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Cretaceous radiolarian fossils from the Ryujin Formation of the Shimanto Belt in the Kawabe area, Wakayama Prefecture, southwest Japan

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ABSTRACT

This study is focused on radiolarian fossils newly found from the Ryujin Formation of the Shimanto Belt, southwest Japan. The Ryujin Formation is an accretionary complex, which is divided into three tectonostratigraphic units; structurally from lower to upper; the Disrupted sandstone and shale (Rl) Unit, the Greenstone-shale (Rm) Unit and the Tuff-shale (Ru) Unit. Due to scarce findings of radiolarian fossils, there had been very little age data from this formation. The present study based on radiolarian defined the detailed age of each unit of the Ryujin Formation as follows; 1) the Rl Unit is the late Campanian, 2) the Rm Unit is roughly correlated with the middle Santonian to earliest Maastrichtian, 3) the Ru Unit is confirmed as late Campanian in age by several newly discovered radiolarian fossils regarded as the *Amphipyndax tylotus* interval zone. Results of the present study have confirmed that the Rm Unit, widely distributing in the Kawabe area, is characterized not by imbricated thrust structure but by the prevalence of folded structure.

INTRODUCTION

The Shimanto Belt in southwest Japan is worldwide famous ancient accretionary complex of Cretaceous to Middle Miocene in age (e.g. Kanmera and Sakai, 1975; Taira, 1985; Taira *et al.*, 1982 and 1988). Accretionary complexes are commonly composed of numbers of tectonostratigraphic units characterized by pile-nappe structure or imbricated fun structure. These units are bounded by thrust faults each other and become younger structurally downward (e.g. Taira *et al.*, 1980; Sakai and Kanmera, 1981; Kumon *et al.*, 1988). The division of each tectonostratigraphic unit is mainly based on occurrence of thrust faults and radiolarian fossil ages. Under a humid climate of Japanese Islands, thick vegetation prevents the recognition of thrust faults. Therefore, the age assignment based on radiolarian fossils is the inevitable work for Japanese geologists engaging in the study of accretionary complex.

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

The Miyama Formation is a typical accretionary complex which is characterized by northward-dipping imbricated structure consisting of three regional-scale thrust sheets (named M1, M2 and M3 Units). Each thrust sheet is composed of the lower mélange containing blocks of oceanic rocks, and the upper terrigeneous trench deposits. The geologic age of both exotic blocks and trench deposits of each thrust sheet

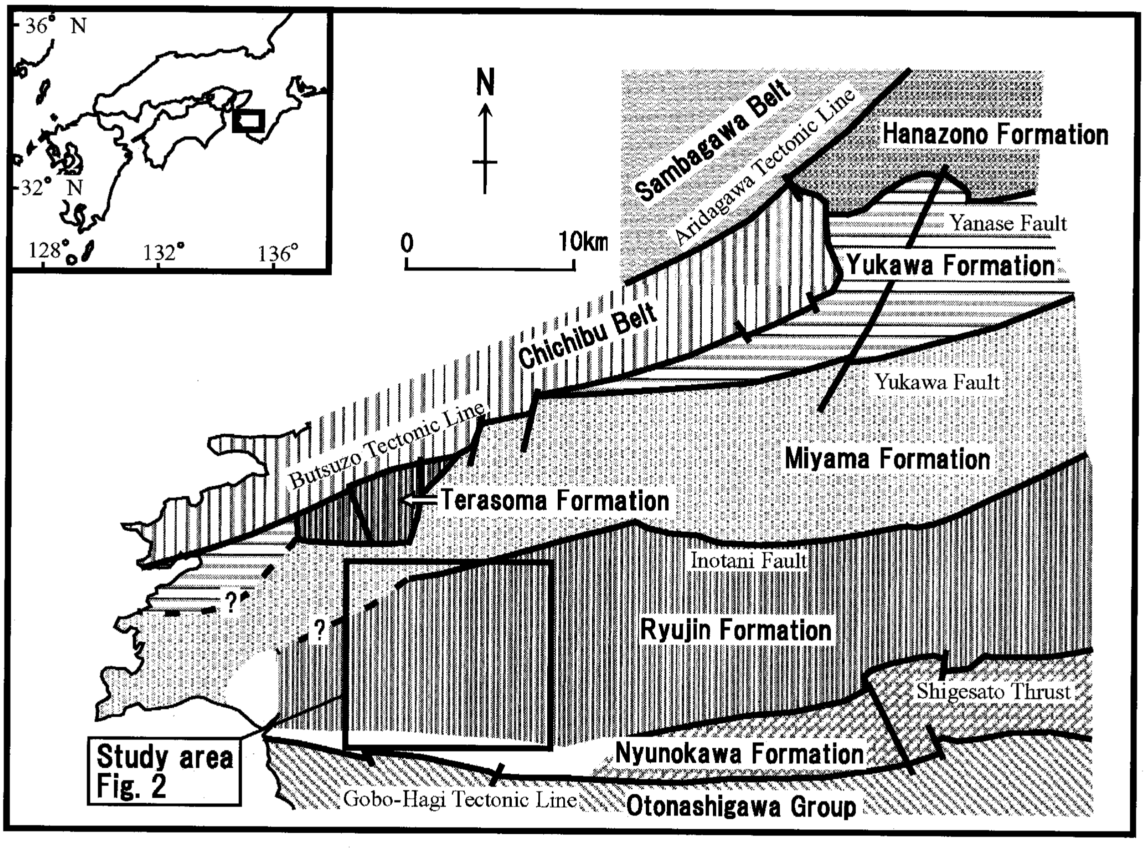

Fig. 1. Generalized geologic map of the northern Shimanto Belt (Hidakagawa Sub-belt) in the western Kii Peninsula, Southwest Japan (modified from Kishu Shimanto Research Group, 1986), and the study area.

has been precisely determined by abundant radiolarian fossils. Each thrust sheet represents an almost complete oceanic plate stratigraphy (Kishu Shimanto Research Group, 1991). Furthermore, the thrust sheets as a whole, show a clear tectonically downward-younging polarity. Recently, Kishu Shimanto Research Group (submitted) has reported the occurrence of the late Campanian M4 Unit to the southern most end of the Miyama Formation.

The Ryujin Formation is composed of the Disrupted sandstone and shale (Rl) Unit, the Greenstone-shale (Rm) Unit and the Tuff-shale (Ru) Unit (Kishu Shimanto Research Group, submitted) (Fig. 2). While the Rl Unit is in fault contact with the Rm Unit, Rm Unit is overlain conformably by the Ru Unit. The lithological succession of the Rm and Ru Units indicates oceanic plate stratigraphy, so that the Ryujin Formation is considered to be an accretionary complex (Kishu Shimanto Research Group, submitted). Imbricate structure is ill-developed and primary stratigraphic succession is well preserved. While the Rl Unit and Rm Unit are repeated several times by thrusut faults

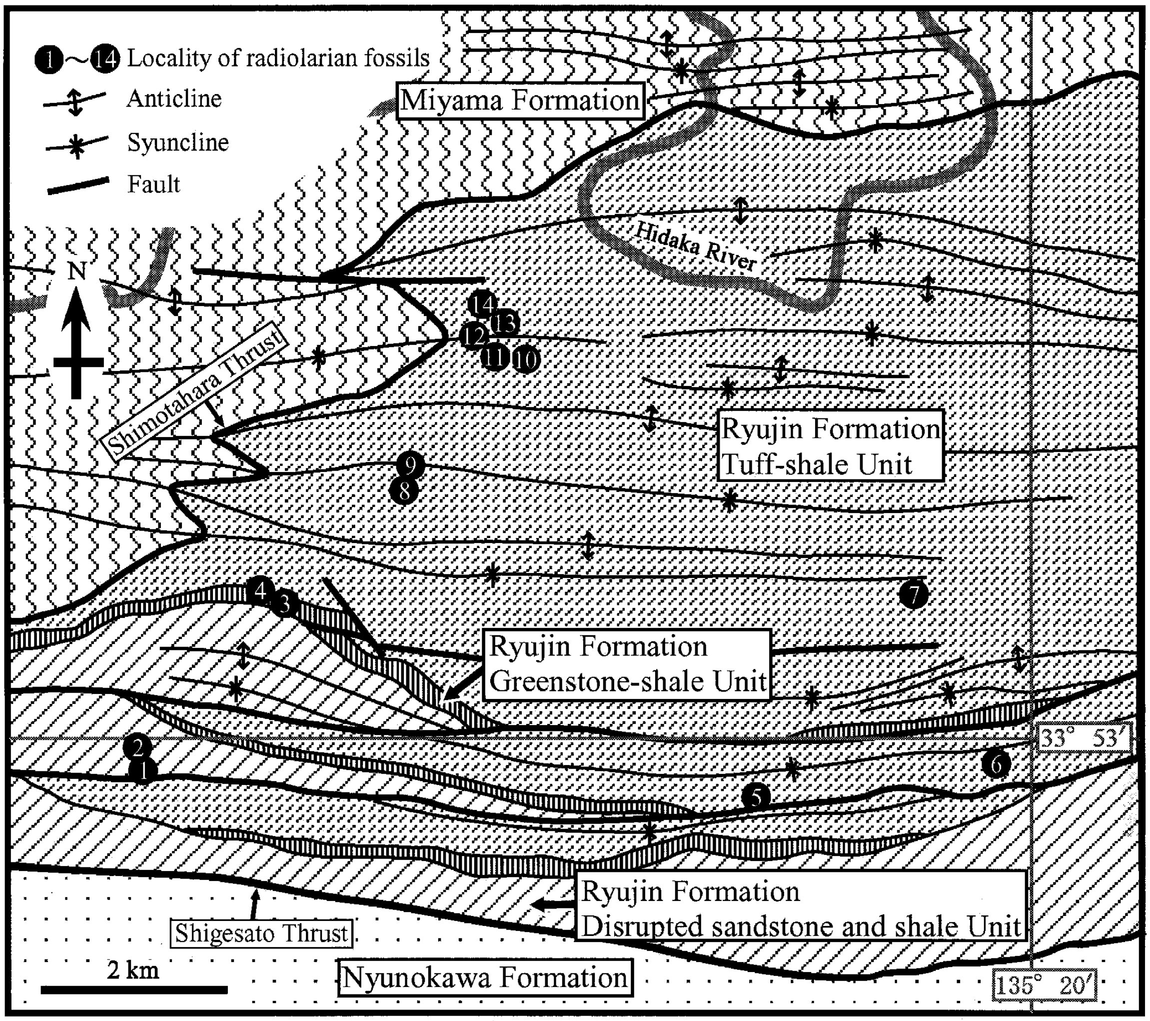

Fig. 2. Geologic map of the study area. Fossil localities are shown (modified from Kishu Shimanto Research Group, submitted).

in the southern part, the Ru Unit occupying a large area of the Ryujin Formation is characterized by folding, not by thrust faults. Furthermore, the geologic age of the Ryujin Formation has been weakly defined. The geologic age of both the Rl and Rm Units has not been precisely determined. The Ru Unit provides rather abundant radiolarian fossils, but their localities are restricted to the southwestern part of the area (Suzuki, 1992; Kishu Shimanto Research Group, submitted). Further finding of radiolarian fossils was eagerly needed for the Ryujin Formation.

In order to understand the geological structure of the Ryujin Formation more precisely, radiolarian study was made in the Kawabe area, Wakayama Prefecture. This paper reports newly obtained radiolarians from the Ryujin Formation, and discusses age and geological structure of the Ryujin Formation.

GEOLOGICAL OUTLINE OF THE KAWABE AREA

The study area is located at the western part of the Ryujin Formation along the lower reach of the Hidakagawa River. The geological structure of the Ryujin Formation in the Kawabe area is characterized by the prevalence of folded structure, but the southern part of this formation shows northward-dipping imbricated structure. The Ryujin Formation in this area is divided into the following three units; structurally in ascending order, the Disrupted sandstone and shale (Rl) Unit, the Greenstone-shale (Rm) Unit and the Tuff-shale (Ru) Unit (Kishu Shimanto Research Group, submitted) (Fig. 2).

The Disrupted sandstone and shale (Rl) Unit is in a fault contact with Greenstone-shale (Rm) Unit. This unit consists of mudstone and mudstone-dominant alternating beds of sandstone and mudstone with minor amount of felsic tuff. The mudstone is gun-metal gray in color and locally includes lenticular-shaped blocks of sandstone. Scaly cleavages commonly occur in the mudstone. The mudstone-dominant alternating beds of sandstone and mudstone consist of 5 to 20-cm thick mudstone and 2 to 10-cm thick sandstone. The mudstone-dominant alternating beds of sandstone and mudstone are commonly deformed and show pinch-and-swell structure.

The Greenstone-shale (Rm) Unit is conformably overlain by the Tuff-shale (Ru) Unit. This unit consists of mudstone and mixed rocks including blocks of greenstone, red mudstone, felsic tuff and sandstone in a matrix of tuffaceous mudstone. The mudstone is tuffaceous, and sage green and gray in color. Scaly cleavages develop in the mudstone. The greenstone slabs consist of massive lava, pillow lava and hyaloclastite.

The Tuff-shale (Ru) Unit is characterized by the prevalence of folded structure and is widely distributed in the Kawabe area. This unit is made up largely of mudstone with abundant intercalations of felsic tuff. Alternating beds of sandstone and mudstone, and bedded sandstones occur locally. The mudstone is well bedded, variable in color such as sage green, gray and gun-metal gray. Each mudstone bed is 10 to 50 cm thick, and intercalates thin felsic tuff beds and thin sandstone beds. The felsic tuff consists of fine-grained vitric tuff in several to 30 cm thick and coarse-grained crystal tuff in several tens cm to several m thick.

RADIOLARIAN FOSSILS AND THEIR AGE

In the present study, radiolarian fossils were newly found in fourteen localities, two localities (Locs. 1 and 2) of which from the Disrupted sandstone and shale (Rl) Unit, another two localities (Locs. 3 and 4) from the Greenstone-shale (Rm) Unit, and the other ten localities from the Tuff-shale (Ru) Unit (Fig. 2). The identified radiolarian species are listed in Table 1 and SEM photographs of representative species are shown in Figs. 4 and 5. Results of age assignments of each sample are shown in Fig. 6.

Radiolarian fossils from the Cretaceous Hidakagawa Sub-belt were summarized and divided into eight assemblage zones by Matsuyama et al. (1982) and Kumon et al. (1986). Later, Hollis and Kimura (2001) critically reviewed and discussed the radiolarian biozonation of Late Cretaceous and Paleocene strata in Japanese Islands, and newly proposed a unified zonation based on interval zones. Therefore, in the present study, the age assignments of radiolarian fossils of the Late Cretaceous are based on Text-figure 3 in Hollis and Kimura (2001). The new zonation proposed by

Table 1. List of radiolarian fossils in the study area. m: mudstone, R1: Disrupted sandstone and shale Unit. Rm: Greenstone-shale Unit. Ru: Tuff-shale Unit.

radiolarian locality	1	2	3	4	5	6	7	8	9	10	11	12	13	14
unit	R1	R1	Rm	Rm	Ru	Ru	Ru	Ru	Ru	Ru	Ru	Ru	Ru	Ru
lithology	m	m	m	m	m	m	m	m	m	m	m	m	m	m
Alievium sp.		○												
Amphipyndax mediocris														●
Amphipyndax pseudoconulus		●										●		
Amphipyndax stocki	●	●		●		○			●	●		●	○	●
Amphipyndax strekta		●												
Amphipyndax tylotus										○		●		
Archaeodictyomitra sp.	○	○	○	○	○	○	○	○		○		○	○	○
Archaeodictyomitra squinaboli	●	●			●	●		●	●			●	●	
Archaeospongoprunum salumi										○				
Archaeospongoprunum sp.								○		○	○			
Dictyomitra formosa	●							●		○				
Dictyomitra koslovae												○		
Dictyomitra multicostata		●											●	
Dictyomitra sp.		○									○			
Lithocampe manifesta														●
Lithocampe wharanui		●										●		
Patulibracchium sp.	○									○				
Pseudoaulophacus floresensis							○							
Pseudoaulophacus lenticulatus			○		○	○	○			○				
Pseudoaulophacus praefloresensis			○											
Pseudoaulophacus sp.		○												
Pseudodictyomitra sp.												○		
Theocampe salillum										●				
Xitus grandis		●												

○: confer

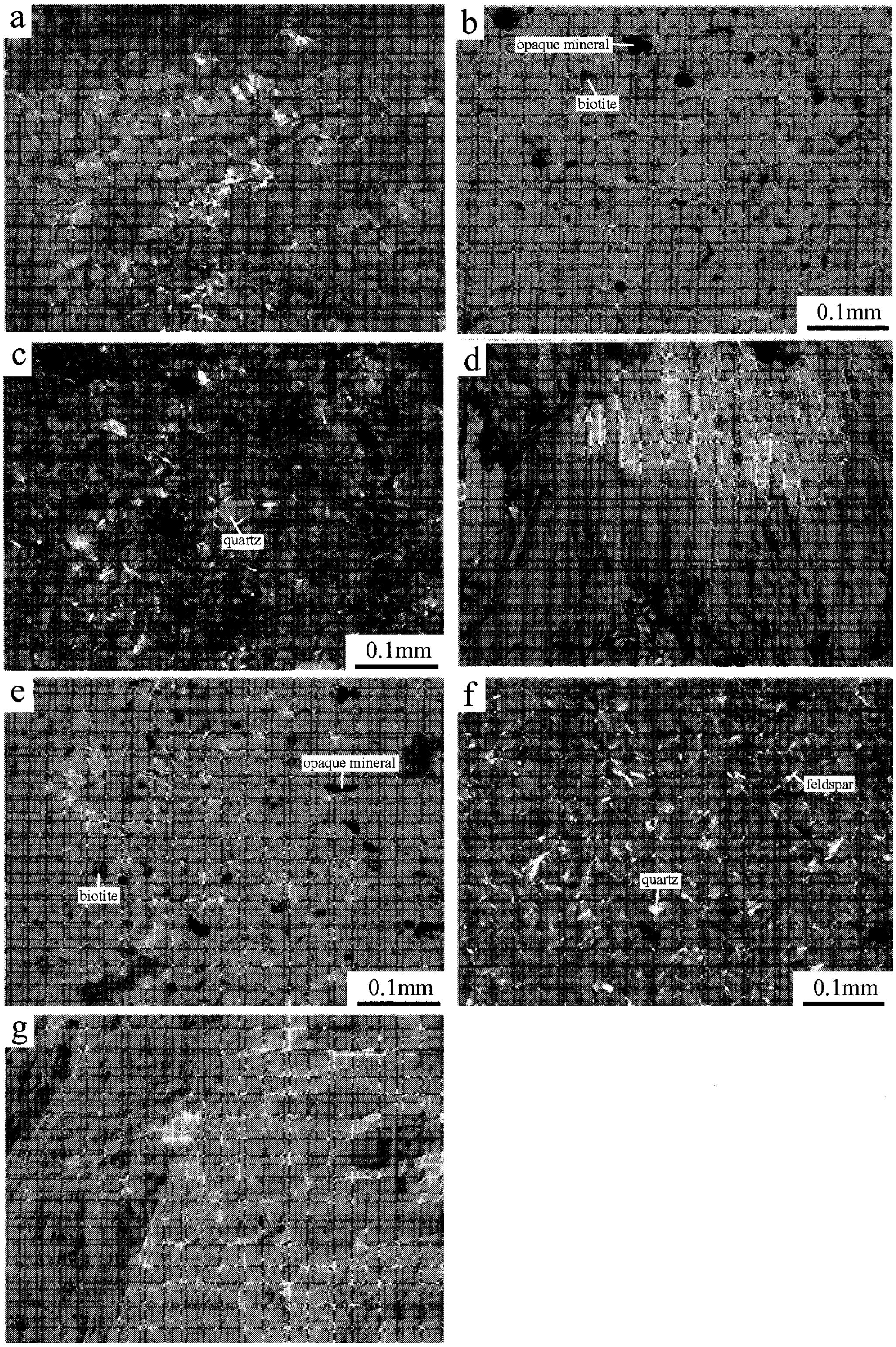

Fig. 3. Photographs (a, d, g) and photomicrographs (b, c, e, f) of the rocks in the study area. (a) Field occurrence of alternating beds of sandstone and mudstone in the Disrupted sandstone and shale (Rl) Unit. (b) and (c) Mudstone in the Rl Unit (b: under single polarized light. c: under crossed polarized light.). (d) Field occurrence of mudstone in the Greenstone-shale (Rm) Unit. (e) and (f) Mudstone in the Rm Unit (e: under single polarized light. f: under crossed polarized light.). (g) Field occurrence of bedded mudstone in the Tuff-shale (Ru) Unit.

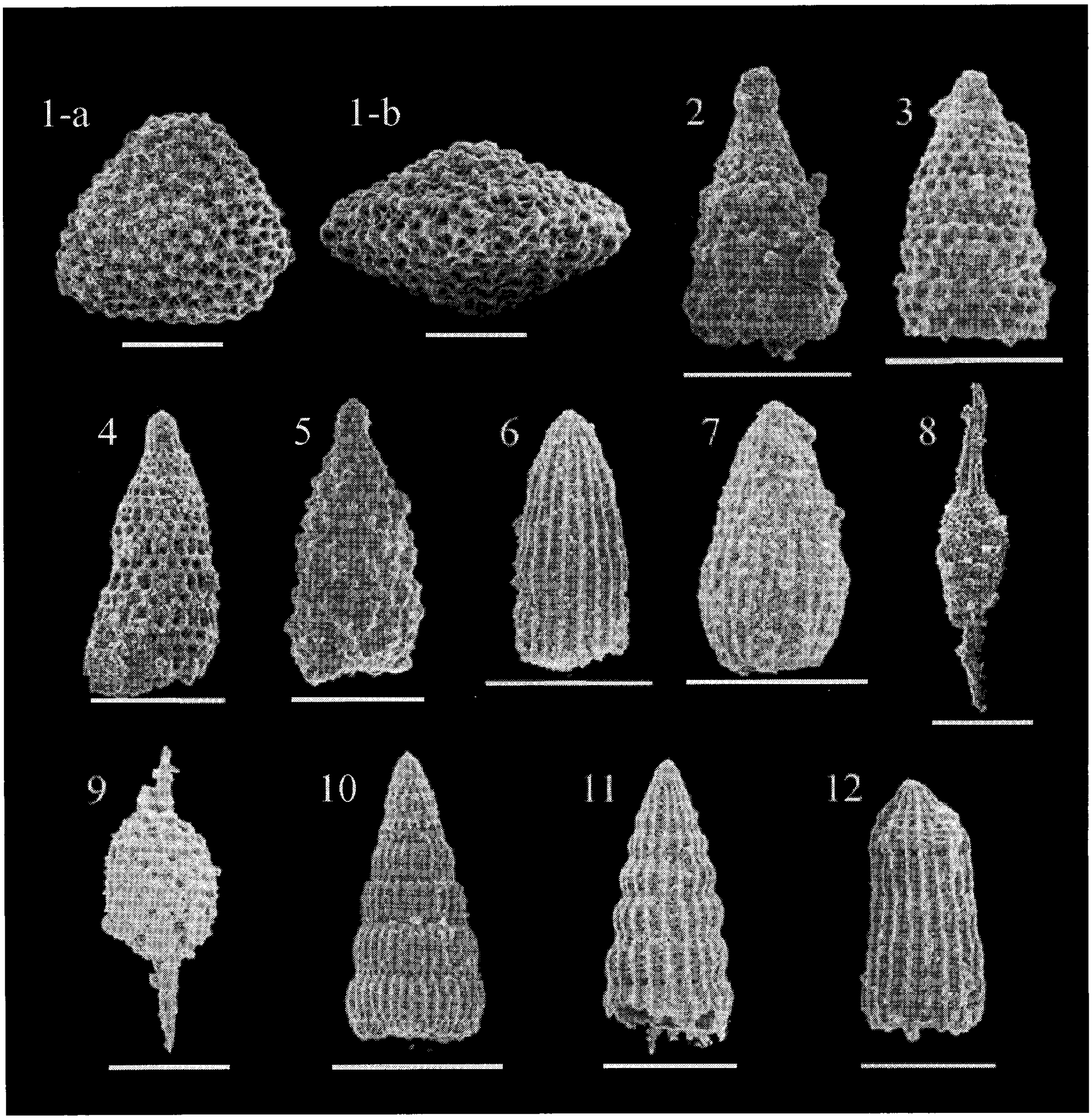

Fig. 4. SEM photographs of Cretaceous radiolarian fossils from the study area (Part 1). Fossil localities are shown in Fig. 2. Each scale bar indicates 100 μm. 1: *Allevium* sp. (Loc. 2). 2: *Amphipyndax pseudoconulus* (Loc. 12). 3: *A. stocki* (Loc. 12). 4: *A. strekta* (Loc. 2). 5: *A. tylotus* (Loc. 12). 6: *Archaeodictyomitra* sp. (Loc. 1). 7: *A. squinaboli* (Loc. 8). 8: *Archaeospongoprunum* cf. *salumi* (Loc. 10). 9: *A.* sp. (Loc. 8). 10: *Dictyomitra multicostata* (Loc. 2). 11: *D. formosa* (Loc. 1). 12: *D.* cf. *koslovae* (Loc. 12).

Hollis and Kimura (2001) consists of six Late Cretaceous interaval zones; *Theocampe urna* zone (Coniacian), *Dictyomitra koslovae* zone (Santonian to early Campanian), *Amphipyndax tylotus* zone (late Campanian), *Pseudotheocampe abschnitta* zone (early Maastrichtian), *Clathrocyclas? gravis* zone (middle Maastrichtian). *Dictyomitra koslovae* zone is subdivided into Santonian and early Campanian subzones based on the first appearances of *Archaeospongoprunum huevi* gr., *Protoxiphotractus perplexus* and *Allevium Gallowayi* (Hollis and Kimura, 2001).

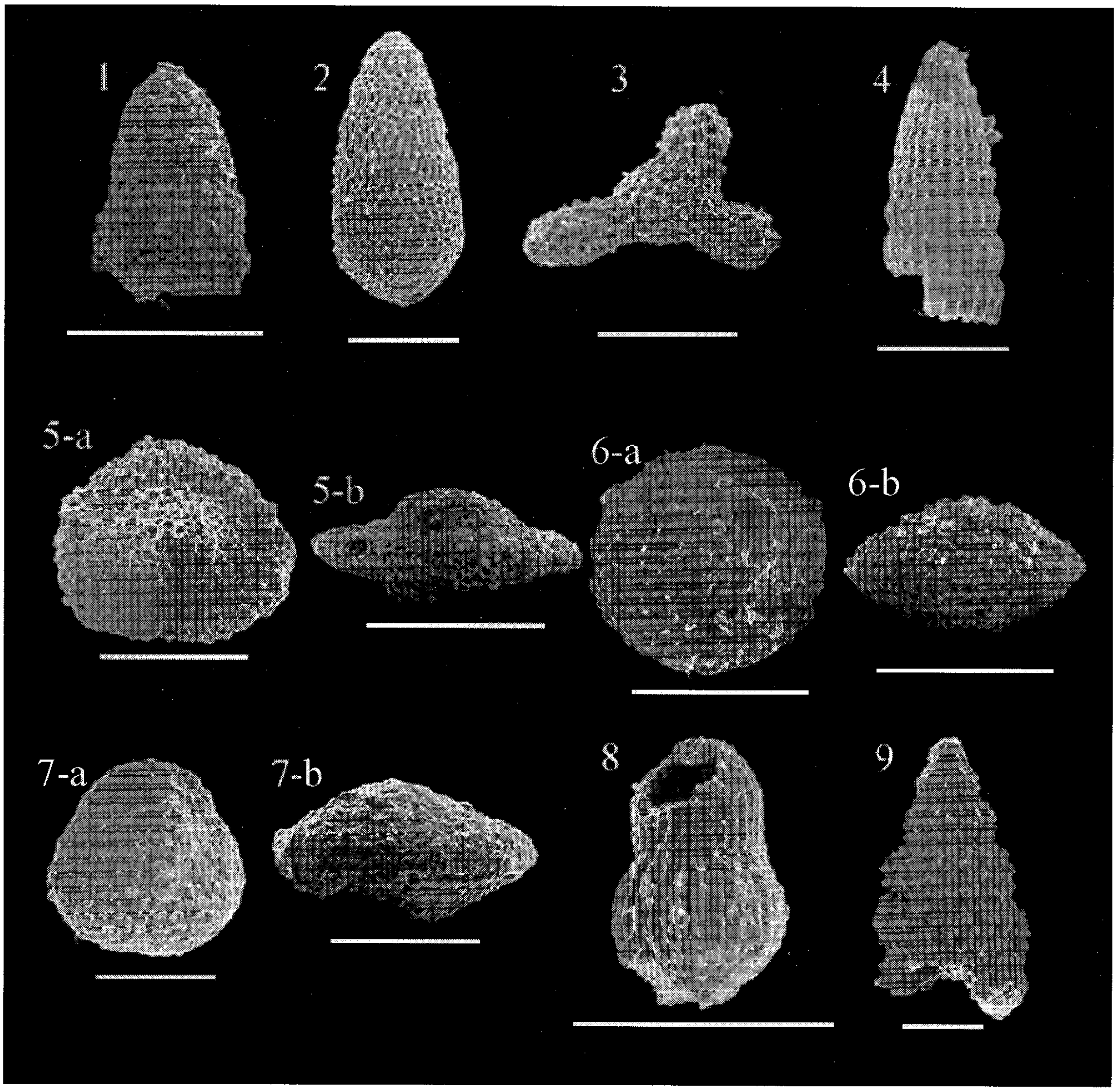

Fig. 5. SEM photographs of Cretaceous radiolarian fossils from the study area (Part 2). Fossil localities are shown in Fig. 2. Each scale bar indicates 100 µm. a: apical view, b: lateral view. 1: *Lithocampe manifesta* (Loc. 14). 2: *L. wharanui* (Loc. 2). 3: *Patulibracchium* sp. (Loc. 1). 4: *Pseudodictyomitra* sp. (Loc. 12). 5: *Pseudoaulophacus* cf. *floresensis* (Loc. 7). 6: *P.* cf. *lenticulatus* (Loc. 10). 7: *P.* cf. *praefloresensis* (Loc. 3). 8: *Theocampe salillum* (Loc. 10). 9: *Xitus grandis* (Loc. 2).

1. Disrupted sandstone and shale (Rl) Unit

The radiolarian fossils were obtained from mudstone of alternating beds of sandstone and mudstone in two localities (Locs. 1 and 2). Sandstone beds of alternating beds of sandstone and mudstone are locally broken into pinch-and-swell or boudinage structure (Fig. 3-a). Cleavages do not developed in the mudstone of alternating beds of sandstone and mudstone. Microscopic observation shows that the mudstone consists mainly of fine-grained clay minerals, biotite, muscovite, chlorite, quartz, feldspar, opaque minerals and organic material (Fig. 3-b and 3-c). The quartz grains are less than 0.05 mm in diameter.

Loc. 1: Only radiolarian fossils of rather wide range were identified. Among them, *Archaeodictyomitra squinaboli* indicates Campanian in age (Fig. 6).

Loc. 2: Mudstone in this locality yields well-preserved various species such as *Allevium* sp., *Amphipyndax pseudoconulus*, *A. stocki*, *A. strekta*, *Archaeodictyomitra* sp., *A. squinaboli*, *Dictyomitra multicostata*, *D.* sp., *Lithocampe wharanui*, *Pseudoaulophacus* sp., *Xitus grandis* (Table 1). Among these species, identification of *A. pseudoconulus* is based on the definition by Hollis and Kimura (2001). This species range from latest early Campanian to earliest Maastrichtian and is common only at early late Campanian in age. *A. strekta* indicates a late Campanian to early Maastrichtian age and *L. wharanui* suggests a Campanian to earliest Maastrichtian age. Some other species indicate wider range; *X. grandis* of Coniacian to earliest Maastrichtian and *A. squinaboli* of Campanian in age. Thus, the age of the mudstone in Loc. 2 is considered to be late Campanian (Fig. 6). Judging from the fossil data, the Disrupted sandstone and shale (Rl) Unit is considered to be the late Campanian (Fig. 6).

2. Greenstone-shale (Rm) Unit

A few ill-preserved radiolarian fossils were obtained from mudstone in Locs. 3 and 4. Scaly cleavages are developed in the mudstone (Fig. 3-d). The mudstone consists mainly of fine-grained clay minerals, biotite, muscovite, chlorite, quartz and opaque minerals, and includes lath-shaped feldspar (Fig. 3-e and 3-f).

Loc. 3: Precise identification was prevented by ill-preservation of fossils, and *Pseudoaulophacus* cf. *lenticulatus* and *P.* cf. *praefloresensis* were contained. Both *P.*

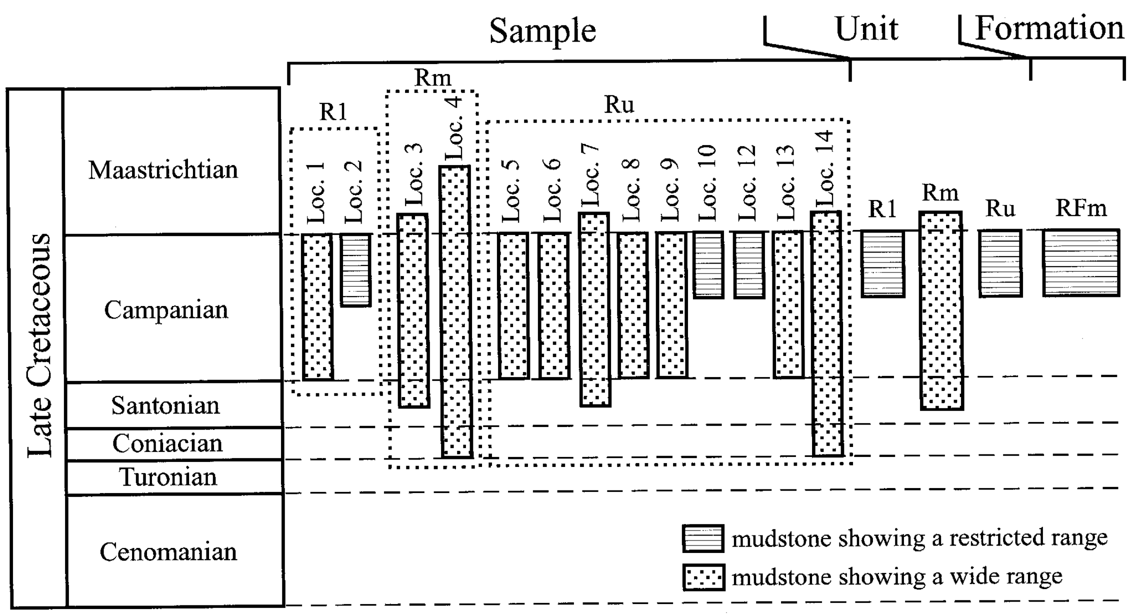

Fig. 6. Inferred range zone of mudstone in each locality, each unit and Ryujin Formation deduced by radiolarian fossils. Localities are shown in Fig. 2. R1: Disrupted sandstone and shale Unit. Rm: Greenstone-shale Unit. Ru: Tuff-shale Unit. R.Fm: Ryujin Formation.

lenticulatus and *P. praefloresensis* indicate middle Santonian to earliest Maastrichtian in age. Thus, the mudstone in Loc. 3 is roughly suggested to be middle Santonian to earliest Maastrichtian (Fig. 6).

Loc. 4: Only one species of *Amphipyndax stocki* was identified in the mudstone of Loc. 4, so the geologic age is suggested to be a wide range from Coniacian to middle Maastrichtian. Results of the fossil data suggest the Greenstone-shale Unit of middle Santonian to earliest Maastrichtian, but the precise age could not be determined.

3. Tuff-shale (Ru) Unit

Radiolarian fossils were obtained from bedded mudstone in ten localities (Fig. 2). Among them, five localities (Locs. 10-14) are concentrated in the northwestern part of the survey area, and other localities are scattered in the southern area. The bedded mudstone consists of 10 to 50 cm thick mudstone layers (Fig. 3-g). Microscopic observations show the mudstone consists mainly of fine-grained clay minerals, biotite, muscovite, chlorite, quartz, feldspar, opaque minerals and organic material. The quartz grains are less then 0.05 mm in diameter.

Among ten localities, samples of two localities (Locs. 10 and 12) yielded late Campanian radiolarian fossils, those from five localities (Locs. 5, 6, 8, 9 and 13) were suggested to belong to the Campanian, and those from two localities (Locs. 7 and 14) were roughly assigned to be Coniacian or Santonian to Campanian in age. Radiolarian fossils of Loc. 11 were not available for the age assignment.

Loc. 10: Mudstone in this locality yielded *Amphipyndax stocki*, *A.* cf. *tylotus*, *Archaeodictyomitra* sp., *Archaeospongoprunum* cf. *salumi*, *A.* sp., *Dictyomitra* cf. *formosa*, *Patulibracchium* sp., *Pseudoaulophacus* cf. *lenticulatus*, *Theocampe salillum* (Table 1). Among these species, *A. tylotus* is the characteristic species of the *Amphipyndax tylotus* interval zone (late Campanian) and is commonly found from a late Campanian to early Maastrichtian time range and disappeared in middle Maastrichtian age. The *Amphipyndax tylotus* interval zone is defined as the interval from first occurrence of *Amphipyndax tylotus* to last occurrence of *Dictyomitra koslovae* and is characterized by co-occurrence of *A. tylotus*, *A. pseudoconulus*, *Dictyomitra koslovae*, *D.* cf. *koslovae*, *D. formosa*, *Pseudotheocampe abschnitta*, *Rhopalosyringium magnificumm*. *D. formosa* indicates early Turonian to Campanian in age and *P. lenticulatus* indicates a Coniacian to earliest Maastrichtian age. Thus, the mudstone in Loc. 10 is considered to be late Campanian (Fig. 6).

Loc. 12: Mudstone in this locality yielded *Amphipyndax pseudoconulus*, *A. stocki*, *A. tylotus*, *Archaeodictyomitra* sp., *A. squinaboli*, *Dictyomitra* cf. *koslovae*, *Lithocampe wharanui*, *Pseudodictyomitra* sp. (Table 1). Range zone of *A. pseudoconulus* is restricted in age from early Campanian to earliest Maastrichtian, *A. tylotus* from late Campanian to early Maastrichtian and *L. wharanui* from Campanian to earliest Maastrichtian. *A. squinaboli* indicates a Campanian age and *D. koslovae* is assigned from latest Coniacian to earliest Maastrichtian in age. Thus, the age of the mudstone in Loc. 12 is precisely determined to be late Campanian (Fig. 6).

Locs. 5, 6, 8, 9 and 13: There is very few radiolarian fossils found in these localities but samples of all the localities yielded *Archaeodictyomitra squinaboli*, which indicates a Campanian age. *Dictyomitra multicostata* (Loc. 13) is assigned to be a middle Campanian to Maastrichtian age according to Pessagno (1976) and *Pseudoaulophacus* cf. *lenticulatus* (Locs. 5 and 6) suggests a wide range in age from Coniacian to ealiest Maastrichtian. Therefore, the geologic age of samples of these localities is assigned to Campanian.

Locs. 7 and 14: Only radiolarian fossils indicating a wide range were found from these localities. *Pseudoaulophacus* cf. *floresensis* (Loc. 7) suggests middle Santonian to earliest Maastrichtian in age, *P.* cf, *lenticulatus* (Loc. 7) and *Lithocampe manifesta* (Loc. 14) suggests Coniacian to earliest Maastrichtian in age. Therefore, above mentioned radiolarian analysis indicates that the Tuff-shale Unit is correlated to the late Campanian (Fig. 6).

DISCUSSION

In this section, both the geologic age and its implication on geologic structure of the Ryujinn Formation will be discussed based on newly collected radiolarian fossils.

1. Geologic age of the Ryujin Formation

1.a Disrupted sandstone and shale (Rl) Unit

In this paper, radiolarian fossils found from this unit in the western area (Loc. 4) clearly show late Campanian in age. Kishu Shimanto Research Group (submitted) reported radiolarian fossils from this unit at only one locality in the central area, and its geologic age was roughly estimated to be Campanian owing to the scarceness of species. Therefore, at present time, the unit was more precisely correlated to the late Campanian (Fig. 6). It means that this unit is biostratigraphically synchronous with the Tuff-shale (Rm) Unit. Based on lithological similarity (Kishu Shimanto Research Group, submitted), the Disrupted sandstone and shale (Rl) Unit may be correlated to the upper part of the Tuff-shale (Ru) Unit. In such a case, the abbreviated names, Rl and Ru, should be revised, because "l" and "u" may be regarded as stratigraphically "lower" and "upper".

1.b Greenstone-shale (Rm) Unit

Radiolarian fossils were obtained for the first time from this unit. Owing to ill-preservation and a few number of identified species, this unit was roughly inhered to be corresponds with the middle Santonian to earliest Maastrichtian (Fig. 6). Considering the conformable relationship with the overlying late Campanian Tuff-shale Unit (Kishu Shimanto Research Group, submitted), this unit may be older than late Campanian in age. On the other hand, considering the southward younging polarity, this unit may be synchronous or younger than the late Campanian M4 Unit of the Miyama Formation. The lower limit of geologic age should be determined by further finding of reliable radiolarian fossils.

1.c Tuff-shale Unit

In this study, late Campanian radiolarian fossils were obtained from the northwestern part and southern part of the study area. Kishu Shimanto Research Group (submitted) also reported late Campanian radiolarian fossils mainly in southwestern part of the area. Therefore the Tuff-shale Unit is safely confirmed to be the late Campanian (Fig. 6).

1.d Geologic age of Ryujin Formation

Summarizing the above mentioned age assignment of three units, the geologic age of the Ryujin Formaiton should be roughly assign to the late Campanian (Fig. 6).

2. Implication to geologic structure of the Ryujin Formation

The present study confirmed that the Ryujin formation, although occupying a wider area in the Hidakagawa Sub-belt (Fig. 1), was correlated to only one radiolarian biozone, that is the late Campanian *Amphipyndax tylotus* interaval zone. Furthermore, such a large scale repetition of strata by thrust faults as seen in the Miyama Formation cannot be found in the Ryujin Formation. Except the southern area, where only middle scale repetition can be found, the geological structure of the Ryujin Formation in the Kawabe area is characterized by the prevalence of folded structure.

From a lithological point of view, the Ryujin Formation is considered to be an accretionary complex, while geological structure of the Ryujin Formation is not typical as an accretionary complex. It will be suggested that subduction-related deformation might be weak during the late Campanian in Kii Peninsula.

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REFERENCES

Hollis, J.C. and Kimura, K. (2001) A unified radiolarian zonation for the Late Cretaceous and Paleocene of Japan. *Micropaleontology*, **47**, 235–255.

Kanmera, K. and Sakai, S. (1975) On the correlation of the past geosyncline of the Shimanto. *GDP Report* II-1-(1), **3**, 55–64 (in Japanese).

Kimura, K. (1986) Stratigraphy and paleogeography of the Hidakagawa Group of the Northern Shimanto Belt in the southern part of Totsugawa Village, Nara Prefecture, Southwest Japan. *Jour. Geol. Soc. Japan*, **92**, 185–203 (in Japanese with English abstract).

Kishu Shimanto Research Group (1983) Terasoma and Shirama Formations of the Hidakagawa Group in the Shimanto Belt, Southwest Japan: The study of the Shimanto Terrain in the Kii Peninsula, Southwest Japan. *Earth Sci.*, **37**, 235–249 (in Japanese with English abstract).

Kishu Shimanto Research Group (1986) Miyama Formation of the Hidakagawa Group around Nakatsumura in the western part of the Kii Peninsula: The study of the Shimanto terrain in the Kii Peninsula, Southwest Japan. *Earth Sci.*, **40**, 227–247 (in Japanese with English abstract).

Kishu Shimanto Research Group (1991) Yukawa and Miyama Formations of Hidakagawa Group in the eastern-middle part of Wakayama Prefecture. *Earth Sci.*, **45**, 19–38 (in Japanese with English abstract).

Kishu Shimanto Research Group (submitted) Geology of the Hidakagawa Belt in the central-western part of Wakayama Prefecture, Southwest Japan. *Earth Sci.*, (in Japanese with English abstract).

Kumon, F., Matsuyama, H. and Nakajo, K. (1986) Revised latest Jurassic to Cretaceous radiolarian assemblages from the Hidakagawa Group in the Shimanto Belt, Kii Peninsula. *Fossils*, **41**, 17–27 (in Japanese with English abstract).

Kumon, F., Suzuki, H., Nakazawa, K., Tokuoka, T., Harata, T., Kimura, K., Nakaya, S., Ishigami, T. and Nakamura, K. (1988) Shimanto Belt in the Kii Peninsula, Southwest Japan. *Modern Geol.*, **12**, 71–96.

Kurimoto, C. (1982) Chichibu system in the area southwest of Koyasan, Wakayama Prefecture: Upper Cretaceous Hanazono Formation. *Jour. Geol. Soc. Japan*, **88**, 901–914 (in Japanese with English abstract).

Kurimoto, C. (1994) Geology of Kudoyama area in the Western Kii Peninsula, Southwest Japan, with reference to disappearance of the Chichibu Terrane. *Bull. Geol. Surv. Japan*, **45**, 235–255.

Matsuyama, H.F., Kumon, F. and Nakajo, K. (1982) Cretaceous radiolarian fossils from the Hidakagawa Group in the Shimanto Belt, Kii Peninsula, Southwest Japan. *News Osaka Micropaleontol., Spec. Publ.*, **5**, 371–382 (in Japanese with English abstract).

Pessagno, E.A. (1976) Radiolarian zonation and stratigraphy of the Ujpper Cretaceous potion of the Great Valley Sequence, California Coast Ranges. *Micropaleontology, Spec. Publ.*, no.15, 1–95.

Sakai, T. and Kanmera, K. (1981) Stratigraphy of the Shimanto Terrain and tecno-stratigraphic setting of greenstones in the northern part of Miyazaki Prefecture, *Kyushu. Sci. Repts., Dept. Geol., Kyushu Univ.*, **14**, 31–48 (in Japanese with English abstract).

Suzuki, H. (1992) On the geologic age of the Ryujin Formation in the Hidakagawa Belt, Shimanto Terrane of Southwest Japan. *Sci. Engin. Rev. Doshisha Univ.*, **32**, 350–361 (in Japanese with English abstract).

Taira, A. (1985) Sedimentary evolution of Shikoku subduction zone: The Shimanto Belt and Nankai Trough. *In* Nasu N. ed. *Formation of active ocean margins*, 835–851, Terra Sci. Publ. Com., Tokyo.

Taira, A., Kato, J., Tashiro, M. and Okamura, M. (1980) The geology of the Shimanto Belt in Kochi Prefecture, Shikoku. *In* Taira, A. and Tashiro, M, eds. *Geology and Paleontology of the Shimanto Belt*, 319–389, Rinyakosaikai Press, Kochi. (in Japanese with English abstract).

Taira, A., Kato, J., Tashiro, M., Okamura, M. and Kodama, K. (1988) The Shimanto Belt in Shikoku, Japan: Evolution of Cretaceous to Miocene accretionary prism. *Modern Geol.*, **12**, 5–46.

Taira, A., Okada, H., Whitaker, J.H. McD. and Smith, A. (1982) The Shimanto Belt of Japan: Cretaceous to lower Miocene active margin sedimentation. *In* Leggett J.K. ed. *Trench-forearc geology*. Geol. Soc. London, Spec. Publ., **10**, 5–26.