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Origin of chaotically mixed rock bodies in the Early Jurassic to Early Cretaceous sedimentary complex of the Mino terrane, central Japan

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Abstract: The Mino terrane, one of the disrupted terranes in Japan, is characterized by heterogeneous assemblage of chaotically mixed rock bodies (melanges) and coherent stratigraphic sequences. The sedimentary complex is divided into the following six tectonostratigraphic units in the central part of the Mino terrane on the basis of composition, fabric, age and structure.

(1) Sakamoto-toge unit:

Early to Middle Jurassic melanges marked by the occurrence of limestone clasts of Carboniferous to Permian age,

(2) Samondake unit:

Late Early Jurassic to late Middle Jurassic coherent stratigraphic sequences of massive sandstone and turbidite, including a small amount of chert blocks only at its lower part,

(3) Funafuseyama unit:

Stacked slices of Middle Jurassic melanges and disrupted turbidites frequently associated with slices of greenstone, limestone and chert of Permian age,

(4) Nabi unit:

Stacked slices of Middle Jurassic to early Late Jurassic turbidite disrupted to varying degrees, associated with slices of Triassic chert, Jurassic massive sandstone and melanges of unknown age,

(5) Kanayama unit:

Late Jurassic (?) to Early Cretaceous melanges including clasts of sandstone, chert, siliceous shale, greenstone and limestone in weakly foliated shale matrix,

(6) Kamiaso unit:

Stacked slices, each of which consists of coarsening-upward succession including Early Triassic (?) "Toishi-type" siliceous shale, Middle Triassic to Early Jurassic bedded chert, Middle Jurassic siliceous shale, dark gray shale, and early Late Jurassic (?) turbidite and massive sandstone in ascending order.

The Sakamoto-toge, Samondake and Funafuseyama units can be correlated to Type II suite of the Tamba area, while the Nabi, Kanayama and Kamiaso units can be compared to Type I suite of the Tamba area.

Of these, the origin of the melanges in the Kanayama unit was investigated in detail by using the criteria such as (1) the relationship to surrounding units, i.e., the contact and ages and lithologies of components, (2) the shape of rock

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bodies, (3) the nature of matrix and clast, (4) the contact features of clast and matrix, and (5) the reconstructed succession of protolith from which the clasts of the melange were derived. Several lines of evidence indicate that the melange of the Kanayama unit is of diapiric origin.

The lithologic features as well as the occurrence of these units show that the sedimentary complex of the Mino terrane is regarded as an ancient accretionary wedge along the western Pacific margin.

The present features of the melanges of the Kanayama unit were caused by progressive process of the fragmentation and mixing, including the diapiric, sedimentary and tectonic process in the ancient accretionary wedge.

INTRODUCTION

The disrupted terranes including chaotically mixed rock bodies such as melanges are widely distributed in the Circum-Pacific region. Detailed structure of each disrupted terrane is poorly understood, because chaotically mixed rock bodies and coherent stratigraphic sequences occur together, combined in a complicated manner in these areas. The origin of chaotically mixed rock bodies in such disrupted terranes and their tectonic significance are controversial, despite their world-wide distribution.

This works is an attempt to clarify the geology of the Early Jurassic to Early Cretaceous sedimentary complex of the Mino terrane, one of the disrupted terranes in Japan, and to present a concept regarding the paleotectonic process which formed the sedimentary complex. This will be based on the discussions relating to the origin of chaotically mixed rock bodies.

The sedimentary complex of the Mino terrane is composed of sandstone, shale, chert, siliceous shale, limestone and greenstone with a small amount of conglomerate. The rocks and the stratigraphy of the terrane were studied and they were previously regarded as constituting normal stratigraphic sequences.

During the past two decades, however, new biostratigraphic tools, i.e. conodonts and radiolarians, became available for age determination of the sedimentary complex in the Mino terrane (e.g. KOIKE *et al.*, 1971; MIZUTANI *et al.*, 1981). Radiolarians and conodonts revealed the geologic ages of shale, siliceous shale, chert and limestone at a number of localities in the Mino area, central part of the Mino terrane.

The results of biostratigraphic studies show that there are two types of rock arrangement in the sedimentary complex (WAKITA, 1985). One can be called "stacked slices". Each slice consists of coarsening-upward succession (KANO, 1979; YAO *et al.*, 1980; OTSUKA, 1985), composed successively of Early (?) Triassic siliceous shale, Middle Triassic to Early Jurassic bedded chert, Middle Jurassic siliceous shale, late Middle Jurassic shale and younger (early Late Jurassic ?) turbidite and massive sandstone. The other is "chaotically mixed rock bodies" containing fragments, blocks and slabs of Early Carboniferous to Late Permian limestone, Early Permian to Early Jurassic (Late Jurassic) bedded chert, Permian to Triassic (Jurassic ?) greenstone, enclosed in Early Jurassic to Early Cretaceous sandstone and shale (e.g. HATTORI and YOSHIMURA, 1979, 1982, 1983; MIZUTANI, 1981; WAKITA and OKAMURA, 1982; WAKITA, 1982, 1983, 1984, 1985, 1987, 1988; ADACHI and KOJIMA, 1983; KOJIMA, 1984; YAMAMOTO, 1985; WAKITA and ISOMI, 1986).

During the past decade, a number of authors (e.g. KANO, 1979; WAKITA, 1983) have stressed that submarine sliding was the main cause of the chaotically mixed rock bodies, and have called them "olistostromes", because the shale matrix of the mixtures is not very strongly sheared. They discussed whether they are tectonic or sedimentary in origin, as HSÜ (1968) did for the Franciscan complex. In recent years, the possibility of mud diapirs in the genesis of chaotically mixed rock bodies such as melanges has been recognized by several authors (e.g. WILLIAM *et al.*, 1984 ; BARBER *et al.*, 1986).

In this report, I will adopt several criteria to distinguish between the two possible origin (i.e. diapiric and sedimentary) of the chaotically mixed rock bodies of the Mino terrane. The criteria are (1) the age, shape and lithology of the clasts, (2) the nature of the matrix, (3) the contact features of the clasts with the matrix, and (4) the contact features between the chaotically mixed rock body and its surroundings.

Since 1977, I have been studying the sedimentary complex in the Mino area in conjunction with the quadrangle sheet mapping project of the Geological Survey of Japan. The major focus of my research has been radiolarian biostratigraphy and the study area covers approximately 1000 km^2, including parts of the Mino and Hida terranes with the Circum-Hida Tectonic Zone in between. The lithology, age, fabric and structure of the rock-assemblages in the sedimentary complex of the Mino terrane were examined in detail. Of over 700 rock samples collected, 157 samples yielded diagnostic species of radiolarians and conodonts, and about 200 samples offered a clue as to the geologic age of the samples from which microfossils had been extracted.

These lithostratigraphic and biostratigraphic studies of mine have revealed that the sedimentary complex of the Mino terrane contains not only "stacked slices" and "chaotically mixed rock bodies" but some other admixtures of rocks. I will propose a new division of the complex into six tectonostratigraphic units on the basis of lithology, age, structure and mode of mixing, describe each unit in detail, and then discuss the origin of the chaotically mixed rock bodies.

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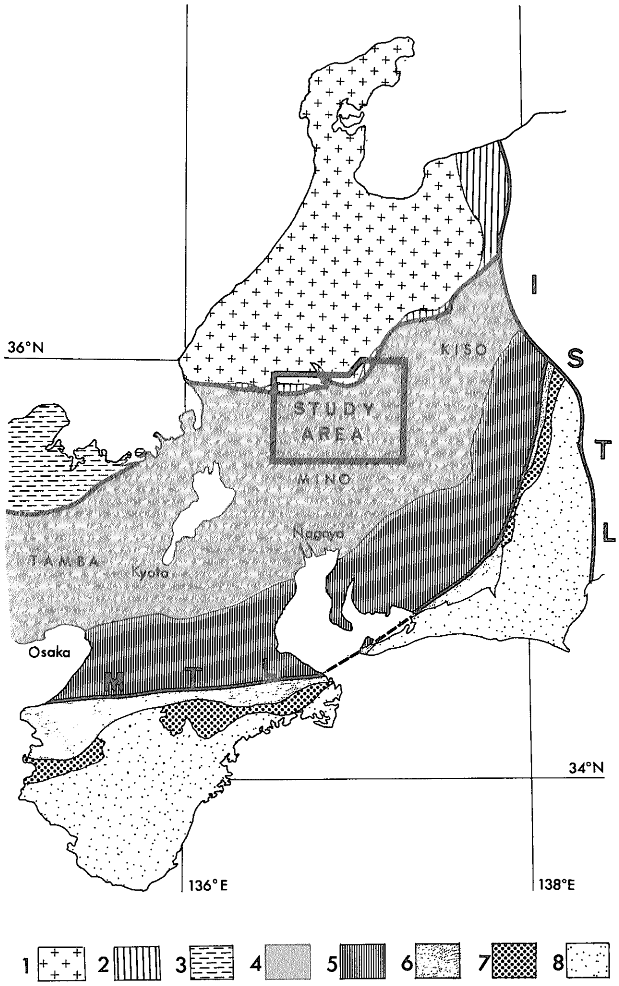


Fig. 1 Tectonic framework in central Japan and location of the study area.
1. Hida terrane, 2. Circum-Hida Tectonic Zone, 3. Chugoku composite terrane, 4–5. Mino terrane (4. unmetamorphosed sedimentary complex, 5. Ryoke metamorphic complex), 6. Sambagawa metamorphic terrane, 7. Chichibu terrane, 8. Shimanto terrane, MTL : Median Tectonic Line, ISTL : Itoigawa-Shizuoka Tectonic Line.

of the melange.

GEOLOGIC SETTING

The study area is located in the central part of the Mino terrane, central Japan (Fig. 1). The sedimentary complex of the Mino terrane comprises sandstone, conglomerate, shale, siliceous shale, chert, limestone and greenstone. Terrigenous clastic rocks such as sandstone, shale, conglomerate and siliceous shale are of Early Jurassic to earliest Cretaceous age, while most of chert, limestone and greenstone are of Permian to Triassic age and they occur in blocks or slabs embedded in the terrigenous rocks. The sedimentary complex gradually grades into the high T/low P type metamorphic rocks (the Ryoke Metamorphic Rocks) in the south.

The Mino terrane is situated to the south of the Hida terrane, the Circum-Hida Tectonic Zone and the Chugoku composite terrane, and to the north of the Sambagawa, Chichibu and Shimanto terranes (Fig. 1). In the study area, the sedimentary complex of the Mino terrane is bordered to the north by the southern margin of the Hida terrane or by the Circum-Hida Tectonic Zone by major faults.

The Hida terrane consists largely of metamorphic rocks such as gneiss, amphibolite and crystalline limestone, and granitic rocks. Many isotopic ages of gneiss samples are clustered around 180 and 240 Ma (SHIBATA *et al.*, 1970) which provide the ages of the latest two metamorphic events. Isotopic ages of granites are clustered also around 180 Ma. Recently, SHIBATA and NOZAWA (1986) reported that Rb-Sr model ages of some other granite samples which are intruded into the surrounding gneissose rocks are about 1100, 700 or 300 Ma. This evidence suggests that part, if not all, of the gneiss of the Hida terrane is of Precambrian age. On the other hand, the Hida terrane includes schistose rocks derived from Paleozoic sedimentary formations ; the evidence for this is the occurrence of Carboniferous fossils in crystalline limestone of the Hida area (HIROI, 1978).

The Circum-Hida Tectonic Zone is characterized by the occurrence of non-metamorphosed Ordovician, Silurian, Devonian, Carboniferous and Permian shallow marine sedimentary rocks, chloritoid phyllite and schistose rocks (greenschist—glaucophane schist facies) of 300−400 Ma. They are tectonically squeezed and embedded in serpentinite.

Lower Jurassic molasse-type sediments, called the Kuruma Group, unconformably overlies a part of the pre-Jurassic rocks of the Circum-Hida Tectonic Zone. The Tetori Group, Middle Jurassic−Early Cretaceous shallow marine to non-marine molasse-type sediments, is an overlap sedimentary cover on the Hida terrane and the Circum-Hida Tectonic Zone.

During Cretaceous to Paleogene time, large bodies of rhyolite and granite were extruded or intruded discordantly into the complexes of the Mino terrane, the Circum-Hida Tectonic Zone and the Hida terrane. Most of the radiometric ages of the rhyolite and granite fall within a range of 100−50 Ma. Some of the granite samples accompanied with the Ryoke Metamorphic Rocks show the ages of 120−100 Ma.

STATEMENT OF THE PROBLEM

Concept

A normal geologic concept of successive accumulation of strata is not effective for understanding the sedimentary complex of the disrupted terranes like the Mino terrane. Normal stratigraphic sequences and chaotically mixed rock bodies (melanges) of various sizes occur in a complicated fashion in the Mino terrane. Stratigraphic classification, e.g. group, formation and member, is not suitable for the study of heterogeneous assemblages of stratigraphic sequences and melanges.

The sedimentary complex of the Mino terrane should be investigated by the approach which HSÜ (1968) and HSÜ and OHRBOM (1969) recommended for the Franciscan melange. The approach is

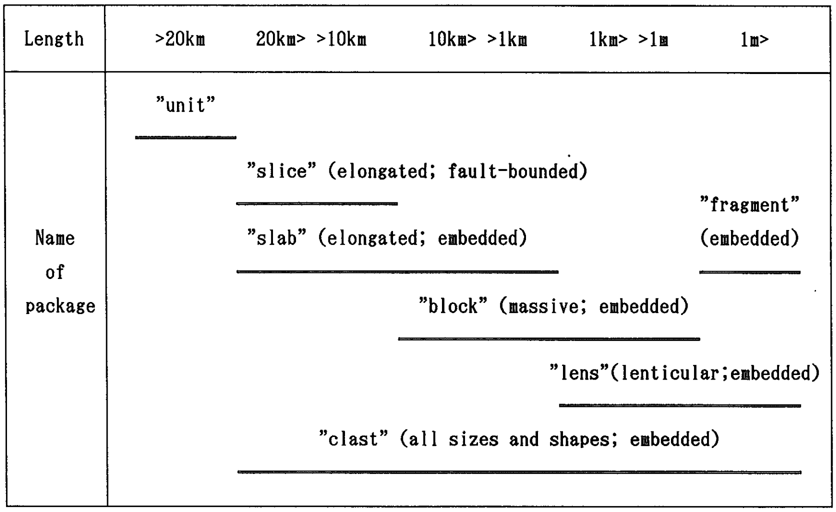


Fig. 2 Name of package.

the same as that of the study of the clasts in conglomerate or breccia by attempting (1) to recognize lithologically distinct clasts, (2) to date or assign an age to the clasts on the basis of fossils or other criteria, and (3) to relate the clasts sequentially on the basis of probable ages and origins.

In this report, I will adopt the concept "*package*" for describing and recognizing a complicated geologic entity characterized by combinations of stratigraphic sequences and chaotically mixed rock bodies. A basic element "*package*" in the concept is defined as a set of rocks surrounded by sharp boundaries. All geologic entities can be described with components, sizes and interrelationship of packages.

There are three types of packages identified in this area : i.e. stratigraphic, chaotic and composite packages on the basis of the types of the components. A "*stratigraphic package*" consists of a stratigraphic sequence, e.g. a turbidite formation. A "*chaotic package*" consists of a chaotically mixed rock body like melange, and it includes smaller-sized stratigraphic packages embedded within shale matrix. A "*composite package*" means a lithologic assemblage of smaller-sized packages.

The packages are divided, according to size, shape and relation, into "*unit*" (>20 km long), "*slice*" (20 km to 10 km long, fault-bounded), "*slab*" (1 km–20 km ; elongated ; embedded), "*block*" (>1 m long ; massive), "*lens*" (<1 m long, lenticular), and "*fragment*" (<1 m across) (Fig. 2).

Six types of interrelationship are recognized between two packages as follows.

(1) "*embedded*" ; smaller-sized packages are embedded within surroundings, all of which constitute another larger-sized package,

(2) "*intercalated*" ; a smaller-sized package is intercalated within a larger-sized package,

(3) "*fault-bounded*" ; a package is in fault contact with another package,

(4) "*interfingering*" ; a package interfingers with another package,

(5) "*intruded*" ; a package is intruded into another package,

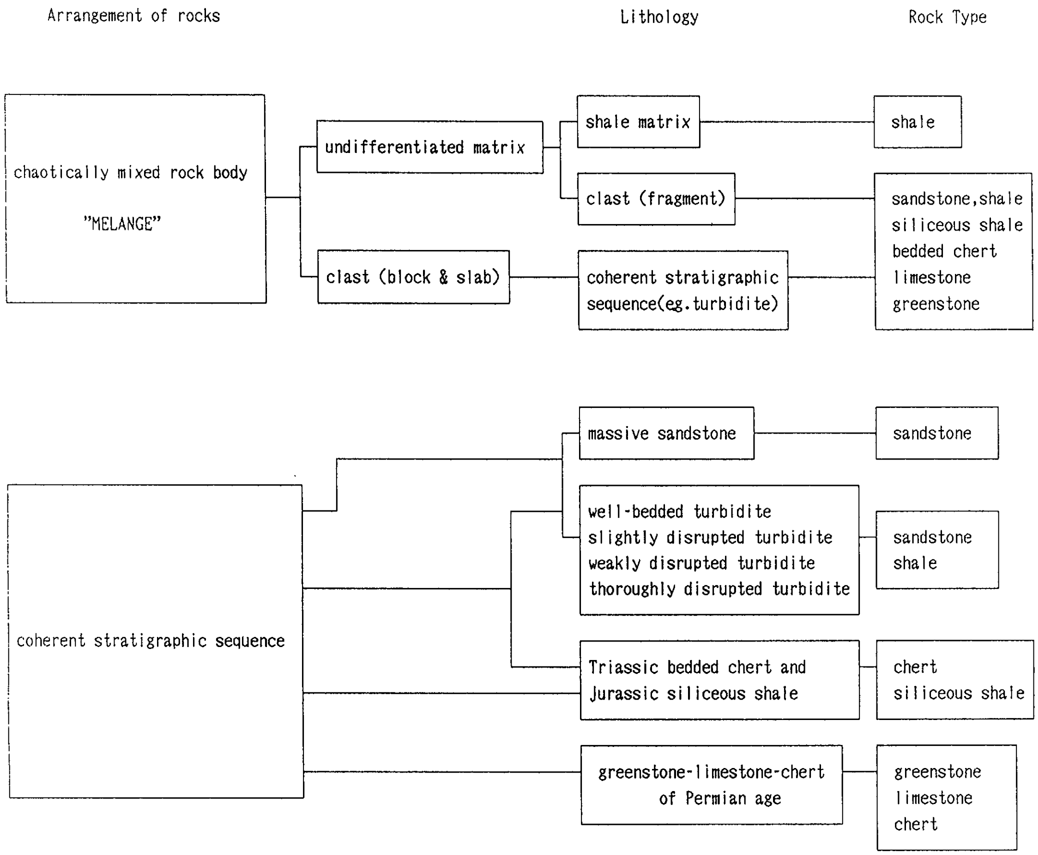


Fig. 3 Main assemblage of rocks in the Mino terrane.

(6) "*stratigraphic*" ; a package overlies or underlies another package conformably or unconformably.

The geology of the sedimentary complexes in disrupted terranes should be investigated on the basis of lithology, age, fabric, structure and size of each package, and interrelationship between adjoining packages, and thus the geology of the complexes will be described.

Main Assemblages of Rocks in the Mino Terrane

The sedimentary complex of the Mino terrane in the study area consists of sandstone, shale, siliceous shale, chert, limestone and greenstone with a small amount of conglomerate. These rocks constitute a number of packages showing a variety of lithology, age, fabric and structure. The following six main assemblages of rocks are recognized in this sedimentary complex (Fig. 3).

A chaotically mixed rock body

Melange

"*Melange*" is a rock body which includes a number of "clasts" of sandstone, shale, siliceous shale, bedded chert, limestone and greenstone embedded in weakly foliated matrix (Plate III-3, 4, 5, 6). In this report, "*melange*" is used as a descriptive term, and is defined as a mappable and non-stratigraphic rock body characterized both by the lack of internal continuity of contacts or of strata and by the inclusion of clasts embedded in shale matrix.

"*Clast*" means inclusions of all sizes and shapes embedded in shale matrix. The "*clast*" ranges in size from a millimeter to several kilometers, and it is also called "*slab*" (>1 km; elongated), "*block*" (>1 m; massive), "*lens*" (<1 m; elongated), and "*fragment*" (<1 m; of various shapes) which represent the sizes and shapes of clasts as well as those of packages. Large-sized clasts such as slabs and blocks often consist of coherent stratigraphic sequences, while small-sized clasts such as lenses and fragments are usually composed of a single rock type.

Coherent Stratigraphic Sequence

Turbidite and massive sandstone

Turbidite and massive sandstone are the most important lithology in the Mino terrane. "*Turbidite*" is often well-bedded, e.g. thin- to thick-bedded (Plate, I-2, 3). Proportion of sandstone to shale is high in the medium- to thick-bedded turbidite and is low in the thin-bedded turbidite. "*Massive sandstone*" (Plate I-1) is a coarse-grained sandstone bed thicker than 5 m, locally showing composite grading.

Turbidite disrupted to various degrees

Disrupted turbidite is a sequence composed of sandstone and shale which are originally interbedded with each other, and shows various fabrics of disruption; —"*slightly disrupted turbidite*" (Plate I-4) cut by a normal fault system, "*weakly disrupted turbidite*" (Plate I-5, 6) mildly deformed in a ductile manner retaining internal stratal continuity; and "*thoroughly disrupted turbidite*" (Plate II-1, 2) showing block-in-matrix texture without internal stratal continuity.

These disrupted sequences constitute a stratigraphic succession within packages, and they grade into undisrupted turbidite laterally as well as vertically in a succession. Even in a case that a sequence is thoroughly disrupted, it grades into an undisrupted one vertically and laterally through a facies of weakly disrupted sequence.

Most of these clastic bodies in the Mino terrane are entirely deficient in fossil evidence, and they are said to be deposited in Jurassic time. In fact, Middle to Late Jurassic ammonites have been reported exceptionally to occur in the study area (SATO, 1974; SATO *et al.*, 1985). Moreover, early Late Jurassic radiolarians are obtained from shale in the disrupted turbidite (see Table 5).

Jurassic siliceous shale and Triassic bedded chert

Triassic bedded chert and overlying Jurassic siliceous shale often constitute a large-sized package. Locally, the bedded chert—siliceous shale sequence underlies the Jurassic massive sandstone and turbidite, and overlies Early Triassic (?) "Toishi-type" siliceous shale.

Permian bedded chert, limestone and greenstone

Limestone, greenstone and bedded chert of Permian age are intimately associated with one another, and often constitute a large-sized package.

Unit Recognition

A "*unit*" is defined as the largest-sized lithostratigraphic package. It is composed of a single rock assemblage or a combination of main packages and associated packages. A main package is formed by characteristic sequences having distinct lithology, age, fabric and

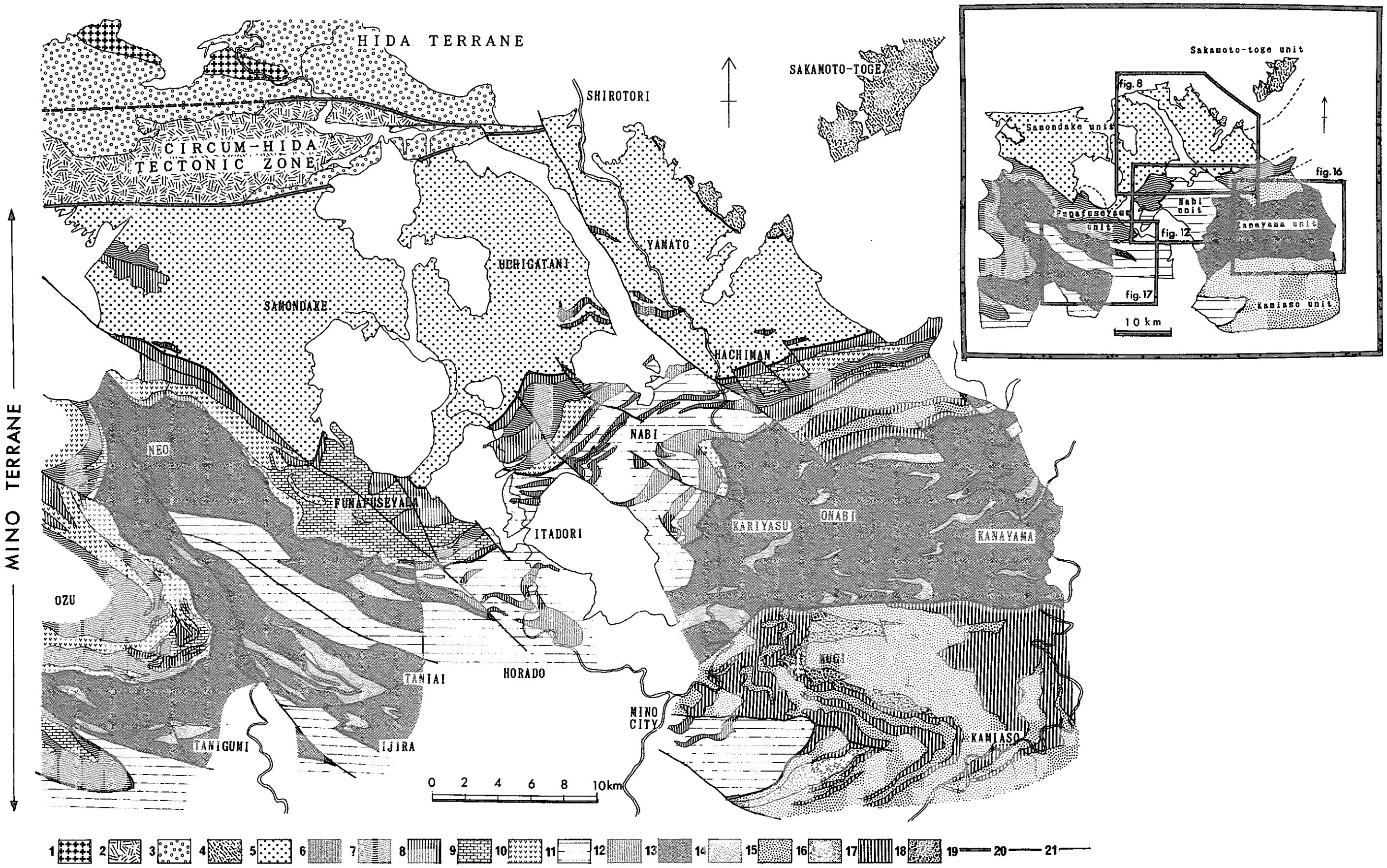
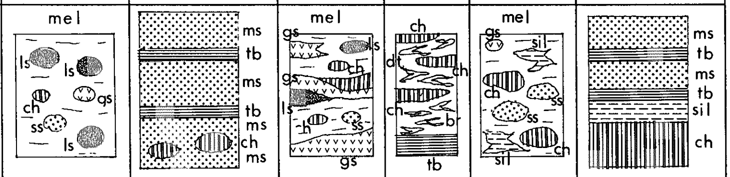


Fig. 4 Generalized geologic map of the study area showing distribution of six units.
1. gneiss of the Hida terrane, 2. Paleozoic strata of the Circum-Hida Tectonic Zone, 3. Tetori Group (overlap sediments on the Hida terrane and the Circum-Hida Tectonic Zone), 4–17. Mino terrane, 4. Sakamoto-toge unit (melange), 5–6. Samondake unit (5. massive sandstone and turbidite, 6. bedded chert), 7–10. Funafuseyama unit (7. melange and weakly disrupted turbidite, 8. bedded chert, 9. limestone, 10. greenstone), 11–12. Nabi unit (11. variously disrupted turbidite, 12. bedded chert), 13–14. Kanayama unit (13. melange matrix: dominantly pelitic, with small clasts, 14. bedded chert), 15–18. Kamiaso unit (15. massive sandstone and turbidite, 16. siliceous shale, 17. bedded chert, 18. Wadano conglomerate), 19. terrane boundary, 20. unit boundary, 21. fault. White part is undivided part of the sedimentary complex of the Mino terrane, Late Cretaceous rhyolite and Quaternary andesites.

	Sakamoto toge unit	Samondake unit	Funafuse-yama unit	Nabi unit	Kanayama unit	Kamiaso unit
Age of shale	Pli-Toa	Bath-Cal	Bath?	Oxf	Oxf-Ber	Cal
Rads in shale	Pg	Ue - Gn	(Hh-Ue)	GS	GS - Pc	Gn
Rads in siliceous sh.	Ue-(Gn)	Pg - Ue	Hh-Ue	Ue-Gn	Gn - Pc	Pg - Gn
Age of chert	E-M TR	MP - LTR	MP - MTR	M-L TR	MTR - LJ	MTR -EJ
Ammonite		Kepplerites				Choffatia
Massive sandstone	----	◎	----	△	△	◎
Well-bedded turbidite	----	◎	----	○	△	◎
weakly disrupted turbidite	△	△	○	◎	△	△
thoroughly disrupted turbidite	△	△	△	○	△	----
Melange	◎	----	◎	△	◎	----
Chert slab and slice	----	----	○	◎	○	◎
Chert block	△	basal part	○	△	◎	----
Greenstone slab	----	----	◎	△	----	----
Greenstone block	○	----	◎	----	△	----
Limestone block	◎	----	○	△	△	----
Length-slow chalcedony	◎	----	----	----	----	----
Idealized succession						
Mode of contact with adjacent unit	fault	depositional	fault	fault	intrusion	fault

Age	Pli:Pliensbachian, Toa:Toarcian, Bath:Bathonian, Cal:Callovian, Oxf:Oxfordian, Ber:Berriasian, E:Early, M:Middle, L:Late, P:Permian, TR:Triassic, J:Jurassic
Radiolarian Assemblage	Td:Triassocampe deweveri Assemblage, Tn:Triassocampe nova Assemblage, Ct:Canoptum triassicum Assemblage, Ps:Parahsuum simplum Assemblage, Ah:Acanthocircus hexagonus Assemblage, Pg:Parahsuum (?) grande Assemblage, Hh:Hsuum hisuikyoense Assemblage, Ue:Unuma echinatus Assemblage, Gn:Guexella nudata Assemblage, GS:Gongylothorax sakawaensis - Stichocapsa naradaniensis Assemblage Ty:Tricolocapsa yaoi Assemblage, PP:Pseudodictyomitra primitiva - Pseudodictyomitra sp. A Assemblage, Pc:Pseudodictyomitra cf. carpatica Assemblage
Rock Type	mel:melange, dt:disrupted turbidite, tb:turbidite, ms:massive sandstone, sh:shale ss:sandstone, sil: siliceous shale, ch:chert, ls:limestone, gs:greenstone Mn:manganese carbonate nodule

Fig. 5 Characteristics of six units in the study area.

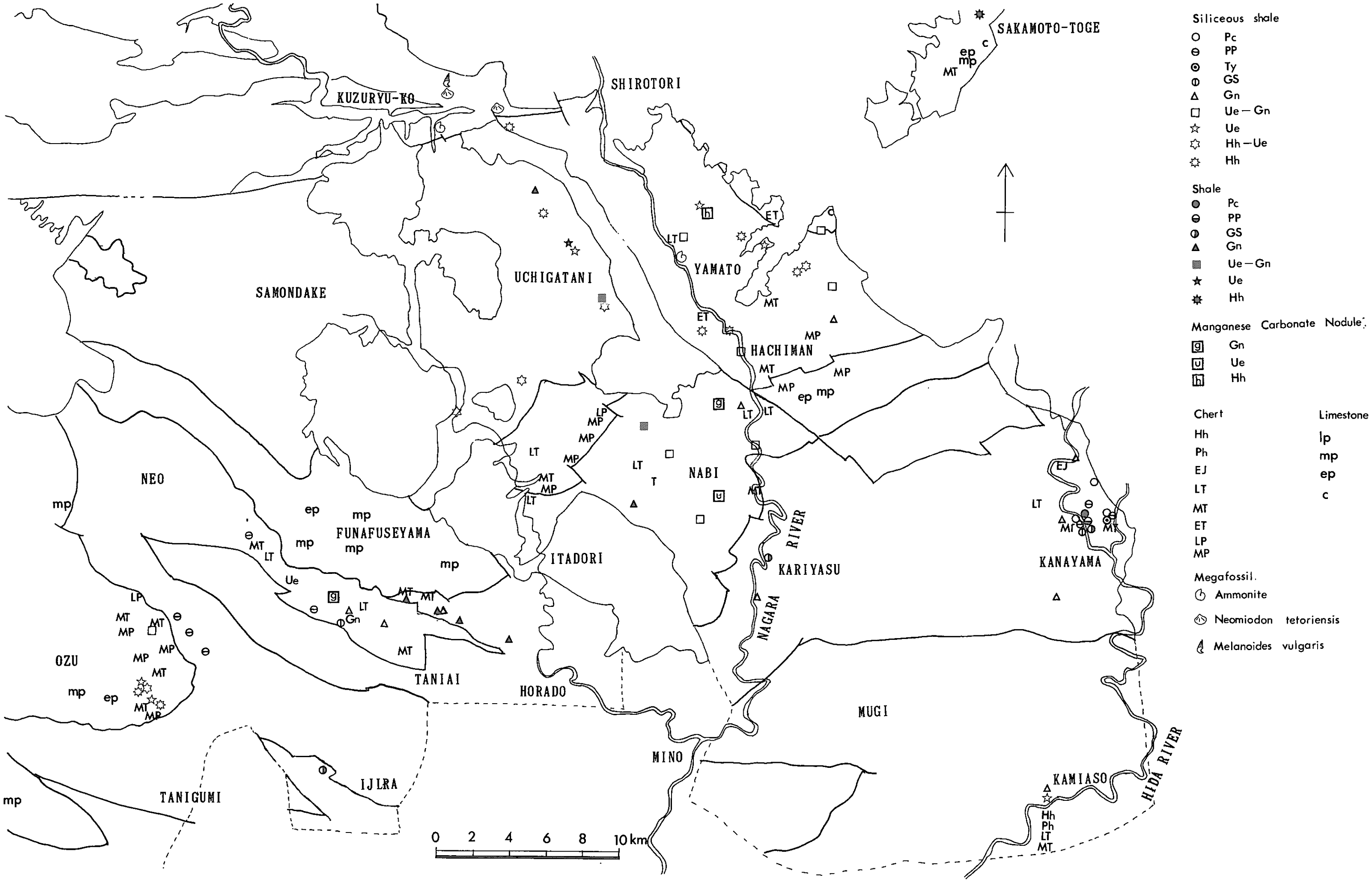


Fig. 6 Main fossil localities in the study area

structure, while associated packages intimately accompany the main one and consist of another assemblage different from the main package in lithology and fabric.

Six tectonostratigraphic units have been recognized on the basis of lithologic assemblage and biostratigraphic data in the study area of the Mino terrane; they are (1) Sakamoto-toge unit, (2) Samondake unit, (3) Funafuseyama unit, (4) Nabi unit, (5) Kanayama unit, and (6) Kamiaso unit (Fig. 4), as summarized in Figure 5.

The Samondake, Nabi, and Kamiaso units are mainly composed of coherent stratigraphic sequences, whereas the Sakamoto-toge, Funafuseyama, and Kanayama units consist of chaotically mixed rock bodies.

The ages (see Fig. 6) and lithologies of the six units are as follows.

(1) Sakamoto-toge unit: Early to Middle Jurassic melanges including blocks and fragments of sandstone, siliceous shale, chert, limestone and greenstone in weakly foliated shale matrix,

(2) Samondake unit: Late Early Jurassic to late Middle Jurassic coherent stratigraphic sequences of massive sandstone and turbidite, including chert blocks in its lower part,

(3) Funafuseyama unit: Stacked slices of Middle Jurassic melanges and disrupted turbidite associated with slices of greenstone, limestone and chert of Permian age,

(4) Nabi unit: Stacked slices of Middle Jurassic to early Late Jurassic coherent stratigraphic sequences consisting of turbidite disrupted to varing degrees, associated with slices of Triassic bedded chert, Jurassic massive sandstone and melanges of unknown age,

(5) Kanayama unit: Late Jurassic(?) to Early Cretaceous melanges including clasts of sandstone, siliceous shale, chert, limestone and greenstone in weakly foliated shale matrix, and

(6) Kamiaso unit: Stacked slices of coherent stratigraphic sequences composed of Early(?) Triassic "Toishi-type" siliceous shale, Middle Triassic to Early Jurassic bedded chert, Middle Jurassic siliceous shale and dark gray shale, and early Late Jurassic turbidite and massive sandstone in ascending order.

Most of the above units are in fault contact with one another, but the Samondake unit unconformably and locally comformably overlies the Funafuseyama unit, while the contact feature of the Kanayama unit and the Nabi unit is "*interfingering*" in places.

Structure

The sedimentary formations in the study area are folded with a wavelength of 1 to 15 km (Mizutani, 1964; Yoshida, 1972; Adachi, 1976), mostly plunging to the west. The axial planes of the folds are vertical or steeply inclined.

Open folds are well observed in the geologic structures of the thick coarse-grained sequences of the Samondake and Kanayama units, and also of large slices of chert, greenstone, limestone and massive sandstone in the Nabi and Funafuseyama units. The sedimentary formations of the Samondake unit constitute a large synclinorium as a whole, while those of the Kamiaso unit form an antiform in the northern half and a synform in the southern one, both plunging to the west.

On the other hand, close- to tight-folds are observed in the melanges of the Sakamoto-toge, Funafuseyama, and Kanayama units. The wave-length of the folds ranges from 1 to 4 km. Mesoscopic folds are seen at numerous localities in the chaotically mixed rock bodies of these units.

The boundaries between two units, mostly fault planes, are usually folded together with the constituent packages of each unit, and can be called "folded fault". The boundary, however, between the Kanayama and Kamiaso units clearly cuts the northern limb of the antiform of the sequences of the Kamiaso unit and the southern limb of the synform of the Kanayama unit.

DESCRIPTION OF SIX TECTONOSTRATIGRAPHIC UNITS

Sakamoto-toge Unit

This is the oldest unit of the Mino terrane with Early to Middle Jurassic age. It is characterized by the wide distribution of melanges including clasts of Carboniferous to Permian limestone and greenstone, Triassic chert and Jurassic siliceous shale and sandstone in shale matrix. Particularly, Carboniferous limestone clasts are characteristic of this unit.

Distribution

The unit crops out at Sakamoto-toge and its vicinity, along the northern margin of the Mino terrane parallel to the Circum-Hida Tectonic Zone.

The Sakamoto-toge unit has been variously described as consisting of the Late Carboniferous Nohi Group (the Oppara and the Akiyama Formation) and the Permian Okumyogata and the Okuzumi Formations and a part of the Permian Kayugawa Formation by KANUMA (1958), the Jurassic Furumichi Formation by WAKITA (1984), and the Jurassic Sakamoto-toge Formation by

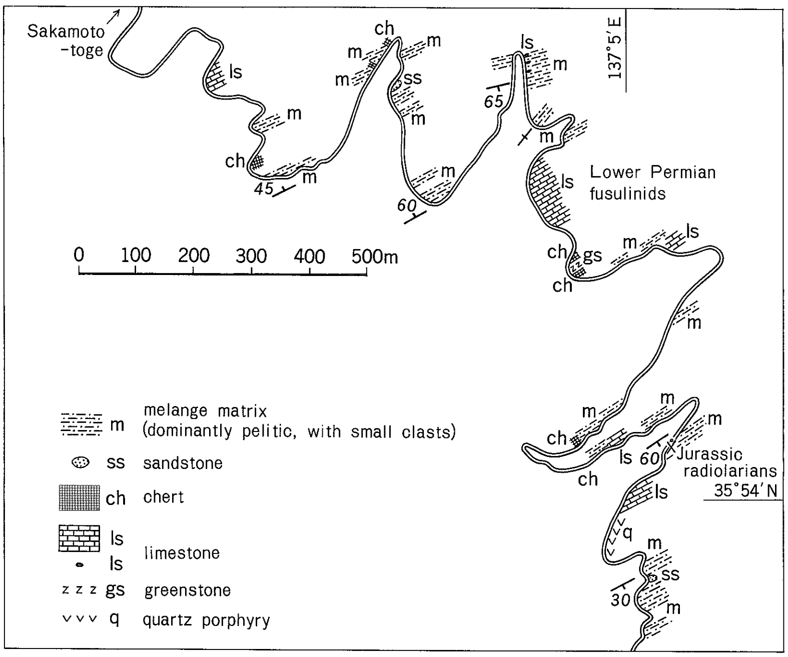


Fig. 7 Route map of the Sakamoto-toge unit at Sakamoto-toge, showing fossil localities.

KAWADA *et al.* (1988).

Contact between the Sakamoto-toge unit and the adjoining units

The Sakamoto-toge unit is in fault contact with the Samondake unit at Yamato, and is separated from the Paleozoic of the Circum-Hida Tectonic Zone by a terrane-boundary fault at Sakamoto-toge.

Lithology

The Sakamoto-toge unit consists mostly of melanges including clasts of sandstone, chert, greenstone and fossiliferous limestone in weakly foliated shale matrix (Fig. 7, Plate III-3). It also contains local intercalations of disrupted turbidites.

White to dark gray limestone is the dominant clasts ranging in size from 0.1 m to 200 m. KANUMA (1958) described the fusulinaceans of Late Carboniferous to Middle Permian age (*Fusulina*—*Fusulinella* zone to *Neoschwagerina* zone), which were obtained from limestone clasts at Sakamoto-toge (Fig. 7). WAKITA *et al.* (1981) reported the occurrence of Early Carboniferous heterocoral genera, *Hexaphyllia* and *Pentaphyllia* from a limestone clast at Hachiman. ISOMI (1988) discovered early Late Permian fusulinaceans of the *Yabeina* zone at 10 localities of Sakamoto-toge. These lines of fossil evidence suggest that the age of limestone ranges from Early Carboniferous to early Late Permian.

Chert is interbedded with much thinner shale partings. The chert and shale partings are gray, black, pale blue and reddish brown in color. The majority of chert clasts ranges from 2 to 300 m in thickness, but much smaller clasts sometimes occur at several localities. Triassic radiolarian genera, *Triassocampe* (WAKITA and ISOMI, 1986) and Early Triassic conodonts, *Gondollela regale*, *Neogondolella elongata* and *N. carinata* (WAKITA and OKAMURA, 1982) are obtained from chert clasts in the melange of this unit.

Siliceous shale is divided into well-bedded siliceous shale and a faintly laminated one. Bedded siliceous shale consists of dark greenish gray or dark reddish brown, 2–15 cm thick siliceous siltstone interbedded with much thinner shaly partings of the same color. Laminated siliceous shale is brownish gray and is less siliceous than bedded one. Middle Jurassic radiolarians, *Tricolocapsa plicarum* and *Dictyomitrella* (?) *kamoensis*, are obtained from siliceous shale clasts at Yamato.

Age of shale matrix

WAKITA and ISOMI (1986) reported Early and Middle Jurassic radiolarians such as *Dictyomitrella*(?) *kamoensis* and *Hsuum* spp. from the shale matrix at Sakamoto-toge. The radiolarian assigned to *Dictyomitrella*(?) *kamoensis* by WAKITA and ISOMI (1986) differs, however, from the original one described by MIZUTANI and KIDO (1983) in possessing one row of pores around the abdomen and post-abdominal chambers. And it is similar to *Parvicingula gigantocornis* of Early Jurassic rather than *Dictyomitrella*(?) *kamoensis*. Therefore, radiolarians obtained from shale at Sakamoto-toge are of Early Jurassic age (Table 1).

On the other hand, Middle Jurassic radiolarians are obtained from siliceous shale clasts at Yamato. Since siliceous shale occurs as clasts in melange, the age of the shale matrix is believed to be slightly younger than that of siliceous shale.

Thus, these fossils indicate that the

Fig. 8 Geologic map of the Samondake unit.
1. Middle ? Cretaceous Hayashidani andesites, 2–4. Tetori Group (2. Akaiwa Subgroup, 3. Itoshiro Subgroup, 4. Kuzuryu Subgroup), 5. Paleozoic strata and serpentinite, 6–12. Samondake unit (6. massive sandstone and turbidite, 7. massive sandstone and conglomerate, 8. turbidite, 9. weakly disrupted turbidite 10. shale, 11. siliceous shale, 12. bedded chert), 13–18. Funafuseyama unit (13. weakly disrupted turbidite, 14. sandstone, 15. siliceous shale, 16. bedded chert, 17. limestone, 18. greenstone), 19. Sakamoto-toge unit, 20. Nabi unit, 21. Kamiaso unit, 22. Quaternary andesites, 23–25. Late Cretaceous acid igneous rocks (23. rhyolite, 24. granites, 25. quartz porphyry), 26. Quaternary, 27. terrane boundary, 28. unit boundary, 29. fault

Table 1 Radiolarian and conodont fossils in the Sakamoto-toge unit.
Symbols are the same as in Figure 5. For localities of samples see WAKITA and OKAMURA (1982) and WAKITA and ISOMI (1986). #: conodont.

sample number	Locality	rock type	Assem-blage	Diagnostic species
R33534	Sakamoto-toge	ms	Pg	Parvicingula gigantocornis
No.173	Yamato	sil	Ue-Gn	T. plicurum
MA8505	Sakamoto-toge	ch	MTR	Triassocampe sp.
G689	Yamato	ch	ETR	Neogondolella elongata #

age of the melange formation in this unit ranges from Early to Middle Jurassic or slightly younger. Melanges including Carboniferous limestone clasts are also of Early or Middle Jurassic in the Mino terrane outside of the study area (HATTORI and YOSHIMURA, 1982; ADACHI and KOJIMA, 1983; KOJIMA, 1984; HATTORI, 1988).

Samondake Unit

This unit is characterized by high proportion of massive sandstone like the Kamiaso unit, and is distinguished from the latter by the lack of coarsening-upward succession (Fig. 5).

Distribution

The Samondake unit is widespread in the northern half of the study area (Fig. 4), and was mapped as the Samondake Formation by KAWAI (1964), as the Kayugawa Formation by KANUMA (1958) and as the Kodaragawa, Kajika and Samondake Formations by WAKITA (1984).

Contact between the Samondake unit and the adjoining units

Massive sandstone and turbidite of the Samondake unit appear to conformably overlie the siliceous shale—chert slab of the Funafuseyama unit at Iwamotobora and Itadori (WAKITA, 1984). Bedded chert of the Funafuseyama unit changes into coarse-grained clastic sequences such as turbidite and massive sandstone of the Samondake unit through Early or Middle Jurassic siliceous shale (WAKITA, 1982), and sandstone dikes occur in the upper part of bedded chert of the Funafuseyama unit. Such coarse-grained sandstones are rare near the chert slab of the Funafuseyama unit (WAKITA, 1984).

On the other hand, the coarse-grained clastic rocks of the Samondake unit are in contact with the Middle Permian bedded chert which constitutes a large slab of the Funafuseyama unit together with greenstone and limestone of Early to Middle Permian age at Hachiman. Basal part of the Samondake unit includes Middle Permian blocks associated with greenstone (WAKITA and OKAMURA, 1982). The position and occurrence of the Middle Permian block suggest that the Middle Jurassic sequences of the Samondake unit were deposited on or near the Permian slabs of the Funafuseyama unit. At Neo, the Samondake unit is in contact with bedded chert of unknown age, and includes several chert blocks only in the basal part. The chert blocks are probably derived from the adjoining chert slab of the Funafuseyama unit.

The occurrence of chert blocks and lithologic change in these three areas described above suggest that the Samondake unit conformably overlies at least a part of the Funafuseyama unit with local unconformities.

Lithology

The Samondake unit is composed mostly of massive sandstones and turbidites with intercalations of shale, laminated siliceous shale and conglomerate beds. It locally contains blocks of bedded chert and bedded siliceous shale

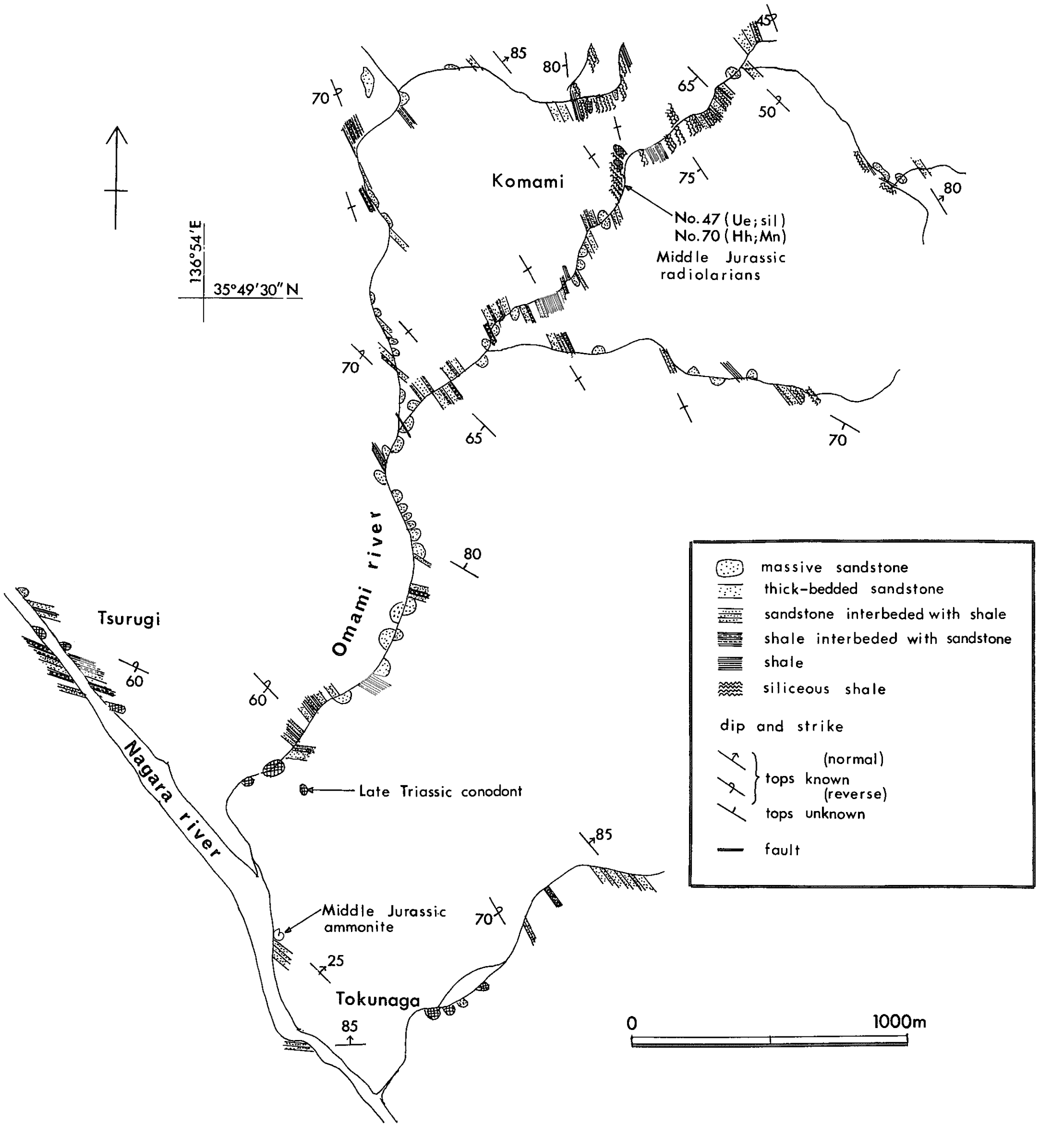


Fig. 9 Route map of the Samondake unit showing some fossil localities. Symbols are the same as in Fig. 5.

(Fig. 8).

The lower part of the sequence consists mainly of alternating beds of massive sandstone and undisrupted to weakly disrupted turbidite. It includes blocks of bedded siliceous shale and bedded chert with local intercalations of shale and laminated siliceous shale beds (Fig. 9). Blocks of bedded siliceous shale and bedded chert occur in the basal part, and are embedded commonly within the alternating beds of massive sandstone and weakly disrupted turbidite or within weakly disrupted turbidite.

The upper part of the Samondake unit is composed largely of massive sandstone and turbidite with interbeds of conglomerate in several localities. Turbidite is undisrupted and thin- to thick-bedded, showing various ratio of sandstone to shale.

Light to dark gray massive sandstone is commonly medium- to coarse-grained. Also there are local intercalations of very coarse-grained sandstone, grading up to granule size. The thickness of each bed generally ranges from 3 to 10 m, with occasional maximum of several tens of meters (Plate I-1). It appears homogeneous on the weathered surface, but amalgamation can be recognized on the fresh surface at some localities. Shale fragments of 3 to 20 mm in diameter are common, and are scattered throughout the massive sandstone beds.

Massive sandstone consists largely of angular to subrounded grains of subequal amounts of quartz and feldspars (about 40 percent each) and minor amounts of rock fragments, micas, heavy minerals and clayey matrix (about 12%). Twenty to fifty percent of the quartz grains show wavy extinction. Plagioclase, often stained with sericite, exceeds potassium feldspars (both orthoclase and microcline) in quantity. Heavy minerals are micas, garnet, zircon, sphene, tourmaline and opaque minerals. Rock fragments include shale, siltstone, felsic volcanic rocks, chert, limestone, basalt, granitic rocks, hypabyssal rocks, quartz-sericite schist, sillimanite gneiss and orthoquartzite.

Turbidite, ranging in thickness from 1

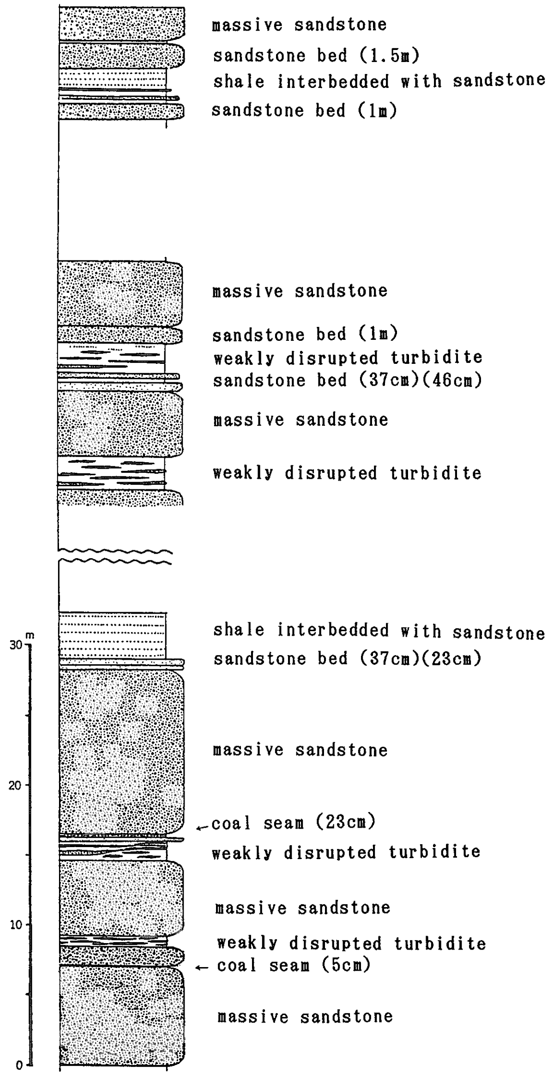


Fig. 10 Columnar section of a part of the Samondake unit (modified from WAKITA, 1984, Fig. 21).

to 20 m, alternates with massive sandstone (Fig. 10). The turbidite consists of gray, fine- to medium-grained sandstone and dark gray shale, and has a wide variety of sandstone-shale ratio. The thickness of sandstone and shale beds ranges from 1 to 100 cm (Plate I-2). Sandstone-dominant turbidite is mostly well-bedded and undisrupted, while shale-dominant one is weakly disrupted. In the latter case, sandstone layers display pinch-and-swell structure and sometimes occur in isolated lenses.

Sandstone beds sometimes show various sedimentary structures, e.g. graded bedding, parallel or cross- lamination and sole markings such as groove cast, flute cast and bounce cast. Petrified woods or carbonaceous fragments are contained in the top of some sandstone beds, showing preferred orientation. The paleocurrent directions inferred from woods, carbonaceous fragments and sole markings indicate that the clastic material was derived largely from the northwest. (WAKITA and OKAMURA, 1982).

Conglomerate is intercalated at several horizons in the upper part of the Samondake unit. Most of the conglomerate beds are thinner than 20 m except for those of the Kajika Formation (WAKITA, 1984). The intraformational conglomerate beds occur as lenticular bodies. They are composed largely of granules, pebbles and cobbles of sandstone, shale and biotite granite with minor amounts of granite porphyry, rhyolitic welded tuff, limestone, marl, chert, quartzo-feldspathic gneiss and sericite-quartz schist (Plate II-6).

Biotite granite exhibits cataclastic texture. Some limestone clasts yield fusulinaceans such as *Misellina* sp. (OKAMURA, 1980) and *Yabeina* sp. and *Codonofusiella sp.* (WAKITA, 1977).

The majority of clasts range form 2 to 10 cm in diameter, but larger ones (10–100 cm in diameter) are not rare. Most of the boulders are granite and sandstone. Clasts of granites or metamorphic rocks are mostly well-rounded, while those of clastics are angular to subrounded. The matrix of conglomerate is composed of medium- to coarse-grained gray sandstone.

Shale beds and shale-dominant formations of 1–200 m thick are locally interstratified in the coarse-grained clastic sequences. The shale is dark gray, laminated, weakly fissile, and rarely includes much thinner sandstone interbeds or lenses.

Siliceous shale is commonly well-bedded. Bedded siliceous shale is composed of gray, dark greenish gray or dark brown graded siliceous siltstone. It also contains much thinner pale yellowish green shale. Siliceous siltstone, commonly 3–30 cm thick, consists of plagioclase, quartz, biotite and clayey matrix which is often replaced with celadonite or chlorite.

Siliceous shale, not bedded but laminated, also occurs in some places, and grades into dark gray shale. Laminated siliceous shale is dark gray or dark green, and contains manganese carbonate nodules or lenses of 20–50cm in diameter.

Bedded siliceous shale often occurs as isolated blocks. Radiolarian biostratigraphy shows that this shale is slightly older than that of the surrounding sequence in the Samondake unit. Therefore, some of this shale may occur as exotic blocks embedded within the coarse-grained clastic sequences. On the other hand, the occurrence of the laminated siliceous shale must be in-situ formation, because it gradually changes into dark gray shale in both lateral and vertical directions.

Chert occurs as exotic blocks ranging from 5 to 400 m thick and from 20 to 3000 m long. Most of chert blocks are present in the lower part of the Samondake unit. Only two of them are associated with greenstone. Chert is white, light to dark gray, black and greenish gray in color, rhythmically bedded, and consists essentially of microcrystalline quartz and radiolarian skeletons. Each bed of chert ranges from 1 to 10 cm in thickness.

Wakita and Okamura (1982) reported Middle Permian conodont *Neostrept-gnathodus prei* and Early to Middle Permian radiolarians such as *Pseudo-albaillella* sp. from chert blocks. The Permian bedded chert constitutes a large block. The chert is associated

Table 2 Radiolarian fossils in the Samondake unit.
Symbols are the same as in Figure 5. See Wakita (1982) and Wakita and Okamura (1982) for localities of samples except for G 677 (Lat. 35°39′21″ ; Lon. 136°49′11″), G 1275 (Lat. 35°46′22″ ; Lon. 136°51′12″) and G420A (Lat. 35°48′46″ ; Lon. 136°49′32″).

Sample number	Locality	rock type	Assem-blage	Diagnostic spieces
G 677	Uchigatani	ms	Gn	Tricolocapsa conexa,Protunuma sp.
G 1275	Uchigatani	ms	Ue-Gn	T.plicarum,E. unumaense,E. sp.
G 420A	Uchigatani	ms	Ue	Tricolocapsa plicarum, Zartus sp.
G1230F	Uchigatani	sil	Ue	Tricolocapsa fusiformis
G 661	Uchigatani	sil	Hh	Hsuum hisuikyoense,Spongocapsula(?) sp.C
Q 288	kuzuryu-ko	sil	Hh	Parvicingula cf gigantocornis
No. 26	Yamato	sil	Gn	Tricolocapsa cf. tetragonna
No. 63	Yamato	sil	Ue-Gn	Eucyrtidiellum pustulatum,E. sp.
No. 69	Yamato	sil	Ue-Gn	T. cf. plicarum, T. fusiformis
No. 67	Yamato	sil	Ue-Gn	T. plicurum, Protunuma sp.
No. 68	Yamato	sil	Ue	T.fusiformis,T. plicurum, Protunuma fusiformis
G 905	Yamato	sil	Ue	C.mastoidea, S. japonicus, T.plicarum
No. 47	Yamato	sil	Ue	Cyrtocapsa kisoensis
No. 20	Yamato	sil	Hh-Ue	T.fusiformis
G 1274	Yamato	sil	Hh-Ue	Unuma echinatus,Andromeda sp.
G 990	Itadori	sil	Hh-Ue	Unuma echinatus,Zartus sp.A,(Hsuum sp. hisuikyouense)
No. 84	Yamato	sil	Hh	T.plicarum, Zartus sp. A, Hsuum hisuikyoense
No. 46	Yamato	sil	Hh	Hsuum cf. hisuikyoense
No. 17	Yamato	sil	Hh	Unuma echinatus, Zartus sp. A, Parvi. gigantocornis
No. 21	Yamato	sil	Hh	Hsuum hisuikyouense, Laxtorum(?) jurassicum
No. 66	Yamato	sil	Hh	Hsuum hisuikyouense,Zartus sp. A, P. gigantocornis
No. 70	Yamato	Mn	Hh	Hsuum hisuikyouense,U. echinatus, Hsuum(?) matsuokai
No.165	Yamato	Mn	Hh-Ue	Unuma echinatus
No.34	Yamato	ch	M TR	Triassocampe sp.
No.36	Yamato	ch	M TR	Triassocampe sp.
No.37	Hachiman	ch	Perm	Pseudoalbaillella spp., Parafollicucullus sp.

with dark green to dark reddish brown basic tuff in the southern margin of the block. Early to Late Triassic conodonts and Middle to Late Triassic radiolarians were obtained from several chert blocks at Yamato (WAKITA and OKAMURA, 1982).

Age of clastic rocks

Shale yields Middle Jurassic radiolarians of the *Unuma echinatus* and *Guexella nudata* Assemblages, while siliceous shale yields late Early to late Middle Jurassic radiolarians of the *Hsuum hisuikyoense*, the *Unuma echinatus* and *Guexella nudata* Assemblages (Table 2). Middle Jurassic radiolarians of the *Hsuum hisuikyoense* and the *Unuma echinatus* Assemblage are also obtained from manganese carbonate nodules embedded in siliceous shale (WAKITA and OKAMURA, 1982). Recently, the occurrence of Middle Jurassic ammonite, *Kepplerites* (*Seymourites*) sp., was reported from fine-grained sandstone of the slightly disrupted turbidite at Yamato by SATO *et al.* (1985). The ammonite shows the age ranging from Upper Bathonian to Lower Callovian. The same genus was obtained from the Tetori Group in the Circum-Hida Tectonic zone (KOBAYASHI, 1947).

The age of deposition should be decided on the basis of fossils obtained from sandstone, shale and laminated siliceous shale, because most of the bedded siliceous shale and the bedded chert occur as exotic blocks. Conclusively, therefore, the clastic sequences of the Samondake unit deposited in Bathonian to Callovian time.

Funafuseyama Unit

The Funafuseyama unit is distinguished from other units by the presence of a number of slices, slabs and blocks which consist of greenstone, limestone and/or chert of Permian age (Fig. 5).

Distribution

The occurrence of this unit is restricted to a narrow zone which extends from east to west in the central part of the study area (Fig. 4). And this unit corresponds to the Tokuyama Formation of KAWAI (1964), to the Akuda and Shimadani Formations of KANUMA (1958) and to the northern part of the Nabigawa Formation of WAKITA (1984).

Contact between the Funafuseyama unit and the adjoining units

The Funafuseyama unit is conformably or unconformably overlain by the Samondake unit, and is in fault contact with the Nabi, Kanayama and Kamiaso units.

Lithology

This unit is composed mainly of stacked slices of melanges and weakly disrupted turbidites, associated with slices, slabs and blocks of greenstone, limestone and bedded chert of Permian to Triassic age and with local intercalations of massive shale (Fig. 5).

Most slabs of Permian basalt, chert and/or limestone are enormous in size, and the largest reaches 2000 m in thickness and extends as long as 20000 m.

Greenstone, limestone and chert are closely associated with one another, totally forming a single slab. Greenstone in one slab often includes blocks of limestone and chert of Permian age, and on the contrary limestone in another slab is associated with greenstone lenses. Light to medium gray chert is interbedded with white or light gray limestone or pale brown dolostone at several localities (Plate II-4). Chert beds

Table 3 Radiolarian fossils in the Funafuseyama unit.
Symbols are the same as in Figure 5. For localities of samples see WAKITA (1983) and YAMAMOTO (1985).

Sample number	Locality	Rock type	Assem-blage	Diagnostic spieces
731	Neo	ms	Ue-Gn	Panatanellium foveatum, Tricolocapsa plicarum
769	Neo	ms	Ue-Gn	Panatanellium foveatum, Zartus sp.
828	Neo	ms	Ue-Gn	Panatanellium foveatum
732,766,852	Neo	ms	Ue	Cyrtocapsa mastoidea
725	Neo	ms	Hh-Ue	Unuma echinatus,Zartus sp.,Hsuum hisuikyoense
767,768,845	Neo	ms	Hh	Hsuum hisuikyoense
G 1687	Itadori	ch	L TR	Capnodoce sp.
773,843	Neo	ch	M TR	Triassocampe deweveri
G 1674	Itadori	ch	M TR	Triassocampe cf. deweveri
690	Neo	ch	M TR	Triassocampe japonica
730,832,847	Neo	ch	M TR	Triassocampe sp.
773	Neo	ch	TR	Tripocyclia cf. acythus
770,842	Neo	ch	L Perm	Albaillella triangularis
871	Neo	ch	L Perm	Albaillella levis, Follicucullus ventricosus
691,723,872	Neo	ch	M Perm	Follicucullus scholasticus
875	Neo	ch	M Perm	Follicucullus ventricosus
764	Neo	ch	M Perm	Follicucullus monacanthus

range in thickness from 2 to 30 cm, while limestone or dolostone beds range from 5 to 50 cm.

Greenstone, generally dark green and partly dark reddish brown, includes basaltic massive lava, pillow lava (Plate II-3), pillow breccia, hyaloclastite and basaltic tuff. Pillow breccia contains basaltic lava fragments ranging from 1 to 5 cm in diameter. Basaltic tuff includes gray limestone clasts of 10–80 cm in diameter and white, gray or red chert blocks of 0.1–5 m in diameter. Basaltic lava contains phenocrysts of plagioclase, colorless or pale brown augite and locally chlorite pseudomorphs after olivine. The phenocrysts are partially altered into chlorite, calcite, sericite, sphene, prehnite and pumpellyite. Vesicles in the pillow lavas are filled with calcite.

Chert, mostly well-bedded, is intensely intraformationally folded at several localities (Plate II-2), and shows such variety of colors as white, light gray, dark gray, pale brown, pale blue, green and red. Each chert bed is 2 to 20 cm thick, and alternates with much thinner shaly or tuffaceous beds of the same color. Middle to Late Permian conodonts and radiolarians were reported (Table 3) from bedded chert closely associated with greenstone and limestone at several localities by IGO (1979), WAKITA (1983, 1984) and YAMAMOTO (1985). Triassic conodonts and radiolarians are also obtained from some other chert slabs at a few localities (Fig. 6).

Large limestone blocks and slabs are exposed at Neo, Funafuseyama and Hachiman, and small blocks are often enclosed in or associated with greenstone. Most limestone is fossiliferous, white, light gray, medium gray, or dark gray in color, and is generally massive and locally well-bedded. It yields fusulinaceans, corals, bivalves, gastropods, brachiopods and calcareous algaes. A number of fusulinacean faunas of Early to early Late Permian age, ranging from the *Pseudoschwagerina* Zone to the *Yabeina* Zone, are reported by KANUMA (1958), IGO and OGAWA (1958), KAWAI (1964), NAKAMURA (1966, 1967 A,B) and SASHIDA (1980).

Melanges are widely distributed to the west of the Neo area, and can be classified into two types, A and B, on the basis of the nature of the matrix and rock type of clasts (Fig. 11). Type A is a major melange consisting of dark gray weakly foliated shale matrix and clasts of sandstone, chert and siliceous shale. Type B melange is less common than type A, and is closely associated with greenstone slabs. The matrix of type B melange is deep-black shale which is more scaly and darker in color than that of type A melange. In type B melange, fragments of greenstone and chert are very common, and those of sandstone and limestone are locally included. Type B melange is in contact with type A melange by sharp "depositional" boundaries in places.

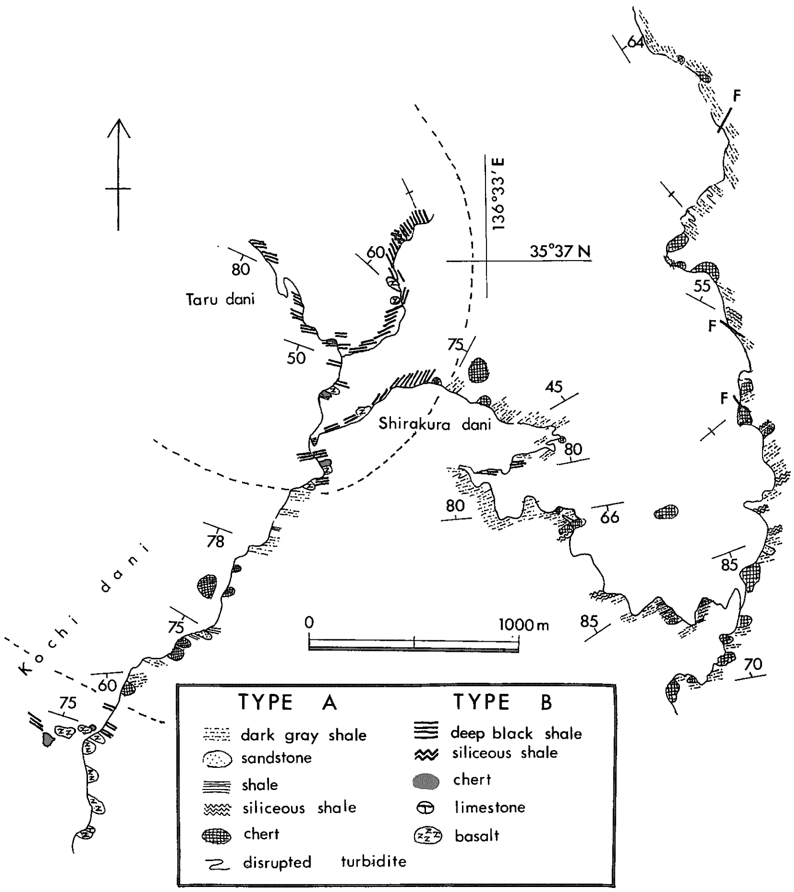


Fig. 11 Route map of the Funafuseyama unit at Ozu showing the occurrence of type A and B melanges.

Shale matrix of type A melange is dark gray and includes a number of detrital grains and rock fragments of siltstone. Most of the clasts in type A melange are composed of one or two rock types. Sandstone clasts, most common in type A melange, range generally from 1 to 50 cm in diameter but locally reach hundreds of meters long. Chert clasts range in size from 2 cm across to several hundred meters long ; chert is light gray, light greenish gray, and reddish brown, and is well bedded. Siliceous shale is associated with chert blocks or occurs as an isolated clast. It is gray, dark gray and reddish brown, and is generally massive but partly bedded. Type A melange includes a 120 m-thick block of a coarsening-upward sequence which consists of chert, siliceous shale, shale, shale interbedded with sandstone and massive sandstone in ascending order. Slices of shale sequences are locally intercalated between slices of the chert, greenstone and limestone. It is gray or dark gray, slightly coarser in grain size than siliceous shale, and is mostly massive but is locally laminated or interbedded with sandstone.

Type B melange is characterized by deep-black shale matrix with common greenstone clasts and less common sandstone clasts. In thin section, the shale matrix of type B melange shows various textures. Typical one is deep-black in color, free from coarse-grained terrigenous grains, and includes numerous greenstone fragments. Some other matrix of type B melange includes various proportion of coarse-grained clastic grains and siltstone fragments as well as greenstone fragments (Plate IV-6). Greenstone clasts, ranging from 1 cm to 100 cm long, consist of light green or dark greenish gray basaltic tuff and dark green or reddish brown basaltic lava. The basaltic tuff clasts often display elongated irregular shape. Chert clasts are gray, light gray or black, and range from 1 to 100 cm in length. Type B melange may be assigned to "slump facies II" of YAMAMOTO (1985).

Disrupted turbidites of the Funafuseyama unit are widely distributed at Itadori where melanges are locally exposed. Sandstone occurs as isolated lenticular clasts enveloped in shale matrix or very thin- to thin-bedded distorted layers which are locally folded and show ductile extensional deformation such as pinch-and-swell structure.

Age of shale matrix

No fossils are obtained from the shale matrix of the melanges and weakly disrupted turbidites. YAMAMOTO (1985) reported the occurrence of late Early to early Middle Jurassic radiolarians (*Hsuum hisuikyoense* Assemblage to *Unuma echinatus* Assemblage) from the shale bed of the Funafuseyama unit to the west of the study area (Table 3). His "shale", however, includes a rock type which is described as siliceous shale in this report. Therefore, the age of shale matrix is as young as or slightly younger than late Early to early Middle Jurassic.

Nabi Unit

The Nabi unit is characterized by wide-spread distribution of variously disrupted turbidites associated with large chert slabs (Fig. 5).

Distribution

The distribution of this unit is different between the eastern and western

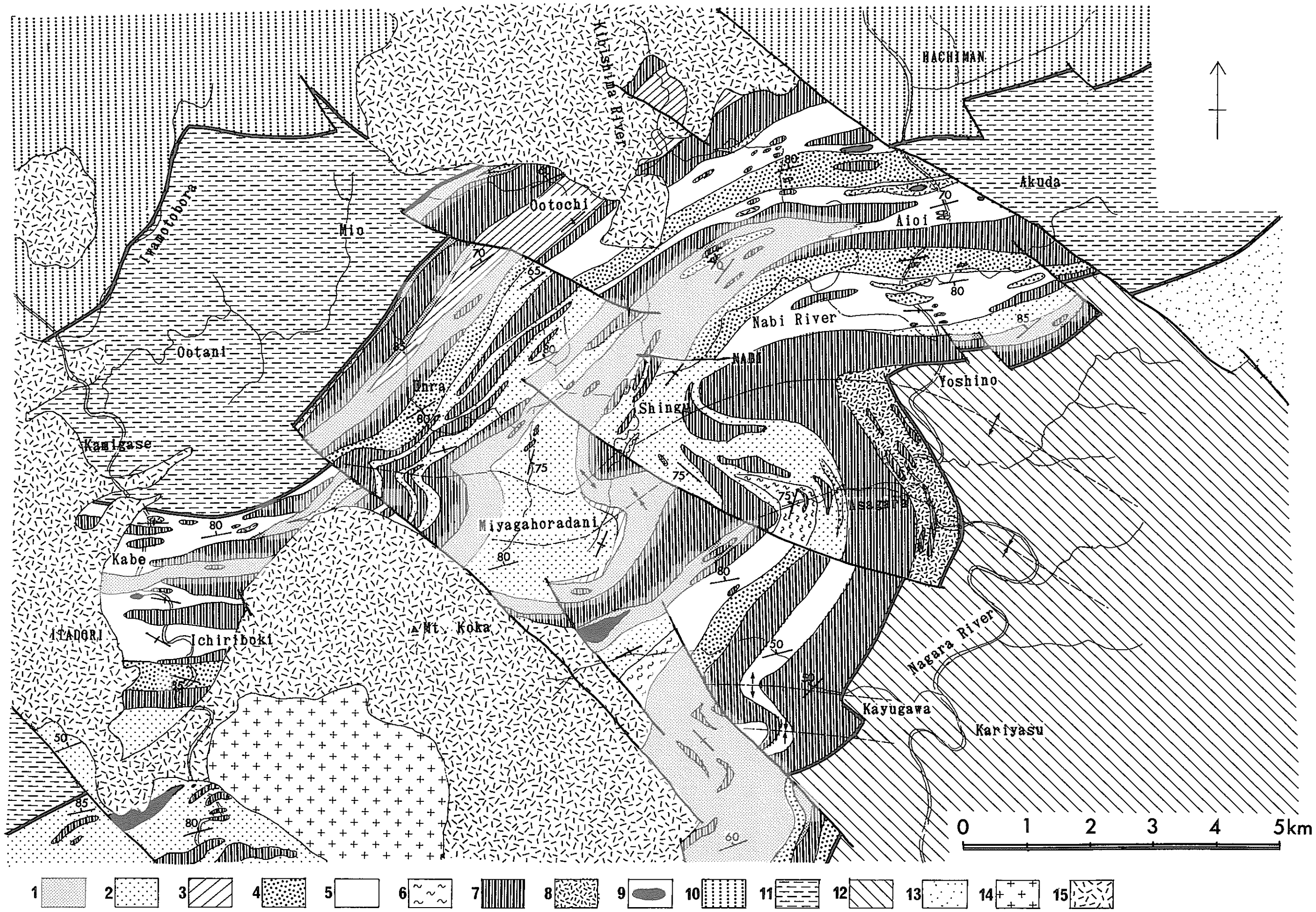


Fig. 12 Geologic map of the Nabi unit.
1–9. Nabi unit (1. shale, 2. weakly disrupted turbidite, 3. well-bedded turbidite, 4. massive sandstone, 5. melange matrix: dominantly pelitic, with small clasts, 6. siliceous shale, 7. bedded chert, 8. greenstone, 9. limestone), 10. Samondake unit, 11. Funafuseyma unit, 12. Kanayama unit, 13. Kamiaso unit, 14–15. Late Cretaceous acid igneous rocks (14. granite, 15. rhyolite).

parts of the study area. On the east it occupies the zone between the Funafuseyama and Kanayama units, whereas in the west it is distributed between the Kanayama and Kamiaso units (Fig. 4). The unit corresponds to the southern part of the Permian Kayugawa Formation (Kanuma, 1958) and to the upper part of the Nabigawa Formation (Wakita, 1984).

Contact between the Nabi unit and the adjoining units

The Nabi unit is in fault contact with the Funafuseyama unit. The relation between the Nabi and Kamiaso units is not clear, but appears to be in fault contact, since there is an abrupt change in lithology. Thin- to thick-bedded turbidites and disrupted turbidites of the Nabi unit locally interfinger with the melanges of the Kanayama unit in the western part of the study area.

Lithology

The Nabi unit consists mainly of slices of coherent stratigraphic sequences of sandstone and shale accompanied with slices of chert, siliceous shale and melanges, including blocks of chert and limestone (Fig. 12). Most of the blocks are embedded within matrix of melanges.

Sandstone and shale are mostly interbedded in varied proportions, and the strata show disrupted features in various ways. The spectrum of the disruption is represented by well-bedded turbidite (Plate I-3) on one end and by thoroughly disrupted turbidite (Plate III-1, 2) on the other end.

Undisrupted, well-bedded turbidite (Plate I-3) is mostly rich in sandstone, and occurs as sequences of 100 to 1000 m thick. Most of the sandstone beds range from 1 to 50 cm in thickness, but thicker sandstone beds also occur locally. Sandstone is gray, fine- to medium-grained, and displays sedimentary structures such as graded bedding, parallel lamination and sole markings (groove cast, flute cast, load cast and rill mark).

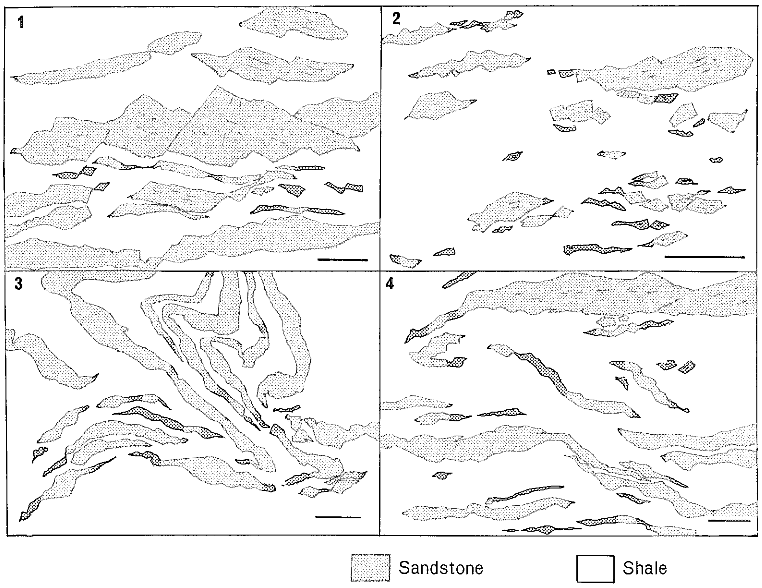


Fig. 13 Weakly disrupted turbidite of the Nabi unit.
Scale bar = 5 cm.

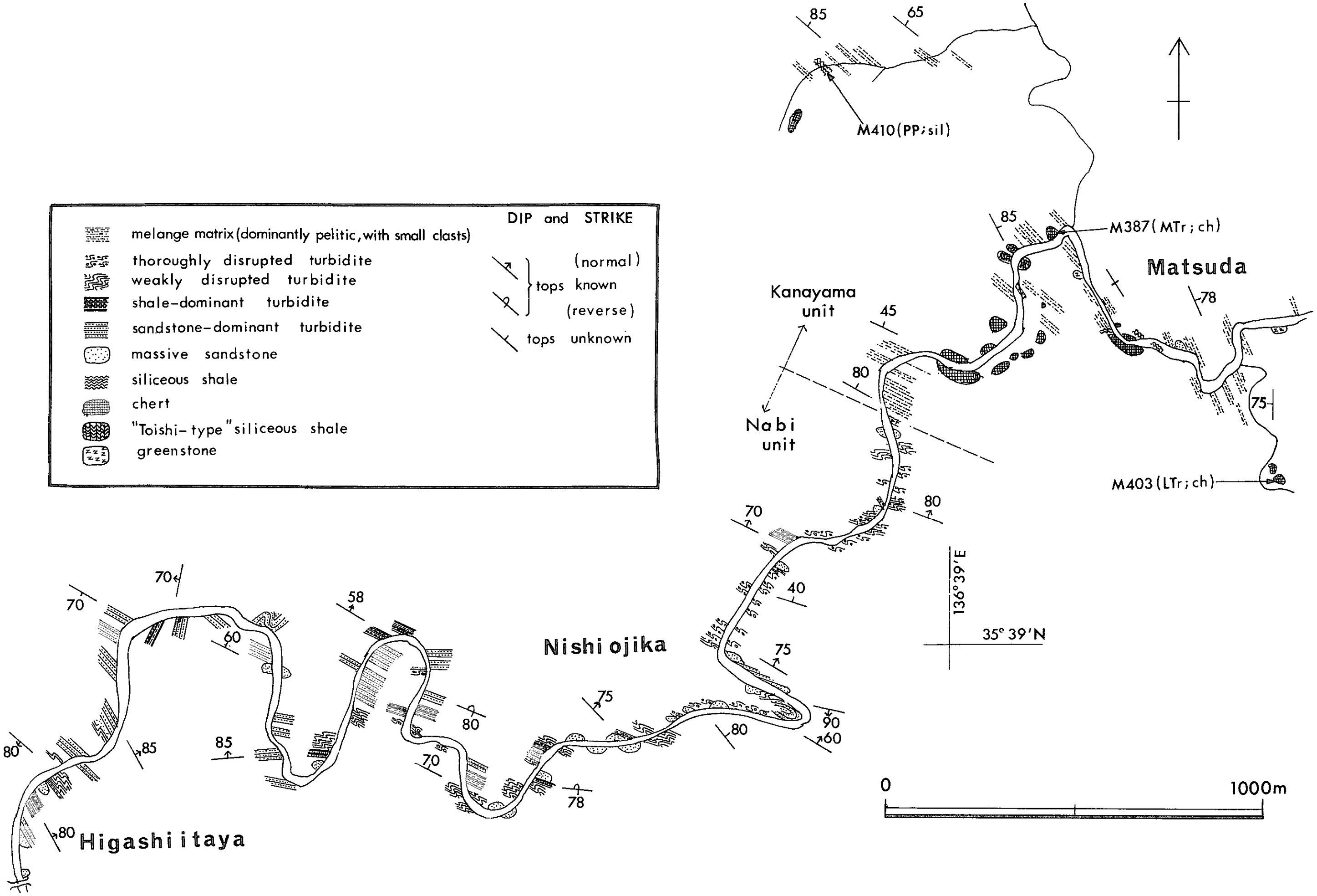


Fig. 14 Route map of the Nabi and Kanayama units at Neo. Symbols are the same as in Figure 5.

Sole markings indicate the divergent paleocurrent directions. The top part of sandstone beds includes carbonaceous fragments in some cases.

Slightly disrupted turbidite is exposed only in the southern part of this unit. In the slightly disrupted turbidite, normal minor faults are developed, by which the turbidite beds are cut and divided into a number of blocks. Inside of the blocks, sandstone layers are, however, rarely disrupted (Plate, I–4).

Weakly disrupted turbidite is developed and well exposed in the central part of the study area. In the weakly disrupted turbidite, deformed sandstone layers or lenses, ranging from 1 to 30 cm in thickness, are enveloped in shale, and show ductile extensional deformation such as pinch-and-swell structure, swelling and necking, sometimes with wispy termination (Plate I–4, 5, 6). A number of layers and lenses of sandstone are split into rhomboidal fragments by normal faults (Fig. 14, Plate I–6). Internal lamination of a sandstone lens is invariably oblique to the trend of the arrangement of the lenses. Some of the rhomboids are deformed in a ductile fashion into elongated clasts (Fig. 13). Nevertheless, the stratal continuity is retained, and each sandstone layer or lens grades into overlying shale; adjacent sandstone lenses are derived from an originally single layer, and the arrangement of the sandstone lenses reflects the original layering of a sandstone bed. In Figure 14, for example, weakly disrupted turbidite is locally interbedded with and grades into well-bedded turbidite and thoroughly disrupted turbidites. The arrangements of sandstone lenses and layers partly is folded at many places.

Thoroughly disrupted turbidite is developed in the western part of the study area (see, Fig. 17) and locally intercalated within weakly disrupted turbidite in this unit. The thoroughly disrupted turbidite includes a number of sandstone clasts, ranging in diameter from 1 to 200 cm, in shale matrix (Plate III–1, 2). Shape of clasts is mostly subrounded to subangular, but locally irregular. Shale of the matrix is gray to black and weakly to highly foliated. In thin section, the shale includes numerous subangular to subrounded fragments of siltstone or sandstone in clayey matrix. The fragments are entirely enclosed in clayey matrix showing "depositional" contact. Cleavages are developed subparallel or slightly oblique to the arrangement of clasts, and clearly cut the block (fragment)-in-matrix texture. This fabric suggests that fragmentation and mixing occurred during ductile deformation process, and cleavages were developed after the disruption of the turbidites and after induration.

Massive sandstone beds are occasionally found in the unit, and some of them show composite grading, cross- or parallel lamination. Sandstone is light to dark gray, and medium- to coarse-grained, and is characterized by numerous shale fragments of 1 to 5 mm in diameter. Coarse-grained sandstone sometimes grades into very coarse-grained sandstone or granule conglomerate. Granules are composed dominantly of chert and shale, with a small amount of granitic rocks, hypabyssal rocks, sericite schist, dacite, basalt, siliceous shale, sandstone and orthoquartzite. Massive sandstone sometimes includes a number of angular chert fragments ranging in diameter from 0.2 to 40 cm and large chert blocks up to hundreds of meters long.

Shale-dominant formations of several hundreds meters thick are closely associated with and grade into weakly disrupted turbidites. The shale is dark gray, generally massive but locally laminated, and weakly fissile. The laminations are undisrupted, and original stratifications are retained.

Melange occurs as slices of several hundreds meters thick and several kilometers long, and includes a number of clasts ranging in size from a millimeter to a kilometer long. The matrix is dark gray weakly foliated shale. Rock types of clasts are sandstone, bedded chert, siliceous shale, greenstone and limestone.

A special type of chaotically mixed rocks occurs as a block enclosed in the normal melange. It was called "Ichiriboki olistostrome" (WAKITA, 1983). Numerous bedded chert blocks and several calcareous clasts are embedded in deep-black shale matrix. The deep-black shale is extremely carbonaceous and includes clay, microcrystalline quartz, opaque minerals and radiolarian remains ; no coarse-grained clastic grains are found under the microscope. Content of carbonaceous material of the shale is 2.68 weight-percent (Table 4). Similar carbonaceous deep-black shale

Table 4 Chemical compositions of deep-black and dark gray shales in the Nabi and Kanayama units.

Rock type	Deep-black shale matrix of "Ichiriboki olistostrome"	Deep-black shale clast	Deep-black shale associated with basalt	Dark gray shale matrix of melange	Dark gray shale interbedded with sandstone	Average of shale in Mino terrane	Average of shale in Inner zone of SW Japan
Sample number	G1686	G1880	G1810	G1876A	G1858	ONO(1976)	MIYASHIRO & HARAMURA (1962)
Locality	ITADORI	KARIYASU	HACHIMAN	KARIYASU	KARIYASU		
(Lat.) (Lon.)	35°40'01" 136°49'21"	35°39'26" 136°57'20"	35°43'40" 136°55'11"	35°39'21" 136°57'23"	35°38'16" 136°54'56"		
unit	Nabi	Kanayama	Nabi	Kanayama	Nabi		
SiO_2	64.77	70.57	77.17	70.26	60.59	64.74	65.31
TiO_2	0.58	0.57	0.24	0.57	0.75	0.65	0.63
Al_2O_3	13.62	12.74	5.59	13.53	18.98	16.29	15.81
Fe_2O_3	2.03	2.13	2.04	1.51	2.19	1.55	1.83
FeO	0.32	0.07	0.26	2.79	2.90	3.63	3.25
MnO	0.16	0.01	0.06	0.04	0.07	0.06	0.08
MgO	3.97	1.23	0.72	1.78	2.04	2.17	2.08
CaO	5.74	0.04	3.40	0.35	0.05	0.66	0.34
Na_2O	0.31	0.18	0.07	1.18	2.47	2.19	2.09
K_2O	1.01	4.01	1.16	3.28	4.34	3.74	3.84
P_2O_5	0.28	0.06	0.06	0.11	0.27	0.15	0.01
$H_2O(+)$	2.17	3.12	1.71	3.37	3.72		3.36
$H_2O(-)$	0.34	0.53	0.27	0.45	0.70		0.61
CO_2	0.70	0.29	3.15	0.07	0.00		
C	2.68	4.17	2.68	0.39	0.45		0.76
S	0.90	0.22	1.61	0.06	0.01		
Total(Wt.%)	99.58	99.94	100.64	99.74	99.98	95.83	100,00
(ppm)							
Zn	14	42	62	69	80		
Cu	20	4	31	42	32		
Co	7	2	9	15	7		
Cr	86	60	35	56	64		36
Ni	53	10	16	35	36		18
Li	55	18	19	32	45		
U	9.5	7.8	1.9	2.4	3.9		
Pb	13	22	5	20	27		
V							103

Table 5 Radiolarian fossils in the Nabi unit.
Symbols are the same as in Figure 5. For localities of samples (G xxxx) see WAKITA (1983).

Sample number	Locality	Lat.(N)	Lon.(E)	rock type	Assemblage	Diagnostic spieces
R38189	Ijira	35°32'59"	136°41'41"	tb	GS	S.spiralis
R38159	Horado	35°36'50"	136°48'17"	ms	Gn	S.himedaruma
R38182	Taniai	35°37'35"	136°45'40"	ms	Gn	T. hemicostata
R38184	Taniai	35°37'41"	136°45'42"	ms	Gn	T.connexa , T. tetragonna
R38183	Taniai	35°37'21"	136°46'32"	ms	Gn	T.plicarum,Eucyrtidiellum pustulatum,S.suboblongus?
R38178	Taniai	35°38'03"	136°44'36"	ms	Gn	T.connexa
R38170	Nabi	35°40'51"	136°52'45"	ms	Gn	E.unumaense,T. aff.fusiformis
R38169	Nabi	35°43'10"	136°53'05"	ms	Ue-Gn	T. plicarum,T.fusiformis,
G 1474	Hachiman	35°43'46"	136°56'32"	sil	Gn	T.aff. fusiformis,Protunuma turbo, P.ochinensis,Williliedellum sp. A,
R38165	Taniai	35°37'33"	136°45'41"	sil	Gn	T. tetragonna
G1486b	Nabi	35°42'16"	136°54'03"	sil	Ue-Gn	Protunuma cf.ochinensis,
G1390A	Nabi	35°42'38"	136°57'20"	sil	Ue-Gn	D.kamoensis,P.dhimenaensis
G 1376	Kariyasu	35°40'26"	136°55'04"	sil	Ue-Gn	D.kamoensis,P.dhimenaensis, Pantanellium foveatum
G1450B	Kariyasu	35°41'10"	136°55'46"	Mn	Ue	T.fusiformis,Cyrtocapsa mastoidea
G1464A	Hachiman	35°43'51"	136°55'40"	Mn	Hh-Ue	Unuma echinatus,Zartus sp. A, Andromeda sp.
G 1063	Nabi	35°41'56"	136°52'52"	ch	L TR	Capnuchosphaera sp.
R38177	Taniai	35°38'09"	136°44'34"	ch	M TR	Triassocampe spp.
R38185	Taniai	35°38'06"	136°45'20"	ch	M TR	Triassocampe spp.
G 1916	Kariyasu	35°41'28"	136°56'58"	ch	M TR	Triassocampe cf. deweveri

is associated with greenstone blocks of the Nabi unit and occurs as a clast in the melange of the Kanayama unit (Table 4).

Siliceous shale occurs as lenticular bodies embedded within weakly disrupted turbidite. It is light gray, medium gray, pale green, dark greenish gray or reddish brown, ranges in thickness from 2 to 400 m, and is divided into bedded and laminated types. Bedded siliceous shale consists of siliceous siltstone beds of 2 to 60 cm thick and shale partings of 1 to 3 cm in thickness. Laminated and weakly fissile siliceous shale contains thin layers of pale yellowish brown tuffaceous shale or manganese carbonate nodules which are ellipsoidal, ranging in length from 10 to 100 cm. Siliceous shale and manganese carbonate nodules yield well-preserved radiolarians. Late Middle Jurassic radiolarians of the *Guexella nudata* Assemblage are obtained from the siliceous shale, while the manganese carbonate nodules contain early Middle Jurassic radiolarians of the *Unuma echinatus* Assemblage (Table 5).

Bedded chert occurs as large slices, slabs or blocks which range from 5 to 1000 m thick and from 20 to 15000 m long. It occurs with various shades of color such as white, light gray, medium gray, dark gray, pale green, greenish gray, pale brownish gray, pale brown, reddish brown and red. Chert beds are 1 to 20 cm in thickness, and alternate with shale layers of 1 to 10 mm in thickness. Several types of folds such as chevron fold and parallel fold are often observed in chert sequences (Plate II-1). Middle to Late Triassic conodonts (IGO, 1979) and radiolarians (WAKITA, 1983) are obtained from chert of this unit (Fig. 6).

In a part of the bedded chert sequences, chert is interbedded with limestone or dolostone. Both beds of chert and limestone are white or light gray and range in thickness from 5 to 50 cm. The interbedded chert and limestone are locally disrupted, and in some cases chert occurs as lenses and blocks enclosed in limestone. Late Triassic conodonts such as *Neogondolella navicula steinbergensis* are reported from limestone interbedded with chert by IGO (1979).

In some large slabs, bedded chert is associated with greenstone. Greenstone

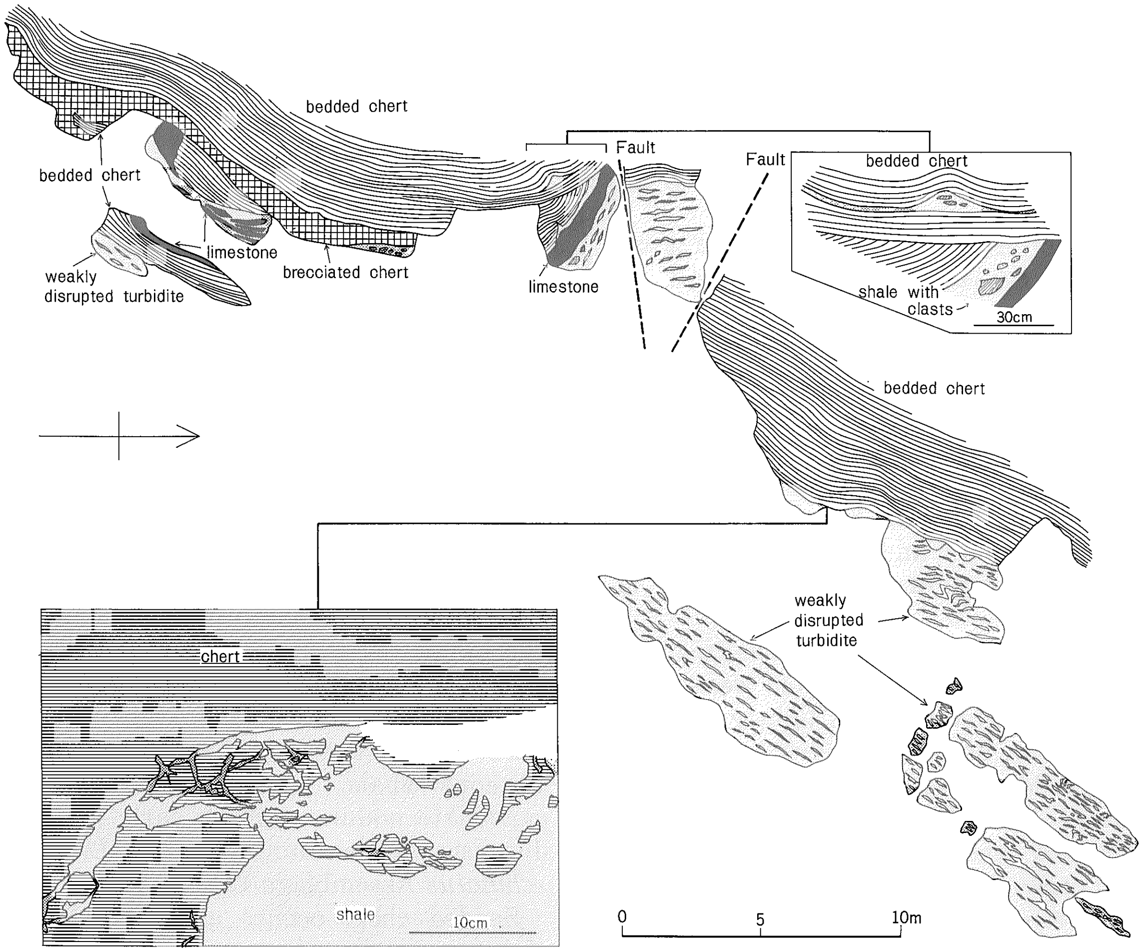


Fig. 15 Contact features between a chert slab and underlying weakly disrupted turbidite at Horado (Lat. 35°37′53″, Lon. 136°49′47″).

is dark gray, dark greenish gray or pale green, and the lithology is basaltic tuff and lava. Basaltic lava is massive and contains phenocrysts of kaersutite and biotite. Basaltic tuff is locally interbedded with chert and grades into tuffaceous partings of bedded chert, suggesting that the basic tuff is closely related to the bedded chert in origin.

Gray limestone occurs as blocks ranging in length from 50 to 1500 m, and is sparsely distributed in weakly disrupted turbidite, in undisrupted turbidite and in shale-dominant formations of the Nabi unit. Late Middle Permian fusulinaceans (Kanuma, 1958) and late Early Permian conodonts (Igo, 1979) are obtained from these limestone blocks.

A chert slab directly overlies weakly disrupted turbidite without distinct shear zone (Fig. 15). Near the boundary, however, the chert slab is brecciated at the basal part, and detached angular clasts of chert are embedded within the top of the weakly disrupted turbidite.

Age of clastic sequences

Radiolarians of the *Guexella nudata* Assemblage and the *Gongylothorax sakawaensis—Stichocapsa naradaniensis* Assemblage are obtained from shale interbedded with thinner sandstone at several localities (Table 5). These fossils show that the age of the clastic rocks in the Nabi unit ranges from late Middle to early Late Jurassic.

Kanayama Unit

The Kanayama unit is composed of Late Jurassic (?) to Early Cretaceous melanges. The melanges contain clasts of a variety of rocks such as sandstone, siliceous shale, chert in dominantly argillaceous matrix (Fig. 5). The clasts range from a millimeter to several kilometers in length.

Distribution and Subdivision

The melanges occupy the western part and the eastern part of the study area (Fig. 4). The eastern melange is named the Kanayama melange which is characterized by a high content of siliceous shale clasts and a low content of greenstone and limestone clasts (Fig. 16). On the other hand, the western melange is designated by the name of the Neo melange which includes commonly greenstone and limestone clasts (Figs. 17, 18). Figures 16 and 17 are the detailed maps of the Kanayama melange and the Neo melange, respectively. The western part of the Kanayama melange was mapped as the Kayugawa Formation by Kanuma (1958) and as the lower member of the Nabigawa Formation by Wakita (1984). The northern part of the Neo melange was mapped as the Neo Formation by Kawai (1964). The Kanayama and Neo melanges have similar rock association, fabrics, and age of each rock type except for the above-mentioned proportion of some clast types; therefore, they are assigned to the same unit and described together as follows.

Contact between the Kanayama unit and the adjoining units

The melanges of the Kanayama unit are usually in fault contact with the Funafuseyama unit. The melanges of the Kanayama unit, however, locally interfinger with the turbidite formations of the Nabi unit.

Lithology

Melanges of the Kanayama unit are composed of clasts of various lithologies and shale matrix, showing block-in-matrix texture (Plate III-3, 4, 5, 6).

Matrix

Matrix of the melanges commonly consists of dark gray to black shale, and shows weakly developed scaly foliation (Plate III-4, 6). In thin section, angular fragments of quartz, feldspars, sericite and siltstone are sparsely distributed in unfoliated clayey matrix (Plates VI, VII). Sericite is arranged subparallel to the elongation of mineral

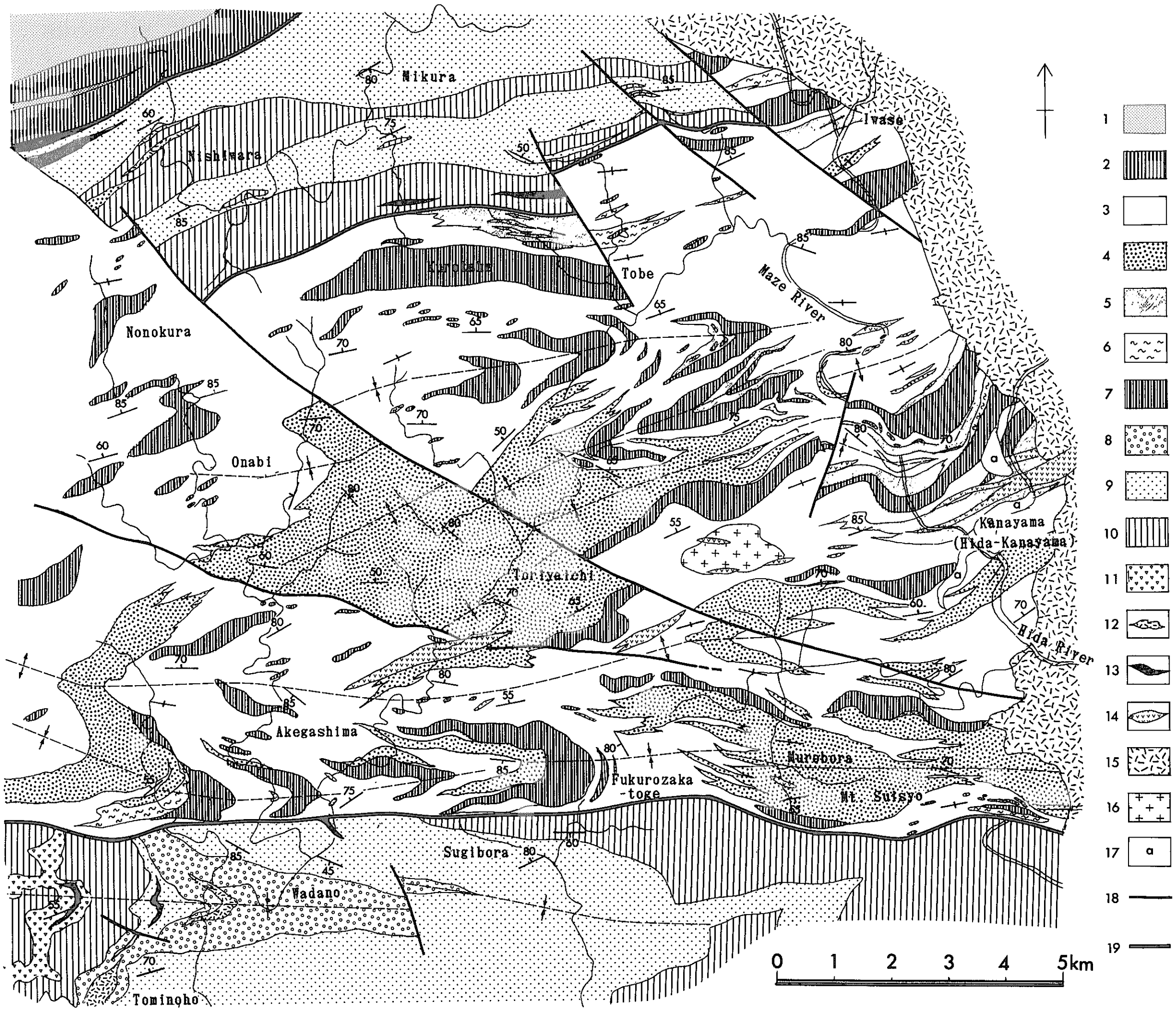


Fig. 16 Geologic map of the Kanayama melange of the Kanayama unit and the adjacent units in the eastern part of the study area.
1–2. Funafuseyama unit (1. melange and weakly disrupted turbidite, 2. bedded chert), 3–7. Kanayama melange of Kanayama unit (3. melange matrix : dominantly pelitic, with small clasts, 4. massive sandstone and turbidite, 5. "pebbly siliceous shale", 6. siliceous shale, 7. bedded chert), 8–12. Kamiaso unit (8. Wadano conglomerate, 9. massive sandstone and turbidite, 10. bedded chert, 11. siliceous shale, 12. greenstone, 13. limestone), 14–16. Late Cretaceous acid igneous rocks (14. granite porphyry, 15. rhyolite, 16. granodiorite), 17. Alluvium, 18. fault, 19. unit boundary

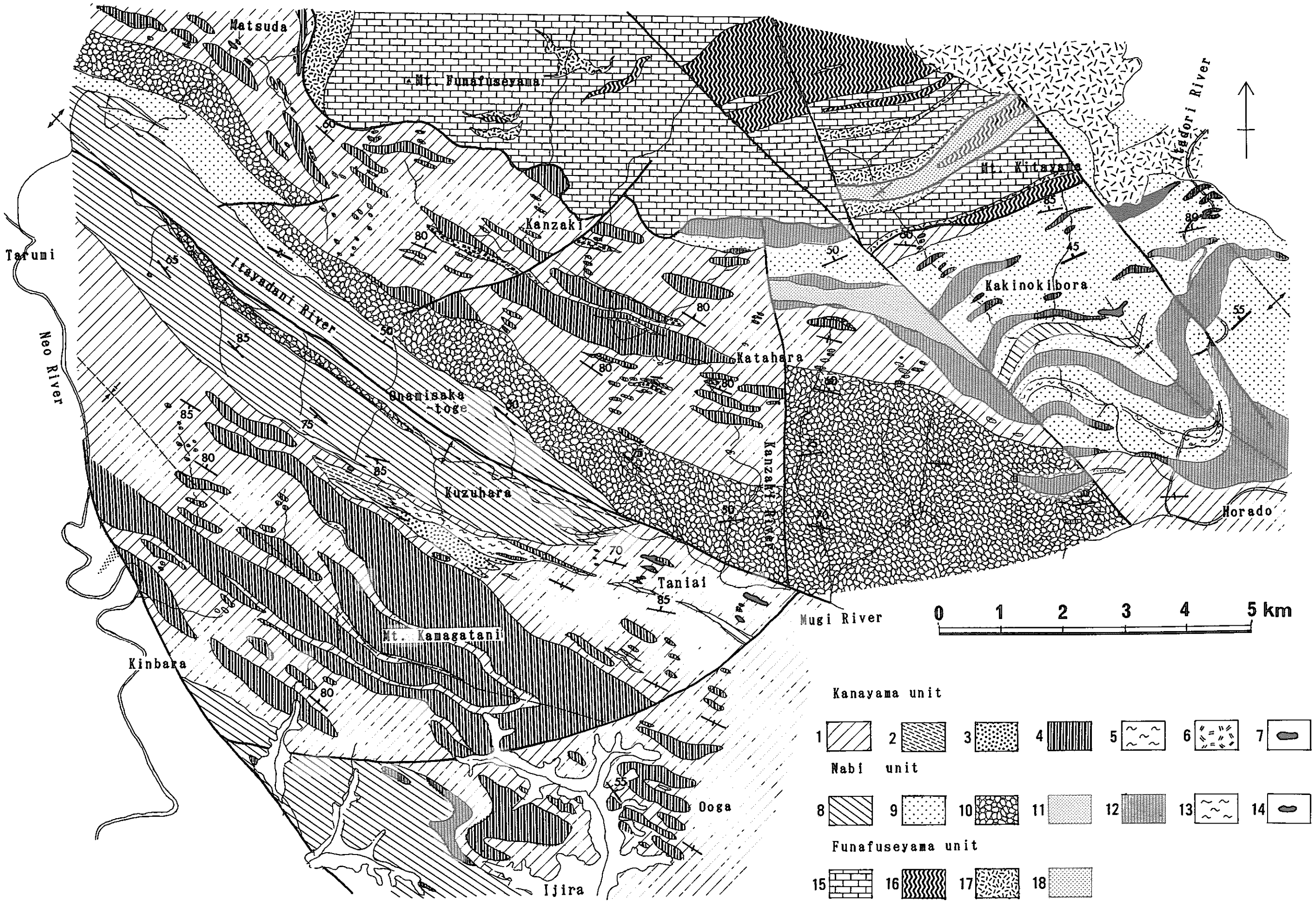


Fig. 17 Geologic map of the Nabi and Kanayama units.
1–7. Neo melange of the Kanayama unit (1. melange matrix : dominantly pelitic, with small clasts, 2. shale, 3. massive sandstone, 4. bedded chert, 5. siliceous shale, 6. greenstone, 7. limestone), 8–14. Nabi unit (8. turbidite, 9. weakly disrupted turbidite, 10. thoroughly disrupted turbidite, 11. shale, 12. bedded chert, 13. siliceous shale, 14. limestone), 15–18. Funafuseyama unit (15. limestone, 16. bedded chert, 17. greenstone, 18. shale)

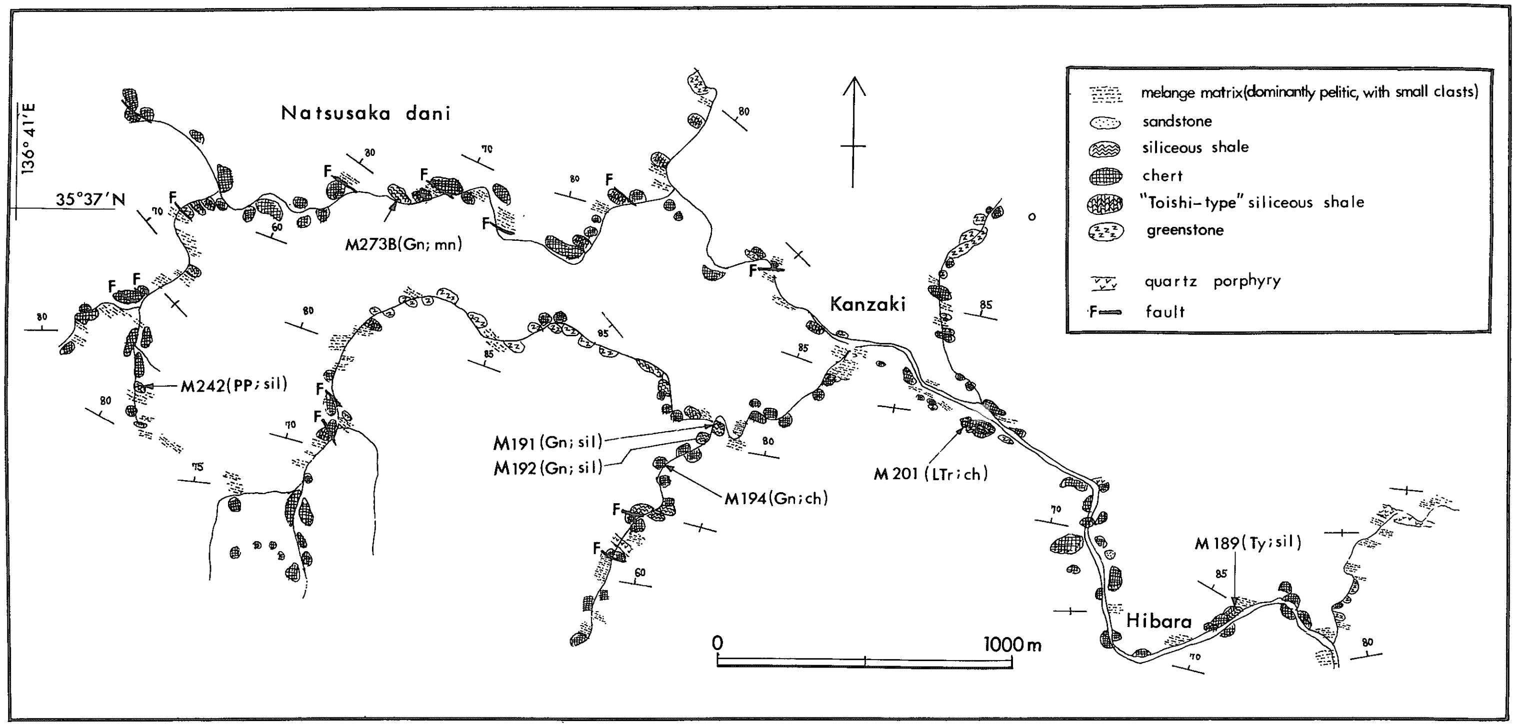


Fig. 18 Route map of the Neo melange of the Kanayama unit in central part of study area, showing fossil localities. Symbols are the same as in Figure 5.

and rock fragments (Plate VII-6). Subrounded to subangular rock fragments of siltstone, fine-grained sandstone and siliceous shale, and occasionally of greenstone, limestone, dolostone and chert occur in shale matrix. Radiolarian remains are rare in the matrix. The contact between rock fragments and matrix is not tectonic but "depositional" (unfoliated, viscous fabric). Scaly foliation trends subparallel or slightly oblique to the arrangement of rock fragments, and clearly cut the original block-in-matrix fabric. Although numerous clasts are supported with lesser amounts of shale matrix in some places (WAKITA, 1988), the shale matrix totally exceeds the clasts in quantity.

General features of clasts

Clasts embedded within the shale matrix consist of various rock types including sandstone, shale, siliceous shale, chert, greenstone, and limestone. Sandstone and chert clasts are predominant, and siliceous shale clasts are common. Greenstone and limestone clasts are rare in the Kanayama melange and locally common in the Neo melange. Long axes of clasts are subparallel to the foliation of the shale matrix.

The following rock associations commonly constitute a block or a slab in the melanges. Chert—siliceous shale—(shale) ; chert—siliceous shale—shale interbedded with sandstone ; chert—greenstone—(limestone) ; greenstone—limestone ; massive sandstone—turbidite—massive or laminated shale. These rocks retain their original stratigraphic succession within a large slab or block.

Sandstone clasts

Sandstone occurs mostly as clasts less than 1 m in diameter (Plate IV-1), and locally constitutes massive sandstone and turbidite in large slabs and blocks ranging from several meters to several kilometers long.

Sandstone clasts (<1 m long) have various shapes such as subrounded, hexagonal, rhombic and irregular. Shale injection is observable on the surfaces of some sandstone clasts. Shale injection grades into a vein or a fracture toward the inner parts of the clasts.

Turbidite in large slabs and blocks is mostly undisrupted but weakly disrupted in places. In turbidite, sandstone beds keep original stratal continuity and display well-preserved sedimentary structures such as graded bedding, cross- or parallel lamination and sole markings. Sandstone layers in weakly disrupted turbidite show pinch-and-swell structure, boudinage and slump structure.

Sandstone is gray, medium- to coarse-grained and ill-sorted. It consists mostly of angular to subangular fragments of quartz, potassium feldspars and plagioclase with a small amount of heavy minerals and rock fragments. Most of the quartz grains show wavy extinction. Rock fragments include shale, felsic volcanic rocks, basalt, hypabyssal rocks, calcareous rocks and sericite schist. Heavy minerals are mostly muscovite, biotite, tourmaline and opaque minerals. Garnet is rare or absent. Some grains of quartz, plagioclase, potassium feldspars and rock fragments and a part of matrix are replaced by calcite or sericite.

Shale clasts

Dark gray and deep-black shale clasts rarely occur as fragments in weakly foliated shale matrix of the melange in the Kanayama unit. Dark gray shale fragments are irregularly shaped and approximately 30 cm in diameter, and deep-black shale fragments are subrounded and apploximately 50 cm in diameter.

Siliceous shale clasts

Siliceous shale occurs as clasts ranging in length from a millimeter to 3000 m, and it is closely accompanied with bedded chert in large slabs. The siliceous shale clasts are highly irregular in shape and size (Plate IV-2), and in places interfinger and mix with dark gray shale of melange matrix (see Fig. 23 and description of "pebbly siliceous shale").

Siliceous shale is light to dark gray or brownish gray, and includes a variety of rock types such as laminated siliceous shale, bedded siliceous shale, massive siliceous shale, tuffaceous siliceous shale, "blended siliceous shale", "pebbly siliceous shale" and "Toishi-type" siliceous shale.

Laminated siliceous shale is gray to dark gray, and is most dominant in siliceous shale clasts of various sizes ranging from several tens of centimeters to several hundred meters in length. It sometimes yields manganese carbonate nodules and trace fossils ; the manganese carbonate nodules range from 3 to 50 cm in diameter. Laminated siliceous shale is composed mainly of detrital grains (0.02-0.08mm across) of quartz, feldspars, sericite and opaque minerals, and includes a varying amount of radiolarian remains. Laminated siliceous shale yields late Middle Jurassic radiolarians (*Guexella nudata* Assemblage) or latest Jurassic to earliest Cretaceous radiolarians (*Pseudodictyomitra* cf. *carpatica* Assemblage). Manganese carbonate nodules also occur as clasts in the melange which contains numerous siliceous shale clasts (Plate IV-6).

Massive siliceous shale is gray to dark gray, and constitutes fragments and blocks in the melanges, locally together with bedded siliceous shale. The texture under the microscope is very similar to that of laminated siliceous shale. Late Jurassic radiolarians are obtained from massive siliceous shale (MIZUTANI, 1981) which grades into laminated siliceous shale of latest Jurassic to earliest Cretaceous age (WAKITA, 1988).

Tuffaceous siliceous shale, mostly light gray, occurs as small-sized (<30 cm) irregular-shaped clasts (Plate IV-2), and consists of a number of radiolarian remains, microcrystalline quartz, sericite and clayey minerals. Sand and silt-sized grains of quartz and feldspars are seldom observed. This siliceous shale yields early Late Jurassic radiolarians of the *Gongylothorax sakawaensis—Stichocapsa naradaniensis* Assemblage.

"Blended siliceous shale", defined by WAKITA (1988), is a mixture of disrupted alternating beds of dark gray siliceous shale and siltstone, and lenticular or irregular light gray tuffaceous siliceous shale. Disrupted layers of siliceous siltstone exhibit pinch-and-swell structure, boudinage or folding. "Blended siliceous shale" yields radiolarians ranging in age from early Late Jurassic to latest Jurassic (*Gongylothorax sakawaensis—Stichocapsa naradaniensis* Assemblage and *Pseudodictyomitra primitiva—P.* sp. A Assemblage).

"Toishi-type" siliceous shale, defined by IMOTO (1984), is light gray, and consists of microcrystalline quartz, sericite and clay minerals having no radiolarian remains. It is often interbedded with deep-black carbonaceous shale, and is sometimes intercalated with chert beds. The proportion of "Toishi-type" siliceous shale to deep-black shale varies from 20 to 95 percent. "Toishi-type" siliceous shale displays intraformational folds in places. "Toishi-type" siliceous shale in the study area yields no diagnostic fossils, but it has been considered to be Early Triassic in age, because Spathian to Anisian conodonts are obtained from a transitional part between "Toishi-type" siliceous shale and overlying chert in the Tamba area to the west of the study area (Imoto, 1984).

"Pebbly siliceous shale" (Plate V-6), also defined by Wakita (1988), is dark gray laminated siliceous shale or "blended siliceous shale", sparsely including sandstone clasts up to 1m in diameter. Sandstone clasts are usually enclosed in siliceous shale. "Pebbly siliceous shale" intercalates thin "layers" of dark gray to black shale and siltstone, and contains small-sized sandstone clasts (<30 cm), and sometimes includes sandstone clasts associated with dark gray shale as if it was tails or pressure shadows in metamorphic rocks. These features are similar to those of the marginal part of siliceous shale clasts. The intercalations of the thin "layers" of shale in the "pebbly siliceous shale" are ascribed to the injection of shale matrix of melange. Sandstone clasts were conveyed together with shale matrix into siliceous shale, and were left alone in siliceous shale after ductile shale were swept away.

The injection of shale including smaller clasts into siliceous shale is common feature not only in "pebbly siliceous shale" but also in other types of siliceous shale of the melange of the Kanayama unit (Plates V-5, VI-5). The injection occurs subparallel or slightly oblique to the original stratification of the siliceous shale. Shale of melange matrix is injected into siliceous shale with sharp boundaries which clearly cut the lamination and layering of the siliceous shale (Plate V-5).

Chert clasts

Chert commonly occurs as large blocks and slabs (several meters to several kilometers in length) with or without siliceous shale, or also forms smaller clasts (1 cm across to 5 m in length) in the melanges (Plate IV-3). Shape of a small chert clast is subrounded, subangular, lenticular, and sometimes irregular.

Chert is mostly light to dark gray, sometimes reddish brown, greenish gray, pale purple or red. Chert formations are always rhythmically bedded. A part of chert formations in slabs exhibits alternating beds of white or dark gray chert of 2–30 cm thick and gray limestone or dolostone of 10–30 cm thick. Bedded chert and chert interbedded with limestone or dolostone display isoclinal intraformational folds (Plate II-1).

Diagnostic radiolarians and conodonts were obtained from chert (Tables 6, 7). Middle Triassic to Early Jurassic radiolarians are commonly obtained from bedded chert of large blocks and slabs of 2 to several kilometers long. Small clasts (<50 cm) of white to light gray chert yields late Middle Jurassic radiolarians (*Guexella nudata* Assemblage) in the Kanayama melange. Gray bedded chert in the large slab (>500 m long) in the Neo melange and pale purple bedded chert in the Kanayama melange also yield late Middle Jurassic radiolarians. Early Middle Jurassic radiolarians (*Unuma echinatus* Assemblage) are obtained from an angular clast (10 cm in diameter) of light gray chert in the Neo area.

Greenstone clasts

Greenstone includes light greenish gray or dark brownish gray basaltic tuff, green to dark greenish gray pillow breccia and pillow lava. Greenstone clasts

Table 6 Radiolarian fossils in the Kanayama melange of the Kanayama unit. Symbols are the same as in Figure 5. See WAKITA (1988) for localities of samples except for R41709 (Lat. 35°39′21″, Lon. 136°57′23″), R38242, R38244 (Lat. 35°39′32″, Lon. 136°57′15″), R38264, R38268, R38255 (Lat. 35°38′14″, Lon. 136°57′04″), R38252, R38261, R38259, R38258, R38260 (Lat. 35°38′13″, Lon. 136°57′04″) and R38192 (Lat. 35°38′11″, Lon. 137°07′43″).

Sample number	Locality	Rock type	Assem-blage	Diagnostic spieces
R38286	Kanayama	ms	Pc	Cinguloturris aff. C. carpatica
R38081	Kanayama	ms	Pc	Pseudodictyomitra leptoconica
R38087	Kanayama	ms	Pc	Pseudodictyomitra sp. aff. primitiva
R38082	Kanayama	ms	Pc	Eucyrtidiellum pyramis
R38083	Kanayama	ms	PP-Pc	Pseudodictyomitra primitiva
R38293	kanayama	ms	PP-Pc	Pseudodictyomitra primitiva
R38107	kanayama	ms	PP-Pc	Pseudodictyomitra primitiva
R38285	kanayama	ms	GS	Stichocapsa cf. naradaniensis
R41709	Kariyasu	ms	GS	S.spiralis, T.conexa, (S. oblongua)
R38149	kanayama	sil	Pc	Eucyrtidiellum pyramis
R38150	kanayama	sil	PP-Pc	Parvicingula aff. P. cosmoconica Pseudodictyomitra primitiva
R38215	Kanayama	sil	Pc	Pseudodictyomitra leptoconica
R38152	Kanayama	sil	Pc	Eucyrtidiellum pyramis
R38211	Kanayama	sil	Pc	Eucyrtidiellum pyramis
R38080	Kanayama	sil	Pc	Eucyrtidiellum pyramis
R38134	Kanayama	sil	Pc	Eucyrtidiellum pyramis
R38201	Kanayama	sil	PP	Mirifusus baileyi, Xitus gifuensis
R38224	Kanayama	sil	PP	Mirifusus baileyi, Parvicingula mashitaensis
R38090	Kanayama	sil	PP	Mirifusus baileyi, Protunuma japonicus
R38114	Kanayama	sil	PP	Mirifusus baileyi, Xitus gifuensis
R38135	Kanayama	sil	PP	Mirifusus baileyi, Protunuma japonicus
R38295	Kanayama	sil	PP	Pseudodictyomitra okamurai, Protunuma japonicus
R38210	Kanayama	sil	PP	Mirifusus baileyi, Xitus gifuensis
R38204	Kanayama	sil	PP	Mirifusus baileyi, Xitus gifuensis
R38203	Kanayama	sil	PP	Mirifusus baileyi, Parvicingula mashitaensis
R38214	Kanayama	sil	PP	Mirifusus baileyi, Parvicingula mashitaensis
R38213	Kanayama	sil	PP	Mirifusus baileyi, Xitus gifuensis
R38212	Kanayama	sil	PP	Mirifusus baileyi, Xitus gifuensis
R38216	Kanayama	sil	PP	Mirifusus baileyi, Xitus gifuensis
R38217	Kanayama	sil	PP	Pseudodictyomitra okamurai Orbiculifroma(?) kanayamaensis
R38205	Kanayama	sil	Ty	Cinguloturris carpatica, Eucyrtidiellum nodosum Hsuum maxwelli
R38209	Kanayama	sil	Ty	Cinguloturris carpatica, Pseudodictyomitra(?) sp. D
R38208	Kanayama	sil	Ty	Cinguloturris carpatica, Pseudodictyomitra(?) sp. D
R38207	Kanayama	sil	Ty	Tricolocapsa cf. yaoi, Eucyrtidiellum nodosum

Table 6 continued

R38228	Kanayama	sil	GS	Stylocapsa(?) spiralis
R38141	Kanayama	sil	GS	Mirifusus fragilis, Eucyrtidiellum nodosum
R38142	Kanayama	sil	GS	Williriedellum sp. A, Pseudodictyomitra(?) sp. D
R38157	Kanayama	sil	GS	Stylocapsa catenarum, Gongylothorax sakawaensis
R38145	Kanayama	sil	GS	Stylocapsa(?) spiralis, Stylocapsa catenarum
R38392	Kanayama	sil	GS	Stylocapsa(?) spiralis, Cyrtocapsa sp. A
R38144	Kanayama	sil	GS	Williriedellum sp. A, Tricolocapsa conexa
R38278	Kanayama	sil	GS	Sticocapsa naradaniensis, Hsuum brvicostatum
R38275	Kanayama	sil	GS	Sticocapsa naradaniensis, Mirifusus fragilis
R38143	Kanayama	sil	GS	Eucyrtidiellum nodosum, Williriedellum sp. A
R38276	Kanayama	sil	GS	Mirifusus fragilis, Eucyrtidiellum nodosum
R38138	Kanayama	sil	GS	Mirifusus fragilis, Hsuum brvicostatum
R38153	Kanayama	sil	GS	Eucyrtidiellum nodosum, Hsuum brvicostatum
R38242	Kariyasu	sil	GS	Stylocapsa(?) spiralis, Stylocapsa catenarum
R38244	Kariyasu	sil	Gn	Tricolocapsa conexa,
R38264	Kariyasu	sil	Gn	Guexella nudata, Tricolocapsa conexa
R38268	Kariyasu	sil	Gn	Guexella nudata, Tricolocapsa conexa
R38252	Kariyasu	sil	Gn	Guexella nudata
R38261	Kariyasu	sil	Gn	Guexella nudata
R38259	Kariyasu	sil	Gn	Tricolocapsa conexa, Stylocapsa cf. tecta
R38255	Kariyasu	sil	Gn	Tricolocapsa conexa, Stylocapsa oblongula
R38388	Kanayama	sil	Gn	Protunuma(?) ochinensis
R38387	Kanayama	sil	Gn	Tricolocapsa conexa
R38384	Kanayama	sil	Gn	Eucyrtidiellum unumaense, Stylocapsa cf. tecta
R38220	Kanayama	sil	Gn	Tricolocapsa conexa, Hsuum brevicaostatum
R38192	Murobora	sil	Gn	Guexella nudata
R38105	Kanayama	ch	L J	Stichocapsa cf. robsta, Xitus sp.
R38236	Kanayama	ch	Gn	Stylocapsa catenarum, Eucyrtidiellum pustulatum
R38290	Kanayama	ch	Gn	Tricolocapsa conexa, Hsuum maxelli
R38291	Kanayama	ch	Gn	Stylocapsa oblongula
R38130	Kanayama	ch	Gn	Tricolocapsa conexa, Guexella nudata, Protunuma(?) ochinensis
R38127	Kanayama	ch	Gn	Tricolocapsa conexa, Dicolocapsa conoformis
R38258	Kariyasu	ch	Hh-Ue	Eucyrtidiellum cf. unumaense, Archicapsa sp. A
R38260	Kariyasu	ch	E J	Parahsuum sp.
R38389	Kanayama	ch	Ps	Parahsuum simplum, Katroma sp., Trillus sp.
R38147	Kanayama	ch	L TR	Archaeospongoprunum (?) hellenicum
R38225	Kanayama	ch	L TR	Canoptum triassicum
R38218	Kanayama	ch	M TR	Triassocampe sp.
R38206	Kanayama	ch	M TR	Triassocampe sp.
R38126	Kanayama	ch	TR	Palaeosaturnalis sp.
R38393	Kanayama	ch	TR	Tripocyclia sp.

Table 7 Radiolarian and conodont fossils in the Neo melange of the Kanayama unit. Symbols are the same as in Figure 5. # : conodont.

Sample number	Locality			rock type	Assem-blage	Diagnostic spieces
		Lat.(N)	Lon.(E)			
R38234	Neo	35°39'49"	136°38'47"	sil	PP	Pseudodictyomitra primitiva, P. sp.,C. carpatica
R38168	Kanzaki	35°37'43"	136°41'17"	sil	PP	P. okamurai,P. sp. D,M. baileyi, Protunuma japonica,T. blakei, Cinguloturris carpatica
R38166	Kanzaki	35°37'17"	136°43'44"	sil	Ty	T.sp. cf T. yaoi, E. ptyctum, C. carpatica,Pseudodictyomitra sp. D,Parvicingula cf.mashitaensis
R38176	Kanzaki	35°37'14"	136°42'18"	sil	GS	E. ptyctum, C. carpatica, Parahsuum stanleiynsis
R38173	Kanzaki	35°37'37"	136°42'34"	sil	Gn	Guexella nudata,T. tetragonna
R38179	Kanzaki	35°37'34"	136°42'32"	sil	Gn	G. nudata,Archaeodictyomitra(?) amabilis, Amphpyndax durisaeptum
R38181	Kanzaki	35°38'02"	136°41'52"	Mn	Gn	Guexella nudata,E. ptyctum,
R38186	Kanzaki	35°37'32"	136°42'27"	ch	Gn	Protunuma ochinensis, T. aff. fusiformis,E. unumaense
R38235	Kanzaki	35°38'34"	136°40'31"	ch	Ue	Stichocapsa japonica, C. cf. mastoidea,E. unumaense
R38187	Kanzaki	35°37'37"	136°43'10"	ch	L TR	Epigondollella bidentata #
R38233	Kanzaki	35°39'14"	136°39'35"	ch	L TR	Capnuchoshaera (?) sp.
R38174	Kanzaki	35°36'32"	136°44'40"	ch	M TR	Triassocampe spp.
R38231	Neo	35°39'34"	136°39'11"	ch	M TR	Triassocampe spp.

are common in the Neo melange but rare in the Kanayama melange. They range in size from a millimeter to several meters in the Kanayama melange but reaches to a kilometer long in the Neo melange. In the Kanayama melange, basaltic lava occurs as angular fragments of microscopic size and as lenticular or subrounded pebbles to boulders. On the other hand, basaltic tuff fragments are swirled with shale, and show highly irregular shape. Pillow lava and basaltic tuff occur also as isolated blocks, or are embedded in the chert sequences of large slabs in the Neo melange. Basaltic tuff locally carries limestone or chert inclusions. In the Neo melange, Late Triassic radiolarians are obtained from chert beds in a large slab within which pillow lava is intercalated (see the locality of sample M201 in Fig. 18).

Limestone clasts

Limestone is white, light gray, medium gray and dark gray, and occurs as clasts ranging in diameter from 10 cm to 50 m in the Neo melange. It is sometimes interbedded with chert, or enclosed in basaltic tuff. Some limestone beds have chert inclusions which are detached from chert interbedded with limestone.

Age of shale matrix

In the Kanayama melange, early Late Jurassic to earliest Cretaceous radiolarians (the *Gongylothorax sakawaensis—Stichocapsa naradaniensis* Assemblage to the *Pseudodictyomitra* cf. *carpatica* Assemblage) are obtained from an argillaceous part of the melange (Table 6). The argillaceous part is usually called "shale matrix", but includes siliceous shale clasts or fragments which yield numerous well-preserved radiolarians.

The same assemblages of the radiolarians as those in the argillaceous parts are obtained from siliceous shale clasts embedded in the melange. For example, early Late Jurassic radiolarians are obtained from an argillaceous part in which a block of late Middle Jurassic to early Late Jurassic siliceous shale is embedded at Kariyasu, while early Late Jurassic radiolarians are obtained from another argillaceous part in which early Late Jurassic to earliest Cretaceous siliceous shale blocks are embedded at Okukanayama (Wakita, 1988).

These facts suggest that most of the radiolarians obtained may have been extracted from siliceous shale clasts and not from clayey part (= true matrix) in the argillaceous parts. Therefore, the age of matrix is as young as or slightly younger than the age indicated by radiolarians from the argillaceous parts, ranging from early (?) Late Jurassic to Early Cretaceous.

In the Neo melange, an argillaceous part yields early Late Jurassic to earliest Cretaceous radiolarians ranging from the intermediate assemblage between the *Guexella nudata* and *Gongylothorax sakawaensis—Stichocapsa naradaniensis* Assemblages to the *Pseudodictyomitra* cf. *carpatica* Assemblage (Sano and Yamagata, 1987), and several siliceous shale clasts yield latest Jurassic radiolarians of *Pseudodictyomitra primitiva—P.* sp. A Assemblage (Table 7). These radiolarians indicate that the age of shale matrix of the Neo melange ranges from early Late Jurassic to Early Cretaceous and is as young as that of the Kanayama melange.

Kamiaso Unit

The Kamiaso unit essentially consists of massive sandstone, turbidite, siliceous shale and bedded chert, and locally includes conglomerate. The components resemble those of the Samondake unit, but thick and large slabs of bedded chert occur more frequently than in the Samondake unit. Since I have mapped and investigated only the northern margin of the unit, I describe this unit on the basis of published articles as well as my own field observation.

Distribution

The unit is mainly distributed in the southern part of the study area, and also distributed to the north of Kanayama (Fig. 4). This unit was mapped by Mizutani (1964) in detail, and numerous radiolarians and conodonts were reported by many authors (e.g. Koike *et al.*, 1971 ; Nakaseko and Nishimura, 1979 ; Kano, 1979 ; Kido, 1982 ; Mizutani and Kido, 1983). This unit also extends to the southwest in the vicinity of Inuyama.

Contact between the Kamiaso unit and the adjoining units

The Kamiaso unit is in fault contact with the Funafuseyama, Nabi and Kanayama units. In the northern margin of the unit, lenses of melange are intercalated within a sandstone-shale sequence. The melanges are possibly related with those of the Kanayama unit.

Lithology

This unit is composed of many stacked slices each of which shows a coarsening-upward succession (KANO, 1979; YAO *et al.*, 1980; KIDO, 1982; KIDO *et al.*, 1982). The succession comprises in ascending order, Early Triassic (?) "Toishi-type" siliceous shale, Middle Triassic to Early Jurassic bedded chert, Middle Jurassic siliceous shale, and turbidite and massive sandstone of unknown age. Conglomerate is locally found within massive sandstone. Thickness of the succession is about 500 m. The slices do not always include all of the reconstructed succession (Fig. 19), and a part of the succession is excluded or dislocated by faults in each slice.

"Toishi-type" siliceous shale

"Toishi-type" siliceous shale is the same as that of the Kanayama unit. It is light gray in color, and consists of microcrystalline quartz, sericite and clayey minerals. It is often interbedded with deep-black carbonaceous shale, and is finer in grain size than Jurassic siliceous shale.

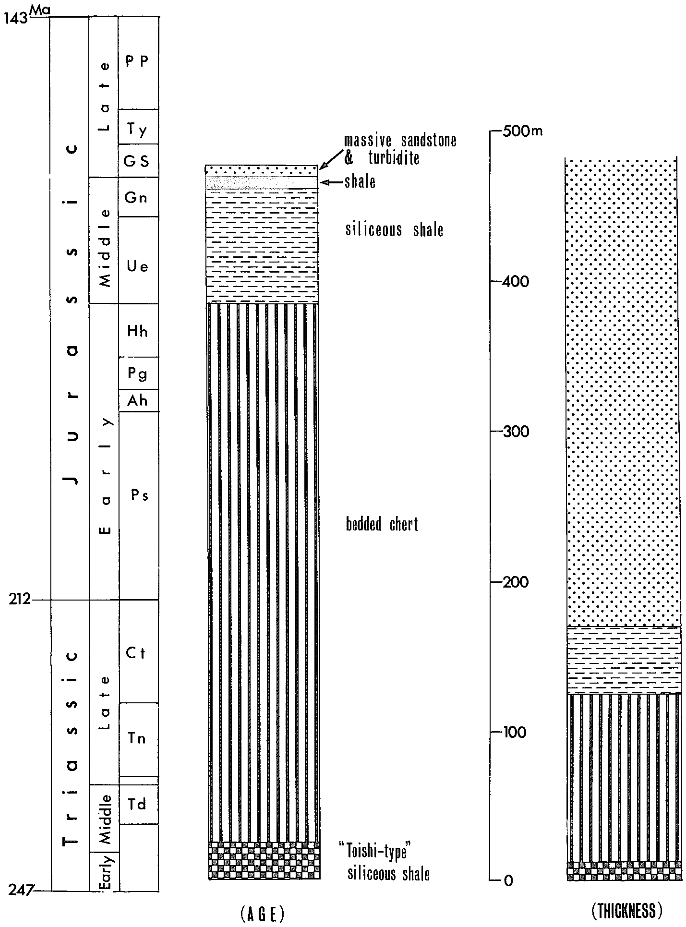


Fig. 19 Generalized columnar sections of the Kamiaso unit. Symbols are the same as in Figure 5.

Bedded chert

Bedded chert exhibits a variety of colors including white, gray, dark gray, pale green and reddish brown, and locally displays intraformational folds. Numerous radiolarians and conodonts are obtained from bedded chert (Table 8) ; They are late Middle Triassic to Early Jurassic radiolarians of the *Triassocampe deweveri* Assemblage to the *Hsuum hisuikyoense* Assemblage (NAKASEKO and NISHIMURA, 1979 ; KIDO, 1982 ; KIDO *et al.*, 1982 ; MATSUDA and ISOZAKI, 1982; ISOZAKI and MATSUDA, 1985), and Middle to Late Triassic conodonts (KOIKE *et al.*, 1971 ; IGO and KOIKE, 1975 ; KANO, 1979 ; MATSUDA and ISOZAKI, 1982).

Jurassic siliceous shale

Jurassic siliceous shale is pale gray, dark gray, dark greenish gray, pale green or reddish brown in color. It is divided into bedded siliceous shale and laminated one. Bedded siliceous shale occupies the stratigraphically lower part of the siliceous shale sequence than laminated one. Bedded siliceous shale consists of siliceous siltstone or sandstone interbedded with shaly partings. Siliceous siltstone or sandstone constitutes a bed of less than 20 cm in thick-

Table 8 Radiolarian and conodont fossils in the Kamiaso unit.
Symbols are the same as in Figure 5. For location of samples see following papers.
IG : IGO (1979), NN : NAKASEKO and NISHIMURA (1980), Ye : YAO *et al.* (1980), Y 2 : YAO *et al.* (1982) MI : MATSUDA and ISOZAKI (1982), MK : MIZUTANI and KOIKE (1982), SK : KIDO (1982), Ke : KIDO *et al.* (1982), IM : ISOZAKI and MATSUDA (1985), AM : MATSUOKA (1986). # conodont.

	Sample number	Locality	rock type	Assemblage	Diagnostic spieces
AM	MHS-C, D	Kamiaso	sil	Gn	Tricolocapsa conexa
Ke	HS 5	Kamiaso	sil	Ue-Gn	Guexella cf. nudata, Stichocapsa japonica
AM	MHS-00-B	Kamiaso	sil	Ue	Tricolocapsa plicarum
Ke	HS 1	Kamiaso	sil	Ue	Cyrtocapsa mastoidea, Unuma echinatus
Ye		Inuyama	sil	Ue	Cyrtocapsa mastoidea, Unuma echinatus
MK	JMP-380, 486	Inuyama	sil	Ue	Cyrtocapsa mastoidea, Unuma echinatus
Ke	BS 14	Kamiaso	ch	Hh	Hsuum hisuikyoense
IM	140-195	Kamiaso	ch	Hh	Hsuum hisuikyoense, Hsuum(?) matsuokai
IM	57-77	Kamiaso	ch	Ps	Parahsuum simplum
MI		Kamiaso	ch	Ps	Parahsuum simplum
Y2	35-39	Inuyama	ch	Ps	Parahsuum simplum
Y2	18-34	Inuyama	ch	Ct	Canoptum triassicum
Y2	13-17	Inuyama	ch	Tn	Triassocampe nova
Y2	3-12	Inuyama	ch	Td	Triassocampe deweveri, T.(?) japonica
MK	JMP-544	Inuyama	ch	Td	Archaeospongoprunum japonicum
NN		Kamiaso	ch	Td	Triassocampe deweveri
SK	BC 2, HC 1	Kamiaso	ch	Td	Yeharaia annulata
IG	255, 264	Mugi	ch	L TR	Epigondolella abneptis #
IG	276	Mugi	ch	M TR	Neogondolella bulgarica #
IG	428	Kamiaso	ch	E TR	Neospathodus homeri #

ness, and includes fragments of quartz, plagioclase, biotite and opaque minerals. Laminated siliceous shale is weakly fissile, and contains manganese carbonate nodules. Most of the siliceous shale yields early Middle Jurassic radiolarians (Table 8) of the *Unuma echinatus* Assemblage (KIDO, 1982; KIDO *et al.*, 1982), and locally yields late Middle Jurassic radiolarians of the *Guexella nudata* Assemblage (MATSUOKA, 1986).

Shale

Shale bed is dark gray, and ranges in thickness from 1 to 2 m. It grades into overlying shale-dominant turbidite.

Turbidite and massive sandstone

Turbidite formations overlie the shale bed and alternate with massive sandstone in the upper part of the succession. Turbidite sandstone varies normally from 10 to 80 cm in thickness, and displays sedimentary structures such as graded bedding, cross-, parallel or convolute laminations and sole markings.

Massive sandstone ranges in thickness from 1 to 3 m, sometimes forming thicker beds, and locally contains thin coal seams.

Both massive sandstone and turbidite sandstone are composed largely of ill-sorted angular grains of quartz, potassium feldspars, plagioclase and rock fragments, and clayey matrix with small amounts of heavy minerals. Most of quartz grains show wavy extinction. Common rock fragments are chert, shale, basalt, quartz porphyry, schist and gneiss. Common heavy minerals are garnet, tourmaline and zircon (MIZUTANI, 1959; ADACHI, 1976).

Conglomerate

Conglomerate is locally embedded in massive sandstone. Mostly it is granule conglomerate, but cobbles or boulders are also included in the Kamiaso, Wadano and Sakahogi conglomerates.

The Kamiaso conglomerate, distributed in the Kamiaso area, commonly includes pebbles and cobbles of sandstone, shale and chert with minor amount of pebbles of orthoquarzite and of cobbles and boulders of garnet gneiss, sillimanite gneiss, two mica granite, quartz porphyry, andesite, basalt and limestone in the matrix of coarse-grained sandstone (ADACHI, 1971, 1973, 1976). Radiometric age data for gneiss samples from cobbles of the Kamiaso conglomerate show episodes of 2000 Ma, 1800–1600 Ma, and 1200–1000 Ma (SHIBATA *et al.*, 1970; SHIBATA and ADACHI, 1974).

The Wadano conglomerate is typically exposed at Mugi (KANUMA, 1956, 1958; MIZUTANI, 1964; ADACHI, 1976; KANO, 1979), and is also distributed in places almost at the same horizon. It consists of alternating beds of conglomerate and sandstone, and includes pebbles and cobbles of sandstone, shale, chert, and limestone in coarse-grained sandstone matrix. Chert is predominant, and sandstone, shale and limestone are common. Greenstone is rare in pebbles, but occurs as large slabs (2000–3000 m long) including limestone blocks. Limestone occurs as large blocks (100–500 m long) as well as in pebbles, and yields Permian fusulinaceans such as *Pseudofusulina* sp. and *Misellina* sp. (KANUMA, 1956).

The Sakahogi conglomerate is distributed at Inuyama to the west of the study area. It contains a number of angular to rounded cobbles and pebbles mainly of sandstone, shale, chert, quartz porphyry, orthoquartzite, calcareous sandstone and gneiss in muddy to sandy matrix (KONDO and ADACHI, 1975).

Melanges locally occur as lenticular bodies, tens of meters thick, discordantly within massive sandstone and siliceous shale near the boundary between the

Kanayama and Kamiaso units.

Age of the clastic rocks

Diagnostic fossils have not been obtained yet from sandstone and shale of the Kamiaso unit in the study area. SATO (1974), however, reported the occurrence of early Late Jurassic ammonite *Choffatia* (*Subgrossouvria*) sp. from sandstone at Inuyama. Mesozoic petrified woods, *Taxacenoxylon* sp. and *Cupressinoxylon* sp., were discovered from sandstone beds of the Kamiaso unit at Inuyama (NISHIDA *et al.*, 1974).

CORRELATION OF UNITS, SUITES AND ZONES AMONG THE MINO, TAMBA AND KISO AREAS

Early Jurassic to Early Cretaceous sedimentary complex of the Mino terrane is widely distributed not only in the Mino area, but also in the Tamba area to the west and in the Kiso area to the east. The stratigraphic and structural studies have been independently made by many geologists in these areas, but few attempts have been made to correlate the complex among these areas. In this chapter, I will discuss the correlation of the six tectonostratigraphic units described in the preceding chapter to suites of the Tamba area and to zones of the Kiso area. The tentative conclusion is given in Figure 20.

Correlation to the Suites of the Tamba Area

The sedimentary complex of the Tamba area is divided into two different stratigraphic successions, namely Type I suite and Type II suite on the basis of age and lithology (ISHIGA, 1983 ; IMOTO, 1984). Type I suite consists of Late Jurassic turbidite and melange which contains blocks of Early Triassic "Toishi-type" siliceous shale, Middle Triassic to Middle Jurassic bedded chert and Middle Jurassic to latest Jurassic siliceous shale. Type II suite consists of Early to Middle Jurassic melanges containing blocks and slabs of Late Carboniferous to Early Permian greenstone, Late Carboniferous to Late Triassic limestone, Late Carboniferous to Early Jurassic chert and Early Jurassic siliceous shale. Type I suite is characterized by the presence of "Toishi-type" siliceous shale and Middle Jurassic chert, and Type II suite is marked by the occurrence of Permian blocks and slabs composed of greenstone, limestone and/or chert.

The lithological features and age of each rock type indicate that the Funafuseyama unit and the Kanayama unit are correlative with Type II suite and Type I suite of the Tamba area, respectively. The Funafuseyama unit includes slices consisting of greenstone, limestone and chert of Permian age as well as slices of the Early to Middle Jurassic melanges and disrupted turbidites. These Permian greenstone, limestone and chert are also characteristic of Type II suite in the Tamba area. On the other hand, the melanges of the Kanayama unit are Late Jurassic (?) to Early Cretaceous in age, and include blocks of "Toishi-type" siliceous shale and Middle Jurassic chert. The age of the melanges and the lithology of the clasts in the Kanayama unit are similar to those of Type I suite of the Tamba area.

The correlation of the Funafuseyama and Kanayama units to Type I and Type II suites were attempted in the southwestern part of the Mino area by YAMAMOTO (1985).

The Samondake unit is likely to be correlated with the Type II suite, be-

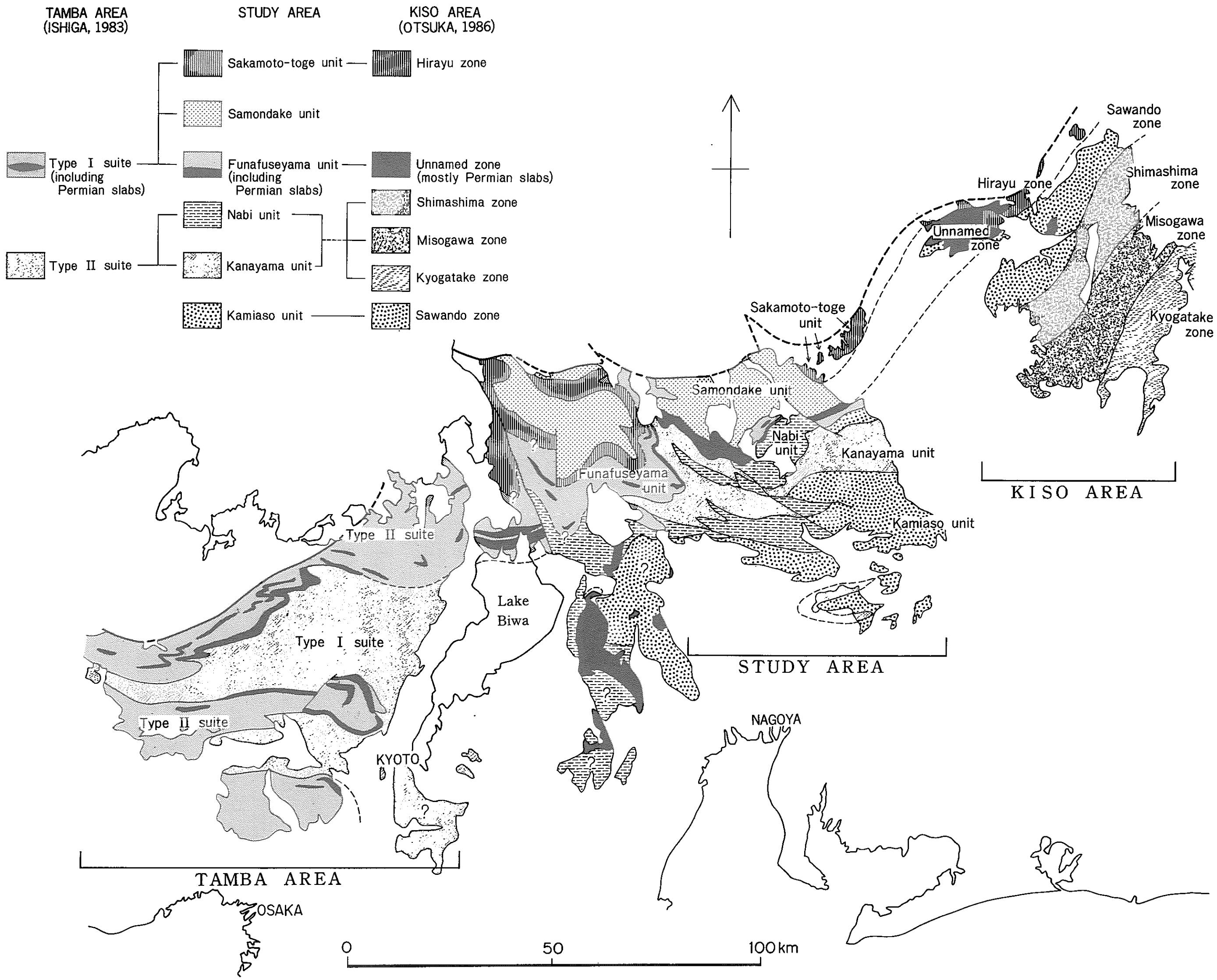


Fig. 20 Correlation of six units of the Mino area to suites of the Tamba area and zones of the Kiso area in central Japan.

cause the unit stratigraphically overlies the Funafuseyama unit in the study area. The remaining two units e.g. the Nabi and Kamiaso units can be correlated with Type I suite of the Tamba area, because the turbidite formations of the Nabi unit interfinger with the melanges of the Kanayama unit, and because the Kamiaso unit contains "Toishi-type" siliceous shale which is characteristic of Type I suite.

Greenstone and limestone clasts occur in the Nabi, Kanayama and Kamiaso units, but are absent in Type I suite of the Tamba area. The Nabi and Kanayama units include Triassic greenstone slabs, although most of greenstone slabs and blocks in these units are unknown in age. The Triassic greenstone of the Nabi unit containing kaersutite is chemically different from Permian greenstone of the Funafuseyama unit.

Late Jurassic turbidite appears to be absent in the study area, although such Late Jurassic coherent sequences are exclusively developed in Type I suite of the Tamba area (ANYOUJI *et al.,* 1983 ; TANABE *et al.,* 1983).

Correlation to the Zones of the Kiso Area

Recently, OTSUKA (1986) divided the sedimentary complex of the Kiso area into six zones, e.g. the Hirayu, Sawando, Shimashima, Misogawa and Kyogatake zones, and regarded large Permian blocks composed of chert, limestone and greenstone as "the other element". ADACHI and KOJIMA (1983), KOJIMA (1984) and YAMADA *et al.* (1985) mapped the northern part of the Kiso area to clarify the age and lithology of the sedimentary complex of the Mino terrane.

KOJIMA (1984) showed that Middle Jurassic siliceous shale occurs between slabs composed of Permian greenstone, limestone and chert, and that Middle Jurassic massive sandstone and turbidite overlie Permian slabs composed of greenstone, limestone and chert. The Permian slabs and the Middle Jurassic siliceous shale may correspond to the Funafuseyama unit of the study area, and the overlying massive sandstone and turbidite (Onishi Formation of YAMADA *et al.,* 1985) may be correlated to the Samondake unit because they have the same geologic setting, age and lithology.

The melange of the Hirayu zone is Early to Middle Jurassic in age (ADACHI and KOJIMA, 1983 ; KOJIMA, 1984), and includes limestone clasts of Middle Carboniferous to Middle Permian age (ISOMI and NOZAWA, 1957 ; FUJIMOTO *et al.,* 1962 ; ISHIZAKI, 1963). The age of melange and the occurrence of Carboniferous limestone clasts strongly suggest that the Hirayu zone corresponds to the Sakamoto-toge unit.

The Sawando zone consists of many stacked slices. Each of these slices is composed of Triassic to Early Jurassic bedded chert, Middle Jurassic siliceous shale and dark gray shale, and younger turbidite in ascending order. Since such stacked slices of coarsening-upward succession are very similar to the components of the Kamiaso unit, the Sawando zone is correlative with the Kamiaso unit.

Late Middle to early Late Jurassic melanges in the Shimashima zone are older than the melanges of the Kanayama unit. There are two possibilities of correlation ; melanges of the Shimashima zone are (1) more disrupted facies of the Nabi unit, or (2) older part of the Kanayama unit. However, there are not sufficient data for narrowing down to one of them.

The Misogawa zone includes massive sandstone, disrupted turbidite and melange with intercalations of Late Jurassic siliceous shale, and the Kyogatake zone is composed mostly of variously disrupted turbidite. The Late Jurassic melange of the Misogawa zone apparently corresponds to that of the Kanayama unit. It is, however, uncertain whether the bedded sequences of the Misogawa and Kyogatake zones are correspond to those of the Nabi unit, or their equivalents are lack in the study area.

ORIGIN OF THE MELANGE IN THE KANAYAMA UNIT

The tectonostratigraphic units in the Mino area consist of lithostratigraphic assemblages of melanges, stacked slices and turbidite formations. All of the units contain blocks and slabs of Triassic bedded chert, Jurassic siliceous shale, and/or Permian greenstone, limestone and bedded chert (Fig. 21). The mode of mixing of the blocks and slabs within sandstone or shale is different among the units as described in the preceding sections.

The fragmentation and mixing of these blocks and slabs in all units were considered to be caused by sedimentary process. For example, melanges of the Sakamoto-toge, Funafuseyama, Nabi and Kanayama units were considered to be formed by submarine sliding, and often called "olistostromes" (ADACHI, 1976, 1979; KANO, 1979; MIZUTANI, 1981; WAKITA, 1983, 1984; YAMAMOTO, 1985; WAKITA and ISOMI, 1986), because the matrix of the sedimentary body is not very strongly sheared, and block-in-matrix texture at each exposures or in each thin section always suggests a "depositional" contact between clasts and matrix. Moreover, stacked slices of coarsening-upward succession in the Kamiaso unit were explained by gravity gliding (KANO, 1979).

Recent progress of the geology of oceanic regions have revealed that various processes are responsible for fragmentation and mixing in melange formation (MOORE *et al.*, 1985). In order to specify the process of fragmentation and mixing, structure and fabric of the mixed rock bodies should be discussed with careful reference to the observations in modern oceanic regions, and it is necessary to investigate the origin of each unit on the basis of several criteria such as relationship between the mixed rock bodies and their surroundings, shape of the mixed body, and nature of the matrix and the clasts.

Although data to understand the origin of all mixed rock bodies throughout the Mino terrane are insufficient, the melanges of the Kanayama unit appear to provide data available for our genetic interpretation. Therefore, in this chapter, I will discuss the fragmentation and mixing process and the origin of the melanges of the Kanayama unit as a step toward the tectonic synthesis of the sedimentary complex of the Mino terrane.

Before the discussion on the origin of the melange, the possible paleotectonic setting of the sedimentary complex of the Mino terrane is discussed first, because precise genetic interpretation of a particular melange requires the information concerning the paleogeographic and paleotectonic setting.

Possible Paleotectonic Setting

The sedimentary complex of the Mino terrane is characterized by the wide

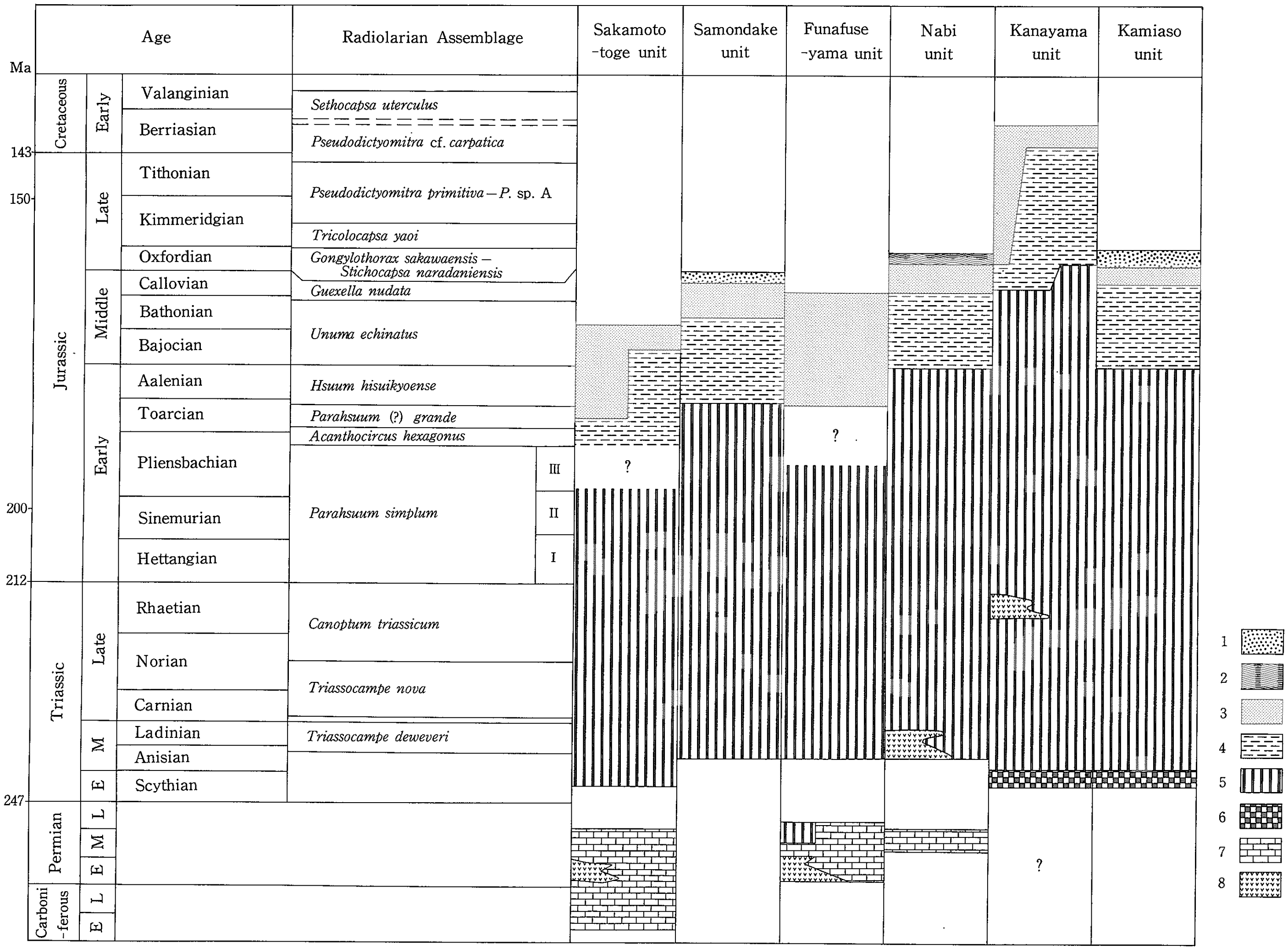


Fig. 21 Reconstructed original successions in the six units of the Mino terrane.
1. massive sandstone and turbidite, 2. well-bedded turbidite and weakly to thoroughly disrupted turbidite, 3. shale, 4. siliceous shale, 5. bedded chert, 6. "Toishi-type" siliceous shale, 7. limestone, 8. greenstone.

distribution of melanges. Melanges are found in orogenic belts throughout the world (e.g. SILVER and BEUTNER, 1980; RAYMOND and TERRANOVA, 1984). A number of melanges are assumed to be formed along convergent plate margins (e.g. HSÜ, 1968; STOREY and MENEILLY, 1983), but some melanges are inferred to be formed in other environments such as in transform-fault zones (SALEEBY, 1984) and on land (LARUE and HUDLESTON, 1987). Since the existence of melange itself does not imply any tectonic setting, it is necessary to find another evidence in order to specify the paleotectonic setting.

The Mino terrane is one of fault-bounded tectonostratigraphic terranes displaced far from their original position, and so it is nonsense to reconstruct paleogeography based on the present terrane arrangements. Several efforts on the provenance analysis using clastic plagioclase (MIZUTANI, 1959), rock fragments and cobbles (ADACHI, 1971, 1973, 1976, 1979; KONDO and ADACHI, 1975), detrital chloritoid (ADACHI, 1977), clastic garnets (ADACHI and KOJIMA, 1983; ADACHI, 1985), and length-slow chalcedony in chert clasts of the melanges (HATTORI, 1985 A, B; MIZUTANI *et al.*, 1987), and on an inter-terrane comparison by means of radiolarian fossils (KOJIMA *et al.*, 1987) were done to reconstruct the paleogeographic and paleotectonic setting. These studies suggest that clastic rocks of the Mino terrane were derived from a Precambrian metamorphic terrane, and were deposited somewhere along the Western Pacific margins.

Components of the sedimentary complex of the Mino terrane provide an useful clue to the paleotectonic setting. The Permian greenstone is inferred to have been derived from abyssal tholeiitic basalts and alkalic basalt (TANAKA, 1970, 1975), and are associated with limestone bodies of the coral-reef type (HATTORI, 1982). Bedded chert is mostly of Permian to Triassic age, consisting mainly of microcrystalline quartz together with abundant remains of radiolarians. It is characterized by the lack of detrital grains. Triassic bedded chert locally interfingers with alkalic basalt (HATTORI and YOSHIMURA, 1983; WAKITA, 1983, 1984).

Chert, greenstone and limestone were formed in an oceanic environment far from the cratonic region. These rocks of oceanic affinity occur as blocks or slabs embedded in variously disrupted sequences of sandstone and shale which consist of detritus derived from a Precambrian continental crust (ADACHI, 1971, 1973, 1976). A convergent plate margin seems to be suitable for the paleotectonic setting where "oceanic" materials were encountered and mixed with terrigenous sediments.

There is another evidence indicating that the sedimentary complex of the Mino terrane is broadly related to plate convergence or subduction. Six tectonostratigraphic units identified in the Mino area are composed of almost the same rock types. Age determination of each rock type suggests that lithostratigraphic assemblages of each unit essentially have similar original coarsening-upward succession (Fig. 21). The age of the same rock type in the succession is slightly different among the six units, and the age of terrigenous rocks varies from Early Jurassic to earliest Cretaceous. The coarsening-upward succession of each unit is usually composed of bedded chert, siliceous shale, dark gray shale and turbidite locally associated with massive sandstone in ascending order. The results of litho- and biostratigraphic reconstruction represent the increase of the influence of terrigenous detrital material as the age becomes younger.

The similar coarsening-upward sequences from pelagic deposits to thick beds of medium- to coarse-grained clastic rocks through hemipelagic argillite are regarded as the ancient trench deposits by PIPER *et al.* (1973), VON HUENE (1974), MOORE and KARIG (1976), DICKINSON (1982) and LASH (1985). Even in the modern sediments, a complete vertical section of a coarsening-upward succession is recovered at Deep Sea Drilling Project Site 298 in the Nankai trough (MOORE and KARIG, 1976).

Accretion of trench-fill deposits and subsequent disruption within an accretionary wedge reasonably explain the variously disrupted heterogeneous assemblage derived from the original coarsening-upward succession in the sedimentary complex of the Mino terrane. Thus I favor the convergent margin for a possible tectonic setting of the sedimentary complex of the Mino terrane.

Nature of the Melange in the Kanayama Unit

The origin of melange is controversial, and many workers have assigned tectonic, sedimentary, diapiric or polygenetic origins to melange. Inasmuch as a variety of origins have been proposed, definitive criteria should be needed to distinguish them (RAYMOND and TERRANOVA, 1984). In this report, I adopt the following criteria : (1) nature of contact of the melange body with its surroundings, (2) whole shape of the melange body, (3) nature of the shale matrix, (4) contact features of the clasts with the shale matrix, (5) shape of the clasts, (6) age, lithology and size of the clasts.

Relationship of the melange to the adjoining units

The Late Jurassic (?) to Early Cretaceous melange of the Kanayama unit are surrounded by the Middle Jurassic Nabi, Kamiaso and Funafuseyama units, and the Kanayama unit is separated from the Funafuseyama unit by one of the major faults in the Mino area. The Kanayama unit is interposed in the distribution of the Nabi and Kamiaso units, and divides them into two segments, respectively (Fig. 4). The contacts of the Kanayama unit with the Nabi and Kamiaso units are not observable directly. Several features such as "interfingering" and the occurrence of small-scale melanges in the Nabi and Kamiaso units imply that the melanges of the Kanayama unit were originally intruded into the Nabi and Kamiaso units and also between them.

"Interfingering" between the Late Jurassic (?) to Early Cretaceous melange of the Kanayama unit and the late Middle Jurassic turbidite sequences of the Nabi unit suggests that the melange of the Kanayama unit was originally intruded into the sequences of the Nabi unit. In the "interfingering" part, the melange of the Kanayama unit includes several blocks of limestone. Strangely enough, a limestone block is also embedded in the turbidite of the Nabi unit. The occurrence of the limestone block appears accidental but it is easily explained by the shale injection into turbidite. The limestone block in the turbidite of the Nabi unit is a remnant after the surrounding shale was swept away from the turbidite during compaction. Similar structure is observed in the siliceous shale blocks of the Kanayama melange (WAKITA, 1988).

The Nabi unit contains many slices of melange (Fig. 12). Since the age of the shale or siliceous shale in the melanges is not determined, I described the melanges as a member of the Nabi unit. The melanges are lithologically similar to those of the Kanayama unit. Shale injection into clasts occurs in the melanges of the Nabi unit as well as in the Kanayama melange. Therefore, the melanges in the Nabi unit may be branches of the melanges of the Kanayama unit.

The melanges of the Kanayama unit are generally in fault contact with the sandstone-dominant stratigraphic sequence of the Kamiaso unit. Small-scale melanges of several tens of meters thick are locally embedded within the bedded sequences only near the boundary between the Kanayama and Kamiaso units.

Shape of the melange bodies

Melanges of the Kanayama unit, deformed by faults, lost their original shape. It is likely that the lateral extension is over several tens of kilometers, and the maximum width in N-W direction is about 10 km.

Microscopic features of the shale matrix

The shale matrix is weakly foliated, but encloses a number of rock fragments having no sheared margin (Plates VI, VII). The rock fragments are usually rounded or subrounded (Plate VI-1, 2, 6), but are sometimes rhombic, lenticular or irregular (Plate VI-3, 4, 5). And, some of the fragments are rotated, and the direction of their elongation is slightly oblique to the elongation of more ductile fragments such as siliceous shale (Plate VII-1, 2).

Densely aggregated sericite are developed and arranged subparallel to the elongation of most clasts (Plate VII-5, 6). The scaly foliation is weakly developed and is oblique to the arrangement of minerals and rock fragments in the shale matrix, suggesting that the scaly foliation was developed after the melanges obtained block-in-matrix fabric (Plate VII-4).

Shale injection into the clasts

Shale injection into clasts is very common feature in the melange of the Kanayama unit. The shale injection occurs particularly in siliceous shale and sandstone clasts, and ranges from microscopic to mappable scale.

The Kanayama melange contains a large block of over 8 km long, consisting of massive sandstone and turbidite which form a coherent stratigraphic sequence (Fig. 22). The shape of the blocks is highly irregular, showing "interfingering" with the surrounding matrix. Even into the interior of the blocks, a branch of melange of several tens of centimeters thick pierces turbidite at steep angles with bedding. In the southern margin where no mappable intrusion occurs, shale matrix containing smaller clasts of sandstone and chert is injected into massive sandstone in a complex manner (Fig. 22).

Mesoscopic features of shale injection are characteristic of siliceous shale clasts (Plate V-2-6), as described by WAKITA (1988) in the Kanayama melange. There is good exposure for observation of such shale injection into siliceous shale (Fig. 23) in the western end of the Kanayama melange. The siliceous shale is of late Middle Jurassic age, and constitutes a block together with Early to Middle Jurassic bedded chert. Shale injection, ranging in width from a millimeter to several meters, occurs in siliceous shale part. Shale

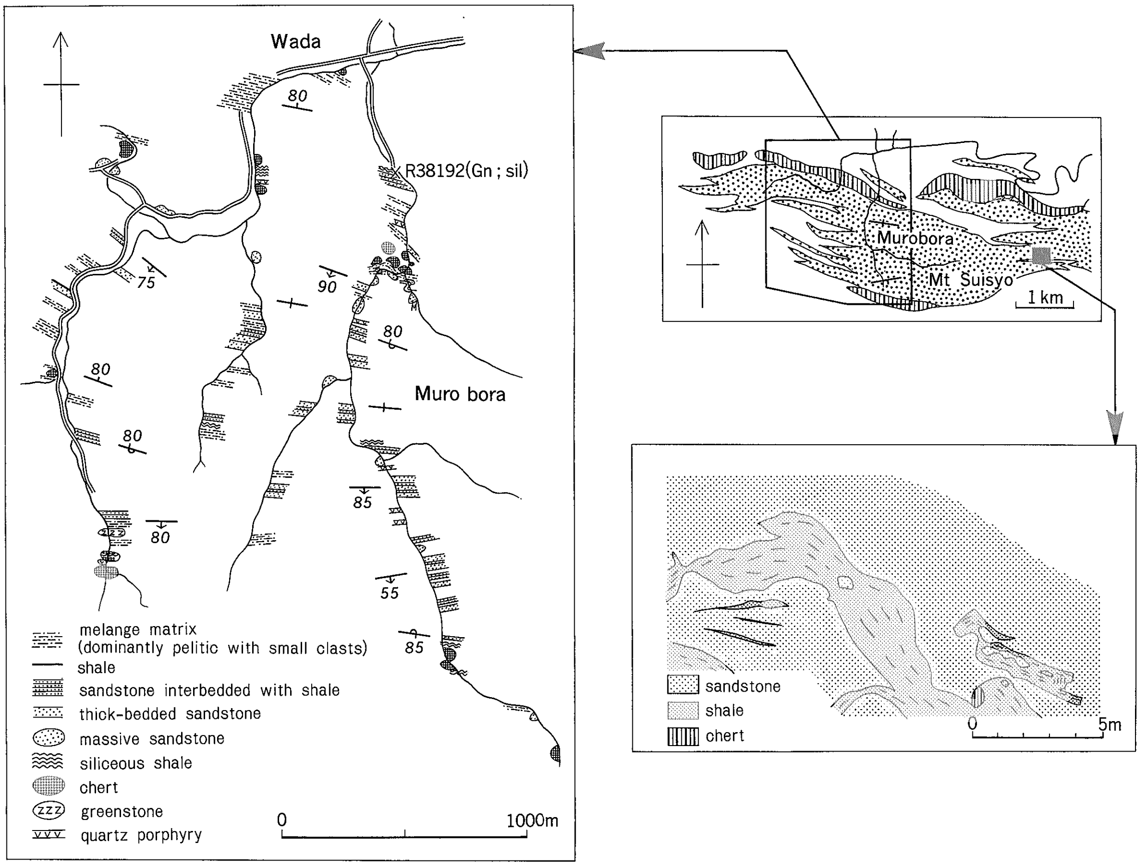


Fig. 22 Route map and geologic sketch map showing relationship between melange matrix and a large block composed of coherent sequence of sandstone and shale in the Kanayama melange in the eastern part of the study area. Symbols are the same as in Figure 5.

injection occurs subparallel or slightly oblique to the stratification of the siliceous shale, and clearly cuts through the stratification. The shale, which is injected into the siliceous shale block, includes angular fragments of siliceous shale which are disintegrated from the host rock. One of the siliceous shale fragments is rotated against the host siliceous shale during the shale injection (Plate V-2).

Siliceous shale, particularly "pebbly siliceous shale" sometimes encloses sandstone fragments. These sandstone fragments are often associated with a small amount of dark gray shale. The shale encloses sandstone fragments in some cases, and is associated with sandstone fragments as "tail" or "pressure shadow" around them in other cases (Plate V-4, 6). These features show deformation of shale during compaction. During the dewatering, ductile shaly parts were swept away from the place of injection, and then sandstone fragments alone were left behind in the host of siliceous shale.

Under the microscope, dark gray

Fig. 23 Shale injection into a large siliceous shale clast in western end of the Kanayama melange, near Shimoda bridge (Lat. 35°38′14″, Lon. 136°57′04″).
1. melange matrix (dominantly pelitic, with small clasts), 2. siliceous shale, 3. sandstone, 4. "Toishi-type" siliceous shale, 5. quartz porphyry, 6. no exposure

clayey materials are injected into siliceous shale (Plate VI-5), and break that part of the siliceous shale into angular smaller-sized fragments (Plate VI-3, 4).

Shale injection occurs not only in sandstone and siliceous shale clasts but also in clasts of basic tuff, "Toishi-type" siliceous shale, chert and disrupted turbidite (Plate V-1).

Shape of the clasts

Clasts ranging in diameter from 5 to 100 cm have diverse shapes such as lenticular, rhombic, hexagonal, triangular, rounded and subrounded.

Some of the sandstone clasts are highly irregular in shape, and they sometimes have re-entrant angles (Fig. 24, Plate IV-1), although the rough external forms are triangular rhombic or hexagonal subangular. Surrounding shale is forcefully injected into sandstone clasts, and a vein extends toward the core of sandstone clasts from the end of each shale injection in places. Small disintegrated sandstone fragments are scattered around the larger

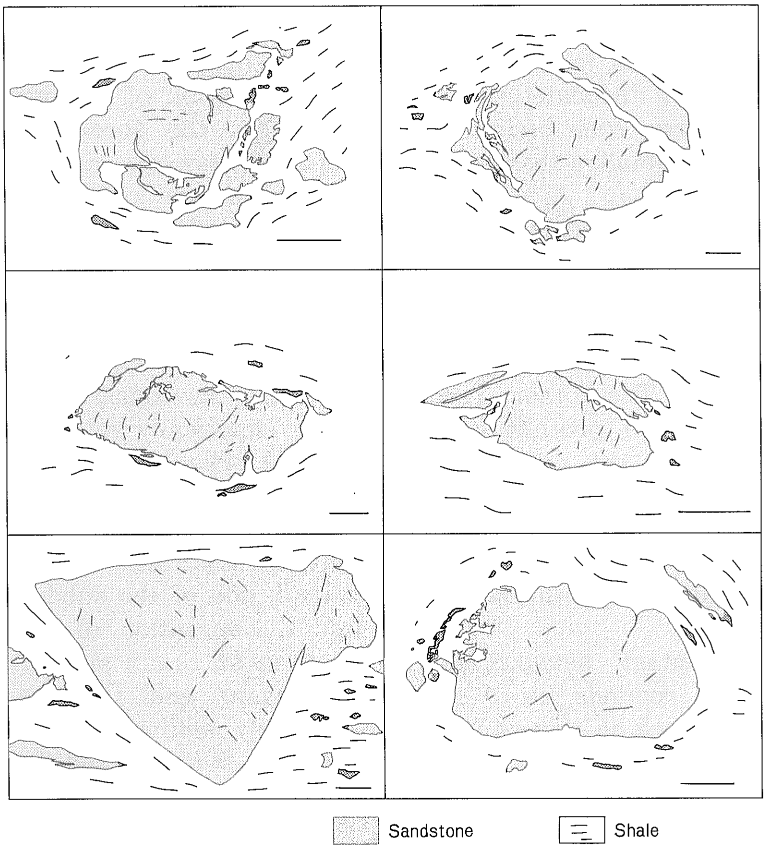


Fig. 24 Shape of sandstone clasts in the Kanayama unit. Scale bar = 5 cm.

sandstone clast (Fig. 24). Some of siliceous shale and chert clasts also show similar features to the irregular shaped sandstone clasts (Plate IV-2, 4).

Age, lithology and size of the clasts

Clasts of the melanges are composed of sandstone, chert, siliceous shale, greenstone and limestone. Chert yields Triassic to Middle Jurassic radiolarians, while siliceous shale yields Middle Jurassic to earliest Cretaceous radiolarians. There is no fossil evidence of the age of sandstone, limestone and most of greenstone, although greenstone is associated with Triassic bedded chert in a slab (Fig. 18).

Small chert clasts (<50 cm) tend to be different in age from larger ones (>50 cm) in the Kanayama melange. The small chert clasts are of Early to Middle Jurassic age and rarely contain Late Jurassic fossils, whereas the larger chert clasts are mostly of Triassic age.

Wakita (1988) has reconstructed three successions of protoliths from which clasts of the Kanayama melange were derived. The reconstruction was done on the basis of age and lithology of clasts in the Kanayama melange. These successions are lithologically similar but different in age among three localities. Clasts derived from several protoliths which originally show distinct stratigraphic successions are distributed almost at the same horizon. The explanation of this lies in a fact that these protoliths were dislocated from an original site as large rock bodies, and then broken into smaller-sized clasts almost at the same time.

One of the reconstructed successions is composed of Triassic to late Middle Jurassic bedded chert, early Late Jurassic to earliest Cretaceous siliceous shale and Early Cretaceous (?) sandstone and shale. The other reconstructed successions of protoliths have similar lithology but the age of each rock type is slightly different from one another (WAKITA, 1988).

Wedge-Collapse Hypothesis

"Depositional contact" between clasts and shale matrix reminds us of sedimentary mixtures such as olistostromes. Small-scale gravitational features such as slumps and mud debris flows are most common near the base of the trench-slopes (KARIG, 1983). Seismic reflection profiles show the occurrence of sliding blocks and slabs or chaotic sediments derived from submarine sliding in various parts of present-day continental slopes (UCHUPI, 1967 ; MOORE *et al.*, 1970, 1976 ; KARIG *et al.*,1980). Although it is clear that the bedding of slump sediments has been disrupted in various ways, most of slump sediments are derived from slope sediments. There is no evidence that chaotic slump sediments contain any blocks derived from previously scraped off pelagic or hemipelagic sediments. Superficial gravitational sliding on the continental slope can provide fragmentation of slope sediments, but seems to be insufficient to mix oceanic materials with trench-fill deposits.

Recently, OKAMURA and YAMAZAKI (1987) has proposed a new idea regarding the origin of melanges on the basis of observation of the modern accretion wedge in the forearc region around Japan. They assumed that an accretionary wedge and slope deposits fall down behind the subducting seamount, break up into fragments and mix with fragments of the top parts of the subducting seamount (Fig. 25).

This "wedge-collapse hypothesis" is attractive in considering the origin of large chaotically mixed rock bodies in which blocks are enclosed in unfoliated to weakly foliated shale matrix. A subducting seamount forces the forearc material landward and makes a swell in a land side of the subducting seamount and a depression of the inner trench slope in an ocean side of the seamount (YAMAZAKI and OKAMURA, in press). Variously deformed or disrupted sedimentary complex can be produced by the subducting seamount.

The melanges of the Kanayama unit contain rounded to subrounded blocks and elongated slabs enclosed in ductilely deformed shale. The wedge-collapse, however, is unlikely to cause the ductile flow of mud, and can only produce numerous angular fragments and blocks into which the accretionary wedge disintegrated.

The Kanayama unit of Late Jurassic (?) to Early Cretaceous age is interposed in the Nabi and Kamiaso units of Middle Jurassic age, and divided these units into two segments, respectively. The age of each rock type is younger in the Kanayama unit than in the adjoining units. If wedge-collapse had produced the melanges of the Kanayama unit, one side (ocean side) of the melanges unit must have been produced later than the Kanayama unit. The discordant occur-

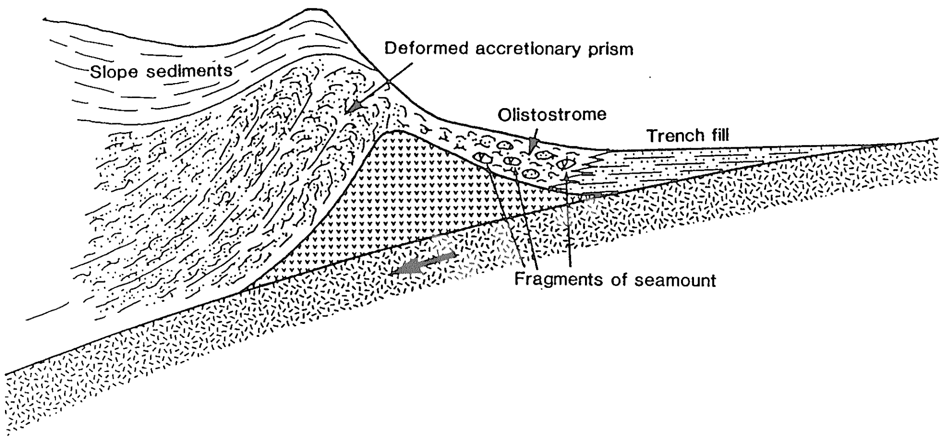


Fig. 25 Wedge-collapse model for the formation of sedimentary melange ("olistostrome"), (after OKAMURA and YAMAZAKI, 1987).

rence of the Kanayama unit with the surrounding units is unlikely to fit the wedge-collapse hypothesis.

Wide distribution of shale injection into clasts in the melanges of the Kanayama unit indicates the existence of overpressured shale in the whole unit. During the collapse the overpressured shale may be intruded into the overriding sequences in the lower part of the wedge, but is unlikely to occur in the upper part.

The above arguments indicate that the wedge-collapse process cannot directly cause the melanges of the Kanayama unit. There is a good possibility, however, that the wedge-collapse by subducting seamounts caused rough fragmentation and mixing in the first stage of the melange formation of the Mino terrane.

Diapiric Hypothesis

An alternative hypothesis for the formation of the melanges in the Kanayama unit is that of diapiric origin (Fig. 26).

Mud diapirism is a common process in active convergent margins as well as passive continental margins. Mud volcanoes, which are superficial manifestation of mud diapirs, cover the surface of the subduction complex in the Barbados. The relationship between mud volcanoes and mud diapirs is clearly shown in seismic profiles (BIJU-DUVAL *et al.*, 1982 ; WESTBROOK and SMITH, 1983 ; BROWN and WESTBROOK, 1987).

Undercompacted and overpressured argillaceous materials rise up through the overlying denser succession toward the surface and then erupt as a mud volcano. Mud volcanoes in West Timor appear to convey some rock fragments from the underlying formations with dominant mud extrusion (BARBER *et al.*, 1986). BARBER *et al.* (1986) has proposed a diapiric model for the formation of melange by linking widely distributed chaotic deposits to the eruption of mud volcanoes in Timor and eastern Indonesia. Recently, it has been widely accepted that mud diapirism is one of the mechanisms for the formation of melanges (WILLIAM *et al.*, 1984 ; COWAN,

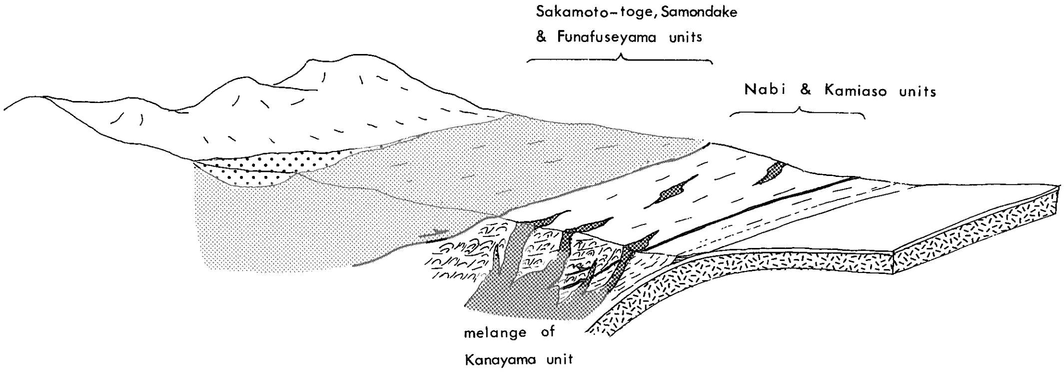


Fig. 26 Diapiric model for the formation of melanges in the Kanayama unit.

1985 A, B; RAYMOND, 1984; BECKER and CLOOS, 1985; BARBER *et al.*, 1986; LASH, 1987).

The most definitive criterion for diapiric melange is the shape of melange body. The diapiric melange in Timor forms a roughly circular plug (BARBER *et al.*, 1986). In the Appalachian region, LASH (1987) reported diapiric melange discordantly surrounded by bedded sequences.

Unfortunately the original shape of the melange is not clear in the Kanayama unit. The relationship between the melange and the adjoining units implies that the melange has been intruded into the adjoining units and divided them into more than two segments. Shale injection into clasts of various sizes and rock types is very characteristic of the melanges in the Kanayama unit. These features can be explained by forceful injection of highly pressured to overpressured mud into the clasts.

The shapes and features of sandstone clasts in the melanges of the Kanayama unit are very similar to those of the diapiric melange in West Timor and Sabah (BARBER *et al.*, 1986). It is likely that the irregular shape and re-entrant angle of the sandstone clasts resulted from the difference of the pore-fluid pressure between the clasts and the shale matrix. The characteristic features due to overpressured shale strongly suggest that the essential mechanism of forming the melanges of the Kanayama unit is diapiric process.

The younger ages of the components of the Kanayama unit relative to the adjoining units are consistent with the diapiric hypothesis. During the formation of the accretionary wedge, younger sediments are accreted on the oceanic side at the toe of the wedge. Imbricated thrusting forces the younger sediments into structurally lower portion of the accretionary wedge. Upward movement of the diapiric shale may bring fragments which consist of relatively younger sediments than the host sequences.

The reconstruction of protolith from which the clasts of the melange were derived suggests that several types of slabs showing coarsening-upward succession broke up into fragments. The upwelling of overpressured shale may break up the overriding wedge composed of previously accreted sediments of coarsening-upward succession.

WESTBROOK and SMITH (1983) and BARBER *et al.* (1986) insisted that overthrusting of allochthonous sheets can be attributed to overpressured shale which is important for the diapirism. The Sakamoto-toge, Samondake and Funafuseyama units thrust up to the Nabi, Kamiaso and Kanayama units in the same manner as the overthrusting of Type II suite on Type I suite (Ishiga, 1983 ; Imoto, 1984) in the Tamba area. In the same way, stacked slices of Triassic bedded chert and Middle Jurassic clastic strata of the Nabi and Kamiaso units moved and rested on the clayey deposits which were original materials of melange matrix of the Kanayama unit (Fig. 26).

The Nabi and Kamiaso units of Middle Jurassic age must have been relatively more densely consolidated than the light buoyant clayey deposits of the tectonically underlying Kanayama unit of Late Jurassic to Early Cretaceous age. Piling up of these thrust sheets may have contributed to produce overpressure and density inversion. Faults must have made paths through which the shale diapirs rose up, but essential mechanism of the faulting is still ambiguous.

Fragmentation and Mixing Process in the Melange

As discussed in the preceding section, mud diapirism was an essential mechanism in producing the melanges of the Kanayama unit. Diapiric process, however, was not exclusive cause for the fragmentation and mixing in the melanges of the Kanayama unit. The melanges had undergone several processes before they obtained the present chaotically mixed fabric.

The fragments and blocks in the melanges display various shapes such as rounded, rhombic and irregular. These clasts of various shapes occur together in outcrops or even in hand specimens. The variety of clast-shape is due to the multiple fragmentation and mixing processes. The rotated lenticular fragments were formed by simple shear under high confining pressure, the rhombic fragments of sandstone and siltstone were produced by layer-parallel extension, and the shape of the highly irregular clasts, into which the surrounding shale was injected, was influenced by the overpressured shale. These shapes of clasts suggest that some processes such as slumping and localized shearing were responsible for the fragmentation prior to mud diapirism.

The arrangement of the larger slabs in the southern margin of the Kanayama melange appears to show the breakup of slabs from the original succession of coarsening-upward sequences. There, slabs of bedded chert, siliceous shale, turbidite and massive sandstone in the melange are arranged in the same order as in the succession of the Kamiaso unit, although each slab is surrounded by the matrix of the melange (Fig. 16). Such occurrences of the slabs in the melange can also be explained by diapiric process by which stacked protoliths exhibiting coarsening-upward succession were broken up and disrupted.

Modern diapirs and mud volcanoes are small, ranging from several meters to several kilometers in diameter. In Barbados, several mud volcanoes are linked in a line and constitute a chain of mud volcanoes (Brown and Westbrook, 1987). By means of linking of numerous mud diapirs, the pre-existing accretionary wedge gradually disintegrated into blocks and slabs of the melange.

Melanges of the Kanayama unit include large blocks and slabs ranging from 10m to several kilometers in length as well as smaller fragments. Most of

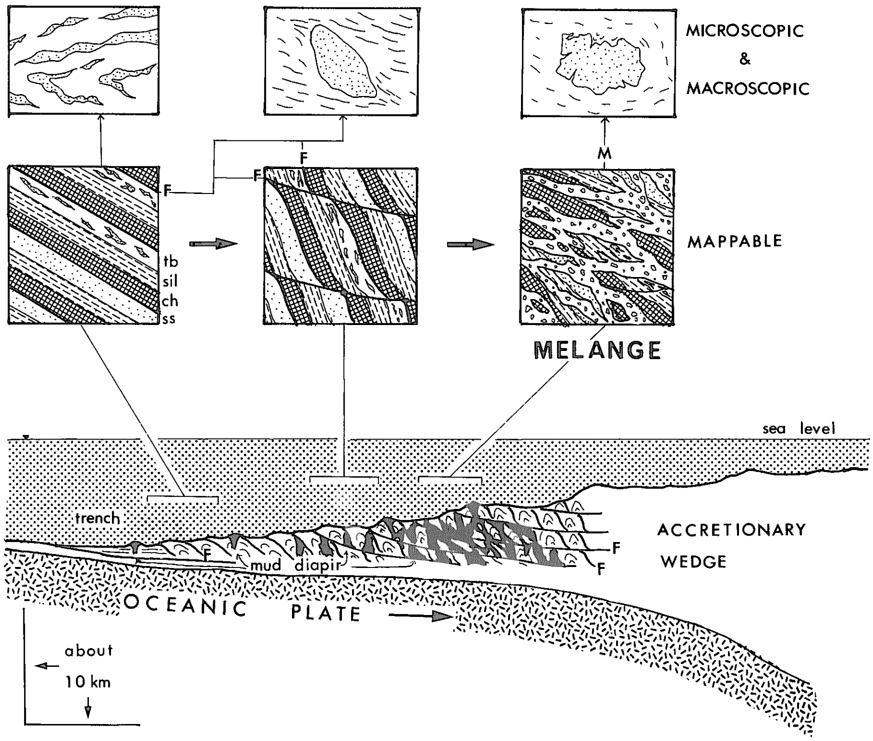


Fig. 27 Fragmentation and mixing process in the melanges of the Kanayama unit. The upper part shows progressive disruption of accreted sediments on various scale.
F : thrust, M : melange matrix, tb : disrupted turbidite, sil : siliceous shale, ch : bedded chert, ss : massive sandstone and turbidite

chert in the large slabs and blocks is of Triassic age, while Early to Middle Jurassic radiolarians are generally obtained from smaller chert fragments (<50cm). These differences in age between the larger and smaller clasts suggest that the smaller fragments of the younger chert may have risen and large blocks and slabs of the older chert may have sunk or stayed in the diapir, although more data are necessary for clarifying the fragmentation and mixing process in the diapir.

It is concluded that the present features of the melanges of the Kanayama unit were caused by progressive process of the fragmentation and mixing, including the diapiric, sedimentary and tectonic processes (Fig. 27).

SUMMARY

I. On the basis of age, composition and fabric, the sedimentary complex of the Mino terrane is divided into six tectonostratigraphic units, namely the Sakamoto-toge, Samondake, Funafuse-yama, Nabi, Kanayama and Kamiaso units.

The Sakamoto-toge unit consists mainly of Early to Middle Jurassic melanges marked by the occurrence of Carboniferous limestone clasts.

The Samondake unit is composed mainly of massive sandstone and turbidite of late Early Jurassic to late

Middle Jurassic age. Small amounts of chert blocks are scattered only at the lower portion of the unit.

The Funafuseyama unit is characterized by slices of Middle Jurassic melanges and disrupted turbidite, and slices of Permian greenstone, limestone and chert.

The Nabi unit comprises slices of Middle Jurassic to early Late Jurassic variously disrupted turbidite, slices of massive sandstone and melange of unknown age, and slices, slabs and blocks of Triassic bedded chert. The bedded chert is locally associated with Triassic greenstone (alkali basalt).

The Kanayama unit is divided into the Kanayama melange and the Neo melange both of which are Late Jurassic (?) to Early Cretaceous in age. The melanges includes various sizes of clasts of sandstone, chert, siliceous shale, greenstone and limestone in weakly foliated shale matrix.

The Kamiaso unit is characterized by stacked slices each of which consists of coarsening-upward succession including Early Triassic (?) "Toishi-type" siliceous shale, Middle Triassic to Early Jurassic bedded chert, Middle Jurassic siliceous shale, late Middle Jurassic shale and early Late Jurassic (?) turbidite and massive sandstone in ascending order.

II. The Sakamoto-toge, Samondake and Funafuseyama units can be correlated with Type II suite of the Tamba area, while the Nabi, Kanayama and Kamiaso units can be compared with Type I suite of the Tamba area.

The Sakamoto-toge and Kamiaso units can be correlated with the Hirayu and Sawando zones in the Kiso area, respectively.

III. Accretion in the convergent margin and subsequent deformation in the accretionary wedge are geologic processes suitable for the formation of the sedimentary complex of the Mino terrane.

The intrusion of the melange body into adjoining units, shale injections into clasts, irregular shaped clasts, and younger age of siliceous shale and chert than surrounding units strongly suggest that the major process of the melange formation in the Kanayama unit is mud diapirism.

Mud diapirism was an essential mechanism but was not exclusive one to produce the melanges of the Kanayama unit. The present features of the melanges of the Kanayama unit were caused by progressive process of the fragmentation and mixing, including the diapiric, sedimentary and tectonic processes.

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美濃帯のジュラ紀前期-白亜紀前期堆積岩コンプレックスにおける混在岩体の成因

脇　田　浩　二

要　旨

美濃地域には，ジュラ紀前期から白亜紀前期にかけて形成された堆積岩コンプレックスが広く分布している．この堆積岩コンプレックスは，主として砂岩・泥岩・珪質頁岩・チャート・石灰岩及び緑色岩類からなる．これらの構成岩類は様々な形で混合し，複雑なコンプレックスを作り上げている．その混合様式を基本に，地質時代，地質構造，巨視的及び微視的組織を考慮に入れて，美濃地域の堆積岩コンプレックスを次の6つのユニットに区分した．

(1) 坂本峠ユニット――ジュラ紀前期-中期に形成されたメランジ．石炭紀の石灰岩岩塊を特徴的に含む．

(2) 左門岳ユニット――ジュラ紀中期に堆積した塊状砂岩及びタービダイトからなる地層群で下位にチャートの巨大岩塊を挟有する．

(3) 舟伏山ユニット――ジュラ紀中期のメランジと二畳紀の石灰岩-緑色岩類-チャート岩体が構造的に繰り返す．

(4) 那比ユニット――ジュラ紀中期-ジュラ紀後期前葉のタービダイトと三畳紀のチャート岩体が構造的に繰り返す．所々にメランジも挟有する．タービダイトは様々な程度の塑性変形をしており，砂岩層はしばしば礫化している．

(5) 金山ユニット――ジュラ紀後期（?）-白亜紀前期のメランジ．三畳紀-ジュラ紀中期の層状チャート及びジュラ紀中期-白亜紀最前期の珪質頁岩を様々な大きさの岩塊として含んでいる．石灰岩・緑色岩類はまれである．

(6) 上麻生ユニット――下位から三畳紀前期の“砥石型”珪質粘土岩，三畳紀中期-ジュラ紀前期の層状チャート，ジュラ紀中期の珪質頁岩及び泥岩，ジュラ紀後期前葉のタービダイト及び塊状砂岩と重なる一連の上方粗粒化を示す地層群が構造的に何回も繰り返している．上麻生礫岩・和田野礫岩・坂祝礫岩などもこのユニットの塊状砂岩部に挟在する．

これらの6つのユニットはふつう互いに断層で接しているが，左門岳ユニットの地層群は舟伏山ユニットのチャート岩体の上へ整合ないし不整合で重なっており金山ユニットは那比ユニットと部分的に指交関係にある．

6つのユニットはいずれも基本的には上麻生ユニットに認められるような上方粗粒化の層序が様々に分裂・混合して形成されている．このうち金山ユニットのメランジの成因について検討した．金山ユニットのメランジは，主に砂岩・チャート・珪質頁岩からなる岩塊とそれをとり囲む泥岩基質からなる．このメランジは従来上麻生ユニットと同種の地層群の崩壊により形成されたオリストストロームと解釈されてきた．しかし，含まれる岩塊には周囲の泥岩基質が割れ目に沿って注入しており，地質図上でも巨大岩塊への泥岩基質の注入が明らかである．このような岩塊の形態は，メランジ形成時に泥が高間隙水圧を保有していたことを示しており，混在化が表層の地すべりよりもむしろ泥ダイアピル的に行われたことを示している．金山ユニットのメランジが那比ユニットと部分的に指交関係にあること，上麻生ユニットや那比ユニット中の金山ユニットに近い部分にしばしばメランジが挟有されること，金山ユニットが那比ユニットや上麻生ユニットを分裂させる形で分布していること，そして金山ユニットの構成岩類が那比ユニットや上麻生ユニットの同種の構成岩類に比べて著しく若いことなどの事実も，金山ユニットのメランジが堆積体であるよりむしろ貫入岩体であることを示唆している．

（受付：1988年2月19日；受理：1988年5月6日）

PLATES

AND

EXPLANATIONS

(with 7 Plates)

Plate I

1 Massive sandstone of the Samondake unit at Nigure, south of Kuzuryu-ko.

2 Turbidite of the Samondake unit at Uchigatani.

3 Well-bedded turbidite of the Nabi unit at Tarumi.

4 Slightly disrupted turbidite of the Nabi unit at Mino city.

5 Weakly disrupted turbidite of the Nabi unit at Horado.

6 Rhomboidal fragments of sandstone cut by normal faults in weakly disrupted turbidite of the Nabi unit, at Horado. Scale is 10 cm long.

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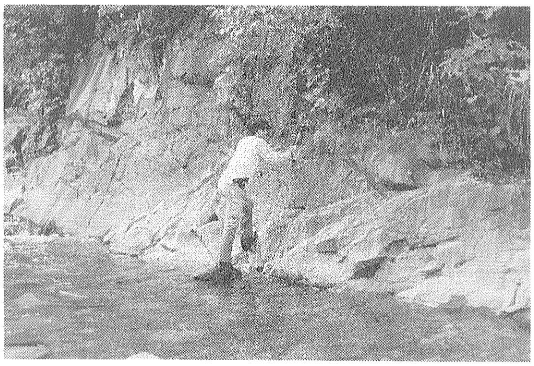

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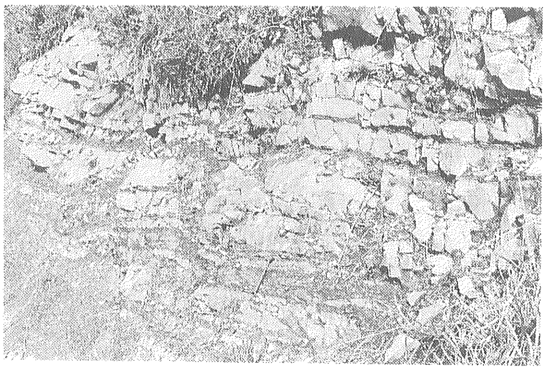

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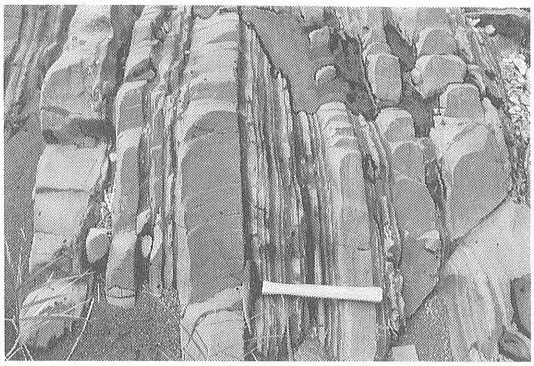

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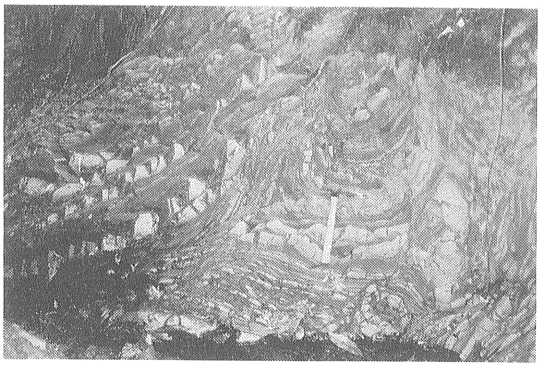

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Plate II

1 Bedded chert as a block of the Kanayama melange showing conjugate fold, south of Kariyasu.

2 Bedded chert as a block of type A melange of the Funafuseyama unit at Ozu.

3 Pillow lava of the Funafuseyama unit, east of Hachiman.

4 Alternating limestone (light gray) and chert (gray) in the Funafuseyama unit at Ozu.

5 Wadano conglomerate of the Kamiaso unit at Mugi.

6 Conglomerate of the Samondake unit including numerous shale fragments, south of Kuzuryu-ko.

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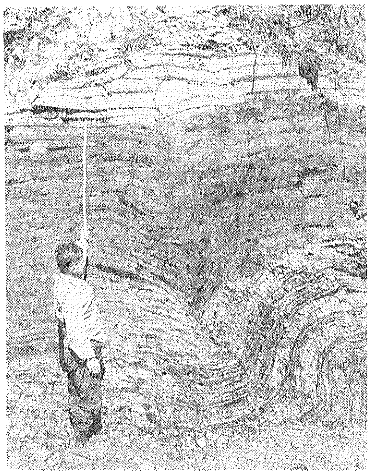

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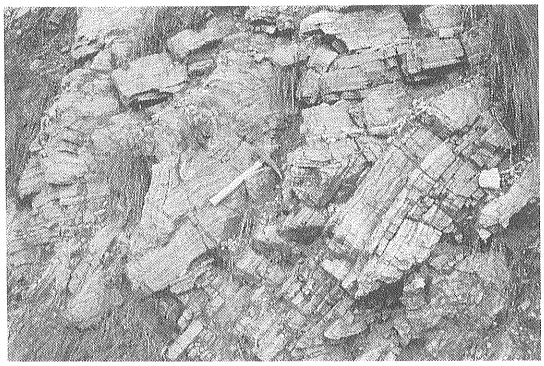

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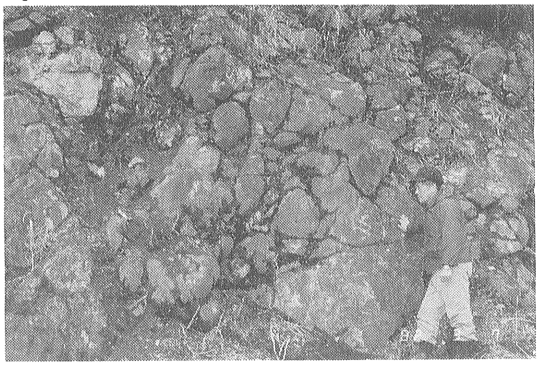

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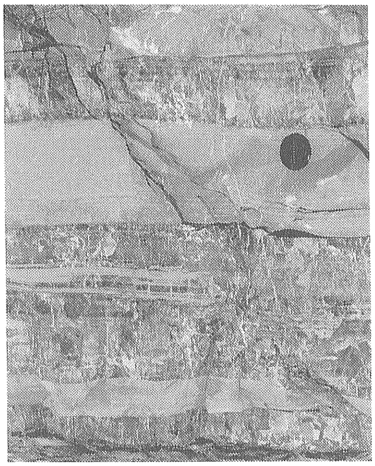

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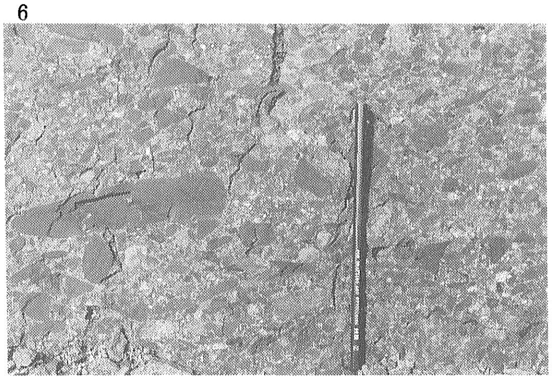


Plate III

1 Thoroughly disrupted turbidite of the Nabi unit at Neo.

2 Dismembered sandstone originally interbedded with shale in thoroughly disrupted turbidite of the Nabi unit at Mino city.

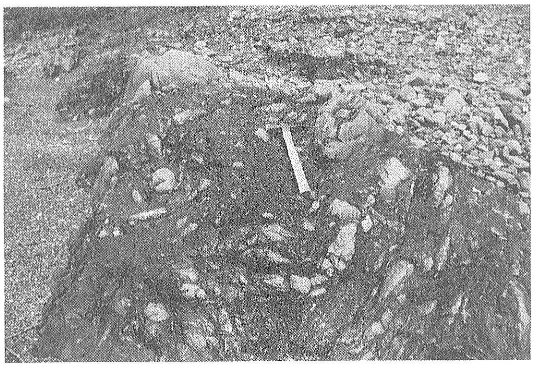
3 Sandstone blocks and shale matrix of melange in the Sakamoto-toge unit at Sakamoto-toge. Wood stick is 25 cm long.

4 Fragmented shale matrix of the Kanayama melange in the Kanayama unit at Kariyasu.

5 Sandstone (ss), chert (ch) and siliceous shale (sil) clasts embedded in shale matrix of the Kanayama melange in Kanayama unit at Kanayama.

6 Sandstone clasts embedded in shale matrix of the Kanayama melange in the Kanayama unit at Kariyasu.

1



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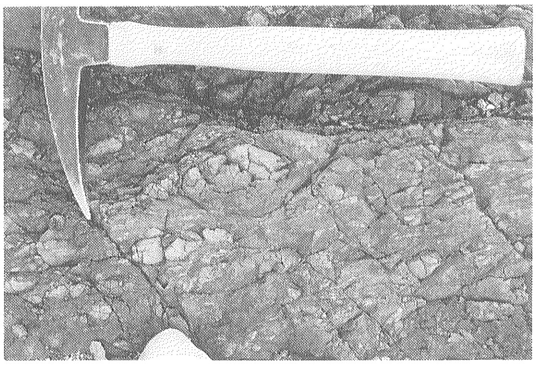

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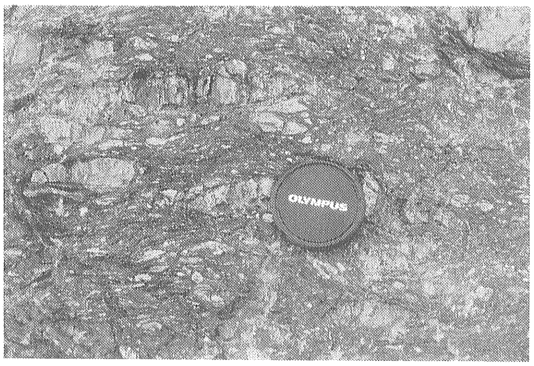

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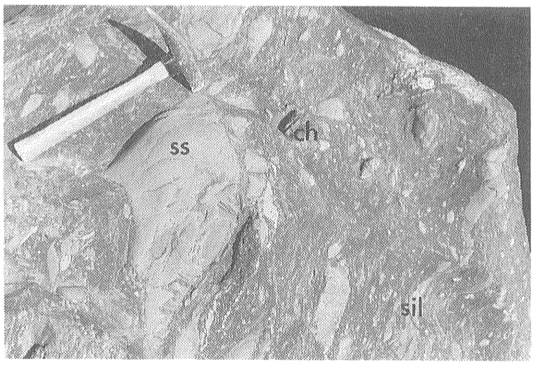

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Plate IV

1 Sandstone clasts in the Kanayama melange of the Kanayama unit at Kanayama. Shale is injected into the margin of the clast.

2 Siliceous shale clasts in the Kanayama melange of the Kanayama unit at Kanayama. Scale is 4×5 cm.

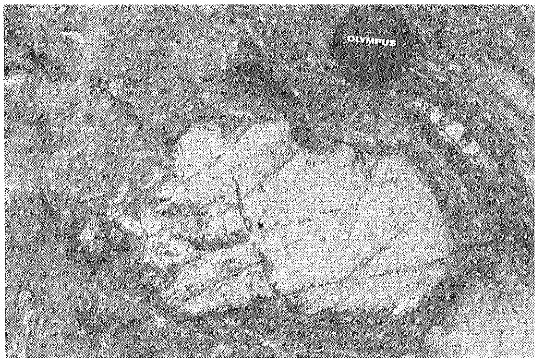
3 Chert (ch) and sandstone (ss) clasts of the Kanayama melange in the Kanayama unit at Kariyasu.

4 Chert (ch) and sandstone (ss) clasts of the Neo melange in the Kanayama unit at Neo.

5 Greenstone (basaltic lava) clasts in type B melange of the Funafuseyama unit at Ozu.

6 A manganese carbonate clast in the Kanayama melange of the Kanayama unit, north of Kanayama.

1



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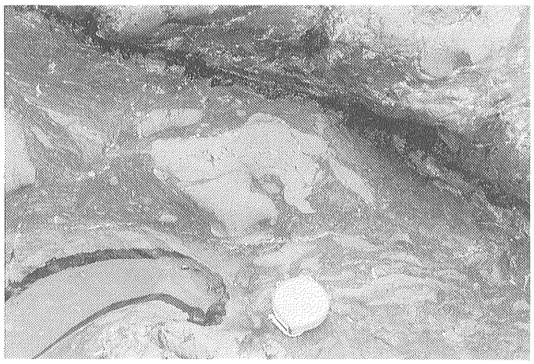

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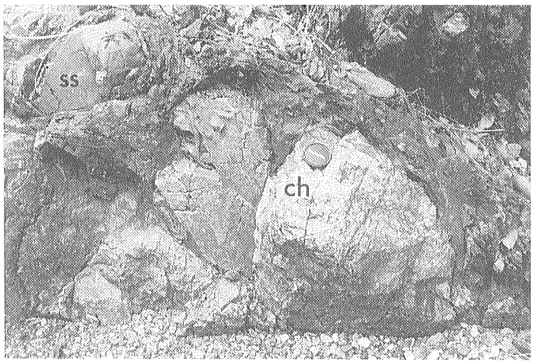

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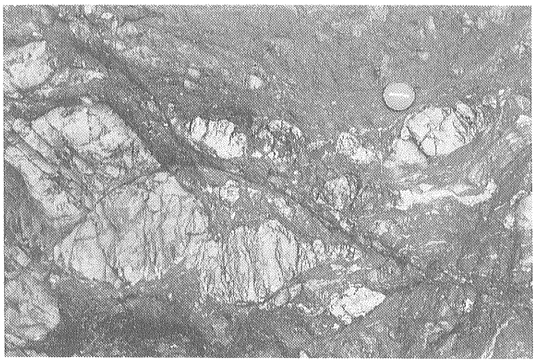

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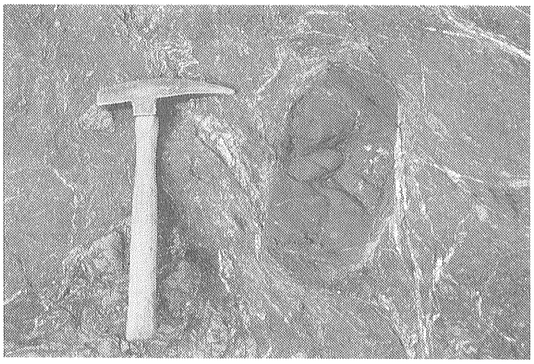


Plate V

1 Shale injection into a large block of disrupted turbidite in the Kanayama melange of the Kanayama unit at Okukanayama.

2 Rotated siliceous shale clast in dark gray shale matrix which is injected into a large siliceous shale block in the Kanayama melange of the Kanayama unit, near Shimoda bridge, south of Kariyasu. Scale is about 18 cm long.

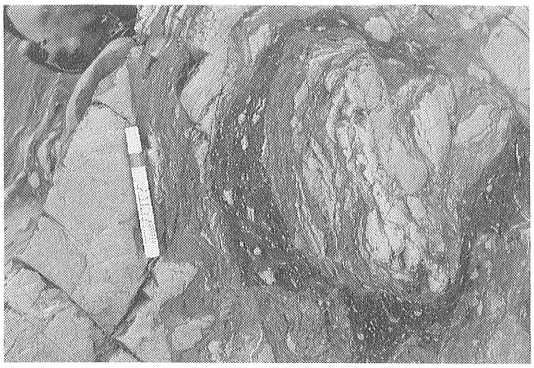
3 Shale injection into siliceous shale block of the Kanayama melange in the Kanayama unit, near Shimoda bridge, south of Kariyasu.

4 Dark gray shale lens embedded in siliceous shale block in the Kanayama melange of the Kanayama unit, near Shimoda bridge, south of Kariyasu. Shale contains smaller sandstone clasts. Shale appears to have been originally injected into siliceous shale and then have deformed into lenticular shape.

5 Shale injection into siliceous shale which occurs as a block in the Kanayama melange of the Kanayama unit, near Shimoda bridge, south of Kariyasu. Shale includes small fragments of siliceous shale and sandstone.

6 Sandstone clast in "pebbly siliceous shale" in the Kanayama melange of the Kanayama unit at Kanayama. The sandstone clast is originally accompanied with shale which is injected into siliceous shale and is swept away during compaction.

1



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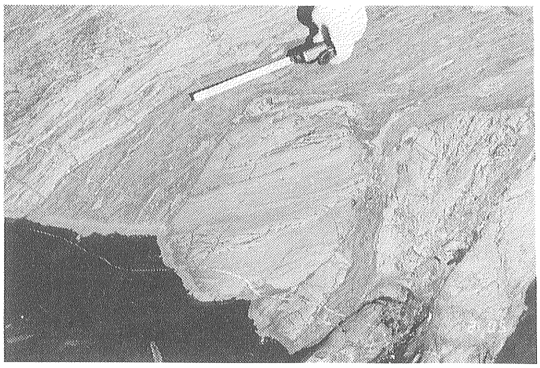

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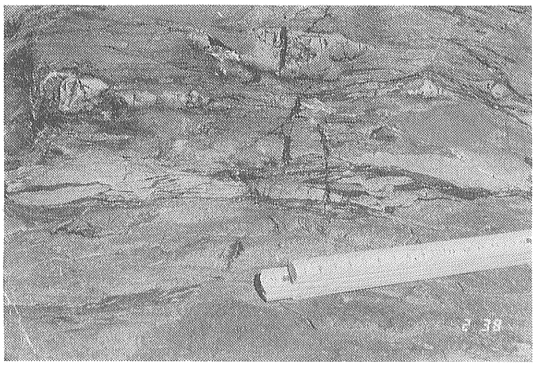

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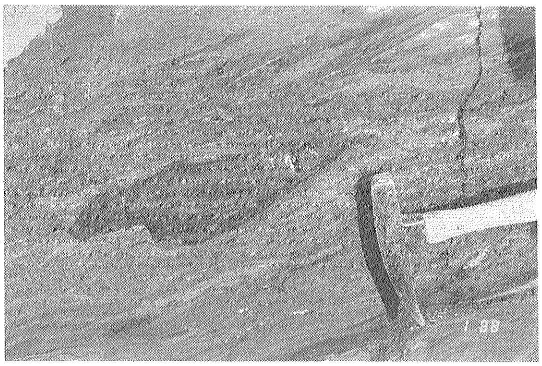

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Plate VI

Photomicrographs of argillaceous part (shale matrix and rock fragments) of the melange of the Kanayama unit.
Plane polarized, section cut normal to the elongation of clasts, and the foliation. Scale bar is 0.5 mm long.

1 Rounded to subrounded siltstone fragments enclosed within unfoliated shale matrix.

2 Close-up of small siltstone fragments in Plate VI-1.

3 Shale matrix injected into a siliceous shale clast which disintegrates into smaller fragments. Note the disruption in the siliceous shale part caused prior to its fragmentation.

4 Shale matrix containing numerous siliceous shale fragments. The shale also includes basalt fragments (bs).

5 Siliceous shale fragment with injection of shale matrix.

6 Subrounded fragments of siliceous shale and siltstone enclosed within unfoliated finer-grained matrix.

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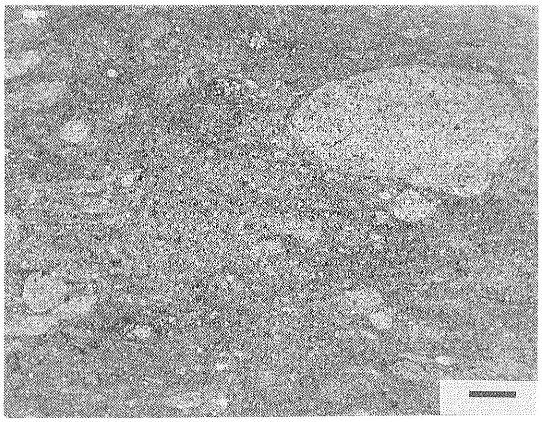

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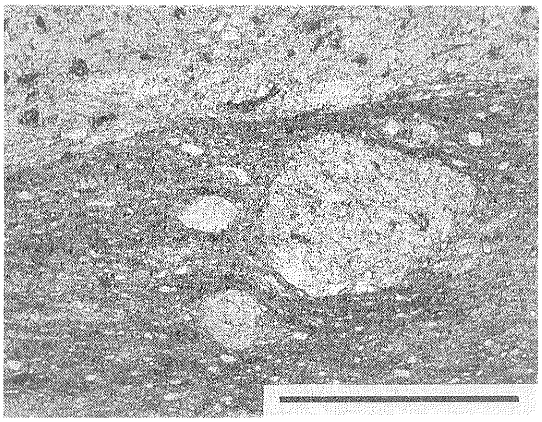

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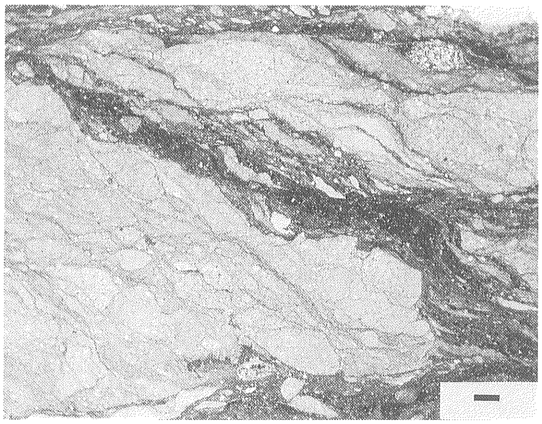

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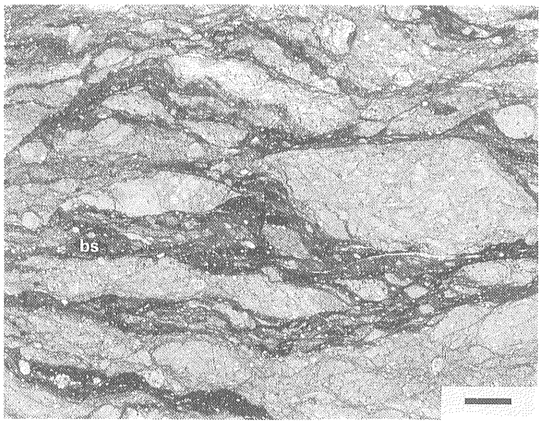

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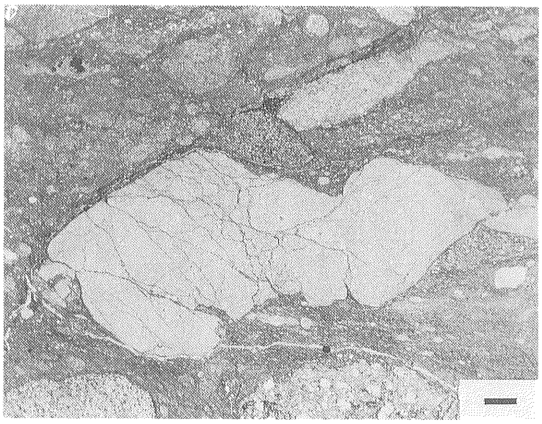

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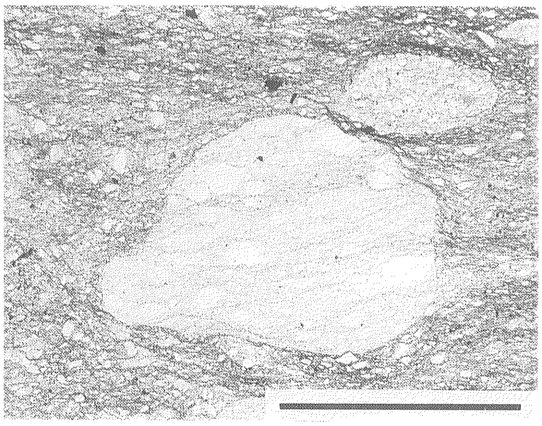

Plate VII

Photomicrographs of the argillaceous parts (shale matrix and rock fragments) of the melanges of the Kanayama unit (1–5 : Plane polarized light, 6 : crossed nicols). Section is cut normal to the elongation of clasts and the foliation. Scale bar is 0.5 mm long.

1 Shale matrix of melange, containing fragments.

2 Close-up of rotated fragments in Plate VII-1.

3 Fragmented clast in the melange caused by shearing.

4 Scaly foliation in shale matrix.

5 Rounded to subrounded fragments of siliceous shale and siltstone in shale matrix.

6 Densely aggregated sericite in shale matrix. (the same position in the same sample as that of Plate VII-5).

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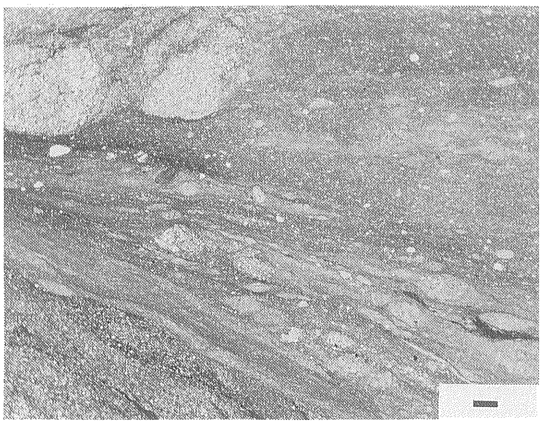

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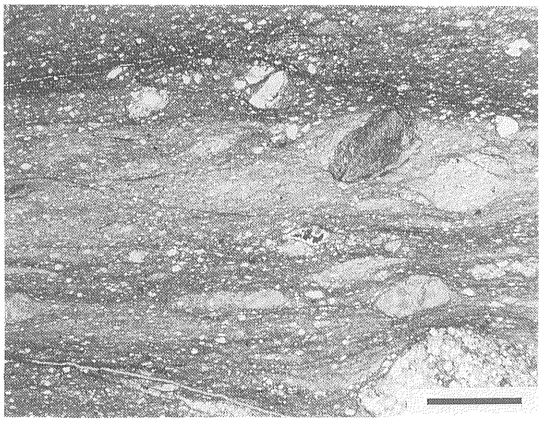

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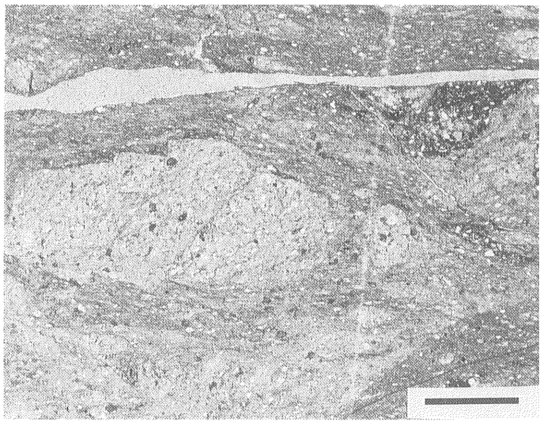

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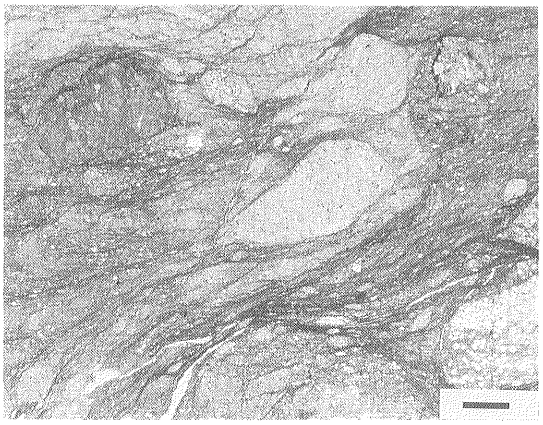

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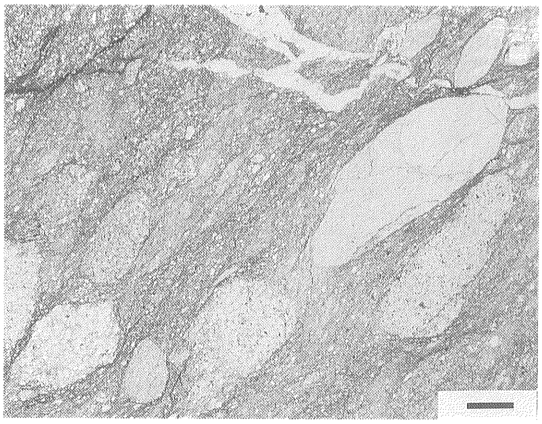

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