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Stratigraphy and Geologic Structure of the Pre-Neogene Strata in the Central Ryukyu Islands

By

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with 11 Tables, 25 Text-figures and 5 Plates

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ABSTRACT

The stratigraphy and geologic structure of the pre-Neogene strata in the northwestern Okinawa islands and the northern Amami islands were investigated in order to clarify the sedimentary and tectonic history of Central Ryukyu during the late Paleozoic to Paleogene period.

The pre-Neogene strata of Central Ryukyu form an asymmetrically folded structure in each of the tectonic units separated by reverse or thrust faults dipping generally toward the northwest, and as a whole they form an imbricate structure. The pre-Neogene strata in the northwestern Okinawa islands are classified into the following formations roughly from northwest to southeast: Iheya, Izena, Maedake and Ie formations (Permian to early Cretaceous ?), Dana and Moromi formations (late Cretaceous ?), Nakijin formation (Carnian) and Gusukuyama formation (Oxfordian to Tithonian), Motobu formation (Permian to Triassic ?) and Yonamine formation (Valanginian to Barremian), Wakugawa formation (late Albian to Cenomanian ?), Nago formation (Cenomanian to Santonian ?) and Kayo formation (early middle Eocene). The pre-Neogene strata in the northern Amami islands are divided, from west to east, into the Yuwan formation (Oxfordian to Berriasian), Yuwandake formation (Valanginian to middle Albian), Odana formation (late Albian to Cenomanian), Naze and Ogachi formations (Cenomanian to Santonian ?) and Wano formation (Eocene). Excepting the Dana, Moromi, Kayo and Wano formations, the pre-Neogene strata become generally younger from northwest or west to southeast or east in both districts. These pre-Neogene strata are characterized by the development of subaqueous slumping or sliding. Especially, the Yonamine, Yuwan and Yuwandake formations comprise a large amount of olistostromes in which olistoliths were derived chiefly from the northwestern area. The polarity in geological age toward the southeast and the inferred source of olistoliths may suggest that the sedimentary basins of these pre-Neogene strata migrated southeastward during late Jurassic to late Cretaceous time.

In the pre-Neogene strata, "slump structures" and tectonic structures are observed. The tectonic structures are classified into I, flexural slip folds ?; II, reverse faults and asymmetric folds with cleavages; III, thrust faults and associated folds; IV, strike slip faults; V, normal, lag and reverse faults. The tectonic structures I, II, and III take part in the asymmetrically folded and imbricated structure parallel to the extension of the pre-Neogene strata, while the tectonic structures IV and V cut it obliquely. The formation of the asymmetrically folded and imbricated structure in the pre-Neogene strata may be closely related to the migration of the sedimentary basins.

CONTENTS

I. INTRODUCTION

The Ryukyu Islands, lying between Kyushu and Taiwan at the northwestern Pacific margin, are divided morphologically as well as geologically into three groups, namely, the north Ryukyu Osumi islands, the central Ryukyu Amami and Okinawa islands and the south Ryukyu Miyako and Yaeyama islands (Fig. 1, KIZAKI, 1978).

In the central Ryukyu islands the pre-Neogene strata constitute the Motobu and Kunigami belts, which correspond to the Chichibu and Shimanto belts respectively (KONISHI, 1963, 1965). Because of the significance on the geologic history of Ryukyu island arc, the pre-Neogene strata have been studied stratigraphically and sedimentologically as well as paleontologically by many authors (KUROIWA, 1894; HANZAWA, 1932, 1935; FLINT et al., 1959; Konishi, 1964; Konishi et al., 1973; MATSUMOTO et al., 1966; ISHIBASHI, 1968, 1969; ISHIDA, 1969; SAKAI et al., 1977; FUKUDA et al., 1978; HASHIMOTO and NAKAGAWA, 1978; OSOZAWA et al., 1977, 1979; TAKAHASHI and KASHIMA, 1979). These studies have fairly clarified the stratigraphy, correlation and geologic history of the pre-Neogene strata in the central Ryukyu islands, but not a few of problems remain unsolved. As for the geologic structure and geotectonic framework, there are also a considerable number of works (KOTO, 1897; HATAE et al., 1959; KONISHI, 1963, 1965; KIZAKI, 1978).

Almost all pre-Neogene strata in Central Ryukyu had hitherto been regarded as coherently stratified deposits. Recently, KASHIMA (1976) claimed that most of the pre-Neogene strata in the southwestern part of Amami-Oshima are represented by an olistostrome containing boulder-to pebble-sized detritus. After that, the stratigraphy and geologic structure have been reexamined, and some authors considered that the pre-Neogene strata in Central Ryukyu, which had once been believed to be the Paleozoic coherent deposits, are mostly the Mesozoic chaotically mixed ones including a large number of exotic blocks and pebbles of limestone, greenstone and chert(KASHIMA and TAKAHASHI, 1977; KASHIMA, 1983; OSOZAWA et al., 1983; OSOZAWA, 1984; NAKAGAWA et al., 1983; FUJITA, 1980, 1983a, b). On the other hand, concerning the pre-Neogene strata in Ie-jima, Iheya-jima and Izena-jima in the inner zone of "Motobu belt", UJIIÉ and HASHIMOTO (1983) reported an imbricate structure, insisting that it is not necessary to introduce the idea of mélange or olistostrome into their mode of occurrence. The data of geologic age on the basis of conodonts and radiolarians have made a contribution to the analysis of complicated geologic structure.

The author has carried out the geological research on the pre-Neogene strata in the northwestern Okinawa islands and the northern Amami islands. The primary purpose of this paper is to describe the stratigraphy and geologic structure of the pre-Neogene strata in Central Ryukyu. The consideration of the geologic age based upon radiolarian fossils and the mesoscopic structural analysis are also added. In conclusion, the sedimentary and tectonic history of Central Ryukyu will be briefly summarized.

Acknowledgments

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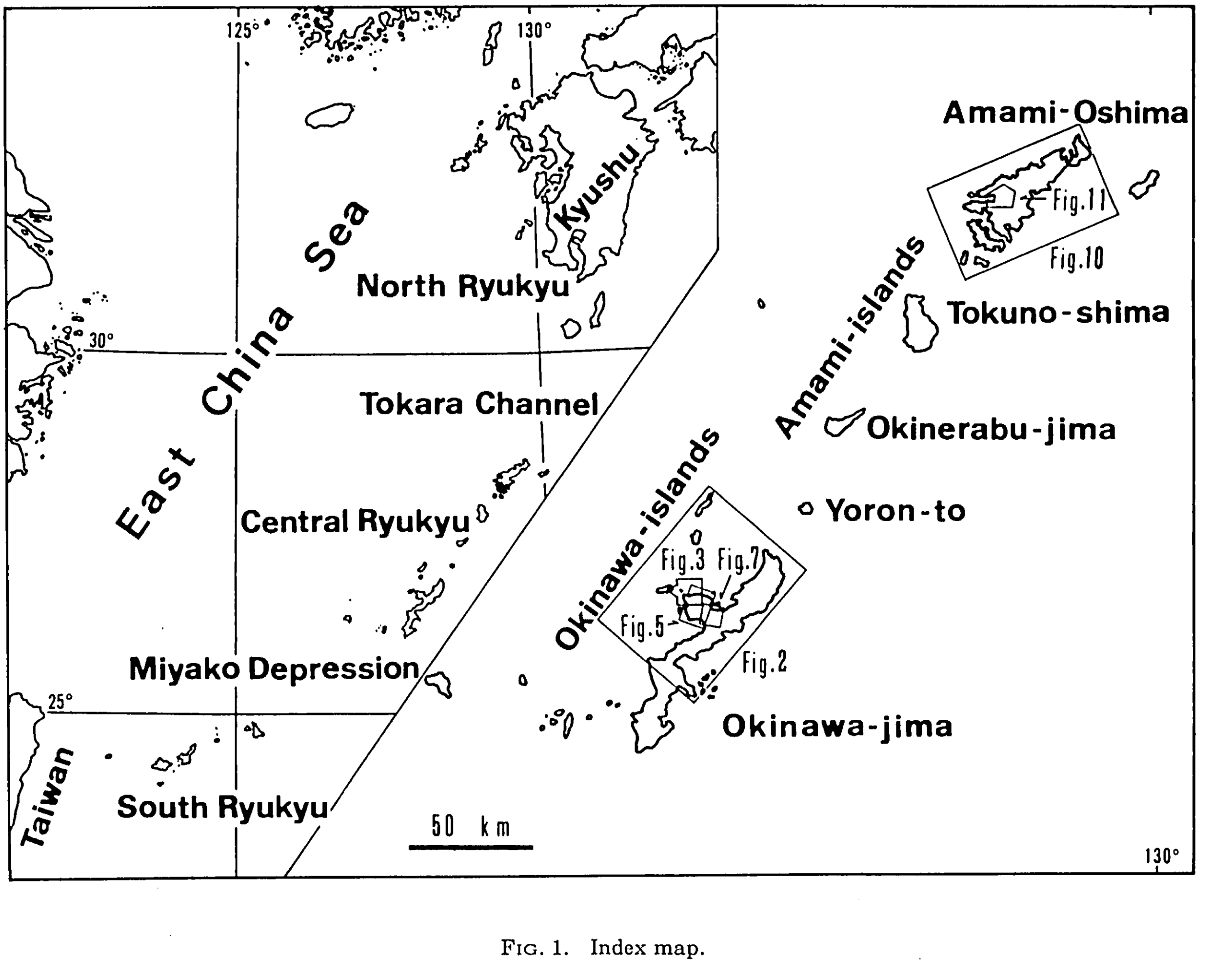


FIG. 1. Index map.

ing radiolarian fossils, and to Dr. Y. KUWANO of National Science Mueseum for his kind help in identifying conodont fossils. Thanks are also due to Prof. S. KAKIDANI, Prof. A. SOEDA, Prof. I. HARA, Dr. T. MIYAMOTO and Dr. T. YANO of Hiroshima University for their kind advice and encouragement. Finally, the author is indebted to Mr. H. TAKAHASHI and Mr. A. MAGAI for preparing thin sections, and to the late Mr. K. OSHIRO, Mr. S. NAKAMURA, Mr. M. NAKASONE, Mr. K. OYOSHI, Mr. K. SATONAGA, Mr. T. NAKAE and many other persons who gave him various helps in field.

II. STRATIGRAPHY

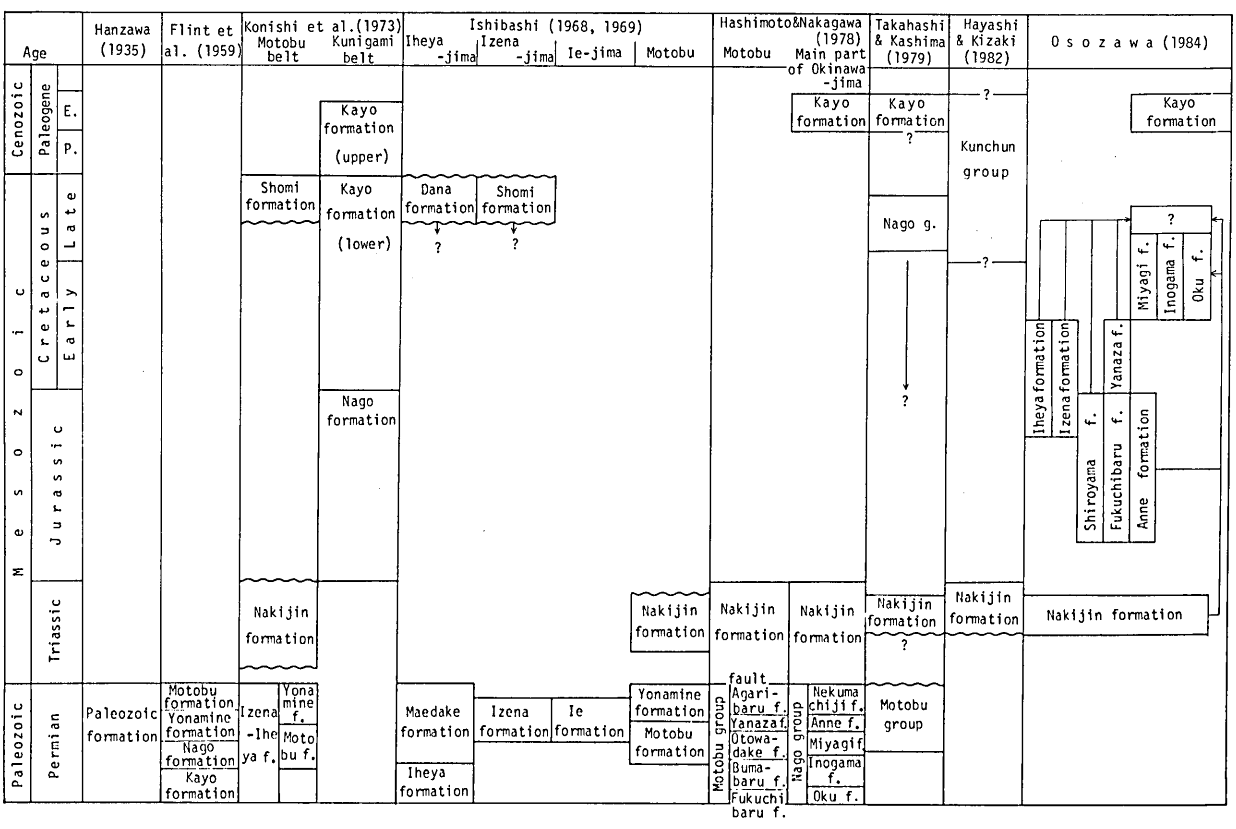
The pre-Neogene strata of Central Ryukyu are exposed in about twenty islands. The detailed investigation has been made primarily in the northwestern Okinawa islands, Okinawa Prefecture and the northern Amami islands, Kagoshima Prefecture. In this chapter, the stratigraphy of the pre-Neogene strata in these two districts are described.

A. NORTHWESTERN OKINAWA ISLANDS

As to the pre-Neogene strata in the northwestern Okinawa islands, there are a considerable number of stratigraphic and paleontological works (Table 1). After the general study by HANZAWA (1932, 1935), FLINT et al. (1959) were engaged in the military geological research of Okinawa-jima, and reported that the pre-Neogene strata are divisible into four formations, namely the Kayo, Nago, Yonamine and Motobu formations from east to west. These formations were regarded as Permian in age on the basis of fusulinids obtained from limestone. Subsequently, ISHIBASHI (1969) distinguished the Triassic Nakijin formation from the Permian Motobu and Yonamine formations by the occurrence of *Halobia styriaca* (MOJSISOVICS), *Sirenites* cf. *nanseni* TOZER, *Sandlingites* aff. *oribasus* (DITTMAR), *Juvavites* cf. *kellyi* SMITH, etc. He also researched the pre-Neogene strata in Iheya-jima and Izena-jima, and subdivided them into the Permian Iheya, Maedake and Izena formations and the Cretaceous(?) Dana and Shomi (represented in this paper by Moromi) formations. Besides, in the Kunigami peninsula the age of Kayo formation was revised to be assigned to the Eocene by the discovery of *Nummulites* (KONISHI et al., 1973). FUKUDA and et al. (1978) and FUKUDA and HAYASAKA (1978) studied on the ichnofauna of the Kayo formation, which was considered to be of lower bathyal to abyssal environment. In Iejima, the presence of the strata of late Jurassic to early Cretaceous age has very recently been made clear by a radiolarian biostratigraphic study (UJIIÉ and HASHIMOTO, 1983).

In the northwestern Okinawa islands, the pre-Neogene strata consist of limestone, greenstone, chert, sandstone and mudstone, showing a zonal arrangement with a general strike of NE-SW or ENE-WSW direction and a dip toward NW or NNW (Fig. 2). They are intruded by granite, porphyrite, porphyry and rhyolite of Miocene age (DAISHI and HAYASHI, 1982), and are unconformably overlain by the upper member of the

TABLE 1. COMPARSION OF THE STRATIGRAPHIC DIVISION OF THE PRE-NEOGENE STRATA IN THE NORTHWESTERN OKINAWA ISLANDS.



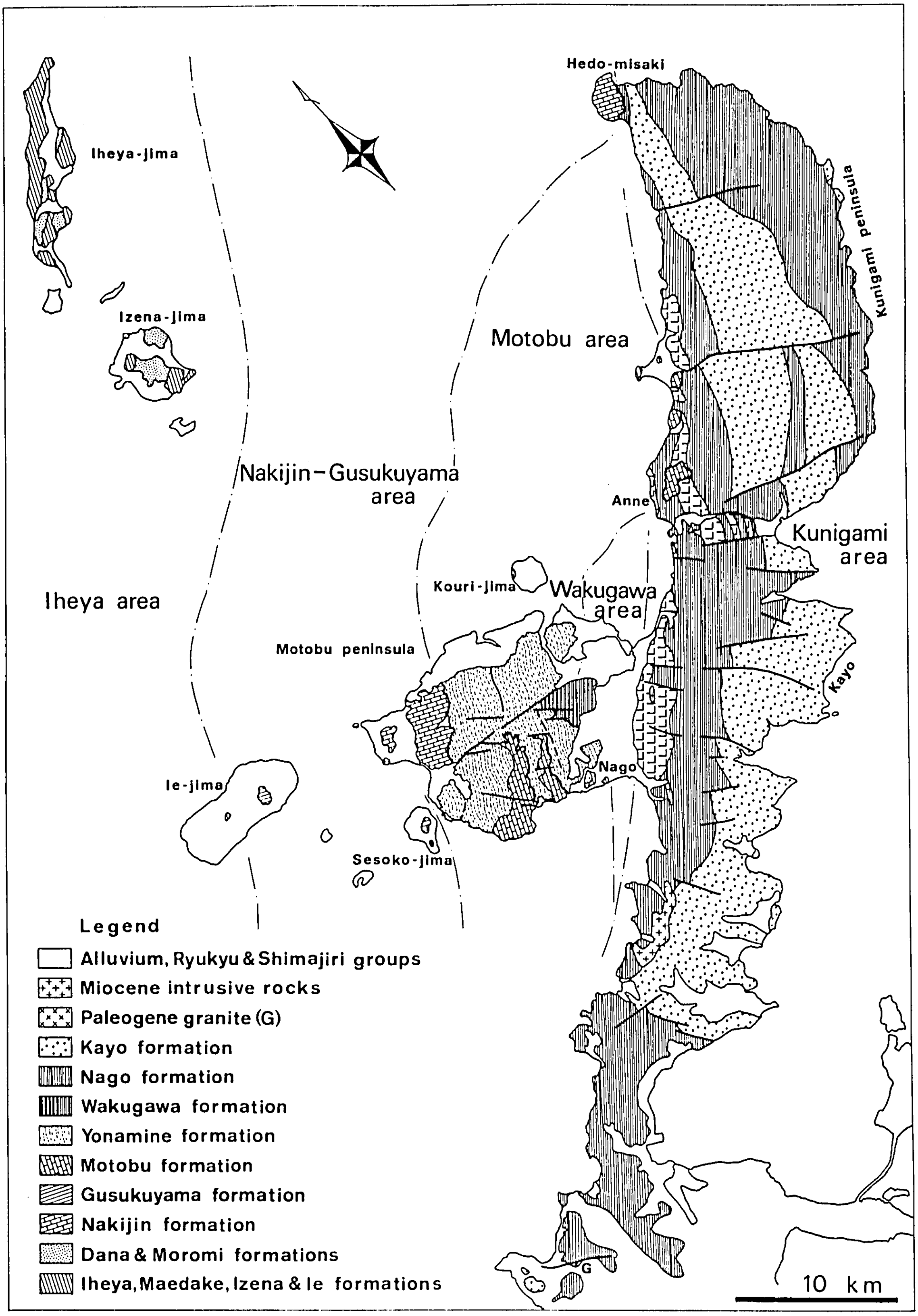


FIG. 2. Geologic map of the northwestern Okinawa islands (Compiled and modified from FLINT et al., 1959; ISHIBASHI, 1968; KONISHI, 1963; HASHIMOTO and NAKAGAWA, 1978; DAISHI and HAYASHI, 1982, 1984; KIZAKI, 1983).

TABLE 2. STRATIGRAPHIC DIVISION OF THE PRE-NEOGENE STRATA IN THE NORTH-WESTERN OKINAWA ISLANDS AND THE NOTHERN AMAMI ISLANDS.

<table>
<tr><th colspan="4" rowspan="2">Geologic Age \ Area</th><th colspan="5">Northwest of Okinawa Islands</th><th colspan="4">North of Amami Islands</th></tr>
<tr><th>Iheya</th><th>Nakijin -Gusukuyama</th><th>Motobu</th><th>Wakugawa</th><th>Kunigami</th><th>Kakeroma -Yadon</th><th>Uken</th><th>Odana</th><th>Naze -Sumiyo</th></tr>
<tr><td rowspan="3">Cenozoic</td><td rowspan="3">Paleogene</td><td colspan="2">Oligoc.</td><td rowspan="4"></td><td rowspan="15"></td><td rowspan="11"></td><td rowspan="8"></td><td></td><td rowspan="14"></td><td rowspan="9"></td><td rowspan="7"></td><td></td></tr>
<tr><td colspan="2">Eoc.</td><td>Kayo f.</td><td>Wano f.</td></tr>
<tr><td colspan="2">Paleoc.</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td rowspan="18">Mesozoic</td><td rowspan="12">Cretaceous</td><td rowspan="6">Late</td><td>Maa.</td></tr>
<tr><td>Cam.</td><td rowspan="4">? Dana -Moromi formations ?</td></tr>
<tr><td>San.</td><td rowspan="4">? Nago formation ?</td><td rowspan="2">? Ogachi f.</td></tr>
<tr><td>Con.</td></tr>
<tr><td>Tur.</td><td rowspan="2">Odana formation</td><td rowspan="2">Naze formation</td></tr>
<tr><td>Cen.</td><td rowspan="6"></td><td rowspan="2">? Wakugawa formation ?</td></tr>
<tr><td rowspan="6">Early</td><td>Alb.</td><td rowspan="13"></td><td rowspan="5">Yuwandake formation</td><td rowspan="13"></td><td rowspan="13"></td></tr>
<tr><td>Apt.</td><td rowspan="12"></td></tr>
<tr><td>Bar.</td><td rowspan="3">Yonamine formation</td></tr>
<tr><td>Hau.</td></tr>
<tr><td>Val.</td></tr>
<tr><td>Ber.</td><td rowspan="8">? Maedake -Iheya -Izena Ie formations ?</td><td rowspan="7"></td><td rowspan="4">Yuwan formation</td><td rowspan="8"></td></tr>
<tr><td rowspan="5">Jurassic</td><td rowspan="3">Late</td><td>Tit.</td><td rowspan="3">Gusukuyama formation ?</td></tr>
<tr><td>Kim.</td></tr>
<tr><td>Oxf.</td></tr>
<tr><td colspan="2">Middle</td><td rowspan="2"></td><td rowspan="4"></td></tr>
<tr><td colspan="2">Early</td></tr>
<tr><td colspan="3">Triassic</td><td>Nakijin formation</td></tr>
<tr><td>Paleozoic</td><td colspan="3">Permian</td><td></td><td>? Motobu formation ?</td></tr>
</table>

Shimajiri group (Pliocene-Pleistocene) and the Ryukyu group (Pleistocene) (TAKAYASU, 1976). From the viewpoint of structural framework, the pre-Neogene strata in the northwestern Okinawa islands are distributed in five areas separated by faults. They are, from west to east, 1) the Iheya area, 2) the Nakijin-Gusukuyama area, 3) the Motobu area, 4) the Wakugawa area and 5) the Kunigami area.

1. *Iheya area*

This area is situated in the inner zone of the Motobu belt (KONISHI, 1965). The pre-Neogene strata of this area, which are exposed in the islands of Iheya, Izena and west of Ie, are divided into the "Paleozoic formations" and the late Mesozoic formations (ISHIBASHI, 1968) (Table 2 and Fig. 2). The former is generally composed of bedded chert, sandstone and greenstone, with subordinate amount of mudstone, conglomerate and limestone. The latter is represented by the Dana and Moromi formations, both of which consist of conglomerate, sandstone and mudstone deposited under shallow marine to blakish environment (ISHIBASHI, 1969). Recently, UJIIÉ and HASHIMOTO (1983) obtained radiolarians of Triassic and late Jurassic to early Cretaceous age from the sandstone of the Iheya formation and the conglomerate of the Izena formation. The chert of the Iheya and Izena formations yields Permian radiolarians.

2. *Nakijin-Gusukuyama area*

This area is characterized by the presence of the pre-Neogene limestone and chert which are exposed in the east of Ie-jima and the western margin of the Motobu peninsula, Okinawa-jima. The pre-Neogene strata are generally divided into two formations, in ascending order: the Nakijin and Gusukuyama formations (Table 2 and Fig. 2).

1). Nakijin formation

The Nakijin formation is distributed in the northwest of the Motobu peninsula, Hedo-misaki and Sesoko-jima. It strikes commonly NNE-SSW and partly NNW-SSE, and dips with 20 to 80 degrees to WNW or 50 to 80 degrees to ESE. The representative good exposures are observed along the pass from the ruin of the Hokuzan castle to Jahana, where the formation is lithologically subdivisible into the lower and upper members (Figs. 3 and 4).

Lower member (about 700m in thickness): This member is made up primarily of bedded limestone interbedded with weakly recrystalized and dolomitized limestone, calcareous siltstone and greenstone. The bedded limestone, ranging in unit-thickness from 2 to 130cm, is dominantly dark gray to gray in color, and is represented by well-sorted micritic calcisiltite, subordinately associated with moderately sorted crinoidal biomicrite-micrudite and intraclast-bearing oomicrite or calcirudite. It has a parallel lamination commonly, and rarely has a graded bedding. The calcareous siltstone is bluish gray to gray in color and has a parallel lamination. The greenstone is chiefly represented by basaltic lavas, and encloses lenticular massive chert, calcareous siltstone and recrystallized limestone. In one specimen of basaltic lava, phenocrysts of plagioclase and pyroxene are set in a weakly fluidal groundmass composed of labradolite, and chlorite, calcite, pyrite and needles of actinolite are seen as secondary minerals.

TABLE 3. LIST OF THE LATE JURASSIC RADIOLARIANS FROM THE GUSUKUYAMA FORMATION.

Radiolarian species	Locality number IE061	IE063
Archaeodictyomitra apiara (Rüst)		•
A. aff. *brouweri* (Tan Sin Hok)	•	•
A. (?) sp.	•	•
Cinguloturris cf. *carpatica* Dumitrica		•
C. sp.		•
Dictyomitra(?) *minoensis* (Mizutzni)		•
D. sp. D Yao	•	•
D. sp.	•	•
Eucyrtidium(?) sp.		•
Hsuum sp.	•	•
Mirifusus aff. *guadalpensis* Pessagno		•
M. *mediodilatatus minor* Baumgartner		•
Parvicingula boesii (Parona)		•
P. *dhimenaensis* Baumgartner		•
P. cf. *haui* Pessagno		•
P. *mashitaensis* Mizutani		•
Podobursa triacantha (Fischli)		•
Protunuma sp.		•
Pseudodictyomitra cf. *carpatica* (Lozyniak)		•
P. *depressa* Baumgartner		•
Ristola altissima (Rüst)		•
Sethocapsa sp.		•
Tricolocapsa sp. A Yao	•	•
Xitus spicularius (Aliev)		•
X. sp.	•	•
Williriedellum(?) sp.	•	
Acaeniotyle umbilicata (Rust)		•
Alievium cf. *helenae* Schaaf		•
Paronaella(?) sp.		•
Spherostylus cf. *lanceola* (Parona)		•
Triactoma sp.		•

Upper member (about 250m in thickness): The upper member conformably overlies the lower member. The lower part, less than 80m in thickness, is composed of poorly stratified limestone with chert lenses of less than 10cm thick. The limestone is represented by biomicrite containing crinoids, sponge-spicules, conodonts and radiolarians. The succeeding upper part consists of gray to white massive limestone, which is represented by pelsparite, intraclast-bearing crinoidal biomicrite-mirudite and stromatoporoidal biomicrudite or coraline(?) biolithite.

Well-preserved ammonoids and bivalves such as *Sirenites* cf. *nanseni* TOZER, *Sandlingites* aff. *oribasus* (DITTMAR), *Juvavites* cf. *kellyi* SMITH, and *Halobia styriaca* (MOJSISOVICS), etc. have been reported by ISHIBASHI (1973) and KOBAYASHI and ISHIBASHI (1970) from the bedded limestone and calcareous siltstone of the lower member. They suggested that the ammonite-bivalve fauna is assignable to Carnian in age.

2). Gusukuyama formation

This formation is exposed in the east of Ie-jima and Bise-zaki of Okinawa-jima, and is equivalent to the Shiroyama formation of HASHIMOTO et al. (1976). It takes a NNE-SSW or N-S strike, dipping generally to WNW or W with 30 to 60 degrees and locally to NW or SE with 10 to 25 degrees. Good displays are seen in the south of Gusukuyama and along the southern coast of Bise-zaki, where the thickness reaches more than 120m (Figs. 3 and 4).

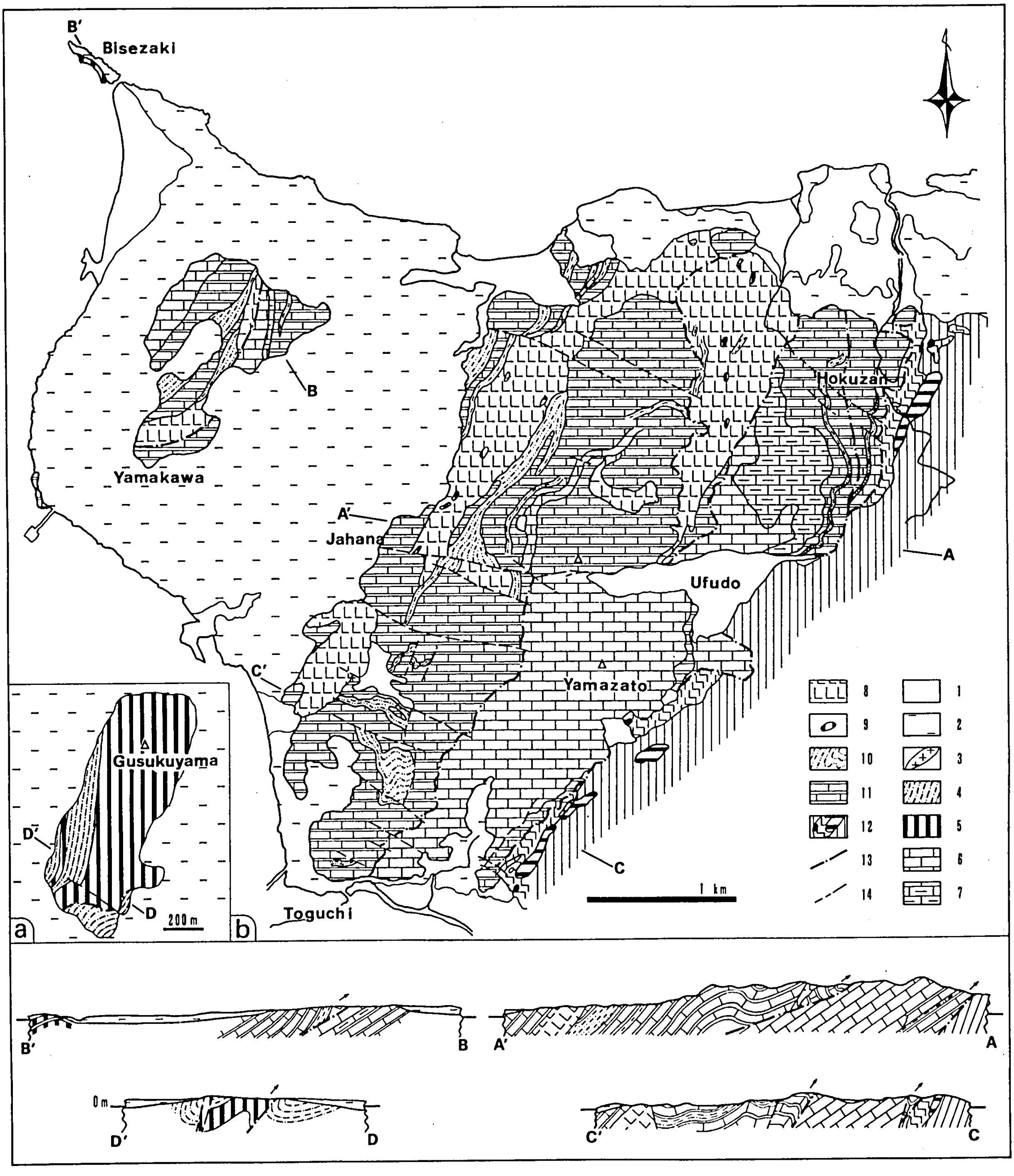


FIG. 3. Geologic map and profiles of the Nakijin-Gusukuyama area, Okinawa-jima and Ie-jima.
1: Alluvium, 2: Ryukyu group, 3: Tertiary intrusive rocks, 4-5: Gusuku yama formation (4: mudstone, 5: chert), 6-11: Nakijin formation (6: massive limestone, 7: limestone with thin chert layers, 8: greenstone, 9: chert, 10: mudstone, 11: bedded limestone), 12: Yonamine formation, 13: reverse fault, 14: fault.

Lower member (more than 100m in thickness): The lower 15m consists of alternating chert and limestone. The chert, 1-5cm in thickness of each layer, is gray in color and includes poorly preserved radiolarians. The limestone, 1-3cm in thickness of each bed, is gray to light gray in color and is represented by moderately sorted radiolarian biomicrite. The succeeding upper 85m is made up of red and gray, bedded chert, which is 1-15cm in unit-thickness and are rhythmically alternated with thinner mudstone.

Upper member (more than 20m in thickness): Composed predominantly of dark gray to gray mudstone with some intercalations of fine-to medium-grained sandstone.

The radiolarians, *Archaeodictyomitra* aff. *brouweri* (TAN SIN HOK), *Pseudodictyomitra* sp. C YAO, *Tricolocapsa* sp. A YAO, etc. (Table 3), obtained from the gray chert (IE061 in Fig. 5) of the lower member are similar to the species constituting the *Gongylothorax sakawaensis-Stichocapsa* sp. C to *Pseudodictyomitra primitiva*-P. sp. A assemblages, which are assigned to Oxfordian to Tithonian in age. On the other hand, the mudstone (IE063) of the upper member yields such radiolarians as *Cinguloturris* cf. *carpatica* DUMITRICA, *Parvicingula boesii* (PARONA), *Pseudodictyomitra depressa* BAUMGARTNER, etc. (Table 3), resembling the diagnostic species of the *Pseudodictyomitra primitiva*-P. sp. A zone (MATSUOKA and YAO 1985) and zones C to D (BAUMGARTNER, 1984), which are referred to the late Tithonian.

3. *Motobu area*

This area lies on the southeastern side of the Nakijin-Gusukuyama area, and is characterized by the distribution of admixed sedimentary facies which may be referred to the so-called olistostrome. The pre-Neogene strata here are divisible into the Motobu and Yonamine formations in ascending order (Table 2 and Fig. 2).

1). Motobu formation

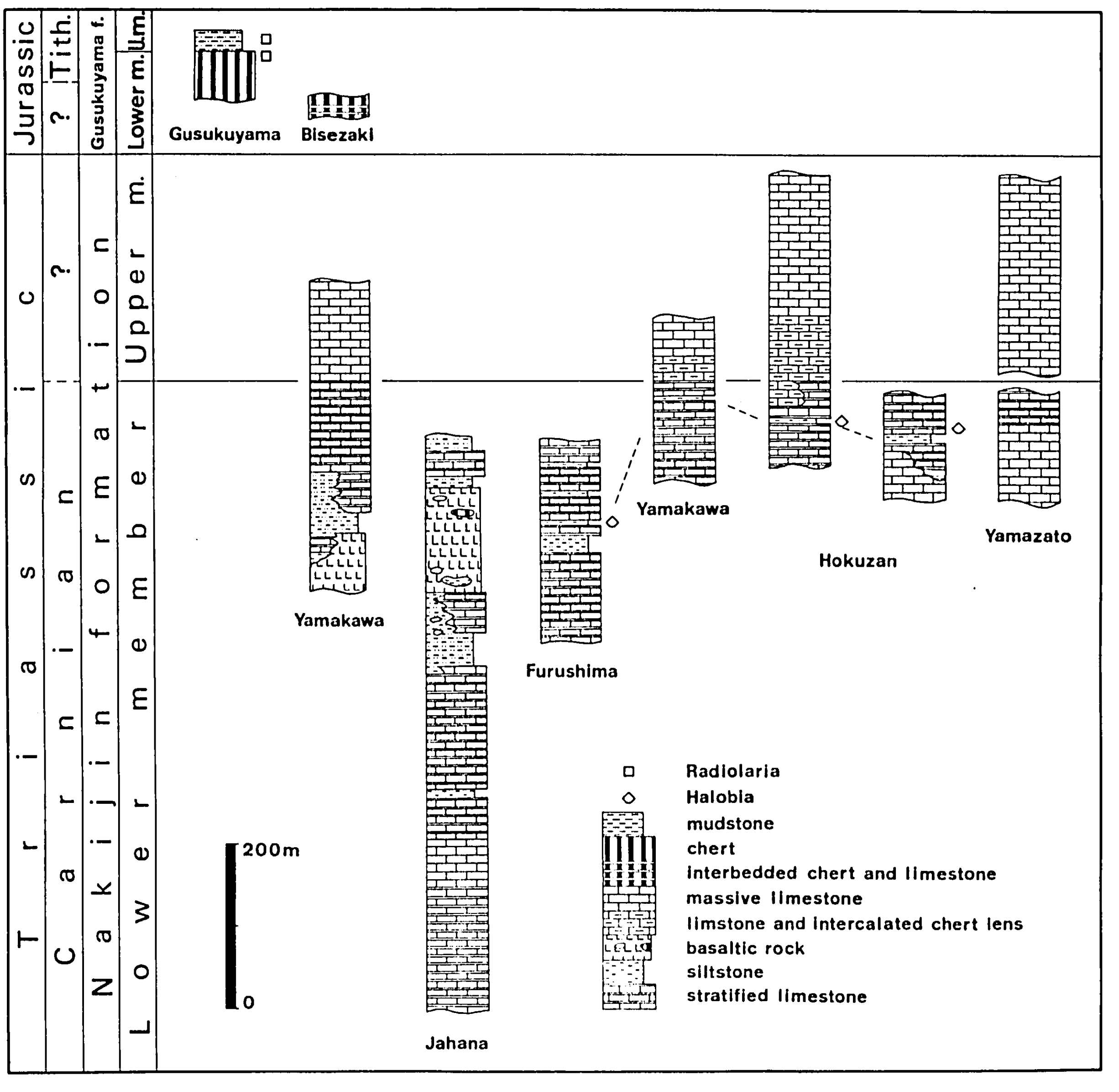


FIG. 4. Columnar sections of the Nakijin and Gusukuyama formations.

The Motobu formation is distributed in the south of the Motobu peninsula and the western margin of the Kunigami peninsula, Okinawa-jima, and takes a general strike of NNE-SSW direction, dipping to WNW with 20 to 70 degrees. A sequence observed along the southern coast of the Motobu peninsula, from Umusa to Buma, is the stratotype of this formation, where the thickness is estimated at about 950m (Figs. 6 and 7).

The lower part, about 70 m thick, consists of dark green to reddish purple greenstone associated with lenses of limestone of 2 to 5m in thickness. Although the greenstone is remarkably recrystallized and the original texture is obscure, such characteristic minerals as epidote, actinolite and chlorite are present (HASHIMOTO, 1978). Therefore, the original rock may belong to basalt.

The succeeding upper part, about 800m thick, is composed predominantly of dark gray to gray limestone interbedded with mudstone, chert and limestone-conglomerate. The limestone (15-200m in unit-thickness) is represented by micrite, pel- and oo-micrite, crinoidal and radiolarian biomicrites, partly containing siliceous nodules of 5cm to 1m in diameter. The interbedded mudstone (5-70m in unit-thickness) is dark gray in color and is intercalated with thinner, fine- to medium-grained, calcareous sandstone ranging in thickness from 2 to 3cm. The limestone-conglomerate varies in thickness from 3 to 50m, consisting mainly of subangular to angular granules to cobbles of limestone and partly of those of chert and mudstone.

The overlying greenstone enclosing chert blocks, about 30 m thick, is distributed only around Umusa. It may represent the uppermost part of this formation.

2). Yonamine formation

The Yonamine formation is dominantly developed with a general trend of NE-SW or NNE-SSW in the major part of the Motobu peninsula. Besides, It is distributed also in the west of Yagachi-jima and the western margin of Kouri-jima. A relatively good succession is observed along the southwestern coast between Shiokawa and Kenken, where the thickness attains about 1400m (Figs. 2, 6 and 7).

The lower part, about 400 m thick, is made up generally of dark grayish mudstone with thin, lenticular, very fine- to medium-grained sandstone. Besides, various-sized olistoliths of greenstone, chert, chert-conglomerate and limestone are included. Olistoliths or exotic masses of greenstone, ranging from 30cm to 1.5 km in length, commonly enclose irregularly deformed chert blocks of 0.3 to 800 m in size, and are partly interstratified with chert beds or lenses of 5cm

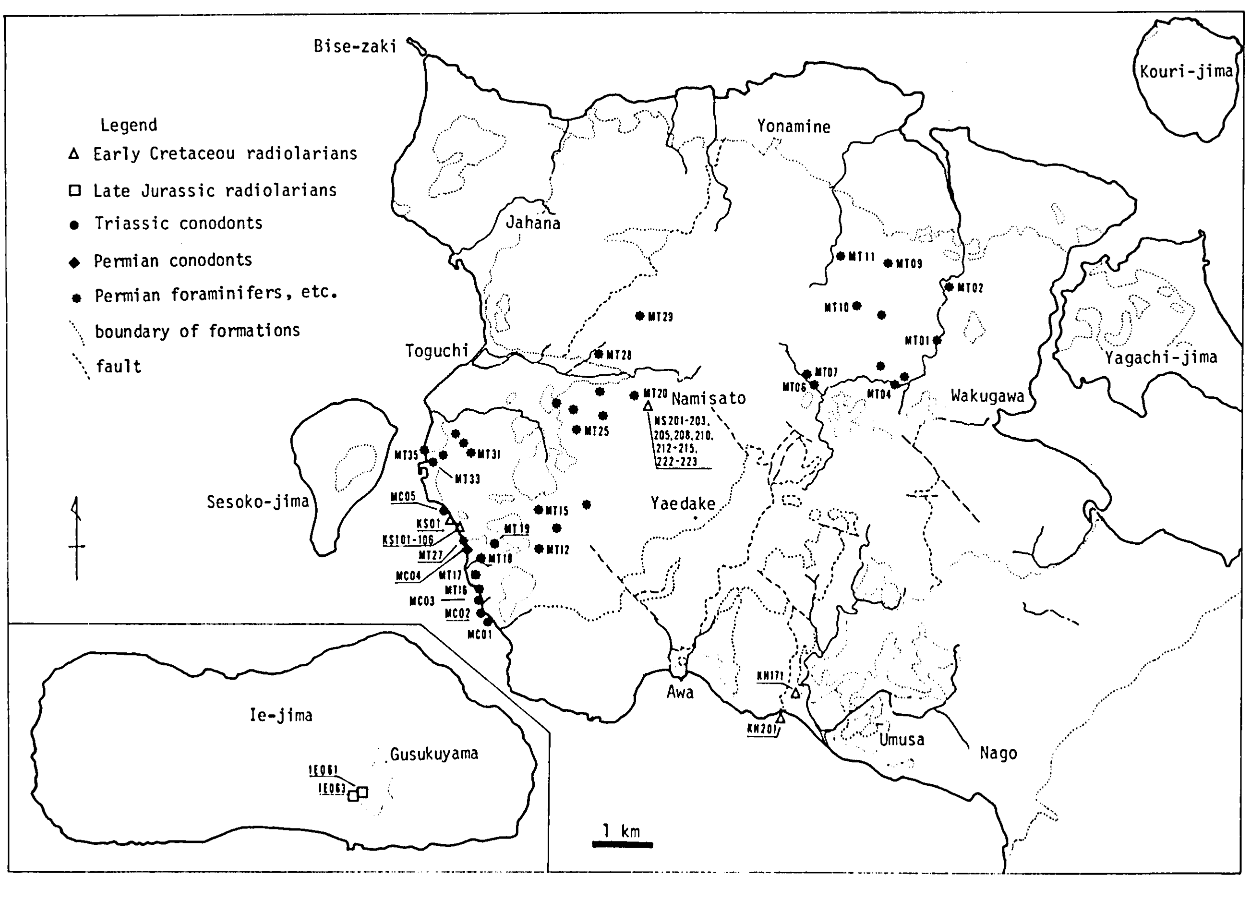


FIG. 5. Localities of radiolarians, conodonts and foraminifers in the Motobu peninsula of Okinawa-jima and Ie-jima.
Black symbols indicate the fossils obtained from olistoliths.

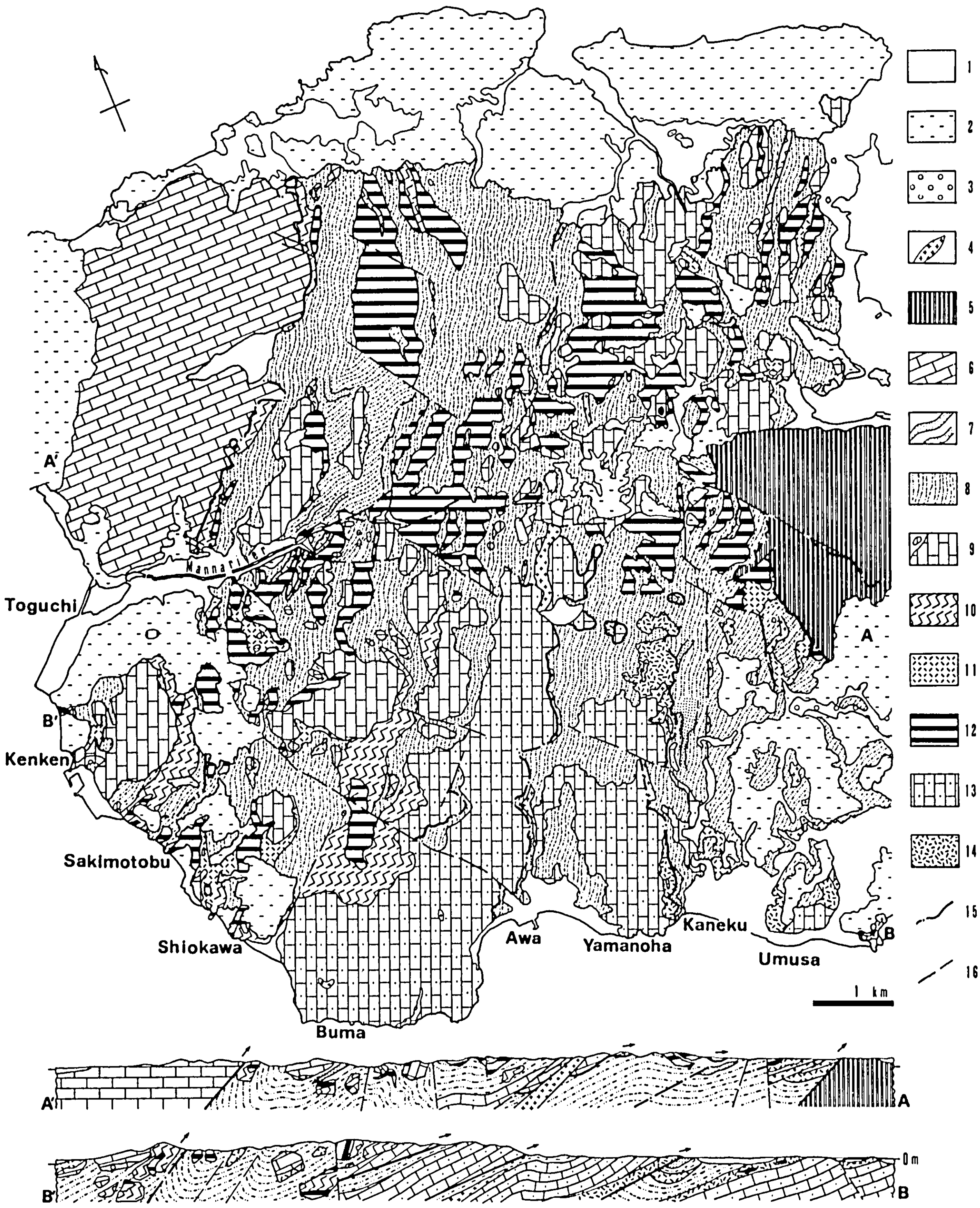


FIG. 6. Geologic map and profiles of the Motobu area, Okinawa-jima.
1: Alluvium, 2: Ryukyu group, 3: Shimajiri group, 4: Tertiary intrusive rocks, 5: Wakugawa formation, 6: Nakijin formation, 7-12: Yonamine formation (7: sandstone, 8: mudstone, 9: limestone, 10: Triassic green stone, 11: Permian greenstone), 12: chert, 12-14: Motobu formation (13: limestone, 14: greenstone), 15: reverse fault, 16: fault.

to 5m in thickness. The greenstone is dark greenish to green grayish in color, consisting of plagioclase, augite, magnetite, chlorite, epidote and needles of actinolite. In fresh specimens, intergranular and subophitic textures are infrequently observed. Limestone blocks, ranging in size from 2m to 100m, are rarely found. The limestone is represented by micrite and oosparite. The chert-conglomerate occurring as blocks is greenish to blue grayish in color and granule-sized, intercalated with thin layers of mudstone.

The upper part, about 1000m thick, is composed mainly of mudstone associated with sandstone, conglomerate, siliceous mudstone, chert and silicified tuff. A large number of limestone and chert olistoliths, together with some greenstone olistoliths, are contained. The sandstone is represented by blue grayish, very fine- to medium-grained lithic wacke. The torn and contorted lenses of sandstone of various shapes (rhomboid, square, obtuse-angled triangle, etc.) are usually irregularly scattered in mudstone (Fig. 15-2). In some cases, however, the sandstone is well alternated with mudstone (the former being 1 to 30cm in thickness and the latter 10 to 50cm). The conglomerate is classified in lithology into two types. One is well-sorted granule-conglomerate (10-50cm thick), and the other is poorly sorted conglomerate (2-30cm) consisting of subangular to angular granules to cobbles of chert, limestone, tuff and siliceous mudstone.

The limestone olistoliths of various sizes (1.5m to 2km in diameter) are developed independently of the stratification. It seems that there is no relation between the stratigraphic horizon and lithologic characters of limestone. The limestone appearing as olistoliths is represented by dark grayish bedded micrite (each bed being 20-50cm thick), with thin intercalations of light grayish massive pel-, oo-, bio-micrite and coraline biolithite in addition to mudstone or chert. Basaltic lavas and poorly sorted limestone-conglomerate are also associated. The limestone-conglomerate consists of subrounded to subangular, granule- to

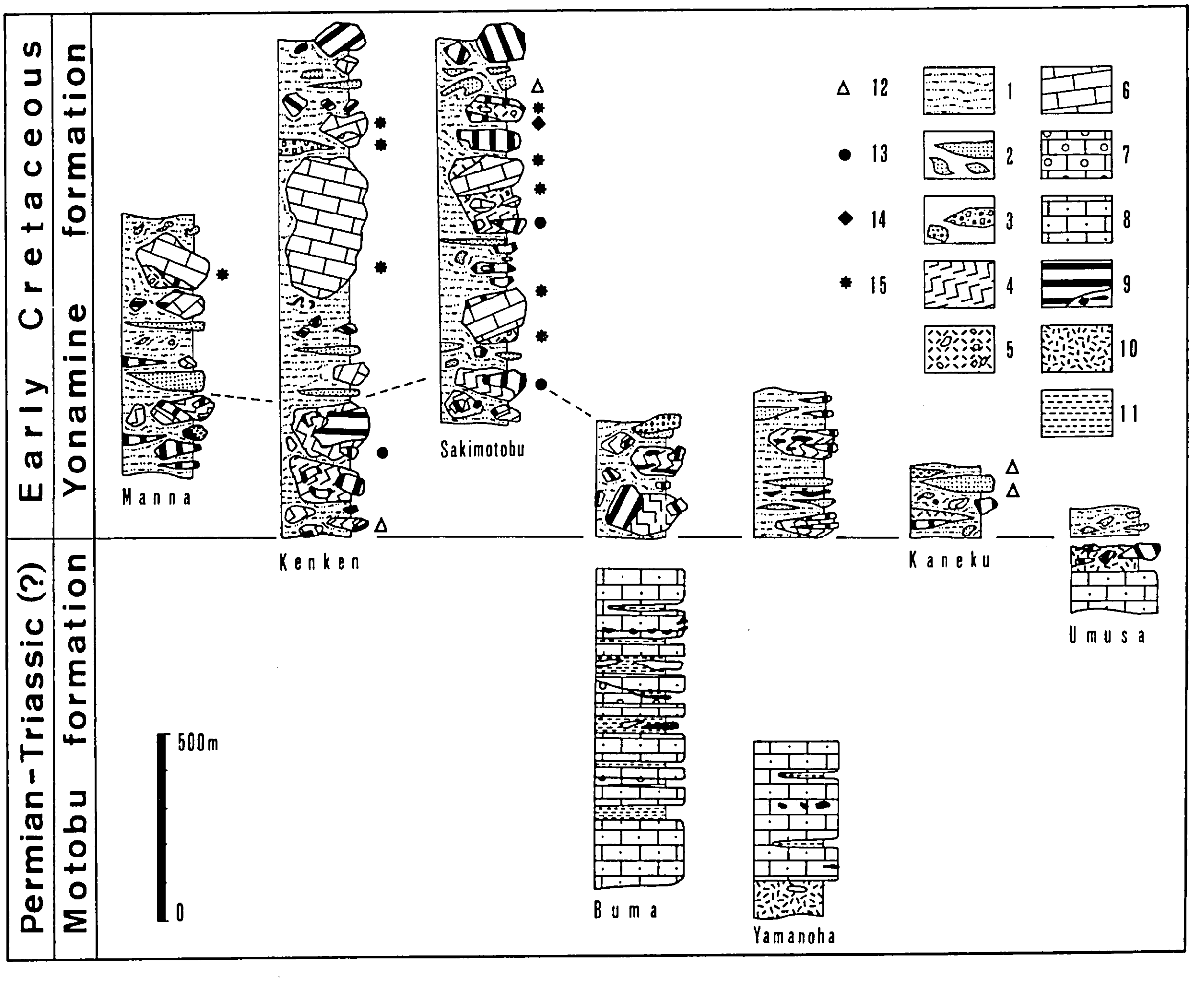


FIG. 7. Columnar sections of the Yonamine and Motobu formations.
1-7 & 9: Yonamine formation (1: mudstone, 2: sandstone, 3: conglomerate, 4: Triassic greenstone, 5: Permian greenstone, 6: limestone, 7: limestone conglomerate), 9: chert, 8-11: Motobu formation (8: limestone, 10: greenstone, 11: limestone), 12: early Cretaceous radiolarians, 13: Triassic conodonts, 14: Permian conodonts, 15: Permian fossils from limestone.

TABLE 4. LIST OF FOSSILS FROM LIMESTONE OLISTOLITHS IN THE YONAMINE FORMATION.

MT35	MT33	MT31	MT29	MT28	MT27	MT25	MT20	MT19	MT18	MT17	MT16	MT15	MT12	MT11	MT10	MT07	MT06	MT04	MT02	MT01	Locality number / Species
																					Larger foraminifer
																	●			●	*Colania douvillei* (Ozawa)
																	●	●		●	*C.* sp.
				●																	*Sumatrina annae* Volz
			●			●														●	*Neoschwagerina craticulifera* (Schwager)
					●										●		●			●	*N.* cf. *margaritae* Deprat
●	●	●	●								●			●		●	●	●		●	*N.* sp.
																	●			●	*Verbeekina verbeeki* (Geinitz)
							●			●	●						●		●	●	*V.* sp.
													●								*Rauserella* sp.
													●								*Parafusulina* sp.
																				●	*Staffella* sp.
																					Smaller foraminifer
		●				●		●	●	●							●				*Hemigordius* sp.
		●																			*Kahlerina* sp.
							●	●				●									*Nodosarina* sp.
		●									●										*Placotextularia* sp.
										●											*Pachyphloia* sp.
		●										●									*Cribrogenerina* sp.
									●												*Glomospira* sp.
																					Other fossil
				●						●											*Waagenophyllum* sp.

boulder-sized fragments of limestone, chert, sandstone and basalt, the matrix being green grayish or red purplish in color and tuffaceous. The micro-to giganto-olistoliths of chert (1m to 2.5km in diameter) are developed in mudstone, tending to increase upward in quantity and size. The chert is gray, green grayish or red browny in color and bedded or massive, each bed ranging in thickness from 1 to 30cm. It is interstratified with contemporaneous mudstone. The greenstone occurring as olistoliths of 30cm to 2km in length is similar in lithology to that of the lower part. In the greenstone near the major reverse fault between the Nakijin and Yonamine formations, such second minerals as chlorite, calcite and needles or granules of actinolite are commonly observed. This greenstone is different in frequency and size of secondary minerals from the other greenstones in the present formation.

From the olistoliths of limestone and limestone-conglomerate a rugose coral, *Waagenophyllum* sp. and such foraminifers as *Colania douvillei* (OZAWA), *Sumatrina annae* VOLZ, *Neoschwagerina craticulifera* (SCHWAGER), *Hemigordius* sp., *Kahlerina* sp. were obtained (Table 4 and Fig. 5). They are of middle Permian age.

The chert block (MC04) of the upper part yields such conodonts as *Diplognathodus* cf. *movschovitschi* KOZUR and PJATAKOVA, which probably show the late Permian age according to the age-determination on the Permian conodont fauna by IGO (1979). The Triassic conodonts, including *Neogondolella mombergensis* (Tatge) of Anisian to Ladinian age (SWEET, et al., 1971), are obtained from the lenticular chert (MC01) within the greenstone block of the lower part (Table 5). The chert (MC02, 03 and 05) associated with the greenstone blocks of the lower and upper parts yields the late Triassic conodonts, comprising *Epigondolella abneptis* (HUCKRIEDE), *Neohindeodella triassica* MÜLLER, etc. These conodonts are analogous to the diagnostic species of the *Epigondolella abneptis* zone described by SWEET et al. (1971) and KOIKE (1979), showing probably the Norian age.

The radiolarian assemblage occurring in the mudstone, siliceous mudstone and chert (Table 6), contains *Archaeodictyomitra* cf. *brouweri* (TAN SIN HOK), *Pseudodictyomitra carpatica* (LOZYNIAK), *Sethocapsa* cf. *uterculus* (PARONA) etc., and is probably assignable to Valanginian to Barremian in age considering the specific composition of early Cretaceous radiolarian faunas of FOREMAN (1975), PESSAGNO (1977), SCHAAF (1984) and YAO (1984).

4. *Wakugawa area*

This area is situated between the Motobu and Kunigami areas (Table 2 and Fig. 2). The pre-Neogene strata of this area are called the Wakugawa formation, which is distinguished from the Yonamine formation by the lack of exotic blocks or masses of pre-Cretaceous limestone, chert and greenstone and also by the development of sandstone.

Wakugawa formation

TABLE 5. LIST OF CONODONTS FROM CHERT OLISTOLITHS IN THE YONAMINE FORMATION.

Form genus and species \ Locality number	MC01	MC02	MC03	MC04	MC05
Epigondollela abneptis (Huckriede)		●	●		
E. sp.		●			
Neohideodella suevica (Tatge)		●			
N. summesbergeri Kosur & Mostler		●	●		●
N. triassica (Muller)		●			●
N. triassica riegeli (Mosher)		●			
N. triassica triassica (Muller)		●			
Prioniodina(Cypridodella) muelleri (Tatge)		●			
Neogondollela mombergensis (Tatge)	●				
Neospathodus(?) sp.		●			
Diplognathodus cf. *movschovitschi* Kozur & Pjatakova				●	

TABLE 6. LIST OF THE EARLY CRETACEOUS RADIOLARIANS FROM THE YONAMINE FORMATION.

Sample number	KH201	KH171	NS223	NS222	NS215	NS214	NS213	NS212	NS210	NS208	NS205	NS203	NS202	NS201	KS106	KS105	KS104	KS103	KS102	KS101	KS 01
Matrix / Radiolarian Species	sm	ms	ms	sm	ms	tf	sm	ms	sm	ms	ms	sm	sm	sm	ms	ms	ms	sm	ms	ms	sm
Archaeodictyomitra apiara (Rüst)	●																				
A. cf. *apiara* (Rüst)	●														●						
A. cf. *brouweri* (Tan Sin Hok)	●						●														
A. cf. *sliteri* Pessagno	●						●														
A. vulgaris Pessagno	●																				
A. cf. *vulgaris* Pessagno	●			●			●				●	●									
A. sp.	●	●		●	●	●	●			●	●				●		●				
Hemicryptocapsa cf. *capita* Tan Sin Hok	●						●														
Mirifusus cf. *mediodilatatus* (Rüst)	●																				
Parvicingula cf. *boesii* (Parona)				●	●		●							●							
P. sp.				●								●									
P.(?) sp.																					
Pseudodictyomitra carpatica (lozyniak)	●																				
P. cf. *carpatica* (Lozyniak)	●						●				●			●							
P. sp.	●				●	●	●										●	●		●	
P.(?) sp.																					●
Sethocapsa cf. *uterculus* (Parona)	●																				
S. sp.	●			●			●	●				●	●	●						●	
Spongocapsula(?) sp.	●			●			●														
Thanarla conica (Aliev)	●	●	●	●	●		●	●		●		●		●		●			●	●	●
T. cf. *pulchra* (Squinabol)							●														
Zifondium(?) sp.																					●
Orbiculiforma sp.	●	●		●	●		●		●					●	●						
Praeconocaryomma(?) sp.	●			●			●														●
Sphaerostylus lanceola (Parona)				●																●	

ms: mudstone, sm: siliceous mudstone, tf: tuffaceous rock.

The Wakugawa formation is distributed limitedly with a general trend of N-S and a gentle dip. The representative sequence is observed along the small valley trending westerly from Kogachi, where the thickness is estimated at about 500m (Figs. 8 and 9).

The lower part, about 260m thick, is made up mainly of dark gray mudston interstratified with layers of green grayish greenstone (10 to 90m in thickness) and thin beds of siliceous mudstone. Chunks and slabs of sandstone of various shapes (rhomboid, square, triangle, etc.) and sizes (2cm and 200m) are irregularly scattered in the mudstone (Fig. 15-3). The sandstone is in common represented by fine- to medium-grained feldspathic wacke. The greenstone lava shows intergranular texture, including phenocrysts of plageoclase, augite and hornblende. Needles or granules of actinolite, small mica, chlorite and quratz are seen as secondary minerals.

The succeedingly upper part, about 240m thick, consists of alternating beds of sandstone and mudstone. The lower half (100m) is composed of repeated alternation of fine- to coarse-grained sandstone and dark gray mudstone. Each layer of sandstone and mudstone varies in thickness from 5cm to 1m. The upper half (about 140m) consists predominantly of thick-bedded medium- to very coarse-grained sandstone, each bed, ranging in thickness from 10cm to 3m. The sandstone of this part is generally represented by moderately to poorly sorted feldspathic wacke.

On careful examination, no fossils except for recrystllized and poorly preserved radiolarians were obtained.

5. *Kunigami area*

This area occupies the outermost part of Okinawa-jima, including the Kunigami peninsula. The

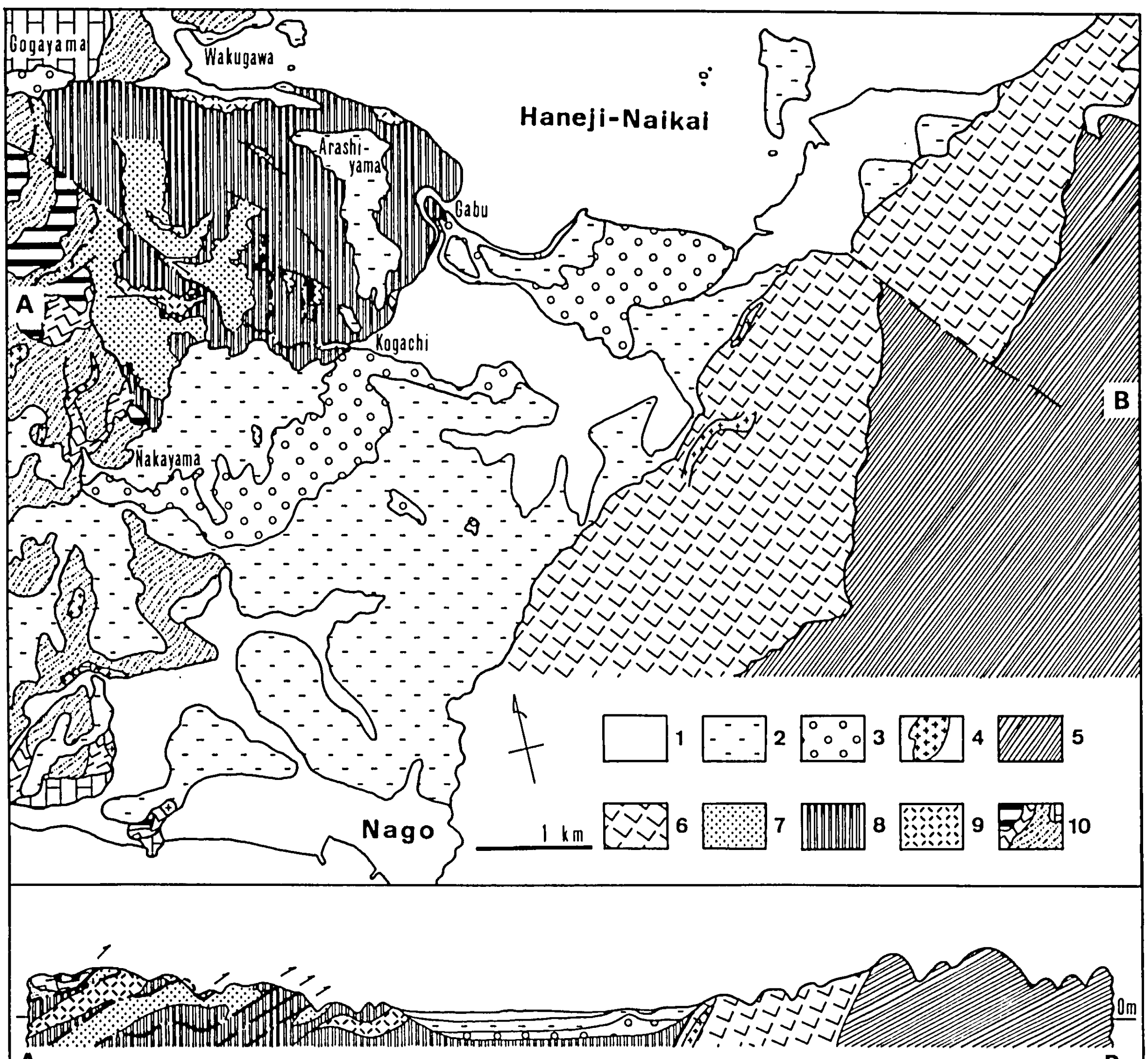


FIG. 8. Geologic map and profile of the Wakugawa and Kunigami areas, Okinawa-jima. 1: Alluvium, 2: Ryukyu group, 3: Shimajiri group, 4: Tertiary intrusive rocks, 5-6: Nago formation (5: mudstone, 6: greenstone), 7-9: Wakugawa formation (7: sandstone, 8: mudstone, 9: greenstone), 10: Yonamine formation.

pre-Neogene strata are divided into the Nago and Kayo formations. HASHIMOTO and NAKAGAWA (1978) mentioned that the distribution of the Kayo formation is restricted to the eastern margin of Okinawa-jima. On the other hand, FLINT et al. (1959), KONISHI et al. (1973) and HAYASHI and KIZAKI (1982) described that from the difference in lithologic characters between the Nago and Kayo formations the pre-Neogene strata in the median part of the Kunigami peninsula also belong to the Kayo formation. Though the author has no evidence to clarify which of the two views is true, for the present he defers to the latter (Tables 1, 2 and Fig. 2).

1). Nago formation

The Nago formation, characterized by the remarkable development of slaty cleavage or schistosity, is exposed in the west of the Kunigami peninsula with a general trend of NE-SW or ENE-WSW (Fig. 2). It is composed chiefly of dark gray slate or phyllite with some intercalations of lenticular fine- to medium-grained sandstone of 1 to 10cm thick. Greenstones, consisting of gray tuff and dark green massive or pillow lava, are also associated. The mineral assemblage of greenstone is epidote-amphibole group (hornblende and actinolite)-chlorite-muscovite-plageoclase-quartz (SUZUKI and OKIMURA, 1979). Any reliable index fossils have never been reported from this formation.

2). Kayo formation

The Kayo formation is narrowly developed on the eastern side of Okinawa-jima, with a general strike of ENE-WSW and a dip toward NNW (Fig. 2). It is in fault contact with the underlying Nago formation. Typical exposures are observed along the eastern coast from Arume to Teniya-zaki, about 3 km northeast of Kayo, where the thickness attains about 850 m (FUKUDA et al., 1978).

This formation consists chiefly of fine- to coarse-grained, bedded sandstone interstratified with dark gray mudstone and conglomerate. After FUKUDA et al. (1978), the sandstone is characterized by the development of parallel lamination, current ripple lamination, small-scale flute casts and load casts. Besides, they described many trace fossils such as *Spirorhaphe* sp., *Helminthoida* sp., *Cosmorhaphe* sp., etc., all of which indicate the lower bathyal to abyssal environment.

The Eocene *Nummulites* from the Kayo formation has been first recorded by KONISHI et al. (1973). Recently, SUZUKI and UJIIÉ (1985) reported *Nummulites amakusaensis* YABE and HANZAWA of the earliest Lutetian age (early middle Eocene), from debris flow deposits which are inserted as independent units in the arkosic sandstone-rich alternation. On the basis of the comparison between the species of *Nummulites* from the Kayo formation and those from the Fukuregi formation in Amakusa-Shimoshima, the Miyara formation in Iriomote-jima and the strata on Amami-plateau, they suggested that the debris flow deposits observed in the Kayo formation may have been derived from the southernmost extention of the Koshiki-jima belt (KONISHI, 1965), west off Okinawa-jima.

B. NORTHERN AMAMI ISLANDS

The pre-Neogene strata in the northern Amami

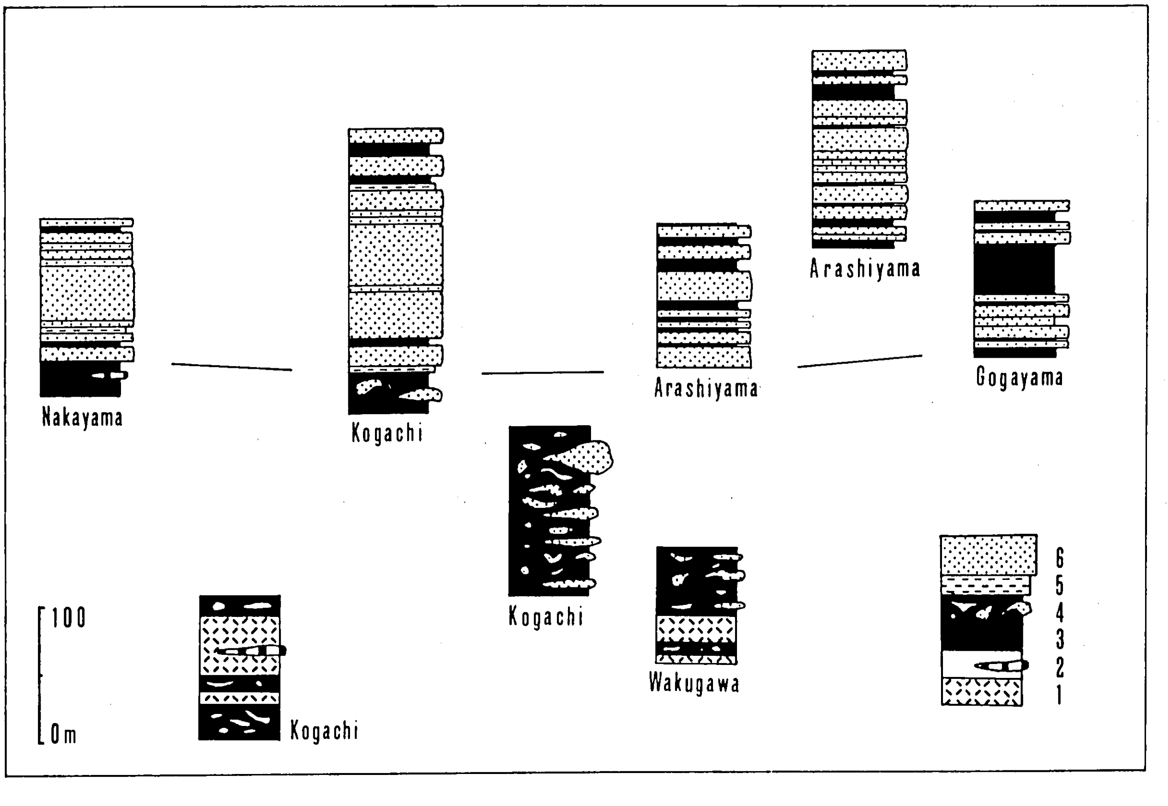


FIG. 9. Columnar sections of the Wakugawa formation, Okinawa-jima.
1: greenstone, 2: chert, 3: mudstone, 4: slump deposit, 5: altenating sandstone and mudstone, 6: sandstone.

TABLE 7. COMPARSION OF THE STRATIGRAPHIC DIVISION OF THE PRE-NEOGENE STRATA IN THE NORTHERN AMAMI ISLANDS.

Age			Hatae et al.(1959)	Konishi et al.(1973) Motobu belt	Konishi et al.(1973) Kunigami belt	Konishi et al.(1973) Shimajiri belt	Sakai et al.(1977) Motobu belt	Sakai et al.(1977) Shimanto belt	Takahashi & Kashima (1979)	Osozawa (1984)
Cenozoic	Paleogene	O.				?				
		E.				Wano formation		Wano formation	Wano formation	
		P.	?			?		Tatsugo formation		
Mesozoic	Cretaceous	Late	Wano formation		Odana -Ogachi formation	Akina formation and Unnamed Subsurface		Ogachi formation	Ogachi formation	? Odana formation / Ogachi f. / Naze formation
		Early						Naze formation	Kakeroma (Yuwan) formation	Yuwan formation
	Jurassic				Naze Shinmura formation	?	? Oganeku formation			
	Triassic		?				Yuwan formation / Toen formation		Naon formation	
Paleozoic	Permian		Naon f. / Odana f. / Shinmura f. / Naze f. / Ogachi f.	Naon formation			Naon formation		?	

islands had been first divided by HATAE et al. (1959) into the Ogachi, Naze, Shinmura, Odana and Naon formations of Carboniferous to Permian age and the Wano formation of Mesozoic age (Table 7). In the geotectonic framework of the Ryukyu Islands by KONISHI (1965) and KONISHI et al. (1973), it was concluded that the Permian Naon formation belongs to the Motobu belt, the Mesozoic Naze, Shinmura, Odana and Ogachi formations to the Kunigami belt and the Cretaceous (?) Akagina formation and the Eocene Wano formation to the Shimajiri belt. Subsequently, SAKAI et al. (1977) divided the pre-Neogene strata in the northern part of Amami-Oshima into the Naon, Toen, Yuwan and Oganeku formations of the Motobu (Chichibu) belt and the Naze, Ogachi, Tatsugo and Wano formations of the Shimanto belt. They mentioned that the geologic structure of the Motobu terrain seems to be characterized by an imbrication, and that the strata of the Shimanto terrain also form an imbricated structure by thrust faults and asymmetric synclinal folds. Recently OSOZAWA et al. (1983), NAKAGAWA et al. (1983) and OSOZAWA (1984) distinguished five formations of late Jurassic to early Cretaceous (Oxfordian to Aptian) Yuwan, late Cretaceous (Cenomanian to Turonian) Naze, Odana, Ogachi and Eocene Wano, and stated that the major geologic structure of Amami-Oshima has been formed by the southeastward gravity transportation in Turonian time. The Yuwan formation slided onto the Odana formation in the western part of Amami-Oshima and the Naze formation onto the Ogachi formation in the central part. The Naze formation slumped also over the Odana formation.

In the northern Amami islands, the pre-Neogene strata, which consist of chert, greenstone, limestone, mudstone, sandstone and silicified tuff, are zonally arranged with a general strike of NNE-SSW direction and a dip toward WNW. These rocks are intruded by biotite granite of Paleogene age (SHIBATA and NOZAWA, 1966) and porphyrite and porphyry of Neogene age, and are unconformably overlain by the Taira formation and Kasari limestone of Quarternary age in the Kasari peninsula.

From the viewpoint of structural framework, the distribution of pre-Neogene strata in the northern Amami islands is subdivided into zonally arranged four areas separated by faults (Fig. 10 and Table 2). They are, from west to east, 1) the Kakeroma-Yadon area, 2) the Uken area, 3) the Odana area and 4) the Naze-Sumiyo area.

1. *Kakeroma-Yadon area*

This area is situated in the innermost zone of the Amami islands. The pre-Neogene strata, called the Yuwan formation (OSOZAWA, 1984), are exposed in the western margin of Amami-Oshima, Edateku-jima, Kakeroma-jima and Uke-jima. According to OSOZAWA et al. (1983) and OSOZAWA (1984), the Yuwan formation is made up of dark gray mudstone interbedded with siliceous mudstone, sandstone and chert, and contains many olistoliths of Carboniferous and Permian limestone and greenstone, together with Permian and Triassic chert (Fig. 10).

Such late Jurassic (Oxfordian to Tithonian) radiolarians as *Eucyrtidium* (?) *ptyctum* RIEDEL and SANFILIPPO, *Parvicingula boesii* (PARONA), etc. have been reported by OSOZAWA et al. (1983) and OSOZAWA (1984) from the mudstone, siliceous mudstone and chert of the Yuwan formation.

2. *Uken area*

This area occupies the great part of western Amami-Oshima. The pre-Neogene strata here are equivalent to the eastern part of the Yuwan formation which has been regarded by Osozawa (1984) as olistostrome of Jurassic to early Cretaceous age, differing in lithofacies and geologic age from the western part of the Yuwan formation. In this paper, the pre-Neogene strata of the Uken area are tentatively named the Yuwandake formation, being separated from the Yuwan formation of the Kakeroma-Yadon area (Fig. 10).

Yuwandake formation

The Yuwandake formation is distributed in the western part of Amami-Oshima, Uke-jima, Yoro-jima, the central part of Kakeroma-jima and the eastern part of Edateku-jima. It takes a general strike of NNE-SSW direction and dips to WNW. The standard succession is observed along the Kawauchi river and along the pass from Yuwan to Yuwandake. This formation is lithostratigraphically subdivided into the lower, middle and upper members, and is structurally separated into the western Unit A and the eastern Unit B by a major thrust fault. The strata of both units somewhat differ from each other in lithofacies and geologic structure (Figs. 11, 12 and 13).

Lower member (less than 70 m in thickness): This member is exposed only in Unit A near Yuwan

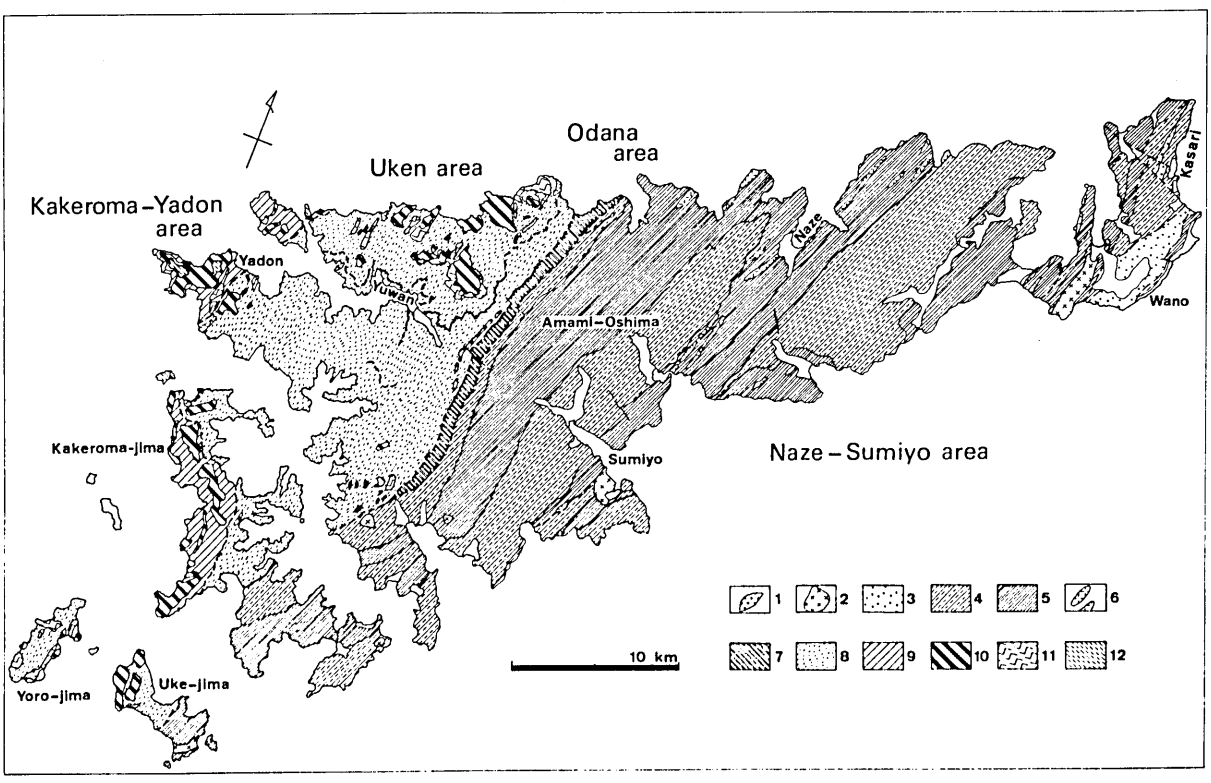


FIG. 10. Geologic map of the northern Amami islands (Compiled and modified from HATAE et al., 1959; SHIBATA and NOZAWA, 1966; SAKAI et al., 1977; KASHIMA and TAKAHASHI, 1977; OSOZAWA, 1984).
1: Tertiary intrusive rocks, 2: Paleogene granite, 3: Wano formation, 4: Ogachi formation, 5: Naze formation, 6: greenstone, 7: Odana formation, 8: Yuwandake formation, 9: Yuwan formation, 10-12: exotic blocks (10: chert, 11: greenstone, 12: mudstone and sandstone).

(route 1), and is composed of greenstone (massive lava) and chert interbedded with thin layers of siliceous mudstone (routes 6 and 7 in Fig. 13).

Middle member (about 800m in thickness): The lower 450 m is developed in Unit B, and is made up predominantly of dark gray mudstone associated with sandstone and siliceous mudstone. The sandstone, which occurs as rhomboidal, triangular, round or irregular-shaped masses ranging from 5mm to 60 m in length or diameter, is represented by dark gray, very fine- to medium-grained feldsparthic wacke. Boulder-sized to huge olistoliths of chert (about 2km in maximum length) are included, being accompanied commonly with greenstone. The succeeding upper part, 150 to 350 m thick, consists mainly of gray to greenish gray siliceous mudstone interstratified with dark gray to bluish gray mudstone, silicified tuff, tuffaceous sandstone, chert and greenstone. The dark gray mudstone, which is developed more frequently in Unit A than in Unit B, contains irregular chuncks and slabs of sandstone. The tuffaceous sandstone, ranging from 5cm to 1 m in thickness, is dark gray to greenish gray in color, very fine- to medium-grained and well-stratified with parallel lamination and graded bedding. A large number of olistoliths of chert, greenstone and limestone, varying from 2cm to 200m in length, are scattered in Unit A.

Upper member (more than 750m in thickness): In the eastern area of Unit B, the lower part (less than 220m) consists mainly of fine- to very coarse-grained sandstone interbedded with thin layers of mudstone (routes 4, 5, and 7 near the lower Kawauchi river) or

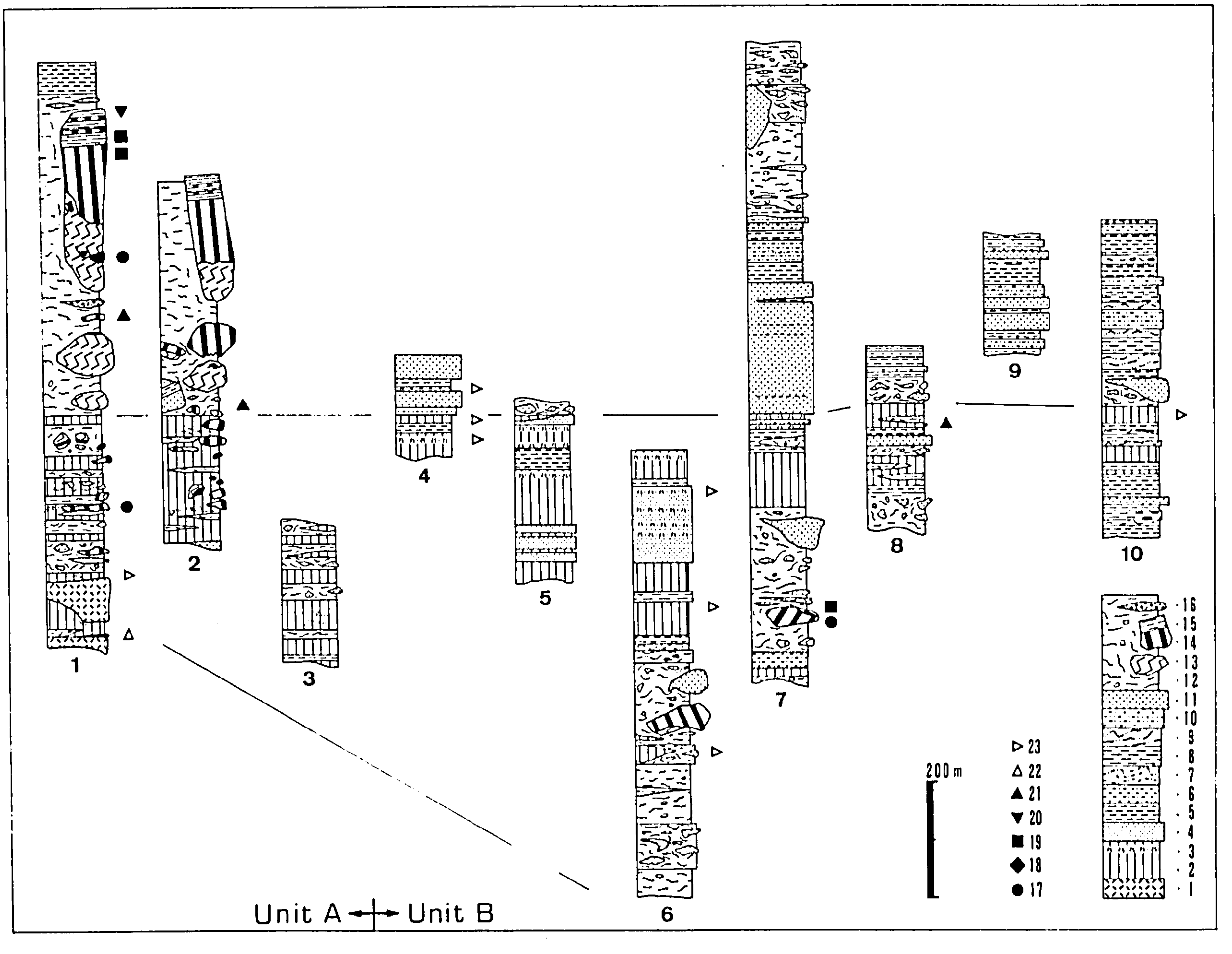


FIG. 11. Columnar sections of the Yuwandake formation.
1: greenstone, 2: siliceous mudstone, 3: silicified tuff or tuffaceous chert, 4: tuffaceous sandstone, 5: mudstone, 6: mudstone with laminae and thin beds of sandstone, 7: slump deposit in 6, 8: mudstone interbedded with sandstone, 9: slump deposit in 8, 10: alternating sandstone and mudstone, 11: sandstone, 12: mudstone enclosing lenses and blocks of sandstone, chert and greenstone, 13–16: olistoliths (13: greenstone, 14: chert, 15: mudstone and sandstone of Jurassic-early Cretaceous age, 16: conglomerate), 17–23: radiolarian fossils (17: middle Triassic, 18: early to middle Jurassic, 19: late Jurassic, 20: Berriasian, 21–22: Valanginian to Barremian, 23: early to middle Albian, black symbols indicate the radiolarians obtained from olistoliths).

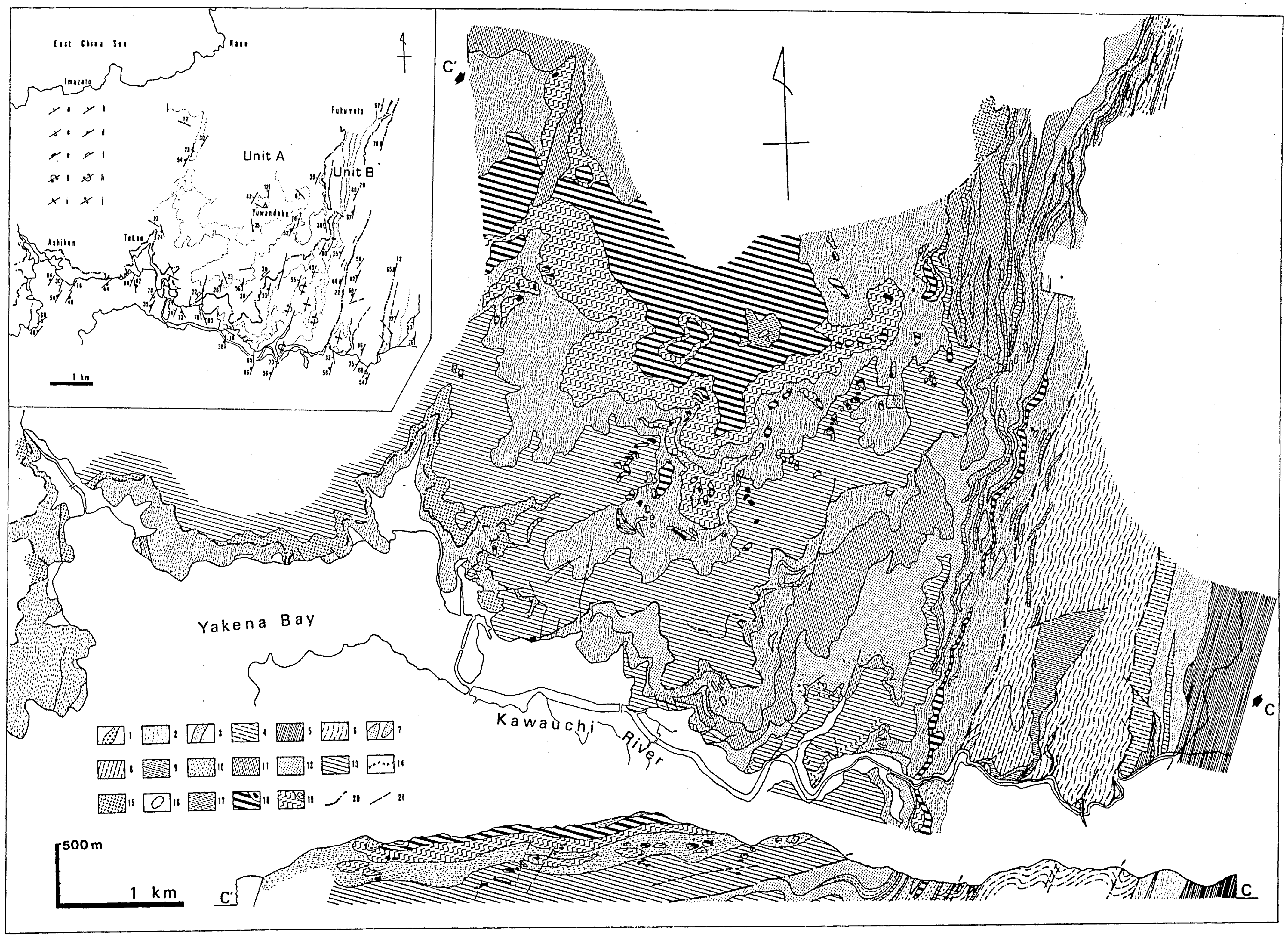


FIG. 12. Geologic map and profile of the western part of Amami-Oshima.
1: Neogene intrusive rocks, 2–4: Ogachi formation (2: slump deposit associated with alternating beds of sandstone and mudstone, 3: sandstone, 4: mudstone), 5: Naze formation, 6–9: Odana formation (6: slump deposit, 7: sandstone, 8: mudstone with intercalation of sandstone, 9: siliceous mudstone), 10-15: Yuwandake formation (10: slump deposit, 11: mudstone with intercalation of sandstone, 12: sandstone, 13: siliceous mudstone, 14: silicified tuff and tuffaceous chert, 15: greenstone), 16–19: olistoliths (16: early Cretaceous sandstone, 17: late Jurassic to early Cretaceous mudstone or siliceous mudstone, 18: Triassic to early Creta ceous chert, 19: Triassic (?) greenstone), 20: reverse or thrust fault, 21: fault with steep dip.
a: bedding, b: graded beddig, c: overturned bedding, d: cleavage, e: reverse fault, f: thrust fault, g: syncline of overfold, h: anticline of overfold, i: syncline, j: anticline.

TABLE 8. LIST OF THE TRIASSIC AND EARLY TO MIDDLE JURASSIC RADIOLARIANS FROM CHERT AND MUDSTONE THE OLISTOLITHS IN THE YUWANDAKE FORMATION.

KW448	KW445	KW444	KW443	KW441	KG372	TK 13	TK 11	UW243	Sample number
ch	ms	ms	ch	ch	ch	ch	ch	ch	Matrix / Radiolarian Species
					●	●			*Triassocampe deweveri* (Nakaseko & Nishimura)
				●	●		●	●	*T.* cf. *deweveri* (Nakaseko & Nishimura)
				●		●			*T.*(?) cf. sp. G Yao
					●	●	●		*T.*(?) cf. sp. H Yao
				●	●	●	●	●	*T.* sp.
						●		●	*T.*(?) sp.
								●	*Yeharaia*(?) sp.
						●			*Cryptostephanidium*(?) sp.
						●		●	*Archaeospongoprunum* sp.
					●				*A.*(?) sp.
						●			*Pseudostylosphaera* sp.
						●			*Stauracontium*(?) *trispinosum* cf. *ladinicum* Dumitrica, Kozur & Mostler
●									*Parahsuum* cf. *simplum* Yao
●	●								*P.* sp.
	●		●						*P.*(?) sp.
●			●						*Parvicingula* sp.
	●								*P.*(?) sp.
			●						*Pantanellium*(?) sp.
	●	●							*Stichocapsa* sp.
●	●	●							*S.*(?) sp.
		●							*Eucyrtidium*(?) sp.
	●								*Hsuum* sp.
	●	●							*H.*(?) sp.
	●	●							*Unuma*(?) sp.
	●								*Tricolocapsa* sp.
	●								*T.*(?) sp.

ch: chert, ms: mudstone.

of alternating beds of sandstone and mudstone (routes 8, 9 and 10 in the south of Fukumoto). These alternating beds are interstratified with some slump beds (Fig. 11 and 12). The succeeding middle part (150m) is made up predominantly of dark gray mudstone with laminae and thin layers of very fine-grained sandstone. The upper part (more than 300 m) is represented by slump beds consisting of dark gray mudstone, very fine- to coarse-grained sandstone and siliceous siltstone. The sandstone and siliceous siltstone are torn and contorted and take various irregular shapes, like rhomboid, triangle and sphere. In the western area of Unit B, almost all of the upper member is represented by slump deposits containing a few chert olistoliths. In Unit A, the upper member of about 520m thick is characterized by the remarkable developmemt of olistostrome which contains numerous olistoliths of chert, greenstone, siliceous mudstone and limestone, varying in length from several meters to 8km. The uppermost part of the upper member (about 80m) is found only in Unit A and is composed mostly of dark gray mudstone with thin intercalations of very fine- to fine-grained sandstone.

From the limestone of the Yuwandake formation, Permian fusulinids have been reported by ISHIBASHI (1969) and OSOZAWA et al. (1983). KOIKE (1979) obtained Triassic conodonts from the chert and siliceous mudstone. Furthermore, Triassic and early Cretaceous (Valanginian to early Aptian) radiolarians have also been reported by OSOZAWA (1984). Triassic to early Cretaceous radiolarians obtained by the author are as follows.

The chert blocks (UW243, KG372, TK11 and 13) in the middle and upper members yield Triassic radiolarians, including *Triassocampe deweveri* (NAKASEKO and NISHIMURA), *Yeharaia* (?) sp. and *Stauracontium* (?) *trispinosum* cf. *ladinicum* DUMITRICA, KOZUR and MOSTLER (Table 8 and Fig. 14). These radiolarians are similar to the constituent species of the Triassocampe deweveri assemblage (YAO, 1982) of middle Triassic age.

Early to middle Jurassic radiolarians are found in the chert (KW443 and 448) and mudstone (KW444 and 445) of the lower part of the middle member in

TABLE 9. LIST OF THE LATE JURASSIC TO EARLY CRETACEOUS RADIOLARIANS FROM THE YUWANDAKE FORMATION.

FmO22	UM 17	UM121	UM012	UM011	UM422	UM421	YW171	KG469	YW 74	YW 75	YW 73	YW 72	YW 71	YW523	YW521	Sample number
sm	ch	sm	ch	sm	ch	ch	ch	ch	sm	ms	ms	ch	sm	ch	ch	Matrix Radiolarian Species
									●	●		●	●			*Archaeodictyomitra apiara* (Rüst)
											●		●			*A.* cf. *apiara* (Rüst)
●	●			●		●	●	●	●							*A.* *brouweri* (Tan Sin Hok)
●	●		●	●	●	●	●	●	●			●	●			*A.* cf. *brouweri* (Tan Sin Hok)
										●	●	●	●			*A.* aff. *brouweri* (Tan Sin Hok)
●								●								*A.* *lacrimula* (Foreman)
●	●			●			●		●	●	●				●	*A.* aff. *praeveneta* (Pessagno)
●		●				●		●								*A.* cf. *puga* Schaaf
	●															*A.* *vulgaris* Pessagno
●					●			●								*A.* cf. *vulgaris* Pessagno
●	●		●	●		●	●		●		●		●		●	*A.* sp.
										●						*Cinguloturris* cf. *carpatica* Dumitrica
											●					*C.* sp.
									●	●				●		*C.*(?) sp.
																Diacanthocapsa sp.
													●			*Dibolachras*(?) sp.
												●				*Dictyomitra*(?) *minoensis* (Mizutani)
											●					*D.*(?) cf. *minoensis* (Mizutani)
											●					*D.*(?) aff. *minoensis* (Mizutani)
									●							*Eucyrtidium*(?) *ozaiensis* Aita & Okada
									●		●					*Eucyrtis*(?) sp.
									●		●		●			*Hsuum* sp.
									●		●					*H.*(?) sp.
									●		●		●		●	*Mirifusus mediodilatatus* (Rust)
											●					*Mita*(?) sp.
											●					*Obesacapsula* sp.
														●		*Parahsuum*(?) sp.
									●		●		●			*Parvicingula boesii* (Parona)
									●		●		●			*P.* cf. *boesii* (Parona)
												●				*P.* cf. *dhimenaensis* Baumgartner
									●							*P.* *mashitaensis* Mizutani
	●	●					●		●			●		●	●	*P.* sp.
						●		●					●	●	●	*P.*(?) sp.
												●				*Protunuma* sp.
					●						●					*Pseudodictyomitra carpatica* (Lozyniak)
	●					●			●		●		●			*P.* cf. *carpatica* (Lozyniak)
									●		●					*P.* *depressa* Baumgartner
									●		●		●			*P.* cf. *depressa* Baumgartner
						●										*P.* *leptconica* (Foreman)
								●								*P.* cf. *leptconica* (Foreman)
												●				*P.* cf. *primitiva* Matsuoka & Yao
									●			●		●		*P.*(?) sp. D Matsuoka & Yao
●	●		●	●				●	●	●	●		●			*P.*(?) sp.
													●			*Ristola altissima* (Rüst)
									●							*R.* *cretacea* Baumgartner
						●										*Sethocapsa uterculus* (Parona)
						●										*S.* cf. *uterculus* (Parona)
	●		●					●	●		●	●		●	●	*S.* sp.
														●		*Solenotrima*(?) *ichikawai* Matsuoka & Yao
											●			●		*Spongocapsula* sp.
				●												*S.* (?) sp.
●								●								*Stichocapsa decora* Rüst
●								●								*S.* cf. *decora* Rust
									●		●					*S.* aff. *decora* Rust
							●	●								*Stichomitra*(?) sp.
															●	*Stylocapsa*(?) *spiralis* Matsuoka
						●										*Thanarla* cf. *pulchra* (Squinabol)
						●		●								*T.* aff. *pulchra* (Squinabol)
											●			●	●	*Tricolocapsa* cf. sp. A Yao
												●		●		*T.* sp.
●	●			●		●		●	●	●						*Xitus spicularius* (Aliev)
●	●				●			●	●	●	●		●	●		*X.* sp.
								●								*Acaeniotyle* cf. *umbilicata* Rust
									●							*Alievium* cf. *helenae* Schaaf
				●												*A.* sp.
															●	*Archaeospongoprunum* sp.
				●		●										*Orbiculiforma* sp.
									●							*Paronaella*(?) sp.
				●										●		*Praeconocaryomma*(?) sp.
●						●		●	●		●					*Sphaerostylus lanceola* (Parona)

ms: mudstone, sm: siliceous mudstone, ch: chert.

Unit B. The radiolarians in the chert, including *Parahsuum* cf. *simplum* YAO, *Parvicingula* sp., etc., bear resemblance to the diagnostic species of the *Parahsuum simplum* assemblage (YAO, 1982) of early Jurassic age. The radiolarians in the mudstone, containing *Eucyrtidium* (?) sp., *Unuma* (?) sp., etc., are analogous to the constituent species of the *Hsuum* sp. B to *Unuma echinatus* assemblages, which are assigned to late early to middle Jurassic in age by YAO (1984).

From the chert (YW521, 523, 72) and mudstone (YW71, 73-75) of the upper member in Unit A, the following late Jurassic to early Cretaceous radiolarians are obtained.

(1). From YW521, such radiolarians as *Mirifusus mediodilatatus* (RÜST), *Stylocapsa* (?) cf. *spiralis* MATSUOKA, *Tricolocapsa* cf. sp. A YAO, etc. are found (Table 9). They are similar to the constituent species of the *Gongylothorax sakawaensis-Stichocapsa* sp. C to *Stylocapsa* (?) *spiralis* assemblages (YAO, 1984; MATSUOKA, 1984) of Oxfordian age. Moreover, the diagnostic species from YW523, comprising *Pseudodictyomitra* sp. D YAO, *Solenotryma* cf. *ichikawai* MATSUOKA and YAO, Tricolocapsa cf. sp. A YAO, etc. (Table 9), resemble those of the *Tricolocapsa* sp. O assemblage (YAO, 1984; MATSUOKA, 1984), which is referred to Kimmerigian in age according to YAO's zonation.

(2). The radiolarians from YW71, 72, 73, 75, containing *Archaeodictyomitra* aff. *brouweri* (TAN SIN HOK), *Cinguloturris* cf. *carpatica* DUMITRICA, *Pseudodictyomitra* cf. *primitiva* MATSUOKA and YAO etc. (Table 9), are analogous to the constituent species of the *Pseudodictyomitra primitiva*-P. sp. A assemblage of MATSUOKA and YAO (1985) and the zones C to D of BAUMGARTNER (1984). They show Tithonian age according to the zonation of MATSUOKA and YAO. The radiolarians from YW74, consisting of *Eucyrtidium* (?) *ozaiensis* AITA, *Pseudodictyomitra* cf. *carpatica* (LOZYNIAK), *Ristola cretacea* (BAUMGARTNER), etc. (Table 9), bear resemblance to those of the *Pseudodictyomitra* cf. *carpatica* assemblage of MATSUOKA and YAO (1985) and the zone D of BAUMGARTNER (1984). They show probably Berriassian age.

The chert (KG409) in the lower member and chert blocks (UM11-12, 17, FM022, UM421-422, YW171) in the middle and upper members yield early Cretaceous radiolarians, including *Archaeodictyomitra brouweri* (TAN SIN HOK), *A. lacrimula* (FOREMAN), *Pseudodictyomitra carpatica* (LOZYNIAK), *Sethocapsa uterculus* (PARONA), etc. (Table 9). These diagnostic radiolarians are similar to those of the *Sethocapsa uterculus* assemblage (YAO, 1984), the *Sethocapsa trachyostraca* to *Eucyrtis tenuis* zones (FOREMAN, 1975), the *Obesacapsula rotunda* to *Parvicingula-Thanarla conica* zones (PESSAGNO, 1977) and the *Alievium helenae* to *Crolanium pythiae* zones (SCHAAF, 1984). They are possibly of Valanginian to Barremian age.

The late early Cretaceous radiolarians are found in the siliceous mudstone, silicified tuff or tuffaceous chert and tuffaceous sandstone of the middle member and the mudstone of the upper member. They are *Archaeodictyomitra praeveneta* PESSAGNO, *Holo-*

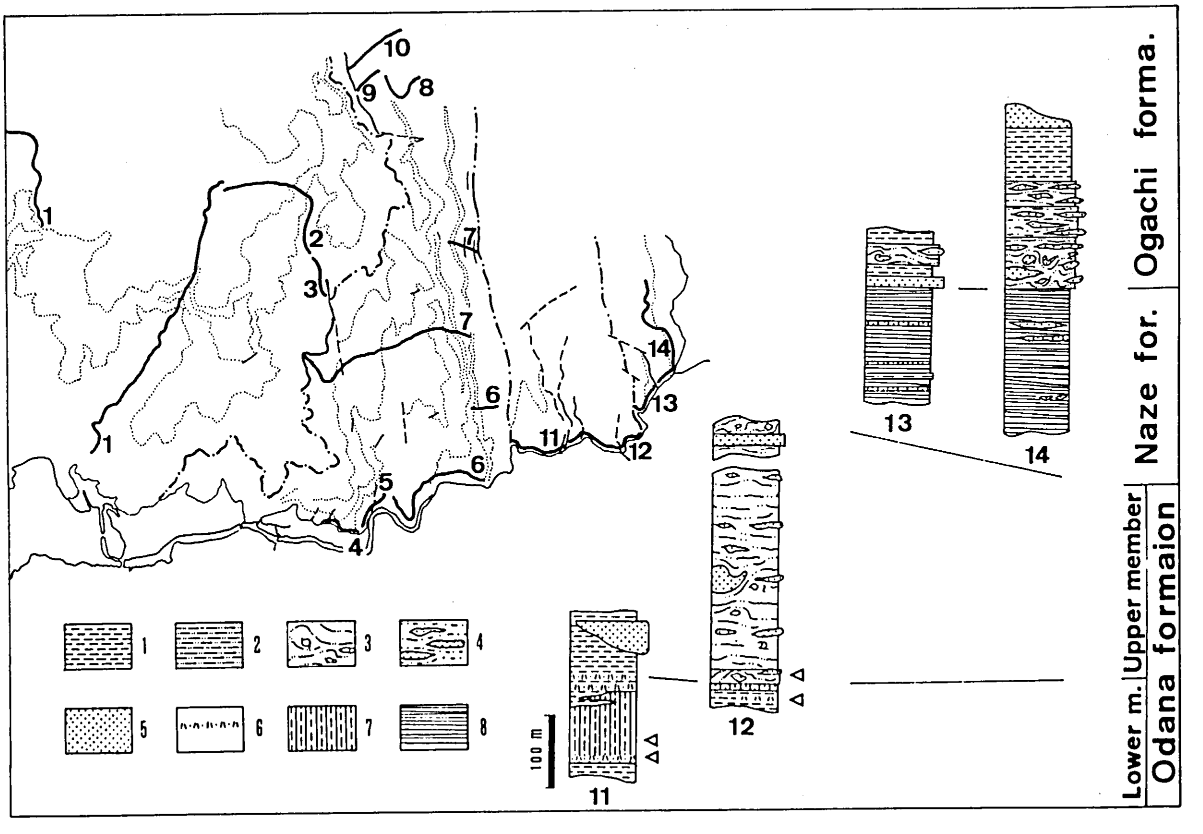


FIG. 13. Columnar sections of the Odana, Naze and Ogachi formations.
1: mudstone, 2: thin sandstone bed, 3: slump deposit of mudstone associated with sandstone, 4: alternating sandstone and mudstone, 5: sandstone, 6: silicified tuff or tuffaceous chert, 8: slate (phyllitic), triangle: radiolarian fossils of late Albian to Cenomanian age.

TABLE 10. LIST OF THE LATE EARLY TO LATE CRETACEOUS RADIOLARIANS FROM THE YUWANDAKE AND ODANA FORMATIONS.

KW161	KW160	KW382	KW381	KW037	IR 24	UW031	FM 08	KG191	KG183	KG181	KG112	KG08a	AG57b	Sample number / Radiolarian Species
tc	ms	sm	ch	ch	sm	sm	sm	ms	ms	sm	sm	sm	sm	Matrix
●					●						●			*Amphipyndax stocki* (Campbell & Clark)
●						●					●			*A.* cf. *stocki* (Campbell & Clark)
●					●	●						●		*A.* sp.
					●	●		●		●	●	●	●	*Archaeodictyomitra*(?) aff. *brouweri* (Tan Sin Hok)
					●	●		●	●	●	●			*A.* *praeveneta* (Pessagno)
					●	●		●	●	●	●	●	●	*A.* cf. *praeveneta* (Pessagno)
●					●		●		●			●	●	*A.* aff. *praeveneta* (Pessagno)
●														*A.* cf. *simplex* Pessagno
●	●	●												*A.* cf. *sliteri* Pessagno
●	●	●	●											*A.* *veneta* (Squinabol)
	●				●	●					●	●		*A.* cf. *vulgaris* Pessagno
					●	●		●		●				*A.* aff. *vulgaris* Pessagno
●		●	●		●	●	●	●	●	●		●	●	*A.* sp.
						●		●		●				*Dictyomitra* sp.
						●		●		●	●			*D.*(?) sp.
●	●	●	●		●	●	●	●	●	●		●	●	*Holocryptocanium barbui* Dumitrica
●	●	●	●											*H.* *geysersensis* Pessagno
						●		●	●			●	●	*H.* sp.
●	●													*Novixitus weyli* Schmidt-Effing
●				●										*N.* sp.
					●				●		●	●	●	*Pseudodictyomitra lodogaensis* Pessagno
●					●	●		●		●	●			*P.* cf. *lodogaensis* Pessagno
			●											*P.* cf. *nakasekoi* Taketani
●														*P.* *pentacolaensis* Pessagno
●														*P.* *pseudomacrocephala* (Squinabol)
●							●		●	●	●		●	*P.* sp.
					●									*Sethocapsa simplex* Taketani
			●		●									*S.* sp.
●														*Stichomitra* aff. *communis* Squinabol
●		●	●		●			●	●		●	●		*S.* sp.
●		●												*Thanarla* aff. *pulchra* (Squinabol)
●														*T.* *elegantissima* (Cita)
●														*Xitus* sp.
								●	●	●				*Acaeoniotyle* cf. *umbilicata* (Rust)
●														*Alievium*(?) sp.
									●					*Archaeospongoprunum* sp.
●														*A.*(?) sp.
										●				*Crucella*(?) aff. *iriwini* Pessagno
										●		●		*Orbiculiforma* sp.
●	●		●	●										*Pseudoaulophacus* sp.
	●													*Pyramispongia glascockensis* Pessagno

ms: mudstone, sm: siliceous mudstone, tc: tuffaceous chert, ch: chert.

cryptocanium barbui DUMITRICA, *Pseudodictyomitra lodogaensis* PESSAGNO, *Acaeniotyle* cf. *umbilicata* RÜST, etc. (Table 10). These radiolarians are analogous to the constituent species of the *Acaeniotyle umbilicata* zone (FOREMAN, 1975), the *Holocryptocanium barbui-Thanarla conica* zone (TAKETANI, 1982) and the *Acaeniotyle umbilicata* to *Mita gracilis* zones (SCHAAF, 1984). According to SCHAAF's zonation, it is suggested that this radiolarian assemblage is probably assignable to early to middle Albian in age.

3. *Odana area*

This area is situated in a narrow median zone of Amami-Oshima. The pre-Neogene strata here comprise the eastern marginal part of the Yuwan formation of OSOZAWA (1984) and the western part of the Odana formation. OSOZAWA et al. (1979,1983) and OSOZAWA (1984) have defined the mudstone and associated sandstone sequence distributed in the eastern part of this area as typical Odana formation. This sequence is conformably underlain by the siliceous mudstone sequence. The author redefines both sequences combined as the Odana formation, which has some difference in geologic age and lithofacies from the Ogachi formation to be described in the next paragraph (Figs. 12 and 13).

Odana formation

The Odana formation is limited in distribution and takes a general strike of NNE-SSW direction with a dip toward WNW. The good exposures are observed along the upper Kawauchi river, where the thickness is estimated at about 600m. This formation is lithologically subdivisible into the lower and upper members.

The lower member, more than 140m thick, is made up mainly of greenish gray siliceous mudstone interbedded with dark gray mudstone and thin silicified tuff or tuffaceous chert.

The upper member, about 460m thick, is composed predominantly of dark gray mudstone. Irregular-shaped chunks and slabs of very fine- to coarse-grained sandstone, varying in diameter from 2cm to 150m, are included.

The siliceous mudstone (KW0382) and silicified tuff or tuffaceous chert (KW037, 0381 and 161) of the lower member and the mudstone (KW160) of the upper member yield radiolarians (Fig. 14 and Table 10), comprising *Archaeodictyomitra veneta* (SQUINABOL), *Holocryptocanium geysersensis* PESSAGNO, *Pseudodictyomitra pseudomacrocephala* (SQUINABOL), etc. The specific composition bears resemblance to that of the *Dictyomitra somphedia* zone (FOREMAN,1975), the *Diacanthocapsa euganea-Thanarla elegantissima*

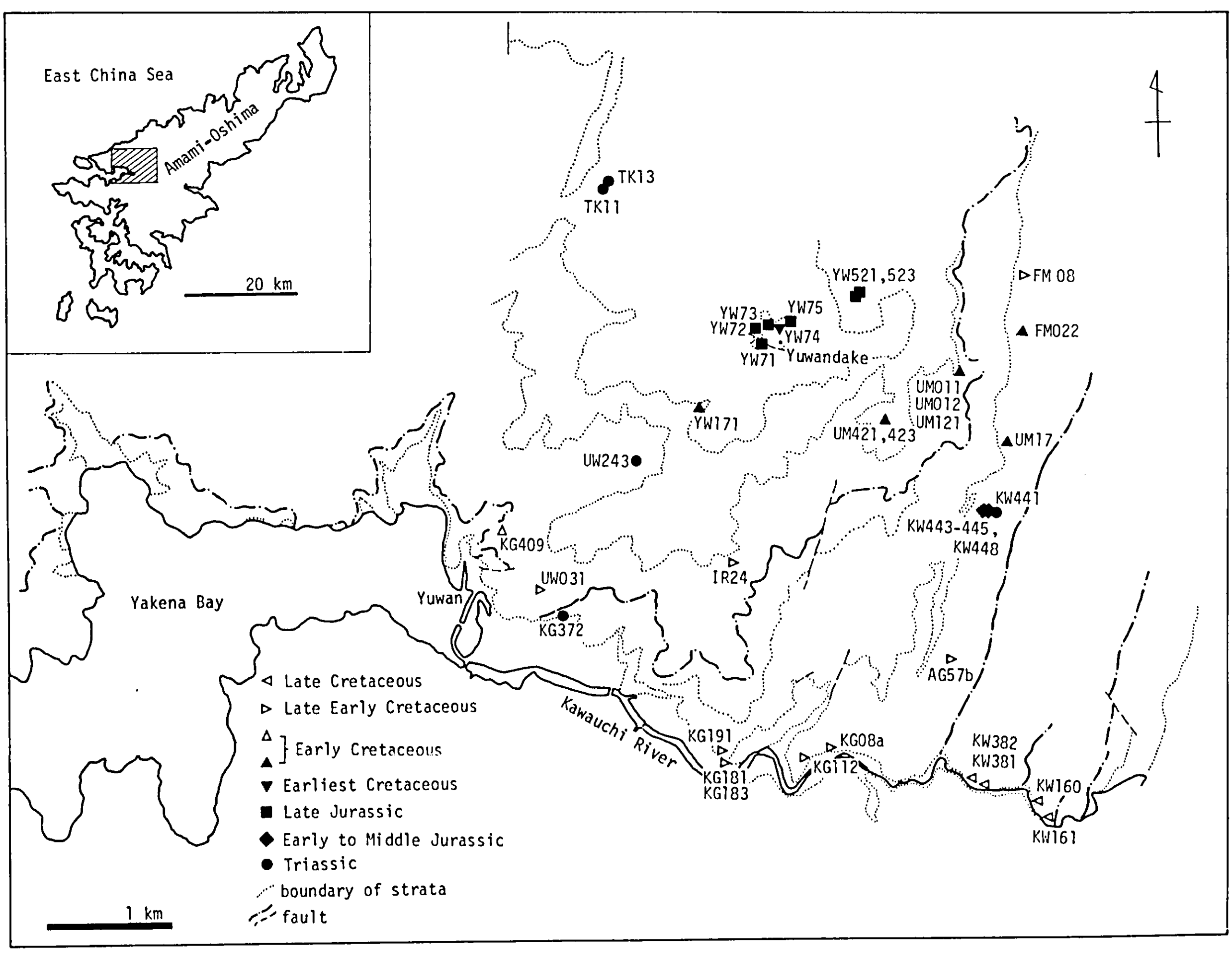


FIG. 14. Localities of radiolarian fossils around Yuwandake, Amami-Oshima.
Black symbols indicate the radiolarians obtained from olistoliths.

zone (TAKETANI, 1982) and the *Pseudodictyomitra pseudomacrocephala* to *Rhopalosyringium majuroensis* zones (SCHAAF, 1984). Therefore, it is suggested that the radiolarians from the Odana formation indicate late Albian to Cenomanian age.

4. *Naze-Sumiyo area*

This area occupies the eastern part of Amami-Oshima, Kakeroma-jima and Uke-jima. The pre-Neogene strata are divided into three formations, namely the Naze, Ogachi and Wano formations in ascending order. According to SAKAI et al. (1977), a conformable succession of the Naze and Ogachi formations is separated into several tectonic units by reverse faults and appears repeatedly (Fig. 10).

1). Naze formation

Agreeably to the definition of SAKAI et al. (1977), the author also regards the late Cretaceous strata, consisting mainly of phyllitic slate associated with greenstone, as the Naze formation. This formation is distributed in the eastern part of Amami-Oshima and Kakeroma-jima. It takes a general strike of NNE-SSW direction and dips to WNW with 70 to 80 degrees. Relatively good exposures are observed along the upper Kawauchi river, where the measured thickness is about 240m (Figs. 10, 11 and 13).

The Naze formation is composed predominantly of dark gray slate or phyllite with some lenticular intercalations of siliceous slate, very fine- to medium-grained sandstone and greenstone. Though the greenstone is not observed near the upper Kawauchi river, near Naze the greenish gray massive lava passes laterally into pillow lava and reddish purple to greenish gray tuff is intercalated.

From the slate near Naze such Turonian radiolarians as *Alievium* cf. *superbum* (SQUINABOL), *Hemicryptocapsa polyhedra* DUMITRICA, etc. have been reported by OSOZAWA (1984).

2). Ogachi formation

According to SAKAI et al. (1977), the Ogachi formation is defined as the late Cretaceous strata consisting of mudstone and sandstone and conformably underlain by the Naze formation. The author partly accept the view of OSOZAWA et al. (1979, 1983) and OSOZAWA (1984), and combines the Tatsugo formation of SAKAI et al.(1977) with the Ogachi formation. The Ogachi formation is distributed in the eastern part of Amami-Oshima and Kakeroma-jima. Relatively good exposures are obseved along the forestry road near the upper Kawauchi river, where the estimated thickness is more than 250m.

This formation consists mainly of slump deposits, together with alternating beds of mudstone and sandstone in which each sandstone layer ranges in thickness from 2cm to 1 m. The sandstone is fine- to coarse-grained, and in the slump beds takes irregular and various shapes.

MATSUMOTO et al. (1966) described a Cretaceous ammonite, *Collignoniceras* (*Selwynoceras*) sp. from the Ogachi formation near Ogachi, and suggested that the formation is referred possibly to late Cenomanian or late Turonian in age.

3). Wano formation

The Wano formation is narrowly distributed in the central part of the Kasari peninsula and is in fault contact with the Naze and Ogachi formations (SAKAI et al., 1977). It is lithologically subdivided into eight members by ISHIDA (1969); the sandstone (W1), conglomerate (W2), shale (W3), sandstone (W4), alternating sandstone and mudstone (W5), sandstone (W6), alternating sandstone and mudstone (W7) and mudstone (W8) members in ascending order. The total thickness is about 880 m. Parallel and cross laminations and flute-, bounce-, groove- and prod-casts are developed.

Molluscan fossils such as *Acila* (*Truncacila*) sp., *Lucina* sp., *Nuculana* sp., etc. (SAKAI et al., 1977) and an Eocene larger foraminifer, *Nummulites* sp. have been reported by ISHIDA (1969).

III. GEOLOGIC STRUCUURE

A. CLASSIFICATION OF MESOSCOPIC STRUCTURES

The post-depositional mesoscopic structures developed in the pre-Neogene strata of the northwestern Okinawa islands and the northern Amami islands are classified into six groups according to their characteristics in shape and relationships with cleavages (Table 11). They are described below in order of their formation (Figs. 15 and 22, Plates 4 and 5).

1. *Mesoscopic structures by subaqueous slumping or sliding*

These structures are present in almost all sequences of all areas and are especially are common in the mudstone and sandstone. They are represented by rheid folds, planar discontinuities and scattering irregular-shaped chunks and slabs, which show no preferred orientation (Figs. 15-2a, 15-3a, 19 and 22-1). No metamorphic mineral is found, and the tectonic structures to be described below are superimposed disharmoniously on these slump or slide-structures. Therefore, it is certain that these structures have been formed under an unconsolidated condition by subaqueous sliding or slumping.

2. *Tectonic structure* I

The tectonic structure I is represented by conjugate fissures (filled with black calcite) which are displaced along cleavages (Fig. 15). This structure is found only in the Nakijin formation. One fissure of a conjugate set is parallel or subparallel to the bedding plane, and the other is at an acute angle with it. The principal stress axes σ_1 and σ_2 determined by the orientation of the conjugate fissures are subparallel to the bedding plane (Fig. 17-5). It is possible that the conjugate fissures constitute a part of the flexural slip fold produced by buckling under lateral compression.

3. *Tectonic structure* II

The tectonic structure II is characterized by the development of reverse or thrust faults and asymmetric folds accompanied with cleavages (axial plane cleavages). This structure is ubiquitous in the pre-Neogene strata of all areas, being parallel or subparallel to the extension of them (Figs. 15 and 22, Plates 4 and 5). The asymmetric folds in competent layers of sandstone, tuffaceous sandstone, chert and limestone are included generally in Class 1C of the fold class of RAMSAY (1967). Their inter-limb angles

TABLE 11. DISTRIBUTION OF MESOSCOPIC STRUCTURES IN THE PRE-NEOGENE STRATA OF THE NORTHWESTERN OKINAWA ISLANDS AND THE NOTHERN AMAMI ISLANDS, CENTRAL RYUKYU.

		Area	Northwestern Okinawa Islnads									Northern Amami Islands					
			Nakijin-Gusukuyama area		Motobu area		Wakugawa area			Kunigami area		Kakeroma-Yadon area	Uken area	Odana area	Naze-Sumiyo area		
		Mesoscopic structures	Gusukuyama formation	Nakijin formation	Yonamine formation	Motobu formation	Wakugawa formation upper p.		lower p.	Nago formation	Kayo formation	Yuwan formation	Yuwandake formation	Odana formation	Ogachi formation	Naze formation	Wano formation
Tectonic structures	V	Normal fault	-	+	+	+	+	+	+	+	+	+	+	-	-	+	
		Lag fault	?	?	-	-											
		Reverse fault (cutting cleavages of II)	?	-	?	?	?	-	?		-						
	IV	Conjugate faults or fissures				-							-				
		Drag flexures along fault surface (on strike slip fault)		-	-		?						-	-			
	III	Fold of cleavage			-	?	?	-	-	+			+	?		-	
		Thrust fault cutting cleavage	?	-	-	-	?	+	-	?		?	+	-	-		
	II	Fold classification		1C	1C		1C	1C-3			1C		1C		1C ?		
		Symmetric or Asymmetric folds		A.	A.		A.	A.	A.?		A.		A.	A.?	A.		A.
		Attitude of fold axial pane	overfold?	inclined-overfold?	overfold	overfold-recumbent?	overfold	overfold-recumbent		overfold recumbent?	overfold	inclined?	inclined-overfold	inclined-overfold	inclined-overfold?	inclined-overfold?	overfold?
		Inter-limb angle of fold	?	60-100			90	70	20	?	25-70	?	50-70	50-80	50-60	?	?
		Cleavage cross to bedding	+	-	+	+	-	+	x	x	-	+	+	+	-	x	
		Cleavage refraction in sand-stone (or limestone) and mud-stone	+	+	+	?	+	+	+	-	+	+	+	+	-	?	
		Transposition of competent layer		-	?	-		-	+	?	-	?	?	?		?	
		Fault parallel to cleavage		?	-	?		?	?	?	-	?	+	+	-	-	
	I	Conjugate fissures filled with black calcite (? by flexural slip fold)		-													
"Slump structures"		Rheid fold		-	-	-		?		?	?	?	-	-		?	
		Planar discontinuity															
		reverse displacement		-									-	-			
		normal displacement			-								-	?			
		Breccia, chunk and slab by slumping or sliding	-	-	x			x	-	+		+	+	+	+	+	

1C: Class 1C fold in the fold classification of Ramsay (1967), A: Asymmetric fold, x: abundant, +: common, -: few, ?: possible.

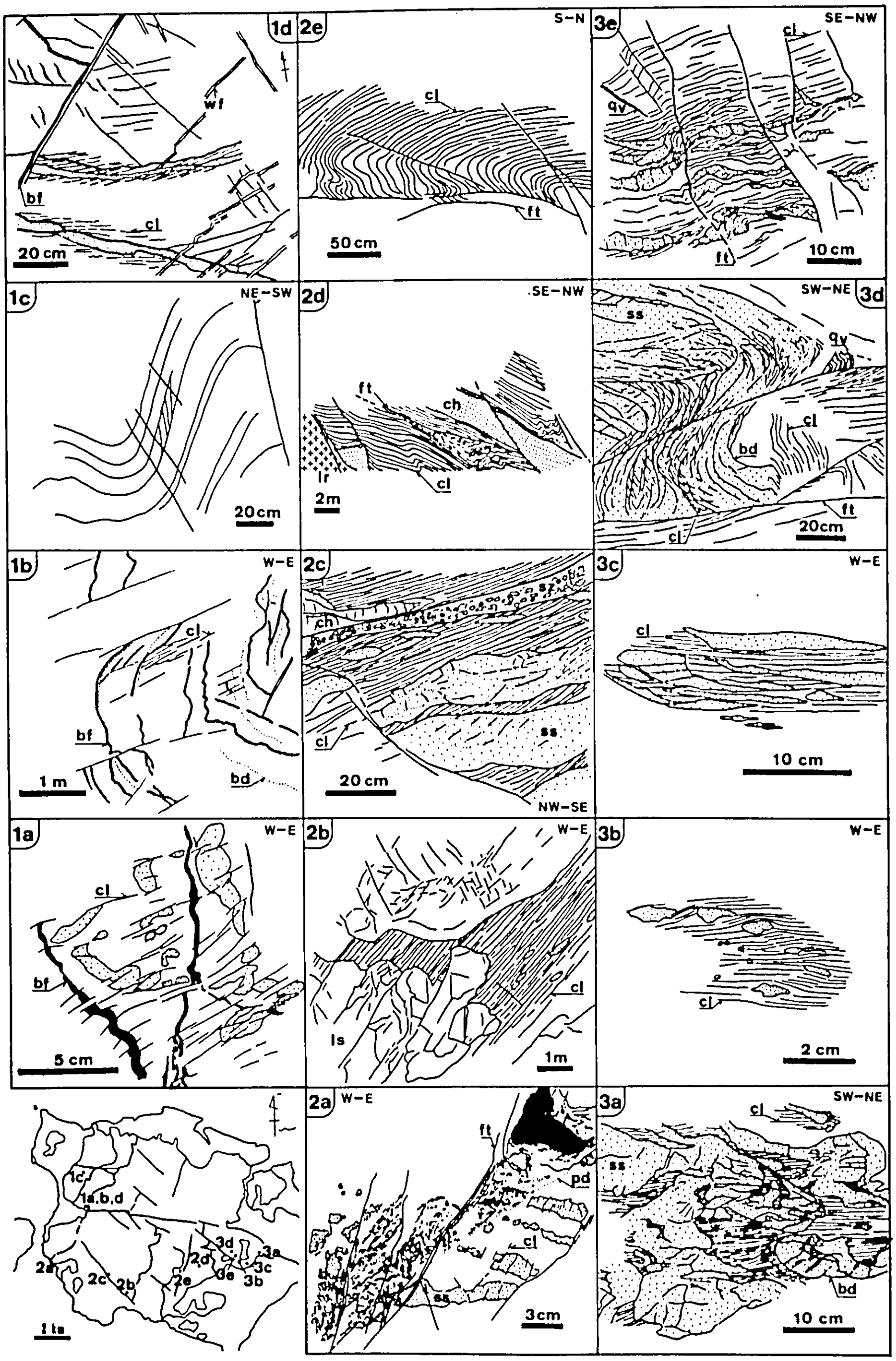


FIG. 15. Mesoscopic structures in the Nakijin, Motobu, Yonamine and Wakugawa formations
1: Mesoscopic structures in the Nakijin formation, a and b: cloven conjugate fissures filled with black calcite in limestone beds, c: asymmetric fold in limestone beds, d: joints and fissures, cutting the cloven conjugate fissures, filled with black (bf) and white (wf) calcite.
2: Mesoscopic structures in the Motobu (b) and Yonamine (a, c, d and e) formations, a: planar discontinuity (pd) produced by subaqueous slumping in mudstone including sandstone chunks, b: cloven limestone (ls) and mudstone, c: cloven mudstone interbedded with sandstone (ss) and chert (ch), and thrust fault cutting the cleavages, d: displaced and flexed cleavages along the faults with gentle dip, and fault cutting the Miocene intrusive rock (ir) as well as the bedding and cleavages, e: displaced and flexed cleavages.
3: Mesoscopic structures in the Wakugawa formation, a: cloven sandstone chunks and slabs in disharmony with the cleavages, b: transposed and isolated sandstone layers arranged in horseshoe shape, c: fold associated with axial plane cleavages, d: flexed cleavages, quarts vein (qv) and beddings along the thrust faults, e: displaced and bended cleavages along the faults with steep dip.
bd: bedding, cl: cleavage, ft: fault, sz: shear zone.

vary from 20 to 100 degrees, as shown in Table 11.

The flattening and elongation of pebbles and chunks of sandstone, limestone and chert, as well as the transposition of thin layers of sandstone in mudstone are observed in densely cloven part. The long axes of flattened or elongated pebbles and chunks are parallel to the cleavages in all sections perpendicular to the cleavage planes. The longest axes of them are perpendicular to the fold axis in each area (Plate 5-8). The refraction of cleavages occurs at the boundaries between the competent and incompetent layers (Figs. 15, 17-c and 22). Metamorphic minerals such as actinolite, chlorite, epidote, etc. appear in parallel to cleavages. The frequency and grain size of them are in proportion to the grade of deformation. From the above-stated facts, it is inferred that the tectonic structure II has been produced by flattening accompanied with simple shear under lateral compression perpendicular to the extension of the pre-Neogene strata after the consolidation of sediments.

4. *Tectonic structure* III

The tectonic structure III is characterized by thrust faults associated with flexures of cleavages and beddings (Figs. 15-2c, d, e, 15-3d and 22-3). It appears in the Nakijin, Yonamine, Wakugawa and Nago formations of the northwestern Okinawa islands and in the Yuwandake, Odana, Naze and Ogachi formations of the northern Amami islands (Table 11), being developed especially near the major thrust faults. Juding from the preferred orientation of axial planes of folds, as well as of thrust fault planes and conjugate fault planes (Fig. 22-3a), the tectonic structure III has been probably produced by lateral contraction perpendicular to the fold axis and the strike of thrust faults.

5. *Tectonic structure* IV

The tectonic structure IV is represented by strike slip faults accompanied with neutral folds, conjugate faults, conjugate fissures (filled with white calcite) and striations (Table 11 and Fig. 16). Neutral folds along the NNE-SSW strike faults with steep dip are observed in limestone of the Nakijin formation and in mudstone of the Odana formation. Conjugate faults appear in thinly alternating beds of sandstone and mudstone of the Yuwandake formation, and show the principal stress axis σ_1 of NNE-SSW direction. Conjugate fissures occur in limestone of the Motobu formation, and take the principal stress axis σ_1 of WNW-ESE direction (Plate 4-2). Striations are present on the planes of the WNW-ESE strike faults in sandstone of the Wakugawa and Yuwandake formations, being parallel or subparallel to their strike. The tectonic structure IV seems to have been produced by horizontal contraction at more than two times. Two fault systems of WNW-ESE and NNE-SSW directions are recognized. The tectonic structure IV intersects in some cases the tectonic structure II, but the relation ship with the tectonic structures I, III and V is uncertain. Therefore, it is difficult to determine the exact stage in a series of deformations.

6. *Tectonic structure* V

The tectonic structure V is characterized by normal, reverse and lag faults which cut the tectonic structures I, II and III and the Neogene intrusive rocks

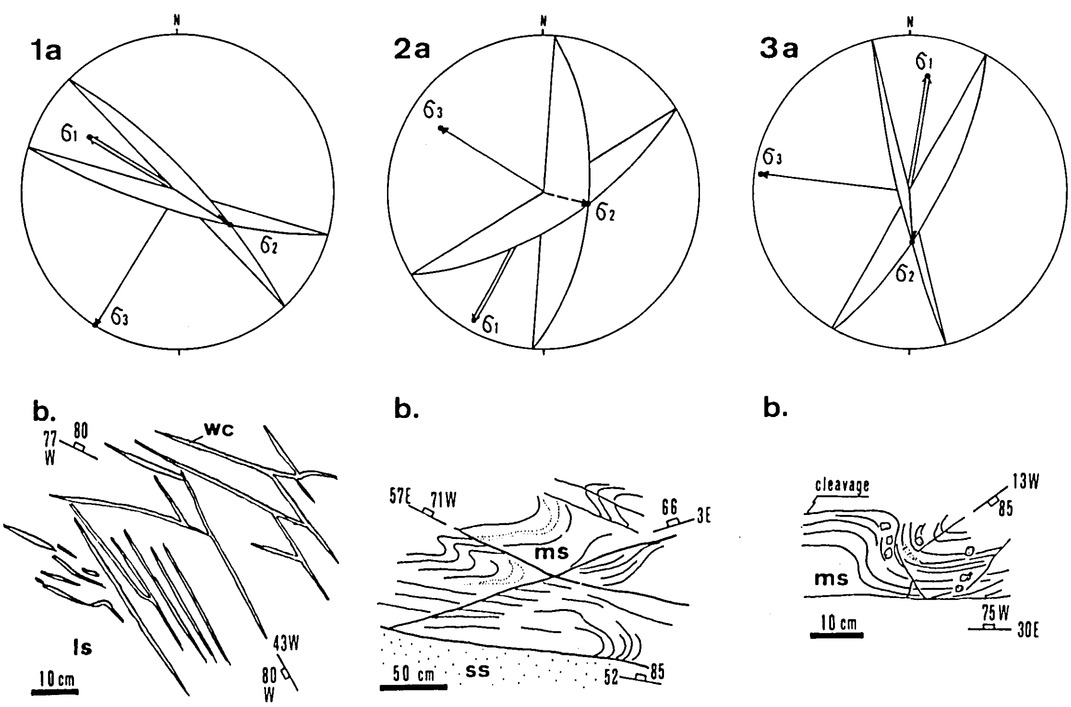


FIG. 16. Conjugate fissures and conjugate fault sets in the Motobu (1), Yuwandake (2) and Ohdana (3) formations.
a: diagram for principle stress axes, upper hemisphere, b: sketch (wc: white calcite vein, ms: mudstone, ss: sandstone, ls: limestone).

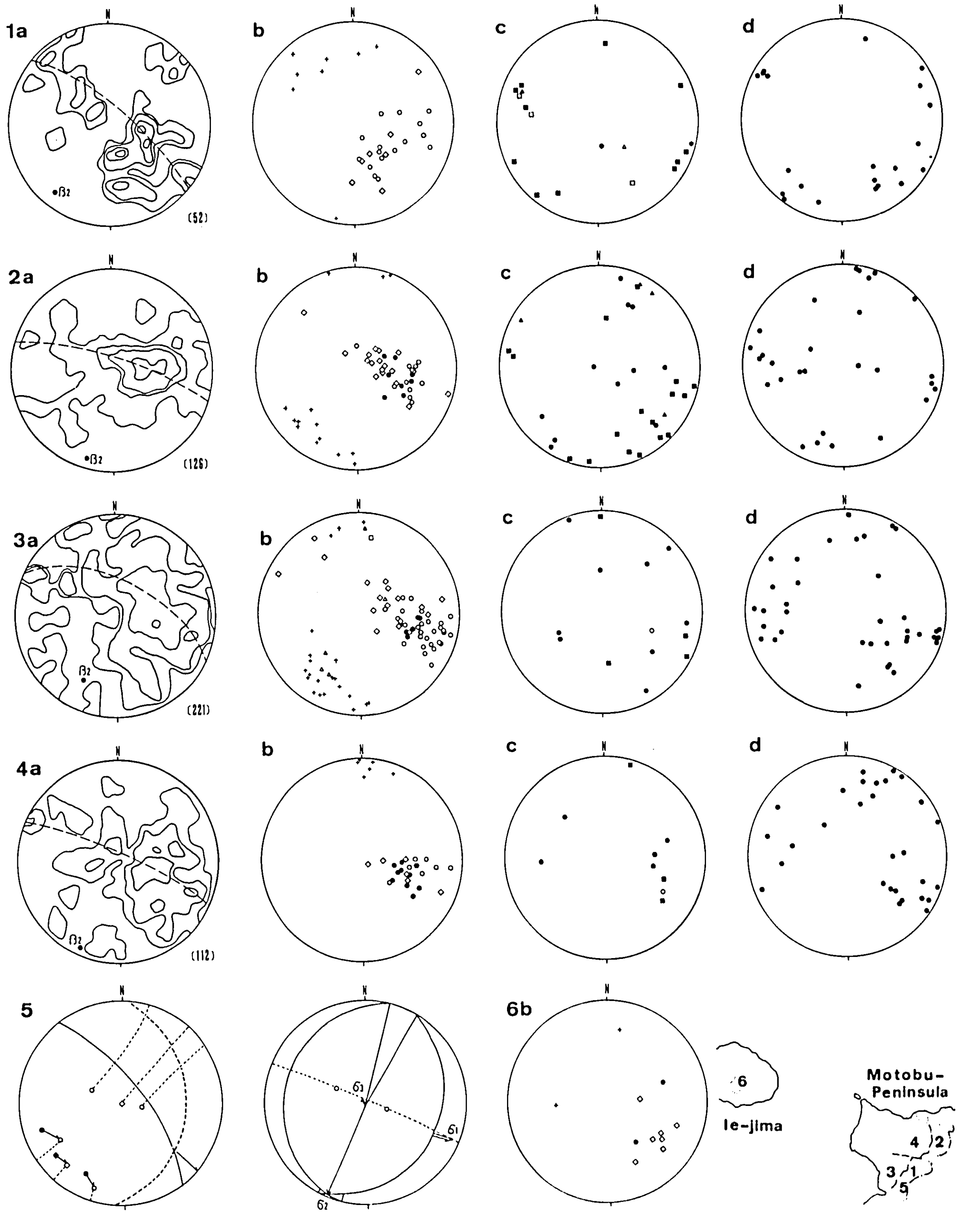


FIG. 17. Structural data for the Nakijin (1-5) and Gusukuyama (6) formations.
Points in diagrams but diagram 5 were projected from the lower hemisphere. Contours in diagram 1a: 10-7-4-2%, contours in diagrams 2a and 4a: 10-5-3-1%, contours in diagram 3a: 5-3-2-1%. Number in brackets: observation numbers.
a: poles to bedding planes, b: poles to bedding planes (square) and cleavage planes (white circle: cleavages in limestone, black circle: cleavages in mudstone), cleavage-bedding intersections (cross) fold hinge lines (triangle), c: poles to fault planes (square, triangle and circle show normal, reverse and indeterminable senses of shear respectively) parallel to cleavage (open symbol) and oblique to cleavages (black symbol), d: poles to joint planes. 5: conjugate fissures in the Nakijin formation, left: correction for the effect of folding or tilting on the measured values in terms of the measured plunge value of cleavage (broken line)-bedding (solid line) intersection (circle: pole to fissure plane, square: pole to bedding plane), right: principle stress axes for conjugate fissures, upper hemisphere.

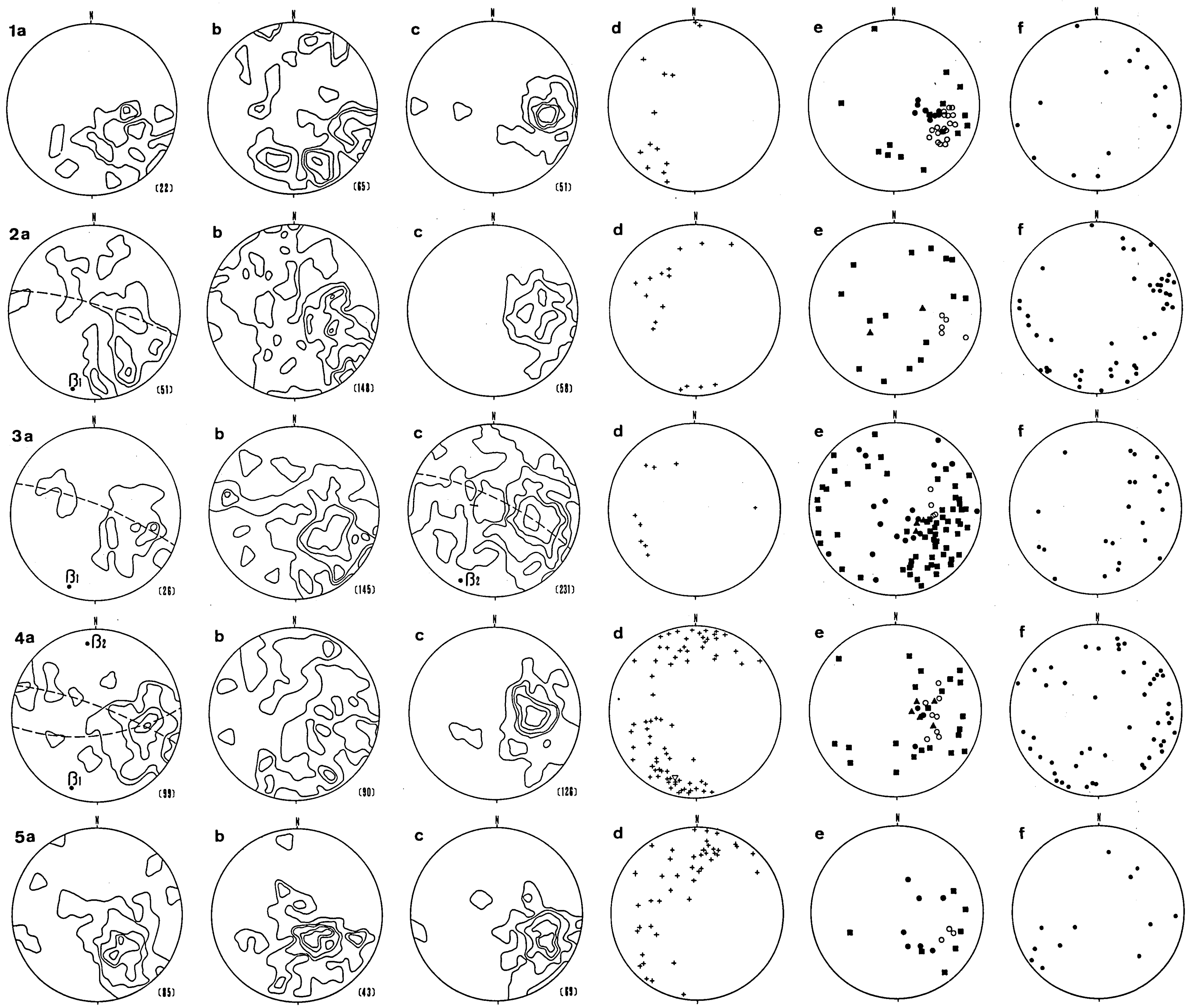


FIG. 18. Structural data for the pre-Neogene strata in the western Motobu area.
Lower hemisphere, equal-area plot. Contours in diagrams 1a and 3a: 15–10–5%, contours in diagrams 1c, 2a, c, 5b and c : 20–15–10–5–3%, contours in diagrams 1b, 4a, b,c and 5a: 15–10–5–3–1%, contours in diagrams 2b, 3b and c: 5–3–2–1%. Number in brackets: observation numbers.
a: poles to bedding planes of sandstone, b: poles to bedding planes within chert and limestone olistoliths, c: poles to cleavage planes, d: cleavage-bedding intersections (cross) and fold hinge line (triangle), e: poles to fault planes (square, triangle and circle show faults with normal, reverse and indeterminable senses of shear respectively) parallel to cleavages (open symbol) and oblique to cleavages (black symbol), f: poles to joints.
See the index map in Fig. 19.

(Figs. 15-1d, 15-2d, 15-3e and 22-4 , Plate 4-1, Table 11). It is observed in all areas, and comprises strike faults of NNE-SSW, NE-SW or ENE-WSW and WNW-ESE directions. Among these faults, normal faults are dominant and reverse and lag faults are rare. These faults are frequently associated with joints, fissures and drag flexures.The tectonic structure V have been formed by horizontal extention after the consolidation of sediments.

B. Northwestern Okinawa islands

1. *Iheya area*

According to the geological map and profiles by ISHIBASHI(1968), the Iheya, Izena, Maedake, Dana and Moromi formations are separated from one another by faults dipping generally toward NW. OSOZAWA (1984) regarded the Permian and Triassic chert, limestone and basalt as exotic masses in the Iheya, Maedake and Izena formations. He concluded that these formations themselves represent a slide mass lying on the Yanaza formation (Table 1) and the Nago group. On the other hand, UJIIÉ and HASHIMOTO (1983) suggested that these formations form an imbricate structure in which the Permian and Mesozoic rocks appear alternately. The author has no enough data to conclude which of the ideas is better. The structure of the pre-Neogene strata in the Iheya area might have been produced by the superimposition of subaqueous sliding and tectonic folding or faulting.

2. *Nakijin-Gusukuyama area*

The Nakijin and Gusukuyama formations are distributed separately and somewhat differ in process of deformation from each other (Table 11).

1). Nakijin formation

Only a few examples of the mesoscopic structures produced by subaqueous slumping are observed in the slump beds inserted between the undisturbed limestone beds. However, some of the poles to bedding planes are scattered and are apart from the π-circle in each of the π-diagrams (Fig. 17). A slump fold and a small-scale slump bedding occur in the outcrops about 1km east of Jahana and 200m south of the ruin of Hokuzan castle, respectively.

Conjugate fissures filled with black calcite seen in limestone beds show the principal stress axis σ_1 of WNW direction (Fig. 17-5). The macroscopic structure inferred from the conjugate fissures has never been made clear because of the insufficiency of available data.

Asymmetric folds, less than 10m in wave-length, associated with axial plane cleavages dipping toward WNW occur in limestone beds interbedded with thin layers of siltstone (Fig. 15-1b and d). The folds are generally inclined, and are overturned especially near the major reverse or thrust fault running from the southern end of the Motobu highschool to Nagataki. The hinge lines of folds, the axes β_2 inferred from the pattern of the poles to bedding planes and the cleavage-bedding intersections commonly plunge gently toward NNE and SSW (Fig. 17).

One example of thrust fault as the tectonic strucure III is observed at the northern side of Ufudo. The sheared limestones exposed along the fault dipping toward WNW with a low angle is too recrystallized to keep the original texture (Fig. 17).

NNE-SSW, NE-SW and WNW-ESE strike faults as the tectonic structure V are associated with joints and fissures. The fissures are distinguished into two types in color of the filled calcite. The fissures filled with black calcite are cut at an acute angle by those filled with white calcite (Figs. 15-1 and 17).

The Nakijin formation is probably separated from the Yonamine formation by a reverse fault parallel to the cleavages, and thrusts on the Nago formation. It seems to form an asymmetrically folded structure separated into several tectonic units of 1-2km in width by reverse faults (tectonic structure II) and thrust faults (tectonic structure III). The axial planes of folds dip toward WNW.

2). Gusukuyama formation

The mesoscopic boudinage-like structures are commonly observed in elongated and isolated sandstone beds in mudstone of the upper member. Such structures have been produced under an unconsolidated condition, and the cleavages with a general dip toward NW are superimposed on them (Fig. 17-6). Judging from the orientation and spatial arrangement of the cleavages and beddings, the Gusukuyama formation seems to form an asymmetrically folded structure in which the axial planes of folds probably dip toward NW.

3. *Motobu area*

The mesoscopic structures formed by subaqueous slumping or sliding are found in limestone of the Motobu formation, sandstone of the Yonamine formation (Fig. 15-2a) and chert within the exotic masses of the Yonamine formation. Many poles to bedding planes of sandstone in the Yonamine formation are dispersed and are apart from the π-circle in each of the π-diagrams. The beddings within the exotic masses in the Yonamine formation also have no preferred orientation, though the long dimensions of the exotic masses are roughly subparallel to the general trend of the tectonic structure II (Figs. 6 and 18). The facing of the slump deposits inferred from the vergence of rheid folds is roughly toward SE (Fig. 21-1).

The mesoscopic folds as the tectonic structure II are hardly found in both the Motobu and Yonamine formations. However, the axes β_1 determined by the pattern of the poles to bedding planes and the cleavage-bedding intersections generally pluge gently toward NNE and SSW in the western tectonic units. The cleavages are commonly observed in both the Motobu and Yonamine formations (Fig. 15-2). The frequency of cleavages shows a tendency to decrease from the eastern units to the western ones. The dip of cleavages and reverse or thrust faults tends to become steeper from the eastern units to the western ones, varying from 20 to 70° WNW (Figs. 18 and 19).

As for the tectonic structure III, several mesoscopic faults with low dip toward WNW are observed in all tectonic units (Figs. 15-2, 18 and 19). In the southeastern units, a few examples of asymmerically folded cleavages are present near such faults. The folds, less than 1m in wave-length, are inclined with the axial planes dipping toward WNW at an angle of 30 to 75 degrees. The inter-limb angles of the folds range from 35 to 75 degrees.

As for the tectonic structure V, normal drag

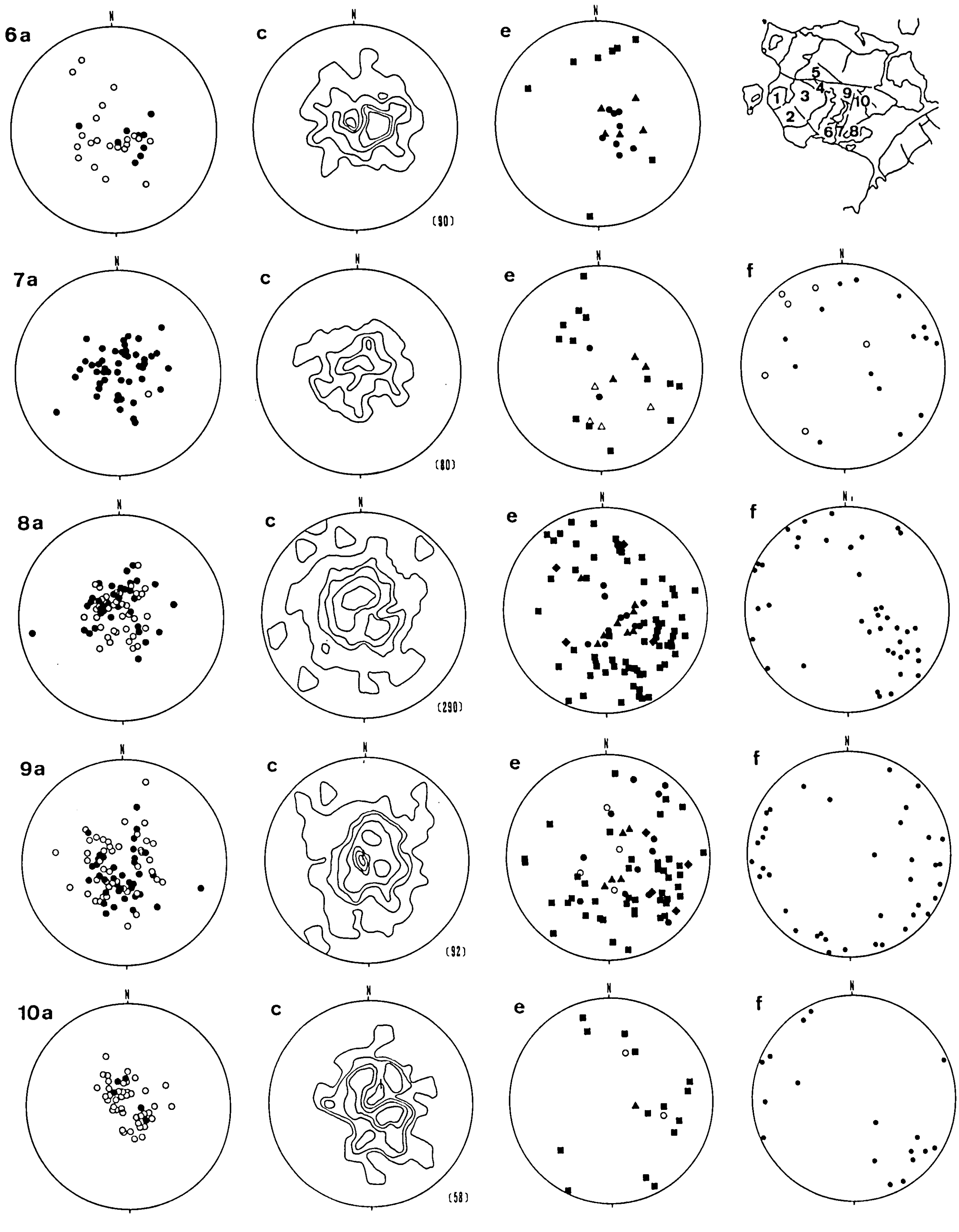
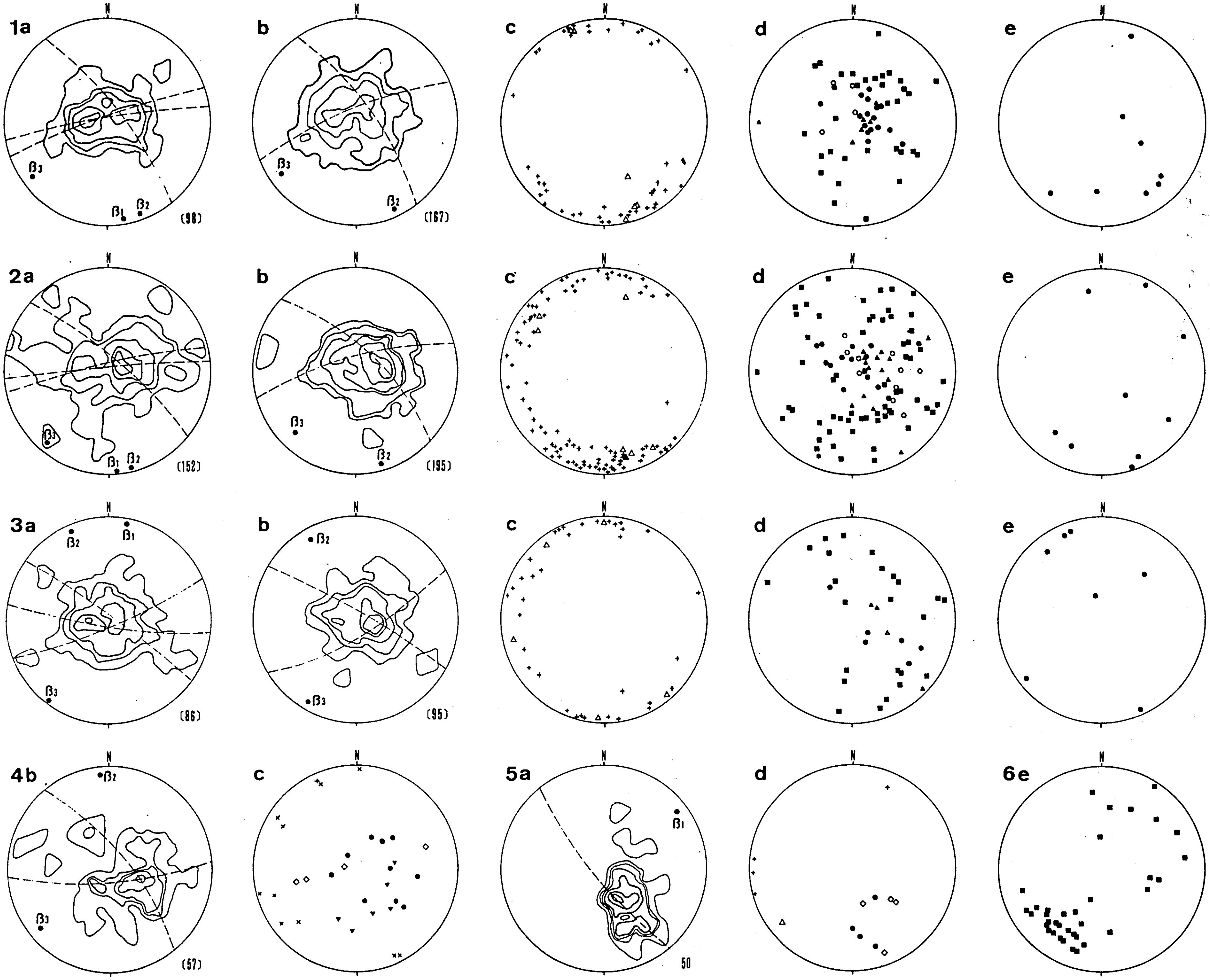


FIG. 19. Structural data for the pre-Neogene strata in the eastern Motobu area.
Lower hemisphere, equal-area plot. Contours in diagrams 6c, 7c, 9c and 10c: 10-8-6-4-2%, contours in diagram 8c: 8-5-3-2-1%. Number in brackets: observation numbers.
a: poles to bedding planes of sandstone (open symbol), limestone and chert (black symbol), c: poles to cleavage planes, e: poles to fault planes (square, triangle and circle show normal, reverse and indeterminable senses of shear respectively) parallel to cleavages (open symbol) and oblique to cleavages (black symbol), f: poles to joint planes (open symbol: joint cutting Miocene intrusive rocks).



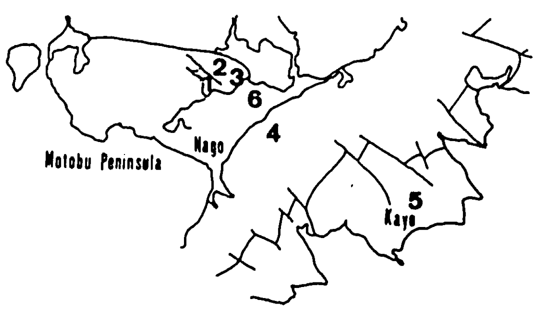


FIG. 20. Structural data for the Wakugawa (1–3), Nago(4) and Kayo (5) formations and the Shimajiri and Ryukyu groups (6).
Lower hemisphere, equal-area plot. Contours in diagrams 1a, 3a and b: 15–10–5–3–1.5%, contours in diagrams 1b, 2a and b: 15–10–5–3–1%, contours in diagrams 4b and 5a: 15–10–7–5–2%. Number in brackets: observation numbers.
a: poles to bedding planes, b: poles to cleavage planes, c: cleavage- bedding intersections (cross), hinge line of folded bedding (open triangle), hinge line of folded cleavage (black triangle), d: poles to fault planes (square, triangle and circle show normal, reverse and indeterminable senses of shear respectively) parallel to cleavage (open symbol) and oblique to cleavage (black symbol), e: poles to joint planes.

flexures of cleavages by the ENE-WSW and NW-SE strike faults occur especially in the southeastern units, as inferred from the pattern of the poles to cleavage planes (Figs. 15-2 and 18).

The macroscopic structure of the Motobu and Yonamine formations seems to be represented fundamentally by the asymmetrically folded structure separated into several tectonic units of 1-5km in width by reverse and thrust faults dipping generally toward WNW. The Miocene intrusive rocks are intruded along these reverse and thrust faults (Fig. 6, Fujita, 1980).

4. *Wakugawa area*

It is difficult to find the evidence of subaqueous slumping or sliding in the pattern of the poles to bedding planes of the sandstone in the Wakugawa formation because of the effect of the remarkable tectonic deformaton, though irregular-shaped chunks and slabs of sandstone are occasionally scattered in disharmony with the cleavages (Fig. 15-3a).

Concerning the tectonic structure II, the mesoscopic folds with an eastward vergence are observed in alternating beds of sandstone and mudstone of the Wakugawa formation. The folds are overfolds or recumbent folds, the axial planes of which dip toward E or W with an angle of 15 to 30 degrees. In a section perpendicular to the fold axis, the transposed and isolated sandstone layers are arranged in horseshoe shape in the intensely cloven part (Fig. 15-3b and c). The axes β_1 inferred from the pattern of the poles to bedding planes and the hinge lines of folds take predominantly NNW-SSE direction and sometimes NNE-SSW to N-S direction. The cleavage-bedding intersections also take NNW-SSE and NNE-SSW directions (Fig. 20-1, 2 and 3). The frequency of cleavages and the grade of deformation tend to decrease from the lower to the upper member (Table 11).

The cleavages and layer silicates parallel to the cleavages are displaced and flexed along the faults dipping gently toward E or W. These faults have been probably produced originally as thrust faults with an eastward facing. A hinge line of fold of the flexed cleavages and the axes β_2 inferred from the pattern of the poles to cleavage planes take NNW-SSE direction (Figs. 15-3d and 19).

Moreover, the cleavages and beddings are remarkably tilted and bended along the NE-SW strike faults with steep dip (Fig. 15-3e). The strike of these faults is parallel to the axes β_3 inferred from the pattern of the poles to cleavage planes and bedding planes, and parallel to the extention of the Shimajiri group near the root of the Motobu peninsula. The WNW-ESE strike fault with normal sense of shear cut the Shimajiri and Ryukyu groups (Fig. 20).

The Wakugawa formation seems to form the imbricate structure associated with overfolds and recumbent folds of 1-3km in wave-length. Moreover, the NE-SW strike folds of about 1km in wave-length, the axial planes of which are nearly vertical, are superimposed on the imbricate structure, as shown on the geologic profile. The strike folds have resulted from the NE-SW strike faulting which has probably taken part in the formation of the sedimentary basin of the Shimajiri group (Fig. 8).

5. *Kunigami area*

There are some remarkable differences in the mode of occurrence of mesoscopic structures and the degree of deformation between the Nago and Kayo formations.

1). Nago formation

Since the Nago formation has been intensely deformed and transposed, it is difficult to determine whether the formation had been influenced by subaqueous slumping or sliding.

The foliations such as slaty cleavage and schistosity commonly appear in rocks of the Nago formation. In an example observed in slate interbedded with layers of sandstone at Kijoka, the cleavage-bedding intersection plunges gently toward NNW (Fig. 20). The foliations are folded with a wave-length of less than 30 cm. The axial planes of folds dip toward SSW and NNW at an angle of 30 to 50 degrees. The axes β_2 and β_3 inferred from the pattern of the poles to foliations and the hinge lines of folds take NNW-SSE and ENE-WSW directions (Fig. 20).

Judging from the repeated distribution of the greenstone sequence around the Shioya bay and the remarkable development of folation, the Nago formation may form an imbricate structure or folded structure. It is probably separated from the Motobu and Nakijin formations by a thrust fault cutting the foliation and related zonal arrangement of the Nago formation.

2). Kayo formation

Though the Kayo formation contains some slump beds between the sandstone beds, the primary beddings are continuous and undisturbed (Fig. 20).

The mesoscopic folds as the tectonic structure II, less than 10 m in wave-length, are inclined and overturned, the axial planes dipping moderately or steeply toward NNW. The mesoscopic folds in alternating beds of sandstone and mudstone are associated with axial plane cleavages (Plate 4). In the east of Nago, the axis β_1 inferred from the pattern of the poles to bedding planes and the cleavage-bedding intersections take NE-SW or ENE-WSW direction (Fig. 20-5c). The tectonic structure II of the Kayo formation may differ in orientation and condition of deformation from that of the Nago formation, and might have been produced at the same age as the tectonic structure III of the Nago formation.

The data mentioned above are insufficient to conclude the macroscopic structure of the Kayo formation. According to Fukuda et al. (1978), it seems that the macroscopic structure of the Kayo formation is represented by a strongly folded structure (anticline and syncline), in which axial planes of folds steadily dip toward NNW.

C. Northern Amami Islands

1. *Kakeroma-Yadon area*

The pre-Neogene strata of this area are irregularly deformed by subaqueous gravity transportation, as Osozawa (1984) mentioned in detail. Moreover, the cleavages with steep dip toward WNW are commonly superimposed on the slump and slide structures. The boundary between the pre-Neogene strata of the Yadon-Kakeroma area and those of the Uken area on the author's geologic map is modified from Kashima and Takahashi (1977) and Osozawa (1984) because of the insufficiency of available data. This boundary may be represented by a reverse fault parallel to the cleavages.

2. *Uken area*

The poles to bedding planes of sandstone of the Yuwandake formation on the western side of this area are scatterd more remarkably than those on the eastern side in proportion to the frequency of slump beds. The facing of the slump or slide deposits inferred from the vergence of the rheid folds and the orientations of planar discontinuities are toward ESE, NNE and SSW (Figs. 20-2, 22-1 and 23 and Plate 4).

The mesoscopic folds as the tectonic structure II, less than 10m in wave-length, occur in alternating beds of sandstone and mudstone and in tuffaceous sandstone interbedded with thin layers of mudstone (Fig. 22-2). They are inclined or overturned, the axial planes dipping generally toward WNW at an angle of 20 to 60 degrees. The axes β_1 determined from the pattern of the poles to bedding planes commonly plunge gently toward NNE (Figs. 23 and 24). The cleavages appear more frequently in slump beds than in undisturbed beds, and in the lower and middle members than in the upper member. The cleavages are concentrated especially on the rocks near reverse faults (Plate 5-6).

The cleavages are folded and displaced in N-S or NNE-SSW direction (Figs. 22-3, 23 and 24). The mesoscopic folds of the cleavages, less than 30cm in wave-length, are commonly asymmetric in almost all sections perpendicular to the fold axes, and are inclined with the axial planes dipping commonly toward ESE and partly toward W at an angle of 40 to 65 degrees. The inter-limb angles of the folds range from 75 to 150 degrees. At the outcrop about 5km west of Yuwan, conjugate sets of thrust faults coexist with the folds of the cleavages. The determined principle stress axis σ_1 takes WNW-ESE direction. Such thrust faults and folds develop densely in rocks near the major thrust fault running from Ashiken to the west of Fukumoto (Plate 5).

Judging from the arrangememt of mesoscopic structures and the distribution of pre-Neogene strata, it seems that the Yuwandake formation forms fundamentally an asymmetrically folded structure, in which the wave-length of the folds ranges from 200m to 1km and the axial planes dip toward WNW. The asymmetrically folded structure related to the tectonic structure II is cut by the major thrust fault facing toward ENE. This thrust fault separates the Yuwandake formation into two tectonic units, namely, the eastern Unit A and the western Unit B (Fig. 11).

3. *Odana area*

Some of the poles to bedding planes of sandstone and silicified tuff in the Odana formation are scattered and are apart from the π-circle on π-diagram owing to the development of slump beds in the upper member. The facing of the slump deposits inferred from the vergence of rheid folds and the orientation of planar discontinuities are toward NNE, SSW and WSW (Fig. 21-3).

No data about the mesoscopic folds as the tectonic structure II were obtained from the Odana formation. However, the axis β_1 inferred from the pattern of the poles to bedding planes plunges toward NNE at an angle of 10 degrees (Fig. 23-10). The frequency of cleavages parallel to the reverse faults dipping commonly toward WNW at an angle of 50 to 80 degrees tends to decrease from the lower member to upper one. The rocks of the eastern tectonic unit are cloven more intensely than those of the western unit.

An asymmetric fold of cleavages, less than 1 m in wave-length, is observed along a branch of the Kawauchi river, about 5km east of Yuwan. Its axial plane is

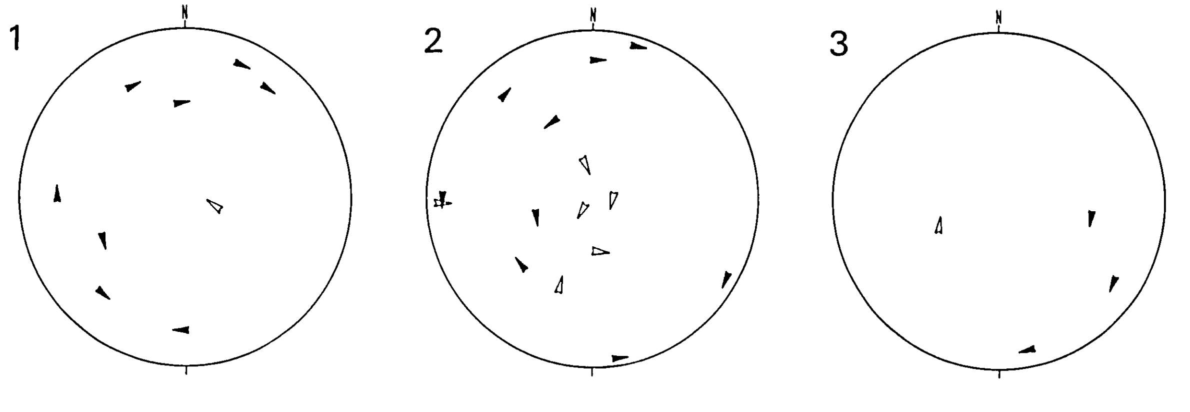


FIG. 21. Corrected orientation of rheid fold and planar discontinuity by suaqueous slumping or sliding in the Yonamine (1), Yuwandake (2) and Odana (3) formations.
Correction for effect of folding or tilting on the measured values was made in terms of each measured plunge value of cleavage-bedding intersection. Lower hemisphere, equal-area plot.
black arrowhead: axes of rheid folds and their facings, open arrowhead: poles to planar discontinuities and their facings.

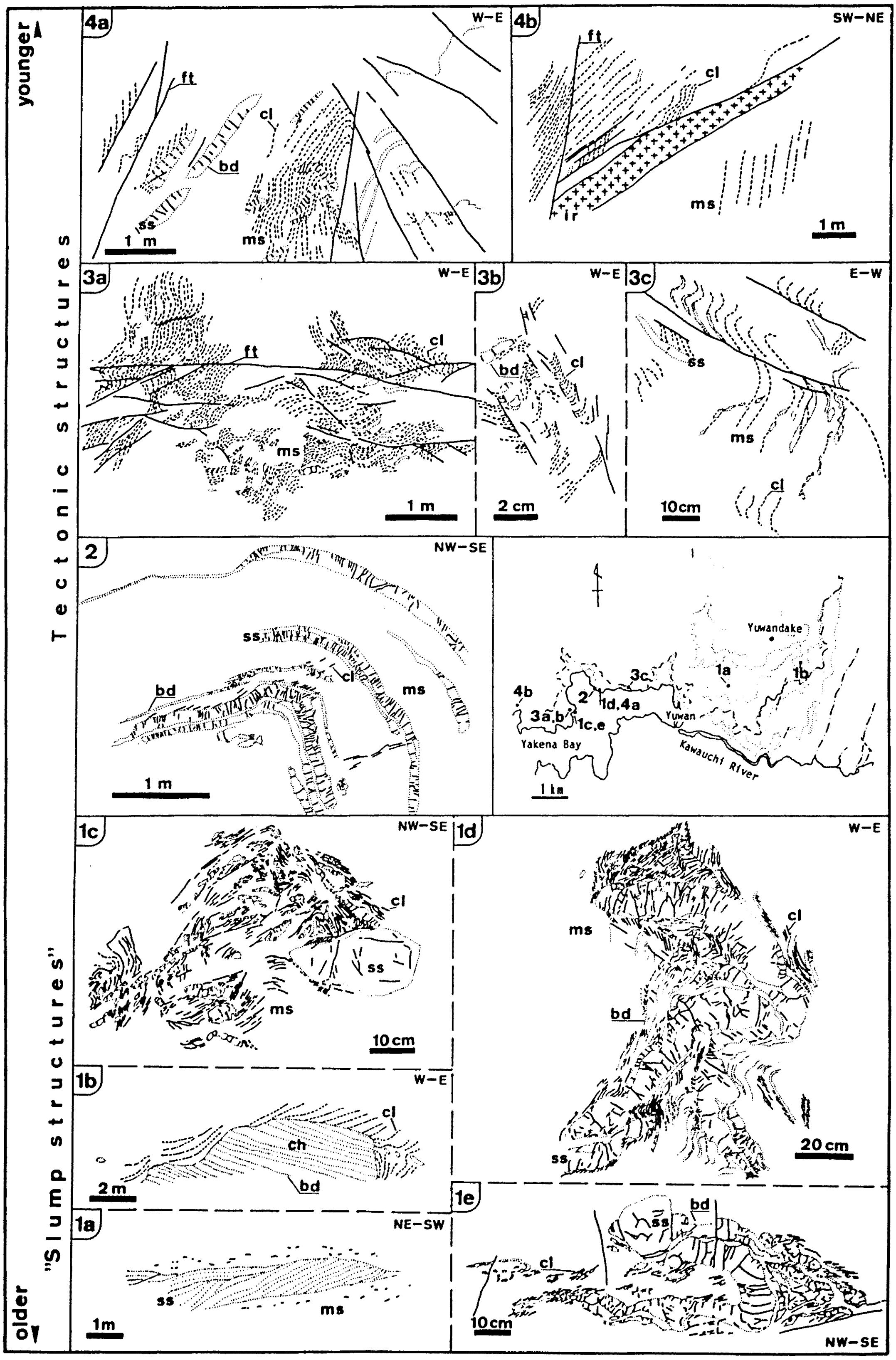


FIG. 22. Mesoscopic structures in the Yuwandake formation, Amami-Oshima.
1: "Slump structures" a: thrust fault-like structure, b: chert (ch) olistolith in mudstone (ms), c and d: irregular-shaped chunks and slabs of sandstone (ss) in mudstone, e: rheid fold of sandstone in mudstone.
2: Asymmetric fold in alternating sandstone and mudstone.
3: Displaced and flexed cleavages, a: thrust fault sets, b: flexed cleavages, c: displaced cleavages.
4: Faults with steep dips, and intrusive rock (ir).
bd: bedding, cl: cleavage, ft: fault.

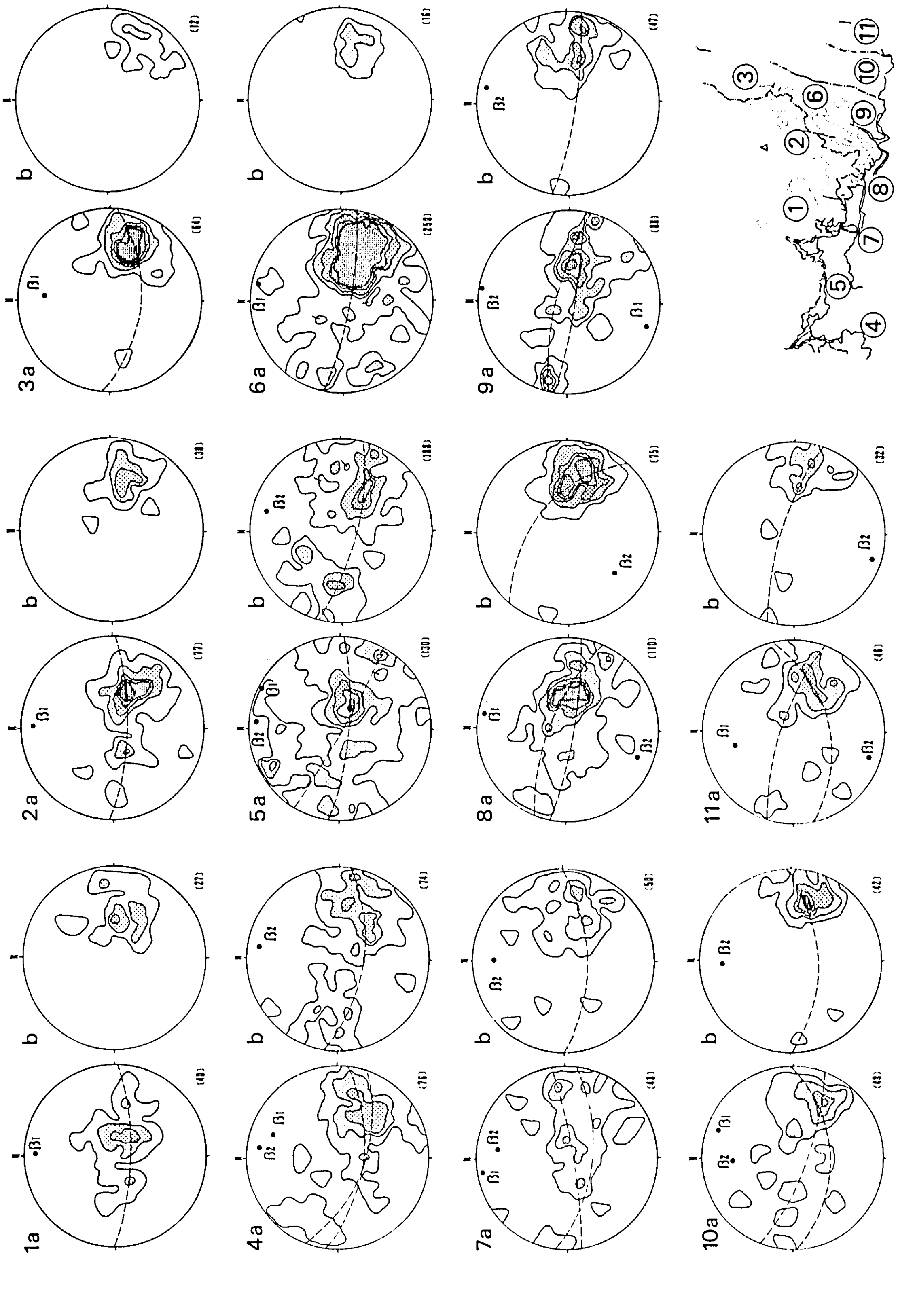


FIG. 23. π-diagrams for bedding planes(a) and cleavages(b) of rocks of the Yuwandake formation. Lower hemisphere, equal-area plot. Contours in diagrams 3b and 6b: 25–7%, contours in other diagrams: 15–10–8–6–3%.
Number in brackets: observation numbers.

nearly vertical and axis plunges toward the direction of N2° W at an angle of 10 degrees. The fold axis is probably parallel with the axis β_2 inferred from the pattern of the poles to cleavages (Fig. 23-10). A mesoscopic thrust fault dipping toward WSW at an angle of 15 degrees also appears as the tectonic structure III. Its facing is toward ENE.

The Odana formation is separated from the Yuwandake and Ogachi formations by reverse faults with a steep dip toward WNW. It forms fundamentally an asymmetrically folded structure, in which the wave-length of the folds ranges from 100 m to 1 km and the axial planes dip toward WNW (Fig. 11). The Odana formatin is separated into the western and eastern tectonic units by the reverse fault. The Neogene porphyrite is intruded along the faults.

4. *Naze-Sumiyo area*

1). Naze and Ogachi formations

Some of the poles to bedding planes of sandstone in the Naze and Ogachi formations are also apart from the π-circle on π-diagram owing to the developement of slump beds at horizons.

Cleavages are commonly present in the rocks of both the Naze and Ogachi formations (Fig. 23-11). They dip steeply toward WNW. The frequency of cleavages is far higher in the Naze formation than in the Ogachi formation.

The mesoscopic structures of flexed and displaced cleavages such as kink folds and kink bands have been reported from the Naze formation near Naze city by SAKAI et al. (1977) and OSOZAWA et al. (1979). The cleavages and beddings bended with a wave-length of more than 1 m are commonly observed at the outcrops along the forestry road extending from the upper Kawauchi river to the northward. The axis β_2 inferred from the pattern of the poles to cleavage planes plunges toward NNE. A mesoscopic thrust fault with a dip toward WNW is also observed in mudstone of the Ogachi formation interbedded with layers of sandstone. The cleavages and beddings are displaced by this fault, along which the Neogene porphyrite is intruded.

According to the study by SAKAI et al. (1977), a conformable sequence of the Naze and Ogachi formations probably forms an imbricate structure associated with asymmetric folds with axial planes dipping generally toward WNW. Near the upper Kawauchi river in Uken village, a sequence of the Naze and Ogachi formations is asymmetrically folded and is separated into two tectonic units by the presumable reverse fault with a steep dip toward WNW. The Neogene porphyrite is intruded along this fault. At Koniya, Sumiyo and Kasari, the Paleogene granite is intruded into the Naze and Ogachi formations and is distributed obliquely to the long dimension of the folded structure.

2). Wano formation

The Wano formation is distributed within th

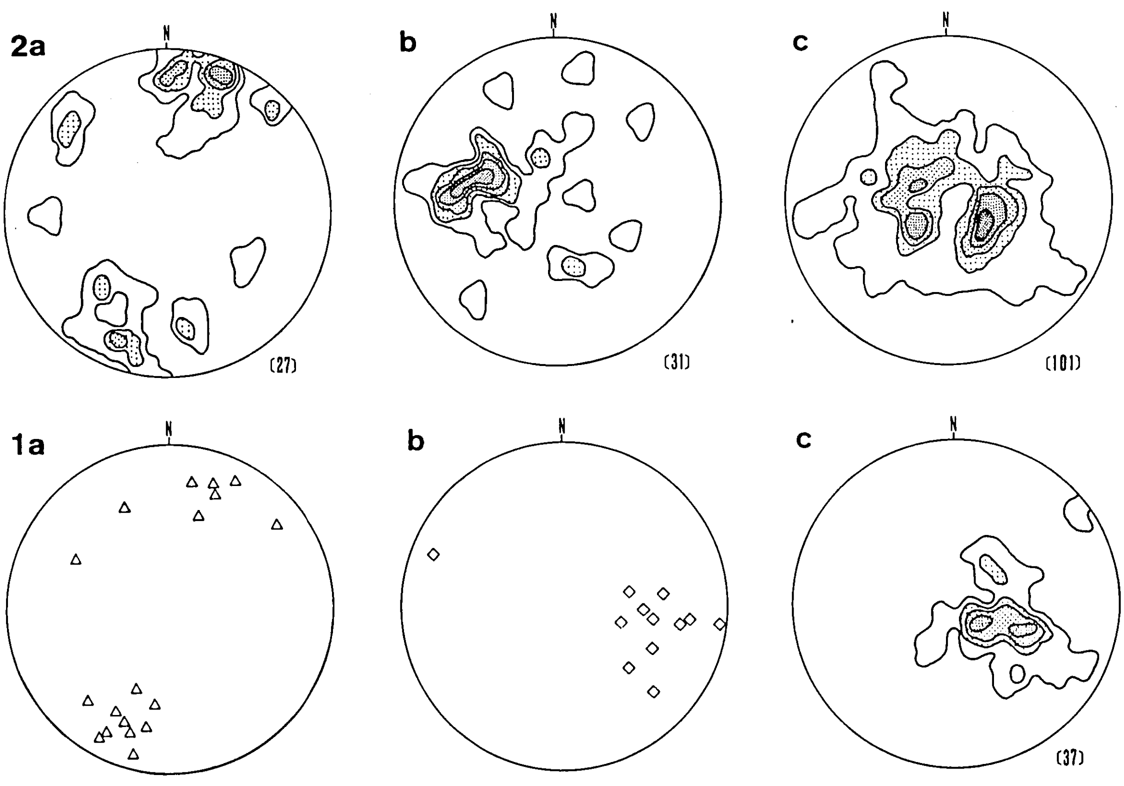


FIG. 24. Structural data of the tectonic structures II (1) and III (2) for the Yuwandake formation. Lower hemisphere, equal-area plot. Contours in diagrams 2a and b: 30-23-17-10-3%, contours in diagram 2c: 10-7-5-3-1%, contour in diagram 1c: 25-17-10-3%.
Number in brackets: obsevation numbers.
a: fold axes, b: poles to fold axial planes, c: poles to fault planes.

province of the Naze and Ogachi formations along the eastern margin of the Naze Sumiyo area. It forms an overturned syncline or an asymmetric synclinorium in which the fold axis takes NNE-SSW diredtion, as ISHIDA (1969) and SAKAI et al. (1977) have reported.

IV. GEOLOGIC AGE AND CORRELATION

1. *"Paleozoic formations" in the Iheya area*

According to the radiolarian biostratigraphical study by UJIIÉ and HASHIMOTO (1983), the pre-Neogene strata of the Iheya area, i. e. the so-called "Paleozoic formations" seem to be composed of the Carboniferous limestone, Permian chert and limestone, Triassic chert and greenstone and late Jurassic to early Cretaceous sandstone. Such admixed lithofacies is similar to that of the lare Jurassic Ebirase formation of Kyushu defined by NISHIZONO et al. (1982).

2. *Nakijin and Gusukuyama formations*

There is no doubt about the age of the Nakijin formation, which is assigned to the late Triassic (Carnian) from the evidence of ammonoids and bivalves (ISHIBASHI, 1969, 1973; KOBAYASHI and ISHIBASHI, 1970) as well as of conodonts (KOIKE and ISHIBASHI, 1974). ISHIBASHI (1969) has clarified that the faunal assemblage of ammonites from the Nakijin formation is comparable with that of Alps, British Columbia of Canada, Timor, Himalaya and Arctic region. Such ammonite fauna has never been reported from any other districts of Japan.

The Gusukuyama formation is referable to the late Jurassic (possible Oxfordian to Tithonian) in age, on the basis of the radiolarian assemblages corresponding to the *Gongylpthorax sakawaensis-Stichocapsa* sp. C to *Pseudodictyomitra primitiva-P.* sp. A. assemblages (MATSUOKA and YAO, 1985).

The radiolarians occur from the non-exotic mudstone and chert the lower and upper members. This formation is correlated to the Yuwan formation of the Kakeroma-Yadon area, though there is a difference in lithofacies. The former contains no pre-Jurassic olistoliths, while the latter is characterized the development of admixed sediments.

In Kyushu, the late Jurassic radiolarians have been obtained from the Ebirase, Nabewaritoge and Takasawa formations in the southern zone of the Chichibu belt (NISHIZONO et al., 1982). Although the Gusukuyama formation is situated in the extension of the Chichibu belt, it is difficult to conclude the correlation among these formations, because radiolarians have not been described with detailed occurrence.

In Shikoku, ISHIDA (1985) reported the occurrence of late Jurassic radiolarians from the Nakagawa group in the southern zone of the Chichibu belt. Besides, from the lower part of the Yura formation in the southern Chichibu belt in Kii-Yura area, YAO (1984) described Tithonian radiolarians. Accordingly, the Jurassic formations correlated with the Gusukuyama formation may be traceable to the Outer Zone of Southwest Japan.

3. *Motobu, Yonamine and Yuwandake formations*

The Motobu formation is quite barren of reliable index fossils. However, it should be noted that the limestone of the upper part and the uppermost greenstone resemble respectively the Permian limestone and the Triassic greenstone appearing as olistoliths in the Yonamine formation.

The Yonamine formation is presumed to be referred to the Valanginian to Barremian in age, on the basis of the radiolarian assemblage comparable with that of the *Sethocapsa uterculus* assemblage-zone of YAO (1984). The radiolarians are found in the probably non-exotic mudstone and siliceous mudstone.

In Kyushu, NISHIZONO et al. (1982) and MURATA et al. (1982) have reported the occurrence of the *Obesacapsula rotunda* assemblage from the mudstone in the Takasawa formation. This assemblage is similar in geologic age to the *Sethocapsa uterculus* assemblage. The Takasawa formation resembles also in lithology the Yonamine formation, being characterized by the development of admixed facies. Accordingly, the present writer tentatively correlates the both formations to each other.

The Yuwandake formation yields the radiolarian assemblage belonging to the *Sethocapsa uterculus* assemblage (YAO, 1984) from the chert of the lower member. It yields also the radiolarian assemblage comparable with that of the *Acaeniotyle umbilicata* to *Mita gracilis* zones (SCHAAF, 1984) from the non-exotic mudstone and siliceous mudstone of the middle and upper members. Therefore, the lower member and middle-upper member are referable to the Valanginian-Barremian and to the early-middle Albian in age, respectively.

In Shikoku, ISHIDA (1985) recorded the occurrence of the radiolarian fauna of possibly Albian to Cenomanian age from the upper part of the Nakagawa group in the southern Chichibu belt. The fauna comprises *Holocryptocanium barbui* DUMITRICA, *Thanarla conica* (ALIEV), *T. praeveneta* PESSAGNO, *Psedodictyomitra pentacolaensis* PESSBGNO etc. These radiolarians are analogous to the diagnostic species of the early to middle Albian radiolarian assemblage obtained from the Yuwandake formation stated above. Therefore, the middle and upper members of the Yuwandake formation may be correlated with the upper part of the Nakagawa group.

4. *Wakugawa and Odana formations*

The radiolarian assemblage corresponding to that of the *Diacanthocapsa euganea-Thanarla elegantissima* zone of TAKETANI (1982) is obtained from the non-exotic mudstone, siliceous mudstone and silicified tuff of the Odana formation. Therefore, the formation is assigned to the late Albian to Cenomanian in age. No reliable fossils are found from the Wakugawa formation, but its upward-coarsening lithofacies resembles that of the Odana formation. According to KIZAKI (1983), these formations are correlated with the Tete formation of Tokunoshima based on their lithologic features, though no radiolarian fossils have been reported from the latter.

In Kyushu, the late Albian to Cenomanian radiolarian assemblage comprisng *Holocryptocanium geysersensis* Pessagno, *Pseudodictyomitra pseudomacrocephala* (SQUINABOL), etc. has been recorded from the Okawa and Takaono formations in Hokusatsu (YONEDA and IWAMATSU, 1979), the upper part of the Morozuka group (SAKAI, 1985) and the Saeki supergroup (OKUMURA et al., 1985). KUMON (1983, 1985) also reported the same radiolarian assemblage from the Hinotani formation and the upper member of the Yukawa formation in the northern Shimanto belt, east of Shikoku. Therefore, the Cretaceous strata correlated with the Odana formation may be traceable to the Outer Zone of Southwest Japan.

5. *Nago and Naze formations and Ogachi formation*

The occurrence of Turonian radiolarians from the argillite of the Naze formation (OSOZWA, 1984) has an important significance with respect to the correlation of the Cretaceous formations in Central Ryukyu. KONISHI (1963) and KIZAKI(1982) correlated the Nago formation of Okinawa with the Naze formation of Amami-Oshima on the basis of the close resemblance in lithology and structural position, though no fossils have been obtained from the former. By the same reason, the Omo formation in Tokunoshima and the Neori formation in Okierabu-jima were also correlated with the Naze formation by KIZAKI (1982).

The Makimine formation of eastern Kyushu, which is characterized by the predominace of phyllitic slate with associated greenstone, is similar in lithologic appearance to the Nago and Naze formations. According to OKUMURA et al. (1985), the Makimine formation in Kamae yields the late Albian to Cenomanian radiolarians from chert and the Coniacian to Santonian radiolarians from slate.

From the Ogachi formation, which conformably overlies the Naze formation, any radiolarian fossils have not yet been found, but an ammonite of late Cenomanian or early Turonian age were described from a block of mudstone (ISHIKAWA and YAMAGUCHI, 1965; MATSUMOTO et al., 1966).

6. *Kayo and Wano formations*

The Kayo formation has recently been referred to the early middle Eocene in age from the discovery of *Nummulites amakusaensis* YABE and HANZAWA (SUZUKI and UJIIÉ, 1985). *Nummulites* occurs also from the Wano formation, though not identified in specific level. Both formations are quite similar in lithology to each other.

V. DISCUSSION

1. *Olistostromes in the Yonamine and Yuwandake formations*

As described in Chapter II, the Yonamine and Yuwandake formations are characterized by the development of olistostromes. Dispersed blocks and isolated masses of chert, greenstone and limestone within these formations are mostly regarded as olistoliths on the basis of the mode of occurrence and the difference in geologic age from the surrounding rocks. Remarks on the source of the olistoliths are given below.

1). Source of olistoliths in the Yonamine formation

As shown in the geologic map and stratigraphic columnar sections of the Yonamine formation (Figs. 6 and 7), the frequency of olistoliths decreases toward the southeastern part of the distributional area of the formation, and the geologic age of them tends to become younger toward the upper member. These facts indicate that the olistoliths had been transported from the northwestern area, and that source provinces had probably risen on occasion. In the Iheya area, the Permian limestone and chert and the Triassic chert have been reported by ISHIBASHI (1968) and UJIIÉ and HASHIMOTO (1983). Moreover, the Motobu formation is predominantly composed of limestone and greenstone, to which some of the olistoliths in the Yonamine formation bear a resemblance in lithology. Therefore, it is possible that the olistoliths in the Yonamine formation might have been derived mostly from the older rocks in the Iheya area and partly from the Motobu formation.

2). Source of olistoliths in the Yuwandake formation

The frequency and size of olistoliths in the Yuwandake formation increase from east to west and from below to above, and sandstone beds are developed dominantly on the eastern side of this formation. The olistoliths of the Triassic and middle Jurassic chert and greenstone are similar in lithology and geologic age to those in the Yuwan formation of the Kakeroma-Yadon area, and the olistoliths of the late Jurassic mudstone and chert are analogous to the autochthonous rocks of the Yuwan formation. Besides, the slump folds of sandstone in the mudstone hardly show the northwestward vergence, and the hanging walls on the planar discontinuities slide up toward or slump down toward almost all directions except the northwest. Therefore, the olistoliths in the Yuwandake formation might have been derived from the older strata in the western area including the Kakeroma-Yadon area.

Judging from the facts mentioned above, it may be concluded that the pre-Neogene strata in the Iheya, Nakijin-Gusukuyama and Kakeroma-Yadon areas on the northwestern side of Central Ryukyu had already risen or had been rising from their sedimentary basins during the sedimentation of the Yonamine and Yuwandake formations. Within a large olistoliths in the Yuwandake formation, a series of the Triassic chert and greenstone conformably passes upward to the late Jurassic chert and mudstone and further to the early Cretaceous mudstone and sandstone. Therefore, it is inferred that the chert and greenstone appearing as olistoliths in the Yonamine and Yuwandake formations had originally occupied the lower stratigraphic position in the source area.

2. *Migration of the sedimentary basin and the tectonic characteristics of the pre-Neogene strata in Central Ryukyu*

Judging from the available data concerning the radiolarian faunas, it is roughly concluded that the geologic age of the pre-Neogene strata except the Dana, Moromi, Kayo and Wano formations has a tendency to become younger from northwest to southeast in both the northwestern Okinawa islands and the northern Amami islands (Table 3). In the Outer Zone of Southwest Japan, such tendency has been first suggested by KANMEKA and SAKAI (1975) on the Shimanto supergroup in Kyushu. Recently, several workers have also offered the similar opinion based upon the radiolarian biostratigraphy (OKAMURA, 1980; NISHIZONO et al., 1982; MATSUOKA, 1984; YAO, 1984; ISHIDA, 1985; KUMON, 1983, 1985). This may probably imply the southward or southeastward migration of sedimentary basins of the pre-Neogene strata in Central Ryukyu and in the Chichibu and Shimanto terrains of

Southwest Japan.

The pre-Neogene strata of Central Ryukyu are characterized by the remarkable development of "slump structures". Judging from the distribution of olistoliths as well as from the transported direction of slumping or sliding deposits proved from the facing of slump folds and the sense of hanging walls on planar discontinuities, it seems that the paleoslope facing to the southeast had always existed on the northwestern side of the sedimentary basin. The presence of such paleoslope suggests the elevation of older sedimentary province. It is possible that the elevation of older sedimentary province had a close relationship with the formation of new sedimentary basin.

As described in Chapter III, the mesoscopic structures developed in the pre-Neogene strata of Central Ryukyu are classified into six groups, namely the slumpor slidestructures and the tectonic structures I, II, III, IV and V in order of their formation. The stratigraphic distribution of the tectonic structures are shown in Fig. 25. Macroscopically, the pre-Neogene strata form an asymmetrically folded structure in each of the tectonic units separated by reverse or thrust faults dipping generally toward the northwest, and as a whole they form an imbricate structure parallel to the extension of the strata. The tectonic structures I, II and III have a close relation to the formation of the asymmetrically folded and imbricated structure, while the tectonic structures IV and V cut it obliquely.

IWAMATSU (1975) studied the relation between the folding styles and the tectonic levels in the Kitakami and Abukuma mountainous lands, Northwest Japan, and concluded that flexure folds and shear folds were produced under conditions of lower pressure at shallower tectonic level and higher pressure at deeper tectonic level, respectively. Following this conclusion, the tectonic structure II seems to have been formed at deeper tectonic level than the tectonic structures I and III. After the deformation related to the tectonic structure II, the pre-Neogene strata might have been shifted from deeper tectonic level to shallower one. At the almost same time when the pre-Neogene strata in the western and older sedimentary province were suffering the deformation related to the tectonic structure III, those in the eastern and younger sedimentary province underwent the deformation of the tectonic structures I and II and subsequently rose from their sedimentary basin. It seems that the elevation of older sedimentary province and the migration of sedimentary basin had progressed during the early stage of tectonic deformation, that is to say, during the formation of the tectonic strctures I, II and III.

3. *The tectonic history in Central Ryukyu*

The asymmetrically folded and imbricated structure characterized by the development of the tectonic structures I, II and III had begun to be formed during (?) or after the sedimentation of the early Cretaceous strata and was partly completed before the intrusion of the Paleogene granite. The Nakijin and Motobu formations overthrust on the late Cretaceous (?) Nago formation after the formation of the tectonic struc-

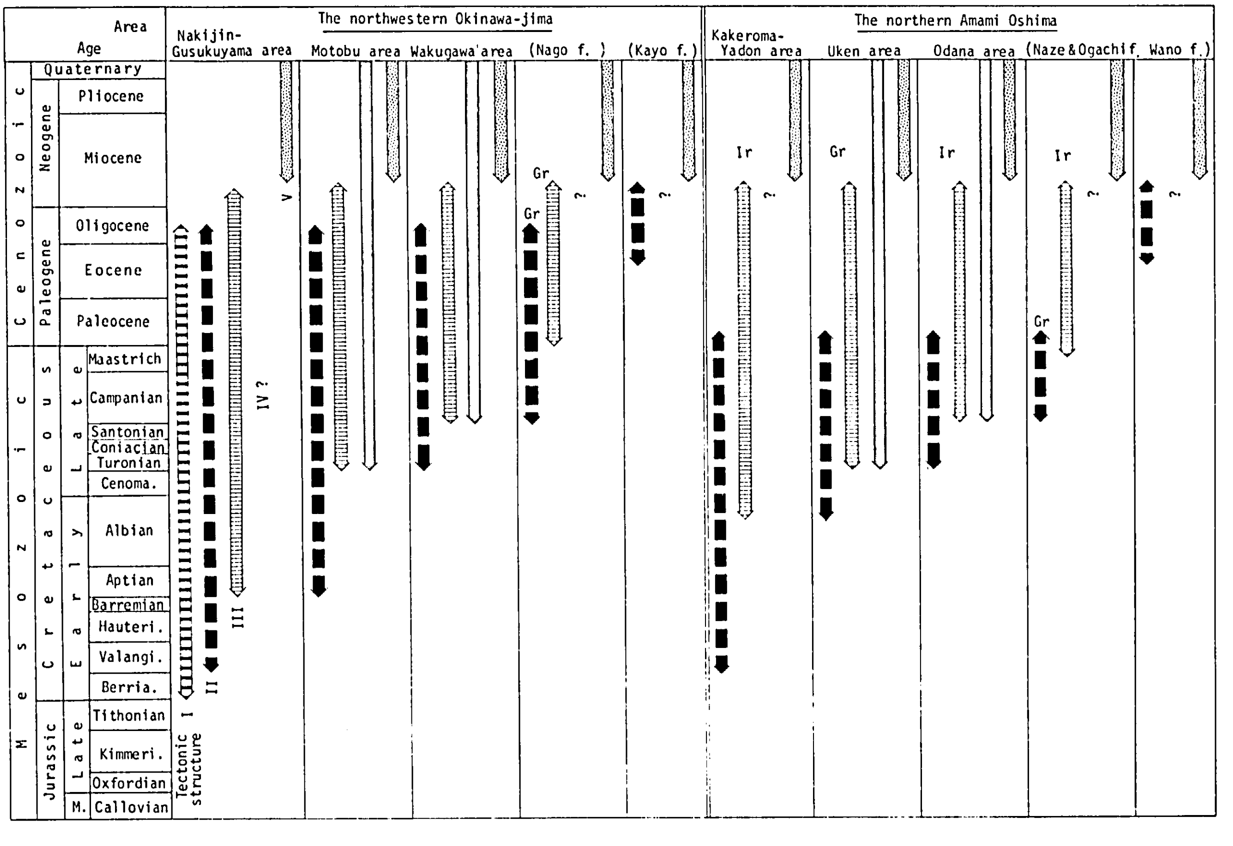


FIG. 25. Stratigraphic distribution of tectonic structures in the pre-Neogene strata of the northwestern Okinawa islands and northern Amami islands.
Gr: granite, Ir: intrusive rock.

ture II and before the intrusion of the Miocene granite and porphyrite. The Eocene Kayo and Wano formations formed the synclinolium structure before the intrusion of the Miocene granite and porphyrite. The formation of the asymmetrically folded and imbricated structure of the pre-Neogene strata in Central Ryukyu probably finally finished before Miocene. The asymmetrically folded and imbricated structure has been more or less modified by strike slip faults and normal faults related to the tectonic structures IV and V from possibly late Cretaceous (?) to Holocene.

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Explanation of Plate 1

Fig. 1. *Triassocampe deweveri* (NAKASEKO and NISHIMURA)
Fig. 2. *Triassocampe* (?) cf. sp. G YAO
Fig. 3. *Triassocampe* (?) cf. sp. H YAO
Fig. 4. *Yeharaia* (?) sp.
Fig. 5. *Stauracontium* (?) *trispinosum* cf. *ladinicum* DUMITRICA, KOZUR and MOSTLER
Fig. 6. *Parahsuum* cf. *simplum* YAO
Fig. 7. *Hsuum* sp.
Fig. 8. *Unuma* (?) sp.
Fig. 9. *Parvicingula* sp.
Fig. 10. *Pantanellium* (?) sp.
Fig. 11. *Stylocapsa* (?) cf. *spiralis* MATSUOKA
Fig. 12. *Solenotryma* (?) *ichikawai* MATSUOKA and YAO
Fig. 13. *Tricolocapasa* cf. sp. A YAO
Fig. 14. *Spongocapsula* sp.
Fig. 15. *Dictyomitra*(?) *minoensis* (MIZUTANI)
Fig. 16. *Mirifusus mediodilatatus* (RÜST)
Fig. 17. *Archaeodictyomitra* aff. *brouweri* (TAN SIN HOK)
Fig. 18. *Ristola altissima* (RÜST)
Fig. 19. *Hsuum* sp.
Fig. 20. *Pseudodictyomitra* cf. *primitiva* MATSUOKA and YAO
Fig. 21. *Parvicingula mashitaensis* MIZUTANI

Locality of figured specimens:
1-3, 5; Loc. TK13, north of Yuwandake, Amami-Oshima.
4; Loc. YW243, east of Yuwan, Amami-Oshima.
6, 9; Loc. KW448, southeast of Yuwan.
7, 8; Loc. KW445, southeast of Yuwan.
10; Loc. KW443, southeast of Yuwan.
11-14; Loc. YW523, northeast of Yuwandake.
15, 17, 19; Loc. YW73, Yuwandake.
16; Loc. YW74, Yuwandake.
18; Loc. YW71, Yuwandake.
20; Loc. YW72, Yuwandake.
21; Loc. IE06, Ie-jima.

Magnification:
1-13, 15, 17, 19-21; x200.
14, 16, 18; x100.

Explanation of Plate 2

Fig. 1. *Archaeodictyomitra apiara* (RÜST)
Fig. 2. *Archaeodictyomitra brouweri* (TAN SIN HOK)
Fig. 3. *Pseudodictyomitra* (?) cf. sp. D MATSUOKA and YAO
Fig. 4. *Pseudodictyomitra depressa* BAUMGARTHER
Fig. 5. *Pseudodictyomitra* cf. *carpatica* (LOZYNIAK)
Fig. 6. *Ristola cretacea* (BAUMGARTNER)
Fig. 7. *Eucyrtidium* (?) *ozaiensis* AITA
Fig. 8. *Parvicingula* cf. *boesii* (PARONA)
Fig. 9. *Pseudodictyomitra carpatica* (LOZYNIAK)
Fig. 10. *Stycocapsa decora* RÜST
Fig. 11. *Thanarla* cf. *pulchra* (SQUINABOL)
Fig. 12. *Archaeodictyomitra* cf. *puga* SCHAAF
Fig. 13. *Sethocapsa uterculus* (PARONA)
Fig. 14. *Pseudodictyomitra leptoconica* (FOREMAN)
Fig. 15. *Archaeodictyomitra lacrimula* (FOREMAN)
Fig. 16. *Sphaerostylus lanceola* (PARONA)
Fig. 17. *Acaeniotyle* cf. *umbilicata* RÜST
Fig. 18. *Alievium* cf. *helenae* SCHAAF
Fig. 19. *Xitus spicularius* (ALIEV)

Locality of figured specimens:
1-3, 6-7, 9, 18, 19; Loc. YW74, Yuwandake, Amami-Oshima.
8; Loc. YW 71, Yuwandake.
4, 5; Loc. IE 061, Ie-jima.
10; Loc. FM022, Fukumoto, Amami-Oshima.
11-14; Loc. UM421, east of Yuwandake.
15, 16; Loc. KG409, Yuwan, Amami-Oshima.
17; Loc. KG183, southeast of Yuwan,

Magnification:
1-19; x200.

Explanation of Plate 3

Fig. 1. *Archaeodictyomitra* cf. *vulgaris* PESSAGNO
Fig. 2. *Archaeodictyomitra* (?) aff. *brouweri* (TAN SIN HOK)
Fig. 3. *Sethocapsa simplex* TAKETANI
Fig. 4. *Holocryptocanium barbui* DUMITRICA
Fig. 5. *Archaeodictyomitra praeveneta* (PESSAGNO)
Fig. 6. *Pseudodictyomitra lodogaensis* PESSAGNO
Fig. 7. *Amphipyndax stocki* (CAMPBELL and CLARK)
Fig. 8. *Stichomitra* aff. *communis* SQUINABOL
Fig. 9. *Archaeodictyomitra* cf. *simplex* PESSAGNO
Fig. 10. *Archaeodictyomitra veneta* (SQUINABOL)
Fig. 11. *Pseudodictyomitra* cf. *nakasekoi* TAKETANI
Fig. 12. *Pseudodictyomitra pentacolaensis* PESSAGNO
Fig. 13. *Pseudodictyomitra pseudomacrocephala* (SQUINABOL)
Fig. 14. *Thanarla elegantissima* (CITA)
Fig. 15. *Novixitus weyli* SCHMIDT-EFFING
Fig. 16. *Holocryptocanium geysersensis* PESSAGNO
Fig. 17. *Pyramispongia glascockensis* PESSAGNO

Locality of figured specimens:
1-8; Loc. IR24, south of Yuwandake. Amami-Oshima.
9-15; Loc. KW160, along the upper Kawauchi river, Amami-Oshima.
16; Loc. KW382. along the upper Kawauchi river.
17; Loc. KW161, along the upper Kawauchi river.

Magnification of figures:
1-12, 14-17; x200.
13; x150.

Explanation of Plate 4

Fig. 1. Strike (normal) faults of WNW-ESE directon in the Shimajiri group, about 3km northwest of Nago, Okinawa-jima.
Fig. 2. Conjugate fissures filled with white calcite in the limestone of the Motobu formation, Awa, Motobu peninsula, Okinawa-jima.
Fig. 3. Asymmetric fold with axial plane cleavages in the mudstone interbedded with sandstone of the Kayo formation, near Teniya-zaki, about 3km northeast of Kayo, Kunigami peninsula, Okinawa-jima.
Fig. 4. Sandstone-rich layers transposed slightly in

the mudstone of the Kayo formation, near Teniya-zaki, about 3 km northeast of Kayo, Kunigami peninsula, Okinawa-jima.

Fig. 5. Flow structure and slump breccias by subaqueous slumping or sliding along the planar discontinuity in the Yonamine formation, about 1km north of Sakimotobu, Motobu peninsula, Okinawa-jima.

Fig. 6. Thinly alternating beds of sandstone and mudstone of the upper member of the Yuwandake formation, Fukumoto, Uken village, Amami-Oshima.

Fig. 7. Rheid fold of sandstone in the mudstone of the upper member of the Yuwandake formation, about 5km west of Yuwan, Uken village, Amami-Oshima.

Fig. 8. Sandstone chunks and breccias by subaqueous slumping or sliding in the mudstone of the upper member of the Yuwandake formation, about 5 km west of Yuwan, Uken village, Amami-Oshima.

Explanation of Plate 5

Fig. 1. Fold of the cleavages and beddings in the Yuwandake formation, 5 km west of Yuwan, Uken village, Amami-Oshima.

Fig. 2. Thrust fault cutting the cleavages and beddings in the Yuwandake formation, 1 km east of Yuwan, Uken village, Amami-Oshima.

Fig. 3. Fold of the cleavages near the major thrust fault between Unit A and B of the Yuwandake formation, 5 km west of Yuwan, Uken village, Amami-Oshima.

Fig. 4. Shear plane cutting the cleavages with gentle angle in the Yuwan dake formation, about 6 km west of Yuwan, Uken village, Amami-Oshima.

Fig. 5. Folded tuffaceous chert and cloven siliceous mudstone of the middle member of the Yuwandake formation, about 2 km southeast of Yuwan, Uken village, Amami-Oshima.

Fig. 6. Reverse (?) fault parallel to the cleavages in the Yuwandake formation, 5 km west of Yuwan, Uken village, Amami-Oshima.

Fig. 7. Asymmetric fold with axial plane cleavages in the alternating beds of sandstone and mudstone of the Yuwandake formation, about 4 km west of Yuwan, Uken village, Amami-Oshima.

Fig. 8. Flattened and elongated fragments or chunks of sandstone on the shear plane in the mudstone of the Odana formation near the reverse fault, about 3km east of Yuwan, Uken village, Amami-Oshima.

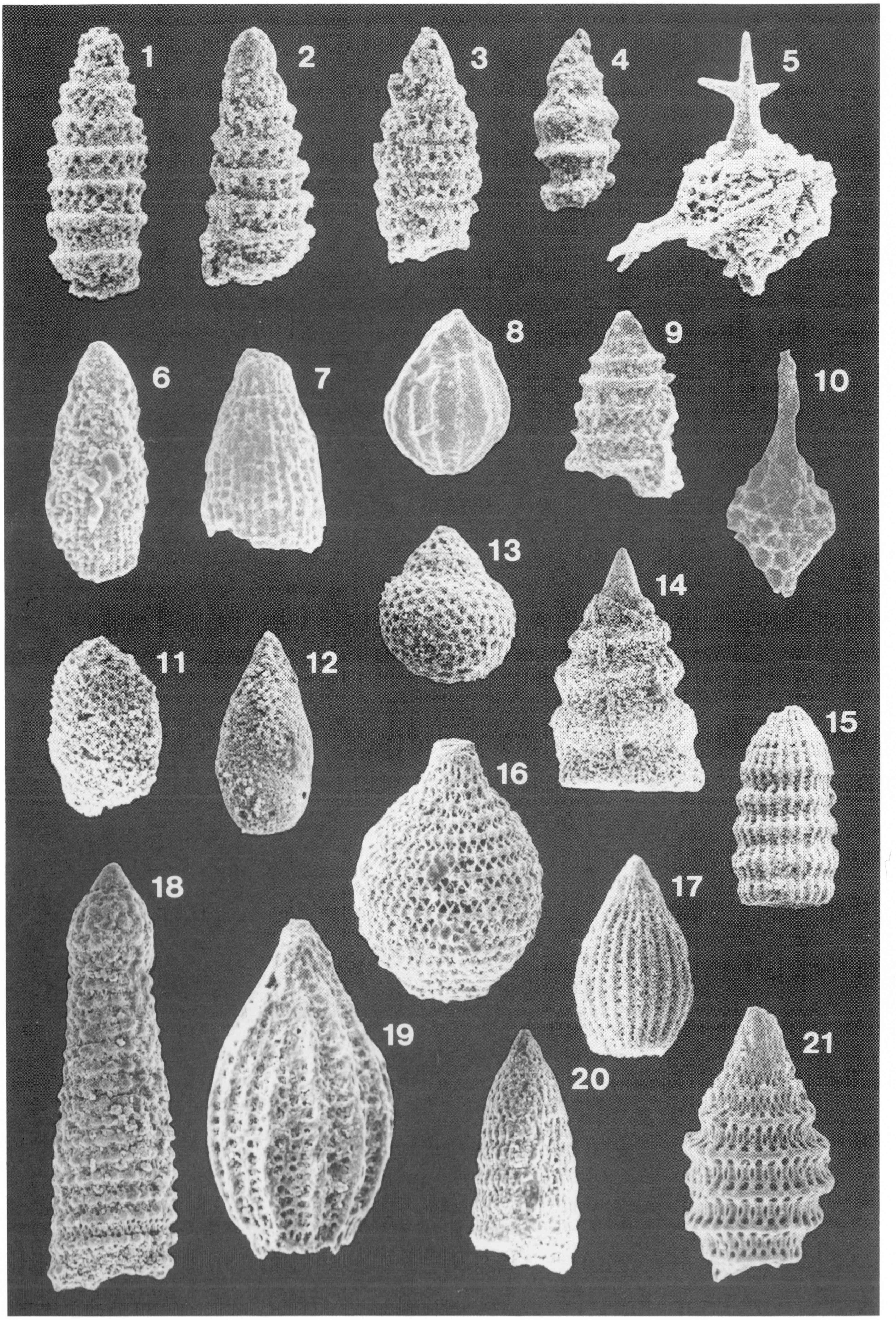

PLATE 1

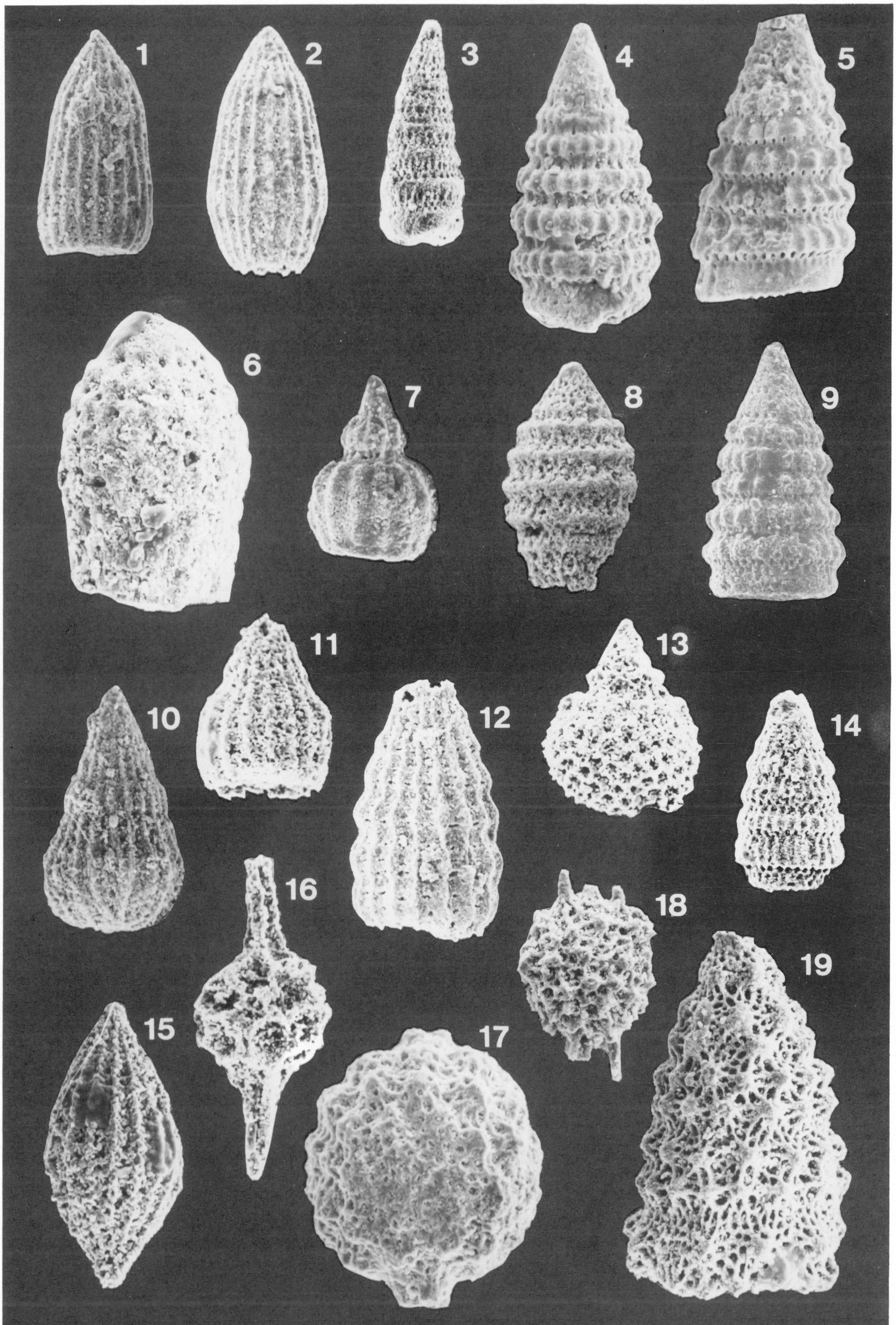

PLATE 2

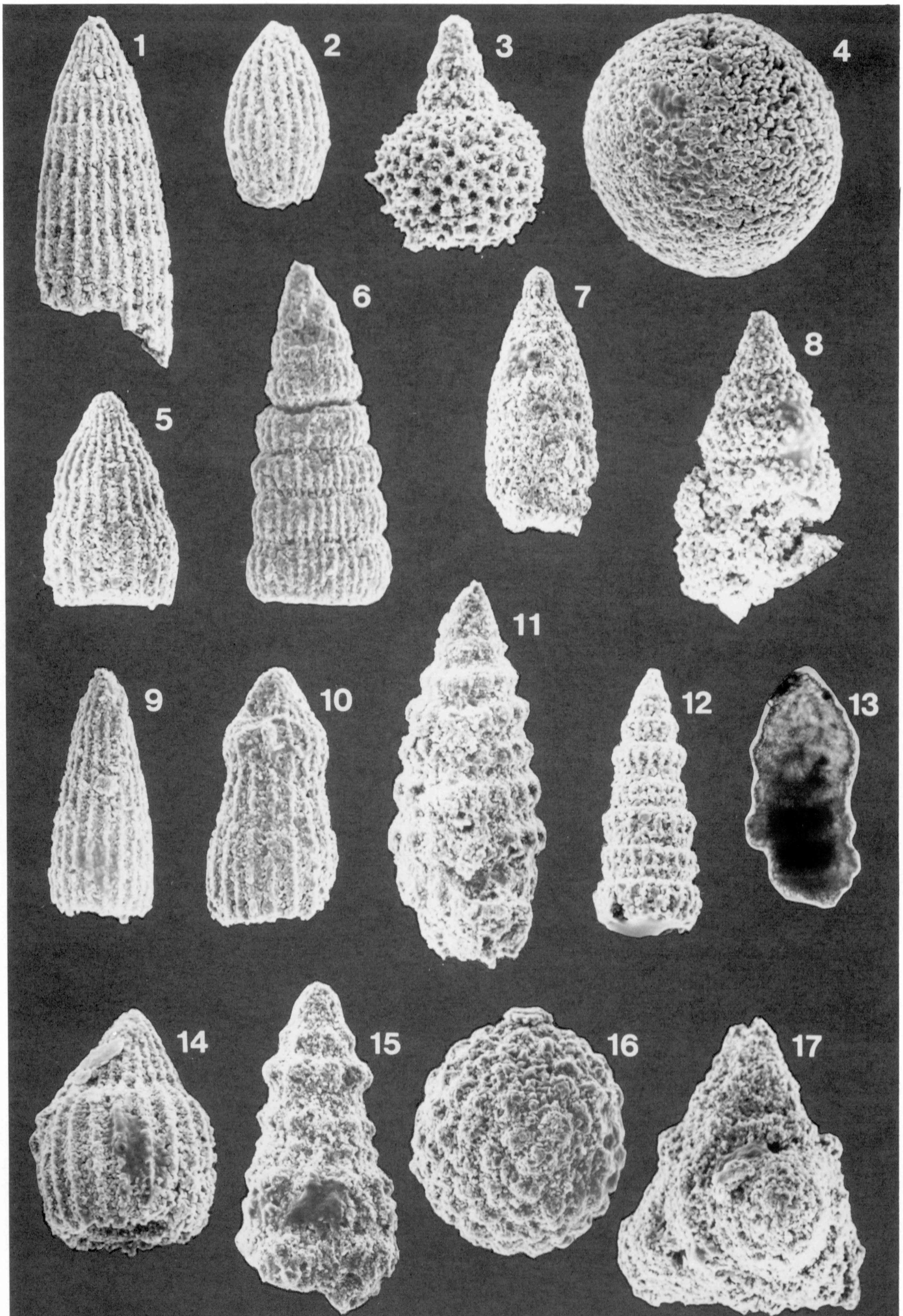

PLATE 3

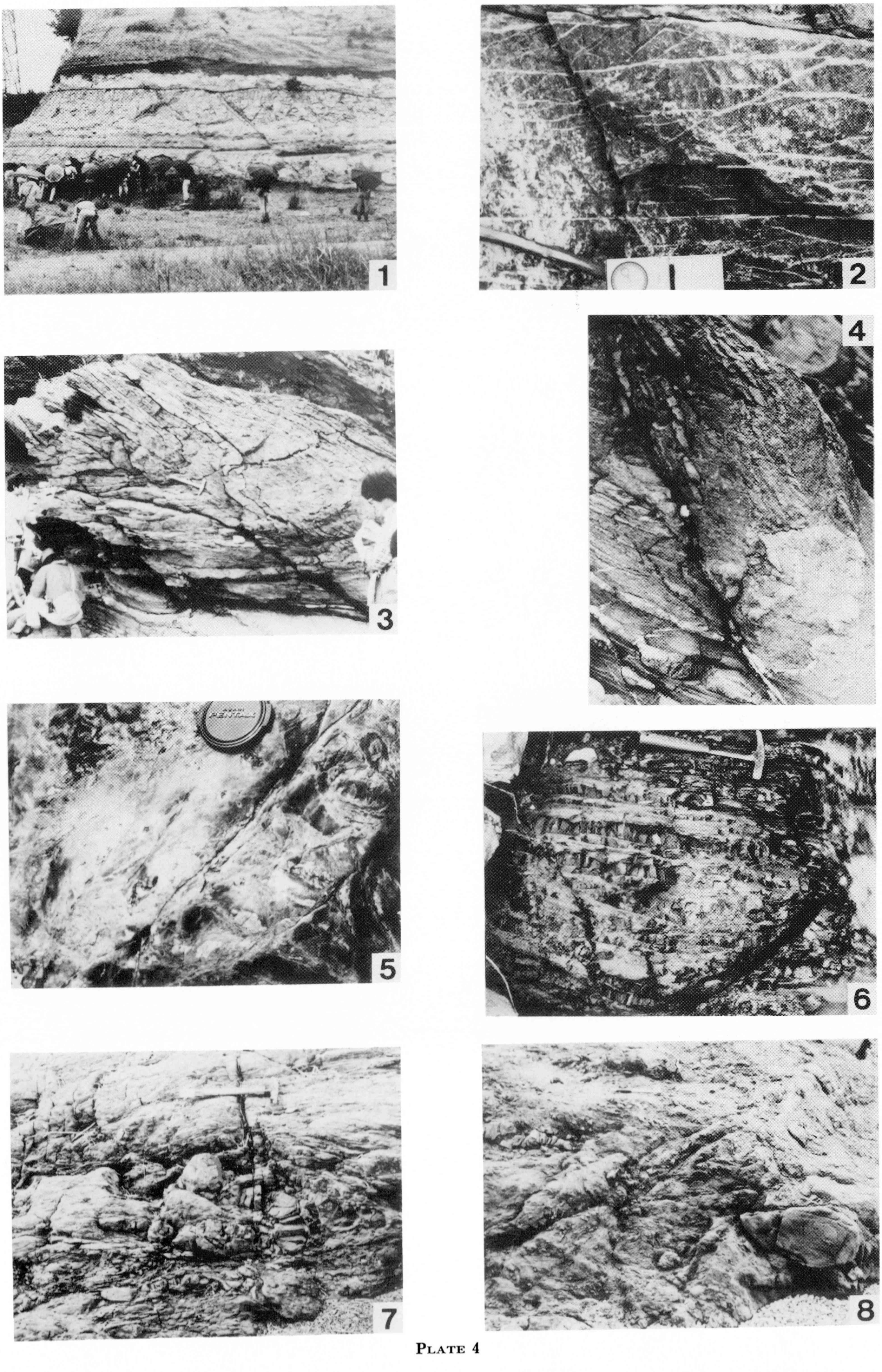

PLATE 4

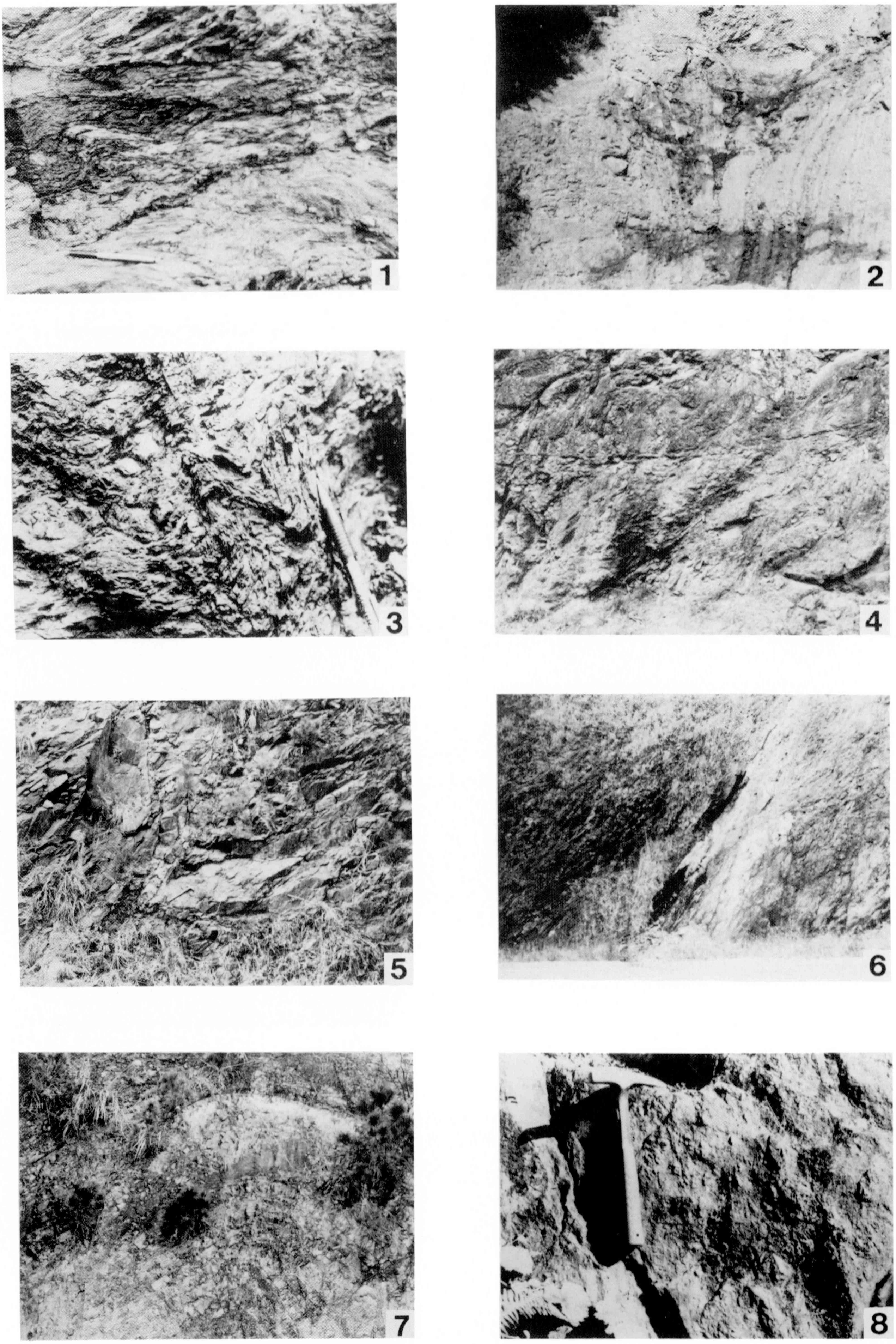

Plate 5