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Research Article

Late Triassic ammonoid *Sirenites* from the Sabudani Formation in Tokushima, Southwest Japan, and its biostratigraphic and paleobiogeographic implications

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Abstract Discovery of *Sirenites senticosus* (Dittmar) in the upper part of the Sabudani Formation of the Kurosegawa Belt, Kito area, Tokushima Prefecture, Japan, establishes a late Early Carnian age for this part of the stratigraphic unit. Because *S. senticosus* was mainly distributed in the Tethyan region, its occurrence provides evidence that Late Triassic ammonoids of Japan had strong affinities with those of the Tethyan faunas. This finding clearly differs from the biogeographic distribution of contemporary bivalves in the region, which are referred to as the Kochigatani bivalve faunas, and show strong affinities to faunas of the Boreal region.

Key words: ammonoid, Carnian, Kurosegawa Belt, Sabudani Formation, *Sirenites senticosus*, Southwest Japan, Tethyan affinities, Tokushima, Triassic.

INTRODUCTION

The Kurosegawa Belt is situated between the Northern and Southern Chichibu Belts in the Chichibu Composite Belt of Southwest Japan (Fig. 1). The southern part of the Kurosegawa Belt is defined as the Sakashu Belt in eastern Shikoku, and is composed of a Permian accretionary complex with unmetamorphosed to weakly metamorphosed Siluro–Devonian blocks (Ishida & Kozai 2003). These accretionary complexes are tectonostratigraphically overlain by the Upper Permian, Middle–Upper Triassic, Jurassic, and Lower Cretaceous deposits (Ishida 1999; Ishida *et al*. 2009).

The Triassic deposits in eastern Shikoku are divided into three formations: Usugatani, Sabudani, and Umegatani formations, in ascending order (Ichikawa *et al*. 1953; Hirayama *et al*. 1956). These formations are distributed in a long and narrow range in the Kito area, Tokushima Prefecture (Ichikawa 1954) (Fig. 1), where geological and paleontological studies have been carried out by many researchers (Yokoyama 1911; Yehara 1927; Ohki 1934; Shinohara 1941, 1946; Kobayashi & Ichikawa 1951; Ichikawa 1954). The age of these deposits has been determined mainly on the basis of cosmopolitan thin-shelled bivalves, such as *Daonella*, *Halobia*, and *Monotis* (Yokoyama 1911; Shinohara 1941, 1946; Hirayama *et al*. 1956), owing to few extractions of radiolarian and conodont microfossils.

Ammonoids provide a strong basis for biostratigraphic zonation and accurate correlation of Triassic marine strata (Ogg 2004; Balini *et al*. 2010). However, ammonoids from Triassic deposits in eastern Shikoku are very rare, with only a few previous findings of a small number of specimens, such as *Protrachyceras* cf. *pseudoarchelaus* (Boeckh) from the Usugatani Formation and

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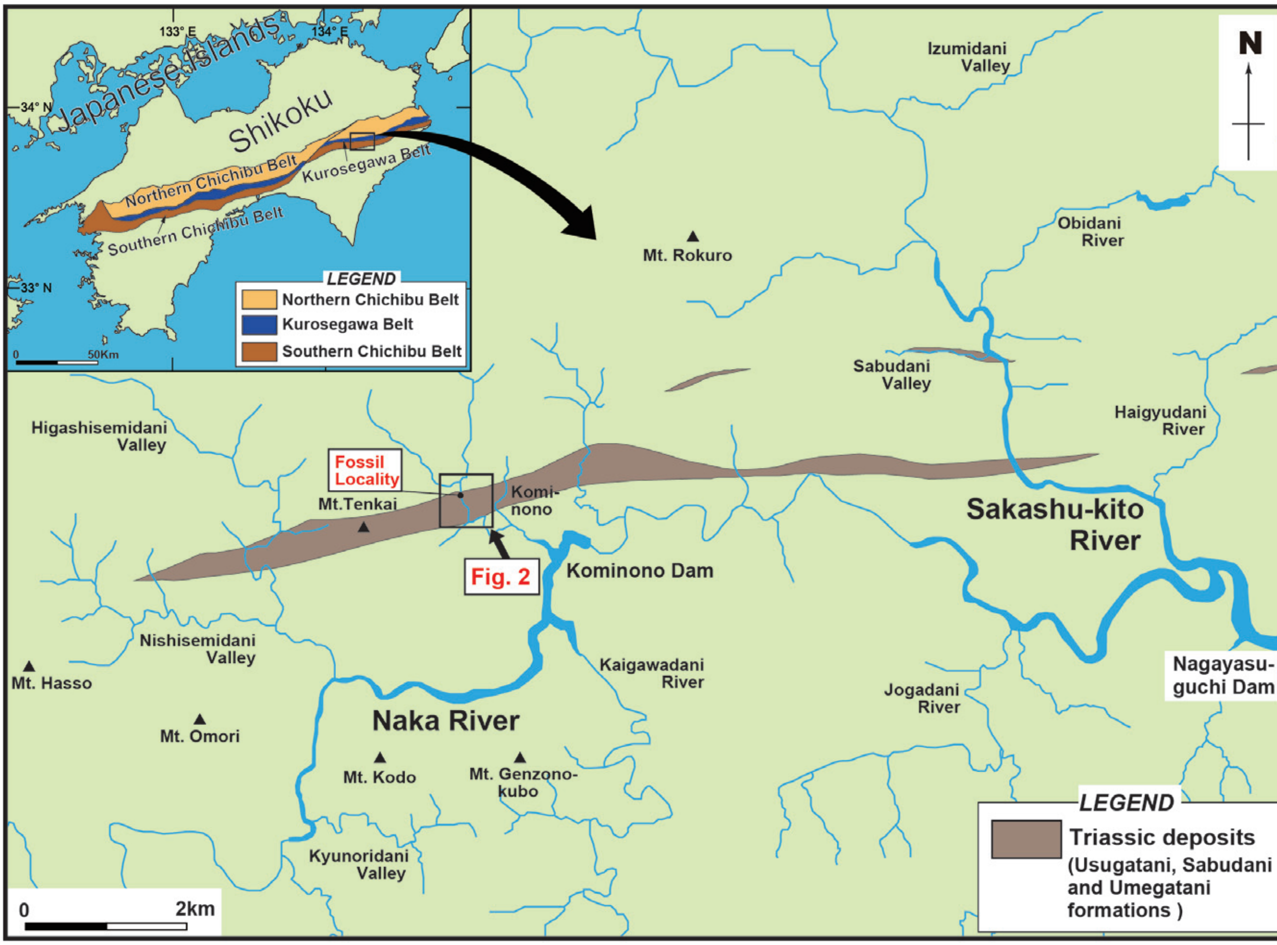

Fig. 1 Index map showing the fossil locality from which the Late Triassic ammonoid *Sirenites* was obtained in the Kito–Sakashu area, Tokushima Prefecture, Japan. Geologic distribution of the Triassic deposits is modified from Hirayama *et al.* (1956).

Paratrachyceras sp. from the Sabudani Formation (Ichikawa 1954; Bando 1964). The latter was reported without description or illustrations (Ichikawa 1954).

Recently, we have found several specimens attributable to *Sirenites senticosus* (Dittmar) from the Sabudani Formation in the Kito area. We describe the specimens in this contribution and discuss their biostratigraphic and paleobiogeographic significance. The studied specimens are housed in the Tokushima Prefectural Museum (TKPM).

GEOLOGICAL SETTING AND STRATIGRAPHY

The Sabudani Formation is exposed along the Nakatani Valley, Kito area. The formation is in fault contact with the Permian accretionary complexes (Fig. 2), although they are in unconformable contact with these accretionary complexes at the type locality in the Sakashu area (Ichikawa *et al.* 1953; Hirayama *et al.* 1956; Ishida *et al.* 2005). The formation generally strikes ENE–WSW with near vertical dips, and becomes younger to the north (Fig. 2). Small faults and folds are exposed in some locations.

The Sabudani Formation is at least 300 m thick in the Nakatani Valley, and is mostly composed of sandstone and sandy mudstone (Fig. 3). The formation is divided into three lithological parts: lower, middle, and upper parts. The lower part is composed mainly of sandstone and sandy mudstone, and contains two thick, fine- to medium-grained sandstone layers. This part shows at least two coarsening-upward tendencies. The middle part is represented by muddy deposits that are characterized by laminated mudstone. The upper part is composed mainly of muddy sandstone and sandy mudstone with lenticular and thin, very fine-grained sandstone layers 2–3 cm thick. The uppermost part yields numerous plant remains and

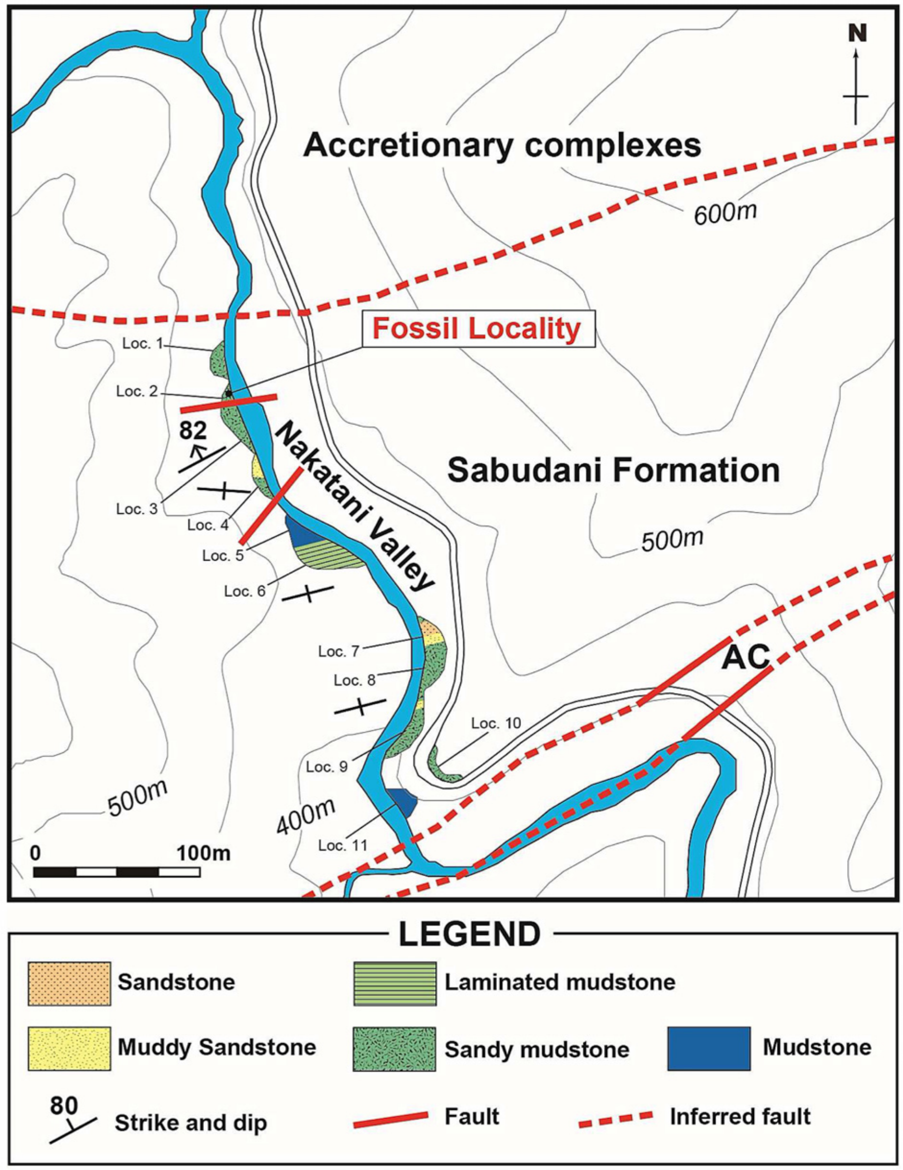

Fig. 2 Route map showing the fossil locality along the Nakatani Valley, Kito area. Loc. 1-11 indicate locations, in which each part of the measured section in Fig. 3 was taken. AC, accretionary complexes.

molluskan fossils (Fig. 3). Most molluskan fossils are dominated by thin-shelled bivalves identified as *Halobia* (*Zittelihalobia*) *ornatissima* Smith (Fig. 4a,b). Furthermore, a few small bivalves of *Tosapecten* sp. also occur in the upper part (Fig. 4c,d). Several specimens of *Sirenites senticosus* co-occur with these fossils (Fig. 3).

The geological map of the Kito area (Hirayama *et al.* 1956) indicates that the Usugatani Formation is predominantly composed of massive black mudstone facies and is distributed along the southern margin of the Triassic deposits exposed in the Nakatani Valley. However, in this study we treat the successive strata of the Triassic deposits along the valley as the Sabudani Formation, because the successive strata are generally dominated by sandy deposits rather than massive black mudstone facies. Furthermore, *Daonella*, which is characterized as a representative bivalve fossil of the Usugatani Formation, was not obtained from the successive strata.

PALEONTOLOGICAL DESCRIPTION

The morphological terms used in this systematic description are from Arkell *et al.* (1957). Quantifiers used to describe the shape of the ammonoid shell replicate those proposed by Matsumoto (1954, p. 246), and modified by Haggart (1989, table 8.1).

Order Ceratitida Hyatt, 1884
Superfamily Clydonitoidea Hyatt, 1877

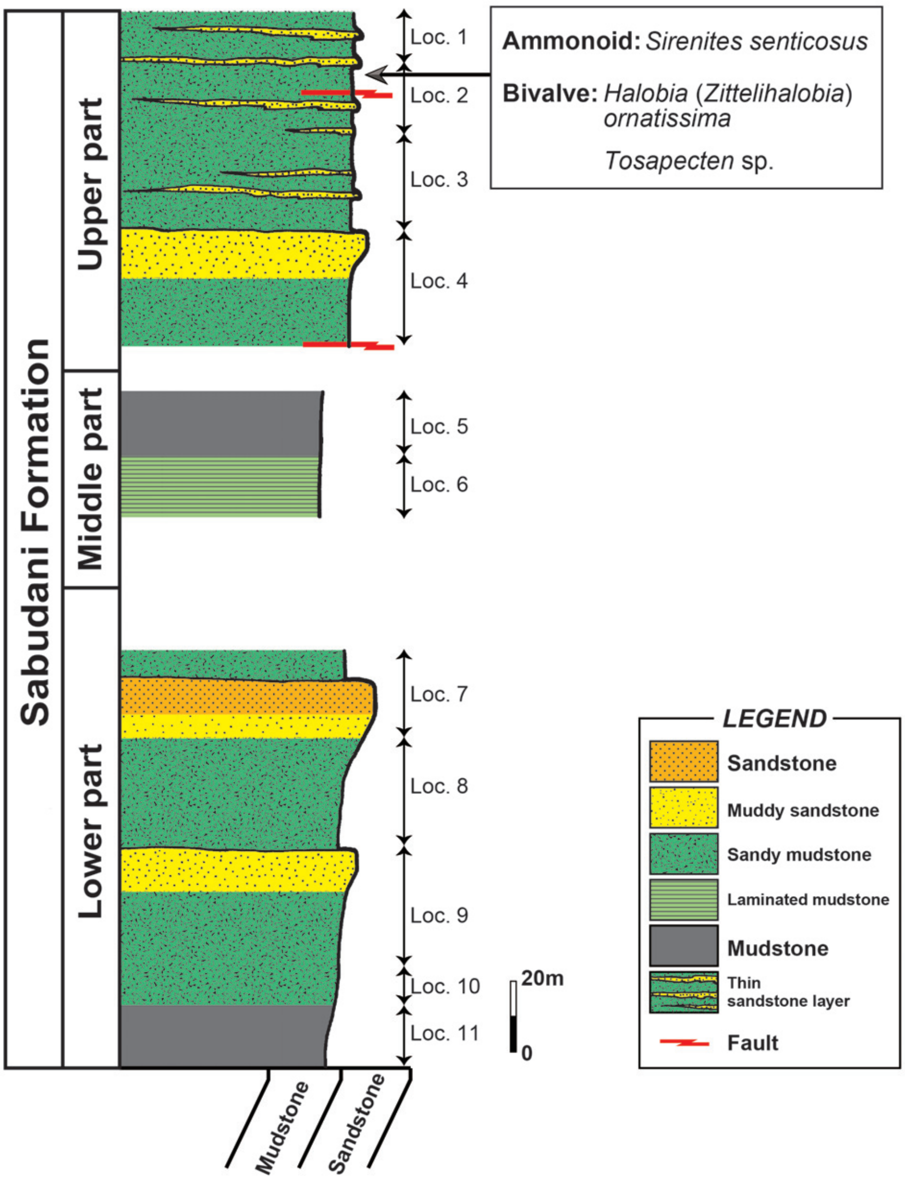

Fig. 3 Stratigraphic column of the Triassic deposits (Sabudani Formation) shown in Figure 2, indicating stratigraphic occurrences of ammonoid and bivalve fossils.

Family Trachyceratidae Haug, 1894
Subfamily Sirenitinae Tozer, 1971
Genus ***Sirenites*** Mojsisovics, 1893

Type species: *Ammonites senticosus* Dittmar, 1866

Sirenites senticosus (Dittmar, 1866) (Fig. 5)

Ammonites senticosus Dittmar, 1866, p. 375, pl. 17, figs 8,9.
Sirenites senticosus (Dittmar). Mojsisovics, 1893, p. 727, pl. 161, figs 8–10,12,14.
Sirenites senticosus (Dittmar). Mojsisovics, 1893, p. 727, pl. 161, figs 11,15.
non *Sirenites senticosus* (Dittmar). Tozer, 1961, p. 75, pl. 24, figs 7–9.
non *Sirenites senticosus* (Dittmar). Astakhova, 1971, p. 67, pl. 4, fig. 1.
Sirenites senticosus (Dittmar). Krystyn, 1978, pl. 4, fig. 3.
Sirenites cf. *senticosus* (Dittmar). Xu *et al.*, 2003, pl. 3, fig. 14.
Sirenites senticosus (Dittmar). Breda *et al.*, 2009, fig. 2d.

MATERIAL EXAMINED

Specimens (TKPM.GFI5501, 5835–5837) of ammonoids were collected at the Loc. 2 from sandy mudstone in the upper part of the Sabudani Formation distributed in the Kito area, Tokushima Prefecture, Japan (33°48' 40.9"N, 134°13' 40.0"E).

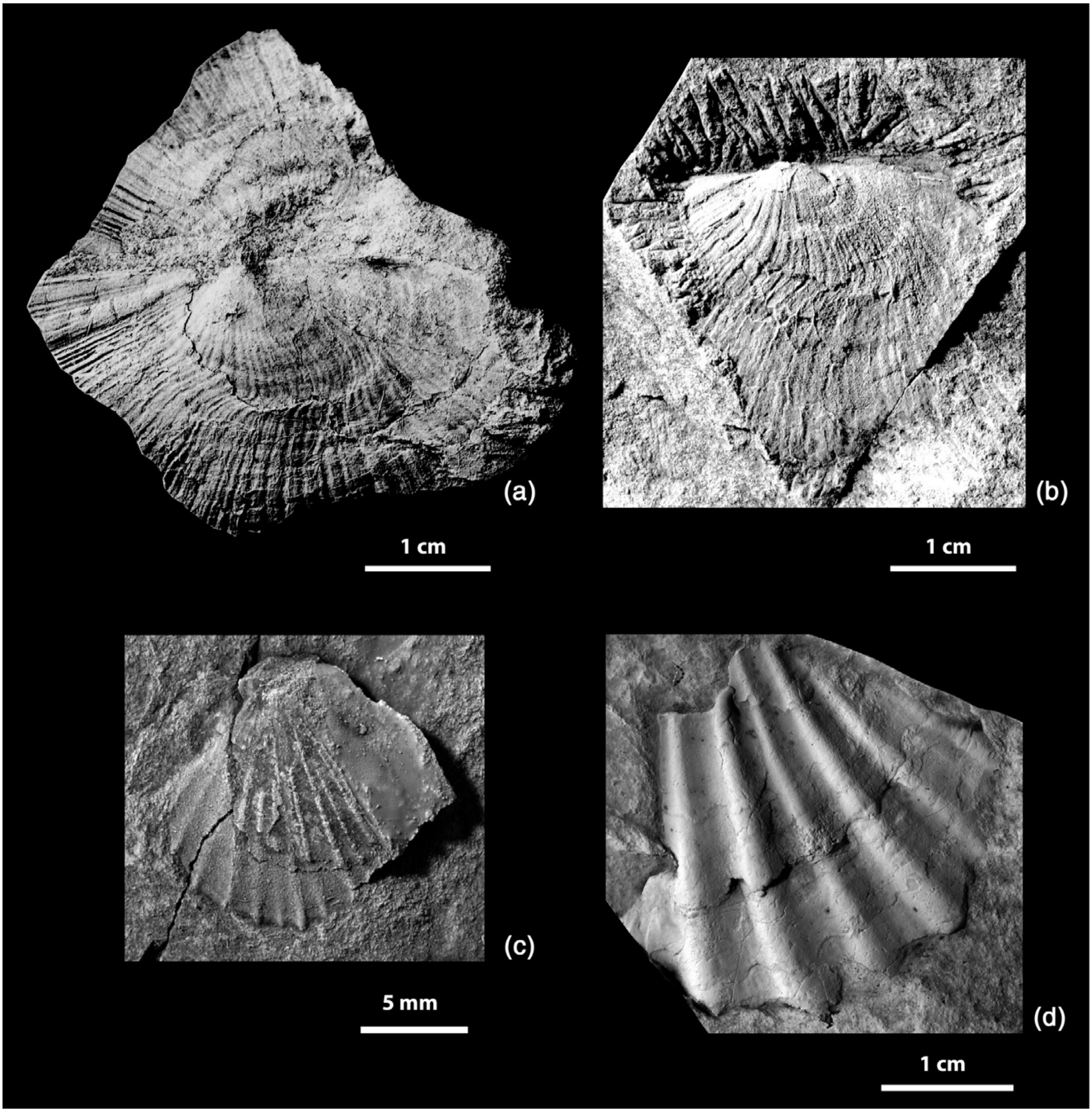

Fig. 4 Bivalve fossils obtained from the same stratigraphic level as *Sirenites* in the upper part of the Sabudani Formation, Kito area. (a,b) *Halobia* (*Zittelihalobia*) *ornatissima* Smith, 1927. (a) TKPM GFI5507-1; (b) TKPM GFI5507-2. (c,d) *Tosapecten* sp.; (c) TKPM GFI5510 (silicon rubber cast); (d) TKPM GFI5508. TKPM, Tokushima Prefectural Museum.

DESCRIPTION

Fairly involute, very compressed shell characterized by slightly convex flanks with maximum thickness at mid-flank and a distinct furrow on venter. The umbilicus is fairly narrow with low, oblique wall and rounded shoulders. Ornamentation consists of highly variable prorsiradiate, sigmoidal ribs, most of which arise from tubercles on umbilical shoulder, but many are bifurcating and a few short intercalatory ribs are present as well. All ribs project forward at tubercles on the ventrolateral shoulder. Five spiral rows of tubercles are arranged on the ribs; one on the umbilical shoulder, two on the flank, one on the ventrolateral shoulder, and one bordering the ventral furrow. The suture is not visible.

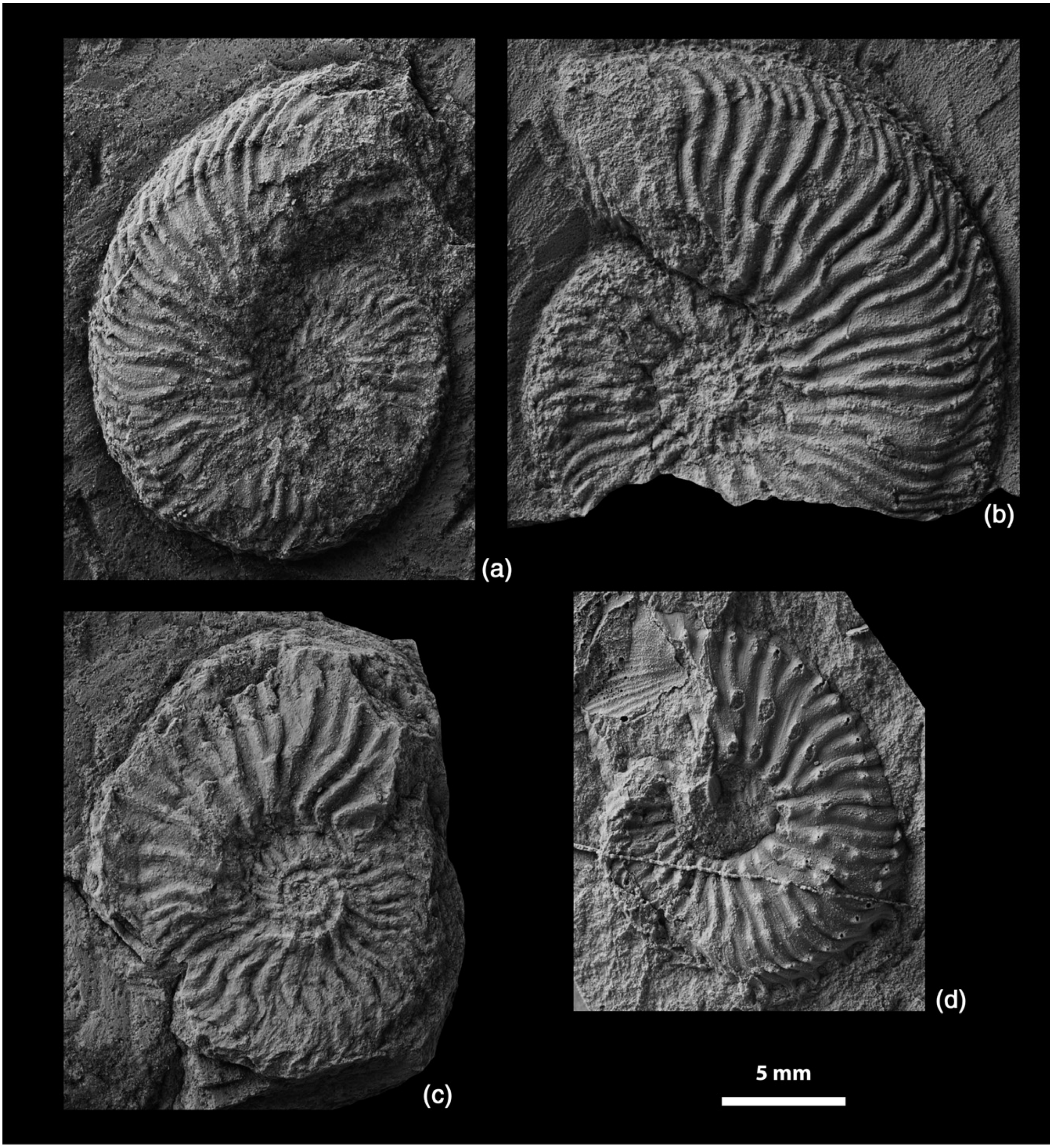

Fig. 5 *Sirenites senticosus* (Dittmar, 1866) from the upper part of the Sabudani Formation, Kito area. (a) TKPM GFI5835; (b) TKPM GFI5836; (c) TKPM GFI5837; (d) TKPM GFI5501 (silicon rubber cast). TKPM, Tokushima Prefectural Museum.

DISCUSSION

The specimens have five rows of tubercles on the prorsiradiate ribs, which is characteristic of *Sirenites senticosus* as described by Dittmar (1866), Mojsisovics (1893), and Breda *et al.* (2009). Therefore, we assign them with confidence to *S. senticosus*. *Sirenites senticosus* is morphologically very close to *S. ovinus* Tozer (1994, pl. 91, figs 2,7) in having five rows of tubercles, but differs by its prorsiradiate ribs, while those of *S. ovinus* tend to be rursiradiate. The range of intraspecific variation in shell morphology and ornamentation of *S. senticosus* has not been fully studied, but

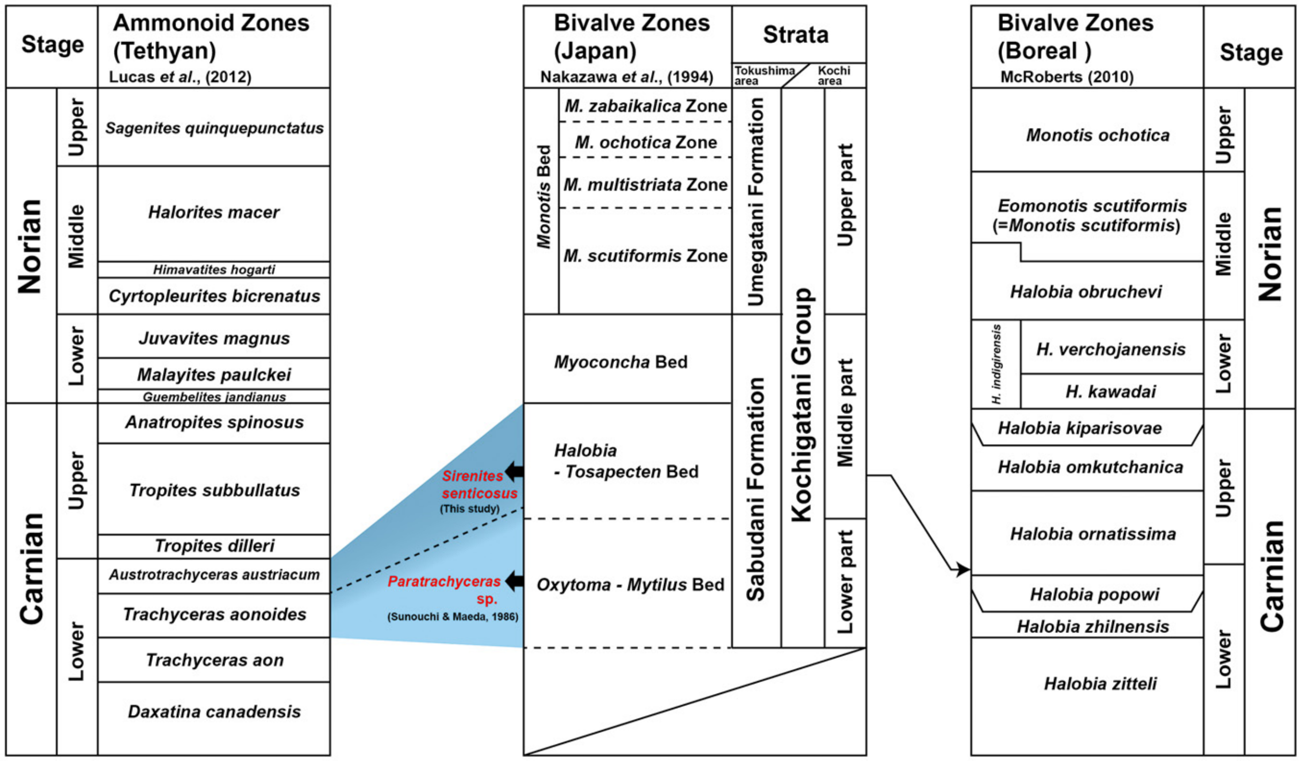

Fig. 6 Diagrams showing fossil zonal correlation of the Carnian–Norian around the Tethyan region (left), Japan (center) and Boreal region (right). Depositional age in a part of the Sabudani Formation together with *Sirenites senticosus* is late Early Carnian of the *Austrotrachyceras austriacum* Zone. Diagrams of the zonation in each region are based on Lucas *et al.* (2012), Nakazawa *et al.* (1994), and McRoberts (2010).

this species may include several morphotypes with additional rows (>5) of tubercles as described by Mojsisovics (1893, pl. 161, figs 11,15) and Krystyn (1978, pl. 4, fig. 3). The specimens described as *S. senticosus* by Tozer (1961, pl. 24, figs 7–9) from Arctic Canada were redescribed as *S. serotinus* by Tozer (1994, 170, pl. 102, figs 2,4–9). The specimen described by Astakhova (1971, pl. 4, fig. 1) from the Crimean peninsula is different from *S. senticosus* because it has four spiral rows of tubercles arranged on the ribs.

OCCURRENCE

The described specimens were collected from the upper part of the Sabudani Formation, Kito area, Tokushima, and occur with bivalves such as *Tosapecten* sp. and *Halobia* (*Zittelihalobia*) *ornatissima* Smith (Fig. 3). *Sirenites senticosus* occurs in the *Austrotrachyceras austriacum* Zone (=upper Lower Carnian) of the Hallstatt Limestone, Austria (Mojsisovics 1893; Krystyn 1978) and from the Dolomites, Italy (Breda *et al.* 2009). This species is also known from the upper Lower Carnian in southern China (Xu *et al.* 2003).

DISCUSSION

BIOSTRATIGRAPHIC IMPLICATIONS

Sirenites senticosus is one of the characteristic ammonoids in the *Austrotrachyceras austriacum* Zone of the uppermost Lower Carnian in the Tethyan realm (Fig. 6; Mojsisovics 1893; Krystyn 1978). Its occurrence in the upper part of the Sabudani Formation in the Kito area demonstrates that this particular horizon is of late Early Carnian age. The formation also yields numerous thin-shelled bivalve fossils of *Halobia* (*Zittelihalobia*) *ornatissima* Smith (Fig. 4) in the upper part of the formation. This bivalve is recognized as a zonal taxon for the Upper Carnian in the North America region, such as in southern Alaska and British Columbia (Fig. 6; McRoberts 1994, 2010, 2011). This species has a stratigraphic range from the upper Lower Carnian to lower Upper Carnian in Northeast Siberia (Polubotko 1986; Zakharov *et al.* 1997; McRoberts 2010). The overall global distribution of *H. ornatissima* supports the inference that the upper part of Sabudani Formation in the Kito area accumulated during the late Early Carnian.

The Sabudani Formation corresponds approximately with the lower–middle parts of the Kochigatani Group in the Sakawa area, Kochi Prefecture (Fig. 6; Toshimitsu *et al.* 2007). The Kochigatani Group has been traditionally divided into four beds based on biostratigraphy of fossil bivalves, in ascending order: *Oxytoma–Mytilus*, *Halobia–Tosapecten*, *Myoconcha*, and *Monotis* beds (Fig. 6; Kobayashi *et al.* 1940; Kobayashi & Ichikawa 1950; Nakazawa *et al.* 1994). Recently, Ishida and Kozai (2004) and Ishida *et al.* (2009) recognized three fossil zones in the Sabudani and Umegatani formations, in ascending order: *Myophoria* sp.–*Oxytoma pulchra*, *Halobia* sp.–*Pseudolimea naumanni*, and *Monotis ochotica* zones. Since *Halobia* and *Tosapecten* co-occur in the upper part of the Sabudani Formation together with *S. senticosus*, this particular horizon correlates with the *Halobia–Tosapecten* Bed or possibly the *Halobia* sp.–*P. naumanni* Zone. This suggests that the *Halobia–Tosapecten* Bed or the *Halobia* sp.–*P. naumanni* Zone correlate with the upper Lower Carnian (Fig. 6).

Sunouchi and Maeda (1986) reported that an ammonoid, *Paratrachyceras* sp. resembling *P. hofmanni* (Boeckh), was obtained from the *Oxytoma–Mytilus* Bed of the Kochigatani Group in the Sakawa area, Kochi Prefecture (Fig. 6). The occurrence of *P. hofmanni* has been recognized from the *Trachyceras aonoide*s Zone in the middle Lower Carnian of the Tethyan realm (Mojsisovics 1882; Arkell *et al.* 1957; Allasinaz 1968). The *T. aonoides* Zone is situated just below the *A. austriacum* Zone in the European Alps (Krystyn 1978; Ogg 2004; Lucas *et al.* 2012). This stratigraphic sequence is consistent with the established relationship between the *Oxytoma–Mytilus* and *Halobia–Tosapecten* beds (Fig. 6). Shimizu (1930) reported a specimen of *P.* cf. *hofmanni* from the *Halobia–Tosapecten* Bed of the Sakawa area (Toshimitsu *et al.* 2007). This may suggest that the *Halobia–Tosapecten* Bed partly includes the *T. aonoides* Zone.

In summary, the *Oxytoma–Mytilus* and *Halobia–Tosapecten* beds have been approximately correlated with a range from the *T. aonoides* Zone to *A. austriacum* Zone.

PALEOBIOGEOGRAPHIC IMPLICATIONS

The Upper Triassic bivalve faunas in Japan are divided into two groups with the Tethyan and Arcto–Pacific (Boreal) affinities (Tamura 1987, 1990, 1992). In particular, bivalve assemblages with Arcto–Pacific (Boreal) affinity are known as the Kochigatani bivalve faunas, and are characterized by taxa such as *Monotis*, *Minetrigonia*, and *Kumatrigonia* (Tamura 1987). The Tethyan bivalve faunas, resembling the St. Cassian-type faunas of the European Southern Alps, occur in limestone blocks within the Sambosan accretionary complex of the Southern Chichibu Belt (Onoue & Tanaka 2005). Thus, limestone blocks bearing Tethyan bivalve faunas are interpreted as exotic blocks derived from plate movement (Matsuoka & Yao 1990; Tamura 1990; Matsuoka 1992). Conversely, the Kochigatani bivalve faunas have very strong affinity to faunas in Northeast Siberia and the Primorye region, and occur within clastic rock facies of the Sangun–Yamaguchi, Maizuru, and Kurosegawa Belts (Tamura 1987, 1990, 1992). It has been inferred that these sediments were deposited in a forearc basin along the Pacific margin of the South China continental block (Isozaki *et al.* 2011, 2012).

Most bivalves of the Sabudani Formation are included in the Kochigatani bivalve faunas (Ishida *et al.* 2005). In particular, the occurrence of *Halobia* (*Zittelihalobia*) *ornatissima*, which is known from relatively high paleolatitude regions, such as Northeast Siberia and North America, confirms a Boreal influence (Smith 1927; Bychkov *et al.* 1976; Polubotko 1986; Zakharov *et al.* 1997; McRoberts 2010). In contrast to the bivalve faunas, the ammonoids from the Kochigatani Group have received little attention, but are known to be related to either Tethyan or Boreal realms, with the exception of a few studies such as Bando (1967) and Sunouchi and Maeda (1986).

The genus *Sirenites* is a cosmopolitan taxon (Tozer 1981). Several groups of the subfamily Sireninae predominate in the Boreal region during Carnian and Norian time, and have an important role as biostratigraphic markers (Dagys 1988; Bychkov 1995; Zakharov 1997; Konstantinov 2008; Konstantinov & Klets 2009; Balini *et al.* 2012). However, *S. senticosus* is mainly known from the Tethyan region, extending from the European Alps to southern China (Fig. 7; Mojsisovics 1893; Krystyn 1978; Xu *et al.* 2003; Breda *et al.* 2009). Shimizu (1930) and Sunouchi and Maeda (1986) reported several specimens resembling *Paratrachyceras hofmanni* from the Kochigatani Group. This species is distributed from the northern margin of Tethys to the Pacific Ocean (Sunouchi & Maeda 1986). Other Upper Triassic ammonoid genera described or reported from the terrigenous clastic deposits in Japan are cosmopolitan or

Table 1 Records of Late Triassic ammonoids reported from terrigenous clastic deposits in Japan

Genus	Geographic distribution based on Tozer (1981)	Referenced species	Strata	References
'*Mojsvarites*'	Tethys	'*M.*' *arakurensis* (Nakazawa)	Arakura Formation	Nakazawa (1958)
Monophyllites	Tethys-Sephardic Province-Pacific	*Monophyllites* sp.	Arakura Formation	Nakazawa (1959)
Rhacophyllites	Tethys–Pacific–Arctic	*Rhacophyllites* sp.	Saragai Group	Nakazawa (1964)
		Rhacophyllites sp.	Tanoura Formation	Ishibashi (1972)
Placites	Tethys–Pacific–Arctic	*P.* aff. *oxyphyllus* (Mojsisovics)	Saragai Group	Shimizu and Mabuchi (1932)
		P. aff. *oxyphyllus* (Mojsisovics)	Takagochi Formation	Ishibashi (1972)
Arcestes(*Arcestes*)	Tethys–Pacific–Arctic	*A.*(*A.*) *oligosarcus* Mojsisovics	Saragai Group	Shimizu and Mabuchi (1932)
		Arcestes sp.	Saragai Group	Nakazawa (1964)
		Arcestes sp.	Kochigatani Group	Tsujino *et al.* (2011)
Arcestes(*Stenarcestes*)	Tethys–Pacific	*Arcestes* (*Stenarcestes*) sp.	Nariwa Group	Nakazawa (1959)
Arcestes(*Proarcestes*)	Tethys–Sephardic Province – East Pacific	*A.* (*P.*) aff. *hanieli* Welter	Kochigatani Group	Shimizu (1931)
		A. (*P.*) aff. *bicarinatu* Münster	Kochigatani Group	Shimizu (1931)
		A. (*P.*) cf. *ausseeanus* (Hauer)	Tanoura Formation	Ishibashi (1972)
Paratrachyceras	Tethys	*P.* cf. *hofmanni* (Boeckh)	Kochigatani Group	Shimizu (1930)
		Paratrachyceras n. sp.	Kochigatani Group	Shimizu (1930)
		Paratrachyceras sp.	Nabae Group	Nakazawa (1957)
		Paratrachyceras n. sp.	Kochigatani Group	Bando (1964)
		Paratrachyceras sp.	Kochigatani Group	Sunouchi and Maeda (1986)
		P. cf. *hofmanni* (Boeckh)	Mine Group	Ishibashi *et al.* (1990)
Trachyceras	Tethys–East Pacific	*T.* cf. *desatoyense* (Johnston)	Mine Group	Ishibashi *et al.* (1990)
Cyrtopleurites	Tethys–East Pacific	*C. sakawanus* (Mojsisovics)	Kochigatani Group	Mojsisovics (1888)
		C. cf. *sakawanus* (Mojsisovics)	Nabae Group	Nakazawa (1957)
Dimorphites	Tethys–East Pacific	*Dimorphites* sp.	Nabae Group	Nakazawa (1957)
Buchites	Tethys–East Pacific	*B. kumamotoensis* Ishibashi	Tanoura Formation	Ishibashi (1972)
Phormedites	Tethys–East Pacific	*Phormedites* sp.	Tanoura Formation	Ishibashi (1972)

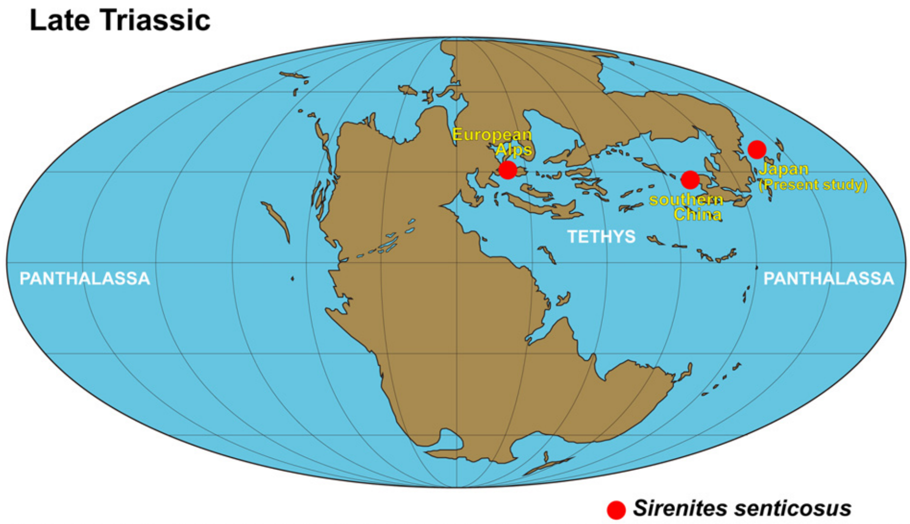

Fig. 7 Paleobiogeographic distribution of *Sirenites senticosus* based on the present study and occurrence data from the European Alps to southern China (Mojsisovics 1893; Krystyn 1978; Xu *et al.* 2003; Breda *et al.* 2009). Late Triassic paleomap is based on Blakey (2011).

Tethyan taxa (Table 1), and there are no exclusively Boreal affinities in the fauna. These data suggest that there is a clear difference in paleobiogeographic tendency between ammonoid and bivalve faunas in the Upper Triassic of Japan.

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