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RESEARCH ARTICLE

Imbricate structure of the Permian Yoshii Group in the Otakeyama area, Okayama Prefecture, southwest Japan

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Abstract The Yoshii Group of the Akiyoshi terrane is distributed over the Otakeyama area, Okayama Prefecture, southwest Japan. The Yoshii Group is composed of siliceous rocks and clastics, comprising chert-clastic sequences. The Yoshii Group is divided into four structural units (Units Ot 1, Ot 2, Ot 3, and Ot 4) in structurally ascending order. Lithological similarities and radiolarian age suggest that these units exhibit almost identical ocean plate stratigraphy. These units are structurally-repeated to form an imbricate structure. This structure was possibly formed by off-scrape accretion at a toe of an accretionary complex. Additionally, a review of previous studies indicates that an imbricate structure is common in the Akiyoshi terrane. The presence of an imbricate structure in the Akiyoshi terrane, Permian accretionary complex, indicates the possibility that a specific horizon of Permian pelagic sequences acted as a décollement zone.

Keywords accretionary complex, imbricate structure, Permian radiolaria, Yoshii Group, Okayama Prefecture, southwest Japan

1 Introduction

Paleozoic and Mesozoic accretionary complexes are widely exposed in the Japanese Islands (e.g., Ichikawa, 1990; Isozaki et al., 2010). Geologic bodies in Southwest Japan, including these accretionary complexes, are divided into the Inner and Outer zones that are bounded by the Median Tectonic Line (Fig. 1). These accretionary complexes contain paleoceanic sediments and should record past information about the ocean. The Akiyoshi terrane, a Permian accretionary complex of the Inner Zone of Southwest Japan, is scattered in a wide area from northern Kyushu to the Hokuriku District over a distance of 800 km (Fig. 1). The Akiyoshi terrane is composed of limestone-dominant facies and siliceous-rock-dominant facies of the Upper Paleozoic (Sano and Kanmera, 1988; Kanmera et al., 1990). Several researchers have observed chert-clastic sequences (CCSs) from siliceous-rock-dominant facies in the Akiyoshi terrane in the 1980s (e.g., Ishiga et al., 1986; Naka et al., 1986; Uchiyama et al., 1986; Sano et al., 1987; Goto, 1988). Generally, a CCS indicates a transition from pelagic through hemipelagic to terrigenous rocks, reflecting the migration of the depocenter from the abyssal plain to the trench floor (e.g., Matsuda and Isozaki, 1991). Kanmera et al. (1990) compared some strata consisting mainly of CCSs, such as the Nishiki Group, the Notabiyama Formation, and the Yoshii Group. They highlighted age differences among the strata on the basis of radiolarian dating. Then, CCSs have also been recognized in other areas (e.g., Yanase and Isozaki, 1993; Kawai and Takeuchi, 2001), indicating that a CCS is a common characteristic in siliceous-rock-dominant facies of the Akiyoshi terrane.

An imbricate structure is formed by the stacking of two or more thrust sheets. In accretionary complexes, an imbricate structure is composed of repeated CCSs. Since the 1980's, several researchers have recognized imbricate structures in the Jurassic accretionary complexes in Japan, such as the Tamba-Mino-Ashio and Chichibu composite terranes (e.g., Yao et al., 1980; Matsuoka, 1984; Otsuka, 1988; Kamata, 2000). Based on investigations of younger accretionary complexes, the imbricate structures in the Jurassic accretionary complexes are interpreted as an accretionary wedge formed by off-scrape accretion at the toe of the inner-trench slope (e.g., Matsuoka, 1992). Nakae et al. (1998) observed an imbricate structure formed of lithostratigraphically-repeated CCSs from the Yobuno Group of the Akiyoshi terrane in Fukuoka Prefecture, Kyushu, southwest Japan. Meanwhile, in contrast to the

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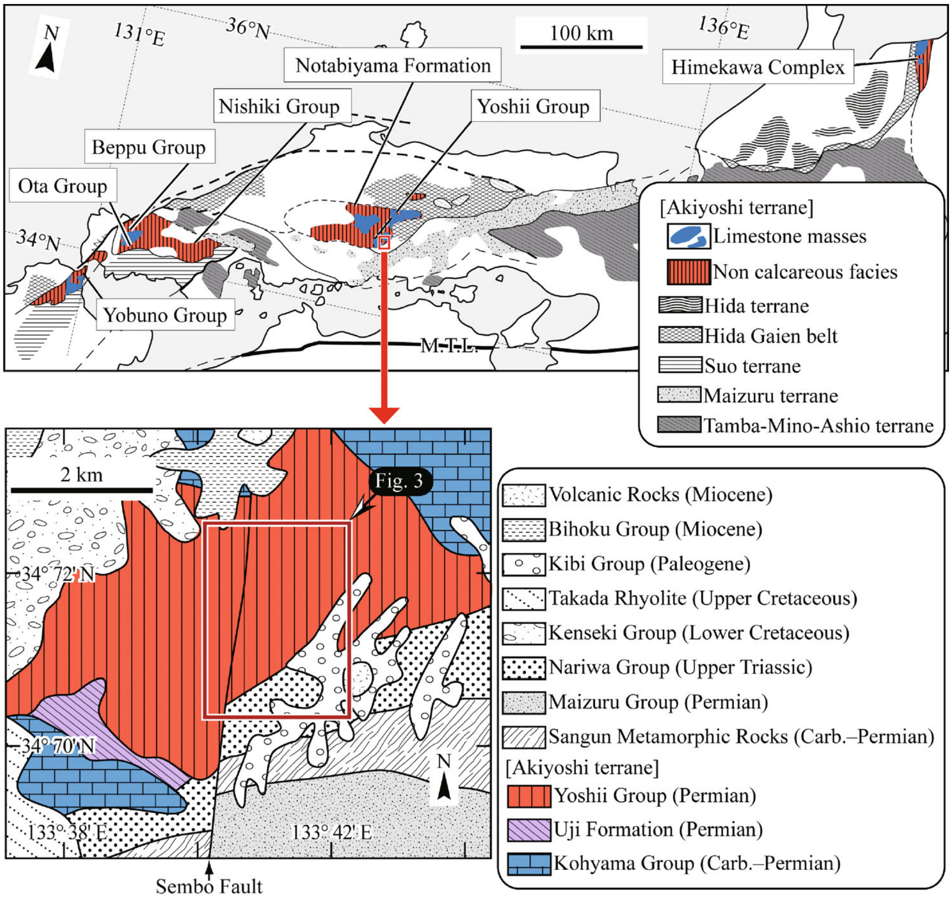

Fig. 1 Simplified geological maps of the Inner Zone of southwest Japan (modified from Kanmera et al., 1990 and Teraoka et al., 1996). M. T. L.: Median Tectonic Line.

Jurassic accretionary complexes, an imbricate structure formed of biostratigraphically-repeated CCSs in the Akiyoshi terrane had not been clarified.

The Yoshii Group, distributed over the western Okayama Prefecture, is one of the representative geologic bodies of siliceous-rock-dominant facies of the Akiyoshi terrane. Although the Yoshii Group consists of the Lower to Middle Permian CCSs (Sano et al., 1987), no imbricate structure has been reported in the area. Some researchers have reported radiolarian occurrences from the Yoshii Group (Sada et al., 1985, 1992; Sano et al., 1987), indicating that the Yoshii Group is available for an investigation of the relationship between lithostratigraphy and biostratigraphy.

We made a geological map of the Yoshii Group in the Otakeyama area and obtained radiolarian fossils from siliceous rocks. On the basis of the results, we recognized an imbricate structure composed of lithostratigraphically- and biostratigraphically-repeated CCSs. In addition to the present study, a review of previous studies indicates the possibility that an imbricate structure is common in the Akiyoshi terrane. In this contribution, we report the lithostratigraphy, geologic structure, and radiolarian occurrences of the Yoshii Group in the Otakeyama area. We then discuss the significance of the presence of an imbricate structure in the Akiyoshi terrane.

2 Geologic setting

The Yoshii Group belonging to the Akiyoshi terrane is distributed over the Yoshii area in the western Okayama Prefecture. Figure 2 shows the stratigraphy of the Yoshii Group in the Yoshii area in this study and previous studies. Kobayashi et al. (1937) showed the geological map of the Yoshii area, including this study area. They thought that the Paleozoic strata in the Yoshii area consists of the following ascending strata: chert, alternating bed of sandstone and slate, and limestone. Choh (1939) divided these strata into the Hina Limestone, Otake Chert, Mihara Sandstone-Slate, Kohyama Limestone formations, and the Uji Formation in ascending order. The Uji Formation was considered Upper Permian on the basis of fusulinid occurrences. Nakano (1952) divided these strata into the Chert and Sandstone-Slate formations and the Hina Limestone. He considered the Chert and Sandstone-Slate formations as an allochthon and the Hina Limestone as a klippe. Yoshimura (1961) named the Chert and Sandstone-

Kobayashi et al. (1937)	Choh (1939)	Nakano (1952)	Yoshimura (1961)			Sano et al. (1987)		This study		
Limestone	Kohyama Limestone									
Alternating bed of Sandstone & Slate	Mihara Sandstone-Slate Formation	Sandstone-Slate Formation	Yoshii Group	Mihara Fm.	Upper Member	Yoshii Group	Sandstone & shale	Yoshii Group	Mihara Fm.	Upper Member
					Lower Member		Siliceous mudstone with acidic tuff			Lower Member
Chert	Otake Chert Formation	Chert Formation		Otake Formation			Radiolarian-bearing chert		Otake Formation	

Fig. 2 Stratigraphy of the Yoshii Group in the Yoshii area in this and previous studies. Dashed lines indicate conformable boundary.

Slate formations, sensu Nakano (1952), the Yoshii Group. He divided the Yoshii Group into the Otake and Mihara formations in ascending order. The Otake Formation consists mainly of chert; the Mihara Formation is composed mainly of clastics. Sano et al. (1987) showed that the Yoshii Group consists of Lower to Middle Permian CCS. They compared it to the Notabiyama Formation in the Taishaku area, Hiroshima Prefecture, on the basis of the lithology and fossil occurrences.

Yoshimura (1961) considered the Yoshii Group as Permian because Permian fusulinid-bearing lenticular limestone occurred in the uppermost part of the Mihara Formation. Some radiolarian and conodont occurrences have been reported from the Yoshii Group since the 1980s (Sada et al., 1985, 1992; Sano et al., 1987). On the basis of the radiolarian and conodont occurrences, the Yoshii Group corresponds to the Lower to Middle Permian.

The Otakeyama area, the present study area, is the eastern part of the Yoshii area, western Okayama Prefecture. We surveyed this area and made a geological map, a cross-section, and a route map (Figs. 3 and 4). The following groups are exposed in the Otakeyama area: Yoshii, Nariwa, and Kibi. The Upper Triassic Nariwa Group is distributed over the southeast part of the study area. Although no contact between the Nariwa and Yoshii groups were observed in the study area, their distributions indicate that the boundary is vertical and strikes NE-SW. Otoh (1985) observed an unconformable boundary between the Nariwa Group and the Paleozoic strata in the Shimotani and Shida areas, located in the east of the study area. The Paleogene Kibi Group unconformably overlies the Paleozoic and Mesozoic strata in the study area. The Sembo Fault (Sadagane and Nose, 1981) is situated in the western part of the study area.

3 Lithostratigraphy

We divided the Yoshii Group into the Otake and Mihara formations in ascending order. The Mihara Formation is subdivided into the Lower and Upper members. The Otake Formation consists of cherts; the Lower Member of the Mihara Formation is composed mainly of siliceous mudstones with interbedded tuff, and the Upper Member consists mainly of sandstones and mudstones. These formations constitute a CCS.

3.1 Otake Formation

Choh (1939) named the chert-dominant strata in the Yoshii area the Otake Chert Formation. Yoshimura (1961) renamed this formation the Otake Formation. Although they had not mentioned the derivation of this formation, it was presumably derived from Mt. Otakeyama. The Otake Formation in this study corresponds approximately to the Otake Formation sensu Yoshimura (1961).

This formation is composed of cherts. Most cherts are gray to dark-gray, but there are a few bright-gray and red cherts. Cherts are massive or bedded (10 to 30 cm in thickness). Bedded cherts interbed thin (<5 mm) siliceous claystones. Cherts contain mainly sponge spicules, but some cherts include minor radiolarian tests. The cherts consist mainly of cryptocrystalline quartz and siliceous microfossils with a few clay minerals. Some cherts are crystallized and include no microfossils. There are some quartz veins in the cherts.

3.2 Mihara Formation

The Mihara Formation consists mainly of clastic rocks. It is subdivided into the Lower and Upper members. This formation was named the Mihara Sandstone-Slate Formation by Choh (1939). Yoshimura (1961) renamed this formation the Mihara Formation. Although they have described no derivation of this formation, it was presumably derived from the Mihara area located in the west of the study area. Yoshimura (1961) divided this formation into the Lower and Upper members. The Lower Member, sensu Yoshimura (1961), consists mainly of sandstones and mudstones; the Upper Member is composed mainly of sandstones. Although we subdivided the Mihara Formation into the Lower and Upper members, the Lower

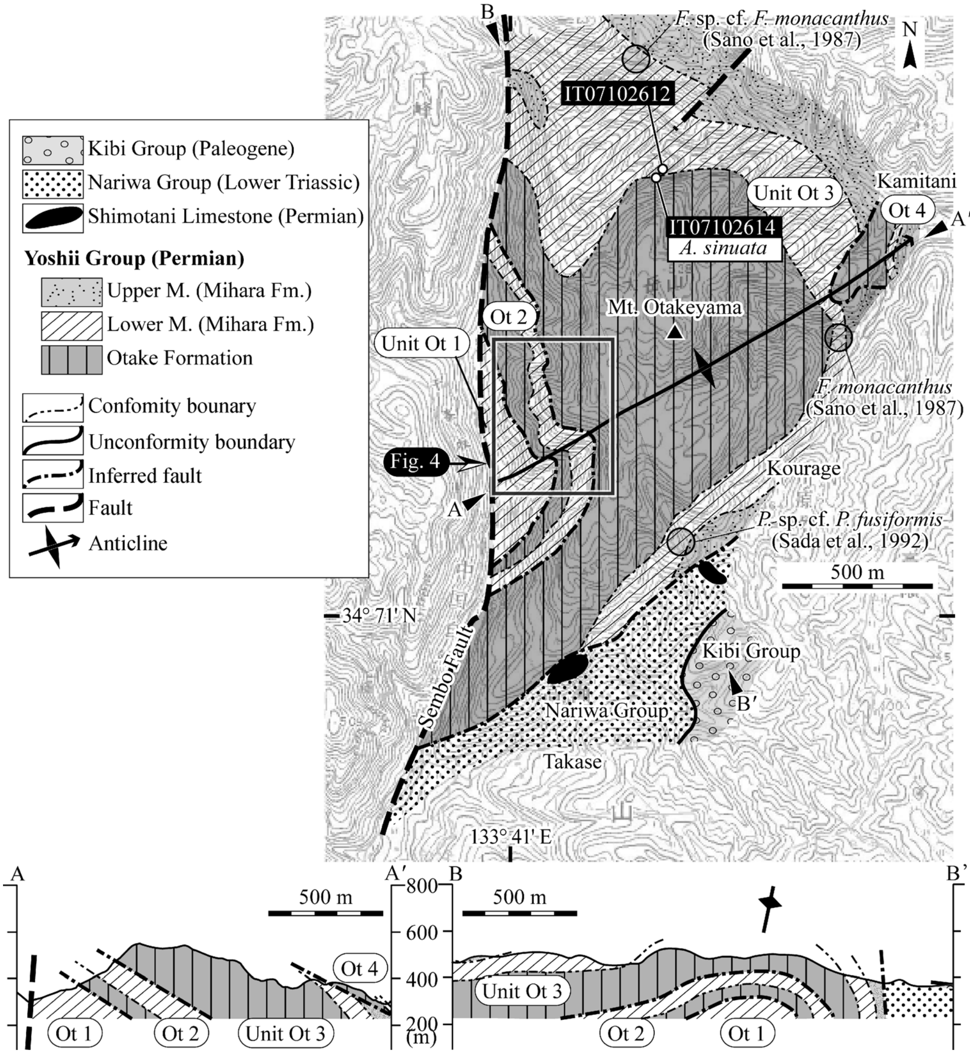

Fig. 3 Geological map and cross-section of the Otakeyama area. Base map is from 1: 25,000 map of "Jito," by the Geographical Survey Institute of Japan.

Member of this study includes no sandstone and differs from the Lower Member sensu Yoshimura (1961).

3.2.1 Lower Member

This member consists mainly of siliceous mudstones with interbedded tuff. We regard the base of the lowermost siliceous mudstone layer as the base of the Mihara Formation. Siliceous mudstones are black, red, gray, dark-gray, and bright-gray. Siliceous mudstones are massive or bedded (5 to 20 cm in thickness). The siliceous mudstones are composed of scattered quartz and siliceous microfossils with matrices of cryptocrystalline quartz and clay minerals. In some horizons, siliceous mudstones interbed with coarse-grained tuff. Tuff beds are grayish-white, greenish-gray, and pale-green. The thickness of tuff is less than 5 cm in most beds; a few tuff beds are 10 cm in thickness. Quartz and plagioclase are observable in the tuff under microscope observation. Some siliceous mudstones and tuff show grading from tuff to siliceous mudstone.

3.2.2 Upper Member

This member is composed mainly of sandstones and mudstones. We regard the base of the lowermost sandstone layer as the base of the Upper Member. The lower part of the Upper Member consists mainly of alternating beds of sandstones, siliceous mudstones, and siltstones; the middle part is composed of alternating beds of sandstones and siltstones, and the upper part consists of sandstones. The sandstones are fine to medium grained and are gray to bright-gray; siliceous mudstones are dark-gray to bright-gray, and siltstones are dark-gray to bright-gray. The thickness of the alternating beds is 5 to 20 cm. Some sandstones and siltstones show grading from sandstone to siltstone. Sandstones of the upper part are gray to bright-

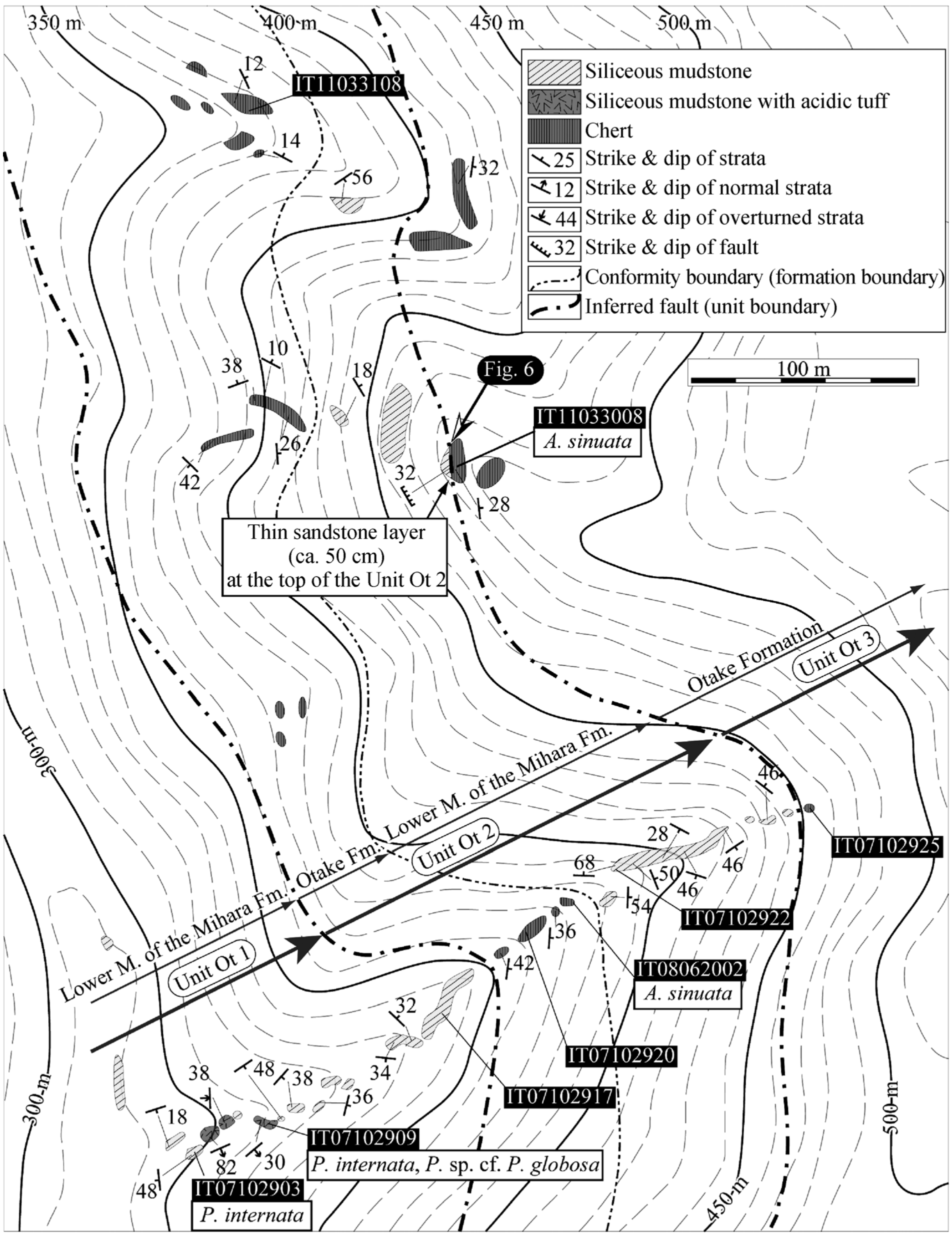

Fig. 4 Route map for the western slope of Mt. Otakeyama.

gray. The sandstones are fine to coarse grained and poorly sorted. The sandstones are lithic arenite composed mainly of quartz, plagioclase, and acidic volcanic rock fragments.

4 Geologic structure and unit division

The Yoshii Group in the Otakeyama area generally strikes NE-SW to NW-SE and dips 20° to 50° SE or NE. The Yoshii Group in the Otakeyama area forms an anticline. The anticlinal axis trends N 46°E and plunges 28° on the basis of a stereo plot (Fig. 5). There are some small open folds; no noticeable closed fold at the scale of the outcrop is observed. We divided the Yoshii Group into four structural units of chert-clastic sequences. We called them Units Ot 1, Ot 2, Ot 3, and Ot 4 in structurally ascending order.

Unit Ot 1 is exposed in the western slope of Mt. Otakeyama. The Lower Member of the Mihara Formation is observable in this unit. Unit Ot 2 is distributed over the western slope of Mt. Otakeyama. The Otake Formation and the Lower Member of the Mihara Formation are widely exposed. The Upper Member of the Mihara Formation is slightly distributed just below the boundary fault between Units Ot 2 and Ot 3, although the distribution is indescribable in the geological and route maps. Unit Ot 3 is widely distributed from near the crest of Mt. Otakeyama to its eastern slope. The Otake and Mihara formations are

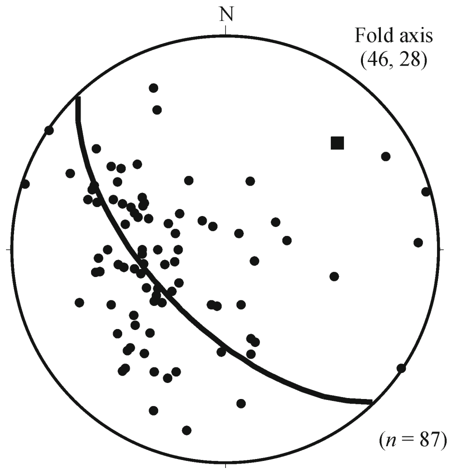

Fig. 5 Equal area lower hemisphere projection of bedding plane in the Yoshii Group. Square shows the trend and plunge of the fold axis.

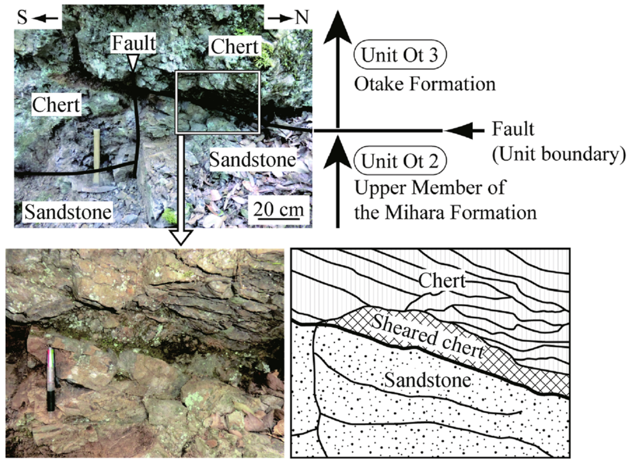

Fig. 6 Field occurrence of the boundary fault between units Ot 2 and Ot 3. The lower half of the enlarged view is sandstone of the Upper Member of the Mihara Formation of Unit Ot 2; the upper half is chert of the Otake Formation of Unit Ot 3.

observed in this unit. Unit Ot 4 is narrowly distributed over the northeast part of the study area. The Otake and Mihara formations are observed in this unit.

The route map in the western slope of Mt. Otakeyama shows an imbricate structure formed by lithostratigraphically-repeated CCSs. Unit distribution is related to topographic elevation. Unit Ot 1 is exposed in the southwestern part of the map where the elevation is lowest in the mapped area; Unit Ot 3 is exposed in the northeastern part, which is the highest place. Unit Ot 2 is distributed between Units Ot 1 and Ot 3. The boundary fault between Units Ot 2 and Ot 3 is exposed at the western slope of Mt. Otakeyama (Fig. 6). The fault surface strikes N 30° W and dips 32° NE. The fault contacts between Units Ot 1 and Ot 2 and between Units Ot 3 and Ot 4 are not exposed in the study area. The fine sandstone is gray and narrowly exposed just below the fault. Sandstone of Unit Ot 2 is observed at this outcrop only. The chert of the Otake Formation is gray. Cherts on the fault are partially sheared (20 cm in thickness). The sheared chert is intensely weathered, and its shear sense was unrecognizable. No fault gouge has been observed. Broken and mixed facies are not observed in the Yoshii Group in the Otakeyama area other than this fault boundary.

5 Radiolarian occurrences

We collected 117 samples from the Yoshii Group in the Otakeyama area. The samples were crushed to fragments of approximately 1 cm, and they were soaked in a 5% hydrofluoric acid (HF) solution for 24 hr at room temperature. The HF solution was removed and the containers holding the etched samples were subsequently refilled with a fresh HF solution. Adequate residues were then collected through a sieve with a mesh diameter of 0.054 mm and dried. A part of the residue of each sample was enclosed within a slide prepared with a mounting medium (Entellan new). These slides were observed under a transmitted light microscope. The well-preserved radiolarians in the residues were mounted on stubs and photographed with a scanning electron microscope.

The preservation of fossil tests within the residues was generally poor. Most samples contain sponge spicules; some samples contain radiolarians. Among the collected samples, 11 samples contained radiolarians other than spherical ones. Photomicrographs of selected radiolarians are shown in Fig. 7; radiolarian occurrence is detailed in Table 1.

5.1 Unit Ot 1

Radiolarian fossils occurred in three samples (IT07102903, IT07102909, and IT07102917) of Unit Ot 1. Sample IT07102903 is black-gray siliceous mudstone; samples IT07102909 and IT07102917 are grayish-green tuffaceous siliceous mudstones.

Two samples (IT07102903 and IT07102909) yielded valuable radiolarians for age assignment. *Pseudoalbaillella* sp. cf. *P. globosa* Ishiga and Imoto, which is the characteristic species of the *P. globosa* Assemblage-Zone (lower Guadalupian) of Ishiga (1986, 1990), was obtained from sample IT07102909. Samples IT07102903 and IT07102909 yielded *Pseudoalbaillella internata* Wang, which is abundant in the upper *P. globosa* Assemblage-Zone in South China (Wang and Yang, 2011). Hence, the radiolarian fauna of these samples corresponds to the upper *P. globosa* Assemblage-Zone.

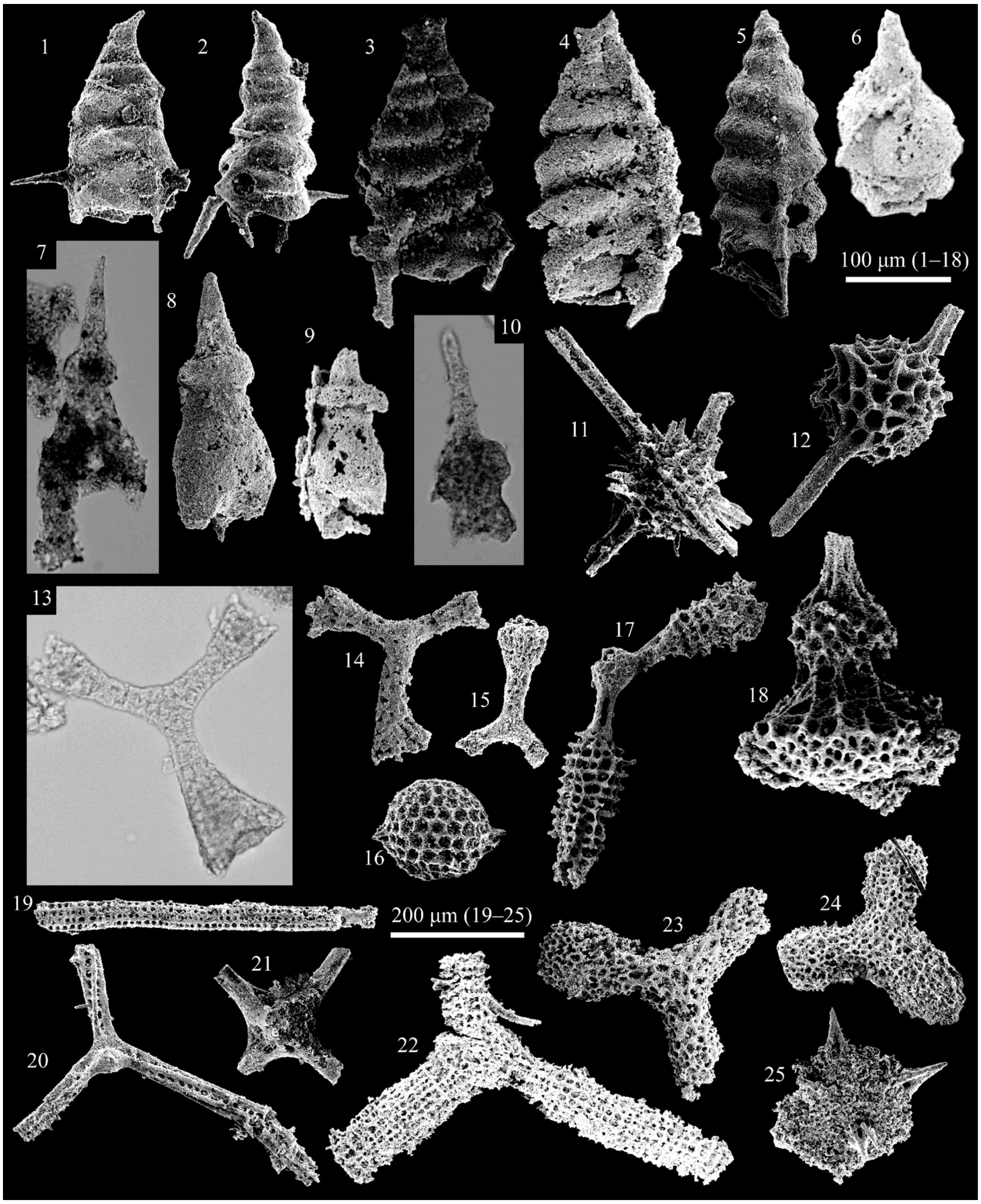

Fig. 7 Photomicrographs of Permian radiolarian fossils from the Yoshii Group in the Otakeyama area. 1, 2, 15, 16, 19, 21, 24: IT11033008; 3, 4, 14, 18, 23: IT08062002; 5, 12, 13, 17: IT07102614; 6, 8–10: IT07102909; 7: IT07102903; 11, 20, 22, 25: IT1103108. 1–5: *Albaillella sinuata* Ishiga and Watase; 6: *Pseudoalbaillella* sp. cf. *P. globosa* Ishiga and Imoto; 7, 8: *Pseudoalbaillella internata* Wang; 9: *Pseudoalbaillella* sp. cf. *P. internata*; 10: *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga and Imoto; 11: *Entactinia itsukaichiensis* Sashida and Tonishi; 12: *Entactinia*? sp.; 13, 14: *Cauletella manica* (De Wever and Caridroit); 15: *Ishigaum trifustis* De Wever and Caridroit; 16: *Trilonche*? sp.; 17: *Pseudotormentus kamigoriensis* De Wever and Caridroit; 18: Latentifistulidae? gen. et sp. indet.; 19: Gen. et sp. indet.; 20: *Quadriremis scalae* (Caridroit and De Wever); 21: Sponge spicule?; 22: *Latentibifistula*? sp.; 23, 24: *Latentifistula texana* Nazarov and Ormiston; 25: *Copicyntra*? sp.

5.2 Unit Ot 2

Radiolarians were obtained from three samples (IT11033108, IT07102920, and IT08062002) of the Otake Formation of Unit Ot 2, and one sample (IT07102922) of the Lower Member of the Mihara Formation yielded radiolarians. Samples IT07102920 and IT11033108 are gray chert; sample IT08062002 is red chert at the upper part of the Otake Formation, and sample IT07102922 is grayish-green siliceous mudstone of the Lower member of the Mihara Formation.

Valuable radiolarians for age assignment were obtained from sample IT08062002. *Albaillella sinuata* Ishiga and Watase were obtained from the sample. *Albaillella sinuata* is the characteristic species of the *A. sinuata* Range-Zone (middle Cisuralian) of Ishiga (1986, 1990). Therefore, this

Table 1 List of Permian radiolarian fossils from the Yoshii Group. Sample localities are shown in Figs. 3 and 4.

Sample number	IT07102903	IT07102909	IT07102917	IT11033108	IT07102920	IT08062002	IT07102922	IT11033008	IT07102925	IT07102614	IT07102612
Unit (Ot-)	1	1	1	2	2	2	2	3	3	3	3
Formation	L	L	L	O	O	O	L	O	O	O	L
Lithology	sm	sm	sm	ch	ch	ch	sm	ch	ch	ch	sm
Radiolarian zone	*Pg*	*Pg*	-	-	-	*As*	-	*As*	-	*As*	-
Albaillella sinuata Ishiga & Watase						+		+		+	
Albaillella spp.						+		+	+		+
Pseudoalbaillella internata Wang	+	+									
Pseudoalbaillella sp. cf. *P. globosa* Ishiga & Imoto		+									
Pseudoalbaillella sp. aff. *P. longicornis* Ishiga & Imoto										+	
Pseudoalbaillella spp.		+	+		+		+	+		+	+
Latentifistula texana Nazarov & Ormiston						+		+			
Latentifistula spp.	+	+			+		+				
Latentibifistula? sp.				+							
Quadriremis scalae (Caridroit & De Wever)				+							
Pseudotormentus kamigoriensis De Wever & Caridroit	+	+						+		+	
Ishigaum trifustis De Wever & Caridroit								+		+	
Arm of *Ishigaum trifustis*				+		+		+			
Cauletella manica (De Wever & Caridroit)						+				+	
Entactinia itsukaichiensis Sashida & Tonishi				+				+			
Entactinia? spp.				+		+		+	+	+	+
Copicyntra? sp.				+							
Trilonche? sp.								+			
Latentifistulidae? gen. et sp. indet.						+					

Notes: Lithology: ch = chert, sm = siliceous mudstone. Formation: O = Otake Formation; L = Lower Member of the Mihara Formation. Radiolarian zone: *Pg* = *Pseudoalbaillella globosa* Assemblage-Zone; *As* = *Albaillella sinuata* Range-Zone.

sample corresponds to the *A. sinuata* Range-Zone.

5.3 Unit Ot 3

Radiolarians occurred in three samples (IT11033008, IT07102925, and IT07102614) of the Otake Formation and in one sample (IT07102612) of the Lower Member of the Mihara Formation. Sample IT11033008 is gray chert near the lowermost part of the Otake Formation of Unit Ot 3 (30 cm above the boundary fault (Fig. 6) between Units Ot 2 and Ot 3); sample IT07102925 is gray chert located near the lowermost part of the Otake Formation of Unit Ot 3, and sample IT07102614 is red chert near the uppermost part of the Otake Formation. Sample IT07102612 is greenish-gray siliceous mudstone near the lowermost part of the Upper member of the Mihara Formation.

Valuable radiolarians for age assignment occurred in samples IT11033008 and IT07102614. Both samples yielded *A. sinuata*. Hence, these samples correspond to the *A. sinuata* Range-Zone of Ishiga (1986, 1990).

Sano et al. (1987) reported radiolarian occurrences in the Yoshii Group at five points in the Otakeyama area. Radiolarians from three samples (G1, G3, and J1) at these points are valuable for age assignment. All points are considered to correspond to the upper part of the Lower Member of the Mihara Formation. *Follicucullus monacanthus* Ishiga and Imoto were obtained from G1 and G3; *F.* sp. cf. *F. monacanthus* occurred in J1. *Follicucullus monacanthus* is the characteristic species of the *F. monacanthus* Range-Zone (middle Guadalupian) of Ishiga (1986, 1990), indicating that these samples correspond to the *F. monacanthus* Range-Zone.

Sada et al. (1992) also obtained radiolarians from the Yoshii Group at five points in the Otakeyama area. Among these, valuable radiolarians for age assignment occurred at one point (85101903). Black siliceous mudstones crop out at this point (Sada et al., 1992). *Pseudoalbaillella* sp. cf. *P. fusiformis* (Holdsworth and Jones) occurred in 85101903. The illustrated specimen of *P.* sp. cf. *P. fusiformis* has a pseudoabdomen similar to *P. fusiformis*, but it has broken wings. *Pseudoalbaillella internata* also has a similar pseudoabdomen but a different wing shape. Therefore, this specimen is assignable possibly to *P. internata*. *Pseudoalbaillella fusiformis* occurs in the upper *P. longtanensis* Assemblage-Zone to the *P. globosa* Assemblage-Zone (upper Cisuralian to lower Guadalupian) (Ishiga, 1986, 1990); *P. internata* is abundant in the upper *P. globosa* Assemblage-Zone. Therefore this sample corresponds to the upper *P. longtanensis* Assemblage-Zone to the *P. globosa* Assemblage-Zone. The occurrence of *F. scholasticus* was also reported by Sada et al. (1992). However, the illustrated specimen of *F.scholasticus* has no flap which is one of the important identification criteria. Hence, we do not deal with this datum in this paper.

5.4 Unit Ot 4

No radiolaria occurred in Unit Ot 4. Most cherts are crystallized and include no fossils. Some siliceous mudstones do not yield radiolarian tests, but contain sponge spicules.

6 Discussion

6.1 Relations between lithostratigraphy and radiolarian age in each unit

In this section, we show the relationship between lithostratigraphy and radiolarian age assignments in each unit. We then reconstruct the ocean plate stratigraphy (OPS) of each unit and compare them. The reconstructed OPS for each unit is summarized in Fig. 8.

The Lower Member of the Mihara Formation of Unit Ot 1 yielded radiolarians corresponding to the upper *P. globosa* Assemblage-Zone. *Albaillella sinuata*, which is

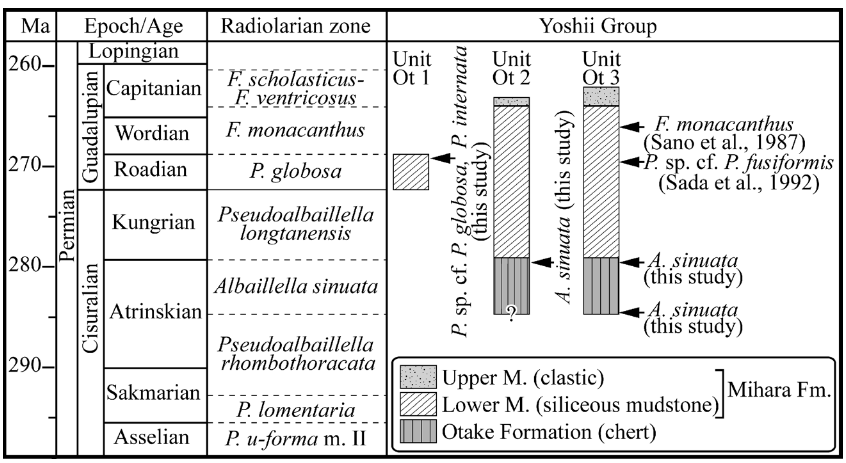

Fig. 8 Radiolarian age of the Units Ot 1, Ot 2, and Ot 3 of the Yoshii Group. Radiolarian zones are after Ishiga (1986, 1990) and Kuwahara et al. (1998).

the characteristic species of the *A. sinuata* Range-Zone, occurred in the uppermost part of the Otake Formation of Units Ot 2 and Ot 3 and the lowermost part of the Otake Formation of Unit Ot 3. Additionally, in previous studies (Sano et al., 1987; Sada et al., 1992), *P.* sp. cf. *P. fusiformis* (corresponded to the upper *P. longtanensis* Assemblage-Zone to the *P. globosa* Assemblage-Zone) and *F. monacanthus* (characteristic radiolarians of the *F. monacanthus* Range-Zone) occurred throughout the Lower Member of the Mihara Formation. The uppermost parts of the Otake Formation of Units Ot 2 and Ot 3 are correlated on the basis of the above-mentioned radiolarian occurrences. The Lower Member of the Mihara Formation of Unit Ot 1 corresponds to at least a part of the Lower Member of the Mihara Formation of Unit Ot 3. In other words, the OPSs for these units are approximately the same age. These results, in addition to the lithological similarities, suggest that these units exhibit almost identical OPSs.

6.2 Imbricate structure in the Akiyoshi terrane

The lithological characteristics and radiolarian age of the Yoshii Group in the Otakeyama area suggest that the units exhibit almost identical OPS. Additionally, these units are structurally-repeated, forming an imbricate structure.

The Yoshii Group corresponds to some geologic bodies of the Akiyoshi terrane on the basis of lithological characters and radiolarian age, such as the Nishiki Group (Ishiga et al., 1986; Naka et al., 1986), the Beppu Group (Kametaka, 2006), the Notabiyama Formation (Goto, 1988), the Ota Group (Uchiyama et al., 1986), the Yobuno Group (Yanase and Isozaki, 1993; Nakae et al., 1998), and the Himekawa Complex (Kawai and Takeuchi, 2001; Tazawa et al., 2002) (Fig. 1).

Nakae et al. (1998) recognized an imbricate structure in the Otsumi Unit of the Yobuno Group. Additionally, the probable presence of imbricate structures in some geologic bodies are confirmable on the basis of their geological maps. For example, the Nishiki Group of the Muikaichi-cho area is composed of the Na, Nb, and Nc formations (Ishiga et al., 1986; Naka et al., 1986). These formations constitute a CCS. Sandstones of the Nc Formation structurally underlie chert of the Na Formation judging from their geological maps (Figs. 2, 3, and 5 of Naka et al., 1986). Uchiyama et al. (1986) showed repetitions of chert and mudstone in the Ota Group in the Akiyoshi area (Fig. 2 of Uchiyama et al., 1986). Tazawa et al. (2002) showed repetitions of chert and mudstone in the Himekawa Complex in the Omi area (Fig. 2 of Tazawa et al., 2002). Previous studies, in addition to the present study, indicate that an imbricate structure is common in the Akiyoshi terrane.

An imbricate structure is common in the Jurassic accretionary complexes in Japan (e.g., Yao et al., 1980; Matsuoka, 1984; Otsuka, 1988; Kamata, 2000). This structure is interpreted as an accretionary wedge formed by off-scrape accretion at the toe of the inner-trench slope (e.g., Matsuoka, 1992). As mentioned above, the Yoshii Group in the Otakeyama area is characterized by an imbricate structure composed of lithostratigraphically- and biostratigraphically-repeated CCSs. If this structure reflects the primary structure, the Yoshii Group was also formed by successive off-scrape accretion (Fig. 9).

In Jurassic accretionary complexes in Japan, the bottoms of most CCSs are characterized by siliceous claystone (e.g., Sugiyama, 1992). The siliceous claystone is assignable to the uppermost Permian to lowermost Triassic (e.g., Sano, 1988; Ezaki and Kuwahara, 1997; Isozaki, 1997), and it is physically weaker than other stratigraphic intervals composed of chert. Accordingly, the siliceous claystone played a role as a décollement zone in Jurassic accretionary processes (e.g., Kimura and Hori, 1993; Matsuoka et al., 1994, 1996). As pointed out previously, an imbricate structure is common in the Akiyoshi terrane. This characteristic indicates the possibility that a specific horizon of pelagic sequences acted as a décollement zone. *Albaillella sinuata*, the characteristics species of the *A. sinuata* Range-Zone (middle Cisuralian), occur in chert near the lowermost part of the Otake Formation of Unit Ot 3 in this study. Consequently, the specific horizon might correspond to the middle Cisuralian if it exists.

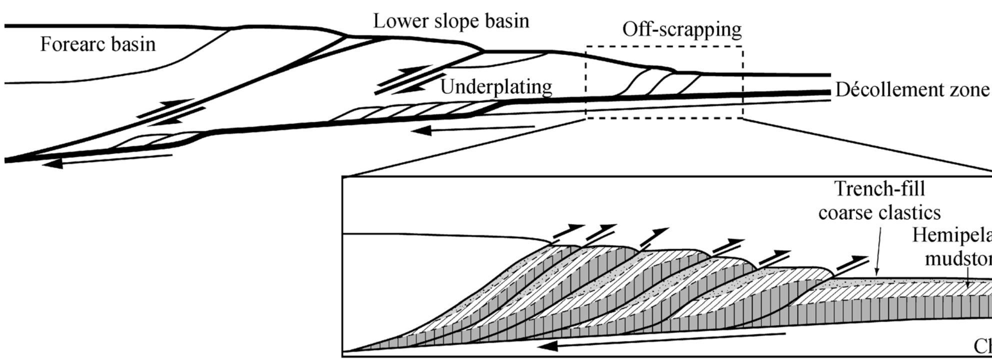

Fig. 9 Schematic reconstruction of off-scrape accretion of the Akiyoshi terrane and overall view modified from previous studies (e.g., Matsuoka, 1992; Kimura, 1997).

7 Conclusions

1) The Yoshii Group in the Otakeyama area comprises the Otake and Mihara formations in ascending order. The Mihara Formation is subdivided into the Lower and Upper members. The Otake Formation is composed of cherts; the Lower Member of the Mihara Formation consists mainly of siliceous mudstones with interbedded tuff, and the Upper Member is composed mainly of sandstones and mudstones. These formations constitute a chert-clastic sequence.

2) Four structural units of chert-clastic sequences (Units Ot 1, Ot 2, Ot 3, and Ot 4) are recognized in the Yoshii Group in the Otakeyama area. These cherts-clastic sequence units are repeated.

3) On the basis of radiolarian occurrences, the uppermost part of the Otake Formation in Units Ot 2 and Ot 3 are assigned to the *Albaillella sinuata* Range-Zone (middle Cisuralian); the Lower Member of the Mihara Formation in Unit Ot 1 partly corresponds to the *Pseudoalbaillella globosa* Assemblage-Zone (lower Guadalupian). The uppermost parts of the Otake Formation of Units Ot 2 and Ot 3 are correlated. The Lower Member of the Mihara Formation of the units Ot1 corresponds to at least a part of the Lower Member of the Mihara Formation of Unit Ot 3.

4) Lithological similarities and radiolarian age suggest that these chert-clastic sequences had almost identical OPSs. These units are structurally-repeated to form an imbricate structure composed of lithostratigraphically- and biostratigraphically-repeated chert-clastic sequences.

5) A review of previous studies indicates that an imbricate structure is common in the Akiyoshi terrane. An imbricate structure in the Jurassic accretionary complexes is interpreted as an accretionary wedge formed by off-scrape accretion at the toe of the inner-trench slope. If the imbricate structure of the Yoshii Group reflects its primary structure, the Yoshii Group was also formed by successive off-scrape accretion.

6) In Jurassic accretionary processes, the uppermost Permian to lowermost Triassic siliceous claystone played a role as a décollement zone because of its physical weakness. An imbricate structure is common in the Akiyoshi terrane, indicating the possibility that a specific horizon of pelagic sequences acted as a décollement zone. The specific horizon might correspond to the middle Cisuralian.

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