunami has affected Ishigaki-shima since that time, but the danger is constantly present. If tsunami are caused by distant earthquakes, the tsunami warning system now in existence in the Pacific area would probably give warning to the inhabitants. However, the only warning for tsunami resulting from nearby earthquakes would be the shocks themselves. If people were alert they would have time to reach high ground, but property loss should be expected.

VOLCANIC ERUPTIONS

Volcanic eruptions have occurred near Ishigaki-shima in historic time, but none are known to have occurred on the island itself since Tertiary time. On October 31, 1924, a ship which was attempting to go from northern Iriomote-jima to Ishigaki-shima was turned back by a submarine volcanic eruption northeast of Hatoma-jima. Successions of explosions and the eruption of large amounts of pumice were reported at a location about 22.2 kilometers north-northeast of lat 24°24′N. and long 123°51′ E. (pl. 3) (Chikyū, 1924, p. 705). The sea water in the vicinity of the eruption was discolored and was described as "boiling." Heaps of pumice 1 meter high were found along a coastal area 5.5 kilometers long and 1 kilometer wide on Akabanare-shima, a small island off the northern coast of Iriomote-jima (Kishō Yōran, 1924, p. 300–302). The Ishigaki-shima Weather Station has a photograph showing extensive accumulations of pumice along the shore of Iriomote-jima which tends to authenticate the written information. Some of the pumice found in the beach deposits of Ishigaki-shima may have come from this eruption and from previous eruptions of this volcano.

Kobi-sho in the Senkaku-guntō, about 225 kilometers north of Ishigaki-shima, has also been reported to have erupted in historic times, but no details of the eruption are known (Ishigaki-shima Weather Station, 1948).

THE OCCURRENCE OF POISONOUS SNAKES AND THEIR PALEOGEOGRAPHIC SIGNIFICANCE

The distribution of the genus of snakes *Trimeresurus* (family Crotalidae) is significant in interpreting the paleogeography of the Ryūkyū-rettō in late Tertiary and Pleistocene time. Hanzawa (1935, p. 56–59) noted that *Trimeresurus* occurs on some islands of the Ryūkyū-rettō (four species and subspecies), on Taiwan, in south China, the East Indies, India, and the northern part of Oceania. *Trimeresurus* is not found north of the so-called Watase line, a demarcation used by Japanese zoogeographers to separate Paleoarctic or northern faunas from Oriental or Indochinese faunas. The Watase line is generally considered to pass through the Tokara strait north of Amami-ō-shima in the northern Ryukyu Islands. In the Sakishima-guntō, *Trimeresurus* (species *elegans*) is found on the islands of Ishigaki, Iriomote, Kobama, Taketomi, and Kuro, but not on the other small islands of the Yaeyama-guntō or on the islands of the Miyako group (Hanzawa, 1935, p. 56). Okinawa-jima and many nearby islands are infested with *Trimeresurus* (species *okinavensis* and *flavoviridis flavoviridis*).

The present distribution of these snakes indicates the following history. One or more species migrated to the Ryukyu Islands, probably from Taiwan, when a land connection existed. They dispersed throughout Ryukyuan land areas and differentiated into the four Ryukyuan species and subspecies. The land areas became separated by fairly wide, deep stretches of water and have remained separate to the present time. Islands that have the same *Trimeresurus* species may have been single large islands which eventually became separated into smaller islands. All islands which do not have *Trimeresurus* are composed largely of Ryukyu Limestone, and their snake populations were destroyed by the submergence which took place during the time the limestone was deposited. Other kinds of snakes and certain mammals also migrated to the Ryukuan land areas when there were land connections.

The time of the Taiwan-Ryūkyū-rettō land connection which enabled the migration of *Trimeresurus* and other land animals is uncertain. It was definitely post-Miocene; venomous snakes probably did not evolve until the Miocene (Swinton, 1954, p. 100), and the marine Shimajiri Formation on Okinawa-jima indicates that much of this region was under fairly deep water then. Deer bones found in clay beneath deposits of Nagura Gravel on Ishigaki-shima show that migration occurred before the deposition of the Ryukyu Limestone in the Pleistocene Epoch. Thus the land connection must have been present in the Pliocene or in the early part of the Pleistocene.

Other lines of evidence, the flora, other aspects of the fauna, sea-level fluctuations, the cutting of submarine canyons, and tectonic movements support this conclusion but do not permit the establishment of closer time limits. The depth of the sea between Taiwan and the Ryūkyū-rettō and between islands within the Ryūkyū-rettō is too great (at least 1,000 m in places) to attribute the formation of land bridges to eustatic lowering of sea level during the Pleistocene Epoch. Land movements in the late Tertiary, Pleistocene, or in both are required.

GEOLOGIC HISTORY

The principal events in the geologic history of Ishigaki-shima and the neighboring islands of the Yaeyama-guntō are summarized as follows:

1. Deposition of sediments and volcanic materials in part of an extensive geosyncline, probably in Paleozoic time.
2. Metamorphism, folding, and uplift of all or part of the geosyncline, probably at the end of Paleozoic time or possibly in Mesozoic time.
3. Erosion of the metamorphic rocks, probably in Mesozoic time, and additional uplift before late Eocene time.
4. Deposition of marine sediments and the beginning of a period of igneous activity during the Eocene epoch.
5. Continuation of volcanism, possibly into Miocene time. Probably considerable uplift in some areas.
6. Weathering and erosion of land areas in the Ishigaki region from middle and late Tertiary time to early Pleistocene time. The Iriomote and Yonaguni regions were sites of deposition of tens or hundreds of meters of sandstone in Miocene time.
7. Local or regional uplifts forming land connections with Taiwan, Asia, and some other Ryukyu Islands.
8. Local submergence followed by uplift. Accumulations of gravel in early(?) Pleistocene time. Beginning of reef development.
9. Development of extensive fringing reefs during the Pleistocene Epoch. Rate of growth and the position of reefs changed with fluctuations of sea level. Marine terraces formed at different stands of the sea. Some land movements probably occurred, breaking many of the connections between islands.
10. Faulting in late Pleistocene and Recent time. Remaining land connections between islands broken. Continued subaerial erosion and growth of fringing coral reefs.

PALEOZOIC ERA

No rocks considered as Precambrian in age are exposed on any of the Ryukyu Islands, and none are known from Taiwan. The existence of Precambrian rocks in Japan is uncertain. The earliest geologic history of the Ryūkyū-rettō is recorded in the rocks of the metamorphic terrane which forms the foundation of some of the islands. These rocks, the Kunchan Group and Motobu Limestone on Okinawa-jima and the Ishigaki Group on Ishigaki-shima, are geosynclinal deposits. They are presumed to be Paleozoic in age because of fossils found in the Motobu Formation (Flint and others, 1959, p. 26). Rocks of similar lithology, structure, and degree of metamorphism in Japan, Taiwan, and other Ryukyu Islands suggest that a geosyncline may have extended from Japan to Taiwan either as a long continuous trough or as a linear series of troughs and basins. A volcanic archipelago may have bordered the geosyncline, at least during part of the time of its existence.

Some time after the deposition of volcanic and sedimentary materials in the geosyncline, a major orogeny occurred. The rocks were folded, thrust faulted, and metamorphosed. This orogeny seems to have been the largest to have affected the Ryūkyū-rettō. The major elements of the Ryukyu arc probably originated at this time. Hanzawa referred to "the great Riukiu Cordillera," which he envisioned as produced by such an orogeny at "very nearly the present site of the Riukiu Islands" (Hanzawa 1935, p. 17). Unmetamorphosed Eocene sedimentary rocks establish that the orogeny occurred before the Eocene. In Japan, this orogeny is considered to have taken place in the late Paleozoic or early Mesozoic, although some geologists consider it Cretaceous in age.

A question arising is whether the present Ryukyu arc occupies virtually the same position as the geosyncline in which the foundation rocks were deposited, as suggested by Hanzawa (1935, p. 17), or whether the rocks have been moved eastward or southeastward by thrusting or drift. Kobayashi (1941, p. 464) believed that the Ryukyu arc advanced toward the Pacific side. The configuration of Ishigaki-shima and the postulated tear faults in the north would fit well with Kobayashi's hypothesis of movement.

MESOZOIC ERA

If all the metamorphic rocks are of Paleozoic age, there is no record of events in Mesozoic time in the Ryūkyū-rettō. The Ryukyu ridge probably stood high and underwent erosion. Hanzawa (1935, p. 17) suggested that during such a period of prolonged subaerial denudation, the "Riukiu Cordillera" was divided into several mountain masses. The presence of fairly coarse conglomerate in the Eocene Miyara Formation suggests uplift in late Cretaceous or early Tertiary time. Granitic intrusions are possibly of Mesozoic age, but the writer prefers to assign them to the Tertiary Period.

TERTIARY PERIOD

Eocene rocks rest unconformably on the eroded surface of the folded metamorphic rocks. They crop out in widely separated small areas at altitudes ranging from sea level to more than 100 meters on Ishigaki-shima and a neighboring island to the west, Kobama-jima. Their distribution suggests that they were deposited in favorable localities around eroded margins of the then-existing islands. Hanzawa (1935, p. 17) proposed a transgression of the sea in Eocene time during which the Miyara Formation was deposited.

Submarine volcanoes began to erupt in the vicinity of Ishigaki-shima about late Eocene (Tertiary *b*) time. As the volcanic rocks accumulated, shoals apparently formed around the margins of some volcanoes, creating conditions temporarily favorable for the formation of reefs and local basins in which sediments accumulated. Shoals also were present along margins of islands composed of metamorphic rocks. The conglomerate, sandstone, and limestone of the Miyara Formation accumulated in the basins and shoal areas, probably during a period of temporary volcanic quiescence. Foraminifera grew in separate small areas where favorable ecological conditions existed. A resumption of volcanic activity produced more lava and pyroclastic rocks, some of which, as on the Yarabu peninsula, were deposited over beds of the Miyara Formation. In the Nobaru-zaki and Tamatori-saki areas, limestone deposited around the margin of the volcano was broken up and incorporated into the volcanic breccia. The later volcanic deposits on Ishigaki-shima might have resulted from the same period of volcanic activity that produced those on the neighboring islands of Yonaguni-jima and Iriomote-jima. Tuffs are found interbedded in Miocene sediments on Miyako-jima and Okinawa-jima, but their source may have been appreciable distances to the west or to the north of the islands. Thus volcanic activity in the southern Ryukyu Islands may have occurred from late Eocene to Miocene.

Emplacement of the granite and granodiorite may have also taken place during the early or middle Tertiary. Some of the rhyolitic rocks of the Nosoko peninsula which resemble rocks closely associated with granite are definitely as young as Tertiary in age because they cut the andesitic volcanic rocks.

Uplift and high-angle faulting took place on Ishigaki-shima after the end of the main volcanism, and the Eocene limestones and submarine volcanic rocks were uplifted to form the Nosoko peninsula and part of the Yarabu peninsula.

While the highlands of Ishigaki-shima and neighboring areas were being eroded, nearby lowlands and basins were receiving heavy accumulations of sediments. The vicinities of Iriomote-jima and Yonaguni-jima received great thicknesses of sand. Crossbedding in the sandstone and some interbedded thin coal seems suggest that these were lowland areas at times, but a large part of the deposition was probably marine. To the northeast on Miyako-jima and Okinawa-jima, fine-grained deposits predominated, and they probably were laid down in fairly deep water. They form the Gusukube Shale on Miyako-jima and the Shimajiri Formation on Okinawa-jima. Doan (Doan and others, 1960, p. 112) on the basis of a change in type of sediments postulated for the Miyako area a change from relatively shallow-water conditions in earlier Miocene time to deep-water in later Miocene time. However, on Okinawa-jima shallow-water conditions came at the end of the Miocene following earlier deeper water conditions (Flint and others, 1959, p. 75–76).

Extensive uplift and faulting followed, and highland areas probably became extensive and fairly continuous in late Tertiary time. Hanzawa (1935, p. 17) postulated that the uplift in parts of the area from Japan to Taiwan was as great as 700 meters. He suggested that the submarine valleys near Taiwan and the Ryukyu Islands may have been cut after this uplift. Migration of land mammals and reptiles from the mainland of Asia to the Ryukyu Islands probably occurred then.

PLEISTOCENE EPOCH

Ishigaki-shima may not have been connected to other Ryukyuan land areas for long, because the deposition of marine clays there, probably in the very late Tertiary Period or early Pleistocene Epoch, indicates a reduction in land area. The position of the gray clay and the ecology of the fossils in it indicates that only the present mountain areas of Ishigaki-shima were land during this period of submergence. Uplift and rapid erosion of the highland areas that produced the Nagura Gravel followed.

Conditions gradually became favorable around much of the island for deposition of limestone and the growth of fringing coral reefs. Some of the Ryukyu Limestone was deposited, mostly around the margins of gravel deposits, although locally limestone and gravel were interbedded. While deposition was occurring on the outer reef margins, earlier formed reefs were eroded and terraced. The limestone deposition on Ishigaki-shima added considerably to the eventual size of the island. Although the number and levels of Pleistocene sea-level fluctuations have not been determined on Ishigaki-shima, the deposition of the Ryukyu Limestone probably correlates with sea-level changes. On Miyako-jima and Okinawa-jima, two or more Pleistocene limestones are distinguishable. At stages of low sea levels, some of the Ryukyu Islands may have been joined together for short intervals, and animals may have migrated from one island to another.

In late Pleistocene time, beach sands and gravels were spread over some limestone deposits and also on other bedrock terraces. On the northern side of Ishigaki-shima along the margin of the granitic mountains where coral reefs previously had grown directly against the mountain front, a change in sea level (probably caused at least partly by tilting) resulted in deposition of granitic sand over the limestone.

In late Pleistocene or early Recent time, high-angle faulting and some tilting occurred. This is more evident on other islands in the Yaeyama-guntō than on Ishigaki-shima, but probably all the southern Ryukyu Islands were affected. The occurrence of numerous earthquakes in historic time indicates that earth movements are still continuing.

The present sea level represents a lowering from the last stillstand. This lowering brought considerable calcareous sand and gravel within the wave zone, and this material formed the present beaches and some dunes and dune ridges. At present, the addition of beach material seems to be small, and the beaches are fairly stable. Typhoons and storm waves modify them slightly at times.

ECONOMIC GEOLOGY

Ishigaki-shima has few mineral resources of economic significance. Although gold, copper, iron, and manganese have been reported, no metallic minerals of economic value have been discovered. Geologic conditions are such that these minerals could be present in economic quantity, but the probability that any valuable deposits will be found is small. A few traverses with a Geiger counter revealed no significant quantity of radioactive minerals. Nonmetallic materials such as clay, quartz sand, dimension stone, and crushed rock for aggregate and road metal are of local importance.

METALLIC MINERALS

Gold.—Specks of gold in the sand of streams have been reported by the natives of Ishigaki-shima, but none were found by the field party. No gold was recognized in the numerous quartz veins and lenses that cut the metamorphic rocks.

Copper.—Japanese geologists and native prospectors have searched for copper deposits without success. Several small abandoned copper prospects are in rocks impregnated with pyrite. In one such area on the eastern coast, 1.8 kilometers southeast of Akeishi, samples were collected by the field party and analyzed for copper. Two samples of schist—which contained abundant pyrite and which were suspected of containing chalcopyrite—on analysis contained 0.245 and 0.0085 percent copper. It is believed that relatively little schist contains the higher percentage of copper and that the concentration represents local spots in a schist which generally contains much less copper. More sampling would be required to determine the amount of copper present in the schist, but foreseeable reserves are far too small to justify further work at present.

Samples of pyrite from a prospect near the east coast, 3.7 kilometers northeast of Akeishi, showed only 0.003 and 0.0027 percent copper.

Manganese.—Manganese oxides occur in small noncommercial amounts impregnating schists of the Ishigaki Group. The Kamiyama manganese "mine" is a prospect located along the main coastal highway 1.2 kilometer south of the Tōro-gawa. It consists of several trenches and pits from 0.9 to 3 meters in depth along a linear distance of 1.6 kilometers. The Kamiyama deposit was investigated in November 1951 by Sherman K. Neuschel, U.S. Geological Survey, and a memorandum report was prepared (1952).

Neuschel reported[4] as follows:

> Rocks exposed in the mineralized area are quartzitic mica schists which strike uniformly N. 45° W. with average dips of 65° to the northeast. The line of prospect trenches and pits are along a linear fault zone in which the schists are weathered and impregnated near the surface by oxides of iron and manganese. In a few pits, manganese oxide seams as thick as one-eighth of an inch were observed. Most of the manganese occurs as a thin film or stain along planes of fracture and schistosity. This mineralization is the result of surface weathering of the schist and is confined to a zone generally not more than six to eight feet below the surface. In the bottoms of the deeper pits fresh, relatively unweathered schist containing no manganese oxide stains is exposed. Existing workings indicate that the area contains about 60,000 tons of manganese impregnated schist that would average not more than 2½ percent of manganese. Grab samples were taken from several of the dumps and channel samples cut in two of the trenches. Assays of these samples were made by the Taihei Mining and Metallurgical Laboratory, Tokyo, Japan, and are presented in table 1 [table 22] of this report. The grab sample No. 6 was selected by the writer as the best appearing manganese oxide. This was found to contain only 4.8 percent of manganese.

TABLE 22.—*Assays of manganese oxide samples from Kamiyama manganese "mine," Ishigaki-shima*

[After Neuschel (1952)]

Sample	Percent			Location of sample
	Mn	SiO_2	Fe_2O_3	
1	1.90	81.32	5.89	8-foot channel sample from pit northwest of road.
2	3.82	53.40	29.04	Grab sample from dumps northwest of road.
3	1.90	53.02	18.24	5-foot channel sample from pit northwest of road.
4	1.90	73.54	11.52	Grab sample from dumps northwest of road.
5	2.93	63.66	20.30	6-foot channel sample from pit southeast of road.
6	4.82	64.32	14.77	Selected, best appearing manganese oxide from dumps northwest of road.
7	2.77	64.38	7.97	Grab sample from dumps southeast of road.
8	3.60	33.12	5.159	Grab sample from dumps southeast of road.

[4] Neuschel, S. K., 1952, The Kamiyama manganese "mine," Ishigaki-shima, Ryukyu-retto: Intelligence Div., Office of the Engineer, Gen. Headquarters, U.S. Army, Far East Command [memo. rept.], 4 p., 1 fig.

Another manganese prospect in a fault zone is along the east side of the main road about 1.3 kilometers northeast of Aka-saki, Yarabu peninsula. Thin films and stains of manganese oxides occur along fracture planes, but there are no concentrations worth exploitation. Similar manganese oxide stains are present at several other places in the schist. Manganese prospects were also found in the vicinity of Hattsua-yama on the Hirakubo peninsula. Here the manganese oxide occurs in a breccia as thin films on rock fragments and along fracture planes. Mineralization seems to be in small patches and only near the surface.

Pyrite.—Pyrite occurs at the contact between schist of the Tumuru Formation and dikes of rhyolite on the eastern side of the Hirakubo peninsula. After World War II, attempts were made to mine this mineral at sites 3.8 kilometers northeast of Akeishi and at several other nearby places. However, the reserves are small and the pyrite could not be mined profitably. Disseminated pyrite is common in schist of the Tumuru Formation, especially on the southwestern coast of the Yarabu peninsula and on the eastern coast of the Hirakubo peninsula 1.8 kilometers southeast of Akeishi. It has no present economic value.

NONMETALLIC MINERAL RESOURCES

Principal nonmetallic mineral resources of Ishigaki-shima are clay suitable for making brick, tile, and pottery; dimension stone; quartz sand; and engineering construction materials such as stone, road metal, aggregate, and riprap. Coal is present on the neighboring island of Iriomote, but none has been found on Ishigaki-shima. No sulfur deposits are associated with the volcanic rocks.

Clay.—Clay used for brick, tile, and pottery is obtained from small borrow pits 1.5 kilometers northwest of Miyara. The pits are 1.5–4.5 meters deep, 3–9 meters across, and as much as 30 meters long. The clay is yellowish brown and mottled and is derived from the weathering in place of an andesite dike or sill and of shaly limestone of the Eocene Miyara Formation along a fault zone. Less than 39,000 cubic meters of clay has been excavated, and about 38,000–76,000 cubic meters more is probably available in this area. Most of the clay products are used locally.

The clay is dug by hand, loaded into wicker baskets, and carried to oxcarts which transport it 45–140 meters to the place where the mixing, molding, and firing is done. Charcoal is used for fuel. Roofing tile is the chief product, but some pottery and brick are also made.

Dimension stone.—The sandy facies of Ryukyu Limestone, locally called awaishi, is quarried for dimension stone in two principal places on Ishigaki-shima. One locality is on the east side of the road 1.3 kilometers north of Isobe, and the other is 2.7 kilometers north-northwest of Ōhama. The quarries are small (3–9 meters long and 2–4 meters deep), hand-excavated pits. The rock is a light tan sandy, porous, poorly stratified, fossiliferous limestone. Though fairly soft when freshly quarried, it hardens slightly on exposure to air. About 36,500 cubic meters of rock have been removed from the quarries near Isobe, and at least 73,000 cubic meters remain. Approximately 13,000 cubic meters have been quarried north-northwest of Ōhama, and an equal amount is estimated to remain. The quarried limestone is used chiefly in walls, for tombs, in foundations, and as paving stone (figs. 46 and 47).

At present, Ryukyu Limestone is the only rock quarried for dimension stone, but other suitable rocks crop out. Use has probably been limited to the Ryukyu Limestone largely because it is soft and easy to work. Dense gray limestone of the Miyara Formation is suitable for dimension stone. Good quarry locations are present in the vicinity of Hoshino. This rock was previously quarried on the neighboring island of Kobama, but it has not been quarried on Ishigaki-shima. Granodiorite, granite, and some of the lava could also be quarried in selected localities, though this rock is hard and difficult to work with primitive equipment. Many of the best locations are in forested mountain areas and would require the construction of access roads. Some large blocks of granodiorite, granite, and lava that are near roads have been broken up to use as stone for bridge foundations and retaining walls. The small outcrop of marble at Ishisoko would provide good dimension stone. It could be used also for ornamental purposes, as it would take a good polish. The amount of marble is limited to an outcrop approximately 60 by 45 by 23 meters in dimensions.

Large coral heads are gathered offshore west of Kabira. They are flattened and used as foundation stones for small buildings (fig. 59).

Quartz sand.—Quartz sand suitable for fine mortar is available in sufficient quantity for local use. The principal deposits are in terraces along the southwest shore of Kabira-wan. The size range of the sand is mostly 0.42–0.74 millimeter, less than 4 percent of each sample checked having a grain size smaller than 0.074 millimeter. Reserves are small, probably about 200,000 cubic meters. This sand could also be used as an abrasive for sandblasting.

Some beach sands along Kabira-wan and at other places along the northern shore of the island contain a fairly high percentage of quartz grains, grains of calcium carbonate forming the remainder. These sands

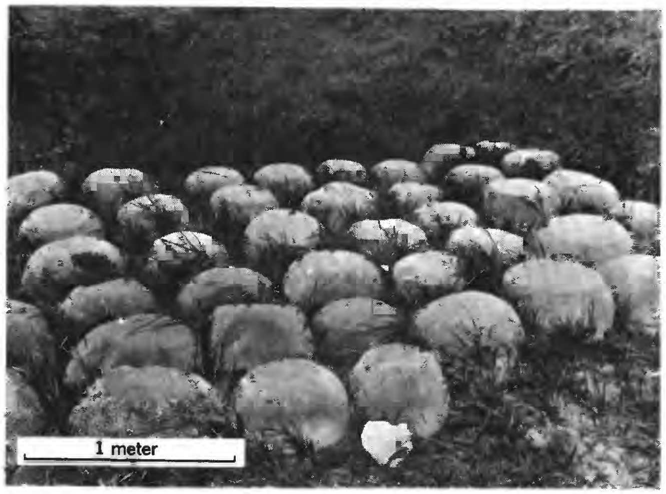


FIGURE 59.—Coral heads for foundation stones. Coral heads are gathered from the reefs and flattened for use as foundation stones in the construction of native houses and other small buildings. November 1955.

generally have a greater range in grain size than the Kabira-wan sands.

Other beach sands on Ishigaki-shima are mostly calcareous.

ENGINEERING CONSTRUCTION MATERIALS

Sufficient material is available on Ishigaki-shima to supply local needs for riprap, aggregate, road metal, and fill. To date, limited use has been made of these resources, as construction needs on the island have been limited. Road materials have mostly been obtained from small borrow pits in raised beach sands along the roads and from small quarries in the softer sandy type of Ryukyu Limestone. Portland cement is imported, and local rock is used as aggregate.

Riprap.—Several kinds of riprap are available on different parts of the island. In southern Ishigaki-shima, chert is probably the most abundant and easily obtained suitable material. Much is available in large, irregular blocks from boulder fields east of Fu-saki. At other places, knobs and cliffs of chert could be blasted, though some chert is too fractured for this use. Ishisoko, the marble hill, would provide a limited number of large blocks. On other parts of the island, riprap is probably best supplied by some of the lava and the hard breccia of the Nosoko Formation. Much of the lava is too weathered, but fresh lava such as some of that in the vicinity of Nosoko and Kūra would be an excellent source of riprap. Very well-cemented breccia such as that on the east side of Kanama-wan and some around Tamatori-saki are good sources. Unweathered granite and granodiorite boulders could also be used.

Aggregate.—Beach gravels composed predominantly of calcium carbonate have been the major source of aggregate on Ishigaki-shima. The limestone of the Miyara Formation and the hard limestones of the Ryukyu Limestone would also provide good readily available rock for aggregate. Fine-grained granite and granodiorite and mafic lava are suitable for aggregate if selected to avoid weathered and altered rock, but these rocks are generally more difficult to obtain than is the limestone.

Road metal.—Raised beach gravels and crushed sandy Ryukyu Limestone have been the chief materials used for surfacing roads on the island. These materials are generally obtained from small borrow pits and quarries as near as possible to the place where they are used. Other rocks, such as crushed limestone of the Miyara Formation and some lava and breccia, will be suitable for this purpose when needed.

Fill and other engineering construction materials.—Material for fill and other local engineering construction uses not already mentioned is available on most parts of the island in quantity adequate for local needs. The quality differs from place to place depending on the local soils and bedrock, but usable material can generally be obtained.

Portland cement and lime.—No Portland cement industry exists on Ishigaki-shima although there is a sufficient supply of calcareous and clayey materials. Minor constituents such as gypsum and iron are not easily available, and fuel would probably have to be imported. Portland cement is imported to supply the fairly limited needs of the island.

A small amount of lime burning has been done in the past and is still done, but Portland cement is now imported for many former uses of lime. Raw materials are abundant, but fuel would have to be imported for quantity production of lime. Chemical analyses of two limestones are given in table 23.

A very small cement-block industry produces handmade concrete blocks by pouring a concrete mixture into molds. The necessary Portland cement is imported,

TABLE 23.—*Chemical analyses of limestones from Ishigaki-shima*

[Analyses were performed by Japan Inspection Co., Ltd., Tokyo, Japan, September 1956]

	A (percent)	B (percent)
CaO	54.02	54.56
MgO	.22	.59
SiO_2	1.82	.60
Al_2O_3	.62	
Total Fe as Fe_2O_3	.30	.40
MnO	.010	
Na_2O	.089	.25
K_2O	.083	.18
H_2O-	.65	2.00
H_2O+	.13	
CO_2	39.00	41.00
Total	96.94	99.58

Sample A. Limestone of the Miyara Formation collected 0.4 km west of Hoshino.
Sample B. Coralliferous Ryukyu Limestone from 1.2 km northeast of Miyara.

and raised-beach sand and gravel is used for aggregate. The blocks are used in local construction.

WATER RESOURCES

Surface water from streams is the only large supply of water presently available on Ishigaki-shima. The Miyara-gawa and Nagura-gawa have the largest flows. Smaller streams of various sizes on nearly all parts of the island are used extensively by the local people for domestic water supplies and irrigation. Water in the upper courses of the streams is fairly pure, but in the lower and middle courses where it is used for irrigation, it is contaminated. Conditions are not favorable for the development of large quantities of ground water, although dug wells are widely used.

SURFACE WATER

SOURCES, QUANTITY, AND QUALITY

Streams are well distributed over Ishigaki-shima except in limestone areas of the southern part. Many short streams that have small drainage areas flow from the mountains to the sea in the northern parts of the island, including the Yarabu, Nosoko, and Hirakubo peninsulas, the northern coast, and the northern part of the eastern coast. To the south of the main mountain mass, many small streams coalesce to form the Miyara-gawa, which drains about 34 square kilometers, and the Nagura-gawa, which drains about 21 square kilometers (pl. 2). The Todoroki-gawa flows east, draining about 7.2 square kilometers (pl. 2). No permanent streams are found on Taketomi-shima because almost the entire island is permeable limestone.

The flow of the mountain streams is perennially maintained, largely by the discharge of ground water. Small streams flowing from hills and lowlands commonly have shallow valleys which do not intersect sufficient ground-water to maintain year-round flow. Nevertheless, because of the fairly large amount of rainfall and the frequency of rainy days, direct runoff provides a fairly constant supply of water for many of these small streams during normal seasons.

The Miyara-gawa downstream from its main tributaries is the only stream that normally flows more than 70 cubic feet (2 cu m) per second (45.24 million gallons per day. The only other stream with a normal flow of more than 20 cubic feet (0.56 cu m) per second (12.93 million gallons per day) is the Nagura-gawa. No other streams, except tributaries to the Miyara-gawa or Nagura-gawa, have normal flows over 5 cubic feet (0.14 cu m) per second (3.23 million gallons per day. Approximately eight streams have normal flows between 3 and 5 cubic feet (0.08 and 0.14 cu m) per second (2.53 and 3.23 million gallons per day). Because most streams are short, the effect of heavy rains is quickly shown by a rapid increase in the discharge of the streams.

The amount of suspended matter in Ishigaki-shima's streams is generally small, except after heavy rains. The water is generally low in dissolved solids (table 24), except in a few small tributaries that flow through areas of limestone of the Miyara Formation or through limy volcanic breccia; in these tributaries the water precipitates calcium carbonate in the channels. Stream waters are not safe for drinking unless they are purified.

DEVELOPMENT AND USE

Surface water has two primary uses on Ishigaki-shima, the irrigation of rice fields and domestic use. The city water supply for Shika and for many of the small villages is largely from surface water. Water diverted from the Miyara-gawa, Nagura-gawa, and Todoroki-gawa irrigates a large part of the rice land. It is first impounded behind several small concrete dams and then is diverted by ditches to the fields. In other parts of the island, small mountain streams are used to water rice fields in small valleys, on terraces, and on coastal flats. Many diversions are simple intersections of ditches with stream channels; in some, the stream levels are raised slightly to ditch level by low boulder and gravel dams or small concrete dams. Many small streams flow directly into the highest of a series of rice fields through which the water moves downward and laterally from field to field over small spillways in the confining dikes.

In many small valleys among the hills and uplands, the valley bottoms are nearly or completely covered by a succession of paddy fields. Most water for these fields is supplied by flow from adjacent slopes during the frequent rains. The fields provide considerable volume for the storage of water, and they tend to retard runoff during heavy rains.

The city of Shika obtains its water from a mountain tributary of the Nagura-gawa. The intake is located at an altitude of about 120 meters, and the water is piped 8.2 kilometers to a reservoir and filtration plant 2 kilometers northwest of Shika. The daily average water flow into the reservoir is 1,700 cubic meters, and the daily consumption reported in October 1956 was 1,350 cubic meters.

The town of Ōhama has newly constructed facilities for obtaining its water supply from a branch of the Miyara-gawa. The intake is in the mountains above present habitation and cultivation.

Most of the villages along the northern coast obtain their water from small mountain streams. Water is

TABLE 24.—*Analyses of water samples from Ishigaki-shima streams*

[Letters refer to locality on pl. 2. Analyses were made by Japan Inspection Co., Ltd., Tokyo, Japan, November 1956. Not tested is indicated (—). Analyses are in mg/l]

Sample	Date collected, 1956	Stream	Type of rock in drainage area	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Total Alkalis (Na+K)	Lithium (Li)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (P)	Total dissolved solids	Sum of dissolved constituents	Methyl orange alkalinity (as $CaCO_3$)	Specific conductance, (in micromhos)	pH
A	July 29	Unknown	Metamorphic	—	—	3.5	—	—	—	—	7.6	43	—	—	—	102	—	64	—	7.10
B	Mar. 24	Miyara-gawa	Granite, schist, limestone.	22	0.6	15.3	3.5	24	.0	80	8.7	35	.1	.0	.8	—	149	—	230	7.52
C	Mar. 24	Todoroki-gawa.	Gravel, schist, limestone.	11	.2	56	4	22	.0	155	9.1	34	.2	.0	1.2	—	214	—	450	7.73
D	Mar. 25	Fuhanan-gawa.	Schist	—	—	35	—	—	—	—	8.9	46	—	—	—	205	—	118	—	7.20
E	Mar. 25	Ōura-kawa	Volcanic	29	.2	39	11	53	.0	194	12	67	.0	.5	.8	—	307	—	530	7.77
F	Mar. 31	Nishihama-gawa.	Volcanic; limestone.	35	.3	39	7.8	53	.0	86	9.8	67	.1	3	1.5	—	250	—	530	7.77
G	July	Ara-kawa	Granite	—	—	3.5	—	—	—	—	4.3	28	—	—	—	102	—	24	—	7.05
H	July 29	Nagura-gawa	Granite, granodiorite, gravel, metamorphic.	34	.5	6.1	1.6	23	.0	42	6.0	35	.2	.3	.6	—	128	—	180	7.32
I	Mar. 25	Shiramizu-gawa.	Granite	—	—	20	—	—	—	—	5.4	28	—	—	—	172	—	17.6	—	7.12
J	Mar. 25	do	do	29	.0	2.3	.6	19	.0	28	4.3	25	.0	.3	.8	—	95	—	120	7.32
K	July 29	Miyara-gawa	Granite and schist.	—	—	47	—	—	—	—	3.5	28	—	—	—	251	—	29.1	—	7.10

either piped or carried in concrete troughs to the villages from intake points on the streams. Faucets are centrally located for public use. For some of the Nosoko area, water is diverted to settling basins by a low concrete dam on a tributary of the Nishihama-gawa and is carried by pipeline to the settlements. Some villages near mountain streams use surface water for drinking and household purposes, but the water is hand dipped from streams or ditches.

POTENTIAL DEVELOPMENT OF SURFACE WATER

Most of the land that can be irrigated by gravity flow has already been converted into paddy land in the three major drainage systems, the Miyara-gawa, the Nagura-gawa, and the Todoroki-gawa. However, in these streams there appears to be considerable surplus water that escapes to the sea. For instance, in October and November 1953 the total surplus was more than 100 cubic feet (2.8 cu m) per second (Carson and Davis, 1954). Additional irrigation projects put into operation since that time have slightly reduced the surplus.

Most of the small streams on Ishigaki-shima have now been or are being diverted for irrigation or for other water-supply purposes. Only a few streams, mostly along the north coast, remain totally undeveloped. The principal undeveloped streams are the Ara-kawa and the stream west of it. Both of these streams drain granitic mountains and have considerable fall. Development of nearby land will be difficult, however, and perhaps not feasible because of the rough, mountainous terrain.

GROUND WATER

Most of the rocks on Ishigaki-shima contain ground water, but the quantity that can be obtained from them by simple inexpensive methods is small. Chemical quality of the water is generally good except near the coasts where sea-water encroachment raises the salinity. Carson and Davis (1954, p. 33) estimated that there are 150–200 dug wells on the island. These are concentrated in and near towns and villages, mostly in the southern part of the island. The wells range from about 1.5 to 23.7 meters in depth and average about 0.75 meter in diameter. Sides of the wells are commonly lined with limestone boulders, unless the well is in bedrock. Concrete curbs and platforms have been constructed around most wells to help prevent contamination. Water is usually drawn in buckets. Most well water is used for domestic purposes. The amount drawn for irrigation is negligible.

Wells have been most successful in Ryukyu Limestone and least successful in Nagura Gravel. Sufficient ground water is available so that small additional supplies can be developed for domestic and industrial use or for supplementing surface irrigation sources. Prospects for development are best in lowlands underlain by alluvium, sandstone, tuff, and metamorphic rocks, and in selected places in the Ryukyu Limestone.

A few small springs in the mountains and in limestone areas have been improved and are sources of domestic water. The village of Kabira obtains considerable water from springs. Analyses of water from representative wells on Ishigaki-shima and a spring on Taketomi-shima are given in table 25.

TABLE 25.—*Analyses of well water from Ishigaki-shima and a spring on Taketomi-shima*

[Location of wells and springs are shown on pl. 2. Analyses were made by Japan Inspection Co., Ltd., Tokyo, Japan, November 1956. Not tested is indicated by (—) Analyses are in mg/l]

Sample	Location	Depth of well (meters)	Depth of water in well (meters)	Type of material	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Total alkalis (Na+K)	Lithium (Li)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (P)	Total dissolved solids	Sum of solved constituents	Methyl orange alkalinity (as $CaCO_3$)	Specific conductance, in micromhos	pH
8	Shika	4.5	0.75	Limestone	—	—	105	—	—	—	—	118	802	—	—	—	1,836	—	230	—	7.67
10	do	15.6	.9	do	—	—	79	—	—	—	—	23	142	—	—	—	501	—	199	—	7.52
47	Kabira	(1)	(1)	do	8.9	0.2	67	28	278	0.1	169	55	369	0.1	1.0	1.5	—	882	—	1,730	7.78
52	Kainan	21	1.4	do	—	139	—	—	—	—	—	3.3	79	—	—	—	509	—	290.5	—	7.15
T-1	Taketomi-shima.	(2)	(3)	Limestone-chert contact.	—	—	4.8	—	—	—	—	17	40	—	—	—	120	—	135	—	7.26

[1] Unknown.
[2] Spring.
[3] Not applicable.

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