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Geologic Notes on Tonaki-jima and Width of Motobu Belt, Ryukyu Islands

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Abstract

Tonaki-jima and its offshore islet (Idesuna-jima) of the Central Ryukyus are geologically mapped for the first time. The main sedimentary beds of Tonaki-jima are thick sequences of the cuesta-forming dark colored, well-bedded crystalline dolostones and limestones which are alternatively interbedded with the lowland-making phyllitic members composed of shales, clay slates, sandstones, greenstones, carbonate rocks, and thinly bedded pale colored cherts. A thin argillaceous limestone (Nagabarasaki Limestone Lentil) at the top of a thick dolostone member yields Late Permian Fusulinids (*Yabeina–Neoschwagerina* assemblage) which, in the Ryukyu Islands, record the second occurrence of the bona fide Paleozoic index fossils next to those from Okinawa-jima. The greenstones are microscopically distinguished as muscovite-epidote-albite, epidote-muscovite-chlorite, epidote-chlorite-albite-quartz, and chlorite-pumpellyite(?)-prehnite schists, but all are referred to greenschist facies.

Different types of porphyritic and porphyric rocks cut into the metasedimentary rocks as sills and dykes. Heterogeneous Nishinomori Diorite of probably middle Tertiary discordantly intruded into the Late Paleozoic rocks (Tonaki Formation) and resulted in the development of hornfels aureoles characterized by biotite-hornfels and garnetiferous skarn rocks. Beach rock at the west coast of Tonaki-jima should be younger than 700 years because it preserves torn pieces of "Early Tsuboya-yaki" (ancient type of Ryukyuan chinas) among the gravels. Inasmuch as Idesuna-jima represents the geotectonically innermost island in the Motobu Belt (KONISHI, 1963) where the Late Paleozoic fossil-bearing and metamorphosed basement rocks crop out, the width of the belt is determined to attain the magnitude from 25 km to 40km.

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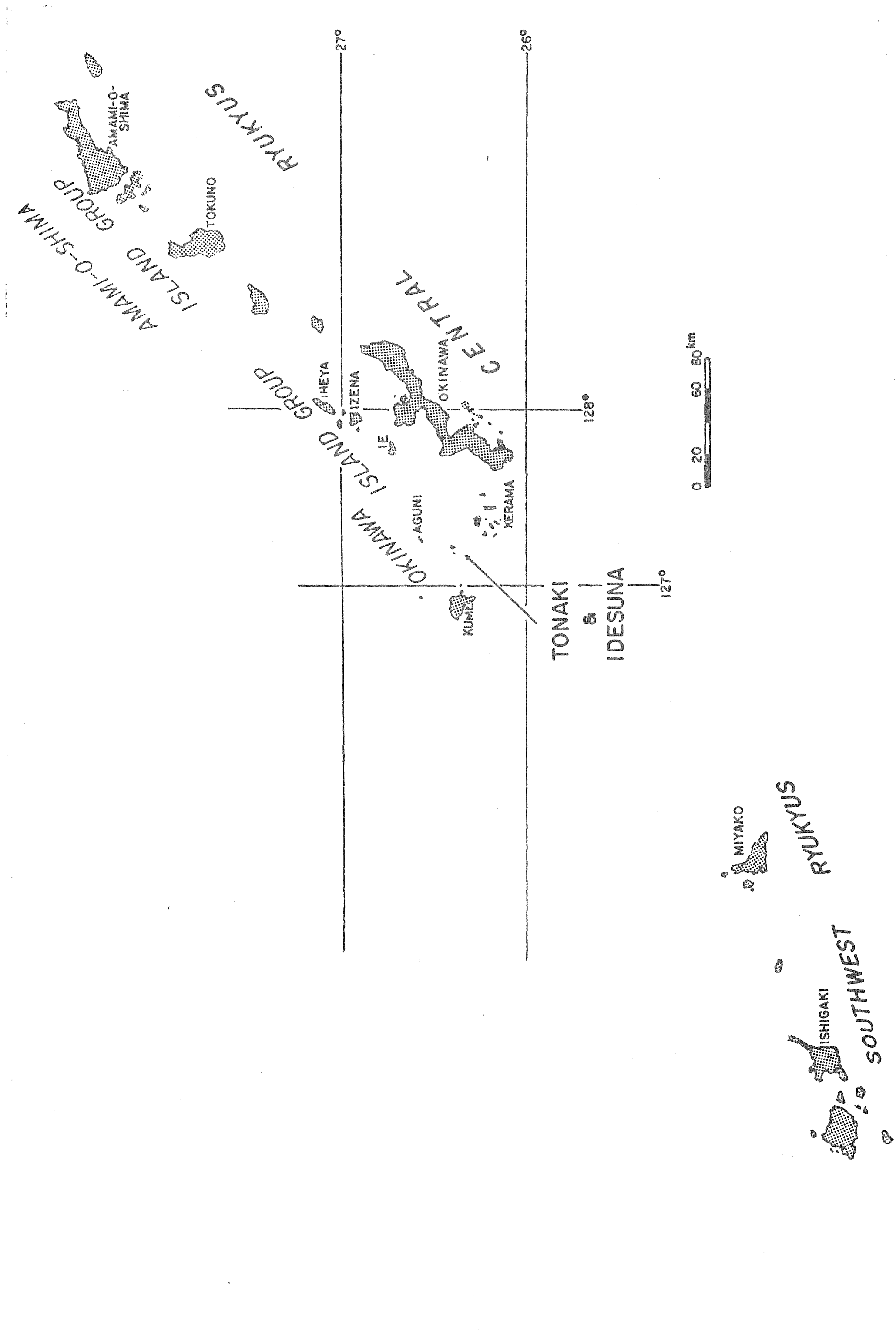
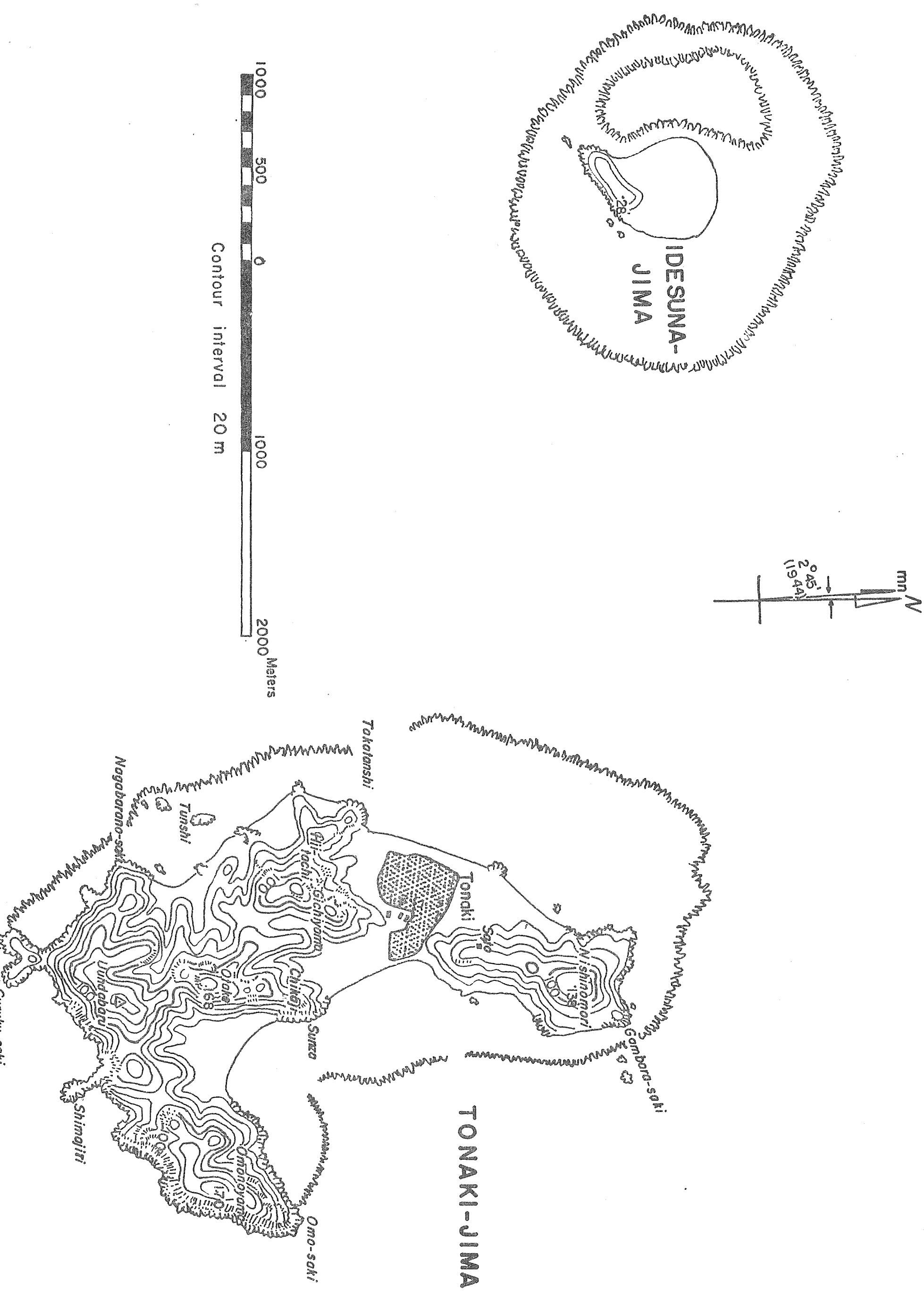
Introduction and acknowledgments

In order to justify my interpretation that the tectonic division of the pre-Miocene basement complex in the Ryukyu Islands is almost identically compared with that of the Outer Zone of Southwest Japan (KONISHI, 1963), it becomes necessary to find any island northwest of Okinawa-jima, where, like northern Ishigaki-jima, metamorphic rocks of glaucophane schist facies crop out, so that successive mutual relations among the Ishigaki, Motobu, Kunigami, and Shimajiri Belts (nomenclature after KONISHI, *ibid.*) can be demonstrated in a single tectonic profile across the Okinawa Island Group (Text-fig. 1). Previous reports by KUROIWA (1898), YOSHIWARA (1900) and HANZAWA (1935) mentioned thick beds of radiolarian chert from Ie-, Izena-, and Iheya-jima, hence to be dated Paleozoic, while they and WAKIMIDZU (1906) reported Kumé-jima and Aguni-jima both north of Tonaki-jima are volcanic islands where pre-Miocene basement complex is subsurface. The "schalstein" described by KUROIWA (*ibid.*) from southeastern Kumé-jima was not confirmed by HANZAWA nor myself. Therefore, Tonaki-jima located between Iheya Islands and Kumé-Aguni Islands appears to be the best site to investigate for the present purpose. So far, practically no geological studies have been carried in Tonaki-jima, except a brief visit by ISHII (1935) who noted the occurrence of garnet and epidote in association with granodiorite.

Tonaki-jima and its offshore islet, Idesuna-jima, are in the Okinawa Island Group of the Ryukyu Islands (Nansei Shotô); they are located at about 50 km west-northwest



Text-figure 1 Location map of Tonaki-jima, and Idesuna-jima, Okinawa Island Group.



Text-figure 2 Topographic map of Tonaki-jima and Idesuna-jima.

of Naha City, Okinawa. The approximate center of Tonaki-jima is Long. 127°08′30″E. and Lat. 26°21′45″N. Because the topographic sheets of these islands are not available in the market at present, they are partly redrawn here to assist the better understanding of general geomorphology and names of local places of the islands by the readers (Text-fig. 2). The 1 : 25,000 maps now considerably reduced were copied from those prepared by U. S. Army Map Service in 1944 which were reproduced from 1 : 50,000 Tonakijima Sheet of the Japanese Imperial Land Survey (1922). The American sheet numbers are registered 3526-III SE (Tonaki-jima SE) and 3526-III SW (Tonaki-jima SW).

I am very grateful to Professor Emeritus Teiichi Kobayashi of the University of Tokyo for his valuable advice and encouragement to this study. My field work was made in the summer of 1963 under the joint arrangement by the University of the Ryukyus and Tonaki Junior High School, to whom I wish to extend my sincere thanks. My deep appreciation also goes to Professor Wataru Ichikawa and other staff members of our department at Kanazawa University, and to Professor Kosei Akaminé and other members of the Department of Geography at the University of the Ryukyus, all of whom kindly made my present work possible. Messrs. S. Uesato, then the Principal, and Y. Nakasoné of Tonaki Junior High School helped with the field work. Dr. Shannon McQune, then the Civil Administrator of the U. S. Civil Administration of the Ryukyu Islands, amiably gave me the opportunity to study Tonaki-jima and Idesuna-jima from a helicopter. Drs. Shohei Banno of the University of Tokyo and Masao Yamasaki of our department kindly supplied the petrographic information of metamorphic and igneous rocks, and they also contributed to the fruitful discussion.

Outline of geology

Geology of Tonaki-jima and Idesuna-jima is summarized as follows;

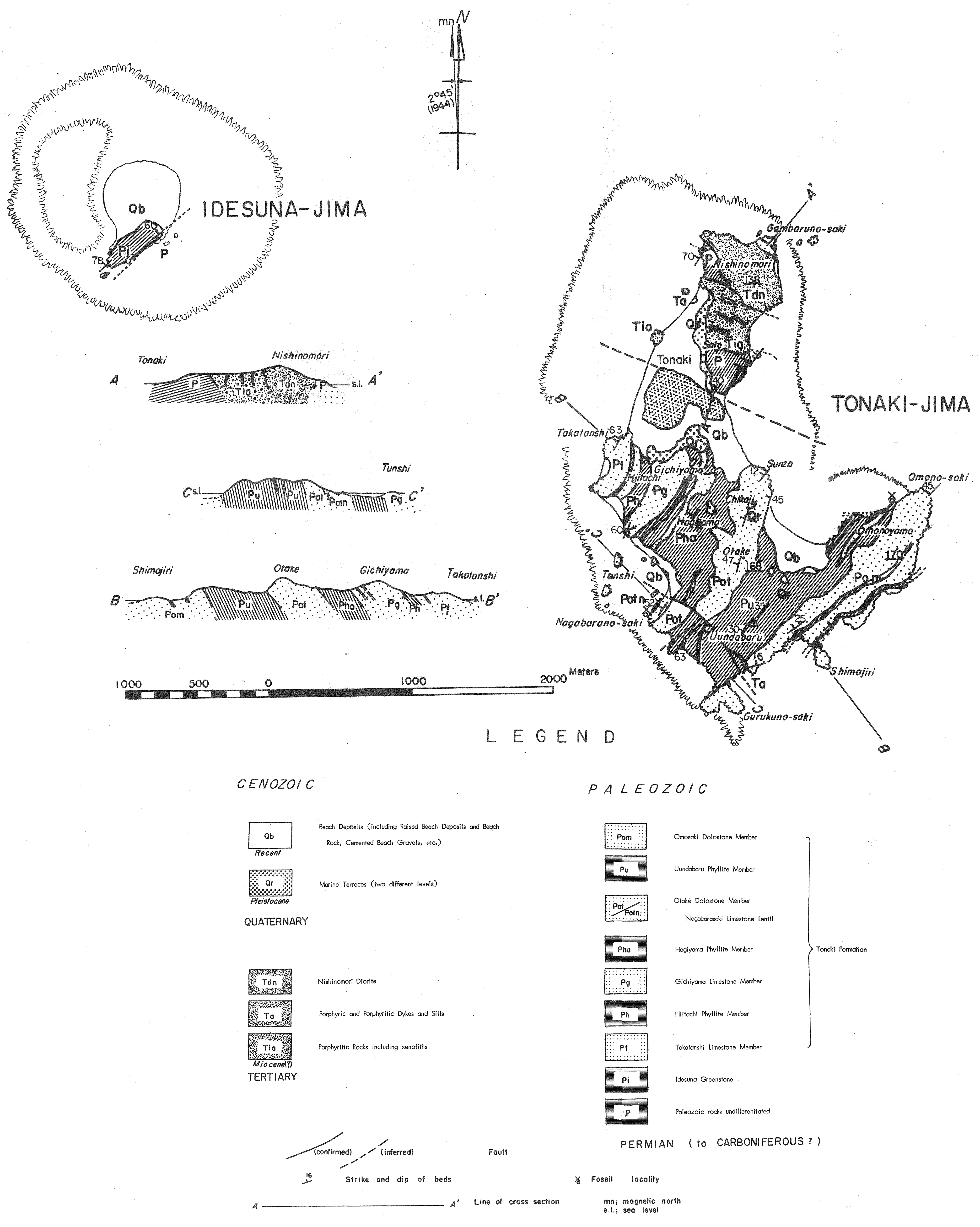
Recent	Reef Rocks
	Beach Deposits
	Beach Gravel and Sand
	Pumiceous Pebbly Gravels
	Cemented Beach Gravels
	Raised Beach Deposits
Pleistocene (?)	Marine Terraces
	Lower Terrace (20~40m level)
	Upper Terrace (80~100m level)
Tertiary	Aplite
	Nishinomori Diorite (*Miocene*?)
	Porphyrite
	Porphyry
Late Paleozoic	Tonaki Formation
	Phyllite members

Dolostone and limestone members
Otaké Dolostone Member
Nagabarasaki Limestone Lentil (*Late Permian*)
Idesuna Greenstone

Tonaki-jima can be divided into two parts both geologically and geomorphologically which are connected by the isthmus of raised beach deposits. The northern part mainly consists of Tertiary dioritic rocks in association with several types of hornfels, while the southern part of the island is characterized by Late Paleozoic sedimentary rocks, though appreciably metamorphosed, which make an alternatively combined topography of hogbacks (or cuestae) and lowlands. These Late Paleozoic and Tertiary rocks represent the bedrocks unconformably overlain by thin veneers of Quaternary sediments. Two marine terraces at different levels are recognized; the lower ones at 20～40m above sea level are probably correlated with Machinato Limestone (Late Pleistocene), while the upper ones represented by only the remnants are probably with Yontan Limestone (middle Pleistocene—Yarmouthian—Mindel-Rissian interglacial stage) of Okinawa. Without any conclusive evidence, however, the proposed correlation must be tentative.

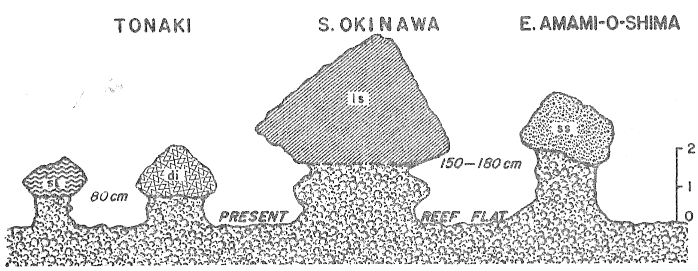
Among the Recent sediments, three units, 1) Pumiceous Pebbly Gravels of Beach Deposits, 2) Beach Rock, and 3) some Mushroom Stacks of Reef Rocks are briefly described here for their general implication to the geology of the Ryukyu Islands. The *Pumiceous Pebbly Gravels* are found just beneath the thin veneer of the Beach Sand in front of the Raised Sand Deposits. It is well observed at the beach of Anzera, 500m southeast of Sunza. The gravelly bed is composed of rounded pebbles of pumice and calcareous coarse-grained sand associated with matrix of brown soil, and characterized by the abundance of land snail shells with marine molluscan and echinoid tests. Similar sediments are common along the coast of Heshikiya, Katsuren Peninsula, where it forms a bench about 20～40 cm above the high tide. The stratigraphic position relative to the present high tide appears to be similar between Tonaki-jima and Okinawa-jima, and it is believed that the sediments are the member of Beach Deposits. Because of the peculiar lithology, this bed might be used as a datum to trace the regional eustatic changes as well as volcanic activities in a limited region.

The origin of *Beach Rock* is still the subject of dispute, but it seems to be convincing to me that the mode of the development of beach rocks and their probable equivalents subsurface at the Okinawa Island Group appears to support the conclusion advocated by RUSSELL (1958 and later). The details of beach rocks of these islands are to be reported elsewhere. In Tonaki-jima and Idesuna-jima, like other islands in adjacence, beach rocks well fringe the coastal margins of the islands and it was proven at the western coast of Tonaki-jima that the beach rocks now exposed at the surface were buried beneath the beach sand until several years ago when the construction of



Text-figure 3 Geologic Map of Tonaki-jima and Idesuna-jima quay-wall changed the shoreline process along the beach coast. Shore currents carried away the veneer of beach sand. According to native people, similar rocks are probably traced into beneath the Raised Beach Deposits at the isthmus as the two beds of biosparite to biosparudite and intrasparudite by shallow boring operation. However, the continuity between the beach rocks cropping out along the coast and these two subsurface beds has not been directly proven yet. Furthermore, the beach rocks at Shogawa and west of Tonaki yield the pieces of chinas among the gravels. (Fig. 3 on Plate I) According to Professor Keiichi YAMAMOTO (personal communication, dated Oct. 5, 1963), of University of the Ryukyus, the pieces found should have been produced some time between 1264 (Eiso 5 years) when the ancient Ryukyuan king laid the first tribute on Kume, Keramas, Iheya and Tonaki, and 1682 when another later type of the Ryukyuan china, Iwaibe-yaki, was first founded. Therefore, the beach rocks concerned cannot be older than 700 years. Recently, YONETANI (1963) records the occurrence of a silver comb from the beach rock of the northern Amami-o-shima, 325 km northeast of Tonaki-jima, and he concludes that the silver comb is probably dated within the last 200 years. These data from the Ryukyu Islands seem to substantiate the considerably "young age" of beach rock formation.

Thirdly, it is noted that there are blocks of diorite, sandstone, marble, shale, and others in boulder size perched on pedestal remnant 50～80 cm higher than the surface of the present reef flat, thus forming a kind of *Mushroom Stacks*, along the coast of Tonaki-jima (Figs. 1 and 4 on Plate I; Text-fig. 4). As already reported by MAC NEIL (1950), these boulders are interpreted as the fallen blocks of the nearby cliff-forming older rocks onto the former higher reef surface. The pedestal surface has been cemented solidly with the capping blocks. In Ie-shima and southern Okinawa-jima, MACNEIL (*ibid.*) recorded this type of mushroom stacks to have pedestal surface approximately 5 to 6 feet (1.7 to 2.0 m) high above the present reef flat, and he tentatively assigned the tops of the pedestals to "the period preceding the so-called 'Climatic Optimum', which is believed to have been 4,000 to 6,000 years ago". An



Text-figure 4 Pedestal surfaces of two different levels as observed at some mushroom stacks of Tonaki-jima, southern Okinawa-jima, and eastern Amai-o-shima; di diorite, ls, limestone, ss, sandstone, sl, clay slate.

example of the mushroom stacks possibly interpreted to this origin is observed at Miibaru, southern Okinawa-jima, and is illustrated here as Fig. 2 on Plate I and also Text-fig. 4. The contact between the capping older block and underlying ancient reef flat sometimes becomes obscure because both units are composed of similar lithologies. A resembling occurrence of the pre-Miocene sandstone boulder cemented on the irregular surface of the former reef flat 1.5 to 2.0 m high above the present one was observed along the eastern coast of the northeastern Amami-o-shima (Text-fig. 4).

The somewhat lower but apparently constant, maximum height of the ancient pedestals observed from the mushroom stacks along the coast of Tonaki-jima may be interpreted two ways; 1) later age of the pedestal surfaces at Tonaki-jima, if compared with those at Ie, southern Okinawa, and Amami-o-shima, or 2) difference in the vertical uplift of land relative to sea level during the last 3,000 years or so between Tonaki-jima and the other islands. In Tonaki-jima, abandoned nips are observed at less than 1 m above the high tide level along the cliffs of the Paleozoic carbonate rocks. Thus, five to six feet drop of the sea level could not be proven in Tonaki-jima directly, whereas it is beyond doubt that the present reef flat of the island has been resulted from planation of a reef at least about one meter higher in relatively recent time. CLOUD (1954) writes that "a temporary halt or slowdown in the rate of withdrawl of water at roughly 2 feet above present sea level is also widely evident, but this is regarded as an incident in the 6-feet fall".

Late Paleozoic beds

Late Paleozoic beds of Tonaki-jima have been segregated stratigraphically into seven units; they are, in descending order,

1. Takatanshi Limestone Member (Pt),
2. Hiitachi Phyllite Member (Ph),
3. Gichiyama Limestone Member (Pg),
4. Hagiyama Phyllite Member (Pha),
5. Otaké Dolostone Member (Pot),
6. Uundabaru Phyllite Member (Pu), and,
7. Omosaki Dolostone Member (Pom).

These are all conformably overlying one above the other, except the contact of possible thrust nature between Otaké Dolostone Member and Uundabaru Phyllite Member, and are grouped under the name of Tonaki Formation. A prominent thick sequence of sheared greenstones consists the major portion of Idesuna-jima and has been mapped separately as Idesuna Greenstone (Pi).

The dominant strike of Tonaki Formation and Idesuna Greenstone is northeast to north-northeast and almost all the beds of the formations consistently dip moderately towards northwest to west-northwest, except a restricted area of southwestern Tonaki-jima, where the Uundabaru Phyllite Member locally dips southeasterly (Cross section C······C′ of Text-fig. 3) in association of porphyritic dyke. The dipping attitude of the carbonate members of Tonaki Formation considerably varies from 63° to almost horizontal. In the members intraformational folds are not uncommon. The southern portion of Otaké Dolostone is truncated by northwest-trending Shidu Fault, along which mylonitization of phyllitic rocks and intrusion of porphyry dyke (Fig. 4 on Plate II) are observed. The other northwest-trending transverse fault, though concealed, is interpreted beneath the village of Tonaki. It is highly probable that the whole section of Tonaki Formation and Idesuna Greenstone may represent a portion of the northwestern limb of an overturned syncline. If this is proven to be true, the stratigraphic order of the formations and members described below should be revised in reverse.

Tonaki Formation

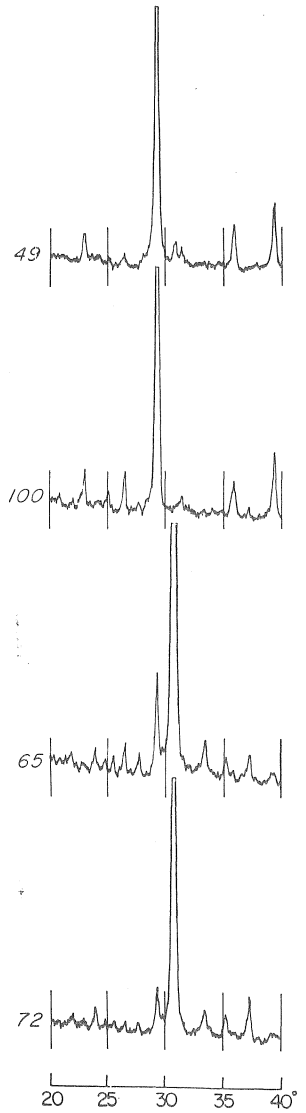
Phyllite Members

All the phyllitic members consist of crystalline schists, phyllites, clay slates, sandstones (feldspathic and lithic subgraywackes), dolostones, limestones, greenstones, and cherts, but, in general, they are so deeply weathered that their stratigraphic details are uncertain. *Hiitachi Phyllite Member* crops out at Hiitachi, and consists of phyllitic greenstone and clay slate. *Hagiyama Phyllite Member* is named after the hill where the member is considerably exposed, and a thick section of clay slate and sandstone together with limestone bed about 10 m thick is observed. Greenstones of mostly intrusive origin—metadolerite (diabase) and metagabbro—seem to predominate in the lower section exposed along the southern coast near Amadarashi, where, besides thick limestone beds about 20 to 30 m thick, interbedded phyllitic white chert and clay slate are recognized above Otaké Dolostone Member.

Uundabaru Phyllite Member is deeply weathered at the north of the type locality, where the member forms the lowland of Anzera, but an almost complete section of the member crops out between the east of Nagabarasaki and Gorokunosaki along the southern coast. Its basal portion is also well exposed along the coast northwest of Omosaki, where, however, a stuctural complication due to intrusion of porphyry dyke makes difficult to obtain stratigraphic succession.

Limestone and Dolostone Members

Four thick carbonate members, all of which intercalate noncalcareous phyllitic beds, have been recognized; they are, in ascending order, Omosaki Dolostone, Otaké Dolostone, Gichiyama Limestone, and Takatanshi Limestone. All the carbonate specimens from the members were examined to identify mineral constituents by X-ray powder diffraction method and staining method (Text-fig. 5). Both Gichiyama and Omosaki Members intercalate non-carbonate phyllitic beds.



Text-figure 5

X-ray powder diffractograms of some carbonate rocks from Tonaki-jima ; scans from 20° to 40° 2θ (Cu Kα) ; *49*, limestone from Takatanshi Limestone Member; *100*, Limestone from Nagabarasaki Limestone Lentil ; *65*, dolostone from Otaké Dolostone Member; *72*, dolostone from Omosaki Dolostone Member.

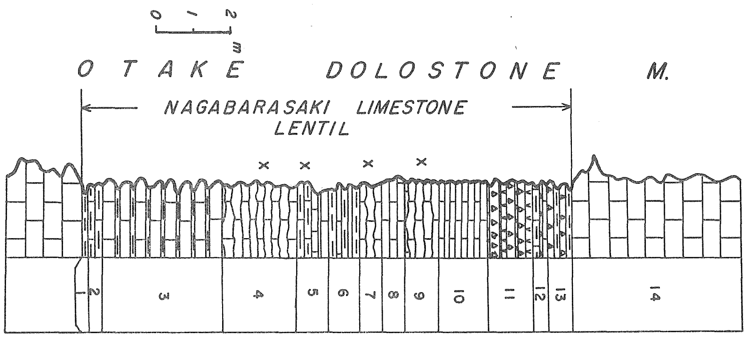
Gichiyama and *Takatanshi Limestone Members* mostly consist of massive, gray to black, crystalline limestones, some of which are very slightly magnesian limestone. *Otakê Dolostone Member* is composed of gray, massive to thickly bedded dolostones and magnesian limestones (Fig. 2 on Plate III). Some show brecciated texture probably of tectonic origin. This member forms pinnacles of knife-edged surface when weathered, and makes the rugged topography of the mountain ridge of Otaké.

Dark gray, metamorphosed, though fossiliferous, argillaceous limestone beds conformably intercalated within the monotonously unfossiliferous, calcitic dolostone and dolostone crop out near Nagabarasaki and are here designated as *Nagabarasaki Limestone Lentil* of Otaké Dolostone Member. The lentil is 13 m thick at the measured section of the type locality and traceable only 200 m or so northwards, but further tracing was failed beyond the Shidu Fault. The limestone beds, weather to brown, are less resistive than the rest of the dolostone member and do not form pinnacles. They develop undulatory beddings parted by argillaceous layers (Fig. 1 on Plate III). Petrographic study of thin sections of the limestone reveals biomicritic texture associated with abundant microstylolite and sporadic microcrystalline quartz grains partly replaced by calcite. X-ray powder diffraction analysis also proves the occurrence of appreciable amount of quartz in the limestone (Sample no. *100* of Text-fig. 5). Besides the profusion of fusulinid foraminifers, the limestone preserves crinoidal detritus, some of which are characterized with deformational features such as wavy extinction and bent lamellae in calcite crystals. A preliminary comparison with the fossiliferous limestones from Motobu Peninsula of Okinawa-jima indicates that much severe metamorphism appears to have undergone to Nagabarasaki Limestone than those of Okinawa. As discussed later, this limestone lentil is dated to Late Permian on the basis of fusulinids. The measured section at the type locality is given as Table 1 and Text-fig. 6.

Table 1 Type section of the Nagabarasaki Limestone Lentil

(along the sea cliff at Nagabarasaki, southern Tonaki-jima; measured by K. KONISHI, Oct. 2, 1963)

	Thickness in meters
Upper Permian (?)	
Otaké Dolostone Member of the Tonaki Formation	
15. Limestone, black, compact, thinly bedded in the order of 5 cm± ; uppermost exposed bed at this measured section	2.5
14. Limestone, gray, dolomitic, sheared, weathers as limestone breccia (black) in white matrix.	4.5
—— conformable (? minor fault contact?) ——	
Upper Permian	
Nagabarasaki Limestone Lentil (top)	
13. Alternation of chert and shale: *chert*, pale green,; *shale*, black, thinly laminated	0.7
12. Limestone, gray, crystalline, intercalated with thinly bedded chert	0.4
11. Alternation of phyllitic greenstone and chert intercalating limestone	1.2
10. Limestone, phyllitic, crystalline, banded structure of black and white layers	1.3
9. Limestone, bedded (10~30cm), intercalating shaly streaks, fossiliferous	0.9
8. Limestone, gray, crystalline, fine-grained	0.55
7. Limestone, gray, undulatorily bedded (10~30 cm), fossiliferous, weathers to brown; uppermost and basalmost 10cm argillaceous	0.6
6. Shale, black to gray, calcareous, intercalating argillaceous fine-grained (calcilutitic) limestone	0.8
5. Limestone, argillaceous, intercalating calcareous shale layers (10cm±) ; uppermost 0.22m encrinitic	0.84
4. Limestone, gray to black, undulatorily bedded (10~30 cm), fossiliferous	2.0
3. Alternation of shale and limestone: *shale*, 2~10cm, thickly bedded ; *limestone*, fine-grained, massive, but with banded structure in the order of 20cm±	3.2
2. Limestone, gray to black, argillaceous, encrinitic	0.4
1. Shale, black, calcareous	0.1~0.15
	(Total thickness 13.04)
—— conformable ——	
Limestone, magnesian, gray, phyllitic, crystalline, weathers to the surfacial appearance of elephant skin with knots; partially dolomitic; intercalates black shale of 1.2m thick	2.5
Limestone, gray, thinly laminated, weathers to knife-edged surface; this is the unit consisting of the very point of Nagabarasaki and is conformably underlain by the thick section of unfossiliferous gray massive, magnesian limestone to dolostone of about 50 meters thick.	



Text-figure 6 Columnar section of the Nagabarasaki Limestone Lentil; x, fossiliferous bed.

Omosaki Dolostone Member consists of white, gray to black, thickly to moderately well-bedded, dolostone and magnesian limestone (Fig. 3 on Plate III). It forms cliffs along the south coast of Tonaki-jima. The member intercalates two distinct phyllitic units, each of which is about 40 m thick. The brief description of one of the units measured at the east of Shimajiri is given below.

Limestone, magnesian, white, saccharoidal	Basal portion of thick limestone bed
Greenstone, phyllitic; stilpnomelane–chlorite–calcite–albite rock	10 m
Dolostone, massive	8
Shale, black, intraformationally contorted	15
Greenstone, coarse-grained, probably doleritic origin	3.5
Clayslate and *sandstone*; black clayslate grades downwards into sandstone through the alternation of sandstone and clayslate.	5
	41.5
Dolostone, thickly bedded	Top of thick dolostone bed

Idesuna Greenstone

As briefly mentioned above, a thick formation of massive greenstone (Fig. 1 on Plate II) mostly tuff breccia in origin is well exposed at Idesuna-jima, 3.8 km northwest of Tonaki-jima. It is conformably underlain by the sequence of sheared phyllitic rocks interbedding conglomerate phyllite, but its stratigraphic position relative to Tonaki Formation is uncertain. This conglomerate phyllite appears to be oligomict exclusively composed of pebbles of sandstone with silty matrix, thus suggesting the possibility of their boudins in origin (Fig. 2 on Plate II). They are microscopically identified as epidote-muscovite-chlorite schist.

Correlation

The Nagabarasaki Limestone Lentil of the Otaké Dolostone Member yields a prolific fauna of fusulinid foraminifers, but, because of the recrystalization and deformation, they do not permit any detailed paleontological study. So far, five of foraminifers, and one form of supposed hydrocoralline have been identified, as follows;

Yabeina sp. cfr. *Y. globosa* (YABE)	(Figs. 4 & 5 on Plate III) abundant
Neoschwagerina sp.	(Fig. 6 on Plate III) common
Kahlerina sp.	(Fig. 7 on Plate III) rare
Schwagerina sp.	(probably more than one species)
(or *Chusenella*?)	(Figs. 8 & 9 on Plate III) abundant
Schubertella (?) sp.	(Fig. 10 on Plate III) rare
and,	
Nigriporella sp.	(Fig. 11 on Plate III) common.

Although none of the fusulinids can be identified beyond the generic names with certainty, it is safely concluded that this Nagabarasaki assemblage is dated to Late Permian, because of the co-occurrence of *Yabeina*, *Neoschwagerina*, and *Kahlerina*.

So far, Late Permian fusulinids---*Neoschwagerina*, *Verbeekina*, and *Schwagerina*---described from the Motobu Limestone (stratigraphic nomenclature after FLINT *et al.*, 1959) of Okinawa-jima by HANZAWA (1933) represent the only index fossils of the Paleozoic in the Ryukyu Islands. FLINT and others (1959) and KONISHI (1963) added the occurrence of the similar assemblages from the new localities of the same formation. The find of Late Permian fusulinids and other microfossils from Tonaki-jima makes the first record of the bona fide Paleozoic index fossils outside of Okinawa-jima. Recently, I (unpublished data) have found another, perhaps later, Late Permian fusulinids from the limestone beds which were mapped as a member of the Yonaminé Formation by FLINT and others (*ibid.*). The paleontological descriptions of this fauna is being progressed. To my best knowledge at present, the Nagabarasaki Limestone Lentil is most probably correlated with the *Yabeina* - *Neoschwagerina*-bearing beds of the Yonaminé Formation rather than the *Neoschwagerina*-*Verbeekina* beds of the Motobu Formation. It must be kept in mind, however, that the fossiliferous Nagabarasaki Limestone Lentil occupies only a small fraction of the Tonaki Formation, and the rest of the formation might include the older section.

Tertiary (Miocene?) diorite and other igneous rocks

The northern part of Tonaki-jima is mostly occupied by a stock of dioritic rocks named hereafter Nishinomori Diorite. It discordantly cut into the Paleozoic beds, stretching northwesterly. It has given the contact metamorphism to both the Paleozoic beds and Tertiary (?) porphyritic and porphyric dykes, and has been intruded into by biotite-aplite and biotite-porphyry. As the contact effect, the Late Paleozoic carbonate beds became skarn yielding garnetiferous ore minerals as seen at Gambaruno-saki, while sandstone and shale have been metamorphosed into biotite-hornfels as observed at Sakashi of the northwestern tip of Tonaki-jima. Besides the garnet, hedenbergite, epidote, chalcopyrite, and pyrite have been recognized in the skarn minerals. Kin-ichi MIYATA, graduate student of our department, (personal communication dated Oct. 20, 1964) kindly informed me that the garnet from this skarn indicated a faint optical anomaly around the marginal rim of the crystal, and appeared to be a Ca-garnet with the chemical composition either close to andradite molecule or intermediate between grossularite and andradite molecules, according to lattice constants (a_0) calculated from X-ray powder diffractograms. The porphyritic rocks, some of which are biotite-hornblende-porphyrite and occur as sills in the Paleozoic rocks, also indicate the alteration effects such as carbonatization, opacitization, and chloritization, and some have been metamorphosed into pyroxene-actinolite-biotite-hornfels. An altered porphyrite occurring as the dyke at the neck of Gorokuno-saki has been used as grindstone by native people (Fig. 4 on Plate II).

The Nishinomori Diorite appears very heterogeneous and varies the mineral composition considerably from biotite-green hornblende-andesine-diorite to biotite-quartz-microdiorite, both of which are characterized by the pidiomorphic-granular texture. It contains xenoliths ranging from pebble to boulder in size, which are occasionally disposed like stratification, along certain planes. Many xenoliths are round in shape. Microscopical study of the xenolith-bearing diorite very commonly shows the contamination effect of the dioritic rock by calcareous xenoliths, thus the hybrid origin of the rocks. The banded structure was microscopically proven that the leucocratic part is due to the abundance of plagioclases and so the melanocratic to that of biotite. The occurrence of cummingtnite among amphiboles in the diorite appears to substantiate the evidence of low pressure (most probably shallow) origin of diorite emplacement. The Nishinomori Diorite may represent the cupola of a large batholith.

These features described above indicate the close affinity of the Nishinomori Diorite with the reported biotite-granodiorite of Tokuno-shima and Okinoerabu-shima (SUZUKI, J., 1937) in the Central Ryukyus (SUZUKI, Y., 1954), as well as the Tertiary (Miocene) granitic rocks in the Outer Zone of Southwest Japan. However, the Nishinomori Diorite differs from the Omoto Granite (FOSTER *et al.*, 1960; quartz-monzonite by SUZUKI, J., 1937) of Ishigaki-jima by the absence of porphyritic texture and graphic intergrowth of quartz and feldspars, and also from the granodiorite of western Amami-o-shima (Koniya area; OBA, 1959) by the absence of chloritized biotite and sauccuritized plagioclase. Inasmuch as the geochemical dating of the Nishinomori Diorite is in progress for the biotite sample, it is, meanwhile, tentatively dated to Miocene from our present knowledge on the granitic rocks of the Outer Zone of Southwest Japan and the Ryukyu Islands.

Width of Motobu Belt

As explained at the beginning of this paper, the present study was initiated to determine the width of Motobu Belt at the Central Ryukyus where the Hedo Thrust (or Hedo Tectonic Line) well defines the southeastern boundary of the belt. The result of the study proves now that Tonaki-jima represents the geotectonically innermost exposure of fossil-bearing Paleozoic basement complex in the Ryukyu Geanticline, hence being placed in Motobu Belt. This conclusion is complemented by petrological data. The greenstones both massive and phyllitic from the Idesuna Greenstone and Tonaki Formation were examined microscopically and the result of the petrographic identification preliminarily supplied by BANNO (personal communication dated July 25, 1964) is summarized in Table 2. No directional change in metamorphic grade seems to

Table 2 Mineral variations in the greenstones from Tonaki-jima and Idesuna-jima; microscopic identification of minerals by S. BANNO and M. YAMASAKI

stratigraphic unit / mineral species	IDESUNA GREENSTONE					TONAKI FORMATION							
						Hiitachi Phyllite	Hagiyama Phyllite			Uundabaru Phyllite			Omosaki Dolostone
	62	60	59a	59b	59c	53	86	88	69	121	145	151	76
Albite	x		x	x							x	x	x
Epidote	x			x	x		x	x			x		
Pumpellyite (?)		x											
Prehnite		x											
Chlorite	x	x			x	x	x	x	x	x	x	x	x
Muscovite	x		x	x	x	x		x	x			x	
Stilpnomelane													x
Calcite	x			x		x				x			x
Quartz			x								x	x	

No. 59a is a conglomerate schist.

be recognized from this result. It is convinced that all the greenstones are referred to greenschist facies, but no crystalline schists can be compared with glaucophane schist facies. The greenschist facies has been recognized in the Paleozoic greenstones and green schists of Ishigaki-jima where two metamorphic belts, the northern one consisting of greenschist facies-glaucophane schist facies series (without jadeite-quartz) and the southern one of greenschist facies, have been recognized (KONISHI, 1965). The crystalline schists and phyllites of Tonaki-jima and Idesuna-jima are best compared with those of the southern Ishigaki-jima. The result of our preliminary study on the mineral zoning of the metamorphic belts in the Ryukyu Geanticline is shown in Table 3. The petrological information concerning Tonaki-jime and Idesuna-jima is incorporated in this table as the representative of the northern Motobu Belt. The poor state of

Table 3 Mineral variations in regional metamorphism in the Ryukyu Geanticline.
(microscopic identification of minerals by S. BANNO and M. YAMASAKI)

Tectonic Belt	ISHIGAKI BELT		MOTOBU BELT			KUNIGAMI BELT	
Metamorphic Facies	Greenschist facies	Glaucophane schist facies	Greenschist facies		HEDO TECTONIC LINE	Epidote-amphibolite facies	Green-schist facies
Mineral Zoning	1	2	3	3′		4	5
Apparent Width (km)	0.3+	6.5	6.0	25.0–35.0		1.3	8.5+
Sodic Plagioclase	—	—	—	—		—	—
Pistacite		—	—			—	—
Pumpellyite (?)			—				
Prehnite			—				
Clinozoisite	—						—
Glaucophane		—					
Actinolite	- - -	—					—
Hornblende						—	
Chlorite	—	—	—	—			—
Muscovite			—	—			—
Stilpnomelane			—				

fossil preservation due to severe deformation and considerable recrystallization suggests that the crystalline rocks of the Tonaki Formation should occupy close to the northwestern boundary of Motobu Belt.

Furthermore, the development of the Otaké and Omosaki Dolostone Members is significant, because thick beds of dolostone similar to the members tend to crop out always close to the northern boundary ("Mikabu Line") in the Chichibu Belt of Southwest Japan (KAWADA, INOUE, and TAKAHASHI, 1963), geotectonically equivalent to Motobu Belt of the Ryukyu Geanticline. Although the very point of the northwestern boundary of Motobu Belt thus deduced could not be observed at outcrop above sea level, it is certain that such a boundary is most probably drawn just northwest of Idesuna-jima or possibly at the channel between the islet and Tonaki-jima. An attempt is being continued to find xenoliths of glaucophane schist or high-grade schists in the pyroclastic rocks at Kumé-jima and Aguni-jima, both of which are located at the northwestern side of the boundary.

The breadth of the apparent exposure so defined by the two tectonic lines in the Central Ryukyus attains about 25 km between the north end of Zamami-jima of the

Kerama Islands, and the southern end of Kume-jima, and about 40 km between the Cape Hedo of Okinawa-jima, and the northwest coast of Iheya-jima. This magnitude is slightly larger than that of Chichibu Belt in the Outer Zone of Southwest Japan (data of Southwest Japan are compared from KIMURA, 1961). Even in Southwest Japan, however, it has been not always simple to pinpoint the boundary ("Mikabu Line") between Sambagawa and Chichibu Belts.

References

CLOUD, Preston E. Jr., 1954, Superficial aspects of modern organic reefs: Sci. Month., v. 79, n. 4, p. 195–208.

FLINT, D. E., SAPLIS, R. A., and CORWIN, Gilbert, 1959, Military geology of Okinawa-jima, Ryukyu-retto; volume V. Geology: 88 p. U. S. Army Pacific Off. Eng., Intell. Div., with personnel of U. S. Geol. Surv.

FOSTER, Helen, STENSLAND, Carl H., MAY, Harold G., FOSBERG, F. Raymond, and ALVIS, Richard J., 1960, Military geology of Ishigaki-shima, Ryukyu-retto: 323 p. Geol. Surv. Branch, Intell. Div. Off. Eng., Hq. U. S. Army Forces, Far East with personnel of U. S. Geol. Surv.

HANZAWA, Shoshiro, 1933, On a *Neoschwagerina*-limestone from Okinawa-jima, the Riukiu (Loochoo) Islands: Japan. Jour. Geol. Geogr., v. 10, n. 3–4, p. 107–110.

HANZAWA, Shoshiro, 1935, Topography and geology of the Riukiu Islands: Sci. Rept. Tohoku Imp. Univ., 2nd ser. (Geol.), v. 17, p. 1–61, 15 pls., 5 maps.

HANZAWA, Shoshiro, and MURATA, Masafumi, 1963, The paleontologic and stratigraphic considerations on the Neoschwagerininae and Verbeekininae, with the descriptions of some fusulinid Foraminifera from the Kitakami Massif, Japan: Sci. Rept. Tohoku Univ., 2nd ser. (Geol.), v. 35, n. 1, p. 1–31, 20 pls.

ISHII, Ken-ichi and NOGAMI, Yasuo, 1964, Contributions to the geology and paleontology of Cambodia. Part 1. Permian Fusulinids: Jour. Geosci. Osaka City Univ., v. 8, art. 2, p. 9–68.

ISHII, Kiyohiko, 1935, Journey in Okinawa Prefecture (Riukiu Islands): (in Japanese) Jour. Geogr. (Tokyo), v. 47, p. 255–265, 318–326, 426–436.

KANMERA, Kametoshi, 1954, Fusulinids from the Permian Kuma Formation, southern Kyushu, Japan, with special reference to the fusulinid zones in the Permian of Japan: Fac. Sci. Kyushu Univ., Mem., ser. D. Geol., v. 6, n. 1, p. 1–38, pls. 6, 2 text-figs.

KANMERA, Kametoshi, 1957, Revised classification of *Cancellina* and *Neoschwagerina* and evolution of Sumatrininae and Neoschwagerininae: *Ibid.*, v. 6, n. 1, p. 47–64, 2 pls., 1 text-fig.

KAWADA, Shigema, INOUE, Kiyoshi, and TAKAHASHI, Hiroshi, 1963, Dolomite: (in Japanese) Geological News (Chishitsu News), n. 103 (March, 1963), p. 1–24.

KIMURA, Toshio, 1961, The lateral faulting and geologic structure of the eastern part of Southwest Japan: Japan. Jour. Geol. Geogr., v. 32, n. 2, p. 317–330.

KOCHANSKY-DEVIDE, V., 1955, Neoschwagerinski Skladi in njih Fuzulinidna favna pri Bohinjski Beli in Bledu: (with German summary) Slov. Akad. Znan., Umet., v. 4, n. 3, p. 361–424, 8 pls.

KONISHI, Kenji, 1963, Pre-Miocene basement complex of Okinawa, and the tectonic belts of the

Ryukyu Islands: Sci. Rept. Kanazawa Univ., v. 8, n. 2, p. 569–602.

KONISHI, Kenji, 1965 (MS), Tectonic framework of the Ryukyu Islands (Nansei Shotô): (in Japanese with English abstract) Jour. Geol. Soc. Japan. (The abstract of this paper was printed on p. 398 of the Jour. Geo.l Soc. Japan, v. 70, n. 826 (1964).)

KUROIWA, T., 1898, Kume-jima (Geology of Kume-jima): (in Japanese) Jour. Geol. Soc.Tokyo (Japan), v. 5, n. 59, p. 409–419.

MACNEIL, F. S., 1950, Planation of recent reef flats on Okinawa: Bull. Geol. Soc. Amer., v. 61, p. 1307–1308.

OBA, Noboru, 1959, Geology, especially granitic rocks, near Koniya, Amamiôshima: (in Japanese) Sci. Rept. Kagoshima Univ., n. 8, p.115–126.

RUSSELL, R. J., 1958, Preliminary notes on Caribbean beach rock: Caribb. Beach Stud., Tech. Rept. No. 11, Pt. A, 9 p., 14 text-figs.

RUSSELL, R. J., 1960, Beach rock investigations: Science, v. 131, n. 3409, p. 1320.

SUZUKI, Jun, 1937, On the granitic rocks of the Outer Zone of Southwest Japan and the Ryukyu Islands: (in Japanese) Jour. Geol. Soc. Japan, v. 44, n. 526, p. 625–660.

SUZUKI, Yoshio, 1954, On the relations between the mineral and chemical compositions of some acidic plutonic rocks in Japan: Jour. Fac. Sci. Hokkaido Univ., ser. IV, v. 8, n.4, p. 431–450.

TORIYAMA, Ryuzo, 1958, Geology of Akiyoshi, Pt. 3, Fusulinids of Akiyoshi: Fac. Sci. Kyushu Univ. Mem., ser. D, Geol., v. 7, n. 1, p. 1–264, 2 range charts.

TORIYAMA, Ryuzo, 1963, The Permian *in* "Geology of Japan" edited by TAKAI, Fuyuji, MATSUMOTO, Tatsuro, & TORIYAMA, Ryuzo: p. 43–58, University of Tokyo Press.

WAKIMIDZU, Tetsugoro, 1906, Report on a trip to Okinawa-jima and its dependent islets: (in Japanese) Jour. Geogr. Tokyo, v. 18, n. 214, p.647–659, 732–742, 812–825.

YONETANI, Seiji 1963, Preliminary notes on beach rock at the South-west Islands of Japan: Lit. Rept., Kagoshima Univ., v. 12, ser. History, n. 9, p. 1–16, 8 pls., 8 text-figs. (The Japanese text of this paper appeared in *Geogr. Review of Japan*, v. 36, n. 9, p. 519–527, under the title of "The preliminary studies on the beach rock of the northern part of Amami Oshima, South-west Japan").

YOSHIWARA (=TOKUNAGA), Shigeyasu, 1900, Notes on the raised coral reefs in the islands of the Riukiu Curve: Jour. Coll. Sci., Imp. Univ. Tokyo, v. 16, art. 1, p. 1–67.

Appendix: Alphabetical List of Place Names

Aguni	（粟国）	Machinato	（牧港）
Amami	（奄美）	Miibaru	（新原）
Hedo	（辺土又は辺戸）	Motobu	（本部）
Heshikiya	（平敷屋）	Naha	（那覇）
Idesuna	（出砂又は出沙）	Nishinomori	（西之森）
Ie	（伊江）	Okinoerabu	（沖之永良部）
Iheya	（伊平屋）	Omoto	（於茂登）
Ishigaki	（石垣）	Otaké	（大嶽）
Iwaibe(—yaki)	（祝部一焼）	Shimajiri	（島尻）
Izena	（伊是名）	Tokuno (—shima)	（徳之一島）
Katsuren	（勝連）	Tonaki	（渡名喜）
Kerama (s)	（慶良間）	Tsuboya (—yaki)	（壺屋一焼）
Koniya	（古仁屋）	Yonaminé	（与那嶺）
Kumé	（久米）	Yontan	（読谷）
Kunigami	（国頭）	Zamami	（座間味）

Postscript ;

Following to my suggestion, Dr. K. Kaneshima of the Department of Chemistry at the University of the Ryukyus, with the assistance from staff members of the Government of the Ryukyu Islands, is currently undertaking the chemical analysis of the Paleozoic carbonate rocks at Tonaki-jima, in order to evaluate the economic potential of the dolomite deposits described in this paper. Kaneshima kindly analyzed twelve representative samples in my collection, and, through his courtesy, the result of the analysis is reproduced herewith as a table. More complete data on the chemical composition of the carbonate rocks at Tonaki-jima will be published by Kaneshima elsewhere. Because the Otaké Dolostone Member intercalates limestone beds as exemplified by sample *141*, the economic evaluation of the dolostone beds of the island needs a detailed geological and geochemical mapping in the field. It is concluded, meanwhile, that two dolostone members of Tonaki Formation are mainly composed of "slightly calcitic dolomite" (terminology after Vishnyakov, 1933 and Frolova, 1959) in which CaO/MgO ratio ranges from 1.5 to 2.2, although some samples (e.g., No. *78*) from the Omosaki Dolostone Member attain very close to the range of dolomite (dolostone).

Stratigraphic Horizon	Takatanshi Limestone	Gichiyama Limestone	Naga-barasaki Limestone	Otaké Dolostone					Limestone *in* Uundabaru Phyllite	Omosaki Dolostone		
Sample No.	*50*	*85*	*100*	*65*	*67*	*68*	*124*	*141*	*143*	*70*	*72*	*78*
SiO_2	0.71	5.77	9.93	1.43	0.20	0.72	1.89	0.57	0.30	2.13	0.56	0.19
Fe_2O_3	0.07	0.28	2.48	0.41	0.06	0.11	0.35	0.04	0.12	0.24	0.06	0.08
Al_2O_3	0.05	0.41	1.67	0.07	0.05	0.09	0.25	0.12	0.09	0.13	0.06	0.03
CaO	53.66	49.67	45.65	32.93	34.92	36.00	36.09	49.33	54.95	39.07	32.97	32.28
MgO	1.40	1.96	1.40	18.48	17.67	16.49	15.43	5.13	0.09	12.91	18.94	20.01
P_2O_5	0.014	0.041	0.24	0.030	0.033	0.011	0.051	0.019	0.214	0.004	0.006	0.010
CaO/MgO	38	25	32	1.7	1.9	2.1	2.3	9.6	62	3.0	1.7	1.6
Rock name (VISHNYAKOV, 1933 and FROLOVA, 1959)	slightly dolomitic limestone	slightly dolomitic limestone	slightly dolomitic limestone	slightly calcitic dolostone		calcitic dolostone		slightly dolomitic limestone	limestone	calcitic dolostone	slightly calcitic dolostone	
X-ray diffraction analysis	limestone	slightly magnesian limestone	limestone	dolostone	calcitic dolostone	dolostone		calcitic dolostone	magnesian limestone	calcitic dolostone	dolostone	calcitic dolostone

PLATE I

EXPLANATION OF PLATE I

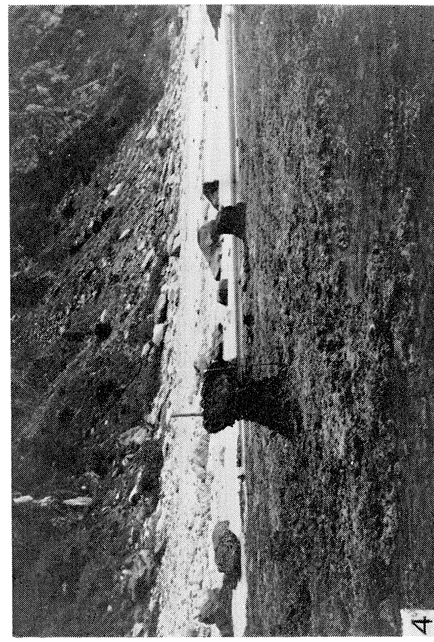
Recent Mushroom Stacks and Beach Rock

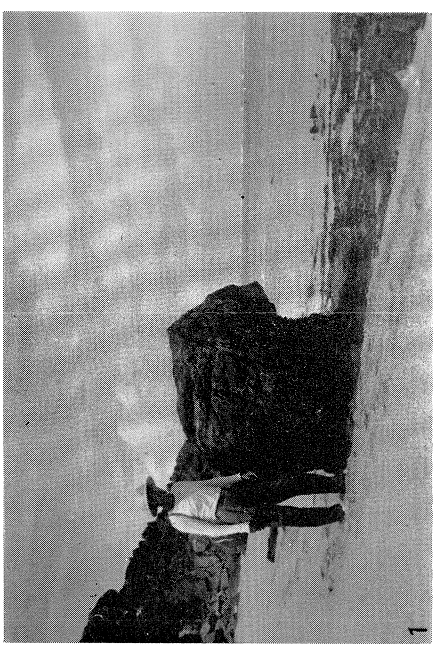
Figure 1 A mushroom stack at the west of Gambaruno- (or Gambara-) saki, northern Tonaki-jima; the boulder from the Nishinomori Diorite is perched on the pedestal surface of the former reef, which is 50~80 cm higher than the present one. The man in the picture is about 1.6 m tall. Tide intermediate.

Figure 2 Mushroom stacks with double notches at Miibaru, southern Okinawa; the block referred to the Pleistocene Machinato Limestone shows so prominent stratifications now in dipping position, that its "allochthonous" origin is self-explaining from a distance. The lower notch corresponds to the present sea level at high tide. Tide intermediate.

Figure 3 Beach rock at Shogawa, western coast of the northern Tonaki-jima; the pencil in the picture points to the pieces of Early Tsuboyayaki (ancient Ryukyuan chinas) preserved in the rock.

Figure 4 Another feature showing the pedestal remnants 60 cm higher than the surface of the present reef flat at the southern coast of Tonaki-jima; the capping boulder is the Paleozoic clay slate. A geologist pick about 45 cm long at the top of the stack. Tide low.





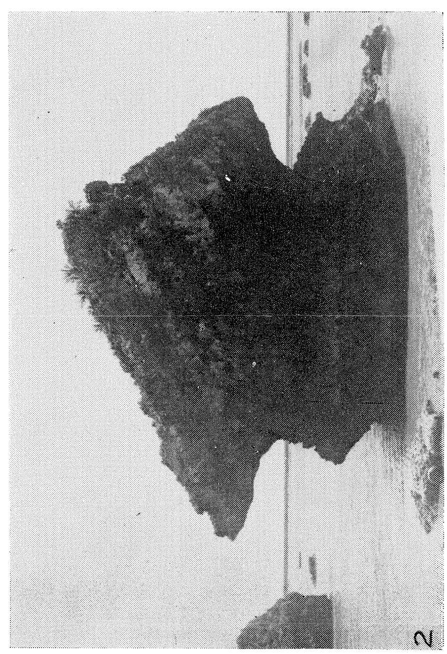


PLATE II

EXPLANATION OF PLATE II

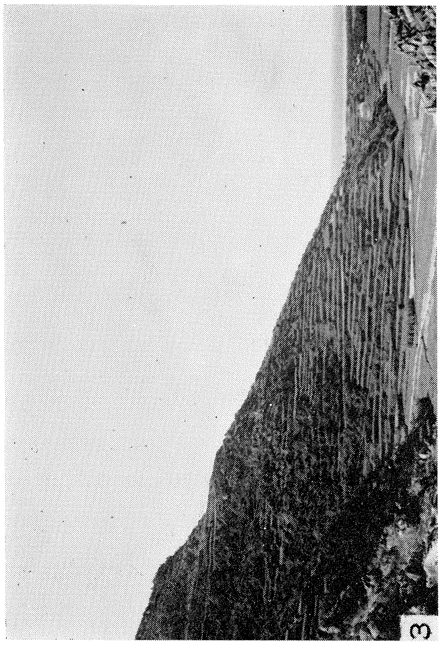
Pleistocene Marine Terraces, Tertiary Porphyritic Dyke, and Late Paleozoic Idesuna Greenstone

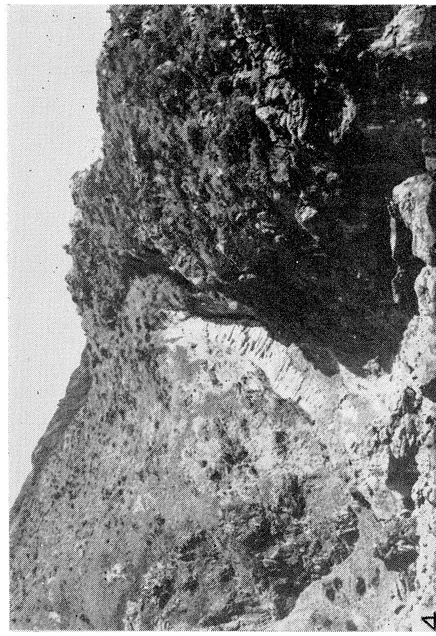
Figure 1 An outcrop of the Idesuna Greenstone at the south coast of Idesuna-jima; breccias of greenstones similar to the matrix in the mineral composition are distinct on weathered surface. The greenstone from this outcrop is microscopically identified as chlorite-pumpellyite (?)-prehnite schist.

Figure 2 A conglomerate schist underlying the Idesuna Greenstone at the eastern coast of Idesuna-jima; pebbles are sandstone in origin. The schist is microscopically identified as epidote-muscovite-chlorite-schist.

Figure 3 Two marine terraces along the northern slope of Gichiyama; the upper terrace represented by only remnants is 80-100m above the present sea level, whereas the lower ones at distance in this picture are 20-40 m high. Both of them are considered to be Pleistocene. Looking at the west from near Chikaji.

Figure 4 A porphyrite dyke in the Uundabaru Phyllite Member, close to the Shizu Fault at the neck of Gorokuno-saki, southern Tonaki-jima; the dyke is well jointed and has been altered. The blocks of this rock is used as grindstone by native people.





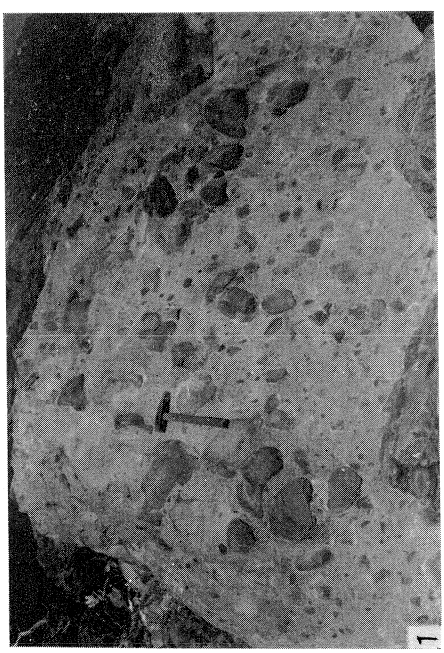


PLATE III

EXPLANATION OF PLATE III

Tonaki Formation and Late Permian Microfossils from the Nagabarasaki Limestone Lentil

Figure 1 Moderately dipping beds of the Nagabarasaki Limestone Lentil at the type locality, Nagabarasaki, southern Tonaki-jima. Looking at north from the very point of Nagabara-saki.

Figure 2 Cuesta-forming, thickly bedded sequences of the Otaké Dolostone Member at the south of Sunza; the trees in the picture are about 10 m tall. Looking at the north from the north of Otaké.

Figure 3 Undulatorily well-bedded parts of the Omosaki Dolostone Member at Gorokuno-saki, southern Tonaki-jima; the beds are parted by thin black, argillaceous layers.

All the photomicrographs are about 10 times natural size.

Figures 4 and 5 Obliquely cross sections of *Yabeina* sp. cfr. *Y. globosa* (YABE)

Figure 6 Obliquely tangential section of *Neoschwagerina* sp.

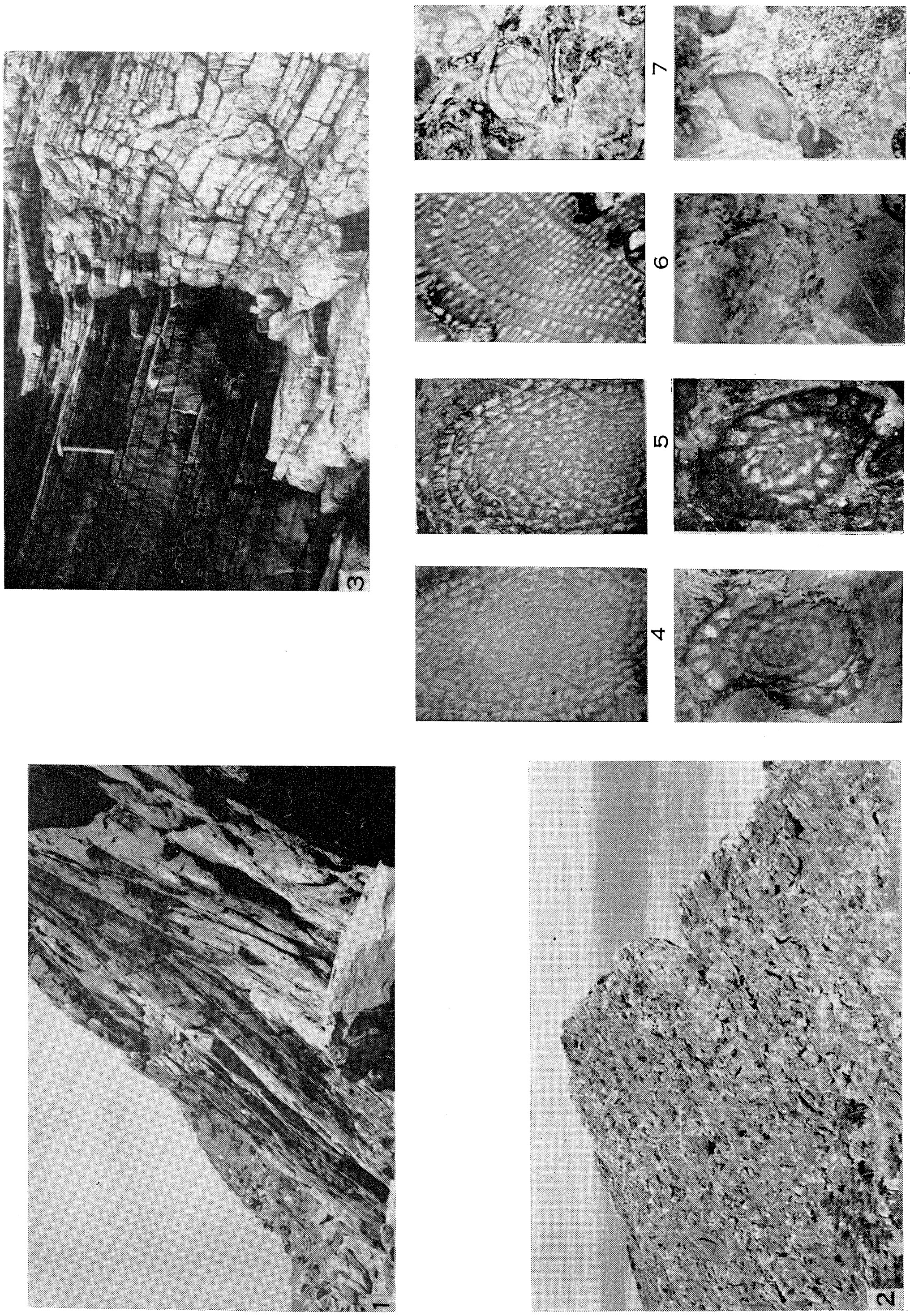
Figure 7 Obliquely tangential section of *Kahlerina* sp.

Figure 8 Part of the cross section of *Schwagerina* (or *Chusenella*?) sp.

Figure 9 Oblique section of *Schwagerina* (or *Chusenella*?) sp.

Figure 10 Oblique section of *Schubertella* (or *Codonofusiella*?) sp.

Figure 11 *Nigriporella* sp.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