Journal of Geosciences, Osaka City University
Vol. 36, Art. 2, p. 15-70
March, 1993

Jurassic Accretionary Complex of the Tamba Terrane, Southwest Japan, and its Formative Process

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(With 15 Figures and 6 Tables)

Abstract

The Tamba Terrane, formed through subduction-accretion during Late Triassic to Jurassic time, occupies a part of SW Japan. Accretionary complexes of this terrane, which are termed the Tamba sedimentary complex, show a chaotically mixed feature and consist of various rock types. These rocks comprise fragments of volcanic seamounts and sedimentary rocks of pelagic and terrigenous realms ranging from Late Paleozoic to Jurassic in age. Middle and Late Jurassic coherent clastic sequences as slope basin deposits are exposed among the accretionary complexes.

In the mainly investigated Wakasa area situated in the northern part of the Tamba Terrane, the Kowaki, Yajiro, Natasyo, Hisasaka, Tsurugaoka and Yuragawa Complexes, which are distributed from north to south, are tectonostratigraphically distinguished. The Kowaki Complex consists of greenstones, cherts and clastic rocks whose ages are unknown. The Yajiro and Natasyo Complexes are composed predominantly of greenstones, limestones and cherts ranging from Late Carboniferous to Early Jurassic in age with a minor amount of Early to Middle Jurassic clastic rocks. The Hisasaka Complex consists of Triassic to Early Jurassic cherts and Middle Jurassic clastic rocks with subordinate greenstones and limestones whose ages are unknown. The Tsurugaoka and Yuragawa Complexes contain Triassic to Middle Jurassic cherts and Middle to Late Jurassic clastic rocks.

The characteristic features including lithologic assemblages, depositional ages and internal structures of the complexes in the Wakasa area, are regarded to be common throughout the Tamba Terrane. Therefore, the standard seven units, Complexes A, B, C, D, E, F and G are applied to represent all tectonostratigraphic units of the Tamba Terrane. The Kowaki, Yajiro, Natasyo, Hisasaka, Tsurugaoka and Yuragawa Complexes respectively correlate to Complexes B, C, D, E, F and G. Further, the complex having Late Triassic clastic rocks together with greenstones and cherts of unknown age, is established as Complex A.

The Tamba Terrane overall exhibits a large scale thrust-imbricate structure that is composed of the tectonic pile of Complex A to Complex G in an apparent descending order, and is folded with gently westward plunging axes.

Original stratigraphies of all complexes can be reconstructed on the basis of interrelation between lithology and depositional age, although the complexes are internally characterized by the chaotic mixture of various lithologies. These stratigraphies begin with basal greenstones and limestones of seamount origin and are followed by a sequence from pelagic cherts to terrigenous clastic rocks. Thus, they record the landward migration of sedimentary realms from an abyssal plain to a trench.

Accretionary times of sediments composing the complexes, that can be inferred from the youngest depositional age of terrigenous clastic rocks, display a continuous spectrum; the times become younger from Late Triassic for Complex A to Late Jurassic for Complex G.

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Taking this systematic younging and the thrust-imbricate structure into consideration, the Tamba Terrane is interpreted to have formed through a multi-stages continuous accretion and to have grown by its downward building. This continuous accretion had not been disturbed in spite of the remarkable subduction of seamount chains which occurred in Middle Jurassic time.

Over 100 m.y. old oceanic crusts had subducted and caused voluminous sediment accretion to form the Tamba Terrane, although it is generally believed that subductions of such old crusts never create any accretionary complex. This event was probably ascribed to Triassic inter-continental collisions and associated Jurassic tectonic movements which occurred in the Asian continent; they possibly supplied a great amount of sediments for the subduction zone, in the similar way to the cases of the Indo-Asian continental and the Izu-Honshu arc collisions. Therefore, voluminous sediments within a subduction zone would conquer the negative buoyancy of an old oceanic crust and could cause the sediment accretion.

Key Words: continuous accretion, accretionary complex, tectonostratigraphy, Jurassic, Tamba Terrane

1. Introduction

Modern accretionary complexes have been formed along parts of convergent boundaries where oceanic crusts are descending and consuming beneath the margins of continents or arcs. Since the 1970's, a great number of researchers, mainly Americans and Europeans have been concerned with subduction-accretion tectonics and have discussed the factors controlling the formation of accretionary complexes and the type of accretion causing in subduction zones (*e.g.*, KARIG, 1974; KARIG & SHARMAN, 1975; SEELY *et al.*, 1974; DICKINSON, 1977; SCHOLL *et al.*, 1980; HILDE, 1983).

Late Paleozoic to Miocene accretionary complexes are widely exposed in the Japanese Islands and for a long time they had been considered to be geosynclinal deposits. During the 1980's, the establishment of Upper Paleozoic and Mesozoic radiolarian biostratigraphy and its advance (*e.g.*, YAO, 1982; YAO *et al.*, 1982; MATSUOKA & YAO, 1986; ISHIGA, 1986b) not only successfully accomplished both the detailed dating and the analysis of various kinds of geologic structures of these complexes, but also greatly contributed to the resolution of subduction-accretion tectonics in cooperation with other geologic methods. The results could clarify that remarkable subductions occurred in Permian, Jurassic and Cretaceous-Paleogene times, and that voluminous accretionary complexes of three major terranes in SW Japan were formed in response to the respective subductions (*e.g.*, TAIRA, 1981; SAKAI & KANMERA, 1981; KANMERA & NISHI, 1983; MATSUOKA, 1984; O-TSUKA, 1985). Further, it seems that these subduction-accretions had episodically occurred (ISOZAKI *et al.*, 1990; ISOZAKI & MARUYAMA, 1991). However, studies of the mechanism and process of subduction-accretion have not progressed so well and are left poorly advanced. The images of the full figure of this dramatic event are dispersed.

Under these circumstances, detailed studies of the litho-biostratigraphy, geologic structure and geochemistry of accreted materials has come to be an urgent and timely topic required to Japanese geologists. Thus, this study was performed in the Tamba Terrane for the sake of resolution of the above problem.

Sedimentary complexes of the Tamba Terrane in the Inner Zone of SW Japan are products of Jurassic subduction and are mainly characterized by melanges with an assemblage of various lithologies. These rocks comprise fragments of volcanic seamounts and sedimentary rocks of pelagic and terrigenous realms ranging from Late Paleozoic to Jurassic in age. Several tectonostratigraphic units are distinguished in the Tamba Terrane by recent works (IMOTO *et al.*, 1989; KIMURA *et al.*, 1989; KURIMOTO & MAKIMOTO, 1990; NAKAE, 1990, 1992), although it was once divided into the type I and II suites (ISHIGA, 1983; IMOTO, 1984).

Previously proposed formative models suggested that the two suites were originally formed in the different oceanic basins and after that they were subhorizontally stacked (ISHIGA, 1983), or that the accretions occurred episodically in the earlier and later stages forming the type II and I suites, respectively (HAYASAKA, 1987; MATSUDA & HAYASAKA, 1987). However, the continuous accretionary process, as revealed from this study, negates the previous models. This aspect has recently been pointed out by NAKAE (1992).

This paper is intended to reveal the Late Paleozoic to Jurassic tectonosedimentary history of the Tamba Terrane and to propose a new aspect of subduction-accretion tectonics. Firstly, a newly proposed concepts and technical terms of sedimentary complexes and geologic framework and tectonostratigraphy will be stated in the chapters 2, 3 and 4, lithologic and structural features will be described in the chapter 5 for the sake of the following discussion. Finally, the formative process of the Tamba Terrane and the factors causing its accretion will be discussed in the chapters 6 and 7.

2. Terminology

For investigating and understanding the accretionary complexes of the Tamba Terrane, it is neither effective nor appropriate to use a normal stratigraphic sense. Newly proposed concepts and terms are useful, being defined as follows.

2.1. Tectonostratigraphy

Lithostratigraphic classification systematically organizes rock strata into units based on lithologic character, but mixtures of lithostratigraphic units resulting from complicated deformation should be distinguished from ordinary lithostratigraphic ones (HEDBERG, 1976). Especially, a mass of mixed rock of various types such as a melange may not conform to classic principles of superposition and stratigraphic succession, because its structural and stratigraphical interpretations cannot be based on presumptions of superposed and lateral stratal continuity.

HSÜ (1968) proposed tectonostratigraphy, a concept for the element of stratigraphy that deals with melanges. According to HSÜ's sense, a large body of melange is designated as a tectonostratigraphic unit, based on the different natures and origins of the inclusions and matrix. In this paper, the tectonostratigraphic sense of HSÜ (1968) will be used.

2.2. Complex

Division into group, formation and member in the normal stratigraphic sense is not appropriate for melanges, which should be divided into tectonostratigraphic units as mentioned above. Therefore, the term *complex* will be used for the unit, although complex originally is a lithostratigraphic unit composed of diverse types of rock or characterized by highly complicated structure. Complexes are fault bounded each other. On the other hand, units which are composed of ordinary stratigraphic coherent sequences still exist. In such a case, the unit name *formation* should be used.

2.3. Age of Complex

Complexes ought to have primarily been composed of a sort of successive sequences. They were probably deformed during incorporation with accretionary wedges, and consequently are characterized by the disruption of stratal continuity and the mixture of various rock types. Each complex having its individual successive sequence is distinguishable from others, and differences among the sequences suggests that complexes respectively have different geologic histories.

The age of complex should be defined as the depositional age of the whole sequence, although a complex may indicate some kinds of geologic age, for instance, the whole age of deposition, the time of accretion or the time of mixture and deformation.

2.4. Melange

Melanges are widely recognized and distributed in zones parallel to convergent plate margins. Melange is a term first introduced by GREENLY (1919), who invoked this term to indicate rock bodies characterized by inclusions of rock enclosed in a schistose matrix. Although GREENLY (1919) originally thought that the formation of this melange was ascribed to tectonic processes, it was later interpreted to have been formed by sedimentary process (WOOD, 1974). Thus, a variety of melange origins including tectonic, sedimentary, diapiric and polygenetic processes has been proposed and discussed for a long time, but unanimous agreement could not be reached even on its definition.

RAYMOND (1984) recently defined melange as a body of rock mappable at a scale of 1:24,000 or smaller, and characterized both by lack of internal continuity of contacts or strata and by inclusion of fragments and blocks of all sizes, both exotic and native, embedded in a fragmented matrix of finer grained material. This definition is useful to describe melanges because it includes no genetic significance. However, more detailed problems were pointed out by WAKITA (1989) and KIMURA *et al.* (1989). They mentioned that the exotic inclusions and the scale of rock mass are not exactly essential for the definition. Under these circumstances, the descriptive term *melange* is defined as a mappable and nonstratigraphic rock body characterized both by the lack of stratal continuity and inclusion of various rock types and sizes embedded in a matrix (NAKAE, 1990).

2.5. Melange Matrix and Slab

It is necessary for the description of characteristic features of melanges to systematically categorize its constituent elements.

WAKITA (1988) proposed the category that melange is divided into blocks or slabs

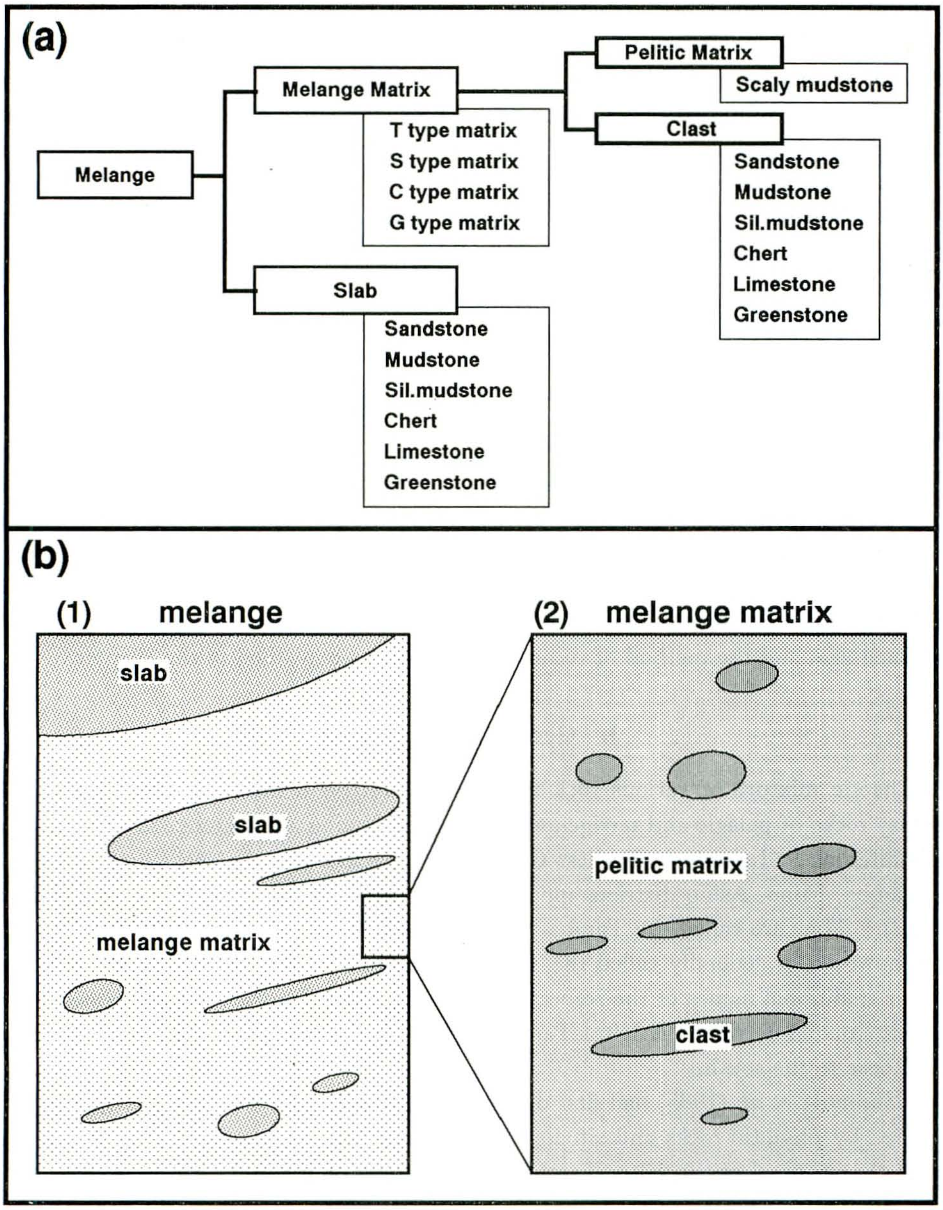

Fig. 1 Terminology and category of rocks forming the Tamba sedimentary complex. (a) A melange is divided into a melange matrix and slabs, the former is further subdivided into a pelitic matrix and clasts. This melange matrix includes four types; the T, S, C and G, being shown in Fig. 6. (b) Schematic geologic maps of an area underlain by the melange. The melange in a smaller-scale map (1) can be differentiated in a larger-scale map (2).

and undifferentiated matrix, the latter being further subdivided into pelitic matrix and fragments. The difference among block, slab and fragment is ascribed to their length. YAMAGATA (1989) mentioned that chaotic formation (melange) consists of chaotic rock and slabs, the former being divided into matrix and blocks. KIMURA *et al.* (1989) summarized that melange is composed of slabs and mixed rock, the latter consisting of pelitic matrix and fragments (or clasts). NAKAE (1990) divided melange into slabs and melange matrix which comprises clasts and pelitic matrix.

Each researcher has separately defined the terms and the size of slab or clast occurring as inclusion; the definitions are slightly different. Nevertheless, they categorized the size of slab and clast in the same sense, and the difference of the size is not essentially important but for convenience of the description. Therefore, this paper follows NAKAE (1990) and defines that slabs are elongated and more than several hundred meter long, and that clasts range from a few millimeter to several hundred meters in length (Fig. 1).

2.6. Original Stratigraphy

Although melanges composing complexes are characterized by a diversity of complicated mixtures and deformations, they might primarily be formed through continuous accumulation of sediments and had possessed as some sorts of successive sequence. Because of this point of view, the succesive sequences, called original stratigraphies in this paper, can be reconstructed on the basis of interrelation between each lithologic type and its depositional age, and the method of reconstruction will be explained in the chapter 6.

3. Geologic Framework

Chaotic mixture of various rock types including fragments of seamounts and sedimentary rocks of pelagic and terrigenous realms and having a wide range in age from Late Carboniferous to Jurassic or Earliest Cretaceous, characterizes the rocks cropping out in the Tamba, Mino, Ashio districts and some other areas in the Inner Zone of SW Japan (Fig. 2). They are called the Tamba-Mino-Ashio Terrane (MIZUTANI, 1987). This terrane, however, is generally called the Tamba, the Mino or the Ashio Terrane according to their traditional names of the respective districts. The Tamba Terrane treated in this paper is situated between the Ultra-Tamba Terrane to the north and the Ryoke Metamorphic Rocks to the south.

CARIDROIT *et al.* (1985) had first defined the Ultra-Tamba Terrane as a tectonic unit occupied by phyllitic rocks and situated between the Maizuru and the Tamba Terranes. Before the proposal of the Ultra-Tamba Terrane, the phyllitic rocks had been regarded to be of the Tamba Terrane (SAKAGUCHI *et al.*, 1973), although these rocks were separated from the proper of the Tamba Terrane in terms of their lithologic features (HIROKAWA *et al.*, 1957; IGI *et al.*, 1961). After that, ISHIGA (1986a) redefined the Ultra-Tamba Terrane, for reasons of recognition of the additional unit that tectonically underlies the originally defined units. The Ultra-Tamba Terrane was formed as an accretionary complex along the margin of the Maizuru Terrane during Middle to Late Permian time (KIMURA,

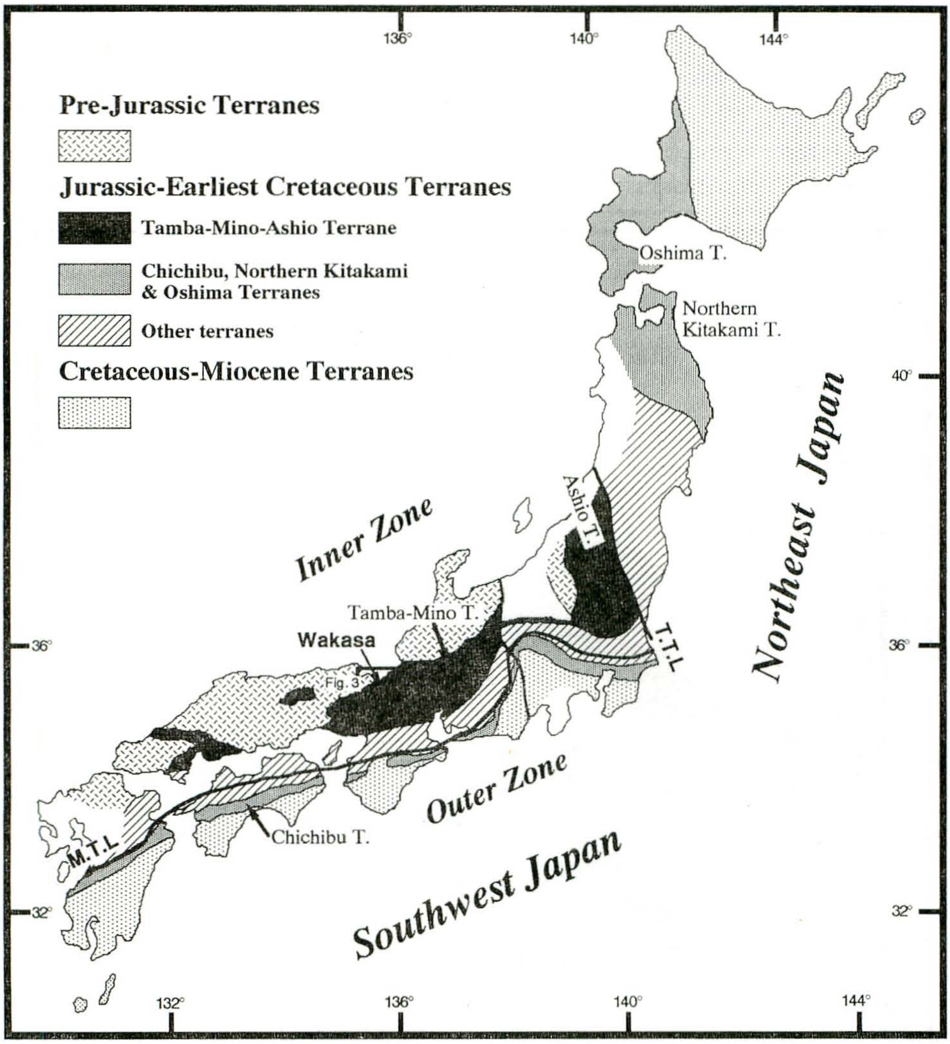

Fig. 2 Distribution of terranes composed of Paleozoic to Cenozoic accretionary complexes in Japan. Modified and simplified from ICHIKAWA (1990). T.T.L: Tanakura Tectonic Line, M.T.L: Median Tectonic Line, T: Terrane.

1988).

The Ryoke Metamorphic Rocks consists of the assemblage of granitic rocks, gneisses and weakly to intensely metamorphosed sedimentary rocks. Rocks of the Tamba Terrane gradually grades southward into the low P/high T metamorphic rocks of the Ryoke (NAKAJIMA, 1960). KUTSUKAKE (1977) concluded that this metamorphism had been ascribed to the effect of granitic intrusion at depth.

The Tamba Terrane consists of both sedimentary complexes and coherent clastic sequences. It is better not to use the term Tamba Group named by SAKAGUCHI (1961) as the entity of this terrane, for reasons of the application of tectonostratigraphic sense (Nakae, 1992). Sedimentary complexes are recently regarded as ancient accretionary complexes (*e.g.*, Nakae, 1990) and will be called the Tamba sedimentary complex in this paper. On the other hand, coherent sequences are considered to accumulate on accretionary complexes in a forearc region (Nakae, 1990). For example, Middle and Late Jurassic formations as trench slope deposits are exposed among the Tamba sedimentary complex, and

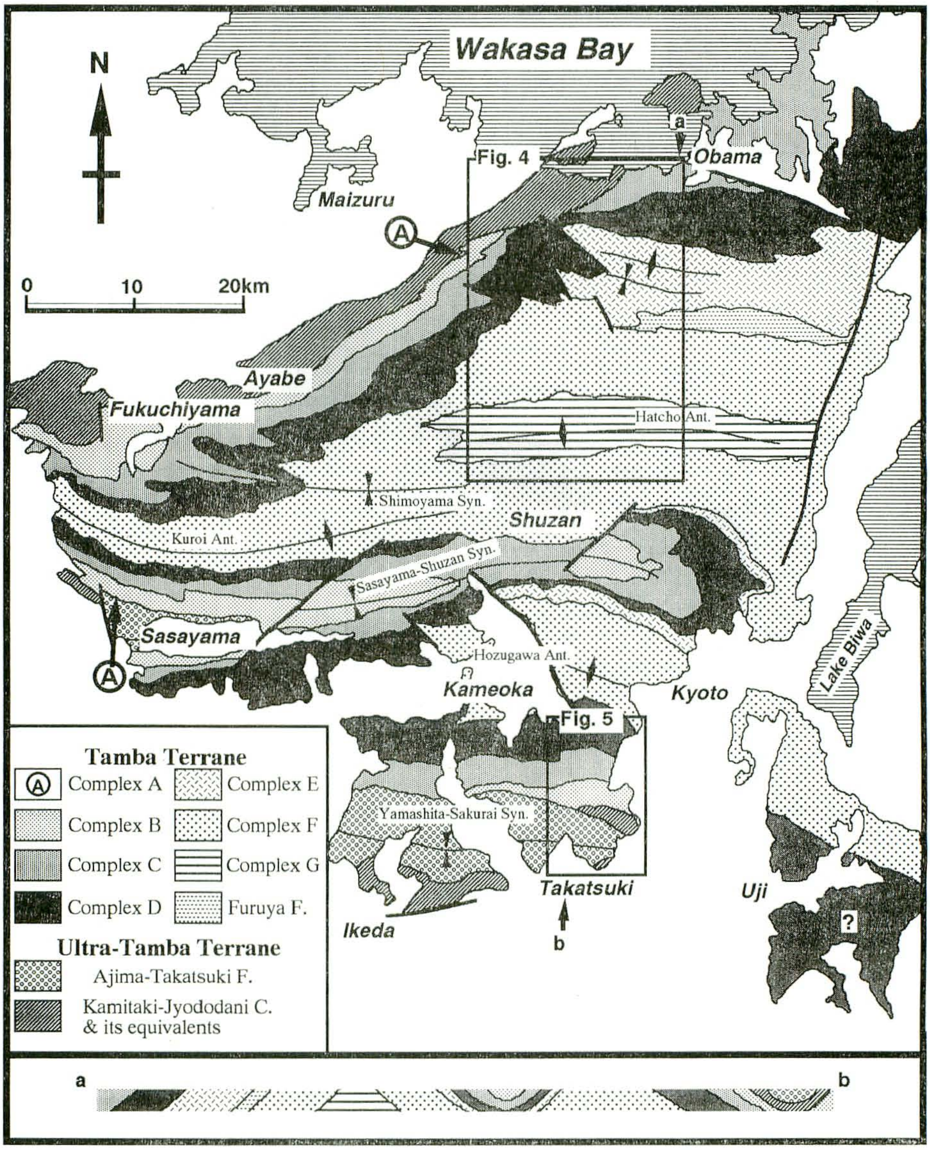

Fig. 3 Generalized geologic map of the Tamba and the Ultra-Tamba Terranes showing distribution of tectonostratigraphic units. Ant.: antiform, Syn.: synform.

Late Jurassic formations as forearc basin deposits are situated on the sedimentary complexes of the Ultra-Tamba Terrane.

The Tamba sedimentary complex is characterized by melanges with the assemblage of greenstone, limestone, chert and clastic sedimentary rock ranging from Late Carboniferous to Latest Jurassic in age. On the basis of the interrelation among lithologies, depositional ages and internal structures, this sedimentary complex has internally been divided into several tectonostratigraphic units, which are thrust fault bounded each other, by recent studies (Imoto *et al.*, 1989; Kimura *et al.*, 1989; Kurimoto & Makimoto, 1990; Nakae, 1990, 1992). Hence, the seven standard units: Complexes A, B, C, D, E, F and G will be adopted here (Fig. 3).

The Tamba Terrane overall exhibits a large scale thrust-imbricate structure that is composed of the tectonic pile of Complex A to Complex G in descending order. Further, it is folded and forms a synform-antiform structure with subvertical axial planes and gently westward plunging axes. The structurally upper units occupy the axial areas of a synform and the lower ones are distributed in the axial areas of a antiform, due to the above-mentioned large-scale structures.

4. Tectonostratigraphy

Complexes as tectonostratigraphic units can be identified on the basis of their lithologic assemblages, internal structures and depositional ages as stated in the chapter 2, and some works have proposed many complexes in the respective areas (*e.g.*, Imoto *et al.*, 1989; Kimura *et al.*, 1989; Kurimoto & Makimoto, 1990; Nakae, 1990, 1992). Formations as ordinary stratigraphic units are also exposed.

4.1. The Tamba Sedimentary Complex in the Wakasa Area

Complexes in the Wakasa area are introduced according to Nakae (1990, 1992). This area is located to the south of Wakasa Bay and is situated in the northern part of the Tamba Terrane (Figs. 3 and 4). Previous works on the geology of this area in the 1950's-1970's were undertaken by means of normal stratigraphic principles. The complexes were regarded as mainly Permian (Hirokawa *et al.*, 1957; Isomi & Kuroda, 1958; Igi *et al.*, 1961; Sakaguchi *et al.*, 1973). Six complexes and one formation were recogniz-

Table 1 Comparison of lithologic assemblages of the complexes in the Wakasa area, after Nakae (1992). Symbols and abbreviations are as follows. Circle: common, triangle: rare, bar: absent, ?: unknown, P.: Permian, Tr.-J.: Triassic to Jurassic.

	Kowaki	Yajiro	Natasyo	Hisasaka	Tsurugaoka	Yuragawa
greenstone	△	○	○	△	—	—
limestone	—	△	○	△	—	—
P. chert	?	○	○	—	—	—
Tr.-J. chert	?	○	○	○	○	○
silica-stone	—	○	—	—	—	—
sandstone	△	○	○	△	△	△

ed by the most recent studies (NAKAE, 1990, 1992). These are the Kowaki, Yajiro, Natasyo, Hisasaka, Tsurugaoka and Yuragawa Complexes, which crop out from north to

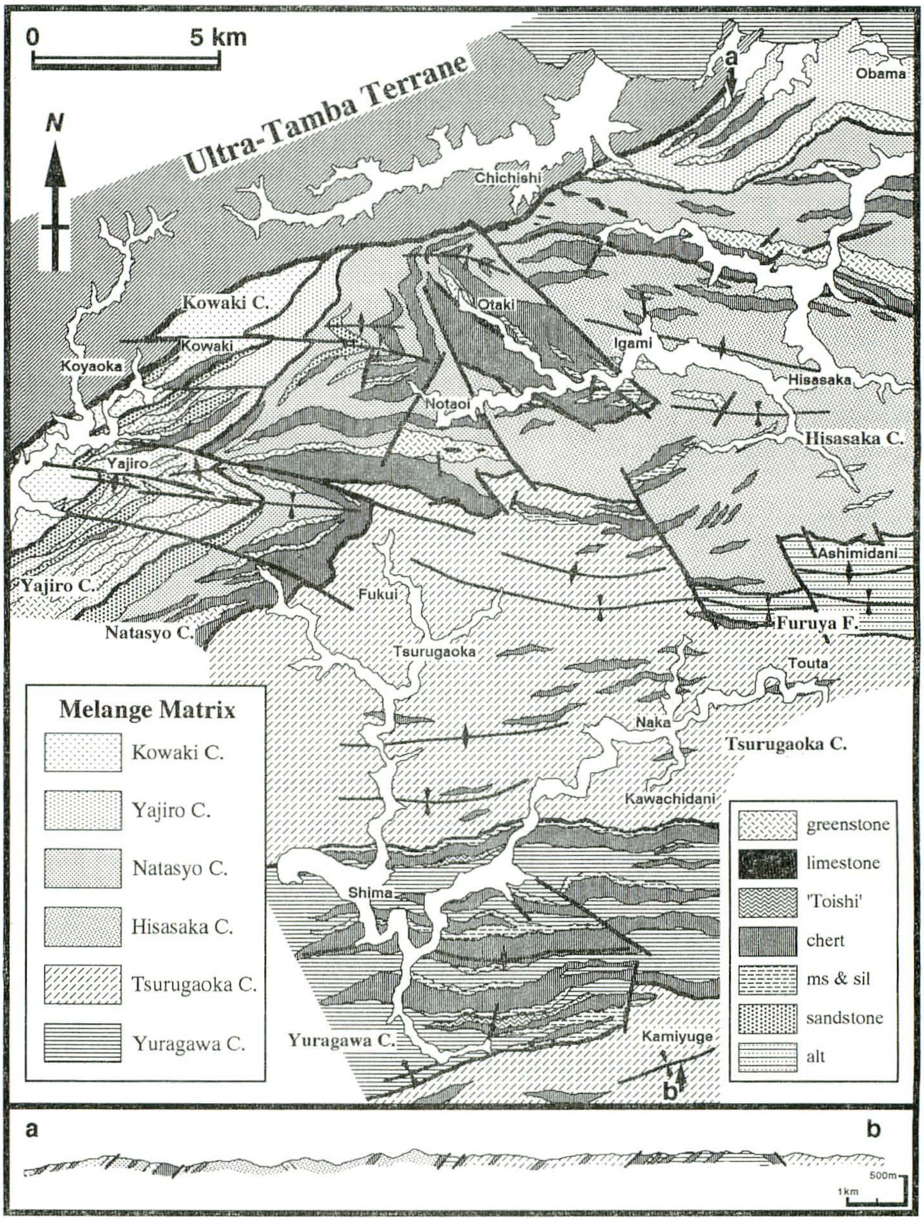

Fig. 4 Geologic map showing the complexes and formation of the Tamba Terrane in the Wakasa area. Compiled from NAKAE (1990, 1992). Abbreviations are as follows; 'Toishi': 'Toishi-type' siliceous mudstone, ms: mudstone, sil: siliceous mudstone, alt: alternating beds of sandstone and mudstone, C: Complex, F: Formation.

south in this order, and the Furuya Formation, which is exposed between the Hisasaka and the Tsurugaoka Complexes (Fig. 4). The last formation will be treated in the section 4.4. Characteristic lithologic assemblages of the complexes are shown in Table 1.

The Kowaki, Yajiro and Natasyo Complexes are divided into western and eastern parts by a NW-SE trending fault. These complexes trend NE-SW in the western part and the trend changes to E-W in the eastern part. Folds with W to NW plunging axes are well developed in the western part, in contrast with the eastern part which is unfolded. The general trend of the Hisasaka, Tsurugaoka and Yuragawa Complexes is discordant with that of the western part of the other three complexes through a thrust fault, due to the nearly E-W trend of the latter complexes.

(1) Kowaki Complex

Designation

The Kowaki Complex is included in the western part of the Kato Formation of Hirokawa *et al.* (1957) which had long been believed to be a Middle Permian stratigraphic unit. This complex, however, can be separated from the Kato Formation proper on the basis of its characteristic lithologic assemblage, thus the newly designated name Kowaki is applied to it.

Distribution

This complex occurs in the northernmost part and is situated at the top of the Tamba Terrane in this area. The complex may be in thrust fault contact with the Ultra-Tamba Terrane to the northwest, although the very contact is not confirmed. To the southeast, it is in contact with the Yajiro Complex through a thrust fault. This complex shows NE-SW trend and NW dip and is slightly folded; it has a width of 1 to 2 km.

Lithologic assemblage

The Kowaki Complex is characterized by a large amount of melange matrix with subordinate slabs. The slabs are rarely included and make it slightly difficult to recognize the distribution area of this complex. These slabs consist of sandstone, chert and greenstone, and their size generally ranges from several hundred meters to 1 km in length. None of more than 2 km in length is observed. These slabs are not laterally continuous so that they do not display a zonal arrangement. Hence, any apparent stratigraphy is not defined. As will be described in the chapter 5, melange matrices are divided into four types on the basis of different assemblages of the clasts which are included in a pelitic matrix. The T and S type matrices are most dominant in this complex. The lower part of this complex locally contains slabs of sandstone, chert and greenstone, and a few small ones are included in the upper part.

Depositional age of complex

The age of the Kowaki Complex cannot be decided, because no fossil which is useful in determining the age has been obtained from this complex (Nakae, 1992).

(2) Yajiro Complex

Designation

The Yajiro Complex roughly coincides with most of the Kato Formation of HIROKAWA *et al.* (1957). The Kato Formation and the overlying Oi Formation (HIROKAWA *et al.*, 1957) had once been called the Kanbayashigawa Formation by S. YOSHIDA (1977), who regarded it as Triassic. Subsequently, these Kato, Oi and Kanbayashigawa Formations were redefined to be Permian accretionary complexes of the Ultra-Tamba Terrane (*e.g.*, CARIDROIT *et al.*, 1985; ISHIGA, 1986a; KIMURA, 1988). Nevertheless, the eastern part of the Kato Formation can be correlated with the Tamba Terrane (ISHIGA, 1986a). Hence, the complex name Yajiro is newly applied instead of the formerly used Kato, as this complex is a constituent of the Tamba Terrane.

Distribution

The Yajiro Complex is situated between the Kowaki and Natasyo Complexes. To the north, this complex is in direct contact with the Ultra-Tamba Terrane in the eastern part, contrary to the western part, where it is in contact with the Kowaki Complex. To the south, a thrust fault contact between the base of the Yajiro and the top of the Natasyo Complexes is found. The Yajiro Complex, 2 to 3 km wide, trends NE-SW to ENE-WSW and dips toward NW to NNW. Two folds with axes trending WNW-ESE are developed in the western part.

Lithologic assemblage

The Yajiro Complex is composed of a melange matrix and laterally continuous slabs. The proportion of melange matrix to the slabs is smaller. The slabs comprise sandstone, alternating bed of sandstone and mudstone, mudstone, siliceous mudstone, chert and greenstone. Most are laterally continuous and are more than 3 km long. Silica-stones (IWAO, 1962), accompanying greenstones, are often recognized in this complex. The T and S type matrices are commonly observed, whereas the C and G type ones locally crop out. The distribution of the G type matrix is in close relation to greenstones.

Laterally continuous sandstone, chert and greenstone slabs extend for several kilometers parallel to the general trend, and display a zonal arrangement. The apparent stratigraphies consisting of a melange matrix, greenstone/chert slab, melange matrix and sandstone slab from the bottom to the top repeatedly crop out.

Depositional age of complex

Neither radiolarian fossil nor any others is included in the Yajiro Complex. Therefore, the age of the rocks composing this complex is unknown, except for greenstones which are probably Late Carboniferous in age (SANO & TAZAKI, 1989). The age is inferred to be Late Permian to middle Middle Jurassic by correlation with the Kamanowa Complex in the Ayabe area and the Mimata Complex in the Fukuchiyama area (NAKAE, 1992).

(3) Natasyo Complex

Designation

The Natasyo Complex is involved in the Formation III of Isomi & Kuroda (1958) and is roughly correlated to the gathering of the Formations f, g, h, i and j of S. Yoshida (1969). Natasyo, used herein for the name of this complex, is named after Natasyo Village.

Distribution

The Natasyo Complex is located to the south of the Yajiro Complex in a thrust fault contact. Furthermore, it contacts with the Tsurugaoka Complex to the southwest and the Hisasaka Complex to the southeast by a thrust fault along the base of the bottom chert slab. In the western part, this complex, 3 to 5 km wide, trends E-W to NE-SW and dips toward north to northwest, and many folds with WNW-ESE to NW-SE trending axes are developed. In the eastern part, on the other hand, it shows E-W trend and N dip with 2 to 5 km width and is not strongly folded.

Lithologic assemblage

The Natasyo Complex as well as the Yajiro is dominated by slabs of various lithologies and includes a subordinate melange matrix. These slabs are of sandstone, alternating bed of sandstone and mudstone, siliceous mudstone, chert and greenstone. A small amount of limestone slabs and clasts is included in the melange matrix or accompany greenstones. The T, S and G type matrices are predominant as the melange matrix, but rare amounts of the C type are often recognized irrespectively of the relation to slabs.

Sandstone, chert and greenstone slabs are elongated and continue laterally for more than several kilometers long. Further, they are distributed parallel to the general trend, displaying a zonal arrangement. The apparent stratigraphy, including greenstone/chert slabs at the bottom through a melange matrix to sandstone slabs at the top, is recognized. In the western part of this complex, sandstone slabs are well developed, but the eastern part is dominated by chert slabs instead of sandstones.

Although the lithologic features of the Natasyo Complex resemble those of the Yajiro, the absence of silica-stones and presence of many limestones in the former distinguish it from the latter.

Depositional age of complex

Radiolarian fossils detected from the Natasyo Complex were reported by Nakae (1992) and are listed in Table 2. Cherts contained Permian and late Middle Triassic species. Some species indicative of Early Jurassic time were also obtained from cherts. Siliceous mudstones yielded many radiolarian species of the *Acanthocircus hexagonus* (Hori & Yao, 1988), the *Hsuum hisuikyoense* (Matsuoka & Yao, 1981) and the *Unuma echinatus* (Yao *et al.*, 1980) Assemblages, indicating late Early to middle Middle Jurassic in age. Middle Jurassic species of the *Unuma echinatus* and the *Guexella nudata* (Matsuoka, 1981) Assem-

Table 2 List of the radiolarian species detected from the Natasyo, Hisasaka, Tsurugaoka and Yuragawa Complexes. Abbreviations are as follows, ch: chert, sil: siliceous, ms: mudstone, + : confer.

	Natasyo			Hisasaka			Tsurugaoka			Yuragawa		
Radiolarian Species	ch.	sil.ms.	ms	ch.	sil.ms.	ms.	ch.	sil.ms.	ms.	ch.	sil.ms.	ms.
Pseudoallbailella scalprata	○											
Ps. fusiformis	+											
Follicucullus monacanthus	○											
Fo. scholasticus	○											
Fo. ventricosus	+											
Albaillella triangularis	+											
Triassocampe deweveri	○			○			○					
T.(?) annulata	+											
T. nova							○					
T. sp. C				+			○					
T. sp. G	○						+					
Archaeospongoprunum sp.				○			○					
Yeharaia sp.	○			○								
Squinabollella(?) sp.	○											
Capnodoce sp.							○					
Dictyomitrella sp. C										+		
Livarella sp.										○		
Canoptum sp.			○	○	○	○	○			○		
Parahsuum simplum				+					+	+		
P.(?) sp. A							○					
P.(?) sp. C				+								
P. transiens		+										
P.(?) grande			+							+		
Eucyrtidiellum(?) sp. C										+		
Stichocapsa sp. A										+		
S. sp. B							+			○		
Hsuum sp.	○	○										
Tricolocapsa cf. rüsti		○					○	○	○			
Stichocapsa japonica		○		○	○	○	○	○	○			○
S. convexa		○										
Syringocapsa sp.		○										
Solenotryma(?) sp.		○										
Laxtrum(?) hichisoense							○					
L.(?) jurassicum		○										
Cyrtocapsa mastoidea					○		+	+				
C.(?) kisoensis						+		+				
Eucyrtidiellum unumaense		+	+		+	+	○	○	○			
Diacanthocapsa normalis							+					
D.(?) operculi		○						○	○		○	
Tricolocapsa cf. parvipora		○	○			○	○	○	○			
T. plicarum		○	○			+	○	○	○			
T. tetragona									○			
Milax sp.								○	○			
Protunuma ochiensis											+	
Guexella nudata									+		○	○
Stylocapsa oblongula									+		+	
S. tecta									+		+	+
S.(?) hemicostata									+			○
S.(?) spiralis									○			○
Williriedellum sp. A								○	○		○	○
Stichocapsa asiatica			+			+			○		+	
Hsuum maxwelli						+			○			
Tricolocapsa conexa									○		○	○
Stichocapsa naradaniensis									○			+
S. robusta									○			
Eucyrtidiellum ptyctum									○			
Archaeodictyomitra rigida						○		○	○			○
A. apiara									○			○
A. minoensis												○
A. brouweri												○
Cinguloturris carpatica												○
Eucyrtidiellum ptyctum												○
E. pyramis												+
Mirifusus mediodilatatus												○
Parvicingula boesii												○
P. dhimenaensis												+
Pseudodictyomitra primitiva												○
Ps. okamurai												○
Ristra altissima												+
Xitus gifuensis												○

blages were obtained from mudstones. Early to Middle Permian fusulinids detected from limestones were reported by HIROKAWA *et al.* (1957) and SAKAGUCHI *et al.* (1973). Furthermore, SANO & TAZAKI (1989) clarified the greenstones were formed at about 303 Ma (Late Carboniferous) by the Sm-Nd radiometric dating. Accordingly, the depositional age of the Natasyo Complex ranges from Late Carboniferous to Middle Jurassic.

(4) Hisasaka Complex

Designation

S. YOSHIDA (1977) first introduced the Hisasaka Formation as a Triassic slump formation. Radiolarian fossils obtained, however, decided its depositional age to be Triassic to Jurassic. It is furthermore revealed that its geologic entity is a melange (NAKAE, 1990). Hence, the formation is redefined as the Hisasaka Complex. This complex roughly corresponds to the eastern part of the Formation III of ISOMI & KURODA (1958).

Distribution

The Hisasaka Complex contacts with the Natasyo Complex to the north, with the Tsurugaoka Complex to the southwest and with the Furuya Formation to the southeast, respectively by thrust faults. Its western margin is limited by NW-SE trending high angle faults. This complex has 3 to 8 km width, trends nearly E-W and dips toward north and south. Two folds with axes pluging to west at a low angle, are developed.

Lithologic assemblage

The Hisasaka Complex is composed of slabs and a predominant melange matrix. The slabs consist of various lithologies including sandstone, alternating bed of sandstone and mudstone, mudstone, siliceous mudstone, chert, 'Toishi-type' siliceous mudstone, limestone and greenstone. Limestone and greenstone slabs are rarely found in this complex. These slabs, a few kilometers long, are not laterally as continous as those in the Yajiro and Natasyo Complexes. The T and S type matrices are widely exposed and the C and G types are rarely observed.

Depositional age of complex

Occurrence of Triassic and Jurassic radiolarian fossils were reported by NAKAE (1990) and are shown in Table 2. Radiolarian species of the *Triassocampe deweveri* and the *Parahsuum simplum* Assemblages (YAO, 1982) were detected from cherts, indicating late Middle Triassic and early Early Jurassic time. Siliceous mudstones contained some species of the *Unuma echinatus* Assemblage of middle Middle Jurassic time. Further, mudstones contained species of the *Unuma echinatus* and the *Guexella nudata* Assemblages indicative of Middle Jurassic time, with some Early Jurassic species. No fossil could be detected from the 'Toishi-type' siliceous mudstones. Nevertheless, KOIKE (1979) pointed out that siliceous mudstones of this type widely crop out through the Japanese Islands and that their ages are Smithian to Anisian; IMOTO (1984) also set the age between Spathian and Anisian. Hence, the age of this siliceous mudstone in this area may fall into late Early to early Middle Triassic. The depositional age of the Hisasaka Complex can be dated as late Early Triassic to Middle Jurassic time.

(5) Tsurugaoka Complex

Designation

The complex name Tsurugaoka is originated from the locality where the complex is typically exposed. This complex is correlated with the aggregation of the Formations c,d and e of S. YOSHIDA (1969) and roughly with the Formation IIII of ISOMI & KURODA (1958).

Distribution

The Tsurugaoka Compex, about 10 km wide, is widely exposed to the north and south of the Yuragawa Complex. A thrust fault contact between the two complexes is not clearly found. The northern margin is a thrust fault separating the complex from the Natasyo Complex and Furuya Formation. The general trend is nearly E-W and the complex dips toward both north and south, resulted from the E-W trending Hatcho Antiform (NAKAE, (1990).

Lithologic assemblage

The Tsurugaoka Complex comprises slabs and a predominant melange matrix; further, it can be easily distinguished from the other complexes by its small variety of lithology.

The slabs are composed of sandstone, alternating bed of sandstone and mudstone, mudstone, siliceous mudstone, chert and 'Toishi-type' siliceous mudstone. Neither limestone nor greenstone slabs are included in this complex. Many of slabs range in length from several hundred meters to several kilometers but are not laterally continuous, in contrast with the Yajiro and Natasyo Complexes. The melange matrix is represented by the T and S types with minor amounts of the C type, but the G type cannot be recognized.

Many features of this complex resemble those of the Hisasaka Complex, but it has two distinguishing features; one is the absence of limestone and greenstone slabs, and the other is its later age of deposition.

Depositional age of complex

Occurrence of radiolarian fossils have been reported (Table 2; NAKAE, 1990). Cherts yielded characteristic species of the *Triassocampe deweveri* Assemblage of late Middle Triassic time, the *Parahsuum simplum* Assemblage of early Early Jurassic time and the *Hsuum hisuikyoense* Assemblage of early Middle Jurassic time. Middle Jurassic species of the *Hsuum hisuikyoense*, the *Unuma echinatus* and the *Guexella nudata* Assemblages were obtained from siliceous mudstones, and mudstones included a large amount of middle Middle to early Late Jurassic species belonging to the *Unuma echinatus*, the *Guexella nudata* and the *Gongylothorax sakawaensis-Stichocapsa naradaniensis* (MATSUOKA & YAO, 1981) Assemblages. 'Toishi-type' siliceous mudstones are probably late Early to early Middle

Triassic in age. These fossil evidences indicate that the rocks comprising the Tsurugaoka Complex were deposited during late Early Triassic to early Late Jurassic time.

(6) Yuragawa Complex

Designation

The Yuragawa Complex is typically exposed along the Yuragawa-River. It corresponds to the gathering of the Formations a and b of S. YOSHIDA (1969) and roughly to the Formation V of ISOMI & KURODA (1958).

Distribution

The Yuragawa Complex occupies the structural lowest position in the Tamba Terrane and is exposed at the axial part of the Hatcho Antiform. This complex trends E-W with 4 to 6 km wide and dips toward north and south.

Lithologic assemblage

The Yuragawa Complex is characterized by laterally continuous slabs and a subordinate melange matrix. These slabs are several to 10 km long and are internally composed of a sequence of 'Toishi-type' siliceous mudstone, chert, siliceous mudstone, mudstone and sandstone in ascending order. Such a lithostratigraphy has been called the chert-clastics sequence (OTSUKA, 1985) and has been reported from many other places. On the other hand, the melange matrix contains dominant siltstone and sandstone clasts and rare amount of chert ones, being represented by the T, S and C types. This aspect is analogous to the Tsurugaoka's matrix. The laterally continuous slabs and the melange matrices repeatedly crop out, forming a thrust-imbricate structure.

Although the Yuragawa's lithologic assemblage essentially has the same features as the Tsurugaoka Complex has, different structural features arises between them; one is the difference in the length and lateral continuity of their slabs; the other is the above-mentioned repetition of slabs and matrices.

Depositional age of complex

In the Yuragawa Complex, radiolarian fossils ranging from Triassic to Jurassic in age were obtained (Table 2; NAKAE, 1990, 1991a). Radiolarian species of the *Parahsuum simplum* and the *Parahsuum*(?) *grande* (HORI & YAO, 1988) Assemblages of Early Jurassic time were detected from cherts, and these also yielded some species indicative of late Late Triassic to earliest Jurassic time. Late Middle Jurassic species belonging to the *Guexella nudata* Assemblage were obtained from siliceous mudstones, and early Late Jurassic ones of the *Gongylothorax sakawaensis-Stichocapsa naradaniensis* Assemblage were included in mudstones, respectively. Furthermore, latest Jurassic (Tithonian) radiolarian species occurred from silty mudstone in this complex (NAKAE, 1991a). 'Toishi-type' siliceous mudstones contained no fossil, but their ages are probably late Early to early Middle Triassic (KOIKE, 1979; Imoto, 1984). Consequently, it can be concluded that the Yuragawa Complex was formed by deposition of the rocks during late Early Triassic to latest Jurassic time.

4.2. Standard Complexes of the Tamba Terrane

As stated before, ISHIGA (1983) and IMOTO (1984) first divided the Tamba Terrane into the type I and II suites. However, subdivision of these suites is possible in the above-described Wakasa area. Hence, the previous division is abolished in this paper. On the basis of the complexes in the Wakasa area, seven complexes A, B, C, D, E, F and G are newly proposed here to make the standard in the Tamba Terrane. The standard complexes have the respective characteristic features and correlate to the complexes both in the Wakasa and the other areas (Tables 3 and 4). The latter areas will be described in the next section.

(1) Complex A

Complxes characterized by Late Triassic terrigenous clastic rocks are established as Complex A, because Late Triassic clastic rocks can differentiate themselves from the other complexes whose clastic rocks are Jurassic in age. Although, the distribution areas of Complex A are not exactly obvious within the Tamba Terrane, only a few localities (Fig. 3), where Late Triassic mudstones and siliceous mudstones were discovered, have been recognized (*e.g.*, KUSUNOKI *et al.*, 1991). Complex A includes slabs of chert and greenstone, whose ages are not certain.

(2) Complex B

Complex B is applied to complexes, including the Kowaki, characterized by a predominant melange matrix. The slabs, which occupy minor amounts of this complex, generally have lengths of several hundred meters, not being laterally continuous. Lithologic assemblage of the slabs includes greenstone, limestone, chert, siliceous mudstone, mudstone and sandstone. The depositional age of each lithologic type is as follows; chert is Permian to Early Jurassic, siliceous mudstone is Early Jurassic, mudstone is middle to late Early Jurassic and greenstone is unknown.

Table 3 Comparison of lithologic assemblages of the standard complexes of the Tamba Terrane. Continuous slabs of more than a few kilometers long is expressed as 'good' and discontinuous one being less than several hundreds of meter in length is indicated by 'poor'. Abbreviations are as follows. >: melange matrix is abundant, <: slab is abundant, E: Early, M: Middle, L: Late, C: Carboniferous, P: Permian, T: Triassic, J: Jurassic, +: present, --: absent.

Complex	A	B	C	D	E	F	G
Relative abundance melange matrix / slab	>	>	<	<	>	>	<
Continuity of slab	poor	poor	good	good	poor	poor	good
Existence and age							
clastic rock	LT	EJ	E-MJ	MJ	E-MJ	M-LJ	M-LJ
chert	+	P-EJ	P-EJ	P-EJ	T-EJ	T-MJ	T-MJ
limestone	--	--	LC-MP	P, T	T	--	--
greenstone	+	+	LC	LC	T	--	--

(3) Complex C

The Yajiro Complex is the type of Complex C. Characteristic features of this complex are the lateral continuity of slabs being several kilometers to 10 km long and their abundance. Lithologic assemblage of the slabs consists of greenstone, limestone, chert, siliceous mudstone, mudstone and sandstone. Silica-stones are often associated with greenstones. Depositional and/or formational age are summarized as follows; greenstone is Late Carboniferous, limestone is Late Carboniferous to Early Permian, chert is Permian to Early Jurassic, siliceous mudstone is Early Jurassic and mudstone is Early to middle Middle Jurassic.

(4) Complex D

The Natasyo Complex is the type of Complex D. Very continuous slabs occupy a large amount of this complex and most of them accentuate the complex's feature, as well as that of Complex C. Lithologic assemblage composed of greenstone, limestone, chert, siliceous mudstone, mudstone and sandstone, is recognized in this complex. Depositional and/or formational age of each lithologic type is as follows; greenstone is Late Carboniferous, limestone is Early to Middle Permian and Middle to Late Triassic, chert is Middle Permian to Early Jurassic, siliceous mudstone is early to middle Middle Jurassic and mudstone is Middle Jurassic.

(5) Complex E

Complex E is proposed as the standard for the complexes including the Hisasaka Complex, which are characterized by a large amount of melange matrix. Lithologic assemblage of the slabs comprises greenstone, limestone, chert, siliceous mudstone, mudstone and sandstone. Greenstones and limestones are rarely contained. In comparison with Complexes C and D, the length of these slabs is shorter. The depositional and/or formational age of each lithologic type is as follows. Greenstone and limestone are probably Middle to Late Triassic, chert is Triassic to Early Jurassic, siliceous mudstone is middle Middle Jurassic and mudstone is late Early to Middle Jurassic.

(6) Complex F

Geological features of Complex F, including the Tsurugaoka Complex, are the same as those of Complex E, except for two distinctive features recognized between them; one is that greenstone and limestone are not included in Complex F, and the other is that Complex F is slightly younger in age. Lithologic assemblage of the slabs is made up of chert, siliceous mudstone, mudstone and sandstone. The depositional age of each lithologic type is as follows; chert is Triassic to early Middle Jurassic, siliceous mudstone is Middle Jurassic and mudstone is Middle to early Late Jurassic.

(7) Complex G

The Yuragawa Complex is the type of Complex G. It is lithologically similar to Complex F, but the former's age is younger than the latter's. Lithologic assemblage of the slabs includes Triassic to late Middle Jurassic chert, late Middle Jurassic siliceous mudstone and late Middle to Late Jurassic mudstone. These slabs are laterally continuous, more than several kilometers long.

4.3. The Tamba Sedimentary Complex in the Other Areas

Some works have already distinguished many complexes in the respective investigated areas. These complexes can be correlated to the standard as shown in Table 4.

(1) Ayabe Area

The Ayabe area is situated to the southeast of Ayabe City (Fig. 3) and few studies were carried out there. The Yamaga, Kamanowa and Wachi Complexes and the type I suite arranging from north to south were described by KIMURA *et al.* (1989).

(2) Fukuchiyama Area

The Fukuchiyama area is located to the south of Fukuchiyama City (Fig. 3) and is situated on the northern limb of the Kuroi Antiform (SAKAGUCHI, 1959). No detailed geological map was available for a long time, but the boundary between the type I and II suites was indicated by ISHIGA (1983). However, KURIMOTO & MAKIMOTO (1990) recently recognized the Mimata, Ashibuchi and Kuroi Complexes from north to south.

(3) Sasayama Area

The Sasayama area is situated in the western part of the Tamba Terrane (Fig. 3). ARAI & SAKAGUCHI (1955) first revealed the stratigaphy and structure; the Sanakatoge, Manajo, Takashiroyama and Ajima Formations cropping out in ascending order (Table 5), which are folded by the E-W trending Sasayama Synform. KURIMOTO *et al.* (in press) newly defines the Mio, Sanaka, Fujioka and Kamitaki Complexes as sedimentary complexes and the Takashiroyama and Ajima Formations as coherent sequences (Tables 4 and 5). The Mio, Sanaka, Fujioka Complexes and Takashiroyama Formation are members

Table 4 Correlation table of the complexes of the Tamba Terrane.

	Tamba Terrane	*Wakasa*	*Ayabe*	*Fukuchiyama*	*Sasayama*	*Shuzan*	*Nishiyama*
Complex A	Type II						
Complex B		Kowaki	Yamaga	Mimata	Fujioka	Shuzan	Izuriha
Complex C		Yajiro	Kamanowa		Sanaka	Kumogahata	Tano
Complex D		Natasyo	Wachi	Ashibuchi	Mio	Haiya	Oinosaka
Complex E	Type I	Hisasaka				Nakagawa	Saihoji
Complex F		Tsurugaoka	Type I	Kuroi	Kuroi	Takao	
Complex G		Yuragawa					
	Ishiga (1983) Imoto (1984)	Nakae (1990,1992)	Kimura *et al.* (1989)	Kurimoto & Makimoto (1990)	Sakaguchi (1959) Ishiga (1983) Kurimoto *et al.* (in press)	Sakaguchi (1973) Imoto *et al.* (1989)	Sakaguchi (1957, 1973) Isozaki & Matsuda (1980) Nakae (1988)

Table 5 Tectonostratigraphic correlation of the complexes and formations in the Sasayama area. Division in this paper follows the sense of KURIMOTO *et al.* (in press). U-T: Ultra-Tamba.

Arai & Sakaguchi (1955)	Sakaguchi (1959)	Ishiga *et al.* (1987)	Tokura *et al.* (1987)	This Paper	
Ajima F.	Shinjo F.	Ajima F.	Ajima F.	Ajima F.	U-T
Takashiroyama F.	Takashiroyama F.	Takashiroyama F.	Takashiroyama F. ? Kamitaki F.	Kamitaki C.	
				Takashiroyama F.	Tamba
Manajo F.	Manajo F.	Manajo F.		Fujioka C.	
Sanakatoge F.	Sanakatoge F.	Sanakatoge F.		Sanaka C.	
				Mio C.	

of the Tamba Terrane, whereas the Kamitaki Complex and Ajima Formation belong to the Ultra-Tamba Terrane.

(4) Shuzan Area

The Shuzan area is located to the northwest of Kyoto City and occupies the central part of the Tamba Terrane (Fig. 3). IMOTO *et al.* (1989) divided the sedimentary complex, which is folded by the Shuzan Synform (MATSUSHITA, 1953), into the Shuzan, Kumogahata and Haiya Units and the type I suite arranging from the axial part of the synform to the south. In this paper, the type I suite is divided into the Nakagawa and Takao Complexes. The Nakagawa Complex redefined here is roughly corresponds with the Nakagawa Formation of SAKAGUCHI (1973), except for its upper part that may be included into the Haiya Complex, and the redefined Takao Complex is correlated to a most part of the type I suite. This paper prefers complex to unit, so the names will be changed, for example the Shuzan Complex.

(5) Nishiyama Area

The Nishiyama area is situated to the west of Kyoto City (Fig. 3). The Hozugawa Antiform (MATSUSHITA, 1953; ISOZAKI & MATSUDA, 1980) to the north and the Sakurai Synform (NAKAMURA *et al.*, 1936) to the south are recognized. Preliminary work was started by NAKAMURA *et al.* (1936) and succeeded by SAKAGUCHI (1957, 1973). Recently, rocks composing the Ultra-Tamba Terrane have been recognized in the axial part of the Sakurai Synform (AN'YOJI *et al.*, 1987; NAKAE, 1988; KUSUNOKI & MUSASHINO, 1990). The Saihoji, Oinosaka, Tano and Izuriha Complexes from north to south, compiled from the previous works, are redefined (Fig. 5, Tables 4 and 6).

Saihoji Complex

The Saihoji Complex is the same as the Saihoji Formation of ISOZAKI & MATSUDA (1980). This complex is mainly composed of a melange matrix that includes minor amounts of discontinuous slabs. The slabs are generally of sandstone, chert and greenstone. Cherts range in age from Middle to Late Triassic and siliceous mudstones are

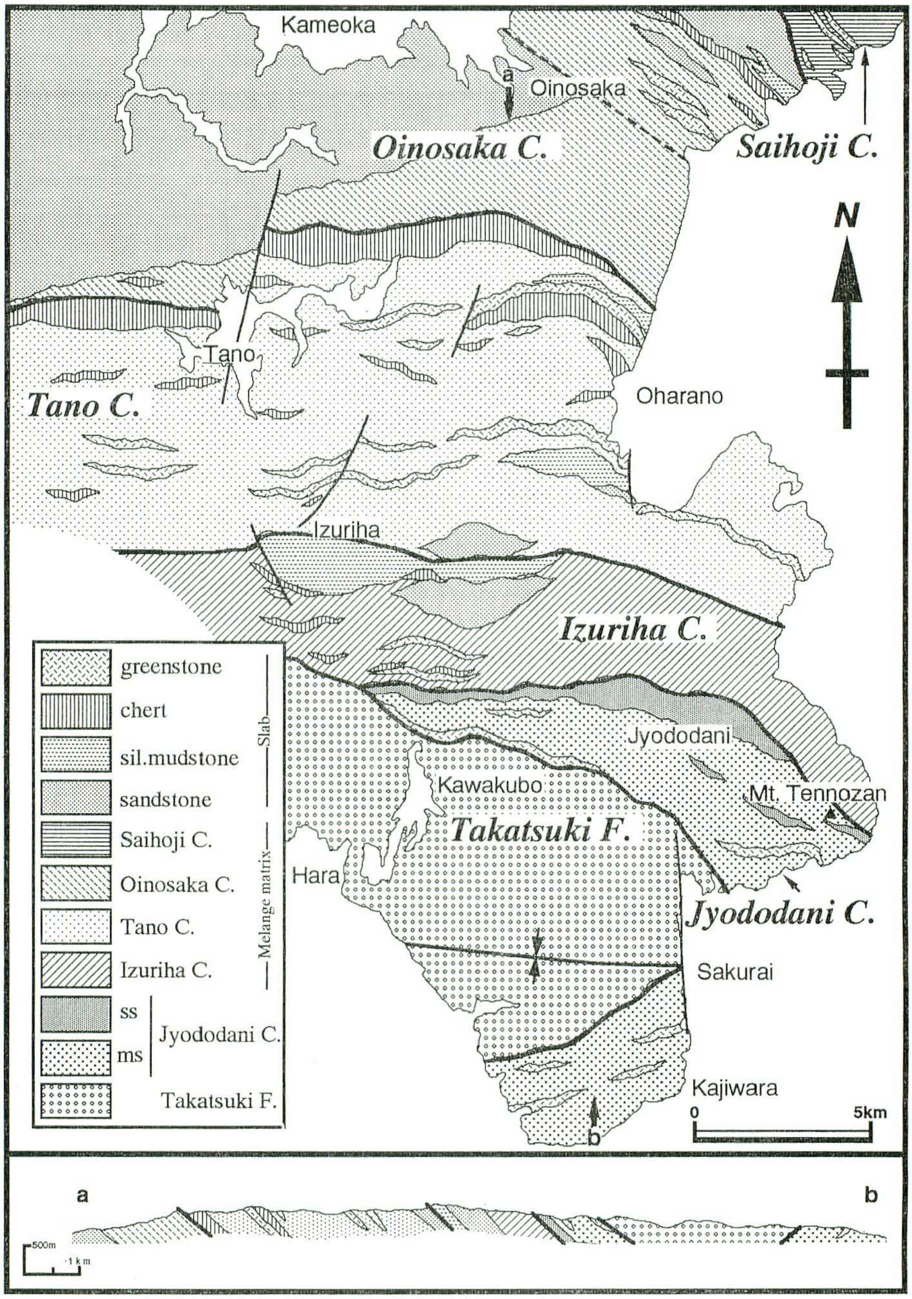

Fig. 5 Geologic map showing the complexes and formation of the Tamba and the Ultra-Tamba Terranes in the Nishiyama area. Compiled from SAKAGUCHI (1957), AN'YOJI *et al.* (1987) and NAKAE (1988). Abbreviations are as follows; ms: mudstone, sil: siliceous mudstone, ss: sandstone, C: Complex, F.: Formation.

Table 6 Tectonostratigraphic correlation of the complexes and formations in the Nishiyama area. U-T: Ultra-Tamba.

Nakamura *et al.* (1936)	Sakaguchi (1957)	Nakae (1988)	An'yoji *et al.* (1987)	This Paper	
e F.	Takatsuki F.	Takatsuki F.	Takatsuki F.	Takatsuki F.	U-T
		Tojo F.	Jyododani F.	Jyododani C.	
d F.	Izuriha F.	T-3 F.		Izuriha C.	Tamba
		T-2 F.			
c F.	Tano F.	T-1 F.		Tano C.	
b F.					

probably Middle Jurassic (Isozaki & Matsuda, 1980).

Oinosaka Complex

The Oinosaka Complex includes the Yamamoto, Oinosaka, Shirusawaike and Toshitanigawa Formations of Sakaguchi (1973). The slabs are made up of chert, greenstone and limestone, and sandstones form large slabs themselves. Early Permian fusulinids and corals from limestones (Sakaguchi & Yamagiwa, 1958), and Triassic and Jurassic radiolarians from cherts and mudstones (Takemura, 1980) were reported.

Tano Comlpex

The Tano Complex includes the Tano Formation of Sakaguchi (1957) with addition of the basal part of the Izuriha Formation of Sakaguchi (1957), and is equivalent to the T-1 Formation of Nakae (1988). Cherts and greenstones are dominant as slabs; sandstones are rarely found. Limestones occasionally accompany greenstones. Early to Middle Permian fusulinids and corals (*e.g.*, Sakaguchi, 1957; Sakaguchi & Yamagiwa, 1958) and Middle to Late Triassic *Halobia* sp. and conodonts (Nakazawa & Nogami, 1967; Yamada *et al.*, 1977; M. Yoshida, 1977) were detected from limestones. Late Permian to Early Jurassic and Early Jurassic radiolarians were included in cherts and siliceous mudstones, respectively (Takemura, 1980; Nakae, 1987MS; Onishi, 1987MS).

Izuriha Complex

The Izuriha Complex is correlative to the Izuriha Formation of Sakaguchi (1957) except for the basal part of the formation, and is equivalent to the T-2 and T-3 Formations of Nakae (1988). The melange including sandstones, cherts and greenstones as slabs widely crops out. No fossil occurrence has been reported.

4.4. Coherent Sequences in the Tamba Terrane

Non-disturbed coherent clastic sequences are also exposed in the Tamba Terrane and no pelagic material is included there. The stratigraphic unit name 'formation' is used here for a coherent sequence by reason of its stratal continuity. The Furuya Formation in the Wakasa area and the Takashiroyama Formation in the Sasayama area are the examples for the sequence.

(1) Furuya Formation

Designation

The Furuya Formation was first defined by S. YOSHIDA (1977) as Triassic clastic coherent sequences rarely including slump formations. However, the slump formations, which can be regarded as melanges, can be incorporated into the Hisasaka Complex, and then NAKAE (1990) redefined this formation as the coherent sequence of YOSHIDA's definition.

Distribution

The Furuya Formation is exposed between the Hisasaka Complex to the north and the Tsurugaoka Complex to the south, and the contacts with these complexes are in a thrust fault. This formation trends nearly E-W, extends for at least 20 km long with the width of 3 to 5 km (S. YOSHIDA, 1977; ADACHI & S. YOSHIDA, 1984). Several folds with WNW-ESE trending axes are developed. High angle faults trending NW-SE are recognized and transect this formation.

Lithologic assemblage

The Furuya Formation consists of only clastic rocks, which include predominant alternating beds of sandstone and mudstone, laminated mudstones and subordinate siliceous mudstones. The alternating beds are divided into thick-bedded and thin-bedded types on the basis of thickness of sandstone beds, although ratio between its sandstone and mudstone beds has a wide range. The thick-bedded type has sandstone beds of 15 to 200 cm or more in thickness; the thin-bedded type is characterized by those of less than 5 cm thick and much thicker mudstone beds. The mudstones are rarely foliated by a weak slaty cleavage parallel to the bedding planes.

Depositional age of formation

TANABE *et al.* (1983) and TAMBA BELT RESEARCH GROUP (1990) reported the occurrence of some radiolarian species resembling those of the *Mirifusus baileyi* Assemblage (MIZUTANI *et al.*, 1981) of middle to late Late Jurassic in age. In several places in the Kutsuki area to the east of the Wakasa area, Late Jurassic radiolarians were obtained by ADACHI & S. YOSHIDA (1984). Thus, the depositional age of the Furuya Formation is middle to late Late Jurassic.

(2) Takashiroyama Formation

Designation

The Takashiroyama Formation had been originally defined as a constituent of the Tamba Terrane by SAKAGUCHI (1959). It was subsequently divided into the redefined Takashiroyama and Ajima Formations, and the Takashiroyama was correlated to the Hikami Complex of the Ultra-Tamba Terrane (ISHIGA *et al.*, 1987). KUSUNOKI & MUSASHINO (1990) have pointed out that the Takashiroyama Formation resembles the Triassic Nabae Group of the Maizuru Terrane in sandstone petrology. Nevertheless, the Takashiroyama Formation cannot be correlated to either the Nabae Group or the Hikami Complex so far as its lithologic characteristics and depositional age of late Middle Jurassic (KURIMOTO, 1992) are concerned. Thus, it may be possible to incorporate this formation into the Tamba Terrane (Table 5).

Distribution

According to KURIMOTO (1992), the Takashiroyama Formation is situated at the topmost of the Tamba Terrane. The exposure is less than 10 km long and 500 m to 1 km wide. The strike is parallel to the axis of the E-W trending Sasayama Synform.

Lithologic assemblage

This formation is about 250 m in thickness, and consists mainly of massive sandstones and minor amounts of alternating beds of sandstone and mudstone. The sandstones are light to greenish grey in color. This formation may be different from the sedimentary complexes, because the absence of cherts and greenstones or of a chaotic mixed feature.

Depositional age of formation

Detailed depositional ages of the Takashiroyama Formation cannot be determined yet, but a few fossils, Late Middle Jurassic radiolarians, have been detected from a mudstone of the formation (KURIMOTO, 1992).

4.5. Ultra-Tamba Terrane

The Ultra-Tamba Terrane also includes both sedimentary complexes and coherent clastic sequences. The former consists abundantly of phyllitic mudstones and sheared sandstones with additional cherts and greenstones, that are Middle to Late Permian in age (CARIDROIT *et al.*, 1985; ISHIGA, 1986a; KURIMOTO, 1986; MUSASHINO *et al.*, 1987; KIMURA, 1988). Coherent sequences are composed of terrigenous clastic rocks and are probably Jurassic in age. These sedimentary complexes and overlying coherent sequences have been identified as thrust-sheets on the Tamba Terrane in the Sasayama and Nishiyama areas (*e.g.*, ISHIGA *et al.*, 1987; AN'YOJI *et al.*, 1987; TOKURA *et al.*, 1987). Complexes as sedimentary complexes and formations as coherent sequences of the Ultra-Tamba Terrane are described below, in order to consider Jurassic subduction-accretion tectonics of the Tamba Terrane.

(1) Sasayama Area

The Takashiroyama and Shinjo Formations had been originally defined as constituents of the Tamba Terrane by SAKAGUCHI (1959). ISHIGA *et al.* (1987) divided the Takashiroyama Formation of SAKAGUCHI's definition into the redefined Takashiroyama and Ajima Formations, the latter of which includes the Shinjo Formation. These formations had once been considered as a part of the Ultra-Tamba Terrane (ISHIGA *et al.*, 1987). TOKURA *et al.* (1987) recognized the presence of sheared sandstones within the Ajima Formation and called it the Kamitaki Formation (Complex). KURIMOTO (1992) has mentioned that the Takashiroyama Formation belongs to the Tamba Terrane rather than to the Ultra-Tamba Terrane. The Kamitaki Complex is considered to unconformably underlie the Ajima Formation, although the relation between them is not clarified yet.

Kamitaki Complex

The Kamitaki Complex is mainly composed of sandstones and minor amounts of mudstone. The sandstones are mediun to coarse grained, pale to greenish grey in color, and usually sheared, becoming cataclasites. No fossil has been obtained from this complex, but the age is considered to be Permian (TOKURA *et al.*, 1987; KUSUNOKI & MUSASHINO, 1990).

Ajima Formation

The Ajima Formation is more than 500 m thick, and is composed of predominant tuffaceous or calcareous sandstones which are light to pale grey in color, with intercalated tuffs and mudstones. KURIMOTO (1992) obtained Jurassic (?), maybe at least Mesozoic radiolarians from a reddish mudstone of this formation.

(2) Nishiyama Area

AN'YOJI *et al.* (1987) and NAKAE (1988) divided the Takatsuki Formation of SAKAGUCHI (1957) into the redefined Takatsuki Formation and the Jyododani or Tojo Formation (Complex). The Jyododani Complex is directly underlain by the Izuriha Complex of the Tamba Terrane, and is overlain by the Takatsuki Formation through a thrust fault (Fig. 5, Table 6).

Jyododani Complex

Jyododani is preferred for the name rather than Tojo, because of wider reference of the former. The Jyododani Complex has the thickness of about 400 m and consists mainly of sandstones and mudstones (AN'YOJI *et al.*, 1987; NAKAE, 1988). The sandstones are greenish to dark grey and are always structureless and sheared. AN'YOJI *et al.* (1987) reported Late Permian radiolarians from a reddish siliceous mudstone of this complex.

Takatsuki Formation

The Takatsuki Formation, about 1900 m thick, is characterized by interbedded sandstones and mudstones, whose stratification is not intensely disrupted. The sandstones are light to pale grey in color and are usually calcareous and tuffaceous (NAKAE, 1987MS). AN'YOJI *et al.* (1987) reported the occurrence of early Late Jurassic radiolarians from this formation.

(3) Correlation

Detailed depositional ages of the complexes and formations in the both areas cannot be determined yet, because few fossils have been detected. However, they may be correlated with others in terms of sandstone petrology.

The Kamitaki and the Jyododani Complexes have close similarity to the Hikami Complex of the Ultra-Tamba Terrane in their lithologies having sheared greenish sandstones and characteristic mineral composition (KUSUNOKI & MUSASHINO, 1990). On the other hand, KUSUNOKI & MUSASHINO (1991) mentioned that the Ajima and the Takatsuki Formations are similar to each other, and their sandstones are petrologically close to those of the Maizuru or the Ultra-Tamba Terrane, especially those of the Oi Complex of the Ultra-Tamba Terrane. However, these formations cannot be equivalent to the Oi Complex in terms of their different lithologies and ages; the Oi Complex consists of predominant mudstones with greenstones and cherts, and was formed in early Late Permian. Deposition of the Ajima and Takatsuki Formations coincided with clastic sedimentation of Complexes D,E,F and G of the Tamba Terrane in age (Fig. 12).

5. Lithologic and Structural Features

Various lithologies of the complexes and their complicated deformation structures feature the Tamba Terrane. These features are described in this chapter for the discussion that will be found in the following chapters.

5.1. Lithology

(1) Melange Matrix

Melange matrices widely exposed throughout the Tamba Terrane consist of a pelitic matrix and clasts of various lithologies. The pelitic matrix is composed of mudstones, black to dark grey in color, and encloses the clasts. The melange matrices are divisible into the T, S, C and G types mainly on the basis of lithology of the clasts (Figs. 1 and 6).

T type matrix

The T type matrix is a bluish black to black mudstone that is characterized by a slaty foliation. The letter 'T' is derived from 'tabular' fissility of the slaty foliation. This matrix usually includes no clast except for only nominal clasts or thin layers of sandstone (Fig. 6a) or siliceous mudstone. It is widely and universally exposed in every complex. As described in the next section, thrust fault contacts are usually observed between the T and S type matrices, which tend to crop out alternately.

S type matrix

The S type matrix is characterized by inclusions of clasts which are always composed of sandstone. The letter 'S' is derived from the 'sandstone' inclusions. The pelitic matrix is a poorly sorted mudstone ranging in color from dark grey to black, and shows a scaly foliation. The sandstone clasts display a wide range of shape, from pinch-and-swell structure through boudinage to isolated lenticular clasts (Fig. 6b, c, d). The S type matrix is also recognized in all complexes and occurs as widely as the T type matrix.

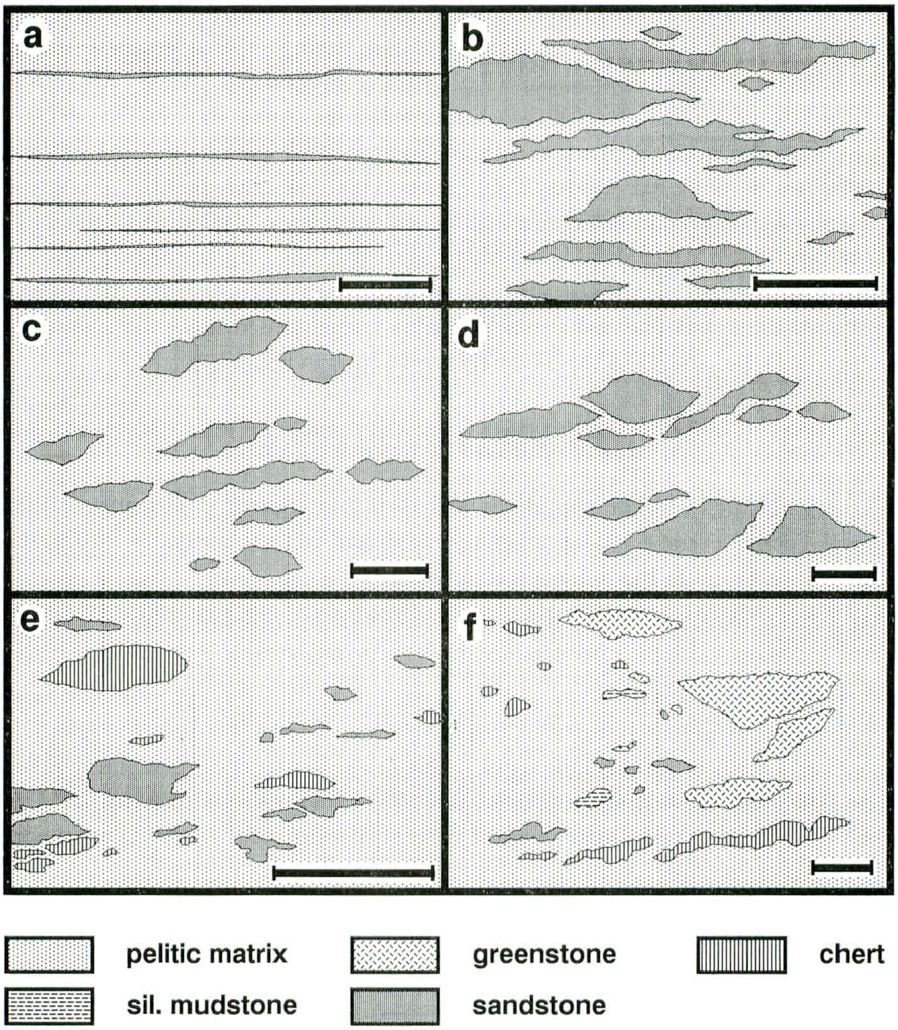

Fig. 6 Mode of occurrence of the T, S, C and G type matrices. (a) the T type, fine sandstone laminae in a pelitic matrix, (b)-(d) the S type, weakly (b) to intensely (d) disrupted sandstones in a pelitic matrix, (e) the C type, clasts of sandstone, siliceous mudstone and chert in a pelitic matrix, and (f) the G type, clasts of sandstone, siliceous mudstone, chert and greenstone in a pelitic matrix. Scale bars are 20 cm.

C type matrix

In the C type matrix, clasts of sandstone and chert are most abundant (Fig. 6e) and siliceous mudstone clasts are also included. The letter 'C' indicates 'chert'. These clasts are lenticular in shape and completely isolated from each other. They are supported by a scaly foliated, dark grey to black mudstone of the pelitic matrix. No distributional regularity for the C type matrix is recognized, as it crops out randomly within the T and

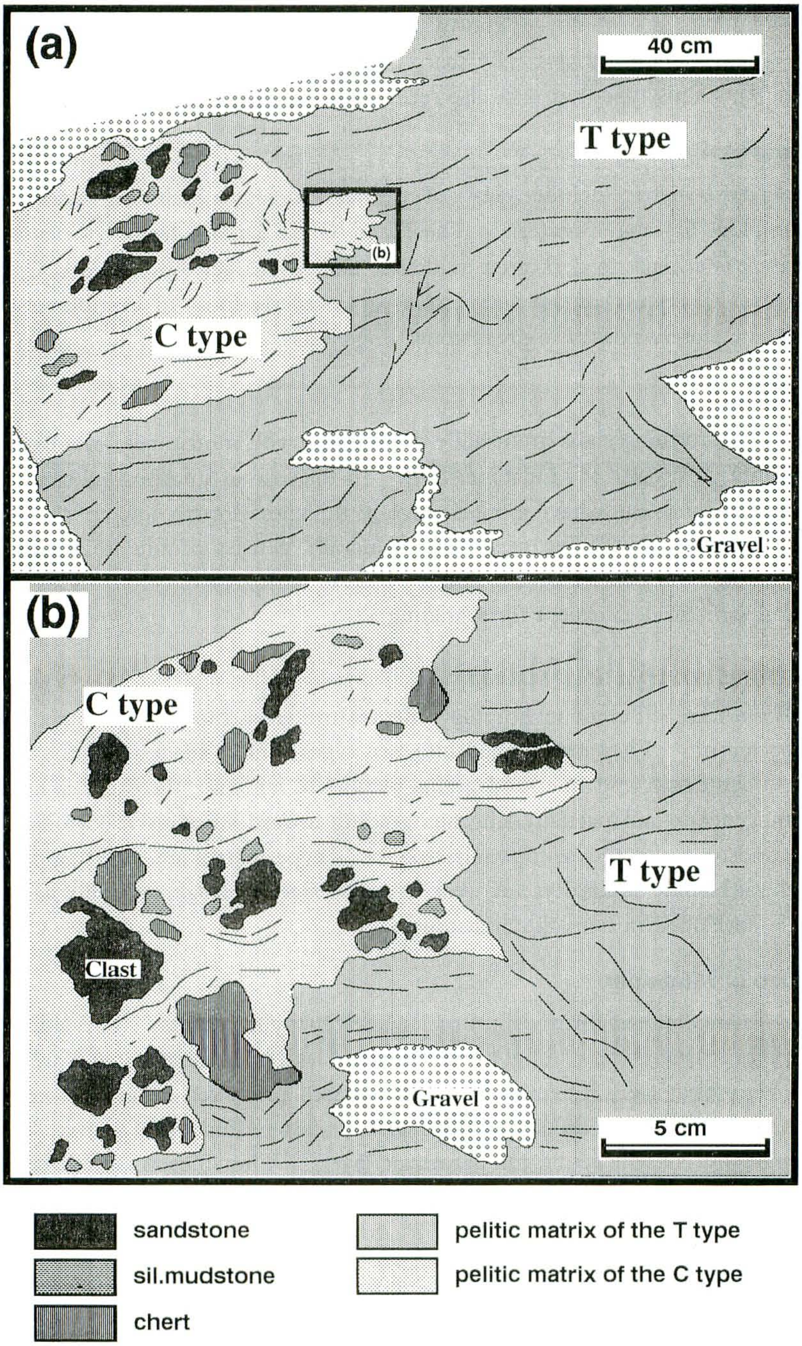

Fig. 7 Sketches showing the contact between the T and C type matrices. The boundary is irregular and sharply divides the two matrices.

S type matrices; its size varies from about 1 m^2 to 300 m^2. The contact between this matrix and the others is generally unknown, but a few examples show that this matrix and the T type matrix are in lithologically sharp contact, the former cutting the bedding of the latter (Fig. 7). This type matrix is also recognized in every complex.

G type matrix

The G type matrix includes clasts of various lithologies including sandstone, chert, greenstone (Fig. 6f) and limestone. The letter 'G' is derived from 'greenstone'. The pelitic matrix is a black to dark grey mudstone and is characterized by a scaly foliation. This matrix is exposed near greenstone slabs, particularly those of Complexes C and D; thus it may be closely related to greenstones in genesis.

(2) Sandstone

Sandstones forming slabs are usually intercalated with mudstones, whereas sandstone clasts are only composed of sandstone itself. In the case of interbedded sandstones and mudstones, the sandstones have a wide range in thickness from a few cm to 2 m, with a maximum of about 5 m. The sandstones generally consist of fine to medium clastic grains, sometimes very coarse grains, and are light to dark grey in color. They are always massive and structureless except for a grading.

(3) Mudstone

Mudstones are different in lithology and texture from the pelitic matrix, except for the T type matrix. They are divided into two types; one is black to dark grey in color and often includes silt and fine sand grains parallel to laminae; the other is light grey in color, homogeneous and partially siliceous grading toward siliceous mudstones. Therefore, the mudstone and the pelitic matrix of the T type matrix are indistinguishable, because of the lithologic similarity. A weak to strong slaty cleavage, generally parallel to the bedding, is developed in both the mudstones.

(4) Siliceous Mudstone

Siliceous mudstones form slabs usually accompanying cherts. The siliceous mudstones, greenish through pale to light grey, are dense and homogeneous, and are rarely foliated by a slaty cleavage. Their constituents are well preserved radiolarian remains and silt size clastic grains such as quartz and feldspar scattered in a clay matrix. Moreover, they occasionally contain acidic tuff lenses or layers. The siliceous mudstones change gradually into cherts or into mudstones, being transitional in lithology between them.

(5) Chert

Cherts occur both as slabs embedded in a melange matrix and as clasts enclosed in a pelitic matrix. The cherts which form slabs are usually accompanied by siliceous mudstones and/or greenstones, contrary to the clasts, which are only composed of chert. In general, these cherts are characterized by rhythmic stratification of siliceous layers and thinner pelitic ones. The thickness of individual siliceous layers ranges from 5 mm to 15 cm, but pelitic layers are less than 1 cm. The color is generally light grey to dark grey and occasionally show some variety, especially in Complexes C and D, whose Permian cherts are frequently reddish.

The principal constituent elements of cherts are radiolarian remains, sponge spicules, very fine grains of quartz, clay minerals and others. Detailed observation on cherts which are exposed around the Shuzan area was made by IMOTO (1983).

(6) 'Toishi-type' Siliceous Mudstone

IMOTO (1984) strictly defined this mudstone as follows; "the 'Toishi-type' shale is generally dense and uniform in texture with weak fissilities. This rock ranges in color usually from light gray where fresh, to pale yellow where weathered. It is composed mainly of microcrystalline quartz and clay minerals such as illite and/or chlorite with a minor amount of feldspar. No clastic grain larger than silt-size is contained except for a small amount bioclasts of compound elements of conodonts". Siliceous mudstones of this type are frequently intercalated with black mudstone beds or chert beds.

The 'Toishi-type' siliceous mudstones are very close to Early Triassic cherts in their occurrence (IMOTO, 1984), and Late Permian siliceous mudstones of this type were recently reported (KUWAHARA *et al.*, 1991; YAMASHITA *et al.*, 1991). Thus, this siliceous mudstone is considered to be stratigraphically situated between Permian and Triassic cherts.

(7) Greenstone

Greenstones are closely associated with limestones and cherts in appearance, and sometimes form single slabs together with them. The greenstones, generally dark green to dark reddish brown, consist mainly of dolerites, basaltic lavas, pillow breccias, hyaloclastites and basaltic tuffs.

The dolerites are composed of predominant plagioclases and augites with ophitic or subophitic texture; olivines are also rarely included. The basaltic lavas, massive and pillowed, contain phenocrysts of plagioclase and augite indicating pilotaxitic texture. Vesicles in the pillow lavas, showing the amygdaloidal textures, are filled with calcites. In the dolerites and lavas, plagioclases, augites, olivines are partially altered into chlorites, calcites, sericites and other minerals. The pillow breccias and hyaloclastites include fragments of basaltic lavas and often contain limestones. The basaltic tuffs are made up of fine grains of fragmented basaltic rocks and a much finer matrix.

5.2. Geologic Structure

Major geologic structures, which basically control the apparent arragements of the complexes, are penetratively presented. Melange fabrics as minor structures are attractive features in melanges and are also worthy of note. A result of the analysis on the minor structures is shown in Fig. 8. However, they are not described here, because their detail description and the tectonic significance have been discussed fully in NAKAE (1990). A synform-antiform structure and thrust-imbricate structure will be described below, al-

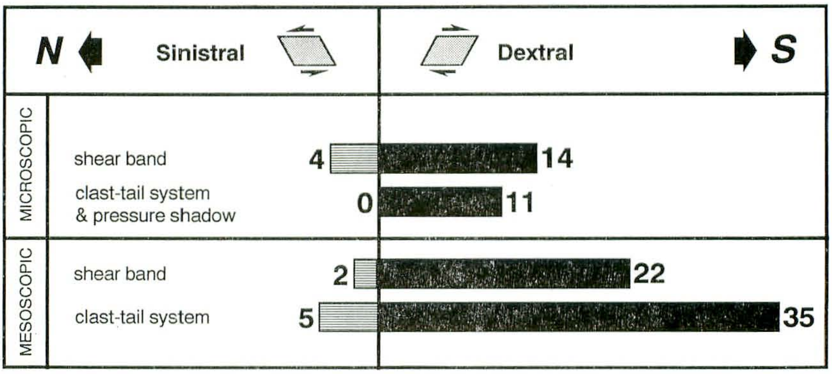

Fig. 8 Diagram to indicate a sense of shear deduced from the asymmetric deformation microstructures, after NAKAE (1990). Dextral (top-to-south) shear sense, viewed from west to east, obviously predominates. The graph shows the number of the observation.

though various kinds of geologic structures are observed.

(1) Synform-antiform structure

A synform-antiform structure has invariably subvertical axial planes and slightly westward plunging axes. It effects the complexes dip toward north and south. This structure is classified from the viewpoint of scale. One type is traditionally called the upright folds, having a wavelength of 10 to 40 kilometers. These folds are called by their respective names, such as the Hatcho Antiform (TAMBA BELT RESEARCH GROUP, 1969), the Shimoyama Synform (newly proposed here), the Kuroi Antiform (SAKAGUCHI, 1959), the Sasayama-Shuzan Synform (SAKAGUCHI, 1959; MATSUSHITA, 1953), the Hozugawa Antiform (MATSUSHITA, 1953) and the Yamashita-Sakurai Synform (NAKAMURA *et al.*, 1936) from north to south (Fig. 3). The widths of the limbs are generally different in appearance; the northern limbs are wider than the southerns. The another type is the folds whose wavelength ranges from several hundreds of meter to a few kilometers and whose axial planes are nearly vertical and parallel to those of the upright folds. These folds are invisible due to their scale being out of the limits of field observation. However, their existence can be inferred, because the structural pattern is figured out by tracing the trend of large lenticular slabs and the strike of foliations in melange matrices.

(2) Thrust-imbricate structure

The other major structure is a large scale thrust-imbricate structure, which is composed of the tectonic pile of Complex A,B,C,D,E,F and G in descending order. Boundaries, which cannot be confirmed sometimes due to the lack of field evidence, are thrust faults. Even if a boundary is not obviously exposed, it can be inferred as a thrust fault contact through field survey. In general, these faults have fracture zones of several meters width which are characterized by strongly sheared materials. A few instances of the thrust fault contacts are given in NAKAMURA *et al.* (1936) as the Oshioyama Thrust, in TAMBA

BELT RESEARCH GROUP (1979) as the Haiyagawa Thrust and in KIMURA *et al.* (1989) as the Honjo Thrust.

Traces of the thrust faults are parallel to the trend of the complexes and are folded together with the constituent elements of each complex by the above-mentioned synform-antiform structure. This fact suggests that the folding was the later movement than the thrusting; the thrusting might have first formed the large scale thrust-imbricate structure and secondarily the complexes together with the thrust faults had been folded. As a result of the thrust-fold structure, the structurally upper complexes occupy the axial areas of a synform and the lower ones are distributed in the axial areas of an antiform.

6. Formative Process of the Tamba Terrane

6.1. Origin of Accreted Materials

Rocks composing the Tamba sedimentary complex have a variety of lithologies and origin. On the basis of the lithologic features described in the chapter 5, their origin will be discussed in this section.

(1) Melange Matrix

Melange matrices are divided into four types, the T, S, C and G types. The T type matrix probably accumulated through normal 'bed by bed' sedimentation, because it frequently includes siltstone and fine sandstone laminae. In the S type matrix, primary sedimentary transitions from mudstones to sandstones as the boundaries between the matrix and clasts, are often preserved in many outcrops. NAKAE (1990) analyzed deformation structures of the sandstones intercalated with mudstones and clarified their deformational history; the sandstones had been isolated as clasts during the deformation which might be related to a subduction-accretion process. The S type matrix is considered to have primarily accumulated as interbedded sandstones and mudstones through the normal sedimentation. The C and G type matrices are impossible to be explained as having formed through the normal sedimentation, on the basis of the evidence that clasts of various lithologies formed under different environments coexist in the pelitic matrix, and that these are completely isolated and supported by the pelitic matrix. Further, boundaries between the clasts and the pelitic matrices are lithologically very sharp, not slip nor fault contact, suggesting a coherent contact. These aspects have some analogues to those of chaotic deposits caused by debris flows (*e.g.*, UNDERWOOD & BACHMAN, 1982). Chaotic deposits may represent terrigenous and hemipelagic materials slumped off the base of trench slopes. Moreover, contacts between the T and C type matrices are lithologically sharp in appearance (Fig. 7), as previously described in the section 5.1. On the basis of these characteristics, the origin of these matrices are interpreted to be debris flow deposits probably derived from lower trench slopes.

(2) Sandstone, Mudstone and Siliceous Mudstone

Continental margins characteristically show terrigenous sedimentation, although background sedimentation on trenches and lower trench slopes is dominated by hemipelagic setting. Modern trench sediments are dominantly turbidites derived from continental margins through trench axes. Submarine canyons have been responsible for funnelling terrigenous sediments from continental shelves directly to the trench floors. Thus, it is considered that the sandstones and much of the mudstones, probably accompanied by the T and S type matrices, had been deposited in a forearc region, mainly in a trench floor. Siliceous mudstones are intermediate between cherts and mudstones, because upward lithologic changes from cherts to siliceous mudstones and from siliceous mudstones to mudstones are recognized in many outcrops. Thus, the siliceous mudstones originally accumulated on cherts in hemipelagic environment.

(3) Chert

Principal constituents of the cherts are microbiogenic siliceous materials, very fine grains of quartz and clay minerals; terrigenous materials are not included. An apparent average sedimentation rate for the Permian cherts is estimated at 0.64 m/m.y. on the basis of radiolarian biostratigraphic data (ISHIGA, 1986b) and chronology (HARLAND *et al.*, 1989), and that for the Triassic cherts concentrates between 1.0 and 4.0 m/m.y. (MATSUDA & ISOZAKI, 1991). These compositional and sedimentological characteristics can provide evidence for the origin of the cherts. The Permian and Triassic cherts, probably including Jurassic ones, were originally formed by slow and constant accumulation of the biogenic siliceous materials in an environment where had been free from abundant terrigenous influx for a long time. Accordingly, an abyssal plain, especially the area far away from continental margins, is suitable for the depositional site of the cherts, although some exceptional cases are recognized, *e.g.*, the abyssal plain seaward of the Sunda Trench (G. F. MOORE *et al.*, 1982) and the Aleutian Abyssal Plain in Gulf of Alaska (SCHOLL, 1974), where terrigenous sediments are transported.

Some works dealing with basement rocks of the cherts have been carried out. Late Carboniferous and Early Permian cherts underlain by greenstones are recognized in some places, and most Permian cherts are generally very close to such greenstones in appearance. Furthermore, IMOTO (1983) proposed that the depositional site of the cherts was above or near a submarine volcanic ridge or a seamount in Permian time. A few possibilities for the depositional sites of the Triassic cherts have also been proposed, *e.g.*, on relatively deeper oceanic floor (IMOTO, 1983; MATSUDA & ISOZAKI, 1991), or on the area similar to the top of a seamount or rise (HAYASAKA, 1987), in a pelagic region. However, it is not completely clarified on what the Triassic cherts immediately accumulated, because their bases are usually faulted. The Triassic cherts probably accumulated on deeper oceanic floor, not directly but through Permian cherts. This point will be discussed in detailed in the section 7.2.

(4) Greenstone

Chemical analyses on greenstones can provide a key to understanding of their origin. In the case of the Tamba Terrane, a first but preliminary study was done by IWAO *et* *al.*, (1951), who described only chemical compositions of a few greenstones. After that, HASHIMOTO *et al.* (1970) analyzed chemical compositions of bulk rock and showed greenstones were chiefly alkalic, whereas a few were tholeiitic. Analysis on relic clinopyroxenes in greenstones (HASHIMOTO, 1972) suggested that the greenstones were derivatives of various types of magma ranging from tholeiite through normal alkalic to peralkalic basalts. The discrepancy between results of the analyses on bulk rocks and relic clinopyroxenes have been ascribed to the chemical changes resulting from metamorphism of the pumpellyite and epidote actinolite facies (HASHIMOTO, 1972). Attempts at deduction of the origin on the basis of detailed analyses of both bulk rock and relic clinopyroxene chemistry and Sm-Nd isotopic studies were examined by SANO & TAZAKI (1989). According to them, various types of rock ranging from tholeiite to alkalic basalt, derived from oceanic islands and oceanic crusts, are included in the studied greenstones.

However, these previous studies paid no attention to the distribution of greenstones. It is necessary and important for revealing the origin to discuss the chemical features after sorting out greenstones into each tectonostratigraphic unit. The most recent study has been carried out using this approach by NAKAE (1991b). Origin of greenstones in the Wakasa area is mentioned here according to NAKAE (1991b). The results are plotted in the $TiO_2/10$-MnO-P_2O_5 (MULLEN, 1983), the Ti/100-Zr-3Y (PEARCE & CANN, 1973) and the Zr-Zr/Y (PEARCE & NORRY, 1979) diagrams. They give the parentage of the greenstones as follows (Fig. 9).

A plot of the Natasyo's greenstones falls in the fields of MORB (mid oceanic ridge basalt) and OIT (oceanic island tholeiite) of Fig. 9a, and in the fields of OFB (ocean floor basalt) and WPB (within plate basalt) of both Figs. 9b and 9d, respectively. The majority of the Yajiro's greenstones occupies the similar fields as the Natasyo's and a few fall in the fields of OIA (oceanic island alkalic basalt) of Fig. 9a. Further, many plots of the Yajiro's greenstones also fall in the fields of OFB and WPB of both Figs. 9b and 9d. The greenstones plotted in the field of MORB coincide with those in the field of OFB, and the greenstones plotted in the field of OIT and OIA are the same samples as those in the field of WPB. Therefore, greenstones of the Natasyo and Yajiro Complexes are considered to be derived from oceanic floor and oceanic islands. All greenstones of the Hisasaka Complex are plotted only in the fields of OIA and WPB, and no one in the field of MORB and OFB is observed (Fig. 9a, b, d). From these results, the Hisasaka's greenstones had been derived from oceanic islands. In the case of the Haiya and Kumogahata Complexes, SANO & TAZAKI (1989) clarified that the Haiya's greenstones are of OIA and those of the Kumogahata are of OIT.

It is concluded from these geochemical studies as follows. Greenstones having tholeiites and alkalic basalts of the Yajiro, Natasyo, Kumogahata and Haiya Complexes are derived from oceanic crust and/or oceanic islands. On the contrary, the Hisasaka's greenstones are alkalic basalts derived from oceanic islands, not including oceanic crust, probably indicating a different tectonic regime of this complex from the others.

On the other hand, other geological evidence can impose some restrictions upon pos-

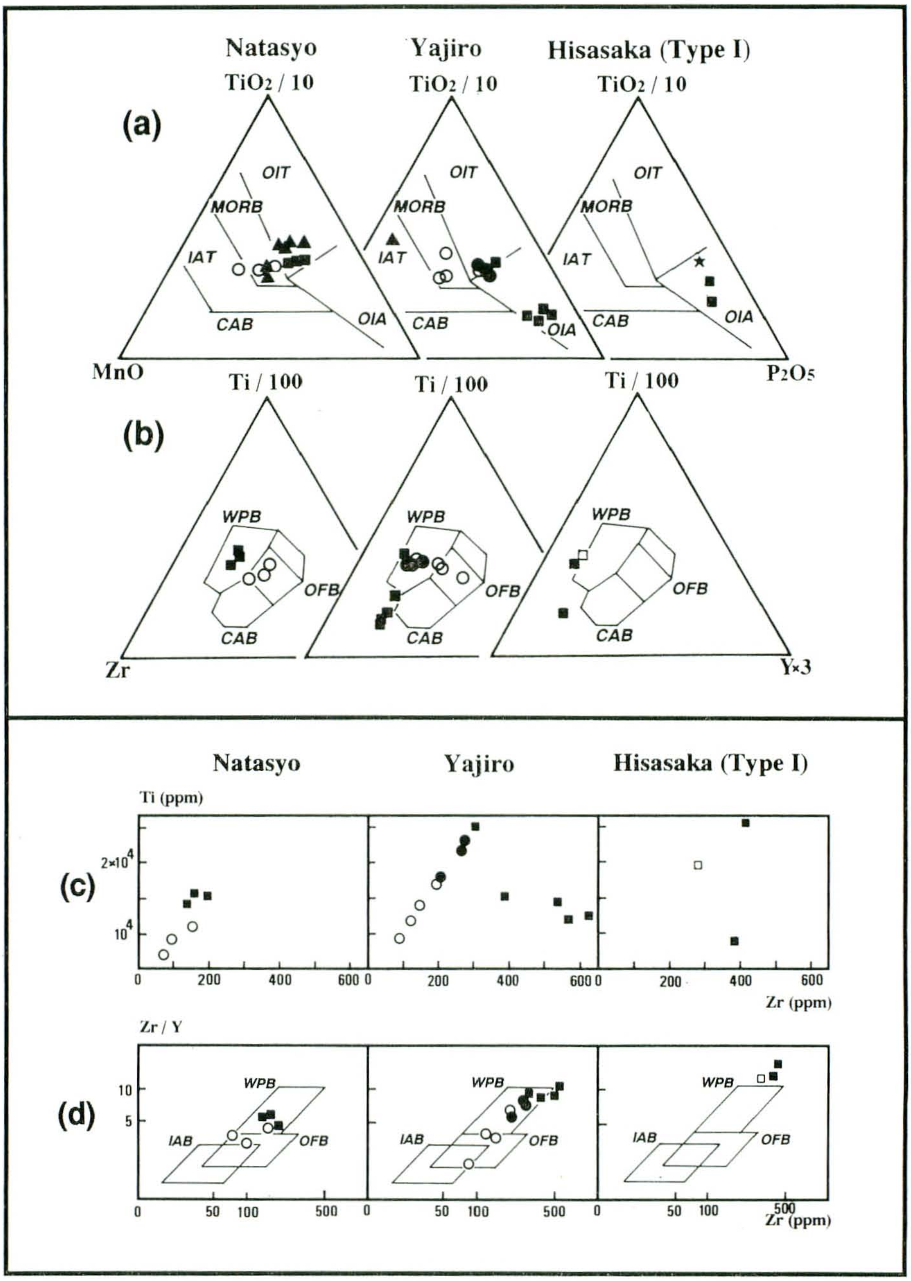

Fig.9 Discrimination diagrams of greenstones of the Tamba Terrane, after NAKAE (1991b). Abbreviations are as follows; MORB: mid oceanic ridge basalt, OIT: oceanic island tholeiite, OIA: oceanic island alkalic basalt, IAT: island arc tholeiite, CAB: calc-alkalic basalt, WPB: within plate basalt, OFB: ocean floor basalt. Solid and open symbols indicate alkalic and subalkalic rocks respectively. Square: NAKAE (1991b), circle: SANO & TAZAKI (1989), triangle: HASHIMOTO *et al.* (1970) and star: IMOTO *et al.* (1989).

sibilities for the origin. Greenstones accompanied by reefal limestones (Musashino *et al.*, 1980) are generally considered to construct some kinds of topographic high on oceanic floor such as an oceanic island and a guyot. In the Tamba Terrane, greenstones following the limestones are included in the Natasyo and Haiya Complexes (Kimura *et al.*, 1989; Imoto *et al.*, 1989; Nakae, 1992). Hence, MORBs are not appropriate for the origin of these complex's greenstones.

6.2. Reconstruction of Original Stratigraphy

At modern trenches, sediment successions show that pelagic clay immediately above an oceanic crust grades upward through hemipelagic mud and toward trench fill turbidite (*e.g.*, Piper *et al.*, 1973; von Huene, 1974; J.C. Moore & Karig, 1976; J.C. Moore *et al.*, 1982b; Lash, 1985). These successions have formed through continuous accumulation on oceanic crusts. On the other hand, the Tamba sedimentary complex, although chaotically mixed, ought to have primarily been formed through the continuous accumulation of sediments, and to have represented some sort of successive sequence. Because of this point of view, original stratigraphies of Complexes A, B, C, D, E, F and G can be reconstructed on the basis of the interrelation between each lithologic type and their depositional age.

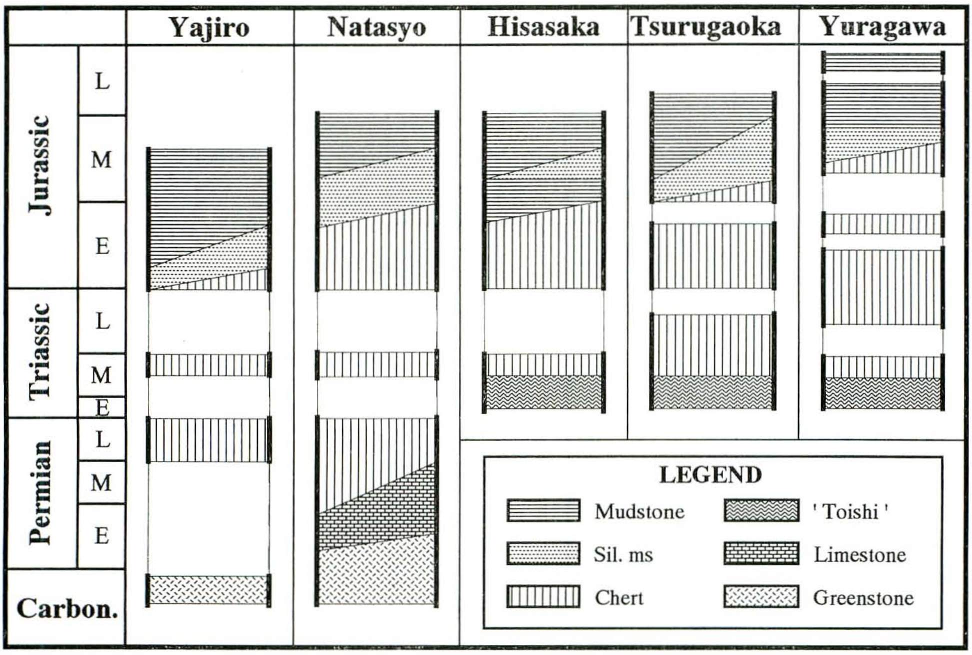

Fig. 10 Depositional ages and lithologies of the complexes in the Wakasa area, after Nakae (1992). The Kowaki's and Yajiro's ages are unknown due to the lack of fossil evidence, but the latter is inferred on the basis of the age of the Kamanowa and Mimata Complexes. Abbreviations are as follows; 'Toishi': 'Toishi-type' siliceous mudstone and Sil. ms: siliceous mudstone.

The method of the reconstruction is explained as follows. Firstly, field observation shows that gradational lithologic changes of each rock type, for example, the changes from chert to siliceous mudstone, from siliceous mudstone to mudstone and from mudstone to sandstone, are internally observed within slabs. However, the slabs never change to the surrounding melange matrix, and they are sharply bounded from the matrix by faults. In the case of boundaries between clasts and pelitic matrices, they are lithologically sharp in general, suggesting coherent contacts; primary sedimentary transitions from sandstones to mudstones are often preserved. These evidences predict that these rocks primarily accumulated continuously on greenstones from cherts through siliceous mudstones to mudstones and sandstones. Secondarily, fossil evidence, mainly radiolarian biostratigraphy, obtained from the rocks determines their depositional ages, and can confirm the above sediment succession, because cherts are older than siliceous mudstones and siliceous mudstones are older than mudstones (NAKAE, 1990, 1992).

Accordingly, the restored original stratigraphies can be represented as a sequence of basal greenstone and limestone succeeded by sedimentary rocks of pelagic cherts, hemipelagic siliceous mudstones, and terrigenous mudstones and sandstones (Figs. 10 and 11). They are closely similar to the modern sediment successions beneath trench floors.

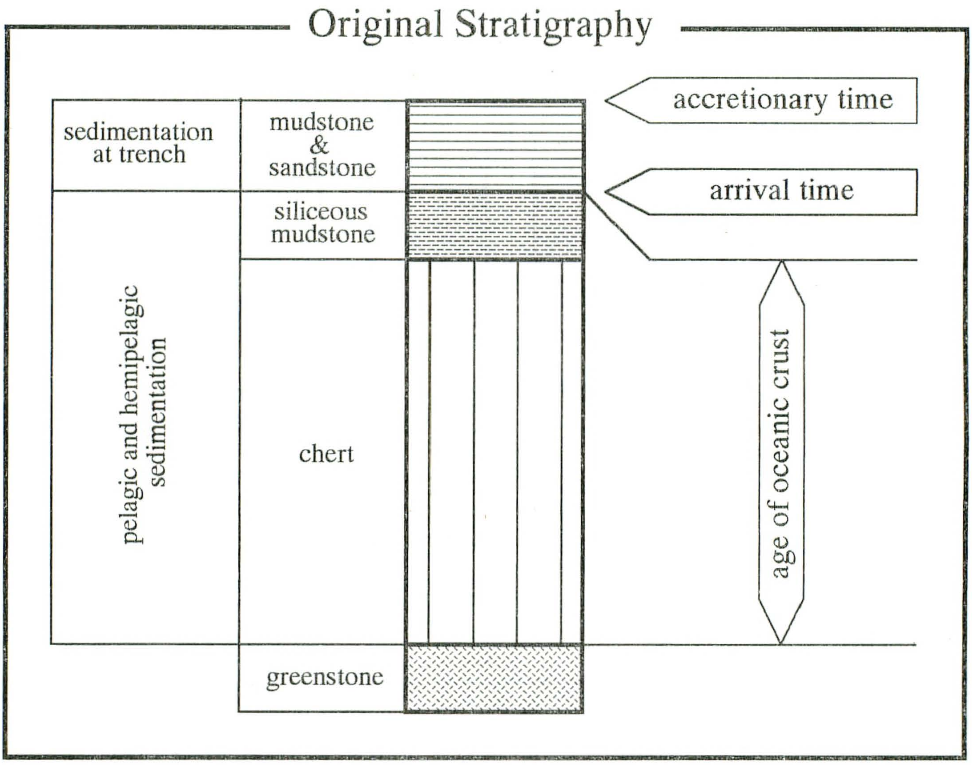

Fig. 11 Diagram showing relationship between the event chronology and the change in lithology within the original stratigraphy. After NAKAE (1992).

6.3. Change of Depositional Environments

The formational or depositional environment of each rock type was fully discussed in the previous section 6.1; greenstones were generated as constituents of seamounts/oceanic islands, cherts accumulated on the area from the foot of a seamount and/or oceanic island to oceanic floor under pelagic setting, and clastic rocks accumulated on a trench floor and adjacent areas.

To sum up the above conclusion, vertical lithologic changes in the original stratigraphies as well as the modern sediment sequences beneath trench floors is very critical for understanding the travel history of oceanic crust and overlying sediments, just prior to their incorporation with an accretionary complex. They record the migration of sedimentary sites on the foot of a seamount/oceanic island through an oceanic floor to a trench. Nevertheless, this change of environments cannot perfectly apply to the original stratigraphies of Complexes E, F and G, due to their lack of greenstone, limestone and a part of chert (Fig. 12). This point will be discussed in the section 7.2.

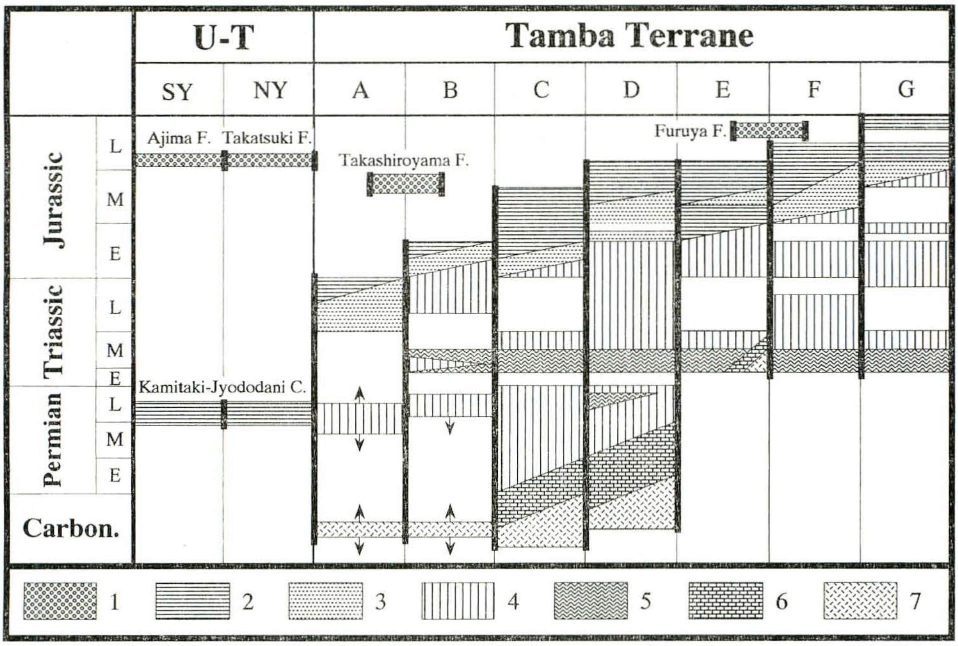

Fig. 12 Age-lithology relationship of the Tamba and the Ultra-Tamba Terranes. The Takashiroyama and the Furuya Formations as the slope basin deposits are exposed between the complexes of the Tamba Terrane, and the Ajima and the Takatsuki Formations as the forearc basin deposits are situated on the complexes of the Ultra-Tamba Terrane. 1: alternating beds of sandstone and mudstone, 2: sandstone and mudstone, 3: siliceous mudstone, 4: chert, 5: 'Toishi-type' siliceous mudstone, 6: limestone, 7: greenstone, U-T: Ultra-Tamba Terrane.

6.4. Accretionary Time

Horizons of lithologic changes assign significant times (ISOZAKI *et al.*, 1990), because the change of depositional environments can be found out through the lithologic changes within the whole stratigraphy, as has been pointed out. The change from pelagic to terrigenous sediments fixes a time for the arrival of an oceanic crust including seamounts/oceanic islands at a trench, because terrigenous sedimentation occurs in trenches and their landward area. The duration of pelagic and hemipelagic sedimentation on an oceanic crust represents the age of the oceanic crust at a trench. In other words, the balance between the generation and arrival times of the crust indicates this age.

Additionally, the youngest age of terrigenous sediments probably indicates the termination of their sedimentation. The sediments on an oceanic crust have instantly accreted toward a continental margin by stacking of imbricate fans at the toe (offscraping) and by development of duplexes at the depth (underplating), just after the arrival of the oceanic crust at a trench (SEELY *et al.*, 1974; SCHOLL *et al.*, 1980; J.C. MOORE *et al.*, 1982a, 1982b; WATKINS *et al.*, 1982; SILVER *et al.*, 1985; SAMPLE & FISHER, 1986). On the basis of these processes, NAKAE (1992) proposed that the accretionary time of sediments on the oceanic crust can be set upon the top of the original stratigraphy, representing the terminal time of terrigenous sedimentation. Fig. 11 explains the relationship between the lithologic changes and the times. In particular, the accretionary time is worth noticing for considering the formative process of the Tamba Terrane.

6.5. Formative Process of the Tamba Terrane

The original stratigraphies represent the landward migration of oceanic crusts and probably the accretion, therefore the Tamba Terrane is interpreted to have been formed as an accretionary complex. The above tectonosedimentary evidences lead to the Late Triassic to Latest Jurassic formative process of the Tamba Terrane as shown below.

The detailed original stratigraphy of Complex A cannot be restored, because the age of their cherts and greenstones is unkonwn. But, the depositional age of terrigenous clastic rocks, mudstones and siliceous mudstones, indicates the accretionary time. Comples A was formed by the accretion in Late Triassic time (Fig. 13a). The accretion of mainly Permian to Early Jurassic cherts and Early Jurassic clastic rocks created Complex B in Early Jurassic time (Fig. 13b). In Middle Jurassic time, Permian to Early Jurassic cherts and Early to Middle Jurassic clastic rocks were accreted by the subduction-accretion of Late Carboniferous to Early Permian seamount chains, forming Complexes C and D (Fig. 13c). Finally, Triassic to Middle Jurassic cherts and Middle to Late Jurassic clastic rocks were accreted during Middle to Late Jurassic time, and forming Complexes E, F and G in this order (Fig. 13d). During the formation of the complexes, the subduction-accretion of seamounts which obviously occurred, is recognized only in Complexes C and D, as the other complexes have no or rare greenstones.

Coherent clastic sequences in the Tamba Terrane, the Takashiroyama and the Furuya Formations, include no pelagic or oceanic rocks. They are not so intensely deform-

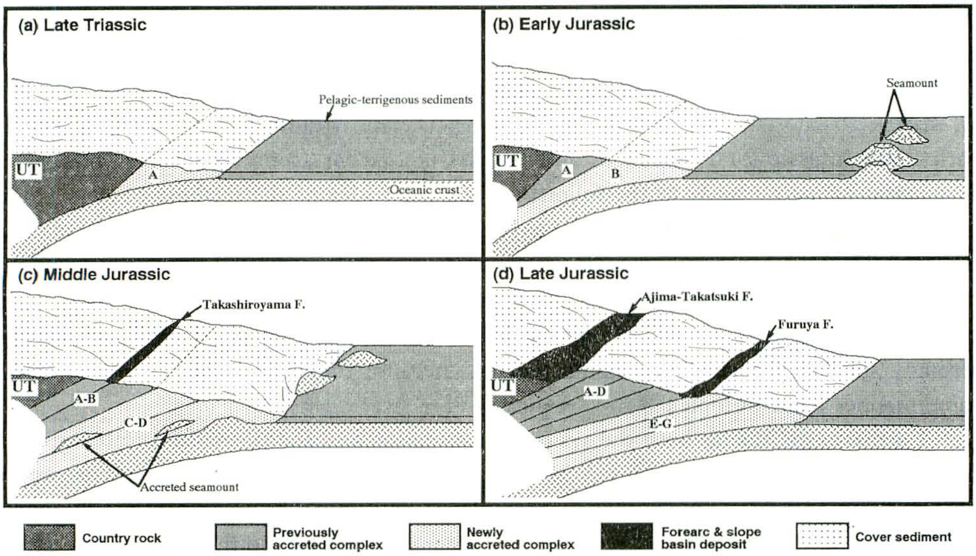

Fig. 13 Schematic model for the formation of the Tamba Terrane. (a) Initiation of subduction-accretion, forming Complex A, (b) succeeding subduction-accretion and the formation of Complex B, (c) subduction of seamounts, forming Complexes C and D, and deposition of the Takashiroyama Formation, and (d) accretion of Complexes E, F and G, and accumulation of the coherent Furuya and the Ajima-Takatsuki Formations on the slope and forearc basins, respectively.

ed, and stratal continuity has been preserved. They crop out between the complexes in fault contact and is intercalated into a continuum of complex's arrangement (Figs. 3 and 4). Further, depositional ages of both formations are obviously younger in comparison with those of the surrounding complexes (Fig. 12). From these geologic features, their depositional environments are thought to have been protected from intense and complicated deformations. Accordingly, they probably accumulated in slope basins on the accretionary complexes of the Tamba Terrane (Fig. 13c, d). On the other hand, the Ajima and Takatsuki Formations in the Sasayama and Nishiyama areas are directly situated upon the Permian accretionary complexes of the Ultra-Tamba Terrane. These formations are regarded to be the forearc basin deposits relative to the Tamba sedimentary complex (Fig. 13d), because of their depositional ages of Late Jurassic (AN'YOJI *et al.*, 1987; KURIMOTO, 1992) and shallower depositional depth (KUSUNOKI & MUSASHINO, 1991). It is considered that the Kamitaki and Jyododani Complexes of the Ultra-Tamba Terrane together with the overlying Ajima and Takatsuki Formations were upthrust over the Tamba Terrane (ISHIGA *et al.*, 1987; AN'YOJI *et al.*, 1987; TOKURA *et al.*, 1987). This upthrusting must be at least after middle Late Jurassic time, as the depositional age of the Furuya Formation can set a time limit for the upthrusting (Fig. 12).

6.6. Presentation of a Continuous Accretionary Model

The youngest ages of terrigenous sediments indicate the terminal time of their sedimentation, and also set a time for the accretions. Among the complexes, the accretionary times show the tendency to be younger toward the lower complex; it was Latest Triassic for Complex A, late Early Jurassic for Complex B, middle Middle Jurassic for Complex C, middle to late Middle Jurassic for Complex D, late Middle Jurassic for Complex E, early Late Jurassic for Complex F and Latest Jurassic for Complex G (Fig. 12). This systematic younging leads to the following significant idea of the tectonic process. The complexes had been continuously formed through a multi-stages accretion with minimal time (10–15 m.y.) gap between each process. The complex accreted in younger time occupies the tectonically lower level in the result. Arrival times of the oceanic crusts in the respective complexes, inferred from the lithologic change from cherts to clastic rocks, strongly support the above younging polarity, because they also become younger in the same manner from Complex B to Complex G.

Furthermore, taking both the systematic younging and the thrust-imbricate structure composed of the pile of Complex A to Complex G into consideration, two inferences appear to be important. One is that the complexes had grown by their tectonically downward (southward) building and resulted in the construction of the thrust-imbricate structure. This characteristic feature is concordant with the tectonic model of SILVER *et al.* (1985). The other is that the subduction had been a nearly northward underthrusting in the present direction. The result proposed by NAKAE (1990), who analyzed the deformation microstructures of the melanges, suggests top to the south sense of shear (Fig. 8). This shearing is not inconsistent with the predicted direction of the subduction, because a northward underthrusting or southward overthrusting may cause such the sense of shear.

The phenomenon that the complexes were formed in response to the respective stage of the accretion as the above, does not conform to the previous models; voluminous sediments were accreted in a short time (*e.g.*, HAYASAKA, 1987; ISOZAKI *et al.*, 1990), but strongly suggests the accretion had continuously succeeded for a long time (for about 70 m.y.). This aspect of the formative process is significant and has to be stressed.

7. Effective Factors Controlling the Subduction-Accretion Tectonics of the Tamba Terrane

To obtain a better model of the subduction-accretion tectonics of the Tamba Terrane, it should be considered from a wider viewpoint. Continuity of accretion, origin of accreted materials and age of subducted oceanic crusts are the main factors to be discussed and to be compared with previously proposed ones controlling subduction-accretion tectonics in convergent boundaries.

7.1. General Knowledge about Subduction-Accretion Tectonics

UYEDA & KANAMORI (1978) suggested that subduction zones are divided into two major types. The Mariana type (low-stress type; UYEDA, 1983) is characterized by backarc spreading, whereas such spreading has never occurred in the case of the Chile type (high-stress tpye; UYEDA, 1983). The difference between the two types essentially contributes to relative motions of continental and oceanic crusts and to intensity of the coupling stress between them. In the Chile type, the coupling stress is stronger as a result of young and hot oceanic crust subducting at a shallow angle. In the Mariana type, old and cold oceanic crusts are denser and gravitationally more unstable, and therefore the angle of subduction becomes higher (UYEDA & KANAMORI, 1978; UYEDA, 1983).

At the same time, MOLNAR & ATWATER (1978) discussed the relation between the age of subducting oceanic crusts and the variety of tectonic evolutions in the Circum-Pacific regions. They proposed the following summary. Back-arc spreading occurs or recently occurred in most of the western Pacific, where the subducting oceanic crust is 65 to 160 m.y. old. On the contrary, Cordilleran tectonics are presented in the eastern Pacific, where the subducting oceanic crust is younger than about 50 m.y. old. Further, KARIG & SHARMAN (1975) compared the development of accretionary complexes with the types of subduction; no or few complexes are recognized in the Mariana type, and complexes tend to be voluminous in the Chile tpye.

It had simply been summarized from the above features as follows: the age of subducting oceanic crusts control the volume of accretionary complexes, *i.e.*, back-arc spreading and no accretionary complex are recognized in where old crusts are descending; accretionary complexes are characteristically built by the subduction of younger crusts.

However, it has been regarded that the formation of accretionary complexes is related not only to the age of subducting crusts but also to the relation between the amounts of sediment fed into subduction zones and the surface features of the crusts themselves (*e. g.*, J.C. MOORE, 1975; von HUENE, 1984, 1986; HILDE, 1983; SILVER *et al.*, 1985). Many other factors have also to be discussed. Thus, (i) age and (ii) topography of subducting crusts, (iii) amounts of sediments fed, (iv) relative convergent rate and (v) direction of subduction, should be emphasized as the factors that can affect and control the mode of tectonic features in subduction zones. The former three are the factors to be discussed about the formation of the Tamba Terrane, because it is difficult to estimate both the relative rate and the direction.

7.2. Effective Factors Controlling the Subduction-Accretion of the Tamba Terrane

(1) Age of Subducted Oceanic Crusts

The age of subducted oceanic crusts at a trench can be estimated from the balance between generation and arrival times of the crust, as mentioned in the section 6.4, and the former is contemporary with or sightly older than oldest pelagic cherts. In the case of Complexes C and D, for example, the generation and arrival times were Late Carboniferous and Middle Jurassic respectively; thus the subducted oceanic crusts are estimated to be about 100 to 150 m.y. old. Moreover, it is stressed that the compositional differences among the original stratigraphies appear through comparison between Complexes A to D and Complexes E to G (Fig. 12). Complexes A to D contain Paleozoic rocks of oceanic realm, contrary to Complexes E to G in which such rocks are not included.

In the case of Complexes E to G, it is questionable whether 'Toishi-type' siliceous mudstones of Early Triassic immediately accumulated on an oceanic crust, or Paleozoic rocks primarily underlay them as well as Complexes A to D.

If the former possibility is likely (Fig. 14a), the age of the subducted oceanic crust is considered to be Late Permian or Early Triassic. Consequently, the age gap between the subducted crusts of Complexes A to D and those of Complexes E to G would be 40 to 60 m.y., since the subducted oceanic crusts of Complexes A to D point to Late Carboniferous. Newly beginning of younger oceanic crust subduction arises as the tectonic event which is required to cause such the chronologic change. Considerable processes are as

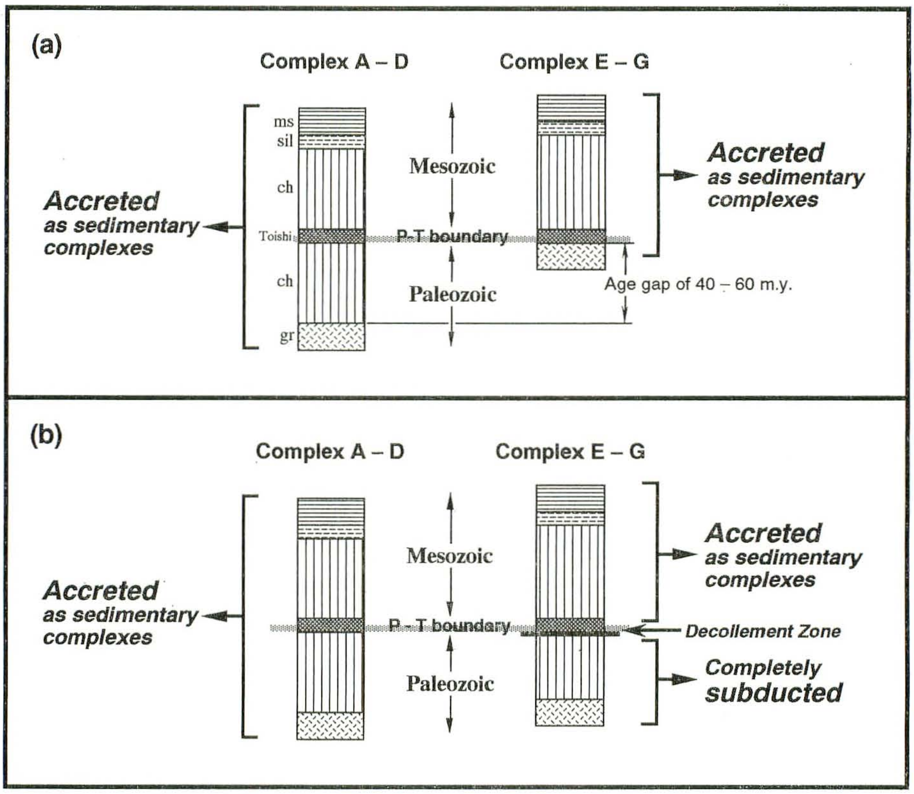

Fig. 14 Diagrams showing the compositional differences among the complexes and the different subduction-accretion processes. Complexes A-D were formed by the accretion of Paleozoic and Mesozoic rocks. In the case of Complexes E-G, the following two processes are alternatively hypothesized. (a) 'Toishi-type' siliceous mudstones immediately accumulated on greenstones of Late Permian or Early Triassic age, and they were accreted as sedimentary complexes. (b) Paleozoic cherts and greenstones primarily underlain 'Toishi-type' siliceous mudstones as well as Complexes A-D and they were completely subducted, hence Mesozoic rocks above the decollement zone were accreted as sedimentary complexes. Abbreviations are as follows; ms: mudstone, sil: siliceous mudstone, ch: chert, Toishi: 'Toishi-type' siliceous mudstone, gr: greenstone.

follows: (i) seaward shift of the subduction zone, (ii) the subduction zone changes to a transform boundary, and then new subduction begins there, or (iii) subduction of transform faults that exist near a mid oceanic ridge. Nevertheless, the processes (i) and (ii) might have broken the continuity of sediment accretion and the process (iii) is unreasonable because of the 20 m.y. maximum age gap in recent examples. None of them can be hypothesized and the possibility that 'Toishi-type' siliceous mudstones directly accumulated on the oceanic crust is rejected.

On the other hand, the latter possibility is that the subducted crust was Late Carboniferous or Early Permian and the Paleozoic rocks might have detached from the base of 'Toishi-type' siliceous mudstones (Fig. 14b). In a word, the Paleozoic rocks had completely subducted downward together with the oceanic crust. 'Toishi-type' siliceous mudstones occur in the specific stratigraphic horizon near the Permo-Triassic boundary (*e. g.*, YAMAKITA, 1987; YAMASHITA *et al.*, 1991; KUWAHARA *et al.*, 1991), and scaly cleavages are always developed at their bases. These features are concordant with those in the DSDP cores from decollement zones in the Barbados Ridge Complex and others (J.C. MOORE *et al.*, 1986, 1988; BEHRMAN *et al.*, 1988). It is considered from these features that the 'Toishi-type' siliceous mudstones would function as decollement zones, hence this possibility is more reasonable.

The age of the subducted oceanic crusts is about 100 to 150 m.y. old from these consideration. According to Molnar & Atwater (1978), if such the old crust would subduct, then back-arc spreading and no accretionary complex might develop. In the present case, however, voluminous sediments had certainly been accreted. In the meantime, the age of the subducted oceanic crust during the formation of the Tamba Terrane is inconsistent with the general understanding of the relationship between the age of oceanic crust and the type of subduction. This inconsistency was first pointed out by MATSUDA & HAYASAKA (1987). They explained that the large positive buoyancy of a giant plateau or rise might have cancelled the negative buoyancy of the old and cold oceanic crust, resulting in the creation of the Tamba Terrane. However, as will be clarified, seamount chain subductions obviously negate the supposition of a plateau or rise.

(2) Seamount Chains as Topographic Highs on the Subducted Oceanic Crusts

It is questionable for a variety of subduction-accretion tectonics, whether topographic highs on an oceanic crust may completely subduct beneath, accrete into or collide with a margin of arcs or continents. Size, thickness and density, in terms of buoyancy of the highs related to the surrounding oceanic crust, are the factors that contribute to the above variety (*e.g.*, KELLEHER & MCCANN, 1976; MOLNAR & GRAY, 1979; TOMODA & FUJIMOTO, 1983).

Many topographic highs exist on oceanic crusts and are divided into (i) mid oceanic ridges, (ii) seamounts/oceanic islands, (iii) oceanic plateaus and rises, and (iv) aseismic ridges. Generally, they are nominated for the origin of greenstones based on the genetic characteristics. However, greenstones occurring as large slabs in the Tamba Terrane

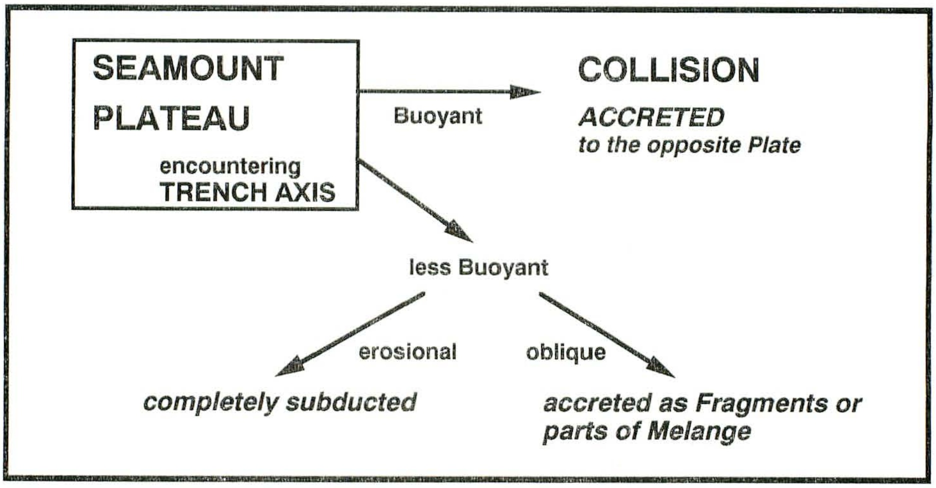

Fig. 15 Diagram showing possible courses of events of seamounts and oceanic plateaus encountering a trench. After KOBAYASHI (1985).

are of oceanic realm (SANO & TAZAKI, 1989; NAKAE, 1991b) and their geochemistry and their coexistence with reefal limestones obviously make a cancellation of (i) as already discussed in the section 6.1. Thus, any one of (ii) to (iv) is admitted as the original topography related to the greenstones.

TOMODA & FUJIMOTO (1983) have classified seamounts and rises into three types from the viewpoint of their buoyancy related to the asthenosphere: (i) seamounts that can easily subduct, (ii) sizable seamounts that will take a long time to subduct, and (iii) rises that will never subduct. According to them, large scale rises and plateaus will presumably collide with a margin of arcs or continents, whereas seamounts of relatively small scale will completely subduct (Fig. 15; TOMODA & FUJIMOTO, 1983; KOBAYASHI, 1985). If it is clarified whether topographic highs subducted beneath or collided with the margin, and/or if it is revealed how deep they subducted, it will be possible to deduce which type of the TOMODA & FUJIMOTO's classification is likely to be adopted for greenstones of the Tamba Terrane.

For the purpose of estimating the possible depth for accretion (underplating) of greenstones, the detailed petrological study of MARUYAMA & LIOU (1989) is worth noticing. They indicated that a bending point in the P-T path for metamorphism may reflect the depth for the underplating of a seamount. The case of the Tamba Terrane is considered from the viewpoint of MARUYAMA & LIOU (1989) below. It should be noted that HASHIMOTO & SAITO (1970) and SANO & TAZAKI (1989) pointed out a high P/T metamorphism from the prehnite-pumpellyite facies to the pumpellyite-actinolite facies occurring in the Tamba Terrane. TAKAMI *et al.* (1990) also clarified the similar metamorphism in the Kuga Group, which is correlated to the Tamba Terrane. The P-T conditions for such the metamorphism was estimated to be around 200–350°C and 2–8 kbar (LIOU, 1971), which denote the depth of about 15–20 km (SAMPLE & MOORE, 1987). Thus, greenstones of the Tamba Terrane once subducted downward up to the depth as above, and the class (iii) of TOMODA & FUJIMOTO (1983) is considered not appropriate for the greenstone slabs.

It is expected that collision of large scale plateaus and rises with continental or arc margins due to their large buoyancy may result in making time gaps in the continuum of accretion, in shifting a subduction zone seaward (TOMODA & FUJIMOTO, 1983), in forming a marginal sea (NUR & BEN-AVRAHAM, 1983), or in the termination of subduction. This, in turn, causes a newly-beginning of subduction in the opposite direction as the case of the collision of the Ontong-Java plateau with the Vanuatu arc (CARNEY *et al.*, 1985). As a matter of fact, however, the continuous accretion of the Tamba Terrane contains only minimal time gaps during the subduction, and the greenstones certainly had subducted to the depth causing the high P/T metamorphism.

In the Tamba Terrane, greenstones occurring as large slabs in Complexes C and D are of oceanic realm (SANO & TAZAKI, 1989; NAKAE, 1991b), and their elongation is presently exposed in areas more than 500 km long from the Tamba through the Mino to the Ashio Terranes. Modern topographic highs on oceanic crusts, except for mid-oceanic ridges, have their own specific scale, *i.e.*, seamounts are of several tens to 150 km in diameter and plateaus, rises and aseismic ridges have lengths of several hundreds kilometers to 5000 km (IWABUCHI, 1982). Therefore, the elongation of the slabs exceed a modern single seamount and may rank with a single plateau or rise. However, each greenstone slab is similar to a single seamount in scale. Thus, seamounts as the slabs can satisfy their subduction to the specified depths in terms of buoyancy. Consequently, the above petrological and physical consideration suggests that a seamount chain having more than 500 km long is nominated for the subducted topographic highs which are documented by the present greenstone slabs.

Among Complex A to Complex G, only Complexes C and D have a great amount of fragmented seamount chains (Fig. 12, Table 3). This fact may accordingly predict that the subduction-accretion of seamount chains has no concern with the formation of the other complexes,and made no time gap in the continuity of sediment accretion of the Tamba Terrane as a result. Therefore, the subduction-accretion of seamount chains is interpreted to have been not necessary for the formation of the Tamba Terrane.

(3) Amount of Sediments Fed into Subduction Zones

The aspect of some trenches probably give a solution for the inconsistency between the age of oceanic crust and the type of subduction-accretion.

The Orinoco river transports a great amount of sediment from South America to the Lesser Antilles Trench, forming the Barbados Ridge Complex (WESTBROOK & SMITH, 1982; BROWN & WESTBROOK, 1988), although the subducting oceanic crust is obviously old, near 100 m.y. old. The other examples are documented by the case of collisions occurring behind subduction zones. The collisions between the Indian and Asian continents and between the Izu-Bonin and SW Japan island arcs feed voluminous sediments to the Java Trench and the Nankai Trough, forming accretionary complexes off the Sunda arc (G.F. MOORE *et al.*, 1982; CURRAY & MOORE, 1974) and off Shikoku, Southwest Japan (TAIRA & NIITSUMA, 1985), respectively. These examples clearly show that the supply of voluminous sediments for trenches can build accretionary complexes. Furthermore, the sediments fed into subduction zones are ascribed to either collisions occurring or large rivers existing behind the subduction zones.

It is generally understood that the Asian continent was amalgamated and consolidated through Permian to Triassic collisional events of some major cratons (*e.g.*, MARUYAMA *et al.*, 1989). The Sino-Korean craton and Siberian Platform, which had already been sutured in the western part after the Permian collision, completely collided each other and unified before the end of Triassic time (MARUYAMA *et al.*, 1989). The Yangtze craton migrated northward and finally collided with the Sino-Korean craton in Late Triassic time (LIN *et al.*, 1985). To the south, the Indosinian, Malaya and Sumatra blocks had collided with and accreted to Asia (probably the Yangtze) by the end of Triassic time (RIDD, 1980). In Late Jurassic time, the Kolyma-Omolon block collided with the Siberian platform (FUJITA & NEWBERRY, 1982).

These collisions and associated tectonic movements probably resulted in supplying a great amount of sediments for the subduction zone where the Tamba Terrane and its equivalents were formed, in the similar way to the cases of the Indian and the Izu collisions. This discussion leads to the following conclusion: the subduction-accretion model of the Tamba Terrane emphasizes that voluminous sediments within the subduction zone can conquer the effect of negative buoyancy of the old oceanic crust, causing the sediment accretion. And further taking the extension of accretionary complexes correlative to the Tamba Terrane, it is possible to say that such a kind of subduction-accretion is a universal phenomenon in the Jurassic subduction zones along the eastern margin of the Asian continent.

8. Summary

This paper describes tectonosedimentary evidences of the Tamba Terrane and discusses its Late Carboniferous to Latest Jurassic formative process. The results reveal episodes of the intensive trench sedimentation and accretion, accompanied by the incorporation of oceanic materials into the accretionary complexes of the Tamba Terrane.

(1) In the mainly investigated Wakasa area situated in the northern part of the Tamba Terrane, the accretionary complexes are divided into the Kowaki, Yajiro, Natasyo, Hisasaka, Tsurugaoka and Yuragawa Complexes from north to south on the basis of lithologic assemblages, depositional ages and internal geologic structures.

(2) The Kowaki Complex consists of greenstones, cherts and clastic rocks of unknown age. The Yajiro and Natasyo Complexes are composed of predominant greenstones, limestones and cherts ranging from Late Carboniferous to Early Jurassic in age and minor amounts of Early to Middle Jurassic clastic rocks. The Hisasaka Complex consists of

Triassic to Early Jurassic cherts and Middle Jurassic clastic rocks with subordinate greenstones and limestones of unknown age. The Tsurugaoka and Yuragawa Complexes contain Triassic to Middle Jurassic cherts and Middle to Late Jurassic clastic rocks.

(3) The characteristic features of the complexes in the Wakasa area are regarded to be common throughout the Tamba Terrane, and therefore the standard seven units, Complexes A, B, C, D, E, F and G, are proposed.

(4) The Middle Jurassic Takashiroyama and Late Jurassic Furuya Formations as the slope basin deposits and the Late Jurassic Ajima and Takatsuki Formations as the forearc basin deposits, relative to the accretionary complexes of the Tamba Terrane, are also exposed. The former formations are exposed within the Jurassic accretionary complexes of the Tamba Terrane in fault contact and are intercalated into a continuum of the complex's arrangement. The latter formations accumulated directly on the Permian accretionary complex of the Ultra-Tamba Terrane.

(5) The Tamba Terrane exhibits a large scale thrust-imbricated structure which is composed of the tectonic pile of Complexes A, B, C, D, E, F and G in descending order and is folded with gently westward plunging axes.

(6) All complexes, although internally characterized by the chaotic mixture of various lithologies, had contained their own original stratigraphies which can be reconstructed on the basis of the interrelation between lithology and depositional age. The original stratigraphies begin with basal greenstones and limestones of seamount origin which are succeeded by a sequence from pelagic cherts to terrigenous clastic rocks.

(7) The accretionary times of sediments composing the original stratigraphies display a continuous spectrum, being oldest for Complex A to youngest for Complex G: it was Late Triassic for Complex A, late Early Jurassic for Complex B, middle Middle Jurassic for Complex C, middle to late Middle Jurassic for Complex D, late Middle Jurassic for Complex E, early Late Jurassic for Complex F and Latest Jurassic for Complex G. Thus, the complexes had continuously been formed through a multi-stages accretion and had grown by tectonically downward building.

(8) Seamount-chain subductions and their voluminous incorporation into Complexes C and D indicate that their effects might have played no important part in the formation of the Tamba Terrane, and had not disturbed the continuity of sediment accretion.

(9) Sediment accretion had occurred in spite of over 100 m.y. old oceanic crust subduction, forming the Tamba Terrane. It suggests that voluminous sediments within the subduction zone conquer the negative buoyancy of the old oceanic crust and can cause the accretion.

(10) The formation of the Tamba Terrane is probably ascribed to the Triassic to Jurassic inter-continental collisions and associated tectonic movements occurring in the Asian continent, which were possible to supply a great amount of sediments into the subduction zone.

Acknowledgement

I wish to express my grateful thanks to Associate Professor Akira YAO (Osaka City Univ.) for his critical reading of the manuscript and for his guidance and helpful suggestions in many aspects during the course of this study. I also express my thanks to Professor Masaru YOSHIDA (Osaka City Univ.) for his critical reading and advice. Special thanks are due to Associate Professor Tsutomu OTSUKA (Shinshu Univ.) for his critical reading and discussion on many aspects of this study. Sincere thanks are extended to Dr. Chikao KURIMOTO (Geol. Surv. Japan) for his critical reading and advice on geology of the Tamba Terrane and for permission to use his unpublished datum. I am thankful to the following: Drs. Katsumi KIMURA and Koji WAKITA (Geol. Surv. Japan) for their fruitful suggestion, Dr. Yasutaka HAYASAKA (Hiroshima Univ.) for advice on the origin of the greenstones, and Associate Professor Katsuhiko FURUYAMA (Osaka City Univ.) and Mr. Seiichiro MITSUI (Power Reactor and Nuclear Fuel Development Corporation) for discussion on the origin of the greenstones and their help with the chemical analysis.

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