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Pre-Miocene Basement Complex of Okinawa, and the Tectonic Belts of the Ryukyu Islands*

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ABSTRACT

Okinawa-jima of the Ryukyu Islands is geologically divided into three tectonic belts of rock-types in its exposed or subsurface pre-Miocene basement complex; southeasterly, the inner Motobu, central Kunigami, and outer Shimajiri. These belts are defined respectively by the Hedo fault between the former two belts, and by the Tengan fault between the latter two. The Motobu belt consists of a gently folded overthrust sheet of limestone and chert in association with the subordinate pyroclastics, greenstones, and shale, and yields Permian fusulinids from the limestone and bedded manganese deposits and radiolarian remains from the chert. The Kunigami belt occupying the principal portion of the basement complex of the island consists of 1) a schistoze and phyllitic Nago Formation associated with greenstones and bedded cupriferous pyrite deposits, and 2) less metamorphosed, volcanic-free, Flysch (turbiditic) Kayo Formation. The Nago Formation contains greenschist facies characterized by actinolite-epidote-chlorite schist. The Kayo Formation near the type locality yields a supposedly fresh-water green alga, ***Palaeodictyon majus*** Meneghini. The polymictic Attsu Conglomerate Lentil of the formation contains limestone cobbles resulting from the penecontemporaneous erosion and redeposition, which preserve the late Mesozoic Torinosu Limestone flora (calcareous algae) and fauna (stromatoporoids and corals). The lentil at the type locality also contains a carbonaceous seam yielding plant remains both palynologic and xylotomic, and also various ichnocoenose. The outermost Shimajiri belt is represented by younger (Miocene and Pliocene) sediments completely overlyng the basement complex deeply buried in the subsurface.

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The comparative geotectonics between southern Kyushu and the Ryukyus north of the Miyako Depression leads to the conclusion that the Hedo and Tengan tectonic lines in Okinawa are most probably comparable to the major tectonic lines of Kyushu in their tectonic position; the Butsuzo-Ohsakama-Ushinohama and Nobeoka-Shibisan Lines, respectively. Thus, the central Kunigami belt of Okinawa is traceable to the northern belt of the Shimanto terrain in Kyushu, keeping a similar width (about 20 km) of exposure throughout the distance for almost 500 km. The outer Shimajiri belt corresponds to the southern part of the Shimanto terrain in the same manner. The northern part of the Yaeyama Islands (Ishigaki and Iriomote) west of Miyako is named as Ishigaki belt and considered to represent the innermost metamorphosed Paleozoic belt (glaucophane schist facies) not exposed at Okinawa-jima. These zonal structures of the Ryukyu Islands were completed before Miocene, but the succeeding geohistory of the islands, especially that of the Miocene and Pliocene Epochs, was more or less controlled by the zonal structure of the pre-Miocene basement complex. Certain Quaternary activities such as the Pleistocene reef-building and Recent (Holocene) volcanism seem to be independent from the zonal structure of the islands.

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INTRODUCTION

The purpose of this paper is to call attention to the fact that the basement complex of Okinawa (Okinawa-jima) is mostly dated late Mesozoic and early Cenozoic (early Tertiary) instead of being exclusively Paleozoic. The geotectonic significance deduced from this new fact is also discussed in this paper.

According to his comprehensive work, Hanzawa (1935) dated the basement complex underlying the partially Miocene (then Pliocene) and Pliocene Shimajiri Formation to be Paleozoic, probably Permian, a conclusion based on his genuine discovery of *Neoschwagerina* and *Verbeekina* from Motobu Peninsula (Hanzawa, 1933). Recent extensive field mapping by Flint, Saplis and Corwin (1959), with assistance of other members of the U. S. Geological Survey, vindicated the occurrence of the similar Permian fusulinids from two other new localities ; the western end of the Motobu Peninsula and in Hedo-misaki. The fourth new locality,

Text-figure 1 Index map of the Ryukyu Islands

though probably close to the second one, of the Permian Neoschwagerinids was also found, in the course of the present study, at the northwest of Shiokawa. Non-diagnostic crinoid stems were found in the limestone basement of Ie-shima (MacNeil, 1960, p. 5). Furthermore, Flint and others made clear that the Permian beds containing the fusulinid-bearing limestone are all thrust over the undated phyllitic metamorphic rocks (MacNeil, *ibid*., p. 12). The thrust sheet is interpreted to have moved "outward" directed from the NW. Because of this structural contact between the Permian crystalline limestone beds and the underlying metamorphosed rocks, the age of the latter was not determined. The rocks east of the thrust have been divided into two units, the Nago and Kayo Formations. The third phyllitic formation named Yonamine has been mapped to occur as windows within the thrust sheet, to which the name of the Motobu Formation has been given because of its extensive exposure at the Motobu Peninsula (stratigraphic nomenclatures are after Flint and others, *ibid.*)

The result of my study of the eastern coast of northern Okinawa in 1960 and 1961, where the type section of the Kayo Formation crops out, indicates that the formation is dated, at the oldest, late Jurassic. So far, no Mesozoic rocks, except possible igneous rocks, have been identified on the Ryukyu Islands (MacNeil, *ibid.*, p.5).

KAYO FORMATION

General Description :

The Kayo Formation (Flint and others, 1959) is primarily composed of sandstone with a considerable amount of interbedded phyllitic clayslate, sandstone, and conglomeratic sandstone and breccia. The Formation seems to exceed 1000 m in thickness. Apparently the lower part consists of thick sequences of clayslate interbedded with very thick sequences of sandstone and siltstone, whereas the upper part is composed of alternations of sandstone and siltstone from a few millimeters to more than four meters thick, interbedded with slate and phyllitic beds or lenses that are generally less than 20 cm thick. The type locality is along Highway 13 from a point just west of Sedake to Kayo and also along the coast to Banno-saki (Text-fig.2). The most common lithology is sandstone, both medium- and coarse-grained and composed of particles of quartz, feldspars (both potash feldspars and plagioclases), and chert in sericitic, chloritic and "argillaceous" matrix. Lithic and feldsparthic graywackes are the most abundant types of sandstone, but the arkose is locally common. Graded bedding is commonly observed where the sandy unit is not thick and dominant. Several thin beds of conglomerate and breccia are met with in the monotonous alternation of sandstone and shale, and as described in the next section, three types of the conglomerates may be distinguished. The primary sedimentary structure such as cross-bedding, ripple marks, and desiccation breccia are locally found to an appreciable amount. A considerable part of the exposed Kayo Formation has been weathered into red color, and the weathering is specially deep in the shaly sequence as around Kin, Taira, and Kawata. The Kayo Formation gradually merges into the underlying Nago Formation as observed along the coast of Kawata, for example, but, in many cases, the relation is fault contact. The Kayo Formation is unconformably overlain by the Pliocene and Pleistocene sediments of the Ryukyu Group.

Three types of conglomerates :

The conglomerate and breccia are not uncommon in the Kayo Formation, and they seem to merge together. This is one of the major characteristics of the

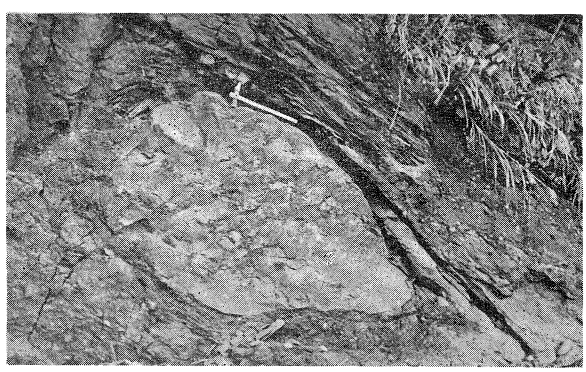
Kayo Formation. The conglomerates are all intraformational and mostly oligomictic, and characterized by the well argillaceous matrix. Hanzawa (1935, p.34) mentioned the conglomenatic beds at three localities ; (1) Sedake, (2) Arumé, and (3) Kawata. The second locality was mentioned by Tokunaga (then, Yoshiwara) previously as early as 1901. Some geologists in Japan refer to this specific conglomerate as the "Usuginu-type" of late Permian (Kuman) age, because of their bearing of granitic pebbles. I reexamined these localities ; the conglomerates at Sedake and Kawata are oligomictic, or almost oligomictic, whereas the ones at Arumé (Attsu of this paper) are polymictic.

At least three types of conglomerates can be distinguished lithologically in the field mapping.

(1) Flat, shale pebble conglomerate and breccia. In this type, all the pebbles are black shale, flattened and angular in shape. This type of breccia is believed to be formed by penecontemporaneous, probably subaqueous fragmentation and redeposition of black shale ("desiccation breccia"). Turbidity flow probably was responsible for the fragmentation and redeposition. This type of conglomerate is the most common in the Kayo Formation and, for instance, observed at Sedake, Kayo, and Kawata.

(2) Oligomictic conglomerate of argillaceous matrix. This type is the next most common in the Kayo Formation. The gravels are mostly schistoze sandstone and chert of granule to pebble size, but, occasionally well-rounded and worn pebbles of quartz schist are also common. Very rarely granitic rocks have been found (at Katabaru, north of Matsuda, Kawata, and east of Yona).

(3) Polymictic conglomerate of silty matrix. This is the conglomerate which contains cobbles and pebbles of fossiliferous limestone, and various other rock types. So far, its distribution is only known along Highway 13 at the south of Arumé. Sandstone and shale are the most common constituents among the cobbles and pebbles. An exceptionally huge boulder of coarse sandstone, about one and a half meters in diameter (Text-fig. 3) was found. Shale also occurs as stringers and angular fragments within the conglomerate. Cherty pebbles and cobbles are also common. As the microscopic examination indicates, the possibility of chertification from the original limestone for some chert pebbles cannot be ignored. Some cherty pebbles are microscopically proven to be quartz schist. Few igneous rocks, graphic gran-



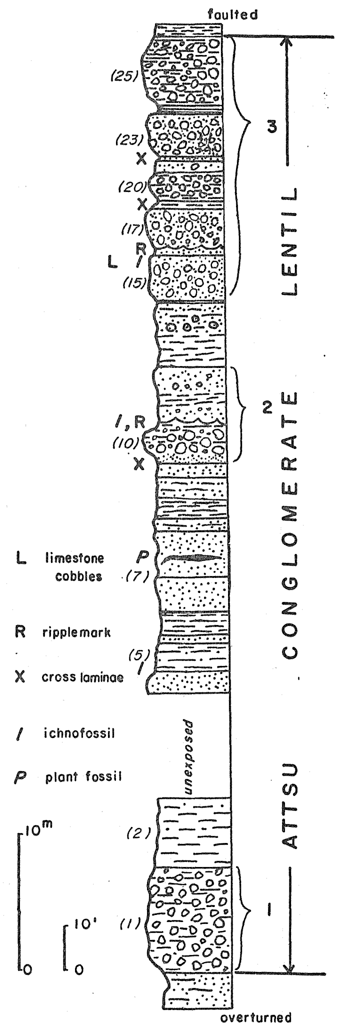
Text-figure 3 Unusually huge boulder of coarse sandstone in the Attsu Conglomerate Lentil ; basal bed (unit 1) of the lentil at the type section.

ite, and altered porphyry. are also found as round and worn pebbles. A peculiar rock type which almost entirely consists of quartz grains with a very small amount of calcite cement but no matrix has been recognized among the pebbles. The matrix of the conglomerate sporadically becomes sandy.

Polymictic Attsu Conglomerate Lentil :

Because the dating of the Kayo Formation is mostly based on the coralline, and stromatoporoidean fauna and algal flora found in the limestone cobbles of the polymictic conglomerates near Attsu, the mode of occurrence of the conglomeratic beds along Highway 13 between Teruku, south end of Arumé village, and Attsu (or Attsubaru) is described below in some detail. Although its distribution has not been mapped areally due to poor state of exposure, the conglomeratic beds are hereafter specifically named as Attsu Conglomerate Lentil within the Kayo Formation. The partial succession of the Kayo Formation between an overturned anticline and a fault represented by a small stream valley (Yamato-gawa) which includes the type section of the Attsu Conglomerate Lentil is shown in Table 1 and Text-figure 5.

Text-figure 4 A couple of polymictic beds in the Attsu Conglomerate Lentil (units 23 and 25 of the measured section) at its type section, along the Highway 13, Attsu, Kushi-son, Okinawa.



Text-figure 5
Columnar section of the Attsu Conglomerate Lentil

Table 1

Measured section of the Attsu Conglomerate Lentil at the type locality
(about 550 m north of Attsu, Kushi-son, northern Okinawa ; measured by K. Konishi, July 22, 1961)

Late Mesozoic (Lower Cretaceous?)

Kayo Formation

Unit	Attsu Conglomerate Lentil (top)	Thickness (meters)
25.	Conglomerate, almost oligomictic, contains flat cobbles of black chert possibly of limestone origin, argillaceous matrix, overlain conformably by laminated sandstone	6.0
24.	Sandstone, medium-grained, laminated	0.5
23.	Conglomerate, polymictic, resistive to weathering, contains lenticular layers of sandstones and shale, pebbles and scarce cobbles of sandstone, rounded pebbles of limestone and granitic rocks	3.2
22.	Sandstone, coarse- and medium-grained, cross-laminated, defined the top and bottom by thin layers of black shale	0.1
21.	Sandstone, granule-conglomeratic, contains angular pebbles of black shale sporadically	1.3
20.	Conglomerate, polymictic, contains exclusively pebbles of shale, sandstone, and igneous rocks, matrix arenaceous	2.2
19.	Sandstone and shale, frequent alternation ; sandstone, medium-to coarse-grained, cross-laminated, rippled surface	0.5
18.	Sandstone, coarse-grained, laminated, gradually transitional from the underlying conglomeratic bed	0.3
17.	Conglomerate, polymictic, same as the unit 15.	3.2
16.	Sandstone, medium-grained, laminated, the top surface rippled broadly (amplitude 1.3cm, wave length 20cm)	0.5
15.	Conglomerate, polymictic, contains angular and flat cobbles and pebbles of shale, sandstone, and fossiliferous limestone, and rounded pebbles of chert, quartz schist, sandstone, and igneous rocks, matrix argillaceous	3.4
14.	Sandstone, medium- to coarse-grained, laminated, rippled at top	4.7
13.	Sandstone, coarse-grained, very thinly laminated, argillaceous matrix, partly conglomeratic	2.3
12.	Shale, black, very thinly alternate with fine sandstone layers	0.5
11.	Sandstone, medium-grained, laminated except massive upper 0.9 m, black shale layers in the middle	1.7
10.	Conglomerate, granular, almost oligomictic and breccia at the basal part, matrix argillaceous, intercalated shaly stringers ; merges upwards into coarse, rippled sandstone preserving ichnofossils	2.3
9.	Sandstone, coarse-grained, cross-laminated and rippled, contains lenticular layers of conglomerate of argillaceous matrix	0.5
8.	Sandstone and shale, finely alternated	4.1
7.	Sandstone, graywacke, coarse-grained, planary cross-laminated, very poorly sorted to unsorted, matrix silty, upper 0.7 m almost mudstone, fossiliferous carbonaceous lentil (3.8-5.0cm thick, 25cm long) 2 m below the top	4.9
6.	Sandstone and shale; sandstone, pale green and gray, laminated, quartzose; shale, black	4.8
5.	Sandstone and shale, thinly alternated, yields tubular and linear ichnofossils up to 7 mm in diameter	2.1
4.	Sandstone, medium-grained, very hard, quartzoze	1.7
3.	Unexposed	8.5
2.	Sandstone and shale ; shale, black, intercalates with sandstone as thin layers ; basal part brecciated because of a minor thrust passing at the base of the unit	5.0
1.	Conglomerate, polymictic, mostly argillaceous matrix, contains huge boulder of coarse sandstone, cobbles mostly sandstone, a few flat shale, rare limestone with pelletoidal structure and igneous rocks (graphic granite and altered porphyry)	7.5
	Total thickness	71.8

Base of Attsu Conglomerate Lentil

Sandstone, sheared, pale green, medium-grained, interbedded with shale; tubular ichnofossils at the base of this unit; the whole sequence is overturned by an overfolded anticline.

Limestone Cobbles and Pebbles ;

In the field, two types of limestone have been recognized ; one is crystalline and gray in color, and the other is faintly recrystallized and dark gray to black. The first is usually pebble or small cobble (64-128 mm in diameter, for instance) in size and seems not to preserve any organic remains. The second type of limestone shows the great degree of variety in the recrystallized state, apparently depending on the size of intraclasts. In general, the larger the intraclasts the less recrystallized. This type of limestone contains more than two types of textures : 1) intrasparudite, and 2) pelsparite (nomenclature after Folk, 1959).

So far, five fossiliferous limestone cobbles (small and large) have been examined under the microscope and a prolific assemblage of calcareous algae, corals, and stromatoporoids were found in the largest, cobble-sized gravel (300×350×500 mm). A poorly preserved coral tentatively identified as a species of *Thamnasteria* was obtained from a fist-sized pebble. Another cobble preserves the pelletoidal texture in association with scattered shell fragments, but no diagnostic remains.

The dark-colored intrasparudite appears to suggest deposition above the wave base. The intraclasts are usually detritus of algae, stromatoporoids, and corals interspaced by clastic calcareous or non-calcareous matrix. The non-calcareous matrix is represented by terrigenous, coarse-to fine-grained sand of quartz, feldspars and rock fragments. The insoluble residue of the limestone was obtained from the solution of 200 grams of crushed sample into a 10 % dilute solution of hydrochloric acid. It exceeds 8 % (8.43 % as the highest, though) on the average of five samples and is mostly composed of medium sand to clay-sized particles of terrigenous quartz. Thin section study also proves to be a similar percentage of the terrigenous quartz of subangular to subround roundness. The quartz grains are partially and peripherally replaced by sparry calcite cement. Some silt and clay-sized grains are coated by bituminous substance, which also occurs as individual aggregate of minute particles ranging from silt to fine-grained sand in diameter.

The lithology and texture of the limestone indicate therefore a shallow site of deposition for the limestone. While the pebbles of the igneous rocks and some cherts are definitely terrigenous, those of the most sedimentary rocks probably resulted from the penecontemporaneous subaqueous erosion or fragmentation due to turbidity flows, which resulted in the deposition of the polymictic Attsu Conglomerate. The graywacke nature and the paucity of other organic remains suggest that the whole sequence of the Kayo Formation was deposited at a certain depth, probably rather below wave base where the water was stagnant for the most time, but episodic introduction of the masses of the terrigenous and much inshore sediment through the turbidity flows has resulted in such intraformational conglomerate as the Attsu Conglomerate Lentil. The limestone was thus probably formed much further inshore than the site of the deposition of the Attsu Conglomerate and was "brought in" through the process of sedimentation of the conglomerate.

Fossil Assemblage in the Limestone Cobbles;

A detailed paleontologic study of the fossil assemblage found in the limestone cobbles is in progress, and the following discussion is based on the result of the preliminary investigation. So far, one coral (*Thamnasteria* sp.), three stromatoporoid (*Parastromatopora japonica* Yabe et Sugiyama, *Milleporidium lobatum* Yabe, and *Milleporella* n. sp.) and two algal (*Pycnoporidium* aff. *lobatum* Yabe et Toyama, and *Petrophyton tenue* Yabe et Toyama) species have been identified. At least one spongiomorphid coral yet unidentified is to be added to the assemblage. As a whole, this assemblage definitely represents the characteristic species of the "Torinosu Limestone facies" which ranges from late Jurassic (Oxfordian) up to early Cretaceous (Miyakoan) (Tamura, 1961) or even the early part of late Cretaceous (Gyliakian) (Katto *in* Katto and Sawamura, 1961). It is believed that the Torinosu Limestone facies is most dominant within the Torinosu Series ranging from Callovian to Tithonian (mostly Kimmeridgian) but also common in the early Cretaceous deposits. Discussing the paleontologic criteria in order to segregate late Jurassic Torinosu fauna in the Torinosu Series from the early Cretaceous "Torinosu-type fauna", Tamura (1961) claims that one can distinguish them only by means of careful analysis of the coral and pelecypod species, and possibly of "*Cidaris*" spines. Either pelecypods or "*Cidaris*" spines are not well represented among the Attsu fauna. The coral species in the fauna is so poorly preserved, and neither stromatoporoid nor algal species can be good index fossil for the purpose. Therefore, the dating of the Attsu assemblage is restricted to a certain span ranging from Oxfordian to Miyakoan (or possibly to Gyliakian), until some short-ranged species is found.

Because stromatoporoids are extinct animals, their ecology is only deduced from the analysis of the ecology of the associated biota and the petrology of the lithologic association. Lecompte (1956) claims that the Mesozoic stromatoporoids occur in a neritic shallow-water environment. A probable ecologic requirement for the algal genus *Pycnoporidium* was suggested by Johnson and Konishi (1961) as being in tropical shallow water ranging in depth to approximately 10 meters, both in sheltered and in more exposed places. These general concepts agree with my interpretation of the sedimentary process of the Attsu Conglomerate Lentil.

Terrestrial Plant Remains in Carbonaceous Seam;

A carbonaceous lentil 3.8—5.0 cm thick (in the sandstone unit no. 7; see Text-fig. 5) within the Attsu Conglomerate Lentil was examined both in thin section and disaggregated particles for a palynological study. As the byproduct of the study, a xylotomic fragment of possibly a bark tissue of conifers has been found. So far, two types of pollen (a vesiculate type pollen resembling ***Pinus*** *strobiformis* Bolkhovitina (Aptian) and a tricolporate type pollen of *Castanea* type), and two types of spores (one similar to *Blechnum brachylohatum* Bolkhovitina (Cenomanian) and the other comparable to *Leiotriletes* aff. *perpusillus* Bolkhovitina (lower Hauterivian)) have been tentatively distinguished by Fuji (personal communication dated March 25, 1962). Even though these microfossils cannot be diagnostic for dating, at present, it is safely concluded that the flora represented by the microfossils is younger than middle Jurassic, because the tricolporate pollen is known only among the angiosperms and the oldest representative of this type of pollen has been recorded from Albian, according to Fuji. Inasmuch as the result of this palynological study is to be reported elsewhere in the near future, it is only mentioned here that this is the first report of the palynological remains from the so-called Undifferentiated Mesozoic and Lower Tertiary terrains of the Japanese Island Arcs.

Ichnofossils:

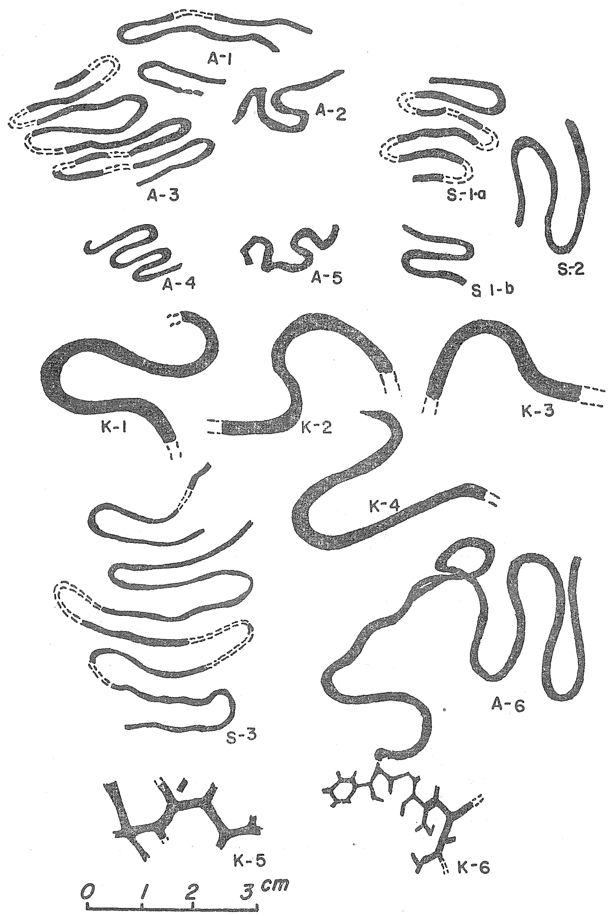
So far three types of ichnofossils have been distinguished in the collection.

1. *Helminthoida*-type A; this type has been found in an appreciable amount from Attsu and Sedake. They are characterized by long, simple, narrow S-shaped round tubes of uniform diameter almost throughout the observable length (Text-figs. 6 and 7). The diameter ranges from 0.9 mm to 1.7mm (1.0mm on average) in Attsu-1 collection, 1.7 mm on average in Attsu-2 collection, and from 1.1 – 1.5 mm (1.3 mm on average) in Sedake collection. The Attsu-2 collection was obtained from the rippled surface in the alternation of sandstone and shale, north of Attsu.

Text-figure 6 *Helminthoida*-type A from Kayo Formation about 20 m north of the type locality of the Attsu Conglomerate Lentil north of Attsu. The average diameter is 1.0 mm.

2. *Helminthoida*-type B; this second type is tentatively compared with *Helminthoida* because of the irregularly S-shaped nature of the tube (K-1,-4 of Text-fig. 7). It has a large diameter, occasionally overlapping pattern of the tubular arrangement. Also the entire length observable is usually much shorter than the type A. The diameter of the tubes ranges from 2.0 to 4.1 mm (3.3 mm on average) in the collection. Furthermore, the sandstone preserving this type seems to be slightly coarser in grain size than that of the type-A. The present type is rather common in the coarse-grained sandstone covered by thin black shale at the east of Kayo.

3. *Palaeodictyon*-type; the collection referred to as this type consists of two slabs, although in the field, this type of fossil was observed extensively on the bedding planes of alternation of sandstone and shale, 200 m east of Kayo. The fossils are represented by flat, reticular impressions with hexagonal meshes partly



Text-figure 7 Ichnofossils from the Kayo Formation : A ; Attsu : K ; Kayo : S ; Sedake ;

destroyed. The mesh structure is asymmetrically hexagonal, when completely preserved. The diameter of the meshes varies from 3.9 to 7.3 mm. Each "cell" of the meshes is 1.5−3.6 mm long and 0.5−1.7 mm thick in a specimen (K-6), and 4.7−6.6 mm long and 1.7−2.1 mm thick in the other specimen (K-5). The statistical values and the regularly hexagonal mesh structure indicate that the Kayo specimens are identified as *Palaeodictyon majus* Meneghini.

Although ichnofossils are usually no indices for any specific time of geologic column, they have been reported mostly in the Flysch type turbidite of late Mesozoic to Cenozoic deposits more than the older ones in Japan; especially in the "Unknown" (or undifferentiated) Mesozoic complex defining the outermost tectonic zone of Southwest Japan. In most common records of the organism preserved, the complex is very scarce, but the rare finds of certain index fossils, either rare planktonic organisms, mainly foraminifers,or few redeposited assemblages of shallow-water animals and plants, have made it possible to date the parts of the complex. The paucity of the life record other than ichnofossils in the complex makes very characteristic Flysch sediments.

Within the last decade, paleontological work on these ichnofossils from southern Shikoku was carried out by Fukada (1951) and Katto (1952, 1960a, 1960b), and they segregated many forms and "species" (Table 2). Apparently no form common in both southern Shikoku and Okinawa can be recognized. A "Helminthoid" named *Tosahelminthes curvata* Katto closely resembles *Helminthoida*-type A of this paper in gross morphology, but differs from it with the smaller diameter. *Helminthoida*-type B from the Kayo Formation differs from *T. curvata* in the irregular pattern and much shorter lengths of the tubes. These two forms of *Helminthoida*-

type from Okinawa are interpreted as the pre-depositional burrows of fossil worms comparable with the Recent genera as *Eteone* and *Paraonis*.

Table 2 List of Ichnofossils from Shikoku and Okinawa (data of Shikoku after Katto, 1960; the dating of these formations in Shikoku is based on Katto's work of the molluscan fossils).

Form	Occurrence	Susaki Fmt. Shikoku (Cret.)	Naharigawa Fmt. Shikoku (Eocene)	Muroto Fmt. Shikoku (Eocene)	Shimizu Fmt. Shikoku (Eocene)	Misaki Fmt. Shikoku (Oligoc.)	Kayo Fmt. Okinawa (Cret.?)
Porifera	*Spongia shikokuensis* Katto					X	
Annelida (Polychaeta)	*Noroitos tosaensis* Katto			X			
	N. murotoensis Katto		X	X			
	Tosalorbis hanzawai Katto			X			
	T. peculiaris Katto			X		X	
	Terebellina shikokuensis Katto		X	X			
	Ophiomorpha nodosa Lundgren					X	
	Cylindrical structure					X	
	Excrements possibly of *Noroites*			X			
	Excrements of unknown affinity		X				
Trail of Casting	*Tosahelminthes curvata* Katto		X				
	Helminthoida-typesA and B						X
Excrements of unknown affinity						X	
Worm borings				X		X	
Worm castings					X		
Molluscan shell-borings		X					
Algae?		X					
Algae?	*Palaeodictyon majus* Meneghini						X

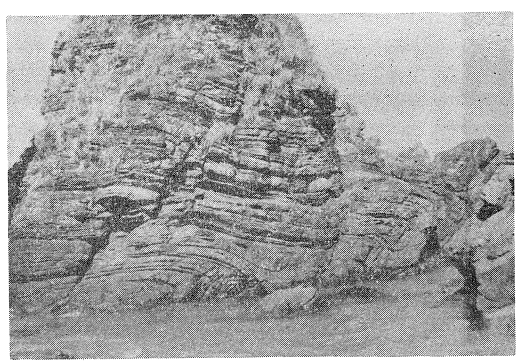
The *Palaeodictyon*-type fossil in the Kayo Formation can be important in the paleoecological implication, if the interpretation to an algal nature advanced by Koriba and Miki (1939) is accepted. Some paleontologists are still skeptical about the taxonomic connotation of the genus and inclined to consider it in terms of animal burrows ("Weidespuren") instead (Seilacher, for example). The question is being raised repeatedly (Fischer, 1957). Polygons similar to, though larger than, the ones from Kayo Formation have even been interpreted as interference ripple marks produced by the thrashing action of the tadpoles (Maher, 1962). Koriba and Miki (1939) concluded that the habitat of *Palaeodictyon* was brackish shallow water of lagoon and estuaries, because the living species of the family Hydrodictyaceae (Chlorococeales,Chlorophyceae) to which the genus is placed are all of fresh water algae in shallow water.

> "They lived then as benthos on the mud, bestowed there with vigorous growth, often attaining several decimeters in size. But the shallow water is easily disturbed by wave and as *Palaeodictyon* is not adhesive to the substratum, the coenobium must have been been exposed very often to the turbulence, ..., show the circumstances clearly. ...... Under the benthonic condition of life the coenobium, ..., cannot advance so far to the deep bottom of open sea, ..., the littoral habitat threatens its life not a little, ... Sudden change of sea-level is therefore in either case menaceful" (Koriba and Miki, 1939, p. 64).

The fact that *Palaeodictyon* has been reported in a strictly marine sequence (Barbier, 1956; Pugin, 1957) indicates that the remains of brackish plants were evidently washed into marine environment and transported by turbidity current.

Structure :

The structural contrast between the pre-Miocene and post-Miocene (partially Miocene in subsurface) rocks in Okinawa is very distinct; the pre-Miocene rocks such as Kayo Formation are highly folded and faulted, and are locally intruded into by igneous rocks, whereas the overlying beds are only faulted and tilted. In general, isoclinal folds consisting of series of anticlines and synclines overturned to south to southeast seem very common within the Kayo Formation (Text-fig. 8). Such folds associated with many large and small thrusts have produced the northwesterly dipping trend of the Formation. These thrusts were complicated by the later high-angled longitudinal faults such as, for example, the Nago fault, and by transverse normal faults of dip direction. The typical structures of the Kayo Formation mentioned above are best observed along the coast and Highway 13 from Kayo to Arumé (Text-fig. 8 of Flint and others, 1959).



Text-figure 8 Typically overturned (recumbent) fold in Kayo Formation west of Kawada.

Correlation :

The Attsu Conglomerate Lentil of the Kayo Formation is dated to a certain time between Oxfordian (late Jurassic) and Gyliakian (late Cretaceous) on the basis of the Torinosu-type flora (calcareous algae) and fauna (stromatoporoids and corals) from the type locality of the Lentil. The palynological remains from the same locality prove that the Lentil cannot be older than the middle Jurassic.

So far no Mesozoic sediments have been paleontologically identified from the Ryukyu Islands. The closest exposure of the definitely Mesozoic sediments is the late Jurassic "upper Torinosu Limestone" at Yamagami, near Noma-no-ike, Kasasa-machi, Kagoshima Prefecture (Eguchi, 1942), which is litologically similar to but paleontogically different from the Attsu Conglomerate Lentil. The comparison of the fossil assemblages between two localities is shown in Table 3. The further difference is that the limestone at Nomo-no-ike is much larger in size (20×80 m) and apparently authochtonous within the alternation of sandstone and shale.

Table 3 List of Torinosu Limestone-type flora and fauna from the Shimanto terrain in Kyushu and Shikoku and from Okinawa

	Location	Okinawa	S. Kyushu	S. Shikoku			Formosa
	Stratigraphic unit	Attsu Cg.	Nomaike Fmt.	Doganaro Fmt.	Hayama Fmt.	Susaki Fmt.	Ls. pebble Suo Series
Species	Age	E. Cret.(?)	Late Juras.	Miyakoan	Gyliakian		Eocene
Anthozoa	*Acanthogyra?* sp.			X			
	Alcyonaria? sp.					X	
	Astrocoenia sp.						X
	Chaetetes? sp.					X	
	Cheaetetopsis crinita Neumayr		X				
	Elephantaria sp.						X
	Latomeandra sp.		X				
	Stylina (*Convexaster*) *motonobui* Eguchi		X				
	Stytina aff. *mabutii* Eguchi		X				
	Stylina sp. A			X			
	Stylina sr. B					X	
	Stylosmilia sp.			X			
	Thamnastrea sp.	X		X			
Hydroida (Spongio-morphid)	"Spongiomorphid coral"	X					
Stromatoporoids	*Actinostromaria shimizui* Yabe and Sugiyama			X			
	"*Circoporella?* sp." (*Burgundia*)					X	
	Milleporella (?) n. sp.	X		X			
	Milleporidium lobatum Yabe	X					
	Milleporidium sp.		X				
	Milleporidium? n. sp.			X			
	"*Stromatopora* sp."			X			
	"*Stromatoporella? undulata* Yabe and Sugiyama"			X			
	Parastromatopora japonica Yabe and Sugiyama	X		X			
	P. inouyei Yabe and Sugiyama					X	
	P. kotoi Yabe and Sugiyama			X			
	P. memorianaumanni Yabe			X			
	P. mitodaensis Yabe and Sugiyama						
	Tosastroma kiiensis Yabe and Sugiyama			X			
	T. tokunagai Yabe and Sugiyama			X			

Algae	*Kitakamiania eguchii* Ishijima					X	
	Lithothamnium sp.			X			
	Lithocodium morikawai Endo			X			
	Nipponophycus sp.			X			
	Parachaetetes tosaensis Endo (MS)				X		
	Petrophyton tenue Yabe	X					
	Pycnoporidium lobatum Yabe and Toyama	X	X	X		X	
	Solenopora alternata Endo (MS)					X	
	Solenopora rothpletzii (Yabe)			X			
	Stenoporidium angularis Endo (MS)				X		
	S. chaetetiformis Yabe and Toyama				X		
	Stenoporidium sinuosum Endo (MS)				X		
	Stenoporidium sphericum Endo			X			

According to Tamura (1960, p. 34-35), the limestone-bearing beds at Nomo-no-ike can be divided into three units, upper limestone-bearing shale, middle sandstone, and lower alternation of sandstone and shale. The upper shale unit includes an oligomictic conglomerate layer about 10 m thick, characterized by cherty round pebbles. He claims that the other polymictic conglomerate with shaly breccia and round cherty pebbles found in the middle sandstone unit is characteristically of the "Shimanto-type". Recently, Hashimoto (1962a) introduced formational names based on his new classification for the same beds. Thus, Tamura's upper shale unit was called Nomaike Formation (late Jurassic; 800±m) and lower and middle units were grouped as Kozakiyama Formation (Cretaceous?; 1000±m). The two formations are in contact by a fault. Polymictic conglomerates are prominent in the lower member of the Kozakiyama Formation.

Similar Torinosu-type limestone facies (occurring as lentils) have been reported from many localities in the northern Shimanto terrain of Shikoku. Doganaro (Miyakoan), Hayama (upper Miyakoan —? Gyliakian), and Suzaki (? Gyliakian) Formations yield the Torinosu-type flora and fauna from the limestone lentils, according to the nomenclature proposed by Katto (Katto and Sawamura, 1961). The dating of these formations has been challenged by Tamura who believes that the Torinosu-type flora and fauna range from late Jurassic to only Aritan. In fact, Matsumoto, Kimura and Katto (1952) reported the occurrence of early Miyakoan ammonites from the Suzaki Formation. The comparisons of the species between the formations, both Shikoku and Okinawa are also shown in Table 3. Lithologically, the Suzaki Formation containing beds of greenstones, limestone and chert seems to resemble the Nago Formation, whereas the conglomerate-bearing Flysch psammite Hayama Formation suggests similarity with the Kayo Formation. The unfossiliferous Nonogawa Formation, another conglomerate-bearing bed, apparently underlies the Suzaki Formation and is lithologically akin to Kayo Formation. The Doganaro Formation contains cherty beds, which seem to be absent in the Kayo Formation.

There is an obvious lithological resemblance of the thick "undated Mesozoic strata" at Yaku-shima (Isso, Miyanoura, Funayuki, and Mugio Formations by Hashimoto, 1956), Tanegashima (Kumage Formation by Hanzawa, 1935), and the northeastern end of Amami-o-shima (Kazuno and Ohgachi Formations by Hatae and others, 1959) with the Kayo Formation at Okinawa. All of them are Flysch-type alternations of rather monotonously repetitive thick sandstone and shale, with peculiar sedimentary structures both physical and organic. Without the diagnostic evidence, however, further comparison of the Kayo Formation with any abovementioned formation is impractical. A comparison between the possible equivalents based on the regional geotectonics is discussed elsewhere (p. 589).

In the northern part of Taiwan where the Ryukyu Islands makes junction, with the Formosa-Luzon (Philippine) arc, one unnamed subsurface late Jurassic bed ("*Holcophylloceras* bed") (Lin, 1961), and many other supposedly Mesozoic formations have been reported (Yen *et al.*, 1956 ; Chang, 1958, p. 14-15). Except for the first bed, however, these formations apparently lack the paleontologic evidence to determine the geologic age. Ma (1951) identified two latest Cretaceous corals, *Asterocoenia* sp. and *Elephantaria* sp., from the limestone pebbles of the conglomerate bed within Eocene Suo Series. These genera are not found in the Attsu fossil assemblage. Thus, it seems unwise at present to compare the Kayo Formation with any of the Mesozoic formations in Formosa without paleontologic data, even though it is highly possible that some Mesozoic formations of Formosa are correlated with the Kayo Formation.

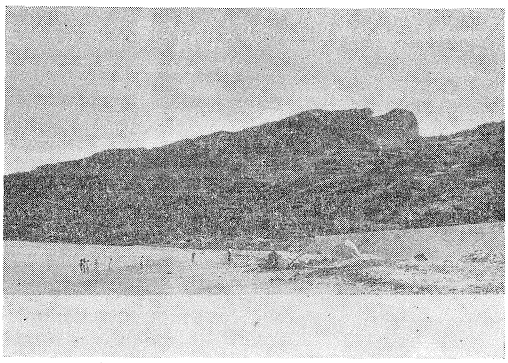
STRUCTURAL ZONATION OF THE RYUKYU ISLANDS

Criteria for tracing the tectonic belts in the Ryukyu Islands :

In order to define the tectonic belts and to trace them within an orogenic belt, an indirect approach other than the tracing of the tectonic lines can be adopted for a poorly exposed terrain. As in the case of the Ryukyu Islands; it can be by tracing 1) the similar association of lithologies and "metamorphic facies", 2) the ore deposits of the similar origin,and 3) the distribution of the similar type of intrusives. In the present case, 1) lithofacies and "metamorphic facies" of the Paleozoic rocks, Nago Formation and Kayo Formation in Okinawa, and their correlatives in the other islands, 2) distribution of the bedded cupriferous iron sulphide and manganese ore deposits, and 3) types of the Tertiary sediments blanketting the basement rocks are used to recognize and differentiate three tectonic belts in the Ryukyu Islands north of Miyako.

Okinawa Islands :

In Okinawa-jima, the crystalline limestome of Permian age is thrust over the phyllitic rocks at Motobu Peninsula (on the Yonamine Formation) and along the western coast of the island north of the peninsula on the Nago Formation (MacNeil, 1960, p. 12). The thrust is best observed "along the north side of Ie-shima" (MacNeil, *ibid.*) and south of Hedo-misaki (or north of Ginama). According to MacNeil (*ibid.*), "a klippe of the same limestone occurs …… north of Shanawan (Shioya-wan) at an altitude of about 300 ft above sea level". This thrust plane is mostly below sea level at the Motobu Peninsula but dips 30-45 degrees southwestwards at the north of Ginama (Text-fig. 9). It is called hereafter as Hedo thrust and represents the tectonic boundary between the metamorphosed (phyllitic and schistoze) non-calcareous rocks and the overlying less metamorphosed fusulinid-bearing calcareous rocks.



Text-figure 9 Distant view of the Hedo thrust north of Ginama; looking at north.

The basement complex east of the thrust or underlying the thrust is composed from the phyllitic rocks of greenstones, clayslate, sandstone, chert and crystalline limestone, and lithologically divided into (1) the Nago Formation of greenschist facies and (2) the Kayo Formation described above. The Nago Formation contains actinolite-epidote-calcite schist, quartz-sericite-oligoclase schist, sericite-graphite-quartz schist, and saussuritized gabbro. The epidote-albite-hornblende-schist mentioned by Taneda (1961) from the Kunigami area must be from the Nago Formation.

The other major tectonic line has been recognized even though its exact location could not be verified in the field (MacNeil, 1960, p. 13). This is the border between the Plio-Miocene Shimajiri Formation on the southeast and the phyllitic Nago Formation on the northwest, passing close to the town of Tengan (Text-fig. 2; also Text-fig. 5 of MacNeil, 1960). The southernmost outcrops of the Nago Formation have been observed along Highways 16 and 24. At the south of Kombu (north of Tengan), the Formation of phyllitic sandstone and clayslate dipping northerly 37 degrees with the strike of N65° W is confirmed as the southernmost outcrop. The term Tengan fault is proposed here for the large, though assumed, tectonic line.

Thus, Okinawa-jima can be roughly divided into three tectonic belts, from northwest to the southeast, 1) Paleozoic (? — Permian) calcareous and cherty thrust sheet (Motobu Belt), 2) Mesozoic (? — Cretaceous) phyllitic and schistoze, and Flysch psammites Kunigami Belt, and 3) Plio-Miocene Shimajiri Belt. The basement complex of the third belt cannot be dated at present, because all the complex of the belt in Okinawa is subsurface. It is postulated to represent the Tertiary (early Tertiary) section as discussed later (p. 591).

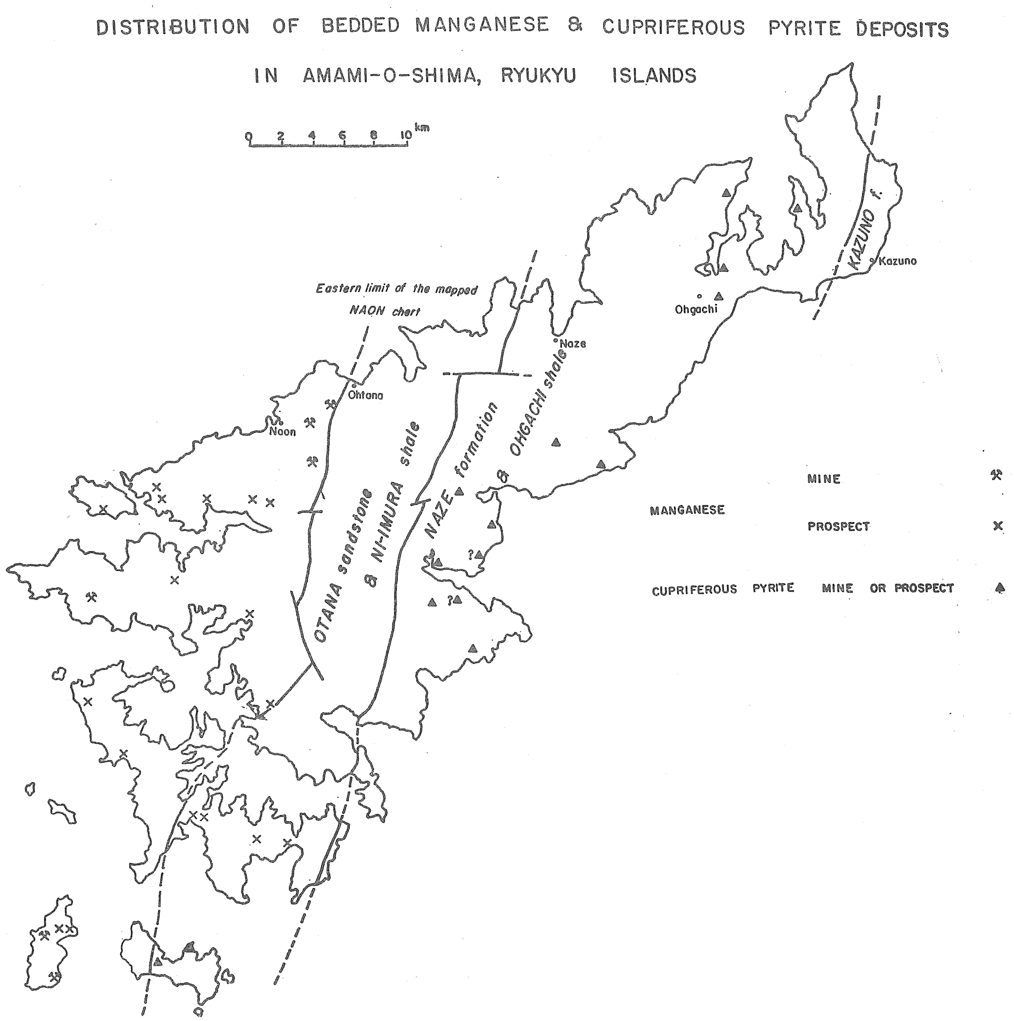
The vein-type and bedded manganese deposits have been reported from the Paleozoic chert at Yonamine (Nakijin-son), whereas the prospects of the cupriferous sulphide (mainly pyrite) deposits such as at Yamada mine in Haneji-son are limited within the Nago Formation especially associated with the greenstones (Flint and others, 1954, p.93, fig. 10).

At the northwestern side of the Hedo thrust, all the pre-Miocene basement rocks cropping out at the small islands are limestone (Sesoko, Ie, Iheya, Izena, Kouri, and Tonaki) and/or chert (Ie, Iheya. and Izena) with a subordinate amount of other types of rocks, and are believed to be continuous with the thrust sheet of the Motobu Formation by Flint and others (1959) at Motobu Peninsula, so that it is dated Paleozoic. On the other hand, all the islets southeast of Okinawa belong to the Shimajiri Belt, where the pre-Miocene basement rocks are subsurface and probably dated to Early Tertiary. Around Okinawa-jima, the Kerama Islands represent the western extension of the central metamorphosed Kunigami Belt of Okinawa, where the sizable copper mine at Yakabi-jima and a copper prospect at Kuba-jima have been known. From the Keramas, Taneda (1961) reported the occurrence of slate, schistoze sericite-sandstone, sericite-quartz-albite-schist, graphite-sericite schist, graphite-schist, and muscovite-chlorite-epidote-schist. The result of my examination has resulted in the addition of albite-actinolite-quartz-chlorite-epidote-schist (Otake, Aka), actinolite-zoisite-albite-schist (Machan, Zamami), and actinolite-chlorite-epidote-albite-schist(Machan, Zamami).

Amami Islands :

The basement complex of Yoron and Okinoerabu consists of limestone and chert which appear to be the more northerly extension of the Paleozoic thrust sheet of similar lithologies from Hedo-misaki of Okinawa. In Amami-o-shima, the calcareous and cherty rocks are limited to its western part and have been grouped under the name of Naon Chert, which has the same lithology as the basement rocks of Yoron and Okinoerabu, so dated to be Paleozoic. On the eastern part, however, there develop phyllitic rocks named Naze Formation, which consists of clayslate and tuff and suggests a strong affinity with the Nago Formation of Okinawa, because of the lithologies and association of the bedded cupriferous iron sulphide deposits. Ohdana Sandstone (Hatae and others, 1959) intercalating certain conglomeratic beds is probably the equivalent of the Kayo Formation. The other possibility that the Kazuno Formation at the easternmost tip (Kasari Peninsula) of the island is correlated with the Kayo Formation cannot be ruled out. Thin coal seams 0.5—3.0 cm thick of lenticular shape are found in the Formation. So far, the boundary between the Naon Chert and Ohdana Formation at Amami-o-shima has been mapped as a conformable contact, but its reexamination may be open for future study. Both the location of the probable boundary east of the Naon Chert thus defined at Amami-o-shima, and the Paleozoic nature of the basement rocks at Okinoerabu suggest that the southern extension of such a boundary line should pass somewhere east of Toku-no-shima. Hatae and others (*ibid.*), however, have mapped this island to consist of Naze and Niimura Formations, so that the boundary might go through the island. The contrast in the distribution between the bedded manganese and cupriferous iron sulphide prospects at Amami-o-shima, and Tokunoshima has been mapped by Flint and others (1954, p. 93). Such a map for Amami-o-shima is revised with additional informations and shown here as Text-figure 10. The bedded manganese deposits seem to be restricted within the Paleozoic belt represented by Naon Chert, and the iron sulphides are within the phyllitic Naze and Ohgachi Formations, except for some manganese prospects at eastern Kakeroma-shima and iron sulphide deposits at Uke-shima.

Text-figure 10



Osumi Islands :

The basement complex of the Osumi Islands has been lithologically referred to as "Unclassified Mesozoic rocks" without paleontologic evidence. The age of the Kumage Formation unconformably overlain by the middle Miocene (Burdigalian) Kukinaga Formation at Tanegashima has been given by Hanzawa as probably lower Eocene(Hanzawa, 1956). A similar type of rocks at Yakushima has been studied by Hashimoto (1956) and classified into several units (Table 4), in which

Table 4 Stratigraphic classification of the Unclassified Tertiary(?) rocks of Yakushima (in descending order) (after Hashimoto, 1956)

Isso Formation
Yahazudake Shale and Sandstone Member (500 m+ thick)
Isso Conglomerate Member (150～300 m)
……………………clinounconformity………………………………

Miyanoura Formation

Kusugawa Shale and Sandstone Member (several hundred m., probably less then 1000 m.)	partly interfingered	Anbo Sandstone Member (several hundred m., probably less than 1000 m.)

————stratigraphic relation unknown————
(fault)

Funayuki Formation (several hundred m., probably 700～800 m.)
shale, siltstone, with pillow lava (upper most in this member), reddish brown shale, etc.

————stratigraphic relation unknown————

Mugio Formation (several hundred m.)
shale, siltstone, with sandstone, etc.

he recognized a pre-middle Miocene (pre-Takachiho) tectonism. The rocks consisting of these units do not show any similarity with those of the Nago or Naze Formation discussed above, but they are much similar to the Kayo Formation, though probably less phyllitic. Hashimoto mentions the association of pillow lava within the Kumage and Funayuki Formations, a feature completely lacking within the Kayo Formation. The southern extension of the Kumage Formation can be traced to Kikai-jima, where the basement complex is buried beneath the Shimajiri Formation, the same situation as the southern Okinawa. Therefore, the outermost Cenozoic Shimajiri Belt is believed to develop from southern Okinawa, through Kikai-jima, to Tanega-shima, and probably at Yaku-shima.

Yaeyama Islands :

About 400 km southwest of Okinawa, Yaeyama Islands, including Ishigaki, Iriomote, Kobama, and other islets, constitute the southern end of the Ryukyu Islands. The pre-Miocene basement rocks exposed at Ishigaki, northeastern Iriomote, and Kobama, beneath the Eocene Miyara, Miocene Nosoko and Yaeyama or Pliocene～Pleistocene Ryukyu Group, consist of crystalline schists, phyllites, hornfels, and granitic rocks. In the northern peninsula of Ishigaki, the glaucophane-chlorite-quartz-albite-epidote-schist has been recognized recently by Foster and others(1960) and Taneda (1961). The crystalline schist with the similar assemblage has been reported from Iriomote and Kobama by Yoshii (1935) based on the boulder collected by Hanzawa. According to Foster and others (1960), the following schists have been identified from this northern part of Ishigaki: albite-chlorite-epidote-quartz-schist, chlorite-crossite-epidote-albite-schist, epidote-glaucophane-schist, albite-chlorite-epidote-actinolite-schist, epidote-crossite-schist, albite-chlorite-quartz-muscovite-crossite-schist, and glaucophane-quartz-schist.

The basement rocks exposed at the southern Ishigaki and Iriomote consists of chert, micaceous and carbonaceous schists, and phyllites (sericite-albite-quartz-phyllite, sericite-phyllite), conglomerate (metamorphosed and tectonic origin), sandstone, shale, and hornfels. The basement rocks consisting of crystalline schists, phyllites and cherts with a small amount of crystalline limestone or marble (Beatty and Westphal, 1960, p.6) crop out only in the northeastern corner of Iriomote in the vicinity of Komidake. The lithologies resemble those of the pre-Tertiary rocks of southern Ishigaki. Although the albite-chlorite-epidote-actinolite-schist is known from the metamorphosed part (Nago Formation) of Okinawa, no glaucophane schists have been found on the island. The chert-dominant lithology of the basement rocks in southern Ishigaki reminds one of the Paleozoic Motobu Belt of Okinawa-jima.

It should also be mentioned that both the Eocene Miyara and Miocene Yaeyama Groups covering the basement rocks accompany the volcanic sediments but are rather thin in total thickness. During the Eocene Epoch, a geosynclinal trough developed at the present site of the Ryukyu Islands, where the Flysch-type sedimentation now recognized as basement rocks of the Shimajiri Belt took place, but also rather thin neritic, calcareous sediments associated with clastics were laid down at the inshore side of the Paleozoic basement rocks exemplified by Yaeyama Islands. The similar contrast in the lithologic association between inshore and trough facies has been recognized through the Outer Zone of Southwest Japan (Table 5). It is also true that the coal-bearing Yaeyama Group

Table 5 Contrast in sedimentary facies between Sambagawa–Chichibu and Shimanto terrains during early Tertiary (Eocene∼Oligocene).

Facies of sediments	Basement complex	RYUKYUS	SOUTHERN KYUSHU	SOUTHERN SHIKOKU	KII PENINSULA
		Hanzawa, 1935	Matsumoto, Shuto, Hashimoto, and others	Nagai, 1956; Katto, 1961	Shiida, 1962
Neritic∼ Inshore	Sambagawa–Chichibu terrain	Miyara Formation	"Mitate Formation" (in part?)	Kuma Group, including Nimyo Formation	Nakaoku Formation
Trough+	Shimanto terrain	Kumage Group	Nichinan and Hyuga Groups	Shukuge Group, including Hirata Formation	Muro Group

+ turbidite facies

represents the Molasse-type of sediments of the mid-Tertiary disturbance, deposited inland, while the Shimajiri Formation is characterized by thick trough sediments resulting from the similar succeeding tectonism, and deposited in abyssal trough like the present Ryukyu Trench (MacNeil, 1960, p.1). Therefore, I am inclined to conclude that the metamorphic zone of the Paleozoic belt which does not crop out near Okinawa does so as the glaucophane schist at Yaeyama. A possible exception may Kume-jima where the basement rocks are subsurface and overlain by the "Shimajiri Formation" interfingering with the hyperthene-bearing augite-andesite, the same type of volcanics as common in Ishigaki. The occurrence of *Carcinoplax prisca* Imaidzumi from the north of Yamashiro, Nakazato-son, southern Kume-jima, proves that at least a part of the "Shimajiri Formation" at the island is dated Miocene. Another possible exception might be Tonaki-jima close to Kume-jima where garnet was mined from a contact metamorphic zone in limestone. These two islands occupy the innermost position of the pre-Miocene rocks near Okinawa. Because of the lack of information about the basement rocks of Miyako, and the discontinuity of the structures at both sides of the island, the northeastern extension of the metamorphosed Paleozoic belt represented by northern Ishigaki cannot be traced exactly. It is only interpreted from the submarine topography that a rather prominent depression possibly of flexure nature exists between Okinawa and Miyako Islands (Hanzawa, 1935 ; Hess, 1948 ; Dietz, 1954). This is called the Miyako Depression in this paper.

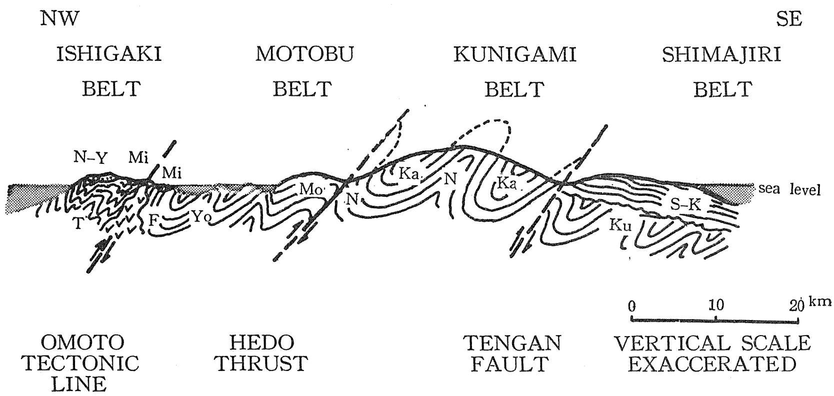
Relation to the tectonic belts of southern Kyushu :

In southern Kyushu, where the northern end of the Ryukyu Island Arc makes the junction with the western end of the Japan Island Arc, three major tectonic lines, 1) Usuki-Yatsushiro, 2) Butsuzo-Ohsakama-Ushinohama and 3) Nobeoka-Shibisan, have been recognized. The former two are the western extensions of the Median Line(Ueda, 1961) and Butsuzo-Itokawa Line of Shikoku, respectively. The third tectonic line was recognized and named by Hashimoto and others (1956) and splits the Shimanto terrain south of the Butsuzo Line into two belts, northern phyllitic and southern non-metamorposed and Flysch-type. The northern Shimanto Belt(Hashimoto, 1962a) is characterized by sporadical occurrence of bedded cupriferous pyrite deposits such as Makimine mine (Tatsumi, 1953), the association of greenstones, and practically almost no records of diagnostic fossils, if compared with the volcanic-free and noticeably fossiliferous southern Shimanto Belt. In southern Kyushu, the northern Shimanto Belt has only four fossil localities, (1) "late Jurassic" Torinosu-type limestone at Yamagami (Eguchi, 1942), (2) undated *Lima*(*Acesta*)-bearing boulder in the river gravel at Hitoyoshi City, Kumamoto Prefecture (Tagami, 1962), (3) plant remains similar to *Ginkgodium* from a sandstone at Morotsuka village, Miyazaki Prefecture, (Saito, and others, 1955) and (4) *Equisetites* sp. from a sandstone of Kominato, Kaseda City, Kagoshima Prefecture (Harunari, 1954), if the undiagnostic Radiolarians are ignored ; while the eastern extension of the same tectonic belt in Shikoku seems to provide more localities of the Torinosu-type limestone dated to range from late Jurassic to early part of the late Cretaceous (Katto *in* Katto and Sawamura, 1961). All the paleontologic data so far available from the southern Shimanto belt in Kyushu indicate Paleogene, and basal Miocene (?) but without Cretaceous (Hashimoto and Miyazaki, 1959; Monden, 1960; Kuwano,; 1960; Hashimoto, 1961), whereas the equivalent belt in southern Shikoku includes Cretaceous.

When the geotectonic elements between the Japan and Ryukyu Island Arc are compared, it is obvious that the Hedo fault of Okinawa occupies the same tectonic location as that of the Butsuzo-Ohsakama-Ushinohama Line of southern Kyushu. But, where would the tectonic line be in Okinawa, one comparable with the Nobeoka-Shibisan Line? The apparent width (not thickness) of exposure of the northern Shimanto belt seems to be somewhat in the magnitude of 20 km in southern Kyushu and Shikoku. In Okinawa, a parallel line running about 20 km southeast of the Hedo thrust which would be the tectonic line will lie along the eastern coast or in the Pacific Ocean near the coast, except for southern Okinawa, where the trend of the longitudinal structure of the basement rocks shifts from northeastnorth to northeast or even to eastnortheast. So far, the largest fault reported with longitudinal trend in southern Okinawa is the Tengan fault which separates the late Tertiary sediments (Shimajiri Formation) in the south from the phyllitic Nago Formation in the north. Beyond this fault, southern Okinawa lacks any outcrop of pre-Miocene rocks. Between the Hedo and Tengan faults, the phyllitic Nago Formation and less phyllitic Kayo Formation crop out to make a complicated folded structure. As far as the metamorphic grade is concerned an increase in a simple southward direction as reported in the northern Shimanto belt at southern Kyushu is unrecognizable in Okinawa. As mentioned above, the less phyllitic Kayo Formation crops out as a core of the huge overturned syncline of overfold isoclinal structure, bordered on both sides by the phyllitic Nago Formation. The boundaries between the Formations have fault contacts at many places but no major thrust fault comparable to the Nobeoka-Shibisan Line of Kyushu has been recognized in Okinawa. Therefore, it seems highly logical at present to locate the tectonic line by comparing the Tengan fault with the Nobeoka-Shibisan Line, extending the latter southerly to coincide with the former.

Schematic model :

Summarizing the above discussion, a schematic model of the tectonic zonation of the Ryukyu Island Arc is illustrated and tabulated (Table 6; Text-figs. 11 and 12). As early as 1897, Koto keenly recognized three structural belts in the Ryukyu Island Arc; the inner belt of the volcanic islands, central belt of the older rocks, and the outer belt of the Tertiary System. The most part of the last belt is called the Shimajiri Belt it this paper. The rocks of the central belt considered as "Archeozoic" by Koto were proven to include Permian limestone in Okinawa



Text-figure 12 Schematic cross section of the Ryukyu Islands ; F, Fusaki Formation ; Ka, Kayo Formation ; Ku, Kumage Formation ; Mi, Miyara Formation ; Mo, Motobu Formation ;N, Nago Formation ; N-Y, Nosoko and Yaeyama Formations ; S-K, Shimajiri and Kukinaga Formations ; T, Tumuru Formation ; Yo, Yonamine Formation.

(Hanzawa, 1933). The basement rocks of the Shimajiri Belt at Tanegashima were compared with the "Unclassified Mesozoic rocks" of the Shimanto terrain of the Japan Island Arc (Hanzawa, 1935) and later with the Nakamura terrain of the Shimanto Belt (Kobayashi, 1941). The sedimentary sequences intruded into by granitic rocks at Yakushima were also compared with those of the same belt by Hashimoto (1956). The Koto's central belt of the older rocks is now divided into three belts, the inner "metamorphosed Paleozoic" (Ishigaki), central Paleozoic Motobu, and outer Mesozoic Kunigami Belt as defined above.

From this model, it is concluded that the sedimentary successions of the Ryukyu Islands can be divided into three major units separable by angular unconformities of regional continuity (Table 7). The upper unit is defined by the unconformity beneath the Ryukyu Group (uppermost Pliocene and Pleistocene). The middle unit consists of the various facies of the Neogene formations ranging from basal Miocene up to the uppermost Pliocene and its lower boundary is defined by the unconformity known on the surface at Tanegashima, Ishigakijma and Iriomote and subsurface at Okinawa and Kikaijima, and possibly Kumějima. The lower unit can be grossly called pre-Miocene basement complex, the subject of this study. The last unit contains only formations which suffered severe folding. The middle and upper units are only faulted and tilted. Furthermore, it is also concluded that the zonal structure of the basement complex controlled the facies pattern of both Eocene (neritic Miyara Formation versus bathyal Kumage Formation) and Neogene (paralic Yaeyama Group and Kukinaga Formation versus bathyal Shimajiri Formation), whereas the much younger (Plio-Pleistocene) Ryukyu Group transgressed

Table 6 Structural zonation of the pre–Miocene basement complex of the Ryukyus

Name of Belt	Age	Main lithologies (original)	Metamorphic facies	Ore deposits: manganese	Ore deposits: cuprif. iron sulfides	Intruded by	Overlain by	Distribution
Ishigaki	Paleozoic	shales, pyro–clastics, lavas, cherts, sand–stones and others.	glaucophane schist facies			granophyre, granite, (Ishigaki); andesite and basalt (Kume)	Miyara Fmt. (Eocene), Nosoko Fmt. (Mio.?) Yaeyama Gr. (Miocene), "Shimajiri Fmt." (Miocene), Ryukyu Group.	Northern Ishigaki and Iriomote; Kume (subsurf.)?; Aguni (subsurf.)?
			OMOTO LINE					
Motobu	Paleozoic (?......Permian)	limestone and chert in assoc. with pyro–clastics and sandstoneshale	phyllite	X		andesitic por–phyry (Okinawa); granite (Tonaki, Okinoerabu, Tokunoshima); diabase or serpentine (Tokunoshima)	Ryukyu Group (late Pliocene–Pleistocene); Guga Formation (late Pliocene)	Okinawa (Motobu), Tonaki, Ie, Iheya, Izena, Yoron, Okinoerabu, Tokunoshima, Amami (western), southern part of Ishigaki
			HEDO FAULT					
Kunigami	Mesozoic (?.................Cretaceous)	shales and pyro–clastics with greenstones and subordinate limestone	greenschist facies		X	granite (Amami), rhyolitic porpyry (Okinawa), andesites (Tokaras)	Mostly gravelly facies ("Kunigami Gravel") of Ryukyu Group (late Pliocene–Pleistocene)	Okinawa (main), Keramas, Amami (eastern)
		sandstones and shales with conglomerate lentils	Only very slightly recrystallized in the original texture					
			TENGAN FAULT					
Shimajiri	Cenozoic (early Tertiary)	sandstones and shales with conglomerate beds; rarely basic lava flows				granite (Yakushima)	Shimajiri and Kukinaga Fmts. (Mio.–Plioc.) and Ryukyu Gr. (late Plioc.–Pleistocene)	Okinawa (southern; subsurf.), Kikai (subsurf.), Tanega–shima, Yakushima

Table. 7 Geohistory of the Ryukyus in terms of the tectonic belts

AGE			RYUKYUS: ISHIGAKI	RYUKYUS: MOTOBU	RYUKYUS: KUNIGAMI	RYUKYUS: SHIMAJIRI	TECTONISM: RYUKYUS	TECTONISM: JAPAN	TECTONISM: TAIWAN
CENOZOIC	Q	PST	"RYUKYU Ls." ? NAGURA G.	MACHINATO Ls. YONTAN Ls. NAHA Ls. NAKAOJI S.	KUNIGAMI G.	CHINENS.	RYUKYU D. KUNIGAMI PH.	SHIKI-SHIMA D.	
	T	PL	?	GUGA F. ?		(SHINZATO T.) SHIMAJIRI F.		OYASHIMA OROG.	PENGLAI (TAIWAN) OROG.
		M	YAEYAMA F. NOSOKO F.			? KUKI-NAGA F. ISSO ? F.	TAKACHIHO PH. ISSO PH.		PULI OROG.
		O				KUMAGE GR.			
		E	MIYARA F.			FUNAYUKI F.	MIYARA PH.	SAKAWA OROG. CYC.	TAIPING OROG.
		P			?	MIYANOURA F. MUGIO F. ?			
MESOZOIC	K				KAYO F.		ATTSU PH.		NANAO OROG.
	J								
	Tr				NAGO F.				
PALEOZOIC	P		? TUMURU F.	? MOTOBU F. YONAMINE F. FUSAKI F.	?			AKIYOSHI OROG. CYC.	

uniformly over all the belts regardless of the zonal structure and yielded the first facies of typically postorogenic nature (Molasse) in the Ryukyu Island Arc. The only possibly recognized contrast in the Plio-Pleistocene sedimentation is the abundance of gravelly facies ("Kunigami Gravel" in part) and the paucity of the Pliocene Naha Limestone within the central Kunigami Belt in Okinawa. This relationship, however, does not hold true in Amami-o-shima. The present shape of the islands may have been created during the last tectonism, which may also be the cause of the vast subsidence in the Ryukyu Basin and Ryukyu Trench. Before this change, the Ryukyu Islands were mountain ranges stretching between south Kyushu and Taiwan, bounding the ocean on the southeastern side. The mountain ranges were produced through the orogenic tectonism during late Cretaceous to latest (?) Oligocene as indicated by the postorogenic sediments of local nature of lower Eocene Miyara Formation and of basal Miocene Kukinaga-Yaeyama-Shimajiri Formations. The only available information for tectonism prior to the late Cretaceous is strong intrageosynclinal volcanism recorded in the Nago Formation and possible rapid upheaval or increase of instability of the inland during the deposition of the polymictic Attsu Conglomerate Lentil. Therefore, in order to analyze the tectonic history of the Ryukyus, it is highly desirable to find neritic or paralic facies both syn-and post-orogenic of the Mesozoic, the counterpart of the geosynclinal facies of the Nago and Kayo Formations, possibly laid down on the metamorphosed Paleozoic (Ishigaki) Belt or Motobu Belt. Inasmuch as the geochemical dating of the metamorphosed rocks from both Ishigaki and Motobu Belt is under way, we may add a little more to our knowledge on the tectonic history of the islands in the near future. Finally, it is specially mentioned that the "belt" of the active volcanoes—volcanoes with the records of the Holocene eruptions—at the northern part of the Ryukyu Islands apparentlly disect obliquely the general trend of the zonal structure preserved in the pre-Miocene basement complex.

CONCLUSIONS

1. Late Mesozoic, probably early Cretaceous, marine fossils characterized by stromatoporoids, corals, and calcareous algae and some spores and pollen of terrestrial plants have been found in the intraformational polymictic conglomerates within the Flysch-type sediments near Attsu, northeastern Okinawa-jima, so that previous attempts to infer a correlation between the conglomerates and the "Usuginu-type beds" of the late Permian Kuman Series are absolutely ruled out.

2. Mainly based on the paleontological evidence in addition to the lithological and structural comparisons of the conglomerate-bearing sequence, it is concluded that the major part of the basement complex of Okinawa is Mesozoic and early Tertiary, comparable with the so-called Undifferentiated Mesozoic Complex of the Shimanto terrain in Southwest Japan and its equivalents in Kanto Mountainland, northern Kitakami Massif, and southwest Hokkaido.

3. The Hedo thrust separating the Motobu Belt, composed of Paleozoic complex including upper Permian, from the Kunigami Belt of Mesozoic rocks is compared with the Butsuzo Line in Southwest Japan, whereas the Tengan fault separating the Kunigami Belt in the north from the Shimajiri Belt in the south is most probably compared with the Nobeoka-Shibisan Line in southern Kyushu.

4. The tectonic zonation established in Okinawa is traceable both northeastwards and southwestwards within the Ryukyu Islands in terms of lithofacies and metamorphic facies of the pre-Miocene basement complex, distribution of the bedded cupriferous iron sulphide and manganese ore deposits, and types of the Tertiary sediments veneering the basement complex. Thus, the Ryukyu Islands can be divided into two major subarcs, northeastern and southwestern, bordered by a topographic depression west of Okinawa-jima, because of the difference in the nature of the basement complex and the sharp change of the structure close to the depression between the Kume-Kerama Islands and Miyako. The outcropping basement rocks of the southwestern subarc are metamorphosed Paleozoic rocks referred to glaucophane schist facies which seems not to be exposed in the northeastern subarc. It is also concluded that the zonal structure of the Ryukyu Islands was completed before Miocene; but the succeeding geohistory of the islands, especially

that of the Miocene and Pliocene Epochs, was more or less controlled by the zonal structure of the pre-Miocene basement complex. However, certain Quaternary activities such as the Pleistocene reef-building and Recent (Holocene) volcanism seem to be independent from the zonal structure of the pre-Miocene complex.

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Appendix : Alphabetical List of Place Names

RYUKYU ISLANDS :

Aka (阿嘉)
Amami (奄美)
Amami-o-shima (奄美大島)
Attsu (有津)
Attsubaru (有津原)
Arumé (有銘)

Bannosaki (バンノ岬)

Funayuki (船行)

Ginama (宜名真)

Haneji (羽地)
Hedo (辺土) (又は辺戸)
Hedomisaki (辺土岬) (又は辺戸岬)

Ie (伊江)
Iheya (伊平屋)
Izena (伊是名)
Iriomote (西表)
Ishigaki (石垣)
Isso (一湊)

Kakeroma (加計呂麻)
Kasari (笠利)
Katabaru (潟原)
Kawata (川田)
Kayo (嘉陽)
Kazuno (和野)
Kerama (慶良間)
Kikai (喜界)
Kin (金武)
Kobama (小浜)
Kombu (昆布)
Komidake (古見岳)
Kouri (古宇利)
Kuba (久場)
Kumage (熊毛)
Kunigami (国頭)

Matsuda (松田)
Miyako (宮古)
Miyara (宮良)
Miyanoura (宮之浦)
Motobu (本部)
Mugio (麦生)

Nago (名護)
Nakijin (今帰仁)
Naon (名音)
Naze (名瀬)
Niimura (新村)

Ohdana (又はOtana) (大棚)
Ohgachi (大勝)
Okinawa (沖縄)
Okinoerabu (沖之永良部)
Osumi (大隅)
Otake (大岳)

Ryukyu (琉球)

Sedake (瀬嵩)
Sesoko (瀬底)
Shimajiri (島尻)
Shiokawa (塩川)
Shioya-wan(=Shanawan) (塩屋湾)

Taira (平良)
Tanegashima (種子ヶ島)
Tengan (天願)
Teruku (照久)
Tokunoshima (徳之島)
Tonaki (渡名喜)

Ukeshima (請島)

Yaeyama (八重山)
Yakabi (屋嘉比)
Yaku (屋久)
Yamada (山田)
Yamatogawa (大和川)

Yono (与那)
Yonamine (与那嶺)
Yoron (与論)
Zamami (座間味)

JAPANESE ISLANDS:

Butsuzo–Ohsakama–Ushinohama (仏像—大坂間—牛之浜)
Chichibu (秩父)
Doganaro (堂ガ奈路)
Hayama (葉山)
Hitoyoshi (人吉)
Itokawa (糸川)
Kasasa (笠沙)
Kaseda (加世田)
Kozakiyama (古崎山)
Makimine (槙峯)
Misaki (三崎)
Morotsuka (諸塚)
Muroto (室戸)
Naharigawa (奈半利川)
Nakamura (中村)
Nobeoka–Shibisan (延岡—紫尾山)
Noma–no–ike (野間ノ池) =Nomaike (野間池)
Nonogawa (野々川)
Sambagawa (三波川)
Shimanto (四万十)
Shimizu (清水)
Suzaki (須崎)
Torinosu (鳥巣)
Usuki–Yatsushiro (臼杵—八代)
Yamagami (山神)

Postscript: Among the several important contributions which have close connection with the present study and were published while this paper was in press, the following three of them are specially mentioned herewith; they are,

1. Matsumoto, Tatsuro, Noda, Mitsuo, and Miyahisa, Michitoshi, 1962, Kyushu–chiho (in Japanese) *in* "Regional Geology of Japan Series", Asakura Book Co., 423 p.
2. Tamura, Minoru, 1963, On the fossil of *Lima* (*Acesta*) *kumasoana* Nagao from the Hitoyoshi Basin, Kyushu. Mem. Fac. Educ., Kumamoto Univ., v.11, p.41–44, and,
3. Matsumoto, Yukio, and Hashimoto, Isamu, 1963, Unconformity below the Mitate Formation in Kyushu (in Japanese with English abstract). Jour. Geol. Soc. Japan, v.69, n. 815, p. 378–387.

In the book by Matsumoto and others, Matsumoto (p. 259–60) refers to the recent discovery of calcareous algae by Hashimoto from the Torinosu–type limestone at southern Ono, Saheki City, which now marks the second record of this type of fossils in the northern Shimanto Belt of Kyushu.

Tamura's paper describes the pelecypod from a boulder of river gravel near Hitoyoshi City (see p. 593 of this paper), and he concludes that, although the locality is located in the northern Shimanto Belt, Eocene strata evidenced with the pelecypod probably develop in the northernmost part of the southern Shimanto Belt nearby. Thus, the paleontologic evidence from the northern Shimanto Belt still appears to be limited to Late Mesozoic.

The last paper by Matsumoto and Hashimoto deals with the controversial stratigraphic position of Mitate Formation. The interpretation lately advocated by some authors who concluded the formation be late Permian is rejected in this paper, and it is assigned to Lower Tertiary based on the stratigraphic and tectonic characters.

KASENO, Y.

Plate I. Geological map of Southern Noto Peninsula, Central Japan. Compiled by Y. KASENO, 1961.

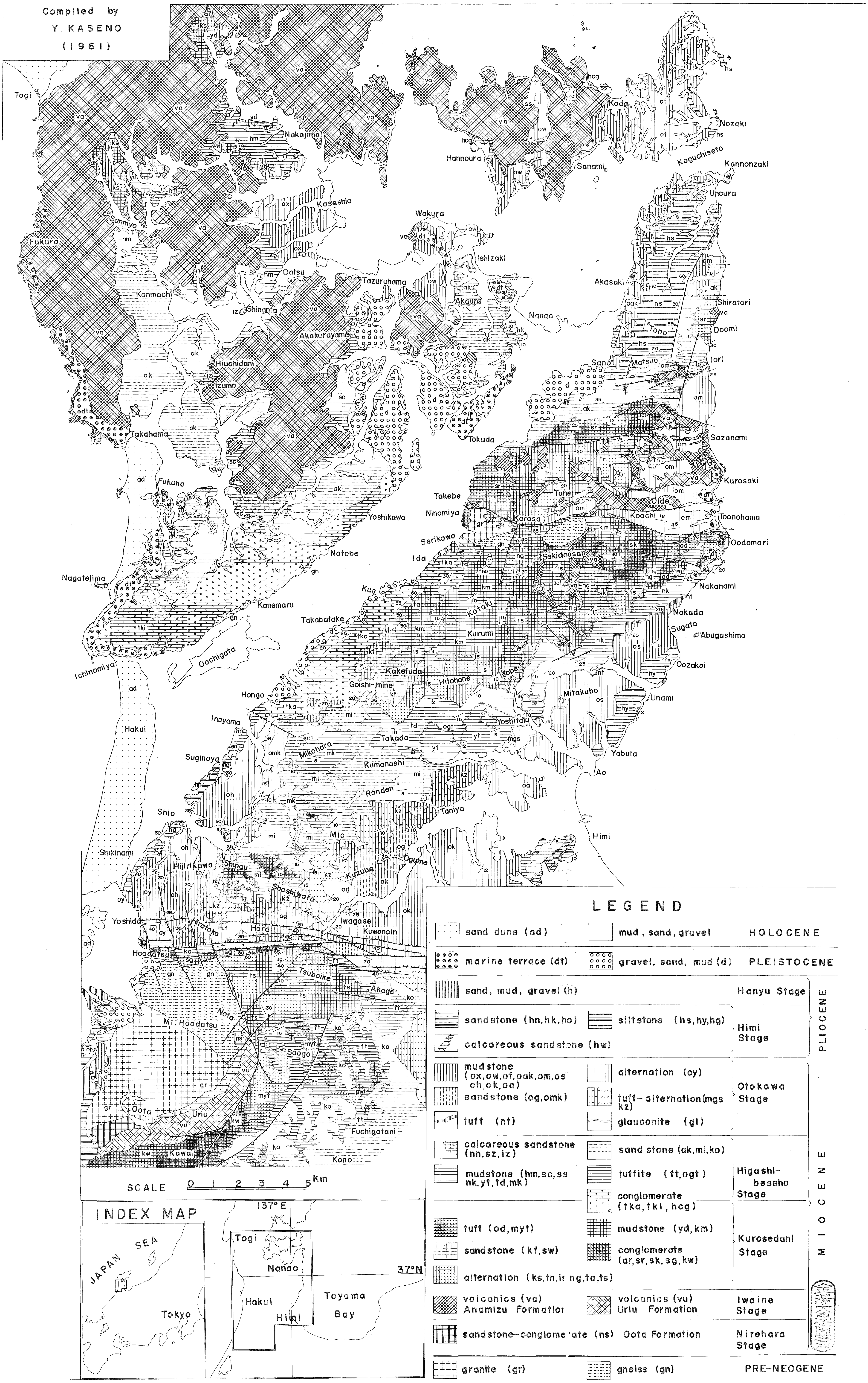
Plate II. Geologic sections in Southern Noto on the basis of Plate I.

Plate III. Geologic structure of Southern Noto area.

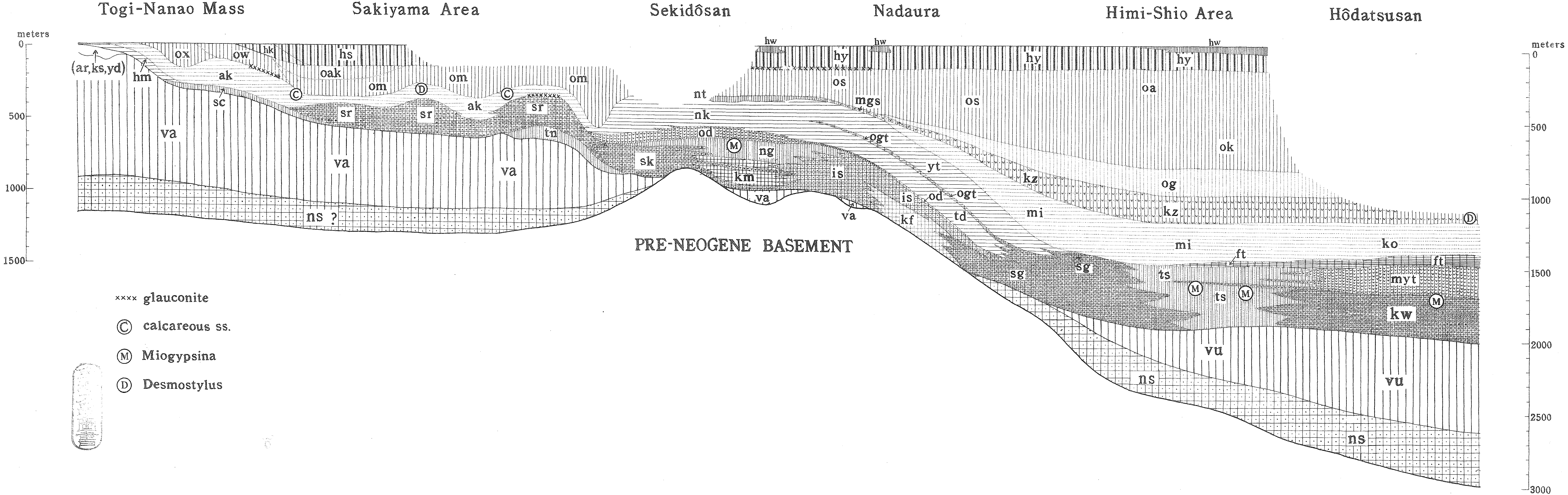
Plate IV. A diagram showing the stratigraphic relations, sedimentary facies and thickness of the Neogene strata in Southern Noto Peninsula, Japan.

Table I. Stratigraphic correlation table of the Neogene strata in Southern Noto Peninsula, Japan. Compiled by Y. KASENO, 1961.

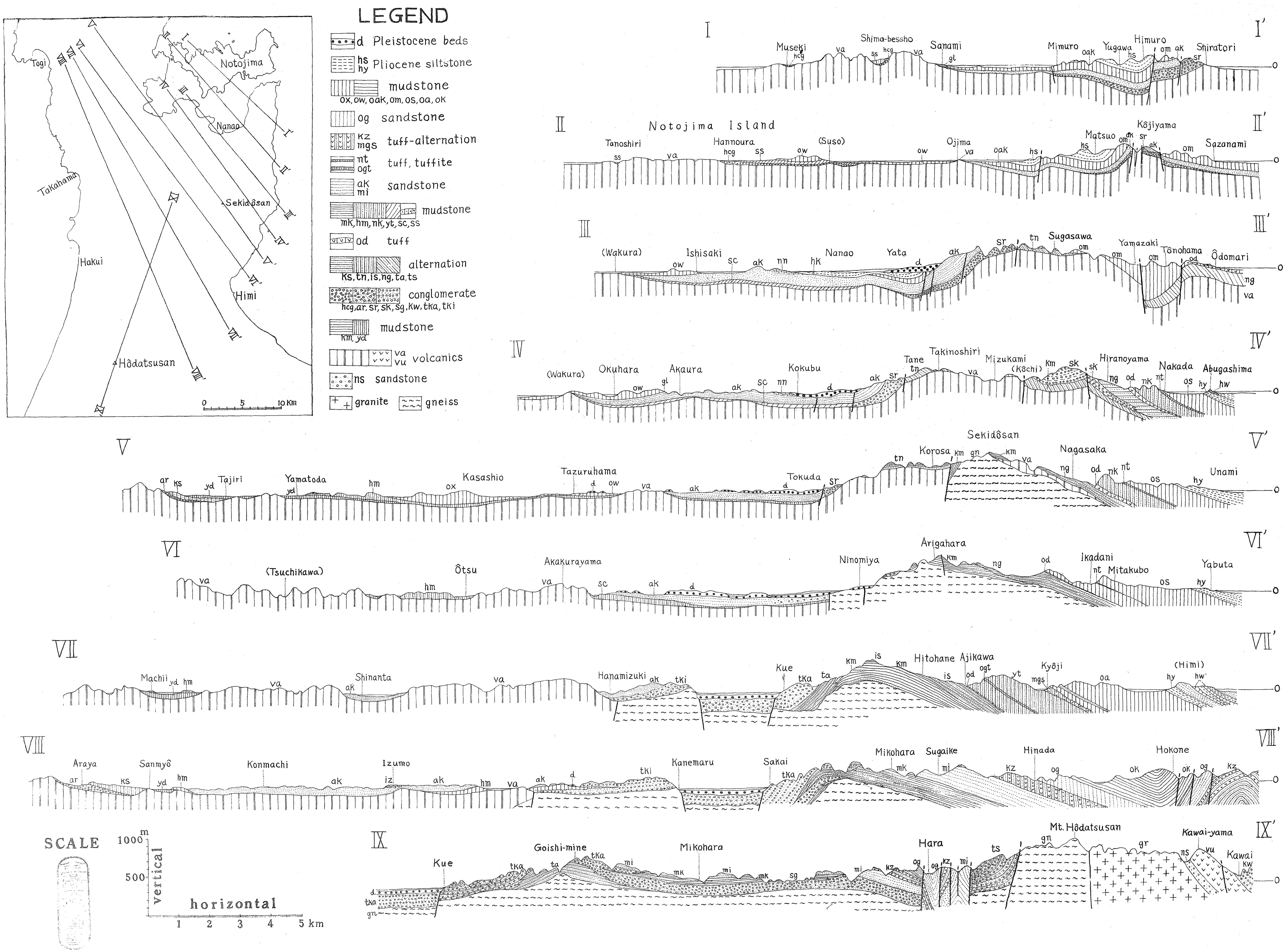
GEOLOGICAL MAP OF SOUTHERN NOTO PENINSULA, CENTRAL JAPAN

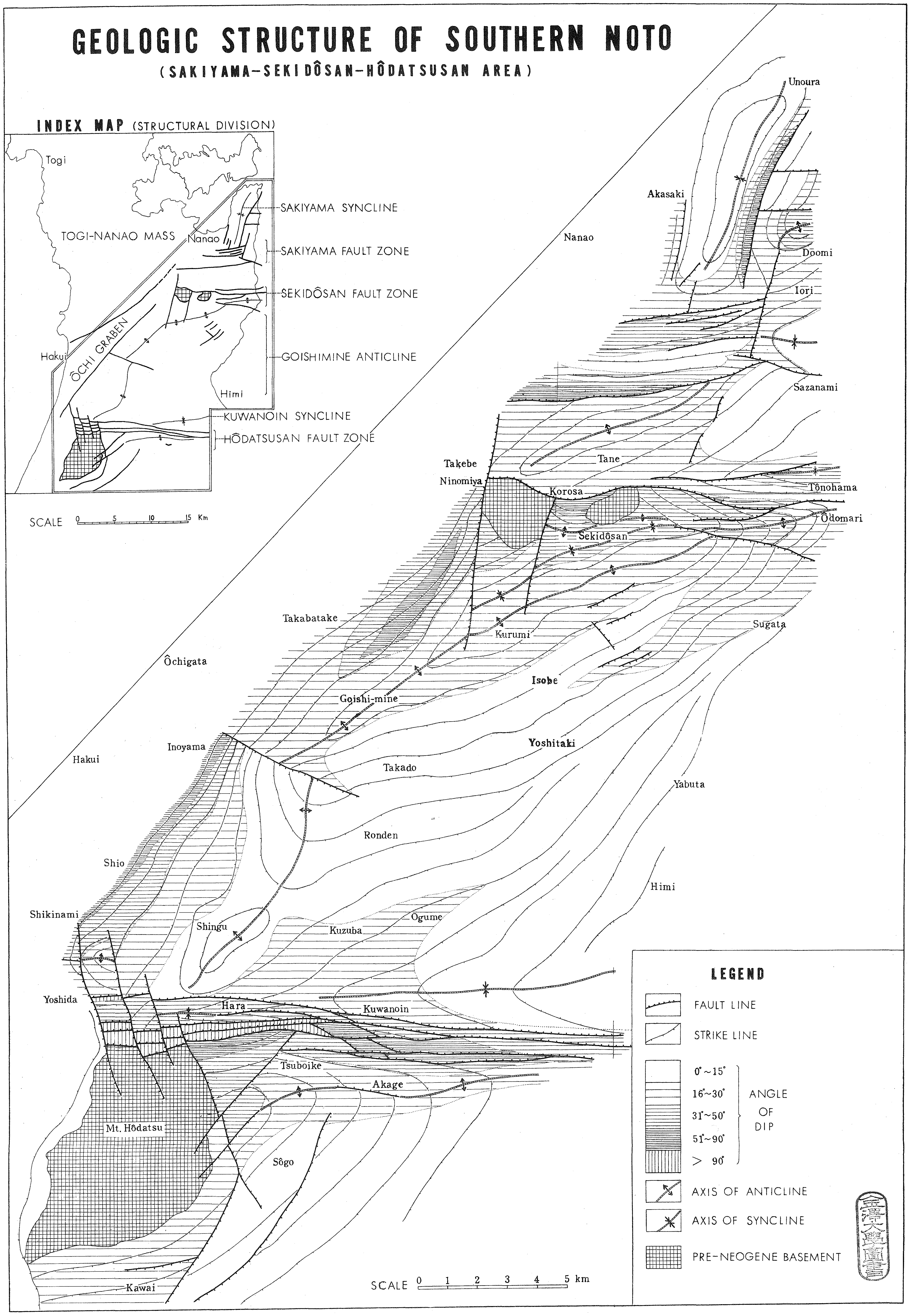


A DIAGRAM SHOWING THE STRATIGRAPHIC RELATIONS, SEDIMENTARY FACIES AND THICKNESS OF THE NEOGENE STRATA IN SOUTHERN NOTO PENINSULA, JAPAN.

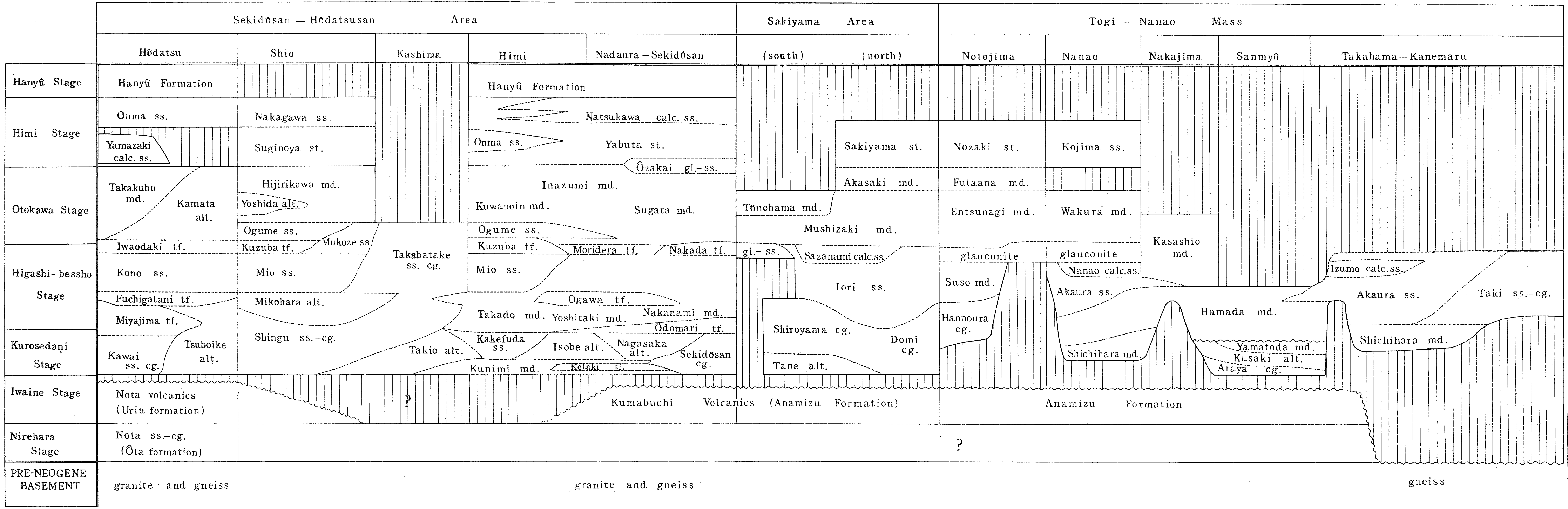


GEOLOGIC SECTIONS IN SOUTHERN NOTO PENINSULA (VERTICAL EXAG. ×2.5)




GEOLOGIC STRUCTURE OF SOUTHERN NOTO
(SAKIYAMA–SEKIDÔSAN–HÔDATSUSAN AREA)
INDEX MAP (STRUCTURAL DIVISION)
Togi
TOGI-NANAO MASS
Nanao
SAKIYAMA SYNCLINE
SAKIYAMA FAULT ZONE
SEKIDÔSAN FAULT ZONE
GOISHIMINE ANTICLINE
KUWANOIN SYNCLINE
HÔDATSUSAN FAULT ZONE
ÔCHI GRABEN
Hakui
Himi
SCALE 0 5 10 15 Km
Unoura
Akasaki
Nanao
Doomi
Iori
Sazanami
Tane
Takebe
Ninomiya
Korosa
Tônohama
Ôdomari
Sekidôsan
Kurumi
Sugata
Takabatake
Ôchigata
Isobe
Goishi-mine
Yoshitaki
Inoyama
Hakui
Takado
Yabuta
Ronden
Shio
Himi
Shikinami
Shingu
Kuzuba
Ogume
Yoshida
Hara
Kuwanoin
Tsuboike
Akage
Mt. Hôdatsu
Sôgo
Kawai
SCALE 0 1 2 3 4 5 km
LEGEND
FAULT LINE
STRIKE LINE
0°~15°
16°~30°
31°~50°
51°~90°
> 90°
ANGLE OF DIP
AXIS OF ANTICLINE
AXIS OF SYNCLINE
PRE-NEOGENE BASEMENT

STRATIGRAPHIC CORRELATION TABLE OF THE NEOGENE STRATA IN SOUTHERN NOTO PENINSULA, JAPAN. COMPILED BY Y. KASENO, 1961.

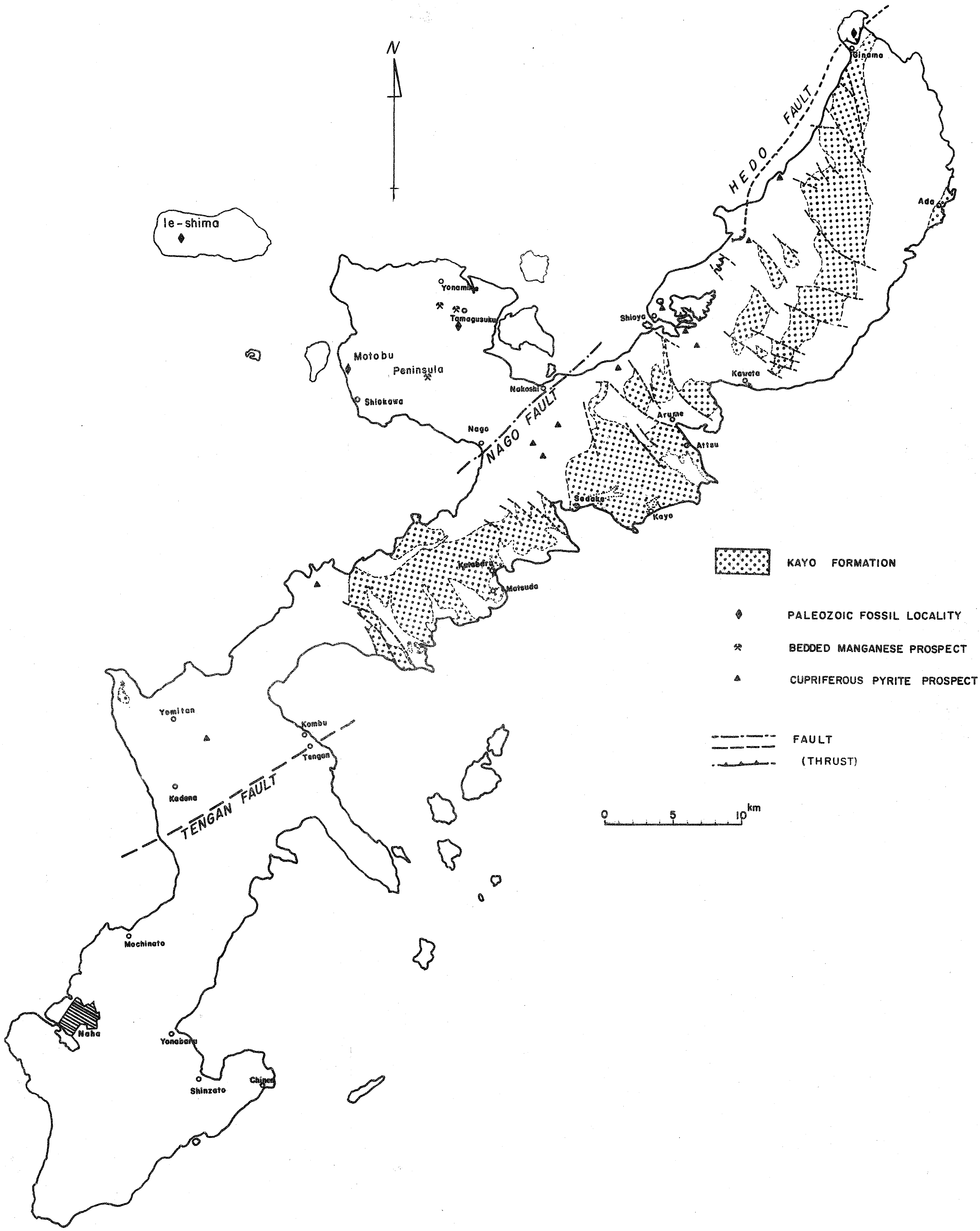


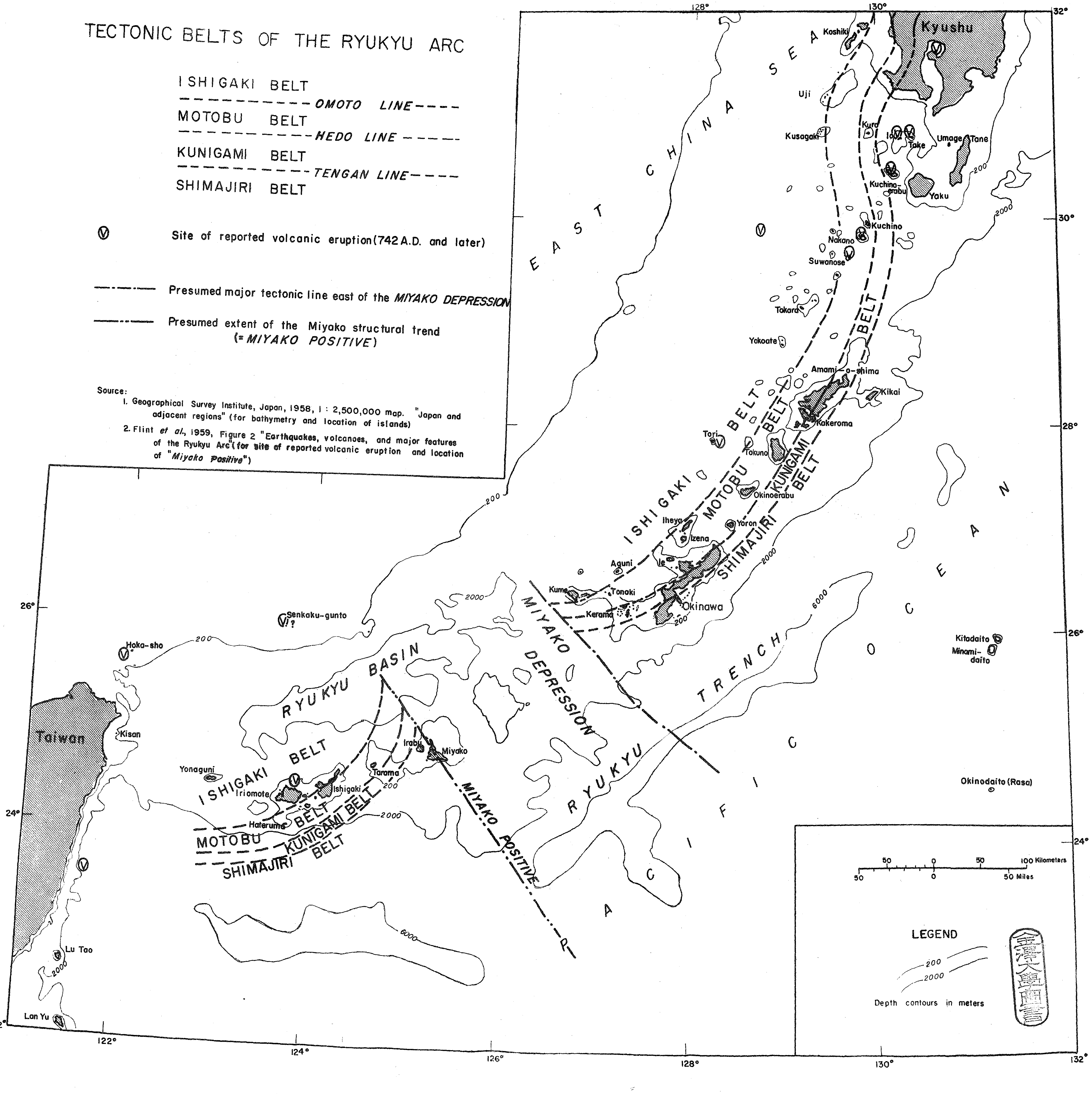
KONISHI, K.

Text–figure 2 Distribution of the Kayo Formation and bedded manganese and cupriferous pyrite prospects in Okinawa

Text–figure 11 Tectonic belts of the Ryukyu Island Arc

DISTRIBUTION OF THE KAYO FORMATION AND BEDDED MANGANESE AND CUPRIFEROUS PYRITE PROSPECTS IN OKINAWA




TECTONIC BELTS OF THE RYUKYU ARC
ISHIGAKI BELT
OMOTO LINE
MOTOBU BELT
HEDO LINE
KUNIGAMI BELT
TENGAN LINE
SHIMAJIRI BELT
Site of reported volcanic eruption (742 A.D. and later)
Presumed major tectonic line east of the MIYAKO DEPRESSION
Presumed extent of the Miyako structural trend
(= MIYAKO POSITIVE)
Source:
1. Geographical Survey Institute, Japan, 1958, 1 : 2,500,000 map. "Japan and adjacent regions" (for bathymetry and location of islands)
2. Flint et al., 1959, Figure 2 "Earthquakes, volcanoes, and major features of the Ryukyu Arc" (for site of reported volcanic eruption and location of "Miyako Positive")
EAST CHINA SEA
PACIFIC OCEAN
RYUKYU TRENCH
RYUKYU BASIN
MIYAKO DEPRESSION
MIYAKO POSITIVE
ISHIGAKI BELT
MOTOBU BELT
KUNIGAMI BELT
SHIMAJIRI BELT
Kyushu
Koshiki
Uji
Kusagaki
Kuro
Iou
Take
Umage
Tane
Kuchino-erabu
Yaku
Kuchino
Nakano
Suwanose
Takara
Yokoate
Amami-o-shima
Kikai
Kakeroma
Tori
Tokuno
Okinoerabu
Iheya
Izena
Yoron
Aguni
Ie
Kume
Tonaki
Kerama
Okinawa
Kitadaito
Minami-daito
Okinodaito (Rasa)
Senkaku-gunto
Hoka-sho
Taiwan
Kisan
Yonaguni
Iriomote
Ishigaki
Hateruma
Tarama
Irabu
Miyako
Lu Tao
Lan Yu
200
2000
6000
122°
124°
126°
128°
130°
132°
22°
24°
26°
28°
30°
32°
50 0 50 100 Kilometers
50 0 50 Miles
LEGEND
200
2000
Depth contours in meters