Upper Triassic reefal limestone from the Sambosan accretionary complex in Japan and its geological implication

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Abstract: Upper Triassic limestone within the Sambosan accretionary complex in Japan contains reefal facies that accumulated on a mid-oceanic seamount in the Panthalassa Ocean. Such limestone is found at the Inaba Cave locality along the Shimanto River, central Shikoku. The reefal limestone occupies part of a bioclast-rich limestone that occurs as an allochthonous tectonic slab. The reefal limestone is characterized by sponge-algal rudstone and coral bafflestone rich in Retiaphyllum. Megalodonts floatstone also occurs in association with the reefal facies. Although the lateral continuity and exact relationship between the Megalodonts floatstone and the reefal facies remain uncertain, this is the first report in which this unique facies association has been described in the Sambosan accretionary complex.

Keywords: Upper Triassic, reef, limestone, Sambosan accretionary complex, Shikoku, Japan

Introduction

Late Triassic has been defined as a period characterized by the rapid development of extensive organic framework produced by scleractinian corals and coralline sponges (Flügel, 2002). Scleractinian corals and coralline sponges evolved at fairly diverse levels in middle Anisian time (Stanley, 1988; Flügel, 1994), and corals become important reef-builders in Late Triassic (Flügel, 1994; Kiessling et al., 1999). Solenoporeacean and dasyclad algae are of particular interest because of their volumetrically important role as reef builders in some Norian reefs of the southern Tethys (Bernecker, 2005). Differing from Lower to Middle Triassic reefs, the wide distribution of Norian-Rhaetian reefs in both Tethyan and Panthalassan realms has been termed the “global reef bloom” (Flügel, 2002).

Compared with the Tethyan margins and the western North American Cordillera, only a few Upper Triassic reefs from western Panthalassa Ocean were sedimentologically and paleontologically studied. Upper Triassic sponge and coral reefs from western Panthalassa have been documented from the Taukha terrane in Sikhote-Alin (Punina, 1997) and the Sambosan accretionary complex in Japan (Onoue and Stanley, 2008). These reefs are considered to have accumulated at the top of seamounts and oceanic plateaus in an open-ocean realm of the Panthalassa Ocean (Khanchuk et al., 1989; Onoue and Sano, 2007). Therefore, their depositional facies are of great significance for understanding the Late Triassic paleoenvironment as well as the reef patterns in the Panthalassa Ocean.

Here, we report a newly-discovered locality of the Upper Triassic reefal limestone in Japan. Upper Triassic limestone, which contains the reefal facies, is distributed in the Sambosan accretionary complex in central Shikoku, and preliminary reported by Taira et al. (1979). This paper describes field properties of the reefal limestone in central Shikoku.

Geologic setting

The Sambosan accretionary complex (Onoue and Sano, 2007; here designated as SAC) is a latest Jurassic to earliest Cretaceous subduction-generated accretionary complex in southwest Japan. The SAC is distributed in a narrow tract with an approximately east-northeast trend in the Outer Zone of southwest Japan (Fig. 1), and it occupies the southern marginal portion of the southern Chichibu terrane.

Our study area of the SAC is located in the Funado area, central Shikoku, southwest Japan (Fig. 1). The SAC of this area trends roughly northeast-southwest and has a 0.8 to 1.1 km width. In this area, the SAC is separated by a fault from the Jurassic Togano Group (Matsuoka, 1992) of the southern Chichibu terrane on the north, and from the Lower Cretaceous Shimanto terrane on the south by the Butsuzo Tectonic Line.

The SAC in the Funado area consists of terrigenous mudstone with minor sandstone, basaltic rocks, limestone, and ribbon chert (Fig. 1). Basaltic rocks, limestone, and ribbon chert occur as fault-bounded and laterally discrete slabs, complexly mingled with mudstone and sandstone. Most characteristics of the SAC in this area are the Upper Triassic bioclast-rich shallow-marine limestones, which occur as km-scale rock bodies (Fig. 1). The limestone is characterized by diverse shallow-marine skeletal debris, including sponges, corals, calcareous algae, mega-
Upper Triassic reefal limestone was discovered at the Inaba Cave (Funado Cave in Kristan-Tollmann, 1991; GPS coordinates: 33°26.20N/133°5.7E) along the upper reaches of the Shimanto River (Fig. 1). The reefal limestone is a part of the bioclast-rich limestone with a maximum width of 170 m (Fig. 1.B). Stratigraphic base and top of the bioclast-rich limestone is truncated by a northward-dipping fault.

The age of the reefal limestone along the Shimanto River is deduced from foraminifer assemblage by Kristan-Tollmann (1991) and recently emphasized by Chablais et al. (2007, 2008). Smaller foraminifers and microproblematica include Agathammina austroalpina, large Alpinophragmium perforatum, Gateanella panticae, Høyenella inconstans, “Trochammina” sp., Reophax sp., Ophthalmidium sp., Palaeolituonella meridionalis, Nubecularia? sp., few aulotortids and duostominids, Microtubus communis and Cheilosporites sp., indicating a Late Triassic, Norian-Rhaetian age, for the reefal limestone.

**Field description of reefal limestone**

Much of the reefal limestone along the Shimanto River is massive, lacks clear stratification, and is rich in shallow-marine skeletal debris. Because of the lack of stratification, orientation patterns of bivalves are used to determine dip and strike of the reefal limestone. On the basis of orientation patterns, the reefal limestone at the Inaba Cave trends to approximately east-northeast and dip to the northwest.

Upper Triassic reefal limestone at the Inaba Cave is mostly gray to light gray. Crude laminae are locally seen, which were formed by concentrations of bioclasts. Based chiefly upon the major constituents, biotic associations, and grain fabrics, two major facies were discriminated in the reefal limestone. They are 1) sponge-algal rudstone-floatstone and 2) coral bafflestone. In addition to these major types and associated bioclastic limestones, Megalodonts floatstone occurs in association with sponge-algal rudstone-floatstone.

1. **Sponge-algal rudstone-floatstone**

Sponge-algal rudstone-floatstone is exposed chiefly on the northern to middle part of the bioclast-rich limestone along the Shimanto River. Typical rocks are exposed near the entrance of the Inaba Cave (INB-08). The rocks of this type also occupy the northwestern part into the Inaba Cave (Fig. 1.C).

Sponge-algal rudstone-floatstone includes sponges, solenoporacean algae, corals, and bivalves. Subordinates are coarse-grained skeletal debris of crinoids, gastropods, and smaller foraminifers as well as peloidal particles. Individual skeletal debris are poorly sorted, densely packed, and in places scattered (Fig. 2.A). Sponges are mostly sphinctozoan types with minor components of inozoans (Fig. 2.D). Sponges and algae are generally well preserved, but they also occur as isolated fragments in places. The walls are partially eroded, and the sponges are distributed irregularly in the sediment. Partial erosion of some sponges is due to reworking with short transport.

The interstitial cavities of sponge-algal rudstone-floatstone are gray to dark gray and filled with isopachous fibrous cements suggesting a submarine cementation (Fig. 2.B). The size of cavities varies from a few centimeters to a few tens of centimeters. Cavities have several generations of isopachous cement, each generation being from 1 to 8 mm thick.

2. **Coral bafflestone**

Coral bafflestone were found at an isolated outcrop along the upper reaches of the Shimanto River (INB-01). It is exposed approximately 120 m south of the entrance of the Inaba Cave. Although its lateral continuity and exact relationship to sponge-algal rudstone-floatstone remains uncertain, this rock is significant because of the first example of *Retiophyllia*-dominated reefal limestone reported from Japan.

Coral bafflestone reaches 60 cm in thickness. It is composed of high-growing, reef-building coral colonies of *Retiophyllia* (Fig. 2.C). Subordinate components are bivalves, crinoids, ostracodes, tubular microproblematica, and smaller foraminifers. *Retiophyllia* exhibit in-situ growth form. They are composed of outward radiating corallites with branched growth forms.
Fig. 2  Field views of reefal limestone at the Inaba Cave locality exposed on the Shimanto River. See Fig. 1 for location. A. Sponge-algal rudstone-floatstone rich in coarse-grained, poorly sorted sphinctozoan sponges (a) and solenoporacean algae (b). INB-08. Scale bar = 10 cm. B. Interstitial cavities of sponge-algal rudstone-floatstone (sa) filled with several generations of isopachous cement (c). INB-08. Scale bar = 10 cm. C. Coral bafflestone containing Retiophyllia sp. (r). Coral bafflestone is overlain by bioclastic wackestone-packstone rich in bivalves, crinoids, and tubular problematica. INB-01. Scale bar = 10 cm. D. Longitudinal section of sphinctozoan sponges in sponge-algal rudstone-floatstone. INB-08. Scale bar = 1 cm. E. Thick-shelled megalodontid bivalve in Megalodonts floatstone. INB-11. Scale bar = 5 cm. F. Megalodonts floatstone containing disarticulated megalodontid bivalves. INB-13. Scale bar = 20 cm.

phyllia are 10 to 20 cm in diameter and 5 to 10 cm in height.

Under the microscope, corals are often encrusted by micritic matrix, attached foraminifers such as Alpinophragmium perforatum and Planinivolvula sp., as well as tubular problematic aggregates. Coralites of Retiophyllia are strongly recrystallized and primary microstructures are difficult to recognize. Skeletal packing is dense, and interstitial cavities among corals are filled with a micritic matrix with tubular microporouscific. The interstitial cavities of coral bafflestone are locally filled with isopachous fibrous cements, which suggest active water circulation. Fibrous isopachous cements are gray to dark-gray and their thickness ranges from 0.5 to 2 mm. The remaining pore space is filled with sparry calcite.

3. Megalodonts floatstone

The excellent exposures of Megalodonts floatstone are in the Inaba Cave about 20 m west from its entrance (Fig. 1.C). It occurs in association with sponge-algal rudstone-floatstone. Megalodonts floatstone is also exposed on the northern margin of the bioclast-rich limestone along the Shimanto River (INB-11 in Fig.1.B; Fig. 2.E).

Megalodonts floatstone is characterized by abundant megalodontid bivalves with subordinate amounts of smaller bivalves (Fig. 2.F). Size of the megalodontid shells ranges from 10 to 20 cm. The megalodontid fossils form shell beds of a few meters thick. The shell beds extend 25 m laterally in the Inaba Cave (Fig. 1.C). The megalodontid fossils occur disarticulated and crowded, but some of their valves are articulated and in life position suggesting an autochthonous assemblage. In the Megalodonts floatstone occurring along the Kuma River, in Kyushu Island (Tamura, 1983), the megalodontid shells are generally supported by micritic matrix with small amounts of fine bioclastic debris, including bivalve shells. By contrast, the Megalodonts floatstone found in the Inaba Cave appears much more coarse-grained, supported by biopelmicrite to biopelc sparite. Subordinate components are skeletal debris of bivalves, sponges, echinoids, crinoids, algae, peloids and rare ooids. Large aulotortid foraminifers, such as Aulotorta sinuosus, also occur. Primary isopachous fibrous cements are sometimes observed around particles. Megalodonts floatstone associated with reefal facies has been never known from Japan. The presence of megalodontids bivalves generally indicates a shallow muddy substrate in low-energy lagoonal environments (Tamura, 1983; Flügel, 2004). Although in the Funado area, lateral continuity and exact relationships of Megalodonts floatstone to Sponge-algal rudstone-floatstone remain uncertain, Megalodonts floatstone might exhibit an overlying or interfingering relationship with sponge-algal rudstone-floatstone.

Geological implications for Upper Triassic Panthalassan reefs

This paper documents field properties of the newly-discovered Upper Triassic reefal limestone in the SAC, central Shikoku, southwest Japan. The limestone in the SAC has long been known to contain Upper Triassic reef facies which accumulated on a mid-oceanic seamount in the Panthalassa Ocean (Kanmera, 1969; Okuda and Yamagawa, 1978; Okuda et al., 2005; Okuda, 2006; Onoue and Stanley, 2008). However, most of pervious material was derived from the allochthonous limestone clasts ranging in size from a few centimeters up to several centimeters in diameter (Kanmera, 1969; Okuda and Yamagawa, 1978; Okuda, 2006). Because the reefal limestone at the Inaba Cave contains a relatively complete stratigraphic section, discovery of the reefal limestone provides a high-quality dataset that can advance understanding the depositional environments and patterns of Upper Triassic reefs in the Panthalassa Ocean.
We discriminated two types of reefal limestone, including sponge-algal rudstone-floatstone and coral bafflestone rich in Retiophyllia. Although the precise age of the reefal limestone at the Inaba Cave remains uncertain, the preliminary investigations of foraminifera indicate a Norian-Rhaetian interval. Therefore, the biotic association and lithologic properties of the reefal limestone provide evidence for the development of reef facies with sphinctozoan sponge, solenoporecan algae, and corals in the Panthalassa Ocean during the Norian to Rhaetian time. Recently, Onoue and Stanley (2008) reported a large block of Upper Triassic reefal limestone in the SAC at Kamase locality on the Kuma River, western Kyushu. The limestone at Kamase indicate inozone sponge and coral reef development in the SAC during Norian time but there has been no evidence of the large buildups of sphinctozoan sponge, solenoporecan algae, and Retiophyllia coral. Deposition of the reefal limestones of both the Kamase and Inaba Cave localities occurred in central reef facies based on the presence of Upper Triassic smaller foraminifers and microproportion. They include Lameltiltus, Microtubus, and Bacinella from Kamase (Onoue and Stanley, 2008) and Alpinophragmium perforatum, Ophthalmidium spp., Galeamella panicata, Microtubus, and Cheilosporites from the Inaba Cave (Kristan-Tollmann, 1991; Chablais et al., 2007, 2008). With an emphasis upon a similar depositional setting for both reefal facies, we postulate that the reefal limestones at Kamase and the Inaba Cave represent two different stages or depositional sites of reef development during the Norian to Rhaetian time. Further investigations of biotic composition and microfacies of the limestone at these localities are pivotal in clarifying the depositional environments and reef patterns for the “Norian-Rhaetian global reef bloom” (Flugel, 2002) in the Panthalassa Ocean.

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