Ofioliti, 2017, 42 (1), 39-54 - doi: 10.4454/ofioliti.v42i2.447

REVIEW OF MICROFOSSIL-BEARING CLASTS WITHIN LATE MESOZOIC STRATA IN EAST ASIA: STAGED DENUDATION OF MID-MESOZOIC ACCRETIONARY COMPLEXES

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Keywords: *radiolaria, conglomerate, denudation, accretionary complex, Late Mesozoic, Japan, Korean Peninsula, East Asia.*

ABSTRACT

Late Mesozoic neritic-continental strata of East Asia show intercalations of conglomerates including microfossil-bearing clasts. Some clasts are presumed to have originated in mid-Mesozoic accretionary complexes (ACs) of East Asia. Microfossils (e.g., radiolaria, conodonts) in these clasts can provide age constraints. Relationships between rock facies and age in sequences of the mid-Mesozoic ACs have been clarified in previous studies; therefore, the rock facies and the age of the clasts offer a clue about denudation history and provenance of the mid-Mesozoic ACs. This study compiles previous studies of microfossil-bearing clasts within the Late Mesozoic in the Outer and Inner zones of Southwest Japan and in the Gyeongsang Supergroup in the southeastern Korean Peninsula.

The compilation, at present, recognizes three denudation stages (Stages A, B, and C) of the mid-Mesozoic ACs. Stage A (Oxfordian-Hauterivian) is characterized by an initial and narrow denudation. The denudation of the mid-Mesozoic ACs started at some point in this stage, but it was of limited extent. Stage B (Barremian-early Albian) is characterized by wide denudation: the mid-Mesozoic ACs became largely exposed. Afterwards, some younger geologic bodies of the mid-Mesozoic ACs, which were structurally underlying, were exposed and denuded. Stage C (late Albian–) is characterized by denudation of almost all the mid-Mesozoic ACs. This denudational evolution might be related to some tectonic and igneous events in East Asia, such as the uplift of the Tetori Group in the late Hauterivian-early Barremian and the initiation of the granitic magmatic activity in the middle Albian.

INTRODUCTION

The Japanese Islands are composed of several geologic units related to active subduction along an orogenic front (e.g., Ichikawa, 1990; Isozaki et al., 2010). These geologic units underwent several processes, such as deformation, metamorphism, exhumation, and denudation. Mid-Mesozoic Accretionary Complexes (ACs), comprising the Tamba-Mino-Ashio, Chichibu composite, Samarka, Khabarovsk, Taukha, and other terranes, are widely exposed in East Asia (e.g., Wakita and Metcalfe, 2005) (Fig. 1a).

Some Late Mesozoic strata show intercalations of siliceous and muddy clasts which are presumed to have originated in the mid-Mesozoic ACs.

In general, clasts within sediments are supplied from the surrounding geologic units and indicate the provenance. Some researchers have investigated the clasts within the Late Mesozoic strata and discussed their provenance by petrology and geochemistry (e.g., Asiedu et al., 2000; Lee and Lee, 2000). Some previous studies have clarified that (i) sediments within the Hayang Group of the Gyeongsang Supergroup in the southeastern Korean Peninsula include clasts which derived from mid-Mesozoic ACs (e.g., Lee and Kim, 2005); (ii) sediments within the Tetori Group of Southwest Japan include quartzite clasts which derived from basement rocks of the southeastern Korean Peninsula (e.g., Kim et al., 2007). These data indicate that Southwest Japan and the southeastern Korean Peninsula had close paleogeographic relationships and exchanged sediment supply in the Middle-Late Mesozoic (Lee, 2008). Microfossils, such as radiolaria and conodonts, can assign the age to the siliceous and muddy clasts which derived from ACs. Some researchers determined the initiation of the denudation of the mid-Mesozoic ACs based on the age of the microfossil-bearing clasts found within Late Mesozoic neritic-continental strata in East Asia. Takeuchi et al. (1991) presumed that Triassic and Jurassic radiolarian-bearing clasts within the Tetori Group in the Toyama Prefecture derived from the mid-Mesozoic ACs. They concluded that the mid-Mesozoic ACs were already uplifted and denuded in the late Neocomian (Early Cretaceous). Matsukawa and Takahashi (1999) found Permian and Triassic radiolarians from chert clasts within the Otaniyama Formation of the Tetori Group in the Gifu Prefecture. They proposed that the mid-Mesozoic ACs had been exhumed earlier than the age presumed by Takeuchi et al. (1991). Kamata et al. (2000) discovered latest Jurassic (Tithonian) radiolarians, which occur commonly in muddy rocks of the mid-Mesozoic ACs, in conglomerates of the Kisadong Formation of the Hayang Group in the southeastern Korean Peninsula. They speculated that the latest Jurassic ACs were uplifted on land during deposition of the Hayang Group. Traditionally, Southwest Japan has been geologically subdivided into the Inner and Outer zones (e.g., Ichikawa, 1990). Ishida et al. (2003) compiled radiolarian-bearing clasts within the Inner and Outer zones of Southwest Japan and the Hayang Group. These authors indicate that denudation of the mid-Mesozoic ACs started during Late Jurassic at least in the Outer Zone and possibly in the Inner Zone, and intensified during Early Cretaceous.

The mid-Mesozoic ACs in East Asia are characterized by long-term accretion, suggesting that their denudation should also occurred in stages. The initiation of the ACs denudation

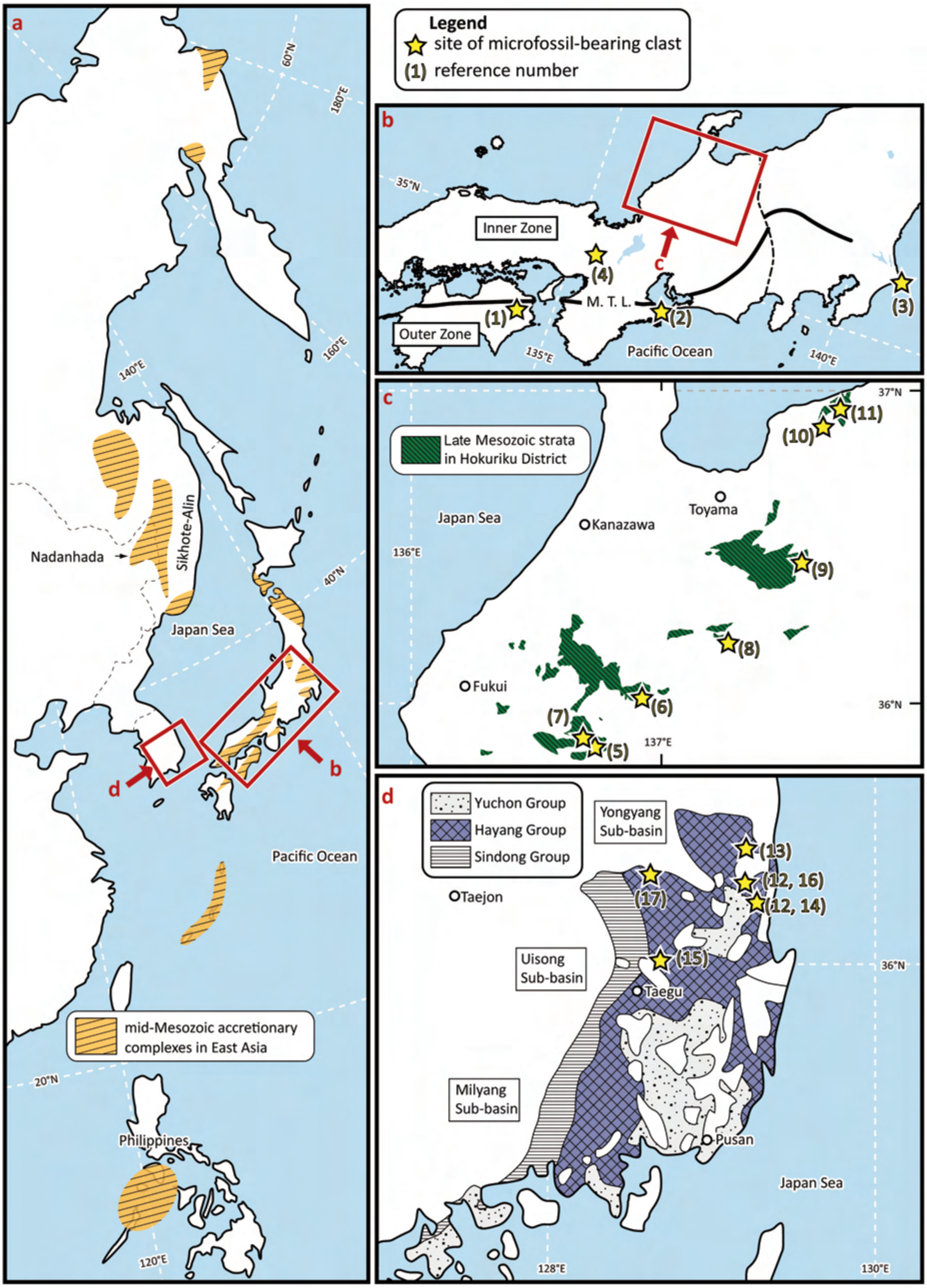

Fig. 1 - Index maps of the examined microfossil-bearing clasts. (a) mid-Mesozoic accretionary complexes in East Asia (modified from Kojima and Kametaka, 2000), (b) Inner Zone and Outer Zone of Southwest Japan, (c) Late Mesozoic strata in the Hokuriku District (modified from Maeda, 1961), (d) Sub-basins of the Gyeongsang Supergroup in the southeastern Korean Peninsula (modified from Mitsugi et al., 2001). M.T.L.: Median Tectonic Line. Reference numbers: 1: Ishida and Hashimoto (1997), Ishida (1999); 2: Umeda and Sugiyama (1998); 3: Kashiwagi and Isaji (2015); 4: Umeda et al. (1995); 5: Saida (1987); 6: Matsukawa and Takahashi (1999); 7: Ito et al. (2015b); 8: Kojima (1986); 9: Takeuchi et al. (1991); 10: Tomita et al. (2007), Takeuchi et al. (2015b); 11: Ito et al. (2012, 2014); 12: Chang et al. (1990), Yao and Chang (1990); 13, 14: Kamata et al. (2000); 15, 16: Mitsugi et al. (2001); 17: Mitsugi et al. (2001), Chang et al. (2003); 18: Adachi and Choi (1995). The reference numbers correspond to Fig. 3 and Tables 1, 2, and 3; however, an occurrence site by Adachi and Choi (1995) (= 18) is not shown in this figure, and there are two occurrence sites by Chang et al. (1990) and Yao and Chang (1990) (= 12).

has been discussed in several papers, but few researches have shown a staged denudation. This is because fossils valuable for age assignments are scarce in microfossil-yielding conglomerates of the Late Mesozoic. Recently, new ammonoid fossils have been found in the Tetori Group of the Inner Zone of Southwest Japan (e.g., Sato and Yamada, 2005; Goto, 2007; Sato et al., 2008; Handa et al., 2014; Goto and Handa, 2014). Additionally, zircon U-Pb ages have been determined on sandstones of the Late Mesozoic in the Inner Zone and the Gyeongsang Supergroup (e.g., Hayashi et al., 2010; Lee et al., 2010; Kawagoe et al., 2012; Takeuchi et al., 2015a). These recent advances allowed to revise the age assignments of the strata. Furthermore, in recent years the authors and others studied microfossil-bearing clasts within the Late Mesozoic strata in the Inner Zone (Ito et al., 2010; 2012; 2014; 2015b; Sakai et al., 2012). This study synthesizes previous studies of microfossil-bearing clasts and recently-revised ages of microfossil-yielding conglomerates of the Outer and Inner zones of Southwest Japan and of the Gyeongsang Supergroup in the southeastern Korean Peninsula. On the basis of this compilation, our paper attempts to draw a staged denudation history of the mid-Mesozoic ACs in the late Mesozoic.

GENERAL FEATURES OF AN ACCRETIONARY COMPLEX AND PROCESSES OF CLAST SUPPLY

The mid-Mesozoic ACs are composed mainly of oceanic deposits and terrigenous clastics comprising chert-clastic sequences (chert, siliceous mudstone, mudstone, and sandstone in ascending order). This lithologic change from pelagic deposits to terrigenous clastics, reflects transition from abyssal plain to trench, indicates an ocean plate stratigraphy (e.g., Matsuda and Isozaki, 1991; Kimura and Hori, 1993) (Fig. 2). Relationships between lithostratigraphy and biostratigraphy of chert-clastic sequences in the mid-Mesozoic ACs have been clarified using microfossils (e.g., Matsuoka et al., 1998; Nakae, 2000): pelagic cherts range from Pennsylvanian (Late Carboniferous) to Late Jurassic; hemipelagic siliceous mudstones and terrigenous clastics range from Late Triassic to earliest Cretaceous. The Tamba Belt Research Group (1995) found Middle Triassic radiolarians in mudstones of the Tamba terrane of Southwest Japan.

An AC grows by accretion at a convergent plate boundary and is characterized most often by landward dipping units (Mascle et al., 1986). Consequently, the age of these units becomes systematically younger seawards and structurally downwards. In the mid-Mesozoic ACs, the age of the uppermost chert and the age of the siliceous mudstone and coarse clastics of the sequences become systematically younger southwards and structurally downwards (e.g., Matsuoka, 1992). Constituents of an AC are landward driven by younger ACs and then exhumed. The exhumed constituents are then denuded and finally supplied to sedimentary basins (Fig. 2).

LATE MESOZOIC NERITIC-CONTINENTAL STRATA INCLUDING MICROFOSSIL-BEARING CLASTS

Some microfossil-bearing clasts, presumed to have originated in the mid-Mesozoic ACs, have been reported from some Late Mesozoic neritic-continental strata in the Outer and Inner zones of Southwest Japan and in the Gyeongsang Supergroup in the southeastern Korean Peninsula (Fig. 1, 3). In this chapter, we report the inferred ages of the conglomerates yielding the clasts. The details of the microfossil-bearing clasts are shown in Tables 1, 2, and 3. Age assignments in this paper are after Gradstein et al. (2012).

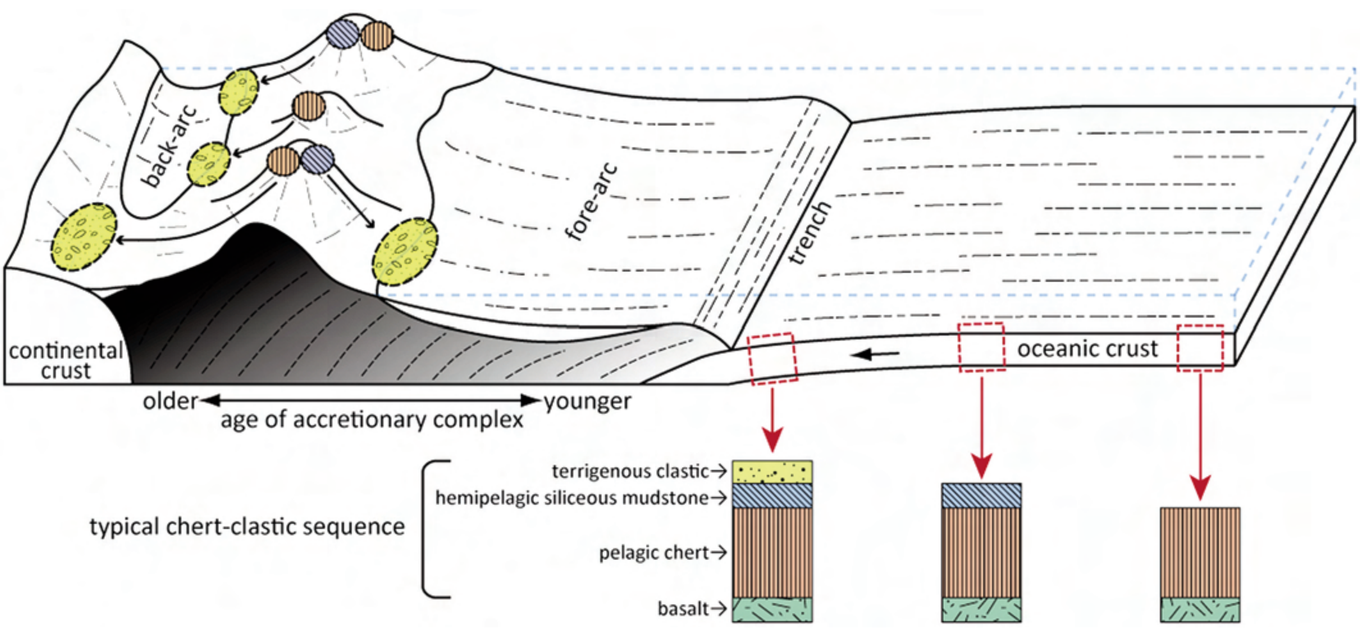

Fig. 2 - Simplified scheme of an orogenic front showing the processes from accretion to re-deposition via exhumation and denudation.

Table 1 - Major microfossil occurrences from clasts within the Late Mesozoic neritic-continental strata in the Outer Zone of Southwest Japan (presumed to have originated in mid-Mesozoic accretionary complexes of East Asia).

large zone and country	No.	reference	area	name of geologic unit (e.g., Group, Formation, Member)		age of conglomerate including microfossil-bearing clasts	rock facies of clast [sample number]	observation method	major fossil occurrence	age of clast [reference]
Outer Zone of Southwest Japan	1	Ishida & Hashimoto (1997); Ishida (1999)	Tokushima area, East Shikoku	Monobegawa Group	Tatsukawa Formation	Hauterivian	dark-gray chert clast [Peb 1 (940815-11)]	residue	*Follicucullus porrectus* Rudenko	late Guadalupian–earliest Lopingian [Ishiga, 1986; Zhang et al., 2014]
							graysh-blue chert clast [Peb 2 (940815-11)]	residue	*Pseudostylosphaera japonica* (Nakaseko & Nishimura), *Beturiella robusta* Dumitrica, Kozur & Mostler	late Anisian–early Ladinian [Dumitrica et al., 1980]
							graysh-green chert clast [Peb 3 (940815-11)]	residue	*Sarla* (?) *extenta* Blome, *Palaeosaturnalis* spp.	early Carnian [Sugiyama 1997; O'Dogherty et al., 2009b]
							plural chert clasts [Pebs 1 (940815-11)]	residue	*Follicucullus porrectus* Rudenko, *Pseudostylosphaera japonica* (Nakaseko & Nishimura), *Pseudostylosphaera* sp., *Eptingium nakasekoi* Kozur & Mostler, *Tiborella cochleata* (Nakaseko & Nishimura), *Capnodoce sarisa* De Wever, *Palaeosaturnalis* spp.	Permian–Triassic (including Capitanian–early Wuchiapingian [Ishiga 1986; Zhang et al., 2014], early Norian [Sugiyama 1997] radiolarians at least)
					Lower Hanoura Formation	Barremian	blue-gray chert clast [Peb 4 (940815-2)]	residue	*Hinedorcus holdsworthi* Sugiyama	Olenekian–early Anisian [Sugiyama, 1992, 1997]
							graysh-blue chert clast [Peb 5 (940815-2)]	residue	*Pseudostylosphaera spinulosum* (Nakaseko & Nishimura), *Pseudostylosphaera* sp.	Anisian–early Carnian [Bragin, 1991; Sugiyama, 1997]
							graysh-blue chert clast [Peb 6 (940815-2)]	residue	*Triassocampe longicephalis* Kozur & Mostler	early Ladinian [Kozur & Mostler, 1994]
							graysh-bark chert clast [Peb 7 (940815-2)]	residue	*Capnodoce sarisa* De Wever, *Theocorys* sp. A of Nakaseko & Nishimura	early Norian [Sugiyama, 1997]
							gray chert clast [Peb 8 (940815 2)]	residue	*Parahsuum simplum* Yao, *Gigi fustis* De Wever	Pliensbachian–early Toarcian [Carter et al., 2010]
							plural chert clasts [Pebs 2 (940815-2)]	residue	*Pseudostylosphaera japonica* (Nakaseko & Nishimura), *Pseudostylosphaera* sp., *Eptingium nakasekoi* Kozur & Mostler, *Palaeosaturnalis* spp.	Middle–Late Triassic (including Anisian [Sugiyama, 1997] radiolarians at least)
							plural chert clasts [Pebs 3 (940815-3)]	residue	*Hozmadia reticulata* Dumitrica, Kozur & Mostler, *Triassocampe* sp. aff. *T. scalaris* Dumitrica, Kozur & Mostler, *Annulotriassocampe campanilis* Kozur & Mostler, *Pararuesticyrtium mediofassanicum* Kozur & Mostler, *Eptingium manfredi robustum* Kozur & Mostler, *Corum speciosum* Blome	Middle–Late Triassic (including early–Middle Norian [Tekin, 1999] radiolarian at least)
							black mudstone clast [Mpeb 1 (940815-11)]	residue	*Striatojaponocapsa plicarum* (Yao), *Striatojaponocapsa conexa* (Matsuoka)	late Bathonian–early Callovian [Matsuoka 1995]
							black mudstone clast [Mpeb 2 (940815-3)]	residue	*Striatojaponocapsa conexa* (Matsuoka)	late Bathonian–Oxfordian [Matsuoka 1995]
	2	Umeda & Sugiyama (1998)	Toba area, Mie Prefecture	Shiranezaki Formation		Oxfordian?	green siliceous rock clast [BD-1]	residue	*Albaillella* sp. cf. *A. asymmetrica* Ishiga & Imoto, *Pseudoalbaillella eurasiatica* Kozur, Krahl & Mostler	late Cisuralian –middle Guadalupian [Ishiga, 1986]
							green siliceous rock clast [BD-2]	residue	*Pseudoalbaillella* sp., *Pseudoalbaillella monacantha* (Ishiga & Imoto), *Follicucullus* sp., *Follicucullus* sp., *Latentifistula* sp., "*Nazarovella*" sp.	Wordian-Capitanian [Ishiga, 1986; Zhang et al., 2014; Ito et al., 2015a; Ma et al., 2016]
							green siliceous rock clast [BD-3]	residue	*Pseudoalbaillella monacantha* (Ishiga & Imoto)	Wordian-Capitanian [Ishiga, 1986; Zhang et al., 2014; Ito et al., 2015a; Ma et al., 2016]
							red chert clast [BD-4]	residue	*Follicucullus* sp.	late Guadalupian–Lopingian, earliest Triassic [Ishiga, 1986; Zhang et al., 2014]
							red chert clast [BD-5]	residue	*Latentifistula* (?) sp.	late Paleozoic? [Nazarov & Ormiston, 1986]
							red chert clast [BD-6]	residue	*Capnuchosphaera* sp., *Triassocampe* sp., Nassellaria gen. et sp. indet.	Carnian–early Norian [O'Dogherty et al., 2009b]
							red chert clast [BD-7]	residue	*Capnuchosphaera* sp., *Triassocampe* sp., *Triassocampe* (?) sp., *Xiphothecaella* sp., Nassellaria gen. et sp. indet.	Carnian–early Norian [O'Dogherty et al., 2009b]
							red chert clast [BD-8]	residue	Spine B1 of Sugiyama (1997), Spine B5 of Sugiyama (1997), *Archaeosemantis cristianensis* Dumitrica, *Capnuchosphaera* sp., *Corum* (?) sp. cf. *C.* (?) *delgado* Sugiyama, *Falcispongus calcaneum* Dumitrica, *Hungarosaturnalis* sp., *Japonisaturnalis* sp., *Poulpus* sp. cf. *P. phasmatodes* De Wever, *Poulpus* sp., *Pseudostylosphaera* sp. cf. *P. nazarovi* (Kozur & Mostler), Saturnalidae gen. et sp. indet., *Spongoserrula* sp. cf. *S. dehli* Cordey, De Wever, Dumitrica, Kito & Vrielynck, *Spongoserrula* sp., *Triassocampe* sp. cf. *T. baldii* Kozur, *Triassocampe* sp., *Triassocampe* (?) sp., *Tritortis* sp. cf. *T. kretaensis* (Kozur & Krahl), *Veles* sp.	late Ladinian–early Carnian [Sugiyama, 1997; O'Dogherty et al., 2009b]
	3	Kashiwagi & Isaji (2015)	Choshi area, Chiba Prefecture	Choshi Group	Ashikajima Formation	Barremian	chert gravel [120723-1-3]	residue	*Amphipyndax* (?) sp., *Eucyrtidiellum* sp., *Sella* sp. cf. *S. chrafatensis* (El Kadiri), *Sethocapsa* (?) sp., *Spongocapsula* (?) sp., *Stichocapsa japonica* Yao, *Stichocapsa* (?) or *Tetracapsa* (?) spp., *Striatojaponocapsa* sp., *Syringocapsa* sp., *Williriedellum* sp. cf. *W. carpathicum* Dumitrica, *Williriedellum* sp. cf. *W. dierschei* Suzuki & Gawlick, and Tri-cyrtid nassellaria	late Bathonian–early Callovian [Baumgartenr et al., 1995; Matsuoka, 1995]
							chert gravel [120723-1-6]	residue	*Pseudoalbaillella* sp. cf. *P. monacanhta* (Ishiga & Imoto)	Wordian-Capitanian* [Ishiga, 1986; Zhang et al., 2014; Ito et al., 2015a; Ma et al., 2016]

* The age assignment is based on compared species (cf.). ** According to Kashiwagi and Isaji (2015), specimens of *Striatojaponocapsa* sp. can be identified as *S. conexa* (Matsuoka), *S. plicarum* (Yao), and/or *S. syn-conexa* O'Dogherty, Goričan and Dumitrica, because of its morphological characters.

Table 2 - Major microfossil occurrences from clasts within the Late Mesozoic neritic-continental strata in the Inner Zone of Southwest Japan (presumed to have originated in mid-Mesozoic accretionary complexes of East Asia).

large zone and country	No.	reference	area	name of geologic unit (e.g., Group, Formation, Member)		age of conglomerate including microfossil-bearing clasts	rock facies of clast [sample number]	observation method	major fossil occurrence	age of clast [reference]
Inner Zone of Southwest Japan	4	Umeda et al. (1995)	Sasayama area, Hyogo Prefecture	Sasayama Group	Lower Formation	Albian–Cenomanian	red chert clast [1]	residue	*Canoptum* sp. cf. *C. rugosum* Pessagno & Poisson	Pliensbachian–early Toarcian* [Carter et al., 2010]
							red chert clast [2A]	residue	conodont	Triassic or older
							red chert clast [2B]	residue	*Deflandrecyrtium* sp., *Gorgansium* sp., *Kozurastrum* sp., conodont	late Norian–Rhaetian [O'Dogherty et al., 2009b]
							red chert clast [2C]	residue	*Mesosaturnalis* sp.	middle Norian–Coniacian [O'Dogherty et al., 2009a, 2009b]
							red chert clast [3A]	residue	*Yeharaia* sp., *Muelleritortis* (?) sp. cf. *M. cochleata* (Nakaseko & Nishimura), *Triassocampe deweveri* (Nakaseko & Nishimura), *Triassocampe* sp. cf. *T. myterocorys* Sugiyama	late Anisian–early Ladinian [Sugiyama, 1997]
							red chert clast [4A]	residue	*Triassocampe coronata* Bragin	Anisian [Sugiyama, 1997]
							red chert clast [5B]	residue	*Neoalbaillella* sp., *Albaillella levis* Ishiga, Kito & Imoto	Changhsingian [Kuwahara, 1999]
							red chert clast [5C]	residue	*Albaillella levis* Ishiga, Kito & Imoto, *Ishigaum* sp.	Changhsingian [Kuwahara, 1999]
							red chert clast [5D]	residue	*Neoalbaillella* sp., *Albaillella levis* Ishiga, Kito & Imoto	Changhsingian [Kuwahara, 1999]
							red chert clast [5E]	residue	*Neoalbaillella* sp., *Albaillella levis* Ishiga, Kito & Imoto, *Ishigaum* sp.	Changhsingian [Kuwahara, 1999]
							red chert clast [5F]	residue	*Albaillella levis* Ishiga, Kito & Imoto, *Ishigaum* sp.	Changhsingian [Kuwahara, 1999]
							red chert clast [5G]	residue	*Neoalbaillella* sp., *Albaillella levis* Ishiga, Kito & Imoto	Changhsingian [Kuwahara, 1999]
	5	Saida (1987)	Uppermost reaches of the Kuzuryugawa River, Fukui Prefecture	Tetori Group	Kamihanbara Formation, Itoshiro Subgroup	early Valanginian	conglomerate [1256]	residue	*Japonocapsa*sp. cf. *J. fusiformis* (Yao), *Parahsuum* sp., *Triassocampe*(?) sp.,	Triassic–Jurassic (including Aalenian–early Bajocian* [Matsuoka, 1995] radiolarians at least)
							chert clast [1298]	residue	*Triassocampe*(?) sp., *Archaeospongoprunum* sp., conodont	Triassic? [O'Dogherty et al., 2009b]
							siliceous shale clast	residue	*Triassocampe*(?) sp., Jurassic radiolaria	Triassic?–Jurassic [O'Dogherty et al., 2009b]
	6	Matsukawa & Takahashi (1999)	Upper reaches of the Shokawa River, Gifu Prfecture		Otaniyama Formation, Itoshiro Subgroup	Valanginian	chert clast	?	?	Permian and Triassic**
	7	Ito et al. (2015b)	Taniyamadani, Kuzuryu area, Fukui Prefecture		Itsuki Formation, Itoshiro Subgroup	Barremian	chert granule [IT13050301-2]	etched surface	Spine of *Pseudostylosphaera* (?) sp., *Neogondolella* sp.	Triassic? [O'Dogherty et al., 2009b]
							chert granule [IT13050301-6]	etched surface	*Pseudostylosphaera* (?) sp., *Triassocampe* sp.	Anisian–early Norian [O'Dogherty et al., 2009b]
							chert granule [IT13050304-3]	etched surface	*Pantanellium* sp., *Parahsuum* sp., *Parvincingula* (?) sp., *Hsuum* (?) sp., *Hexasaturnalis* (?) sp.	Hettangian–Kimmeridgian [O'Dogherty et al., 2009a]
							chert granule [IT13050305-1]	etched surface	*Pantanellium* sp., *Parvincingula* (?) sp., closed-end Nassellaria	Carnian–Aptian [O'Dogherty et al., 2009a, b]
							chert granule [IT13050311-2]	etched surface	*Unuma* sp. cf. *U. typicus* Ichikawa & Yao, *Pantanellium* sp., *Eucyrtidiellum* (?) sp., Nassellaria, closed-end Nassellaria	Bajocian–early Bathonian* [Matsuoka, 1995]
							chert granule [IT13050313-2]	etched surface	*Stichocapsa japonica* Yao, *Parahsuum* (?) sp., *Eucyrtidiellum disparile* (Nagai & Mizutani), *Archaeodictyomitra* sp., closed-end Nassellaria	Bajocian [Nagai & Mizutani, 1990; Matsuoka, 1995]
	8	Kojima (1986)	Yokoo, Nyukawa area, Gifu Prfecture	Tetori Group?	Itoshiro Subgroup? (Nozawa et al. 1975)	Early Cretaceous or older	chert clast [JMP882	residue?	*Albaillella levis* Ishiga, Kito & Imoto, *Follicucullus* sp.	Changhsingian [Kuwahara, 1999]
							chert clast [JMP959]***	residue?	*Follicucullus ventricosus* Ormiston & Babcock, *Follicucullus scholasticus* Ormiston & Babcock, *Pseudoalbaillella monacantha* (Ishiga & Imoto), *Pseudoalbaillella* sp., *Ruzhencevispongus* sp.	Capitanian [Ishiga, 1986; Zhang et al., 2014]
	9	Takeuchi et al. (1991)	Upper reaches of the Kurobegawa River, Toyama Prefecture		Yakushizawa-migimata Conglomerate Member, Akaiwa Subgroup	Aptian	conglomerate [Yr64]	residue	*Follicucullus* sp. cf. *F. scholasticus* Ormiston & Babcock morphotype I Ishiga, *Triassocampe deweveri* (Nakaseko & Nishimura), *Pseudostylosphaera* sp. cf. *P. coccostyla* (Rüst)	Permian–Jurassic (including Capitanian–early Wuchiapingian [Ishiga, 1986; Zhang et al., 2014] and late Anisian–Ladinian [Sugiyama, 1997] radiolarians at least)
							chert clast [part of Yr64]	etched surface	*Triassocampe* sp., *Pseudostylosphaera* sp.	Anisian–early Carnian [O'Dogherty et al., 2009b]
							conglomerate [Mt722]	residue	*Hsuum* sp., Nassellaria	Pliensbachian–early Cenomanian [O'Dogherty et al., 2009a]
	10	Tomita et al. (2007); Takeuchi et al. (2015b)	Northeast part of Toyama Prefecture		Lower part of the Kurobishiyama Formation	Aptian	chert clast	?	*Pseudoalbaillella* sp. cf. *P. fusiformis* (Holdsworth & Jones), *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga & Imoto sensu Ishiga et al. (1982)	Kungurian–Wordian* [Ishiga, 1986]
							chert clast [sample c]	?	*Pseudostylosphaera japonica* Nakaseko & Nishimura, *Triassocampe* sp.	Anisian–early Carnian [Sugiyama, 1997]
	11	Ito et al. (2012)	Sakaigawa, Itoigawa area, Niigata Prefecture		Shiritakayama Formation	Albian?	chert clast [IT10050407-1]	etched surface	*Triassocampe* (?) sp.	Middle–Late Triassic?
							chert clast [IT10050201-1]	etched surface	*Pseudostylosphaera* sp. cf. *P. japonica* Nakaseko & Nishimura, Spine A2 of Sugiyama (1997), *Triassocampe* (?) sp.	late Anisian–early Carnian [Sugiyama, 1997]
							chert clast [IT10050302-1]	etched surface	*Archaeodictyomitra* sp.	Jurassic (Pliensbachian–Campanian) [O'Dogherty et al., 2009a]
							chert clast [IT10050302-2]	etched surface	spherical radiolaria? with four spines	?
							siliceous mudstone clast [IT10080721-1]	etched surface	*Archaeodictyomitra* sp., closed-end Nassellaria	Pliensbachian–Campanian [O'Dogherty et al., 2009a]
		Ito et al. (2014)					black siliceous mudstone pebble [IT12050102-1]	etched surface	*Striatojaponocapsa plicarum* (Yao), *Cyrtocapsa mastoidea* Yao, closed-end nassellarians, *Hsuum* sp., *Archaeodictyomitra* sp., *Parvicingula* sp.	Bajocian–early Bathonian [Matsuoka, 1995]

* The age assignment is based on compared species (cf.). ** There is no description of specific radiolarian name. *** There is the possibility that this clast derived from the Akiyoshi terrane because this terrane also contains late Guadalupian Permian cherts (Uchiyama et al., 1986).

Table 3 - Major microfossil occurrences from clasts within the Gyeongsang Supergroup in the southeastern Korean Peninsula (presumed to have originated in mid-Mesozoic accretionary complexes of East Asia).

large zone and country	No.	reference	area	name of geologic unit (e.g., Group, Formation, Member)		age of conglomerate including microfossil-bearing clasts	rock facies of clast [sample number]	observation method	major fossil occurrence	age of clast [reference]
Gyeongsang Supergroup (Korea)	12	Chang et al. (1990); Yao and Chang (1990)	vicinity of Yongdok town, Yongyang Basin	Hayang Group	Kisadong and Donghwachi formations	Albian	conglomerate? [28]*	residue?	*Archaeospongoprunum* sp., *Diacanthocapsa*(?) sp., *Tricolocapsa* sp. A, *Tricolocapsa* sp. B, *Sethocapsa* sp., *Stichocapsa* sp. aff. *S. japonica* Yao, *Canoptum* sp., *Parvicingula* sp., *Hsuum* sp.	Jurassic (including Bajocian–Callovian [Matsuoka, 1995] radiolarians at least)
							conglomerate? [44a]*	residue?	*Follicucullus*(?) sp., *Archaeospongoprunum japonicum* Nakaseko and Nishimura, *Triassocampe deweveri* (Nakaseko & Nishimura), *Triassocampe* sp. cf. *T.*(?) sp. G of Yao (1982), *Corum* sp. cf. *C.* sp. E of Yao (1982), *Palaeosaturnalis* spp., *Archicapsa* sp., *Tricolocapsa* sp. D, *Archaeodictyomitra* sp., *Parahsuum* sp., *Trilonche*(?) sp., Sponge spicule, Conodont	Permian?, Triassic–Jurassic (including Anisian–early Ladinian [Sugiyama, 1997] radiolarians at least)
							conglomerate? [44b]*	residue?	*Tricolocapsa* sp. C, Hagiastrid	Middle? Jurassic [O'Dogherty et al., 2009a]
	13	Kamata et al. (2000)			Donghwachi Formation	early Albian	conglomerate [97071508 and 97071509]	residue?	*Follicucullus* sp., *Triassocampe* sp., *Pseudostylosphaera* sp., *Poulpus* sp., *Capnuchosphaera* sp., *Staurodoras variabilis* Nakaseko and Nishimura, *Katroma* sp. cf. *K. clara* Yeh, *Pantanellium* sp., *Tricolocapsa* (?) sp.	Middle Permian–Jurassic (including Anisian [Sugiyama, 1997], Pliensbachian–early Toarcian [Hori 1990; Carter et al., 2010] radiolarians at least)
	14				Kisandong Formation	late Albian	conglomerate [97071504]	residue?	*Follicucullus porrectus* Rudenko, *Albaillella triangularis* Ishiga, Kito and Imoto, *Albaillella levis* Ishiga, Kito and Imoto, A. sp., *Tetrarchiplagia simplex* Sugiyama, *Triassocampe coronata* Bragin, *Triassocampe annulata* (Nakaseko and Nishimura), *Pseudostylosphaera japonica* (Nakaseko and Nishimura), *Mulleritortis cochleata* (Nakaseko and Nishimura), *Eptingium* sp., *Anisicrytis* sp., *Triassospongosphaera* sp., *Capnodoce* (?) sp., *Archicapsa* (?) *pachyderma* (Tan), *Plafkerium abbotti* Pessano, *Hsuum altile* Hori, *Gorgansium* sp., *Striatojaponocapsa conexa* (Matsuoka), *Striatojaponocapsa* sp. cf. *S. ruesti* (Tan), *Guexella nudata* (Kocher), *Hsuum maxwelli* Pessagno, *Eucyrtidillum nodosum* Wakita, *Eucyrtidillum pyramis* (Aita), *Eucyrtidillum ptyctum* (Riedel and Samfilippo), *Eucyrtidillum* sp. cf. *E. quinatum* Takemura, *Dictyomitrella* (?) *kamoensis* Mizutani and Kido, *Unuma* sp., *Gongylothorax* sp. cf. *G. sakawaensis* Matsuoka, *Gongylothorax* sp. aff. *G. favosus* Dumitrica, *Archicapsa* sp., *Protunuma* (?) *ochiensis* Matsuoka, *Stylocaps catenarum* Matsuoka, *Sethocapsa* sp. cf. *S. pseudouterculus* Aita, *Williriedellum crystallium* Dumitrica, *Williriedellum* sp. cf. *W. crystallium* Dumitrica, *Parvicingular* sp., *Cecrops* (?) sp. cf. *C.* (?) *sexaspina* Jud, *Thanarla conica* (Aliev), *Praeconocaryomma* (?) sp., *Archaeospongoprunum imlayi* Pessagno, *Pseudodictyomitra primitiva* Matsuoka and Yao, *Cingoloturris carpatica* Dumitrica, *Cingoloturris* sp., *Vallupus laxus* Pessagno and Blome, *Sethocapsa* sp. cf. *S. pseudouterculus* Aita, *Diacanthocapsa* sp. cf. *D. ancus* (Foreman), *Pantanellium* sp., *Archaeodictyomitra* sp., *Parvicingula dhimenaensis* Baumgartner, *Amphipyndax stocki* (Cambell and Clark), *Amphipyndax conicus* Nakaseko and Nishimura	Middle Permian–Early Cretaceous (including Capitanian–early Wuchiapingian [Zhang et al., 2014], Changhsingian [Kuwahara, 1999], Anisian [Sugiyama, 1997], middle Toarcian–early Aalenian [Hori, 1990; Carter et al., 2010], Tithonian [Matsuoka, 1995], Aptian–middle Albian? [O'Dogherty, 1994], Albian–Maastrichtian? [Bragina, 2004], Albian–middle Cenomanian? [Bragina, 2004] radiolarians at least)
	15	Mitsugi et al. (2001)	near Yongchon City		Kumidong Formation	early Albian	red chert pebble [GM1-1]	residue?	*Archicapsa* (?) *pachyderma* Tan, *Striatojaponocapsa plicarum* (Yao), *Striatojaponocapsa* sp. cf. *S. parvipora* (Tan), *Striatojaponocapsa* sp. cf. *S. ruesti* (Tan), *Striatojaponocapsa* sp., *Striatojaponocapsa* (?) sp., *Stichocapsa convexa* Yao, *Eucyrtidiellum unumaense unumaense* (Yao), *Archaeodictyomitra* sp. cf. *A. primigena* Pessagno & Whalen, *Archaeodictyomitra* sp., *Parvicingula* (?) sp., *Hsuum* sp.	Bajocian–early Bathonian [Matsuoka & Yao, 1986; Matsuoka, 1995]
							red chert pebble [GM1-9]	residue?	*Trialatus* sp.	Carnian–early Norian [O'Dogherty et al., 2009b]
							gray chert pebble [GM1-14]	residue?	sponge spicule	?
							gray chert pebble [GM1-15]	residue?	*Silicarmiger* sp.	middle Anisian–early Norian [O'Dogherty et al., 2009b]
							red chert pebble [GM1-21]	residue?	*Triassocampe* sp.	Anisian–early Norian [O'Dogherty et al., 2009b]
							gray siliceous mudstone pebble [GM1-30]	residue?	*Triassocampe* sp., *Canoptum praeanulatum* Pessagno & Whalen, *Canoptum* sp., *Canoptum* (?) sp.	Anisian–early Norian [O'Dogherty et al., 2009b], Rhaetian–Hettanginian [Pessagno & Whalen, 1982]
	16		near Uchondong village		Kisadong Formation	late Albian	red chert pebble [GS-1]	residue?	*Pantanellium* (?) sp.	Jurassic?
							red chert pebble [GS-2]	residue?	*Striatojaponocapsa* sp. cf. *S. ruesti* (Tan), *Striatojaponocapsa* sp., *Eucyrtidiellum unumaense dentatum* Baumagartner, *Protunuma* sp., *Arcanicapsa* (?) sp.	middle Bathonian–early Callovian [Matsuoka, 1995; Baumgartner et al., 1995]
	17	Mitsugi et al. (2001); Chang et al. (2003)	near Andong City		Kumidong Formation	early Albian	red chert pebble (mixed?) [GM2]***	residue?	*Albaillella* sp. cf. *A. protolevis* Kuwahara, *Albaillella* sp. cf. *A. yamakitai* Kuwahara, *Triassocampe coronata* Bragin, *Triassocampe* sp. aff. *T. scalaris* Dumitrica, Kozur & Mostler, *Triassocampe deweveri* Nakaseko and Nishimura, *Pseudostylosphaera* sp. cf. *P. compacta* (Nakaseko and Nishimura), *Pseudostylosphaera japonicum* (Nakaseko and Nishimura), *Parasepsagon* sp. cf. *P. asymmetricus* Kozur & Mostler, *Pararuesticyrtium* (?) *illyricum* (Kozur and Mostler), *Eptingium manfredi* Dumitrica, *Latium* sp., *Parahsuum ovale* Hori and Yao, *Parahsuum takarazawaense* Sashida, *Parahsuum simplum* Yao, *Parahsuum* sp.	Permian–Jurassic (including Wuchiapingian** [Kuwahara, 1999], Anisian [Sugiyama, 1997], and Early Jurassic [Matsuoka, 1995] radiolarians at least)
							gray chert pebble (mixed?) [GM2]***	residue?	*Plafkerium* (?) *anisicum* Kozur & Mostler, *Triassocampe* sp. cf. *T. coronata* Bragin, *Triassocampe diordinis* Bragin, *Triassocampe* sp., *Pseudostylosphaera japonicum* (Nakaseko and Nishimura), *Pseudostylosphaera* sp., *Hozmadia* sp. cf. *H. rotunda* (Nakaseko and Nishimura), *Hozmadia* sp. cf. *H. reticulata* Dumitrica, Kozur and Mostler, *Staurodoras* (?) *variabilis* (Nakaseko and Nishimura), *Tiborella florida* (Nakaseko and Nishimura)	Middle–Late? Triassic (including Anisian [Sugiyama, 1997] radiolarians at least)
	18	Adachi and Choi (1995)	Northern margin of the Yongyang Basin	Hayang Group?	-	middle Aptian–middle Albian	red-brown chert (slightly muddy)	thin section	*Follicucullus scholasticus* Ormiston and Babcock	Capitanian–Wuchiapingian [Ishiga, 1986; Zhang et al., 2014]

* These microfossil occurrences are reported on the basis of plate caption. ** The age assignment is based on compared species (cf.). *** There is no report that these radiolarians were obtained from multiple chert clasts but we assume it so. This is because the authors mentioned that this clast is "less than 10 mm in diameter" and also due to the co-occurrences of different-aged microfossils.

Outer Zone of Southwest Japan

Monobegawa Group

This group is distributed along the Suita-Shokuta tectonic line in Shikoku (Fig. 1b). In the Tokushima area, the Monobegawa Group is subdivided into the Tatsukawa, Lower Hanoura, Upper Hanoura, Hoji, and Fujikawa formations, in ascending order (e.g., Kozai et al., 2005). The Lower Hanoura Formation yielded Barremian ammonoids (e.g., *Shasticrioceras nipponicum* Matsumoto) (Matsukawa and Eto, 1987). Based on the lithostratigraphical relationships with the Lower Hanoura Formation, we inferred that the Tatsukawa Formation correlates to the Hauterivian.

The Tatsukawa and Lower Hanoura formations have conglomerate interbeds including microfossil-bearing clasts (Ishida and Hashimoto, 1997; Ishida, 1999). The Tatsukawa Formation includes Permian chert clasts. Middle and Late Triassic radiolarians are found in chert clasts within both the Tatsukawa and Lower Hanoura formations. In the Lower Hanoura Formation, a chert clast yielded Pliensbachian-early Toarcian radiolarians, such as *Gigi fustis* De Wever; mudstone clasts yielded late Bathonian-early Callovian radiolarians, such as *Striatojaponocapsa plicarum* (Yao) and *Striatojaponocapsa conexa* (Matsuoka).

Shiranezaki Formation

The Shiranzaki Formation is distributed over the Toba area (Fig. 1b). This formation and the Imaura and Matsuo groups cover the mid-Mesozoic ACs and the Kurosegawa belt. Sugiyama et al. (1993) found latest Tithonian-early Valanginian radiolarians [*Pseudodictyomitra carpatica* (Lozynyak)] from the Matsuo Group, which conformably overlies the Shiranezaki Formation. Oxfordian radiolarians [e.g., *Kilinora spiralis* (Matsuoka)] occur in a mudstone bed of the Shiranezaki Formation (Sugiyama et al., 1993). However, *Tricolocapsa tetragona* Matsuoka, which does not occur in Late Jurassic but in Middle Jurassic, co-occurred with radiolarians from the mudstone bed. Umeda and Sugiyama (1998) pointed out the possibility that the Oxfordian radiolarians from the mudstone bed are not autochthonous but redeposited fossils.

Clasts within conglomerates of the middle Shiranezaki Formation yielded radiolarians (Umeda and Sugiyama, 1998). Permian radiolarians occur in siliceous rock clasts; Permian and Middle-Late Triassic radiolarians occur in chert clasts. No Jurassic radiolarians were found in any clasts.

Choshi Group

The Choshi Group, distributed over the Choshi area (Fig. 1b), comprises five formations: the Ashikajima, Kimigahata, Inubozaki, Toriakeura, and Nagasakihana formations in ascending order (Obata et al., 1975; 1982). Barremian ammonoids were found in the Ashikajima and Kimigahata formations (e.g., Obata and Matsukawa, 2007; 2009); Aptian ammonoids occur in the Inubozaki and Toriakeura formations.

Kashiwagi and Isaji (2015) obtained radiolarians from two chert clasts within the Ashikajima Formation. A chert clast yielded Middle Permian radiolarians; another chert clast yielded Middle Jurassic radiolarians (e.g., *Stichocapsa japonica* Yao, *Striatojaponocapsa* sp., *Eucyrtidiellum* sp.).

According to Kashiwagi and Isaji (2015), the specimens of *Striatojaponocapsa* sp. obtained from the chert clast can be identified as *S. conexa*, *S. plicarum* and/or *S. synconexa* O'Dogherty, Goričan and Dumitrica. They therefore concluded that the chert clast has a late Bathonian-early Callovian age.

Inner Zone of Southwest Japan

Sasayama Group

The Sasayama Group, distributed over the Sasayama area (Fig. 1b), is divided into the Lower and Upper formations (Yoshikawa, 1993). It had been thought that the Sasayama Group corresponds to the Tithonian-Cenomanian on the basis of a fission-track dating of tuff (e.g., Matsuura and Yoshikawa, 1992; Yoshikawa, 1993). Hayashi et al. (2010) revised the age assignment of the Sasayama Group. According to them, Albian-Maastrichtian ostracods (e.g., *Mongolocypris*, *Eucypris*) occur in the Lower Formation; the youngest zircon age of the tuff of the Lower Formation is 106±9 Ma. Hayashi et al. (2010) concluded that the Lower Formation corresponds to the Albian-Cenomanian.

Umeda et al. (1995) found conodonts and latest Permian, Middle-Late Triassic, and Early Jurassic radiolarians in chert clasts within the Lower Formation. *Canoptum* sp. cf. *C. rugosum* Pessagno and Poisson was obtained from a chert clast. *Canoptum rugosum* occurs in the Pliensbachian-early Toarcian.

Tetori Group

The Middle Jurassic-Early Cretaceous Tetori Group is distributed over the Hokuriku District (Fig. 1c). This group is characterized by marine and continental clastic deposits and is subdivided into the Kuzuryu, Itoshiro, and Akaiwa subgroups, in ascending order (Maeda, 1961).

Saida (1987) found Triassic and Jurassic radiolarians in clasts within the Tetori Group in the Tamodani area. *Japonocapsa* sp. cf. *J. fusiformis* (Yao) (described as *Tricolocapsa*? cf. *fusiformis* Yao) was obtained from a conglomerate. *Japonocapsa fusiformis* occurs in the Aalenian-early Bajocian. He did not specify the strata, but Fujita (2002) recognized it as the Kamihambara Formation. The Kamihambara Formation yielded early Tithonian ammonoid (*Parapallasiceras*) (Sato and Yamada, 2005).

The Otaniyama Formation of the Itoshiro Subgroup is distributed over the upper portion of the Shokawa River. This formation was assigned to the Late Jurassic-earliest Cretaceous on the basis of the stratigraphic relationship with the underlying Mitarai Formation, which is an ammonoid-bearing level. However, Sato et al. (2008) discovered Berriasian ammonoids (*Neocosmoceras*) in the Mitarai Formation. The overlying Okurodani Formation has a concordant age of 135±7 Ma based on a fission-track dating (Gifu-ken Dinosaur Research Committee, 1993), which corresponds to the Valanginian (139.4-133.9 Ma). Kusuhashi et al. (2006) determined zircon U-Pb ages of 130.0±1.7 Ma and 129.8±1.0 Ma for the Mitarai Formation and of 132.9±0.9 Ma, 131.4±0.9 Ma, and 117.5±0.7 Ma for the Okurodani Formation. According to these datings, the Otaniyama Formation probably corresponds to the Valanginian. Matsukawa and Takahashi (1999) found Permian or Triassic radiolarian fossils from chert clasts of the Otaniyama Formation, although their detailed taxonomic names were not shown.

Ito et al. (2015b) reported Triassic and Jurassic radiolarians from chert clasts of the Itsuki Formation. Two chert clasts yielded Aalenian and Bajocian-early Bathonian radiolarians, respectively. The youngest zircon grain from the sandstone of the lower Itsuki Formation has a concordant age of 127.2±2.5 Ma (Kawagoe et al., 2012) corresponding to the Barremian (130.8-126.3 Ma).

Yokoo Conglomerate

The Yokoo Conglomerate is distributed over the Yokoo area. Some researchers have considered it as a component of the Tetori Group (e.g., Nozawa et al., 1975). Campanian-Maastrichtian pollen occur in the Oamamiyama Volcanic Rock (Kasahara and Shimono, 1974), which covers the Yokoo Conglomerate.

Chert clasts within the Yokoo Conglomerate yielded Permian radiolarians (Kojima, 1986). One chert clast includes Lopingian (Late Permian) radiolarians, but another chert clast includes Guadalupian (Middle Permian) radiolarians. Although the Akiyoshi terrane, a Permian AC of Southwest Japan, also contains Permian cherts (e.g., Ishiga et al., 1986; Ito and Matsuoka, 2015; 2016), the youngest Permian cherts in the Akiyoshi terrane correspond to the late Guadalupian (Uchiyama et al., 1986). Hence, at least the former chert clast derived from the mid-Mesozoic ACs.

Late Mesozoic strata in the Toyama and Niigata prefectures

Late Mesozoic strata which are distributed over the western Gifu, Toyama, and Niigata prefectures have been thought to belong to the Tetori Group. Recently, Matsukawa et al. (2014) defined the Late Mesozoic strata in the eastern Gifu and Toyama prefectures as the Jinzu Group based mainly on lithological differences. In contrast, Takeuchi et al. (2015a) redefined the Late Mesozoic strata in the northern Toyama Prefecture. According to Takeuchi et al. (2015a), the Mizukamidani and Kurobishiyama formations belong to the Tetori Group, but the overlying formations (Shiritakayama, Uchiyama, and Oyashirazu formations) are not comprised in the group. On the other hand, Sano (2015) stated that the Mizukamidani and Kurobishiyama formations can be correlated with the Managawa, Jinzu, or Tetori Group. The Minami-matadani Conglomerate Member, the Wasabu Alternation Member, and the Yakushizawa-migimata Conglomerate Member belong to the Akaiwa Subgroup of the Tetori Group according to Takeuchi et al. (1991) whereas Matsukawa et al. (2014) considered that the Minami-matadani Conglomerate Member is comprised in the Jinzu Group. This paper does not deal with the belonging of these Late Mesozoic strata.

The Yakushizawa-migimata Conglomerate Member is distributed over the upper portion of the Kurobegawa River. The Wasabu Alternation Member underlies conformably the Yakushizawa-migimata Conglomerate Member and has the following ages based on a fission-track dating: 119±6 Ma in the Kamioka area (Gifu-ken Dinosaur Fossil Excavation Party, 1996); 125±10 Ma in the Kamioka area (Gifu-ken Dinosaur Fossil Excavation Party, 1997); 113±6 Ma in the Jinzu area (Board of Education of Toyama Prefecture, 2003). These ages correspond to the Aptian (126.3-113.0 Ma), although the Gifu-ken Dinosaur Fossil Excavation Party (1996; 1997) pointed out the possibility of rejuvenation of their fission track ages. In this study, the Yakushizawa-migimata Conglomerate Member is assigned tentatively to the Aptian. Takeuchi et al. (1991) obtained Permian, Triassic, and Jurassic radiolarians from conglomerates within the Yakushizawa-migimata Conglomerate Member. They found also Permian radiolarians in mudstone pebbles of the Minami-matadani Conglomerate Member, but probably these mudstone pebbles have not originated in the mid-Mesozoic ACs. This statement comes from previous studies of the mid-Mesozoic ACs, that reported no Permian mudstone except for latest Permian siliceous claystones.

The Kurobishiyama Formation is distributed over the northeastern Toyama and western Niigata prefectures. Based on stratigraphical relationships to the underlying Mizukamidani Formation and dacite dykes, Takeuchi et al. (2015a) concluded that the Kurobishiyama Formation corresponds to the Aptian. Tomita et al. (2007) reported Permian and Middle-Late Triassic radiolarians from chert clasts within conglomerates of the lower Kurobishiyama Formation; Takeuchi et al. (2015b) then showed the radiolarian images. They also reported Permian radiolarians from a mudstone clast of the Mizukamidani Formation. However, the clast probably did not originate in the mid-Mesozoic ACs.

Ito et al. (2012) obtained Middle-Late Triassic and Jurassic radiolarians from chert clasts, and Jurassic radiolarians from a siliceous mudstone clast within sections exposed in the right bank of the Sakaigawa River in the Itoigawa area, Niigata Prefecture; Ito et al. (2014) discovered Bajocian-early Bathonian radiolarians from a siliceous mudstone clast within the same sections. Ito et al. (2012; 2014) interpreted these sections as the Mizukamidani Formation. Takeuchi et al. (2015a), however, redefined the Shiritakayama Formation and designed the sections as the type locality. Although further lithostratigraphic study is necessary to discuss the belonging, this paper tentatively follows the latter opinion. Two tuff layers of the Oyashirazu Formation, which overlies the Shiritakayama Formation, have ages of 89.7±4.5 Ma and 96.6±4.8 Ma on the basis of a K-Ar dating (Yamada et al., 2001), which correspond to the Coniacian (89.8-86.3 Ma) and Cenomanian (100.5-93.9 Ma), respectively. Takeuchi et al. (2015a) presumed that the Shiritakayama Formation corresponds to the Albian, our study follows this interpretation.

Gyeongsang Supergroup in the southeastern Korean Peninsula

The Gyeongsang Supergroup is a non-marine deposit distributed over the southeastern Korean Peninsula (Fig. 1d). This supergroup is subdivided into the Sindong, Hayang, and Yuchon groups in ascending order (e.g., Chang et al., 1990; Chang and Park, 2003). Aptian-early Albian pollen (e.g., *Retimonocolpites*, *Clavatipollenites*, *Tricolpites*) occurs in the Hayang Group (Choi, 1985; 1989; Yi et al., 1993). Kim et al. (2005) obtained an $^{40}Ar/^{39}Ar$ hornblende age of 113.4±2.4 Ma from a volcanic pebble of the Silla Conglomerate in the lower part of the Hayang Group. Sano et al. (2006) determined a U-Pb age of 115±10 Ma on a dinosaur tooth from the Hasandong Formation of the upper Sindong Group. The youngest zircon age in the Jinju Formation of the upper Sindong Group is 106.0±1.9 Ma (Lee et al., 2010). In this paper, the Hayang Group corresponds to the Albian (113.0-100.5 Ma).

Hayang Group

Microfossil-yielding conglomerates are interbedded in the Dongwhachi, Kumidong, and Kisadong formations of the Hayang Group (Chang et al., 1990; 2003; Yao and Chang, 1990; Kamata et al., 2000; Mitsugi et al., 2001). The Kisadong and Donghwachi formations are distributed over the Yongyang Sub-basin; the Kumidong Formation is distributed over the Uisong Sub-basin; the Kumidong Formation corresponds to the lower Donghwachi Formation (e.g., Chang and Park, 2003). On the basis of the aforementioned age assignments of the Hayang Group, in this study we assign the Donghwachi (Kumidong) and the Kisadong formations tentatively to the early and late Albian, respectively.

Chang et al. (1990) and Yao and Chang (1990) reported radiolarian occurrences from conglomerates within the Donghwachi and Kisadong formations. They classified these radiolarians into the following four age groups: latest Middle-Late Permian, Middle Triassic, Late Triassic, and middle Early-early Middle Jurassic.

Kamata et al. (2000) obtained Permian-Cretaceous radiolarians from a conglomerate within the Kisadong Formation. Although they reported the occurrence of *Amphipyndax stocki* (Cambell and Clark) which appeared in the Albian (Bragina, 2004), no specimen was imaged by Kamata et al. (2000). *Amphipyndax* ? spp. shown by Kamata et al. (2000, Plate 2, T) can be identified as Jurassic species of *Amphipyndax*. Kamata et al. (2000) also extracted Permian, Middle-Late Triassic, and Early-Middle Jurassic radiolarians from conglomerates within the Donghwachi Formation. Pliensbachian-early Toarcian radiolarians (e.g., *Katroma* sp. cf. *K. clara* Yeh) were obtained from the conglomerates.

Mitsugi et al. (2001) reported Permian, Triassic, and Jurassic radiolarian occurrences from the Kumidong Formation. They also found middle Bathonian-early Callovian radiolarians (e.g., *Eucyrtidiellum unumaense dentatum* Baumgartner) in a chert pebble and Rhaetian-Hettanginian radiolarians (e.g., *Canoptum praeanulatum* Pessagno and Whalen) in a siliceous mudstone pebble. The latter pebble, however, also yielded *Triassocampe* sp., which occurs in the Anisian-early Norian. Subsequently, Chang et al. (2003) reviewed the Cretaceous stratigraphy in Korea and showed part of the results of Mitsugi et al. (2001).

Hayang Group?

Adachi and Choi (1995) found Permian radiolarians in the Gyeongsang Supergroup from the Yongyang Basin. However, they did not mention the name of the radiolarian-yielding formation. According to previous studies, the radiolarian-bearing formation is probably the Hayang Group, but it is not certain.

DENUDATION STAGES OF THE MID-MESOZOIC ACCRETIONARY COMPLEXES

Fig. 3 shows a summary of the aforementioned age assignments of each neritic-continental deposit and the microfossil-bearing clasts. On the basis of the features of the mid-Mesozoic ACs in East Asia and of this summary, we recognize three stages of the denudation history and a pre-stage.

Pre-stage (Callovian)

Previous studies of microfossil-bearing clasts indicate that the mid-Mesozoic ACs had not been denudated until the Kimmeridgian at the earliest. Permian, Triassic, and Jurassic radiolarians were obtained from chert clasts within Middle Jurassic conglomerates of the mid-Mesozoic ACs (e.g., Saito and Tsukamoto, 1993; Ito et al., 2016, in press) but not from neritic-continental strata. Microfossil-bearing clasts have occurred in some pre-Tithonian neritic-continental strata in the Inner Zone of Southwest Japan (e.g., Kumazaki and Kojima, 1996; Takemura et al., 1996; Kametaka, 1997). These clasts, however, have yielded only Permian radiolarians which could have originated in pre-Mesozoic units (e.g., Akiyoshi and Maizuru terranes).

Stage A (Oxfordian-Hauterivian)

This stage is characterized by an initial and narrow denudation. The Shiranezaki Formation includes mid-Mesozoic AC-derived clasts (Umeda and Sugiyama, 1998). The Shiranezaki Formation corresponds to the Oxfordian if the radiolarians are not re-worked, indicating that the denudation of the mid-Mesozoic ACs started in the Oxfordian at the earliest. The Kamihambara Formation, corresponding at least partially to the Tithonian based on the early Tithonian ammonoid occurrence (Sato and Yamada, 2005), has interbeds of microfossil-bearing clasts presumed to have originated in the mid-Mesozoic ACs (Saida, 1987). This occurrence indicates that the initiation of denudation of the mid-Mesozoic ACs started in the Tithonian. However, there are a few reports of mid-Mesozoic-AC-derived clasts in previous studies, suggesting that the denudation was narrow in extent. The Tatsukawa Formation of the Monobegawa Group, corresponding to the Hauterivian on the basis of the lithostratigraphical relationship with the Barremian Lower Hanoura Formation, yielded Permian and Triassic radiolarians from chert clasts presumed to have originated in the mid-Mesozoic ACs (Ishida and Hashimoto, 1997; Ishida, 1999). The Otaniyama Formation, which can correspond to the Valanginian in this study, also has intercalated chert clasts yielding Permian or Triassic radiolarian assemblages (Matsukawa and Takahashi, 1999) although there is no detailed description of these radiolarians.

However, the stratigraphic position of the interbedded microfossil-bearing clasts and their age is not fully elucidated. Further studies of the clasts within the Kamihambara Formation together with the age assignment of the formation are important for the estimation of the timing of the initial denudation.

Stage B (Barremian-early Albian)

This stage is characterized by a wide denudation. Microfossil-bearing clasts presumed to have originated in the mid-Mesozoic ACs occur in the following geologic bodies: the Lower Hanoura Formation of the Monobegawa Group, the Lower Formation of the Sasayama Group, the Ashikajima Formation of the Choshi Group, the Itsuki Formation of the Tetori Group, the Kurobishiyama Formation, the Yakushizawa-migimata Conglomerate, and the Donghwachi and Kumidong formations of the Hayang Group. The ages from the previous studies suggest that these formations correspond partially to the Barremian-early Albian. The Yokoo Conglomerate and the Shiritakayama Formation might correspond to these strata although their age assignments remain matter of debate. In contrast to Stage A, more occurrences of microfossil-bearing clasts have been reported. This increment suggests that the mid-Mesozoic ACs had been denuded widely during this stage. The following facts are consistent with this suggestion. The Obuchi Formation of the Tetori Group is characterized by orthoquartzite-dominant conglomerates in contrast to the overlying Itsuki Formation characterized by chert-bearing conglomerates (Ito et al., 2015b). The Tatsukawa Formation does not include evident Jurassic clasts whereas the Lower Hanoura Formation includes some Jurassic clasts (Ishida and Hashimoto, 1997; Ishida, 1999). Both the Itsuki and Lower Hanoura formations correspond to the Barremian on the basis of zircon dating and ammonoid occurrences, respectively.

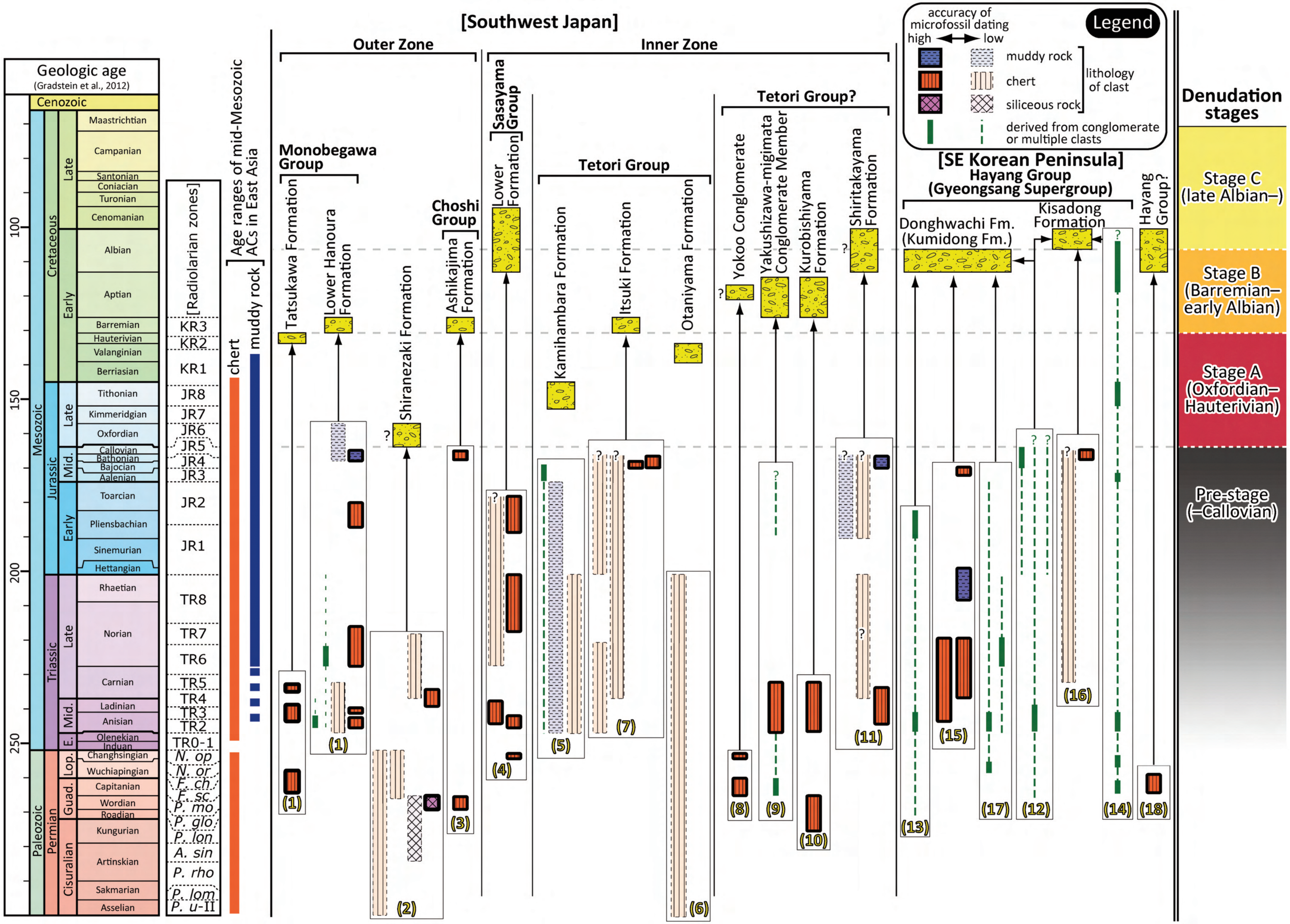

Fig. 3 - Age relationships between neritic-continental strata and microfossil-bearing clasts in East Asia. Guad. = Guadalupian; Lop. = Lopingian. Radiolarian zones are after Ishiga (1990), Matsuoka (1995), Sugiyama (1997) and Kuwahara et al. (1998). *P. u*-II = *Pseudoalbaillella u-forma* m. II Zone; *P. lom* = *Pseudoalbaillella lomentaria* Zone; *P. rho* = *Pseudoalbaillella rhombothoracata* Zone; *A. sin* = *Albaillella sinuata* Zone; *P. lon* = *Pseudoalbaillella longtanensis* Zone; *P. glo* = *Pseudoalbaillella globosa* Zone; *P. mo* = *Pseudoalbaillella monacantha* Zone; *F. sc* = *Follicucullus scholasticus* Zone; *F. ch* = *Follicucullus charveti* Zone; *N. or* = *Neoalbaillella ornithoformis* Zone; *N. op* = *Neoalbaillella optima* Zone.

Additionally, this stage is characterized by supply of clasts yielding Middle Jurassic radiolarians (Ishida and Hashimoto, 1997; Ishida, 1999; Ito et al., 2015b; Kashiwagi and Isaji, 2015). Based on the general features of the mid-Mesozoic ACs, Middle Jurassic siliceous mudstone clasts derived from Middle Jurassic or early Late Jurassic ACs; Middle Jurassic chert clasts derived from late Middle Jurassic or younger ACs. Because the mid-Mesozoic ACs range in age from the Late Triassic to earliest Cretaceous (e.g., Matsuoka et al., 1998; Nakae, 2000), Middle Jurassic and younger ACs are younger in whole the mid-Mesozoic ACs. In addition, the age of each sequence within the mid-Mesozoic ACs become systematically younger southwards and structurally downwards (e.g., Matsuoka, 1992), Middle and younger ACs were structurally located in a lower position. These results indicate that some younger geologic bodies in the mid-Mesozoic ACs, which were structurally located in a lower position, had been exposed and denuded by the time when these formations were deposited.

The uplift event of the Tetori Group, caused by strike slip movements involving duplication of the mid-Mesozoic ACs, has been suggested on the basis of lithological and some fossil faunal changes (e.g., Matsukawa et al., 2006; Haggart et al., 2006; Matsukawa and Fukui, 2009). According to these authors, this event and a marine transgression occurred in the late Hauterivian-early Barremian in East Asia, which is consistent with the initiation of Stage B.

Stage C (late Albian-)

This stage is characterized by denudation of almost all the mid-Mesozoic ACs. The Kisadong Formation yielded abundant Tithonian and Cretaceous radiolarians (Kamata et al., 2000), although these radiolarian origins are uncertain and some Cretaceous radiolarian images were not shown. Some of the radiolarians occur in the Early Cretaceous ACs in the mid-Mesozoic ACs (e.g., Matsuoka, 1998), which are nearly the youngest of the mid-Mesozoic ACs (e.g., Matsuoka et al., 1998; Nakae, 2000) and are structurally located in the lowest position. Meanwhile, the Donghwachi and Kumidong formations, which stratigraphically underlie the Kisadong Formation, did not yield Tithonian and Cretaceous radiolarians. Consequently, if part of these radiolarians did not derive from the matrix but from a clast, Tithonian and Cretaceous microfossil-bearing clasts probably started to be supplied between the depositional time of the Donghwachi (Kumidong) and Kisadong formations in the Hayang Group. These results suggest that the Early Cretaceous ACs, which are almost the youngest and are structurally located in the lowest position, started to be denuded in the late Albian.

The mid-Mesozoic ACs have been denuded earlier and supplied the latest Mesozoic and Cenozoic strata with microfossil-bearing clasts (e.g., Umeda, 1997; Kashiwagi, 2012), although some clasts are possibly re-reworked deposits.

Isozaki et al. (2010) highlighted that the dated zircon grains are clustered into seven distinct groups, including 110-90 Ma granites (middle Albian-late Turonian). The 110-90 Ma granites probably belonged to the continental arc system that can be traced for more than 3000 km along East Asia (Takahashi, 1983). Subduction of the Izanagi-Kula ridge, probably associated to the granite implacement, occurred around 120-110 Ma (Isozaki et al., 2010), which corresponds to the late Aptian-middle Albian. The initiation of granite emplacement could be consistent with initiation of Stage C.

CONCLUDING REMARKS

This study analyzed microfossil-bearing clasts within Late Mesozoic neritic-continental deposits in the Outer and Inner zones of Southwest Japan and the Gyeongsang Supergroup in the southeastern Korean Peninsula from the standpoint of staged denudation of the mid-Mesozoic ACs. On the basis of the collected data, the denudation history and the clasts provenances of these regions is summarized below. The mid-Mesozoic ACs started to be denuded in the Oxfordian-Tithonian. Since the Barremian, the denudation of the mid-Mesozoic ACs became extensive. Furthermore, supply of Middle Jurassic microfossil-bearing clasts within Jurassic ACs became common since the Barremian. The Early Cretaceous ACs, which are nearly the youngest in the mid-Mesozoic ACs, started to be denuded in late Albian. These denudational changes seem to be correlated to some events in East Asia, such as the uplift of the Tetori Group in the late Hauterivian-early Barremian and the initiation of granite emplacement in middle Albian. However, further investigation is needed to prove this correlation of events.

On the other hand, the lithology of some microfossil-bearing clasts from previous studies remains undetermined. This is because they were obtained from residues of whole conglomerates with use of hydrofluoric-acid (HF) solution. Microfossils in residues can be extracted from the matrix too. An effective method to elucidate relationships between rock facies of clasts and their age, such as observation of HF-etched surfaces to determine the radiolarian markers (Ito et al., 2015b), will provide information for further discussion of staged denudation history of the mid-Mesozoic ACs.

ACKNOWLEDGEMENTS

This study was financially supported by NSFC (40839903 and 40921062) and by the "111" Project (B08030) of China University of Geosciences, Wuhan. We thank Dr. Naoto Handa (Shinshushinmachi Fossil Museum) for his suggestions and comments on the Tetori Group geology. The manuscript was greatly improved by the constructive comments provided by Dr. Marco Chiari (C.N.R. Istituto di Geoscienze e Georisorse) and Prof. Michele Marroni (Università di Pisa).

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Received, October 7, 2015
Accepted, November 23, 2016