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Lithology and radiolarian age of the Hidakagawa Sub-belt of the Shimanto Belt in the western Kii Peninsula, southwest Japan

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ABSTRACT

This study focuses on the lithology and radiolarian age of the Hidakagawa Sub-belt in the Shimanto Belt, Southwest Japan. The rocks of the Hidakagawa Sub-belt are divided into the Unit 1 consisting of only terrigenous deposits and Unit 2 consisting of terrigenous deposits with chert and red shale. The Unit 1 is subdivided into the Sub-unit 1A composed largely of thick-bedded sandstone with unknown age and Sub-unit 1B composed largely of late Albian to late Cenomanian sandstone-rich alternating beds of sandstone and shale. The Unit 2 is subdivided into the Sub-unit 2A composed largely of early Coniacian shale-rich alternating beds of sandstone and shale with mixed rock including sandstone, chert, and red shale, and Sub-unit 2B composed largely of latest Santonian to early Campanian thick-bedded sandstone with mixed rock including sandstone and red shale.

On the basis of lithology, radiolarian age, and stratigraphic position, the Sub-units 1A and 1B are correlated to the Y3 and Y1 Members of Yukawa Formation in the central Kii Peninsula, and they can be correlated with the Ogui and Nagasaki Sub-units of Yukawa Unit in the coastal area of Kii Peninsula, respectively. The Sub-unit 2A and 2B correspond to the M1 and M2b Members of Miyama Formation in the central Kii Peninsula, and these sub-units can be correlated with the Karakozaki and Chidenohana Sub-units of Miyama Unit in the coastal area of Kii Peninsula, respectively.

INTRODUCTION

The Shimanto Belt is composed mainly of Cretaceous to Middle Miocene accretionary complexes (e.g. Kanmera and Sakai, 1975; Taira, 1985; Taira *et al.*, 1982, 1988). Detailed mapping and radiolarian biostratigraphic studies have advanced our understanding of accretionary complexes which are commonly composed of numbers of tectonostratigraphic units characterized by pile-nappe structure or imbricated fan structure (e.g. Taira *et al.*, 1980; Sakai and Kanmera, 1981; Kumon *et al.*, 1988). In particular, the radiolarian age of trench-fill terrigenous sedimentary rocks is important to make the correlation of the accretionary complexes, because it makes it possible to determine the age of accretion (e.g. Nakae, 2000). However, there is little agreement

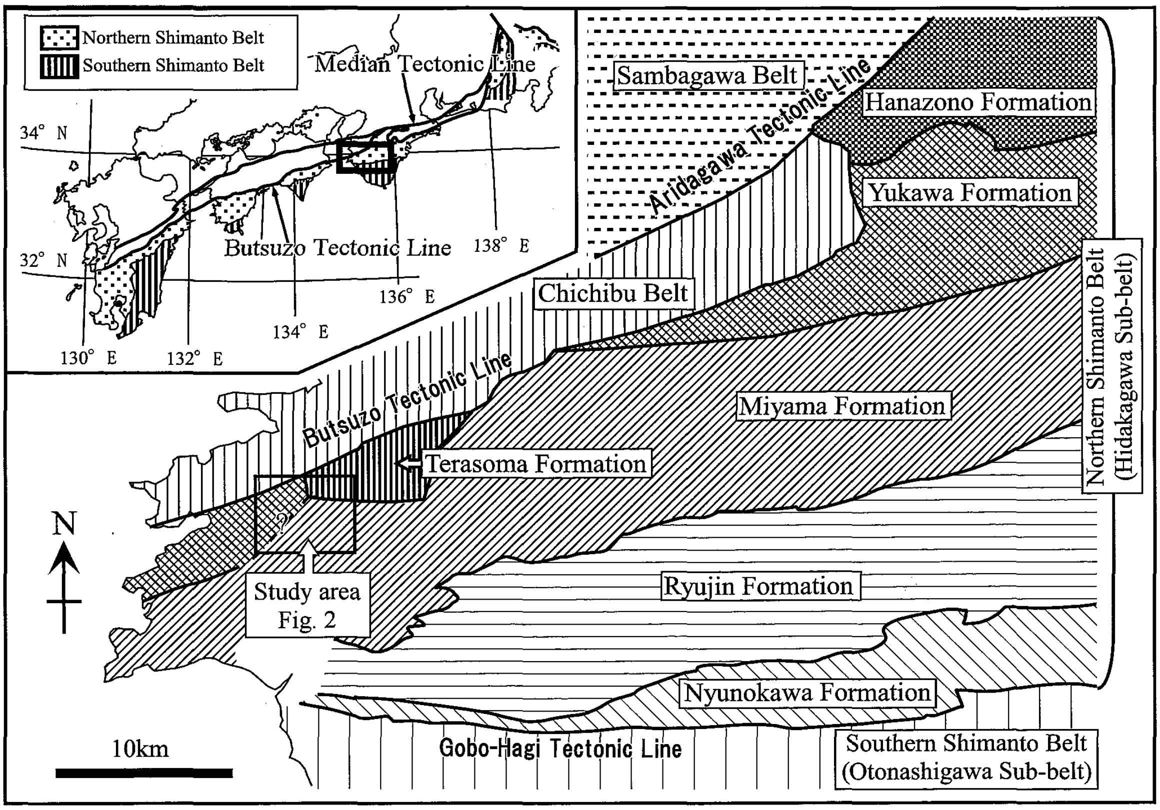

Fig. 1 Distribution of the Shimanto Belt in the western Kii Peninsula, Southwest Japan (modified from Kishu Shimanto Research Group, 1986, 2006).

on the correlation of the units in the Shimanto Belt, because detailed lithology and age in some areas have not been revealed precisely.

The study area is located at the western Kii Peninsula, Southwest Japan (Fig. 1), and occupied by the Northern Shimanto Belt named Hidakagawa Sub-belt. Although a few lithology and radiolarian studies were reported (Tatebayashi, 1930; Hashimoto, 1968; Morozumi, 1970; Kishu Shimanto Research Group, 1983), detailed lithology, age and regional correlation of these formations are still controversial. In this paper, lithology and radiolarian fossils of the Hidakagawa Sub-belt in the western Kii Peninsula are described in detail.

GEOLOGICAL OUTLINE

The Shimanto Belt in Kii Peninsula is divided into the northern Cretaceous Hidakagawa, the southern Paleogene Otonashigawa and Muro Sub-belts (Kumon *et al.*, 1988). The Sambagawa and Chichibu Belts to the north of the Hidakagawa Sub-belt are in fault contact with the Aridagawa and Butsuzo Tectonic Lines, respectively (Kumon *et al.*, 1988; Kurimoto, 1994) (Fig. 1). The Hidakagawa Sub-belt is limited by the Gobo-Hagi Tectonic Line in the southern end, and in contact with the Otonashigawa Sub-belt (Kumon *et al.*, 1988).

The Hidakagawa Sub-belt is divided into six formations from north to south: the Hanazono (Coniacian~late Campanian), Yukawa (Albian~Cenomanian), Terasoma

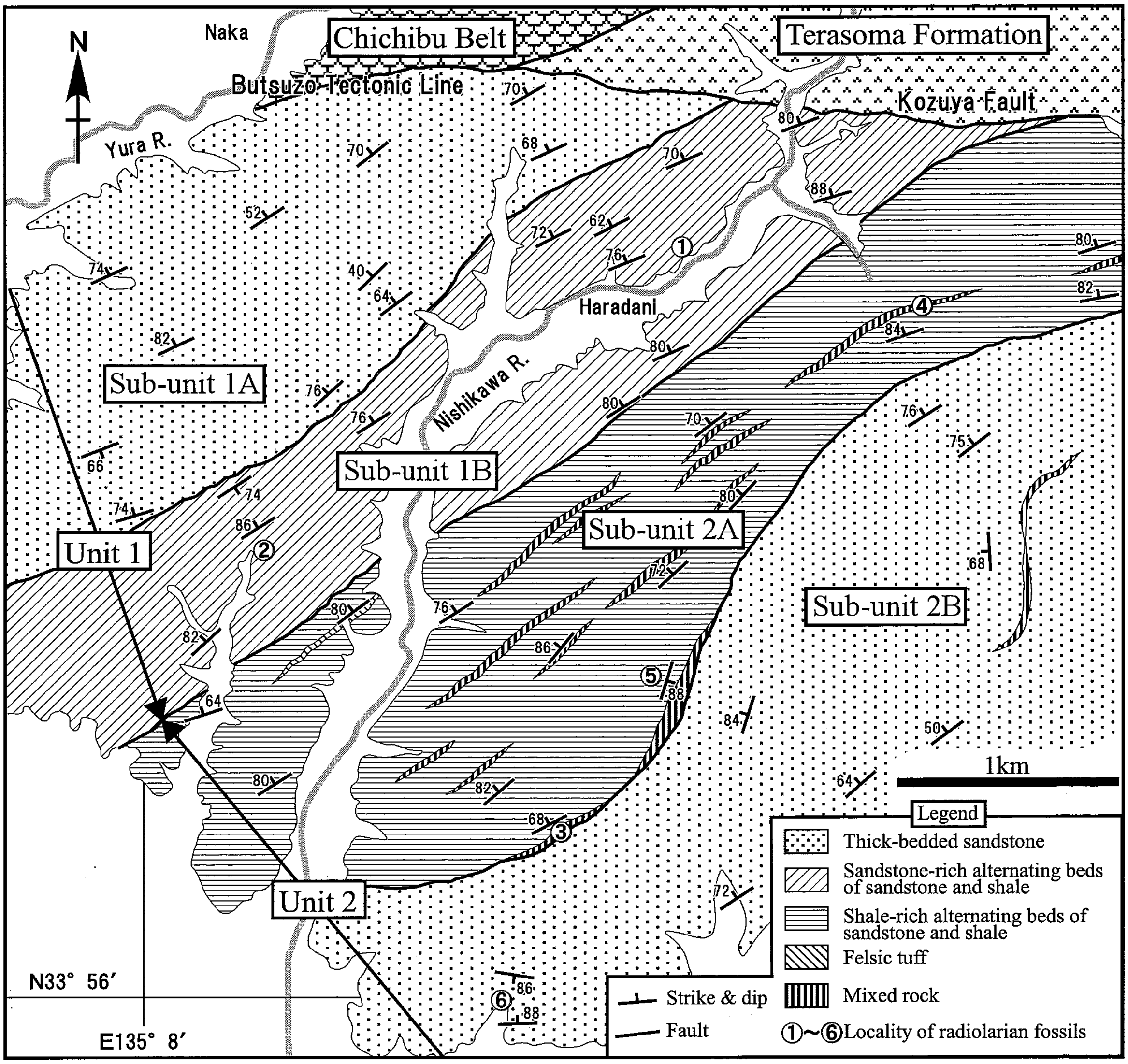

Fig. 2 Geological map of the study area with radiolarian fossil localities. Location is shown in Fig. 1.

(Turonian~Santonian), Miyama (Turonian~late Campanian), Ryujin (late Campanian), and Nyunokawa (late Campanian?) Formations (Kishu Shimanto Research Group, 1983, 1986, 1991, 2006; Kimura, 1986; Kurimoto, 1982, 1994; Kumon *et al.*, 1988; Hollis and Kimura, 2001; Tokiwa *et al.*, 2005). Among them, the Yukawa, Terasoma and Nyunokawa Formations are referred to as slope-basin deposits, whereas the Hanazono, Miyama and Ryujin Formations are regarded as subduction-related accretionary complexes (Kumon *et al.*, 1988).

The study area is situated at the western part of the Hidakagawa Sub-belt. Rocks of the Hidakagawa Sub-belt in this area were already divided into the sandstone-dominant part at northern side and shale-dominant part at southern side (Hashimoto, 1968; Morozumi, 1970). The rocks of the Hidakagawa Sub-belt in this area are in contact with the Kamiya Formation of the Chichibu Belt by the Butsuzo Tectonic Line in the western part and the Terasoma Formation by the Kozuya Fault in the eastern part.

On the basis of our field survey, the Hidakagawa Sub-belt in the study area is divided into the two units from their lithology (Fig. 2). Furthermore, each unit is subdivided into two sub-units.

GEOLOGY

The rocks in the study area can be classified into two units, based upon existence of mixed rock including sandstone, chert, and red shale, and main constituent rock. Unit 1 is located at the north side of Unit 2, and is subdivided into Sub-unit 1A, composed largely of thick-bedded sandstone and Sub-unit 1B, composed largely of sandstone-rich alternating beds of sandstone and shale. Both of these two sub-units are lack of mixed rock including chert and red shale. On the other hand, Unit 2 is subdivided into Sub-unit 2A, composed largely of shale-rich alternating beds of sandstone and shale with mixed rock including sandstone and red shale, and Sub-unit 2B, composed largely of thick-bedded sandstone with mixed rock (Fig. 2). The bedding planes of these units strike ENE-WSW to NE-SW and steeply dip northward. Each of the unit and sub-unit is in fault contact with each other.

Sub-unit 1A

Sub-unit 1A is composed largely of thick-bedded sandstone with minor amounts of alternating beds of sandstone and shale, and conglomerate (Fig. 3a). The thick-bedded sandstone is commonly medium- to coarse-grained and partly intercalates very coarse-grained sandstone. The very coarse-grained sandstone gradually changes into granule conglomerate in some places. The sandstone locally includes shale patches of several millimeters in size of major axis. Graded bedding and cross or parallel laminations are partly developed in the sandstone of the alternating beds. Sandstone in this sub-unit is composed of feldspathic wacke, and contains quartz, plagioclase, K-feldsper, and felsic to intermediate volcanic rock fragments (Fig. 3b).

Sub-unit 1B

Sub-unit B is composed largely of alternating beds of sandstone and shale with minor amounts of thick-bedded sandstone, felsic tuff and conglomerate. The alternating beds generally consist of 20 cm to 1 m thick medium- to coarse-grained sandstone layers and 1 to 20 cm thick shale layers (Fig. 3c). Some alternating beds of sandstone and shale are rich in shale; 20 to 50 cm thick shale layers and 1 to 30 cm thick fine- to medium-grained sandstone layers. The alternating beds of sandstone and shale are locally broken and show pinch and swell structure. The sandstone partly includes shale patches of several millimeters in size of major axis. Graded bedding and cross or parallel laminations are partly developed in the sandstone. Sandstone in this sub-unit is similar to sandstone of the Sub-unit 1A, which is composed of feldspathic wacke and contains quartz, plagioclase, K-feldsper, and felsic to intermediate volcanic rock fragments. Shale in this sub-unit consists mainly of fine-grained clay minerals, biotite, muscovite, chlorite, quartz, feldspar, opaque minerals and organic material (Fig. 3d). The quartz grains in the shale are less than 0.05 mm in diameter.

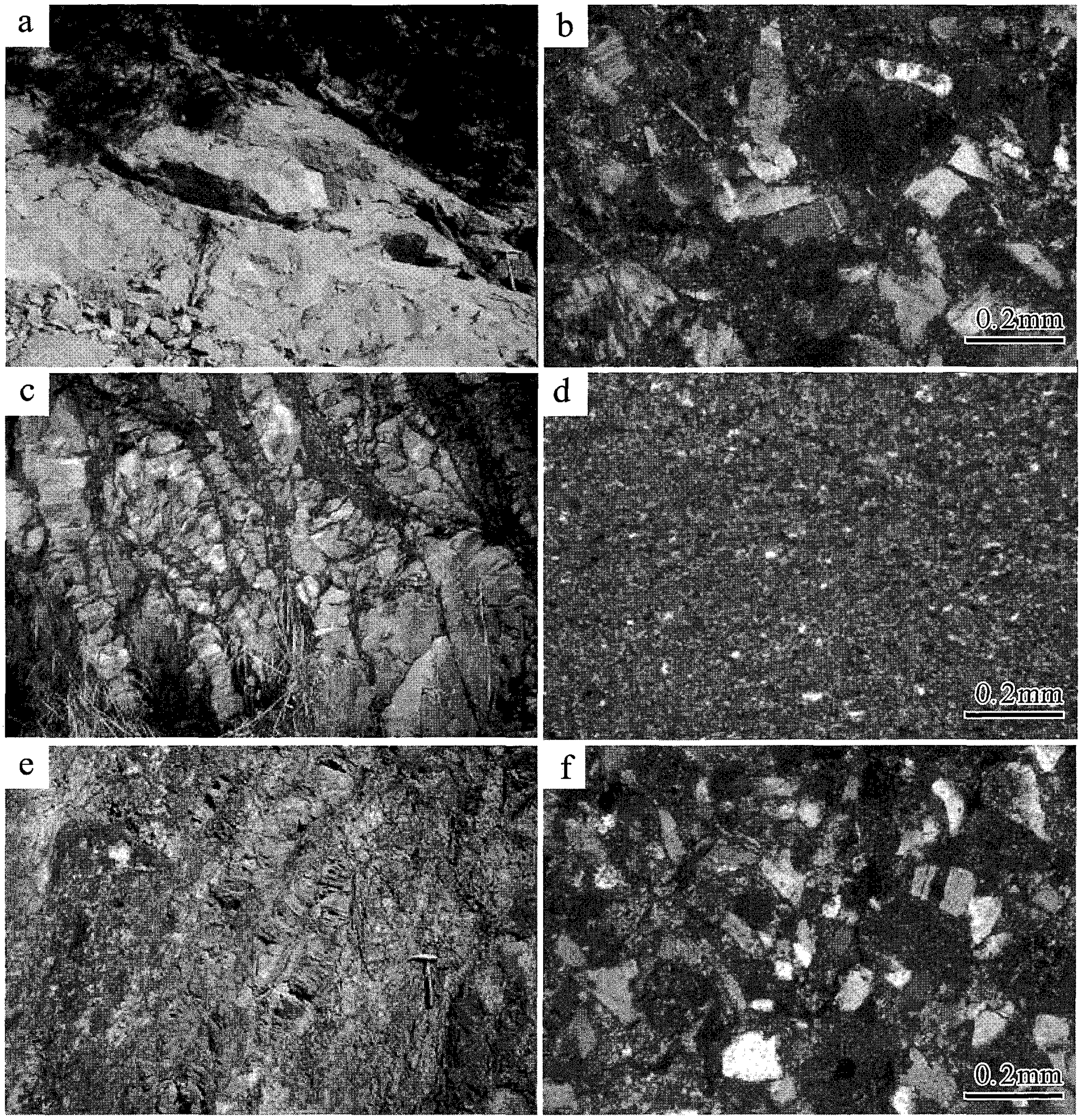

Fig. 3 Photographs (a, c, e) and photomicrographs (b, d, f) of the rocks in the study area. (a) Thick-bedded sandstone of the Sub-unit 1A. (b) Feldspathic wacke sandstone of the Sub-unit 1A. This sandstone consists largely of quartz and plagioclase grains. Crossed polarized lights. (c) Sandstone-rich alternating beds of sandstone and shale of the Sub-unit 1B. (d) Shale of the alternating beds of sandstone and shale in the Sub-unit 1B. Crossed polarized lights. (e) Shale-rich alternating beds of sandstone and shale of the Sub-unit 2A. (f) Lithic wacke sandstone of the Sub-unit 2A. This sandstone consists largely of quartz grains and volcanic fragments with plagioclase. Crossed polarized lights.

Sub-unit 2A

Sub-unit 2A is characterized by alternating beds of sandstone and shale, and mixed rock including sandstone, chert, and red shale. This sub-unit is rarely accompanied with thick-bedded sandstone.

In the alternating beds of sandstone and shale, shale layers are thicker than sandstone ones (Fig. 3e), 20 to 50 cm thick shale layers and 1 to 40 cm thick fine- to

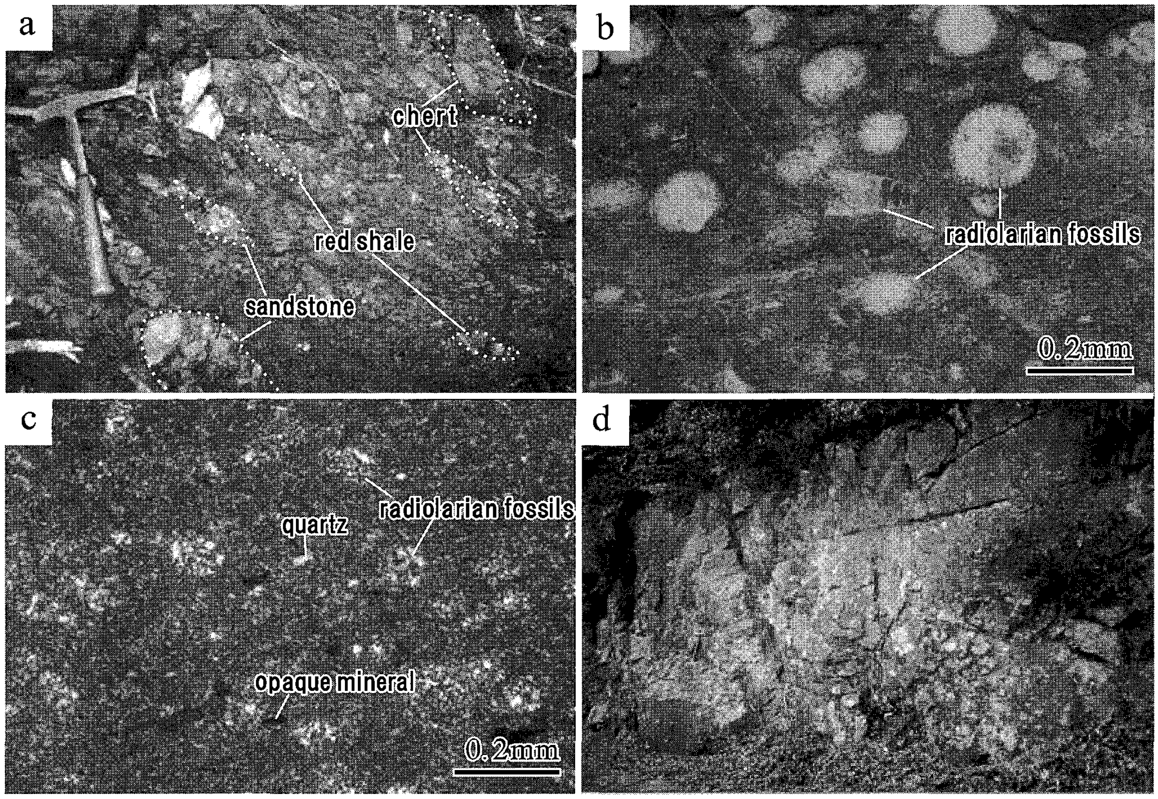

Fig. 4 Photographs (a, d) and photomicrographs (b, c) of the rocks in the study area. (a) Mixed rock of the Sub-unit 2A. This mixed rock includes chert, red shale and sandstone clasts in a matrix of shale. (b) Photomicrograph of chert from the Sub-unit 2A. This chert includes abundant radiolarian fossils. Parallel polarized lights. (c) Photomicrograph of red shale from Sub-unit 2A. This shale includes radiolarian fossils and quartz grains. Crossed polarized lights. (d) Thick-bedded sandstone of the Sub-unit 2B.

medium-grained sandstone layers. Alternating beds of 20 cm to 1 m thick medium- to coarse sandstone and 1 to 20 cm thick shale are locally observed. The sandstone partly includes shale patches of several millimeters in size of major axis. The alternating beds of sandstone and shale are commonly broken and show block-in-matrix structure (Fig. 3e). The alternating beds rarely show sedimentary structures such as graded bedding and lamination. The foliation defined by an alignment of scaly cleavage can be observed in the shale of alternating beds of sandstone and shale. Sandstone in this sub-unit is lithic wacke and contains quartz, plagioclase, K-feldsper, and abundant felsic to intermediate volcanic rock fragments (Fig. 3f). Shale in this sub-unit consists mainly of fine-grained clay minerals, biotite, muscovite, chlorite, quartz, feldspar, opaque minerals and organic material. The quartz grains of the shale are less then 0.05 mm in diameter.

The mixed rock includes clasts of sandstone, chert, red shale and felsic tuff in a matrix of black shale (Fig. 4a). The clasts are lenticular in shape, and their major axis ranges from a few millimeters to several tens of meters. Scaly cleavage develops in the matrix of black shale. The chert consists of microquartz and yields radiolarian fossils (Fig. 4b). The red shale includes radiolarian fossils, grains of quartz, and opaque minerals in a fine-grained matrix of quartz (Fig. 4c). Most of grains are less than 0.04 mm in size.

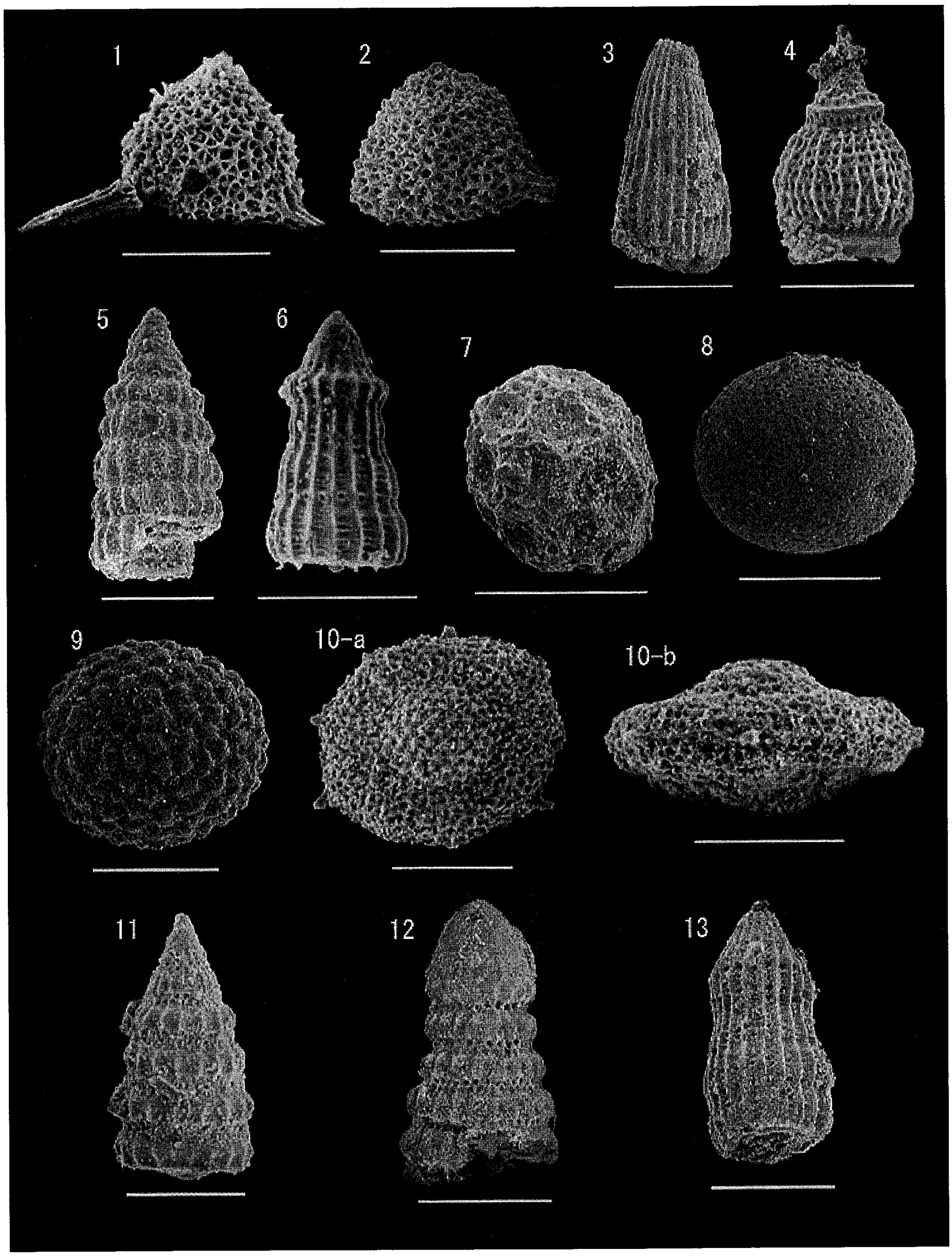

Fig. 5 SEM photographs of the Cretaceous radiolarian fossils from the study area. Each scale bar represents 100 µm. 1: *Alievium* cf. *superbum* Squinabol (Loc. 5). 2: *Alievium* sp. (Loc. 4). 3: *Archaeodictyomitra* sp. (Loc. 4). 4: *Artostrobium* sp. (Loc. 5). 5: *Dictyomitra formosa* Squinabol (Loc. 5). 6: *Dictyomitra koslovae* Foreman (Loc. 6). 7: *Hemicryptocanium polyhedra* Dumitrica (Loc. 4). 8: *Holocryptocanium barbui* Dumitrica (Loc. 1). 9: *Holocryptocanium geysersense* Pessagno (Loc. 1). 10: *Pseudoaulophacus lenticulatus* (White) (Loc. 6). a: apical view, b: lateral view. 11: *Pseudodictyomitra* cf. *carpatica* (Lozyniak) (Loc. 3). 12: *Pseudodictyomitra pseudomacrocephala* (Squinabol). 13: *Thanarla veneta* (Squinabol) (Loc. 4).

Sub-unit 2B

Thick-bedded sandstone is the representative constituent rock in this sub-unit (Fig. 4d), and mixed rock is minor constituent rock. This sub-unit is rarely accompanied with disrupted alternating beds of sandstone and shale.

The sandstone of thick-bedded sandstone is commonly medium- to coarse-grained and partly intercalates very coarse-grained sandstone. The sandstone locally includes shale patches of several millimeters in size of major axis. Graded bedding and cross or parallel laminations are partly developed in the sandstone. Sandstone in this sub-unit is similar to the sandstone of Sub-unit 2A, composed of lithic wacke and contains quartz, plagioclase, K-feldsper, and abundant felsic to intermediate volcanic rock fragments. Grains and rock fragments in the sandstone are poorly rounded, and the latter are relatively rich in this sub-unit.

The mixed rock includes clasts of sandstone, red shale and felsic tuff in a matrix of black shale. The clasts are lenticular in shape, and their major axis ranges from a few millimeters to several meters. Scaly cleavage developed in the matrix of black shale. The red shale consists of radiolarian fossils, grains of quartz and opaque minerals in a matrix of microquartz. Most of grains are less than 0.04 mm in size.

RADIOLARIAN FOSSILS AND THEIR AGE

Radiolarian fossils are obtained from black shale of the Sub-units 1B, 2A and 2B, and clasts of chert and red shale in the Sub-unit 2A. The identified radiolarian species are listed in Table 1 and SEM photographs of representative species are shown in Fig. 5. Age assignments of samples are shown in Fig. 6.

Table 1 A list of radiolarian fossils from the study area.
bs: black shale, ch: chert, rs: red shale.

Unit	1B		2A			2B
Locality	1	2	3	4	5	6
Lithology	bs	bs	ch	rs	bs	bs
Alievium superbum Squinabol					○	
Alievium sp.				●	●	●
Archaeodictyomitra sp.	●	●	●	●		●
Artostrobium sp.					●	
Dictyomitra formosa Squinabol					●	●
Dictyomitra koslovae Foreman						●
Hemicryptocapsa polyhedra Dumitrica	●	●		●		
Holocryptocanium barbui Dumitrica	●	●	●	●		
Holocryptocanium geysersense Pessagno	●	●		●		
Pseudoaulophacus lenticulatus (White)					●	●
Pseudodictyomitra carpatica (Lozyniak)			○			
Pseudodictyomitra pseudomacrocephala (Squinabol)				●		
Thanarla veneta (Squinabol)				●		

○: confer

Sub-unit 1B

Radiolarian fossils are obtained from black shale of the alternating beds of sandstone and shale in Locs. 1 and 2.

Locs. 1 and 2: Black shales in these two localities yield *Archaeodictyomitra* sp., *Hemicryptocapsa polyhedra*, *Holocryptocanium barbui*, and *H. geysersense*. The latter three indicate late Albian to late Coniacian (Schaaf, 1985; Taketani, 1995), late Berriasian to late Cenomanian (Baumgartner *et al.*, 1995; Taketani, 1995) and late Albian to late Cenomanian in age (Yao, 1984; Taketani, 1995), respectively. Thus, the alternating beds of sandstone and shale in Locs. 1 and 2 are considered to be late Albian to late Cenomanian. Judging from the fossil data, the age of the Sub-unit 1B is considered to be late Albian to late Cenomanian.

Sub-unit 2A

Radiolarian fossils are obtained from the lenticular chert clast in Loc. 3, lenticular red shale clast in Loc. 4, and the black shale of the alternating beds of sandstone

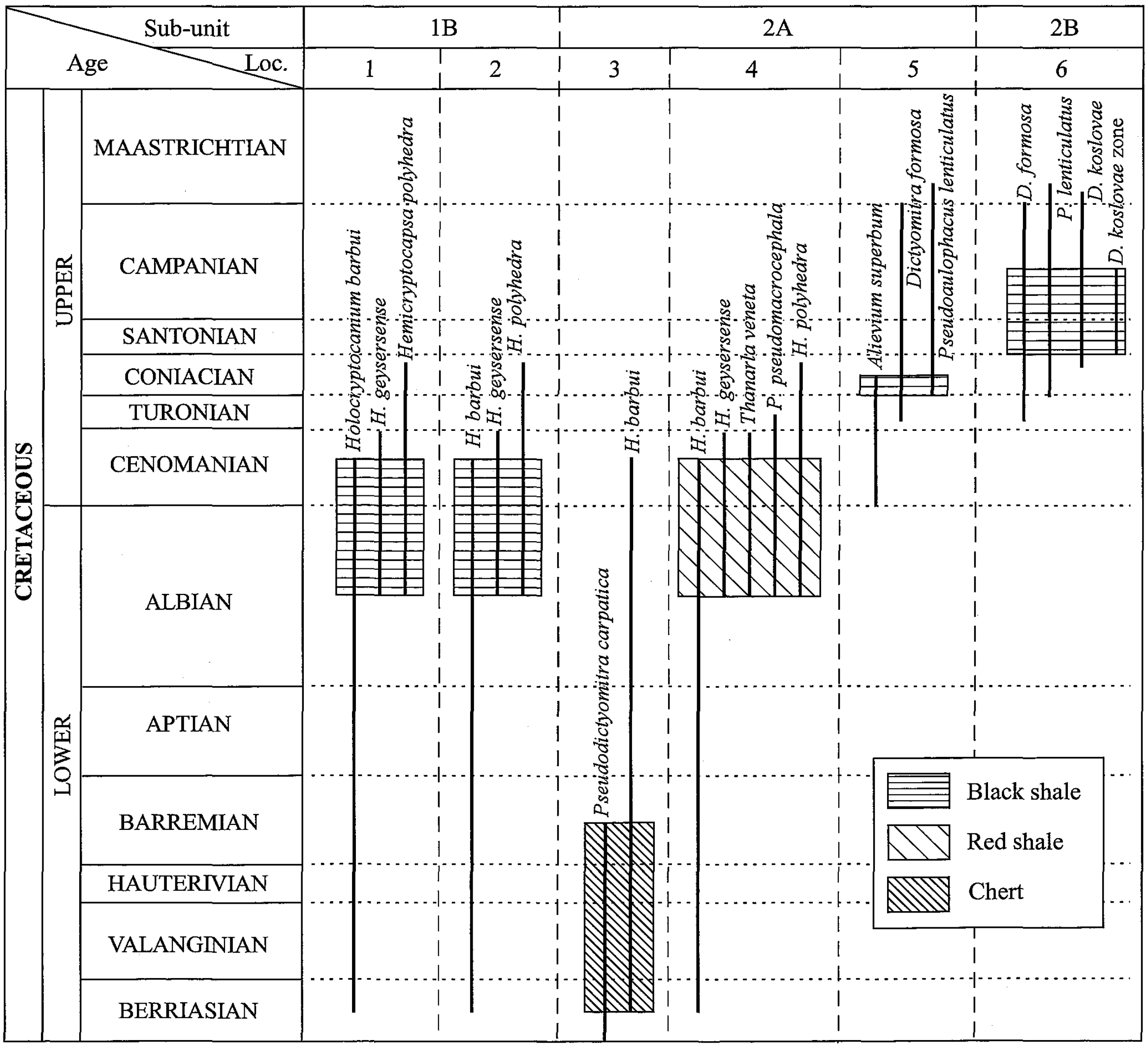

Fig. 6 Ages of samples. Localities are shown in Fig. 2.

and shale in Loc. 5.

Loc. 3: The chert in this locality yields *Archaeodictyomitra* sp., *Holocryptocanium barbui*, and *Pseudodictyomitra* cf. *carpatica*. *P. carpatica* indicates late Kimmeridgian to early Barremian in age (Baumgartner *et al.*, 1995), and *H. barbui* has its first appearance in the late Berriasian. Thus, the chert in Loc. 3 is considered to be late Berriasian to late Barremian.

Loc. 4: Red shale in this locality yields *Alievium* sp., *Archaeodictyomitra* sp., *Hemicryptocapsa polyhedra*, *Holocryptocanium barbui*, *H. geysersense*, *Pseudodictyomitra pseudomacrocephala*, and *Thanarla veneta*. Among these radiolarians, *H. geysersense*, *T. veneta*, *P. pseudomacrocephala* and *H. polyhedra* have their first appearance in the late Albian (Shaaf, 1985; O'Dogherty, 1994; Taketani, 1995). According to Taketani (1995), *H. barbui* has its last occurrence in the late Cenomanian. Therefore, we conclude that the age of this red shale ranges from late Albian to late Cenomanian.

Loc. 5: Black shale in this locality yields *Alievium* cf. *superbum*, *Alievium* sp., *Altostrobium* sp., *Dictyomitra formosa*, and *Pseudoaulophacus lenticulatus*. According to Taketani (1995) and Hollis and Kimura (2001), *A. superbum*, *D. formosa* and *P. lenticulatus* indicate Cenomanian to early Coniacian, early Turonian to Campanian, Coniacian to ealiest Maastrichtian in age, respectively. Thus, the alternating beds of sandstone and shale in Loc. 5 and this sub-unit are considered to be early Coniacian.

Sub-unit 2B

Radiolarian fossils are obtained from black shale of the alternating beds of sandstone and shale in Loc. 6.

Loc. 6: Black shale in this locality yields *Alievium* sp., *Archaeodictyomitra* sp., *Dictyomitra formosa*, *D. koslovae*, and *Pseudoaulophacus lenticulatus*. According to Taketani (1995) and Hollis and Kimura (2001), *D. formosa*, *D. koslovae* and *P. lenticulatus* are assigned to the ages from early Turonian to Campanian, latest Coniacian to earliest Maastrichtian, Coniacian to ealiest Maastrichtian, respectively. On the other hand, it is quite likely that the black shale is Santonian to early Campanian, considering that this black shale includes abundant *D. koslovae* which is the characteristic species of the *Dictyomitra koslovae* zone (Santonian to early Campanian; Hollis and Kimura, 2001). We conclude that the age of the alternating beds of sandstone and shale in Loc. 6 is considered to be Santonian to early Campanian. Therefore, this sub-unit is considered to be Santonian to early Campanian.

CORRELATION

The rocks in the study area can be divided into two units based on their lithology. The Unit 1 is characterized by sandstone dominant facies such as thick-bedded sandstone and sandstone-rich alternating beds of sandstone and shale without mixed rock. The sandstone in this unit is feldspathic wacke. Moreover, the Unit 1 yields late Albian to late Cenomanian radiolarian fossils. Thus, the Unit 1 can be correlated to the Yukawa Formation. On the other hand, the Unit 2 is composed of early

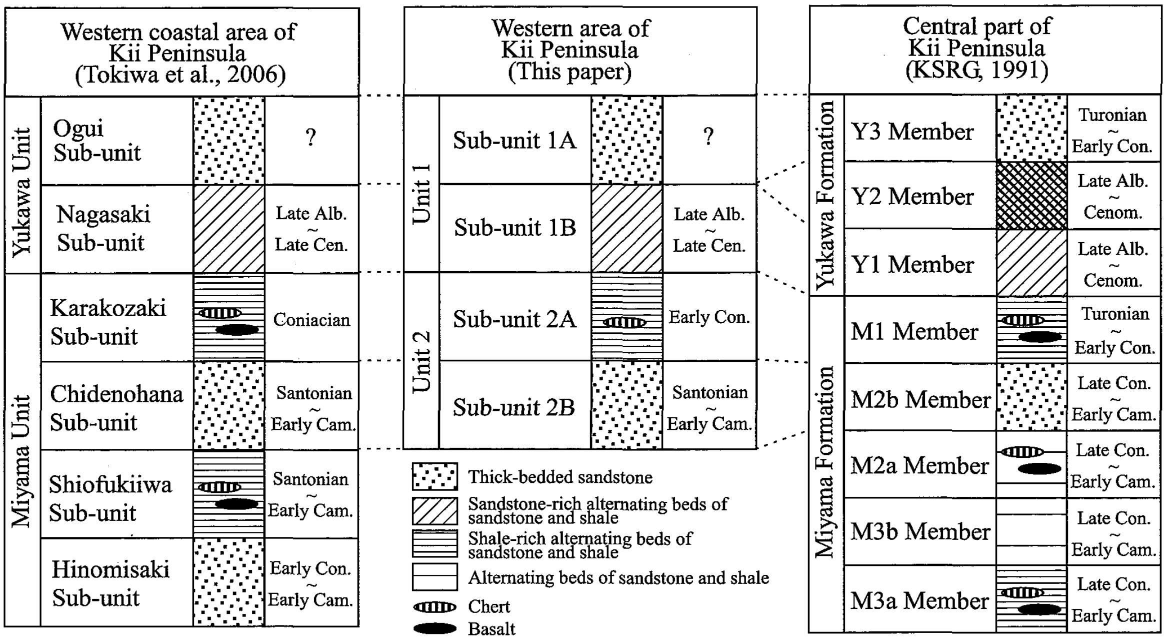

Fig. 7 Correlation of the Hidakagawa Sub-belt among the western coastal, western and central areas of the Kii Peninsula. KSRG: Kishu Shimanto Research Group.

Coniacian shale-rich alternating beds of sandstone and shale, and Santonian to early Campanian thick-bedded sandstone with mixed rock including sandstone, chert, and red shale. Therefore, the Unit 2 can be correlated to the Miyama Formation in view of lithological features and radiolarian age (Fig. 7).

According to Kishu Shimanto Research Group (1991), the Yukawa Formation in the central part of Kii Peninsula is subdivided into following members from north to south; Y3 Member consisting largely of Turonian to early Coniacian thick-bedded sandstone, Y2 Member consisting largely of late Albian to Cenomanian shale and pebbly mudstone, Y1 Member consisting largely of late Albian to Cenomanian sandstone-rich alternating beds of sandstone and shale. The Miyama Formation is also subdivided into five members from the north to the south; M1 Member consisting largely of Turonian to early Coniacian shale-rich alternating beds of sandstone and shale, M2b Member consisting largely of late Coniacian to early Campanian thick-bedded sandstone, M2a Member consisting mainly of late Coniacian to early Campanian alternating beds of sandstone and shale, M3b Member consisting mainly of late Coniacian to early Campanian alternating beds of sandstone and shale, and M3a Member consisting largely of Coniacian to Campanian shale-rich alternating beds of sandstone and shale.

In the western coastal area of Kii Peninsula, the Yukawa Formation and Miyama Formation have been correlated to the Yukawa Unit and Miyama Unit, respectively, according to Tokiwa *et al.* (2006). Moreover, the Yukawa Unit is subdivided into two sub-units; the Ogui Sub-unit composed largely of age-unknown thick-bedded sandstone and the Nagasaki Sub-unit composed largely of late Albian to late Cenomanian sandstone-rich alternating beds of sandstone and shale. The Miyama Unit is subdivided into four sub-units from the north to the south; the Karakozaki Sub-unit composed largely of Coniacian shale-rich alternating beds of sandstone and shale, the Chidenohana Sub-unit with Santonian to early Campanian thick-bedded sandstone, the Shiofukiiwa Sub-unit composed largely of Santonian to early Campanian shale-rich alternating beds of sandstone and shale, and the Hinomisaki Sub-unit of early Coniacian to early Campanian thick-bedded sandstone.

On the basis of lithology and stratigraphic position, the Sub-units 1A and 1B of this study area are correlated to the Y3 and Y1 Members of Yukawa Formation in the central Kii Peninsula, and these sub-units can also be correlated with the Ogui and Nagasaki Sub-units of Yukawa Unit in the coastal area of Kii Peninsula, respectively. The Sub-units 2A and 2B correspond to the M1 and M2b Members of Miyama Formation in the central Kii Peninsula, and then, these sub-units can be correlated with the Karakozaki and Chidenohana Sub-units of Miyama Unit in the coastal area of Kii Peninsula, respectively.

SUMMARY

This study focuses on the lithology and radiolarian age of the Hidakagawa Sub-belt in the Shimanto Belt, Southwest Japan. The results are as follows.

(1) The rocks of the Hidakagawa Sub-belt are divided into the Units 1 and 2. Unit 1 is subdivided into Sub-unit 1A (thick-bedded sandstone) and Sub-unit 1B (sandstone-rich alternating beds of sandstone and shale). Unit 2 is subdivided into Sub-unit 2A (shale-rich alternating beds of sandstone and shale with mixed rock including sandstone, chert, and red shale) and Sub-unit 2B (thick-bedded sandstone with mixed rock including sandstone and red shale).

(2) Radiolarian fossils show that the Sub-units 1B, 2A and 2B are considered to be the late Albian to late Cenomanian, early Coniacian, and Santonian to early Campanian, respectively.

(3) On the basis of lithology and stratigraphic position, the Sub-units 1A and 1B of this study area are correlated to the Y3 and Y1 Members of Yukawa Formation in the central Kii Peninsula, and they can be correlated with the Ogui and Nagasaki Sub-units of Yukawa Unit in the coastal area of Kii Peninsula, respectively. The Sub-units 2A and 2B correspond to the M1 and M2b Members of Miyama Formation in the central Kii Peninsula, and these sub-units can be correlated with Karakozaki and Chidenohana Sub-units of Miyama Unit in the coastal area of Kii Peninsula, respectively.

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