Sci. Rep. Kanazawa Univ.,
Vol. 13, No. 1, pp. 51–72
June 1968

Bedrock Geology of Iheya Islands, Okinawa Island Group

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(Received 30 May 1968)

Abstract

Iheya Islands of Okinawa Island Group were geologically mapped for the first time. It was confirmed that the bedrocks of these islands were composed of the Lower Permian Iheya Formation, Middle and Upper Permian Maedake Formation, Late Paleozoic Izena Formation, and probably Late Mesozoic Dana (at Iheya-jima) and Shomi (at Izena-jima) Formations. These bedrocks are veneered by the Quaternary sediments of diverse origins such as, reefy limestone, fluviatile and marine terraces, dune sand, and beach deposits.

The Permian formations which are most widely distributed are characterized by prominent bedded chert associated with the subordinate amounts of sandstone, conglomerate, greenstone and limestone. At least three fusulinid assemblage zones are established among the lenticular layers of the limestones; i. e. *Pseudoschwagerina-Pseudofusulina*, *Parafusulina*, and *Yabeina-Neoschwagerina*. The Middle Carboniferous fusulinid *Fusulinella* and *Beedina* have been found as secondarily derived worn tests in some Permian limestones. Polymict conglomerates close to the top of the Maedake Formation may be correlated to the similar conglomeratic beds common in the Late Permian Kuman series of the Japanese Islands.

Both the Dana and Shomi Formations are in tectonic contact with the underlying Permian formations on the top and bottom of the exposed sequences, and consist of alternation of sandstone and shale, carbonaceous black shale, and coarse- to medium-grained feldspathic wacke, although the poorly sorted, wedge-shaped polymict conglomerates are common in the Shomi Formation. Some alternations of sandstone and shale in the Shomi Formation yield probably Late Mesozoic palynomorphs and unidentified leaf fossils. A predominantly nearshore or swamp environment could be postulated for the Shomi Formation, based on the paleontologic and lithologic associations.

Discoveries of the Lower and Middle Permian formations and probably Late Mesozoic nearshore formations are new addition to the stratigraphic column of the Ryukyu Islands.

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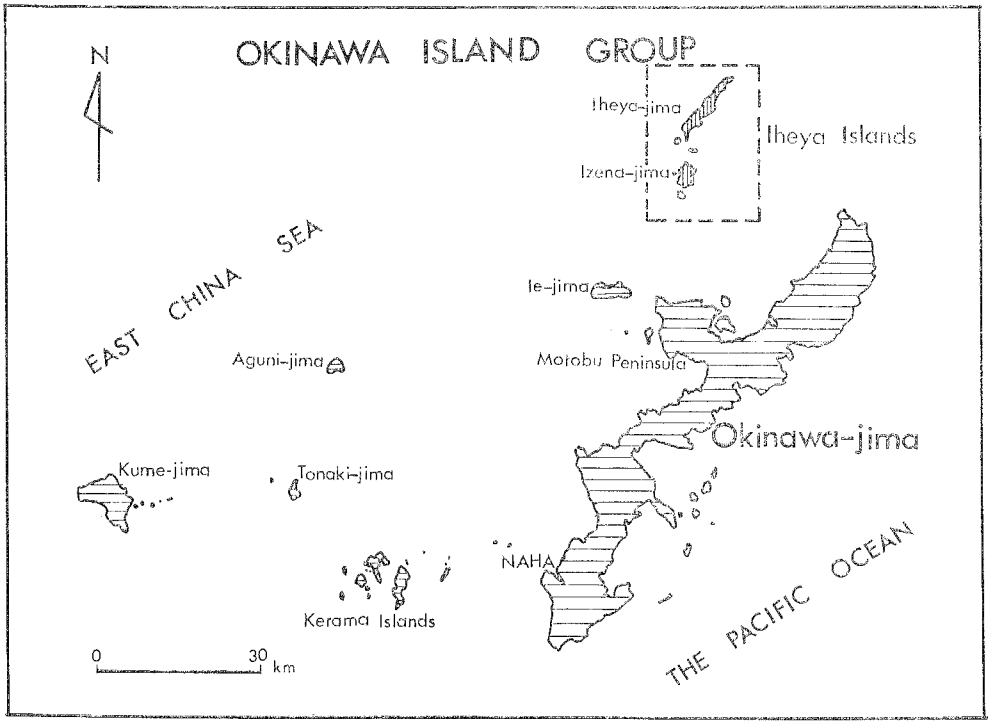
Introduction and Acknowledgments

Iheya Islands are the member of the Okinawa Island Group in the Ryukyu Island Arc. Iheya Islands, Ie-jima, Tonaki-jima and the Motobu Peninsula of Okinawa-jima are geotectonically situated in the Motobu Belt (nomenclature after KONISHI, 1963, 1965) where the pre-Miocene basement complex is mostly characterized with the weakly metamorphosed Paleozoic rocks. Previously no geological report has been published about Iheya Islands.



Text-figure 1. Index map of Iheya Islands, Okinawa Island Group

Iheya Islands lie between latitudes 27°06′ and 26°52′ north, and longitudes 127°53′ and 128°02′ east, about 50 km. north-westnorth of Naha City of Okinawa and consist of two main islands, Iheya-jima and Izena-jima, and four offshore islets. (Text-figure 1)

At present, three topographic sheets of these islands are available:

(1) 1:50,000 Iheya-mae-jima, Tana-saki and Iheya-ushiro-jima. (1923, Japanese Imperial Land Survey),

(2) 1: 29,530 Southern part of Iheya-retto (navigation chart) (1930, Hydrographic Division of Japanese Imperial Navy), and

(3) 1 : 50,000 Iheya-ushiro-jima, AMS series L761, sheet number, 3628 II; Tana-saki, s.n., 3628 III, and Izena, s.n., 3627 I. (1947, United States Army).

1 : 20,000 maps enlarged and compiled from these sheets were used for the field works.

I wish to express my most sincere thanks to Dr. Kenji Konishi of Kanazawa University, under whom I have been studying various aspects of geology of the Ryukyu Islands since my undergraduate years. I am grateful to Professor Yoshio Kaseno and other staff members of the Department of Earth Sciences at Kanazawa University, where the most parts of this work were performed. My deep appreciation also extends to Professor Ryuzo Toriyama of Kyushu University for his encouragement and interest to this work. Dr. Norio Fuji of Kanazawa University kindly made the palynological study of the carbonaceous rocks from the Shomi Formation. I wish,

further, to express my hearty thanks to many persons who gave me kind assistance in carrying out the field works; the personnels of the Department of Geography at the University of the Ryukyus for their amiable help during the present study, Mr. Senjiro HIRAKAWA, then the managing director of the Ryukyu Broadcasting Co. Ltd., who gave me many facilities for passages to the Ryukyu Islands, and also Messrs. Masataka NAKADA, Masaei HAMADA, Tamio NISHIME, and Eiho NAKA, Mrs. Natsu MAEZATO and members of the Board of Education at Izena and Iheya Villages.

Outline of Topography

Iheya Islands consist of two main islands of Iheya-jima and Izena-jima, and four offshore islets around them. They are Noho-jima, Gushikawa-jima, Yanoshita-jima and Yanaha-jima (Text-figure 2).

Iheya-jima: Iheya-jima (Iheya-mae-jima) extends northeast to southwest direction, about 14 km. long and is about 3 km. in the maximum width. The mountains ranging from 100 m. to 300 m. high above sea level are arranged along the western coast of the island, and end with steep slopes straight down to the shore at almost everywhere; Kuba-yama (104 m.), the unnamed peak (167 m.), Kitakushi-dake (233m.), Kushi-dake (224 m.), Asa-dake (216 m.), Minamikushi-dake (221m.), Kayo-dake (308 m.), and Awa-dake (207 m.) from north to south along the western coast, while Mae-dake (178 m.) is isolated at the eastern coast. The flat grounds occupy very narrow areas of the island, though the coastal terraces are developed from 10 to 25 m. high above sea level along the east coast of Iheya-jima.

Izena-jima: Izena-jima (Iheya-ushiro-jima) is situated at about 4 km. south of Iheya-jima and is nearly pentagonal in shape, having about 20 km. of the total shore lines. The topography of this island is flatter than Iheya-jima (Plate 1, Figure 1.). The mountain ridges less than 150 m. high above sea level pass the center of the island from northwest to southeast, where Ôno-yama (120 m.), Amagusuku-dake (101 m.), Aka-dake (83 m.), Jijin-dake (120 m.) and Izena-gushiku-dake (120 m.) are prominent. Isashi-dake (Menna-dake) (94 m.) is isolated at the northeastern area. Some of the mountains are fringed by the coastal terraces as high as the same level of those at Iheya-jima.

The offshore islets: Two islets, Noho-jima and Gushikawa-jima lie between two main islands, the former is flat and has the highest point of 42 m. at the near center of the islet, while the latter is elongated in the east-west direction and has the highest point of 28 m. above sea level at Nogami-yama. Yanoshita-jima, an islet of 2 km. in circumference and 9 m. high at the maximum elevation, is connected to the western shore of Izena-jima at low tide. Yanaha-jima close to the southern end of Izena-jima has the highest point of about 16 m. above sea level and coastline of 5 km. long which is complex along the western shore due to the occurrence of the basement rocks. The rock reefs named as Adan-se (9 m. high above sea level),

Takakusa-se (23 m.) and Yamakusa-se (11 m.) lie between Izena-jima and Yanaha-jima.

General Geology

Iheya Islands are composed of the Late Paleozoic, Late Mesozoic and Quaternary sedimentary rocks (Text-figure 3).

The Paleozoic rocks which are the basement complex consist of mainly bedded chert, sandstone and greenstone with subordinate amounts of shale, conglomerate and limestone, and are divided into the Iheya and Maedake Formations, in ascending order, at Iheya-jima, on the basis of lithofacies and fusulinid occurrences.* In Izena-jima, the Paleozoic Izena Formation does not yield any paleontological evidences other than radiolarians and smaller foraminifers, but it is very similar with the Maedake Formation in both lithofacies and stratigraphic sequences.

The Iheya Formation about 90 m. in thickness occurs only near Yahei-iwa, northern coast of Iheya-jima and composed of sandstone and shale with interbedded limestone lentils which yield the Lower Permian fusulinids. The overlying Maedake Formation is estimated to be about 1,200 m. thick, and contacts with the Iheya Formation by a high-angled reverse fault (Yahei Fault). The Izena Formation which seems to exceed 1,000 m. in thickness crops out at Izena-jima, Gushikawa-jima and Yanaha-jima. It consists of bedded chert in association with the alternation of sandstone and shale, altered igneous rocks, and limestone preserving only smaller foraminifers.

The Late Mesozoic formations are developed in Izena-jima and Iheya-jima. The Shomi Formation cropping out in the central part of Izena-jima contacts with the Paleozoic Izena Formation by faults on both lower and upper limits, and is overlain by the Quaternary terrace sediments. This formation is about 1,300 m. in thickness and lithologically divided into two members, as the Nakata Conglomeratic Sandstone Member and Matecha Sandstone-Shale Alternation Member in ascending order. The former includes two beds of cobble to pebble conglomerate. In Iheya-jima, the Dana Formation lies in the central part from north-northeast to south-southwest direction and consists of sandstone-shale alternations about 500 m. thick which resemble the Matecha Alternation Member of the Shomi Formation in both lithologies and degree of structural deformation.

The Quaternary sediments consisting of both the Pleistocene and Holocene crop out at all the islands. The former is composed of reefy limestone accompanied with beach sand facies, and of terrace deposits. Two terrace deposits at different levels are distinguished, the higher one of which appears to be restricted around Kiura-dake in Izena-jima, occupying 40 to 60 m. above sea level. The Holocene sediments are

* Results of the paleontological studies will be published elsewhere as a separate paper.

composed of raised beach deposits and present beach deposits including beachrocks along the coastal areas.

SYS.	Iheya-jima FORMATION	T.(m)	Izena-jima FORMATION	T.(m)
QUATERNARY	Beach deposits			1+
	Raised beach deposits			5+
	Yanoshita-jima? limestone			30+
	Uchihana gravel bed			3+
			Kiuradake g. bed	2.6+
CRETA.?	Dana F.	500	Shoji Matecha M.	500
			Nakata M.	600
PERMIAN	Maedake Formation	1200	? Izena Formation ?	1000+
	Iheya Formation	90		

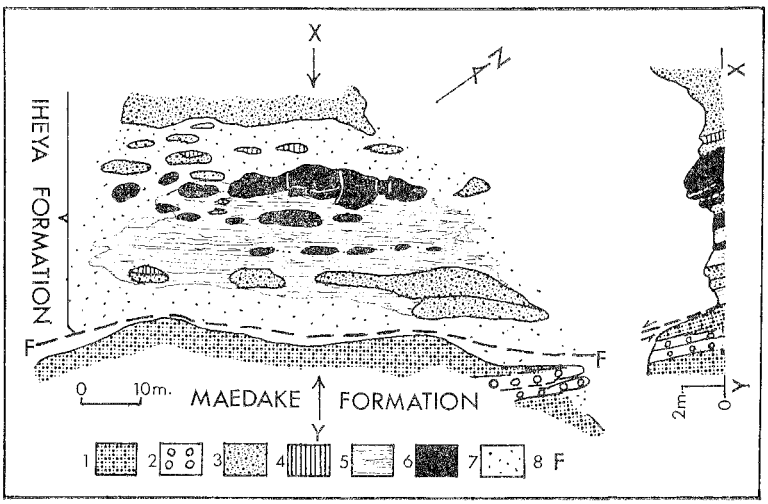
Table 1. Stratigraphic sequence of Iheya Islands

Paleozoic Formations

The Paleozoic formations consist of the Iheya and Maedake Formations, which are in ascending order, at Iheya-jima, and the Izena Formation at Izena-jima.

Iheya Formation

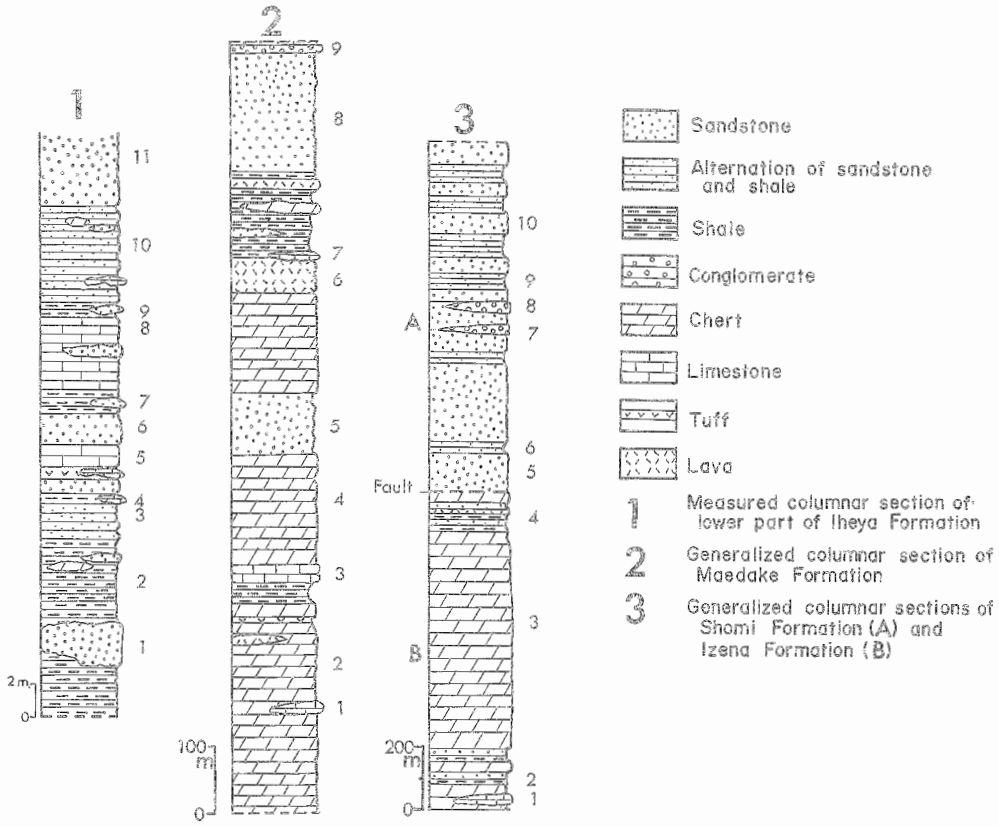
Type locality; the neighborhood of Yahei-iwa at the northern coast of Iheya-jima.
Thickness; ca. 90 m.
Distribution and lithology; the Iheya Formation is exposed only near Yahei-iwa, northern coast of Iheya-jima (Text-figure 4). It is composed of sandstone, chert and shale with interbedded limestone lentils which yield the Lower Permian fusulinids. At



Text-figure 4. Geologic sketch map and cross section of Iheya Formation

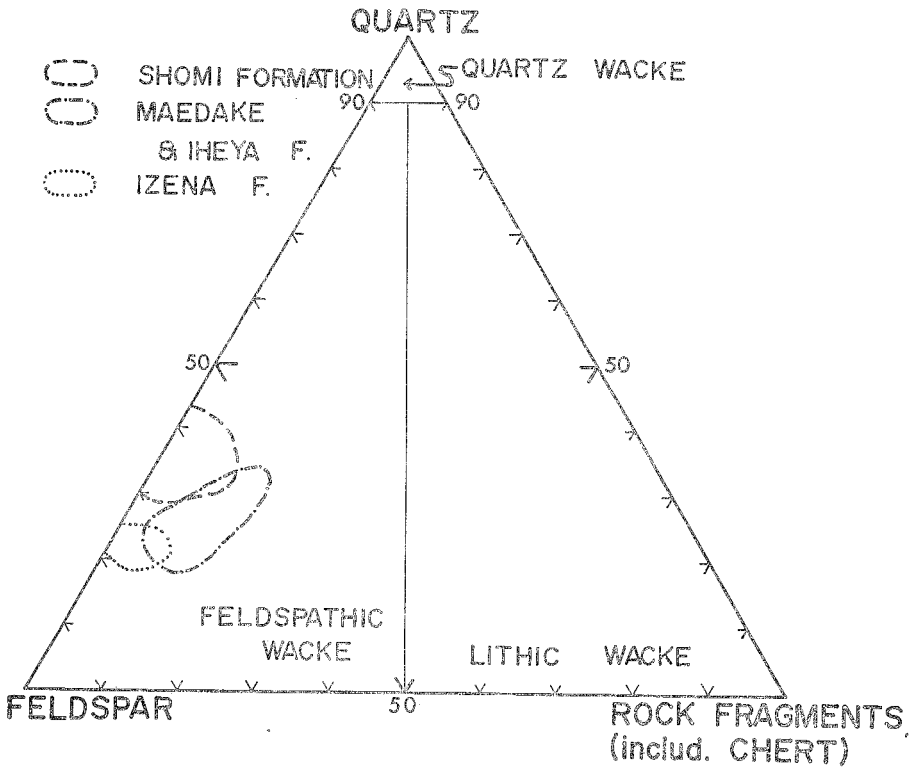
least three limestone lentils are recognized in the field and stratigraphically divided into four units tentatively, from IhL-1 to IhL-4 in ascending order (Text-figure 5) (Plate 1, Figure 2). The IhL-1 limestone interbedded in a black shale as a lentil is brownish gray, compact, brecciated in part, and about 40 to 50 cm. in thickness. The limestone breccias are divided into two types under microscope; the one is dark gray, compact, pelletoidal with sporadically dolomitic and yields *Pseudofusulina* sp.; the other is brownish gray, compact and biosparite yielding *Beedina* spp. and Codiacean algae. The IhL-2 limestone is gray, hard, massive, biosparry dolomitic and about 1 to 1.4 m. in thickness. Calcite grains are about 2 to 5 mm. in diameter. A number of the authigenic euhedra of dolomite are observed in thin section. This limestone yields bryozoans and fusulinids such as *Fusulinella* and *Triticites*, both of which are interpreted as secondarily derived fossils. The IhL-3 and IhL-4 are about 6 m. thick in the maximum and reduce by half at the western end. The IhL-3 is dark gray, compact and brecciated at the lower part, and is biosparite yielding fusulinids of *Fusulinella*, *Triticites*, *Pseudoschwagerina*, *Nankinella*, *Staffella* and bryozoans, chaetetid corals, and crinoid stem-joints, while the IhL-4 is gray, massive, and unfossiliferous.

The sandstones of this formation are predominant at the upper part, and pale greenish gray, fine to medium in grain size with a moderate degree of sorting and fairly jointed. The grains are angular to subangular and are composed of quartz, plagioclase, potash feldspars and fragments of chert and shale. Feldspars have been partly altered to sericite and kaolinite. The results of the modal analysis of sandstones summarized in terms of the classification scheme of Okada (1968) are shown in Text-figure 6.



Text-figure 5. Columnar sections of the Paleozoic and Mesozoic Formations

1. 1: Sandstone, coarse-grained. cataclastic, massive
   2: Shale, black, contains layers of sandstone and chert in middle part, and lenticular layers of sandstone and chert in upper part
   3: Sandstone and shale, alternated; shale, black, sandstone, gray, fine, very thin layers
   4: Limestone, gray, lenticular, shale matrix, (IhL-1)
   5: Limestone, gray, massive in upper part, lenticular layer in lower part, tuffaceous matrix (IhL-2)
   6: Sandstone, medium-grained, thinly bedded
   7: Shale, black, contains lenticular of sandstone
   8: Limestone, light-gray to brownish-gray, hard contain lenticualer layers of sandstone in middle part, massive in upper part (IhL-4), bedded in lower part (IhL-3)
   9: Shale, black, contains sandstone lentil
   10: Sandstone and shale; sandstone, weathering brown, very coarse-grained: shale, black, cataclastic, contains cobbles of limestone in lower part, and lenticular layer of chert
   11: Sandstone, gray, weathering brown, medium-grained, thinly bedded
2. 1: Limestone (ML-1), 2: Chert, white-green, thinly bedded
   3: Tuff, pale green 4: Shale, black 5: Limestone (ML-2)
   6: Chert, white-green-red, thinly bedded, contains layers of tuff and shale 7: Sandstone, gray, medium-grained thinly bedded 8: Chert, white-green, massive in part 9: Limestone (ML-3) 10: Sandstone, gray medium- and coarse-grained, thinly to thickly bedded, contains thin layers of shale 11: Conglomerate.
3. (A) 1: Limestone 2: Shale with sandstone 3: Chert, banded 4: Sandstone, arkosic, including shale 6: Shale 7 & 8: Conglomerate 9: Shale, black, including fragments of plant fossil and sandstone 10: Sandstone, fine-medium grained



Text-figure 6. Classification of sandstones

Maedake Formation

Type locality; coastal area of the eastern slope of Mae-dake in Iheya-jima.
Thickness; ca. 1,200 m.
Distribution and lithology; the Maedake Formation is distributed at Iheya-jima and Noho-jima and is in contact with the Iheya Formation by a high-angled reverse fault. It is characterized by lithofacies of prominent bedded chert with the subordinate amounts of sandstone, conglomerate, greenstone and lenticular layers of limestone. The upper part is composed of mainly sandstone accompanied with shale, greenstone and conglomerate, while the lower and middle parts are mainly composed of chert interbedded with greenstone, shale, sandstone and limestone. At least three stratigraphic units are recognized in the field among the limestone layers.

The Maedake Formation indicates strike N 30° to 60° E and dip 20° to 80° N, but the dip changes to the south along the eastern coast of the northern Iheya-jima. Thus, an anticline is inferred at the northern area. The minor folds are abundant in the bedded chert and shales. Slickensides rising 10 to 15 m. high above the ground are recognized within the chert unit of the formation (Plate 2, Figure 2).

The chert is prominent at the lower to middle part of this formation. It is white,

pale green, reddish brown or gray, and usually bedded into layers of 5 to 20 cm. thick, except for the massive ones at Hizabaru of Iheya-jima. The chert member about 300 m. in thickness interbeds with a sandstone bed of about 100 m. thick in the upper part, besides the layers of limestone, shale, sandstone and greenstone, which range from 5 to 20 m. in thickness. Silicified crinoid stems (Plate 2, Figure 3) are only fossils recognized other than radiolarians, which were reported by HANZAWA (1935). Radiolarians are observed as minute lucid spots in thin section.

The sandstone beds are predominant at the middle and upper parts and are about 150 m. thick. Thin layers of the sandstone about 10 m. thick are recognized in black shales in the lower part. The sandstone of this formation is almost dark brown on weathered surface except for the area of Tana-saki at the northern tip of Iheya-jima where it is pale greenish gray, and medium in grain size. The grains are angular to subangular and are composed of quartz, feldspars, hornblende, mica (?), and rock fragments of chert and shale. Feldspars have been partly altered to clay minerals. Calcite is recognized as cement. Some of quartz grains show wavy extinction. Sandstones of the upper part are medium to coarse in grain size, well-bedded from 50 cm. to 2 m. thick and interbed a thin layer of dolostone, about 15 cm. thick. The matrix of the sandstones is rich in altered feldspars and opaque minerals. The grains are angular and are composed of feldspars subordinated with quartz, and rock fragments of shale and chert. The sandstones in shale have been folded and torn into pieces as boudins. The results of the modal analysis with respect to textural composition of sandstones are shown at text-figure 6. These sandstones are situated as near as the area of the Iheya Formation's, though the specimens analyzed were not sufficient enough to distinguish from the sandstone of the Mesozoic formations.

The conglomerate occurs in the uppermost part of the sandstone unit and is 5 to 8 m. in thickness. The conglomerate bed crops out at the following four points, Yahei-iwa, N-, M-, and L-outcrop from north to south, along the western coast of Iheya-jima. The conglomerate at Yahei-iwa (Plate 2, Figure 4) is well exposed and about 8 m. in thickness. The gravels of the conglomerate are composed of granitic rocks, quartz-porphyry, limestone, sandstone, shale and chert. The gravels vary from pebble to boulder in size, and very angular to well-rounded. While the gravels of hard rocks such as igneous rocks and chert are generally well-rounded, those of clastic rocks are very angular and moderately to poorly sorted. The limestone cobbles and pebbles yield the Carboniferous and Permian fusulinids such as *Fusulinella*, *Pseudofusulina*, *Parafusulina*, *Neoschwagerina* and *Yabeina*. The matrix of the conglomerate is coarse to granular sandstone with dark brown color. The conglomerate of L-outcrop at the southernmost is similar to that of Yahei-iwa in thickness, rock types and size of gravels. The conglomerate at N-outcrop, south of Yahei-iwa, is about 2 m. thick, and includes a lentil of chert. The matrix of conglomerate consists of black shale in the upper part and coarse sandstone in the lower part. The gravels are composed of sandstone, chert, limestone, quartz-porphyry, granitic and basaltic rocks. Another outcrop of the conglo-

merate at about 100 m. west of the preceding is 2 m. in thickness but gravels, smaller than those at the other outcrops, are 1 to 5 cm. in diameter, well-rounded and well-sorted. The matrix is coarse sandstone in the upper part, while that of the lower part, about 50 cm. in thickness, is fine sandstone. The gravels consist of mostly chert (ca. 80 %) subordinated with black shale, sandstone and igneous rocks. No limestone has been found among the gravels. Although there is a possibility that the inner two, M- and N-outcrop, may be stratigraphically different from the others as seen in the size of gravels and matrix, they are tentatively treated as the stratigraphically same horizon.

The thin layers and lentils of limestone are recognized at three stratigraphic units (ML-1, -2 and -3 in ascending order) in the Maedake Formation in the field. The exposures are distributed along the eastern coast of Mae-dake (type locality) and the coast of the Ashichi at Shimajiri hamlet. The limestone lentil named as ML-1 is interbedded into shale and greenstone (tuff?) beds in the lower part of the formation. This lentil is about 1 to 1.2 m. thick, gray and yields fusulinids such as *Parafusulina* spp. and *Misellina claudiae* (DEPRAT), corals and crinoid stem-joints. The ML-2 is situated at about 500 m. southwest of the ML-1. It is about 4 m. in thickness, white to dark gray, and massive in the lower 3 m., which is overlain by the limestone breccias. The fusulinids such as *Parafusulina* sp., *Misellina* sp. and *Pseudofusulina* sp. have been found only from the breccias. The ML-3 limestone crops out at about 600 m. southwest of ML-2 and is white, massive hard and oölitic, yielding *Neoschwagerina* cfr. *margaritae* (DEPRAT).

The greenstone beds are 50 to 70 m. thick in the upper part and 5 to 10 m. in the lower. The greenstone is reddish purple to green, massive hard and interbedded with lenticular layers of sandstone, limestone and chert. The greenstone of the lower part cropping out at the type locality may be called altered basalt with fine-grained texture. The constituent minerals recognized under microscope are serpentine minerals (antigorite ?), iddingsite, chlorite (?), vein quartz and opaque minerals as magnetite and ilmenite. The groundmass consists of brown devitrified glass.

Izena Formation

Type locality; the Gushiku-yama in the southeast area of Izena-jima.
Thickness; more than 1,000 m.
Distribution and lithology; the Izena Formation is distributed at Izena-jima, Gushikawa-jima and Yanaha-jima. It is mainly composed of bedded chert with subordinate of alternations of sandstone and shale (Plate 2, Figure 1), limestone lentil and greenstone. According to the lithologies and exposed areas, the Izena Formation is divided into three units. The lower part is distributed at Izena-jima, Yanaha-jima and Adan-se, and mainly consists of chert accompanied with the alternation of sandstone and shale, and limestone. The limestone has been recognized only at Yanaha-jima and occurs as a lenticular layer about 7 m. in thickness, massive, grayish white, in which microfossils

such as *Nubecularia* sp. and *Calcisphaera* sp. are recognized under microscope. The alternation of sandstone and shale is 10 to 30 m. in thickness and interbedded in chert. Sandstones are brown, hard and fine-grained. The chert considered to be the upper unit is distributed at Yanaha-jima, Orogame-jima and Izena-jima. The upper part of the formation is distributed at Gushikawa-jima and is composed of bedded chert, about 100 m. in thickness, alternation of sandstone and shale, 150 to 200 m. thick, and greenstone of 5 m. thick. The sandstone beds exhibit a similar trend in strike (N40°-60°E) and dip (80°N- 90°), while the cherty beds there show the strike ranging from N20° to 50°E.

The Izena Formation strikes generally N20°−60°E and dips 50°N−90°. It contacts with the Shomi Formation by a normal fault in the upper and by a reversal fault at the lower limit, respectively, and is unconformably covered with the Quaternary sediments.

It is considered that the Izena Formation may be correlated with the upper part of the Maedake Formation by lithofacies, though any paleontological evidence has not been substantiated at present.

Mesozoic Formations

Shomi Formation

Type locality; the eastern coast of Shomi hamlet of Izena-jima.
Thickness; ca. 1,300 m.
Distribution and lithology; the Shomi Formation distributes at the central area of Izena-jima from northeast to southwest direction and contacts at the lower limit with the Izena Formation by a normal fault, while the upper with the same formation by a reversal fault. The Shomi Formation is divided into two members in ascending order, the Nakata conglomeratic sandstone member and Matecha sandstone-shale alternation member. At the northeastern coast of Izena-jima, a part of the Nakata member characterized with two conglomerate beds occurs bounded with a tectonic fault.

Nakata Conglomeratic Sandstone Member

Type locality; the eastern coast of Shomi hamlet of Izena-jima.
Thickness; ca. 800 m.
Distribution and lithology; this member is distributed from Nakata to Izena hamlet at the southern area of Izena-jima.
The lower limit contacts by a normal fault with the Izena Formation, the upper does conformably with the Matecha member at the eastern area, but presumably by a normal fault at the western. The lower part of the member is composed of conglomeratic sandstone accompanied with shale. The sandstone is bedded from 10 to 40 cm. in thickness and interbedded with thin layers of shale. It is conglomeratic and contains chert grains and patches of shale. The sandstone is overlain with the sequence which

consists of, in ascending order, the lower conglomerate bed (45 m. in thickness), conglomeratic lentil bearing granule sandstone bed (150 m. in thickness), and the upper conglomerate bed (120 m. in thickness). These two conglomerate beds are the thickest at the type locality, but decrease the thickness to the southwest merging into the conglomeratic sandstone. The upper conglomerate bed disappears near the Village Office, central area of Izena-jima due to faulting, while the lower one decreases to 2 m. in thickness at the northern area of Izena hamlet and finally disappears at the southwestern coast, turning into a conglomeratic sandstone.

Matecha Alternation of Sandstone and Shale Member

Type locality; the eastern coast of Matecha at Izena-jima.
Thickness; ca. 500 m.
Distribution and lithology; this member is distributed at the north of the Nakata Member, and crops out at the type locality, the area west of Amagusuku-dake and the coast west of Jitchaku hamlet.
The limit of this member contacts conformably with the Nakata Member in the eastern area and by fault in the western, while the upper limit contacts again with the Nakata Member which reappears by a fault, and with chert of the Izena Formation by the reverse fault. Sandstone and shale are stratified from 10 to 30 cm. thick. Almost all the shales alternate with sandstones in 5 to 10 cm. unit. The sandstone is prominent in the lower part and bedded from 10 cm. to 2 m. in thickness, but they are frequently alternated with shales at the upper part. A few beds of massive sandstone crop out along both eastern and western coasts.

The sandstone of the Nakata Member is gray, compact, hard and medium-sand to granular in grain size. The grains are angular to subangular in shape and composed of quartz, feldspar, rock fragments of shale and chert, mica and carbonate. Quartz grains are angular, and occupy 14 to 32% of rock in the modal percent. Some of them show wavy extinction. Feldspar grains consist of plagioclase, orthoclase, microcline and perthite, which have been altered by kaolinitization and sericitization, and minute grains make the detrital matrix. The matrix is composed of the detrital feldspar and dark brown clay minerals considered as chlorite. Rock fragments are small in amount and mainly consist of patches of chert and shale, 1 to 3 mm. in length. Sandstones alternated with shale are fine to medium in grain size, and are stratified into beds 10cm. to 2 m. in thickness. Fragments of fossil plants are abundantly contained in this fine grained sandstone. The modal analysis of the sandstones of this formation was carried out (Text-figure 6).
The sedimentary structures, both cross-bedding and graded bedding, are recognized at the upper part of conglomeratic sandstone between two conglomerate beds at the type locality.

Shales are rich in the upper part of the lower member. They are mostly gray to grayish purple on weathered surface, but black, hard and compact when fresh. Shales

are stratified from a few to 40 cm. and tend to increase thickness ascendingly. In the upper member, a shale bed, 30 to 50 m. thick, occurs in the lower part, where almost all shales bedded in the units of 5 to 20 cm. thick, are black on fresh, pale to grayish purple on weathered surface, and alternate with sandstones (Plate 3, Figure 4). This black shale is only observed at about 200 m. east of Jitchaku hamlet. Sometimes similar black shales are obtained by well boring from the subsurface at the areas of the Village Office and Jitchaku hamlet.

Both the lower and upper conglomerate beds are thickest at the type locality. The gravels of both beds are composed of granitic rocks, quartz-porphyry, chert, sandstone and shale, and are granule to boulder in size, attaining at 50 cm. in diameter. Conglomerate layers characterized with shale breccias, 70 to 80 cm. in the longer diameter, are interbedded between the poorly sorted lower conglomerate bed (Plate 3, Figure 3). As a rule, the hard rocks as chert and igneous rocks are well-rounded, while the clastic rocks are angular to very angular and are smaller than the hard ones in size (Plate 3, Figure 2). Quartz-porphyry is most plentiful among the igneous rocks. Protoclastic graphic biotite-granite was identified in thin section. The matrix of the conglomerates is mainly quartz and feldspar associated with granular chert and black shale.

Palynomorphic Fossils

A palynological study of the carbonaceous sediments in this formation was carried out by FUJI (1965, MS), who preliminarily identified the following fossil pollen grains and spores.

Abietineaepollenites minimus COUPER
A. *microalatus* R. POTOMIE
Eucommiidites sp.
Monosulcites sp.
Elatides williamsoni (BRONGN.) SEWARD
Sphagnumsporites psilatus (ROSS) n. comb. COUPER
S. sp. a
S. sp. b
S. sp. c
Lycopodiumsporites cerniides (ROSS) DEL et SPRUM
Eboracia sp.
Matonisporites equiexinus COUPER
Trilites bossus COUPER
Osumundacidites sp.
Cingulatisporites sp.
Triporopollenites sp. a
T. sp. b
T. sp. c

Tricolporopollenites sp. a
Alnipollenites sp. a
Monoporisporites sp. a
M. sp. b
Inapertisporites sp.

According to Fuji (*ibid.*), *Sphagnumsporites* which comprises about 30% of the identified individuals is a good facies fossil suggesting the marine near-shore or swamp environment. The lithologic association of prominent cobble conglomerate and fossiliferous carbonaceous black shale may also support this interpretation.

Dana Formation

Type locality; the western wing of Mae-dake at Iheya-jima.
Thickness; ca. 500 m.
Distribution and lithology; the Dana Formation is found at the type locality, east of Kushi-dake and west of Kayo-dake; both the lower and upper limits of the formation are in contact with the Maedake Formation by faults which are recognized at the mouth of the Dana river and at the dam site in Gakiya hamlet, respectively.
This formation is mainly composed of the alternation of sandstone and shale, and the sandstone predominates in the middle to the lower parts. Layers of shale are, 5 to 20 cm. in thickness, and thinner than those of sandstone. The sandstone in the lower part is conglomeratic, containing gravels of chert, shale and the others. (Plate 3, Figure 1). The gravels of shale are larger than the others, 1 to 3 cm. in length and 1 to 2 cm. in width. The matrix is coarse sandstone of arkosic wacke type. The sandstones except for the conglomeratic unit are fine to medium, brown to pale brown on fresh, and loose, light brown when weathered. The shale is black, hard and compact on fresh, but almost all shales are brown to purple on weathered surface. The alternations contain a number of the fragments of unidentified plants as much as in the Shomi Formation. Fossil pollen grains and spores have been confirmed but have not been identified.

Geologic Structure

Iheya Islands are situated at the Motobu Belt in terms of the tectonic divisions of the pre-Miocene basement complex in the Ryukyu Geanticline (Konishi, 1963, 1965). The Motobu Belt is divided into three sub-belts, Tonaki (or North), Izena (or Middle) and Katsuu (or South), and Iheye Islands belong to the Izena Sub-belt, which is characterized by the thick chert beds and abundant clastic rocks, and the development of the Mesozoic or Paleogene shallow marine or swamp deposits (Konishi, 1965). Not only the topographic trend of Iheya Islands but also the arrangement between the Paleozoic and Mesozoic formations are parallel to the tectonic belts. Many major faults

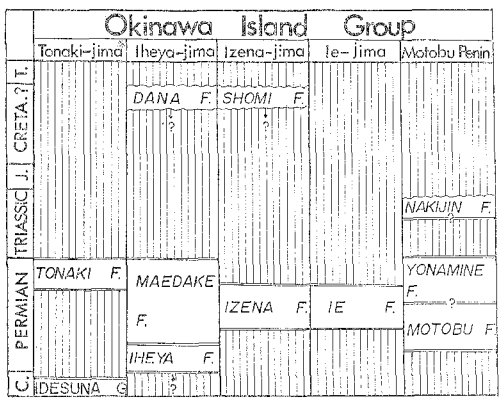
runnig in the Paleozoic and Mesozoic formations could be grouped into two types; one is longitudinal fault (parallel to the island arc), the other is transeverse fault. These tendencies have been recognized in the pre-Miocene basement complex of Okinawa-jima (HANZAWA, 1935: FLINT *et al.*, 1959: KONISHI, 1963: ISHIBASHI, 1965 MS, 1967 MS), and Amami-oshima (HATAE *et al.*, 1959: ISHIDA, 1967 MS). One of the major faults through Yahei-iwa in Iheya-jima probably extends along the western coast, because the conglomerate of the upper Maedake Formation and thin layers of dolostone crop out more or less continuously along the coast. The Iheya Formation which is the oldest sediments in the Ryukyu Geanticline at present had been exposed by this fault movement. Also many longitudinal faults are recognized at Iheya Islands and some of them make up the slickensides. The fault clay zones, 5 to 20 m. in width are recognized at the contacts between the Paleozoic and Mesozoic formations. The transvese faults, west-east direction, cross these faults and make up the each mountain and valleys. The Menna-dake consisting of chert of the Izena Formation thrust onto the Mesozoic formation and the contact between them is observed at the northern riverlet of Menna-dake. The minor faults are abundant in the Paleozoic beds of chert and the Mesozoic formations, especially in the alternation of sandstone and shale. They show a throw ranging from a few centimeters to 2 m. usually. An anticlinal fold, the axis of which runs from NE to SW has been inferred within the Maedake Formation at the northern area of Iheya-jima, as already described above. Many minor folds have been recognized in the beds of chert and alternation of sandstone and shale.

The gross structure of the Shomi Formation has been interpreted to represent the southeastern wing of a huge syncline, of which the supposedly overturned sequence at the northwestern wing has been eroded off after displaced with a thrust. However, the structural detail of the formation is a question open to future study. The minor folds both anticlinal and synclinal, which are sometimes overturned, are commonly accompanied with minor faults. A spoon-like synclinal structure, the axis of which plunges gently to SSW has been observed in the sandstone beds of the Nakata Member at the east coast of Izena-jima.

Correlations

The Iheya and Izena Formations both defined through the present work are correlated with the Permian formations of the other islands in Okinawa Island Group (Table 2). HANZAWA (1933) reported the occurrence of the Permian fusulinids, *Neoschwagerina* sp., *Verbeekina douvillei* (DEPRAT), and *Pseudofusulina* sp. from the Motobu Limestone (nomenclature after FLINT *et al.*, 1959), then correlated with the Chichibu System in Japan. Also the Permian fusulinids, from other localities of the same peninsula, have been found by FLINT *et al.* (1959), KONISHI (1963, 1965) and ISHIBASHI (1967, MS). KONISHI (1964) described the Tonaki Formation, which was

correlated with the Motobu Limestone based on the find of the Permian fusulinids such as *Yabeina* cfr. *globosa* (YABE), *Neoschwagerina* sp., *Schwagerina* sp. and *Schubertella* sp. in the former. FLINT *et al.* (*ibid.*) divided the Paleozoic beds at the Motobu Peninsula into two formations, the Motobu and Yonamine Formations which are, according to their interpretation, in the contact relation of a huge thrust fault (MACNEIL, 1960). ISHIBASHI and KONISHI (1967) distinguished the Triassic Nakijin Formation in the area hitherto mapped as the Paleozoic formations in the Motobu Peninsula. Futhermore, ISHIBASHI (1967, MS) found the following Permian fusulinids, *Yabeina katoi* (OZAWA), *Yabeina* sp., *Neoschwagerina* cfr. *margaritae* DEPRAT, *Neoschwagerina craticulifera* (SCHWAGER), *Cancellina* sp., *Sumatrina annae* VOLZ, *Pseudofusulina* sp., *Verbeekina* sp. and redefined the Paleozoic formations, as the Motobu and Yonamine in ascending order, thus correlated the Yonamine Formation with the Tonaki Formation and the upper part of the Maedake Formation. The lower part of the Maedake Formation belonging to *Parafusulina* Zone is correlated with the Izena and Motobu Formations, though the paleontological evidence from the latter two formations have not been obtained at present. The Iheya Formation which yields the Lower Permian fusulinids and the reworked Middle Carboniferous ones is the oldest among the reported formations in the Ryukyu Geanticline, and may be roughly correlated with the Sakamotozawan in Japan. The Miyara Formation (HANZAWA, 1935) in Yaeyama Islands is similar to the Shomi and Dana Formations in lithofacies and presumable sedimentary environment, except the Miyara Formation contains the Upper Eocene foraminiferal-algal limestone. Although neither the Shomi nor the Dana Formation has yielded any well-established index fossils, the pollen grains and spores from the Shomi Formation such as *Abietineaepollenites minimus*, *A. microalatus*, *Elatides williamsoni*, *Sphagnumsporites psilatus*, *Matonisporites equiexinus*, and *Trilites bossus* have been found in the Jurasso-Cretaceous sediments in the other regions (FUJI, 1965, MS.) In addition to these data, the lithofacies and degree of deformation may suggest that the Shomi Formation is the Late Mesozoic, possibly Cretaceous rather than Paleogene. The Dana Formation similar to the Shomi Formation in lithology and geologic structure may be correlated with the upper member of the Shomi Formation, but the further paleontological studies are needed before reaching a definite conclusion.



※ KONISHI, 1964.

Table 2. Correlation chart of the pre-Trtiary Formations in Okinawa Island Group

Conclusions

(1) Iheya Islands (Iheya-, Noho-, Gushikawa-, Izena-, Yanoshita- and Yanahajima) are geologically mapped for the first time. It is confirmed that these islands are composed of the Late Paleozoic (the Iheya and Maedake Formations, in ascending order), the Late Mesozoic (the Shomi and Dana Formations), and the Quaternary sedimentary deposits.

(2) The Lower Permian fusulinids (*Triticites*, *Pseudoschwagerina*, *Pseudofusulina*) associated with the secondarily derived Carboniferous ones (*Fusulinella* and *Beedina*) recognized from the Iheya Formation make the oldest Paleozoic fossils in the Ryukyu Geanticline.

(3) The Maedake Formation is mainly composed of chert associated with sandstone, shale, greenstone, conglomerate and limestone. The last one is recognized at three stratigraphic units in the field, lower two of which yield *Misellina claudiae* (DEPRAT), *Parafusulina* spp., while the third containing *Neoschwagerina* cfr. *margaritae* (DEPRAT), hence probably correlated with the Tonaki Formation at Tonaki-jima and the Yonamine Formation at the Motobu Peninsula of Okinawa-jima.

(4) Conglomerates included in the upper part of the Maedake Formation are composed of pebbles to boulders of granitic rocks and sedimentary rocks. The gravels of limestone yield the fusulinids of diverse ages ranging from the Middle Carboniferous to Late Permian. These conglomerates may be correlated to the similar formations of the Late Permian Kuman in Kyushu and other parts of Japan.

(5) The Izena Formation consisting of chert, sandstone, shale, limestone and altered igneous rocks is tentatively correlated with the middle part of the Maedake Formation by the lithological similarities.

(6) The Shomi Formation is divided into the Nakata Conglomeratic Sandstone Member and Matecha Alternation of Sandstone and Shale Member. A number of the fragments of unidentified fossil plants are found in the shale and fine sandstone of the Matecha Member. Fossil pollen grains and spores were recovered from the carbonaceous sediments of the same member. The palynological examination and field evidences suggest the Late Mesozoic, possibly Cretaceous, and the sedimentary environment of shallow marine to brackish water or swamp for the formation.

(7) The Pleistocene sediments are composed of low and high coastal terrace deposits, the former is partly represented with reefy limestone beds. The Holocene consists of the raised beach deposits, the present beach deposits, and fluviatile deposits.

(8) According to these new finds described in this report and the data by previous works, a working hypothesis postulating that "the tectonic configulations, stratigraphic sequences and lithologies of the pre-Miocene rocks are similar between the Ryukyu Geanticline and the Outer Zone of Southwest Japan" (KONISHI, 1965: KONISHI, ISHIBASHI and ISHIDA, 1966) appears to be tenable.

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Appendix-1

Notes on the Quaternary Sediments

Pleistocene

The Pleistocene series is composed of the low and high coastal terrace deposits which are partly represented with reefy limestone bed. The stratigraphic relation between the low coastal deposits and reefy limestone could not been exactly certained in the field, but it is considered to be contemporaneous.

(1) Kiuradake gravel bed

Type locality ; the saddle between Kiura-dake and Jijin-dake of Izena-jima.

Thickness; 3.5 m. +

Distribution and lithology; this gravel bed crops out only at the surrounding area of Jijin-dake, of which surface has 40 to 60 m. in height above sea level. The outcrops are along the ditch at the northern area of Jijin-dake, where four layers are observed in descending order as follows; the layer A is about 60 cm. thick and consists of well-rounded pebbles to cobbles, which are mostly composed of chert. The layer B is about 20 cm. thick in which well-rounded pebbles nearly 1 cm. in diameter are abundant. The gravels of chert are especially concentrated at the upper part of this layer. Matrix is reddish, fine-grained sand. The layer C is about 30 cm. thick and contains chert gravels of boulder size. The basal layer D, more than 1.5 m. thick, consists of unconsolidated mud and contains granules of chert at the upper part.

(2) Uchihana gravel bed

Type locality; the western area of Uchihana hamlet in Izena-jima.

Thickness; 5 m.

Distribution and lithology; this deposits form the terraces occupying from 5 to 20 m. above sea level in the islands except Yanoshita-jima, Orogame-jima and Noho-jima, and cover unconformably the Paleozoic and Mesozoic formations. The lower part is composed of brown unconsolidated mud and contains scattered debris of molluscs and well-rounded, granular gravels of chert, while the upper part is made up of few condensed, cross-bedded gravel layers which contain a small quantity of molluscan debris. Almost all the gravels of this part are composed of well-rounded chert of 2 to 3 cm. in diameter.

(3) Yanoshita-jima limestone

Type locality; the southern cliff of the middle hill in Gushikawa-jima.

Thickness; ca. 30 m.

Distribution and lithology; the Yanoshita-jima limestone has been recognized at all the islands. The thickness is about 30 m. at Noho-jima, 15 m. at Gushikawa-jima, and 9 m. at Yanoshita-jima. In the larger islands such as Iheya- and Izena-jima, this limestone is restricted at scattered areas; the northwest shore, Guha at the northern coast and the cemetery 250 m. northwest of Sabro-pond in Izena-jima, and Kumaya in Iheya-jima. The limestone overlies unconformably the Paleozoic and Mesozoic formations, and is divided into two units, lower reefy unit and upper millet-stone (calcarenite) unit in ascending order. The reefy unit is about 9 m. thick, typically developed at Yanoshita-jima and follows on the fringing reefs. The limestone is massive, hard, containing of corals, molluscs, algae, foraminifers and their debris, but one or two layers of calcarenite, about 40 to 60 cm. thick, are intercalated at the middle part. The gravels included in this unit are mainly chert accompanied with sandstone and shale, which are pebble to cobble in size and well-rounded. The upper millet-stone unit merging into the lower unit is distributed at the type locality and Noho-jima, and attains about 30 m. in thickness at the latter. It mostly consists of foraminiferal tests and develops planary cross bedding.

Holocene

(1) Raised beach deposits

(a) Old sand dune; the old sand dune develops at the southern coast of Yanaha-jima and at the northwestern coast of Iheya-jima. This is about 3 m. in height and consists of consolidated fragments of corals, molluscs and foraminiferal tests, in which pebble of well-rounded chert are contained.

(b) Dana swamp mud deposits; this deposits occur around the Dana-pond in Iheya-jima and are more than 1 m. in thickness, yielding a number of molluscs and foraminiferal tests. Matrix is unindurated black mud. The deposits were formed probably during the period of shallow inlet or swamp.

(c) Raised beach deposits; other than two deposits mentioned above were recognized at the level of 2 to 5 m. above sea level. They overlie the pre-Holocene sediments and consist of calcareous sands containing abundant foraminiferal tests, molluscan debris and pebbles of sedimentary rocks.

(2) Beach deposits

This deposits developing along the coastal-line at all the islands are composed of calcareous sands with fragments of corals, molluscan debris and foraminiferal tests, and reef fringing the islands and beach rocks. The beachrocks cropping out at the coastline in the tidal zone are stratified and 30 to 50 cm. in thickness, dipping about 5 degrees toward the off-shore.

Appendix-2

Alphabetical list of place names

Adan-se	阿旦瀬	Katsuu	嘉津宇
Aka-dake	阿賀岳	Kayo-dake	嘉陽岳
Amagusuku-dake	天城岳	Kitakushi-dake	北腰岳
Amami	奄美	Kiura-dake	基浦岳
Asa-dake	阿佐岳	Kuba-yama	クバ山
Ashichi	アシチ	Kumaya	クマ屋
Awa-dake	阿波岳	Kushi-dake	腰岳
Dana	田名	Mae-dake	前岳
Gakiya	我喜屋	Maedomari	前泊
Guha	具波	Matecha	真手茶
Gushikawa	具志川	Menna-dake	メンナ岳
Gusuku (Gushiku)	城	Minamikushi-dake	南腰岳
Hizabaru	ヒザ原	Miyara	宮良
Ie-jima	伊江島	Motobu	本部
Iheya-jima	伊平屋島	Naha	那覇
Iheya-mae-jima	伊平屋前島	Nakata	仲田
Iheya-ushiro-jima	伊平屋後島	Nakijin	今帰仁
Isashi-dake	伊佐志岳	Nogami-yama	野上山
Ishigaki-jima	石垣島	Noho-jima	野甫島
Izena-jima	伊是名島	Okinawa	沖縄
Jijin-dake	地神岳	Ôno-yama	大の山
Jitchaku	勢理客	Orogame-jima	降神島
Kasari	笠利	Ryukyu (Riukiu)	琉球

Saburo	三郎	Yahei-iwa	屋兵衛岩
Shimajiri	島尻	Yamakusa-se	山草瀬
Shomi	諸見	Yanaha-jima	屋那覇島
Takakusa-se	高草瀬	Yanoshita-jima	屋の下島
Tana-saki	田名崎	Yonamine	与那嶺
Tonaki	渡名喜	Yone-saki	米崎
Uchihana	打鼻（内花）		

Postscrlpt: Besides the maps listed on page 53, two topographic sheets, Iheya-shima and Izena-shima, in the scale of 1:50,000 can be purchased since January of 1966. These maps were issued by the Land Survey of the Government of the Ryukyu Islands, based on the various sources of informations available on May 1, 1959.

PLATE 1

Explanation of Plate 1

View of Izena-jima and Type locality of the Iheya Formation.

Figure 1. View of the northeastern area of Izena-jima from Kiura-dake.
A: Ōno-yama (120m.) B: Aka-dake (83m.)
D: Isashi-dake (94m.) E: Shomi hamlet
F: Nakata hamlet N: Noho-jima I: Iheya-jima

Figure 2. Outcrop of the Iheya Formation at Yahei-iwa of Iheya-jima (type locality); looking west.
A: Yahei Fault B: The uppermost sandstone bed of the Maedake Formation
C: Limestone (IhL-2) D: Limestone (IhL-4) E: Sandstone
The highest point of the E sandstone in the center of the photograph is about 10 m. above sea level.

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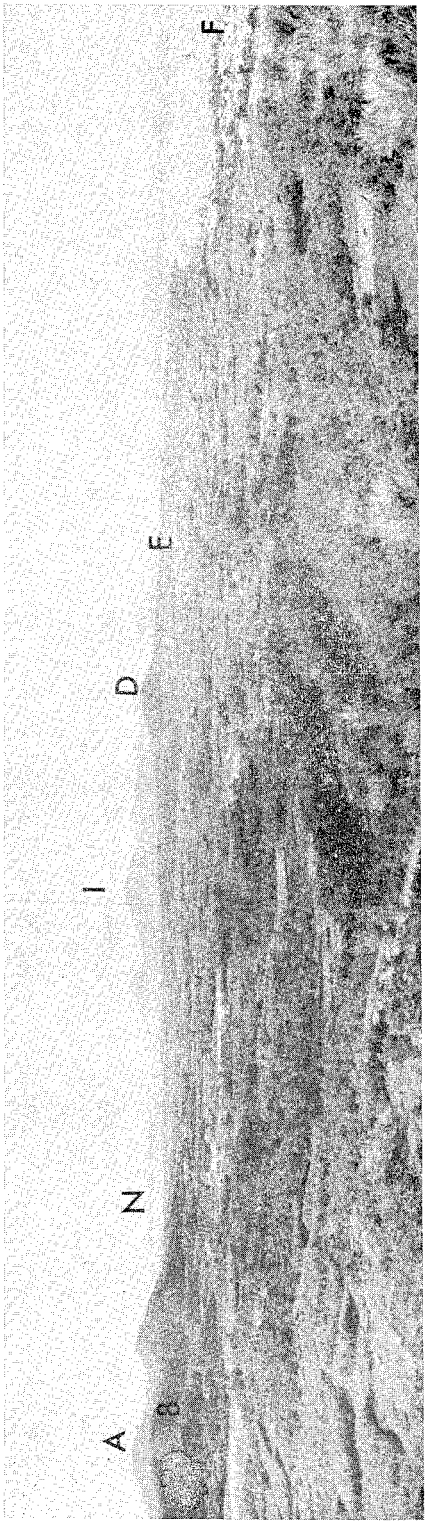

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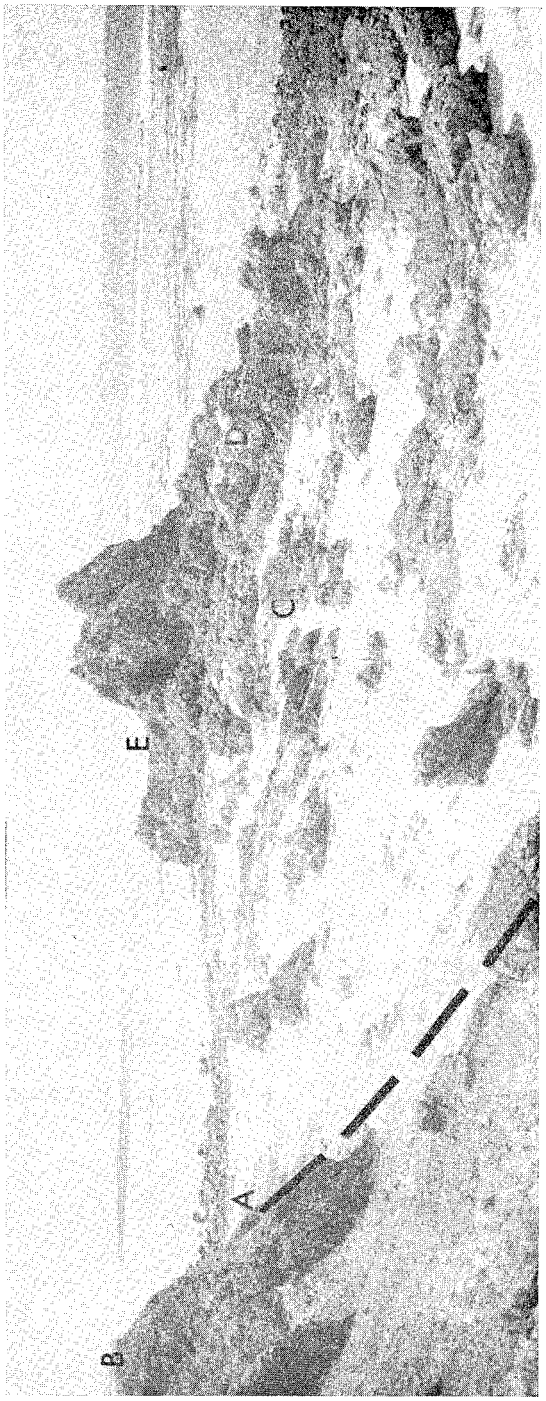

PLATE 2

Explanation of Plate 2

Late Paleozoic (Permian) Maedake and Izena Formations

Figure 1. Outcrop of bedded chert in the Izena Formation at the northern area of Izena-jima.

Figure 2. A slickenside in bedded chert of the middle part of the Maedake Formation; looking north from the Village Office in Iheya-jima. The outcrop is about 30 m. in height.

Figure 3. Dolomitic limestone (dark part in photograph) partly replaced by silica, which yields the crinoid stem-joints in the middle part of the Maedake Formation, at the coast northeast of Mae-dake in Iheya-jima.

Figure 4. Outcrop of the Yahei Conglomerate in the near top of the Maedake Formation at the Yahei-iwa, Iheya-jima. The measure is 50 cm. long.

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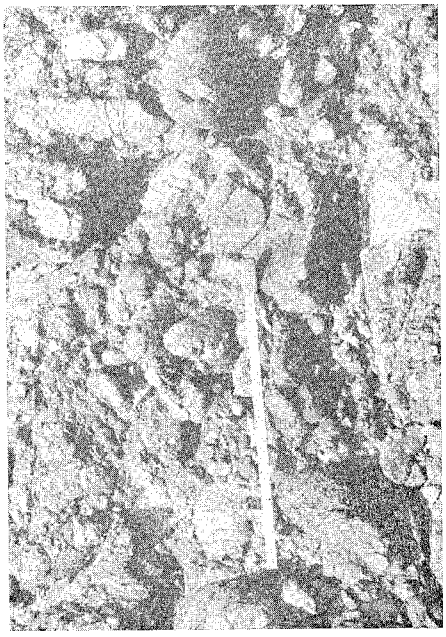

PLATE 3

Explanation of Plate 3

Late Mesozoic Shomi and Dana Formations

Figure 1. A conglomeratic sandstone in the basal part of the Dana Formation at the mouth of the Dana river in Dana hamlet, Iheya-jima. Gravels are mostly sedimentary rocks. Shale breccias of cobble size are prominent at this outcrop.

Figure 2. Outcrop of pebble to cobble conglomerate bed (lower) in the Nakata Member of the Shomi Formation, at the type locality in Izena-jima. Well-rounded cobbles of protoclastic graphic biotite-granite were collected from this outcrop.

Figure 3. A conglomerate layer characterized with shale breccias, 70 to 80 cm. in the longer diameter, interbedded between the poorly sorted lower conglomerate bed in the Nakata Member at the type locality of the Shomi Formation.

Figure 4. Outcrop of the sandstone-shale alternations in the Matecha Member, where the pollen grains, spores, and leafy plant fossils have been collected from the carbonaceous shale in the silty sandstone bed of 20 cm. thick. The sandstone bed at this outcrop ranges from several to 35 cm. in thickness and top of some beds is rippled.

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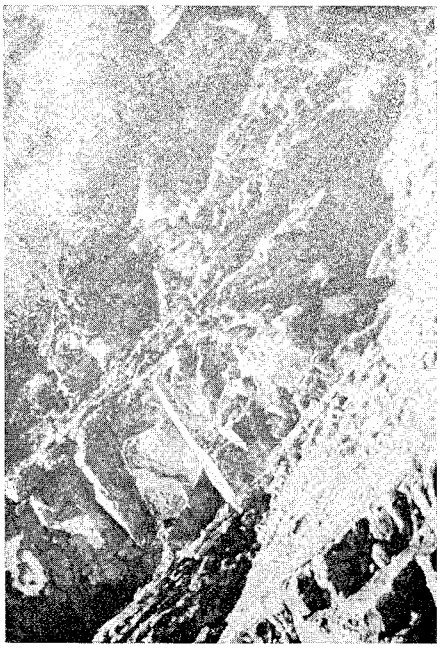


PLATE 4

Explanation of Plate 4

Quaternary sediments

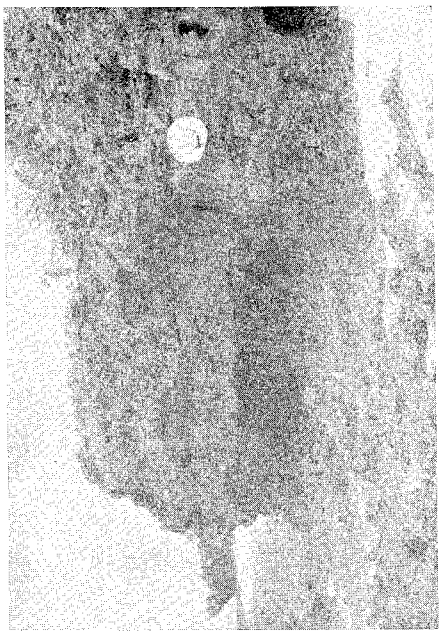
Figure 1. Reefy limestone of the lower part of the Yanoshita-jima Limestone at the western coast of Yanoshita-jima; a calcarenite bed interbedded in the middle part of the outcrop can be seen.

Figure 2. A distant view of the lower marine terrace in the left background of the photograph beyond the outcrop of the Nakata Member at the type locality; looking north from the coast of Shomi in Izena-jima. The terrace ranges from 5 to 20 m. in elevation.

Figure 3. Lower terrace deposits (Uchihana gravel bed) at the Uchihana area (type locality) in Izena-jima. The outcrop is about 3 m. high, and located at the elevation of 6 to 7 m.

Figure 4. The upper part of the Yanoshita-jima Limestone at the southern coast in Gushikawa-jima, the type locality. The outcrop is about 16 m. high. The limestone consists of planarily cross-laminated calcarenite.

1



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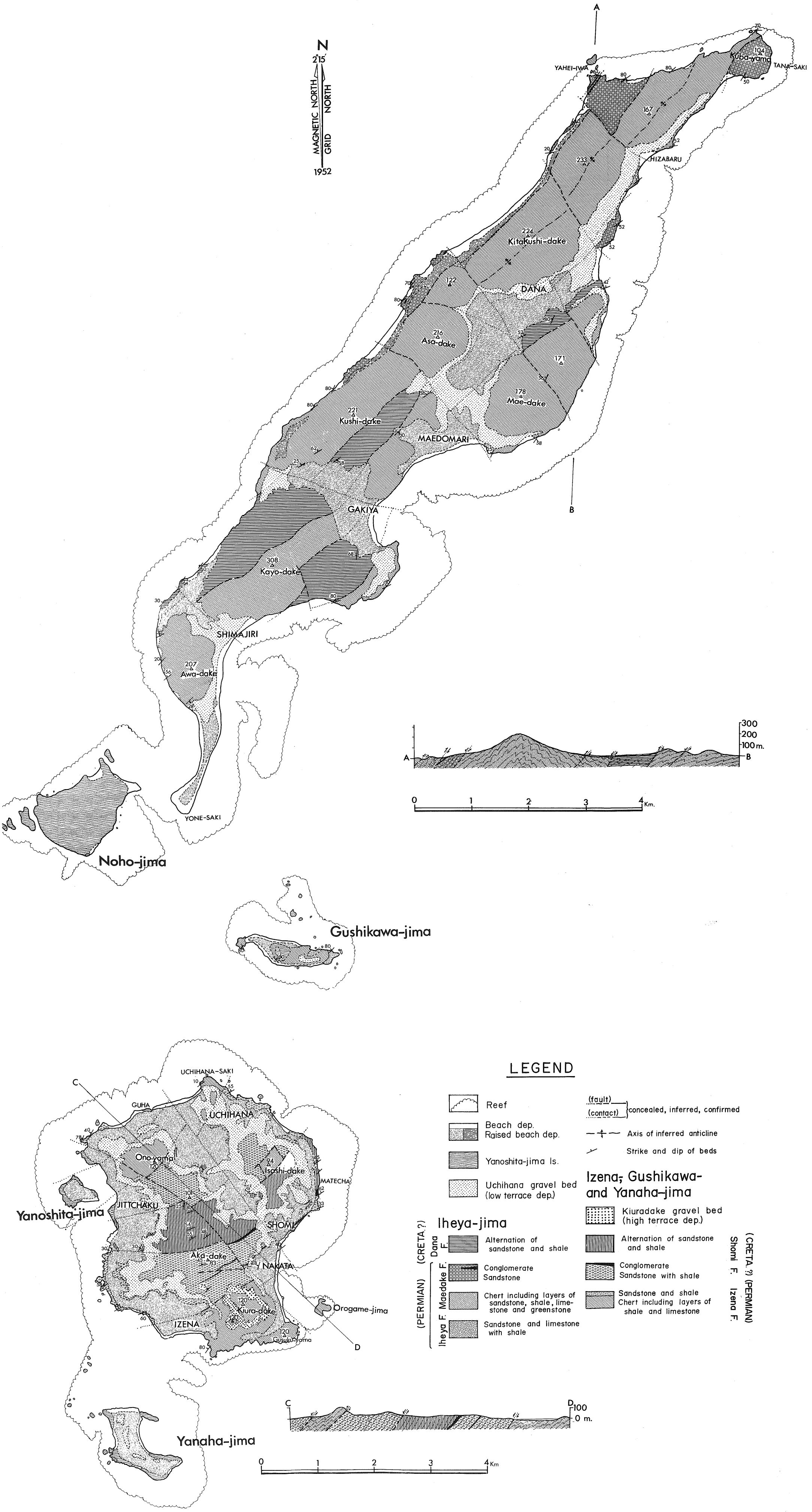
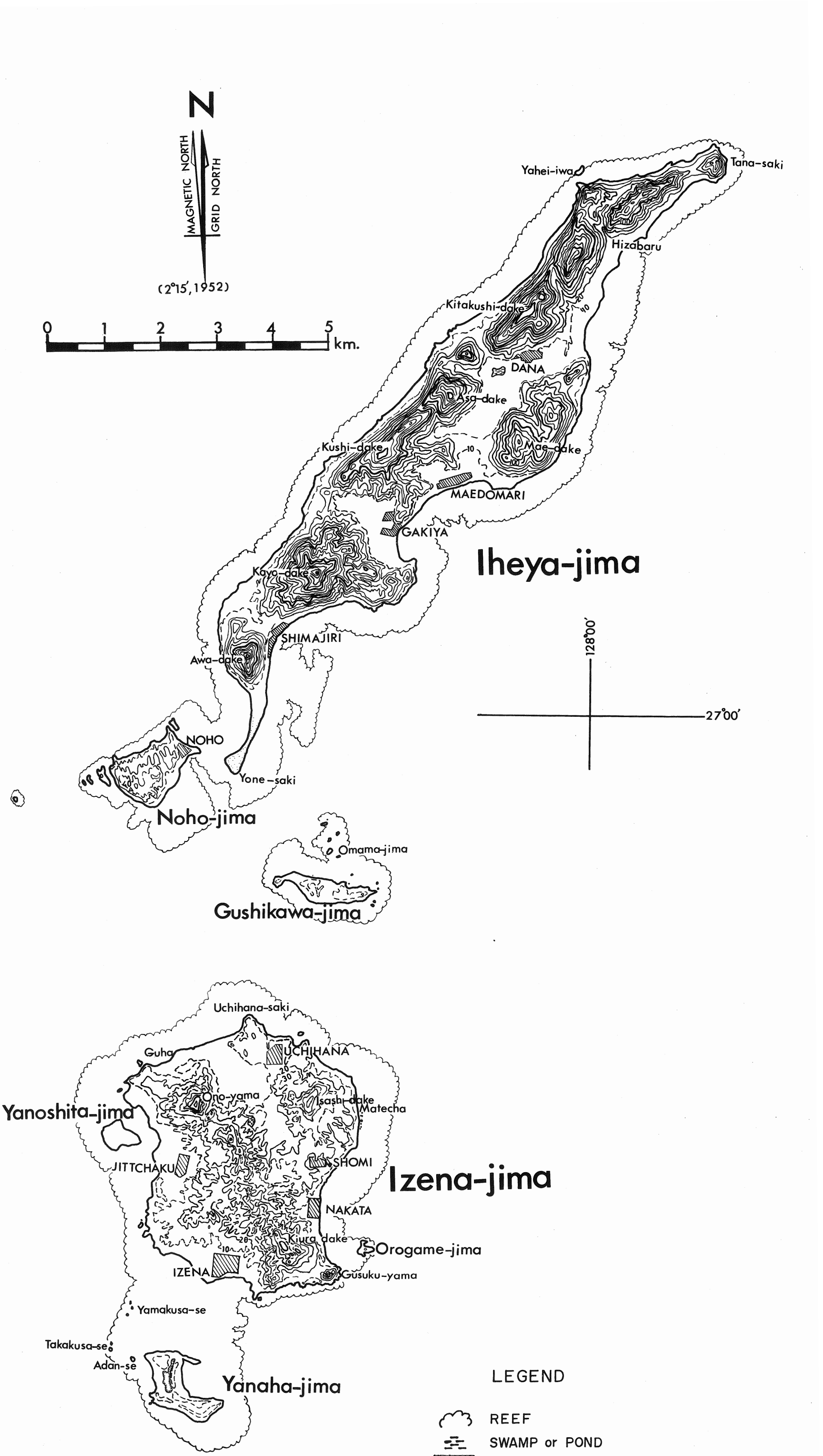


Text-figure 3. Geologic map of Iheya Islands, Okinawa Island Group



Text-figure 2. Topographic map of Iheya Islands, Okinawa Island Group