

# Orbitolinid foraminifers in the Northwest Pacific: Their taxonomy and stratigraphy

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**ABSTRACT:** Orbitolinid foraminifers supply important information for the understanding of Cretaceous marine biogeographic and paleoclimatic conditions. A pre-requisite for these palaeoenvironmental interpretations is a sound taxonomy. The taxonomy of the orbitolinids from the Northwest Pacific has been controversial, and this paper aims at a taxonomic and stratigraphic revision of this group. Four orbitolinid species (“*Palorbitolina lenticularis*”, *Praeorbitolina* cf. *wienandsi*, *Mesorbitolina parva*, and *M. texana*) have been recognized. Orbitolinids occurred almost continuously from the Late Hauterivian to the late Early Albian. Species belonging to the *Praeorbitolina cormyi*–*Mesorbitolina aperta* evolutionary lineage are most common, while dictyoconids are missing in the Northwest Pacific. Following the last occurrence of *M. parva* in the *Douvilleiceras mammilatum* Zone of the Early Albian, no orbitolinids have been recognized in the Northwest Pacific. It is possible that provincialism in orbitolinid foraminifers occurred during the Early Cretaceous of the North Pacific.

## INTRODUCTION

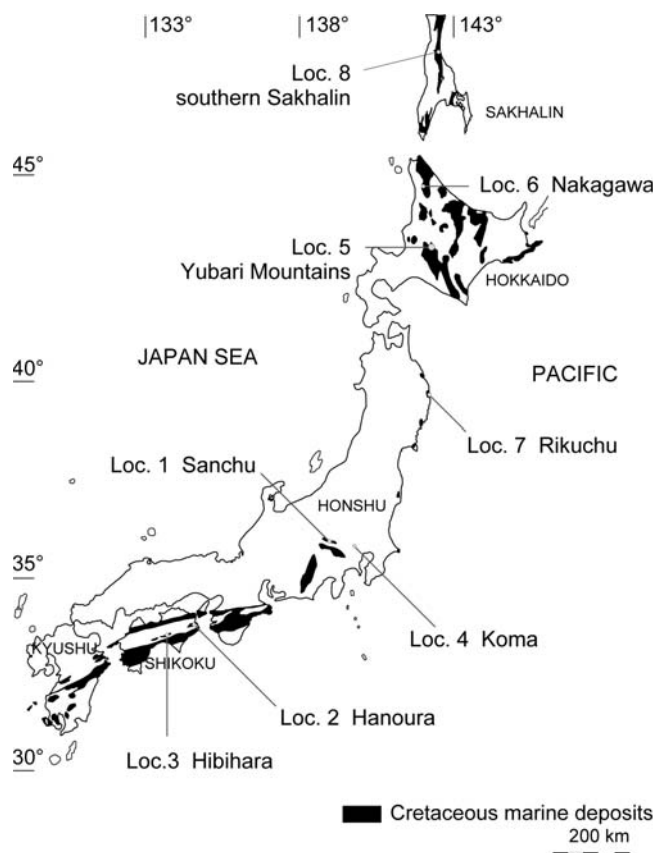
The Orbitolinidae are large benthic foraminifers with highest diversities in the Early to Mid-Cretaceous. This family flourished in shallow marine carbonate facies deposited under subtropical to tropical conditions. The species have relatively short temporal ranges and thus provide valuable chronostratigraphic information (e.g., Arnaud-Vanneau 1998; Schroeder et al. 2010). Furthermore, orbitolinids are important as indicators of tropical climates typical for the Tethyan Realm (e.g. Masse, 1992). The role of orbitolinids in the North Pacific, which was already at that time the world’s largest ocean, has been discussed by Iba and Sano (2007) and Takashima et al. (2007).

The Orbitolinidae are classified into two “subfamilies”, the Orbitolininae and the Dictyoconinae (Moullade 1965). In Orbitolininae, the structure and size of the embryonic apparatus is significant for generic- and species-level classification (Schroeder 1962, 1975, 1979). Schroeder (1975, 1979) and Schroeder et al. (2002, 2010) paid attention to the developmental pattern of the orbitolinid embryonic apparatus and recognized several phylogenetic lineages within the Orbitolininae. They classified the Orbitolininae into several short-ranging genera and species groups based on the concepts of phylogenetic lineages, and they proposed six evolutionary phylogenetic lineages: 1) *Montseciella glanensis* (Foury)–*Rectodictyoconus giganteus* Schroeder (Late Hauterivian–Early Aptian), 2) *Valserina primitive* Schroeder–*Eygalerina turbinata* (Foury) (Late Hauterivian–Early Barremian), 3) *Eopalorbitolina pertenuis* (Foury)–*Palorbitolinoides hedini* Cherchi and Schroeder (Early Barremian–Early Albian), 4) *Praeorbitolina cormyi* Schroeder–*Mesorbitolina aperta* (Ewan) (Early Aptian–Early Cenomanian), 5) *Orbitolina sefini* Henson–*O. concave* Lamarck

(Late Albian–Early Cenomanian), and 6) *Conicorbitolina moulladei* Bilotte–*C. conica* (d’Archiac) (Late Albian–Middle Cenomanian) (Schroeder 1964, 1975, 1979; Schroeder et al. 2002, 2010; Cherchi and Schroeder 2004). This classification is now regarded as a standard for taxonomic studies of the Orbitolininae (e.g., Simmons et al. 2000; Cherchi and Schroeder 2004; Schroeder et al. 2010).

Since the first brief report by Yabe (1901) and early taxonomic work by Yabe and Hanzawa (1926), orbitolinids have been recovered from several Cretaceous localities in Japan and Sakhalin (Russian Far East), which were located at the Northwest Pacific margin at that time. Later, Hofker (1963) considered that all the Early to Mid-Cretaceous orbitolinid species including the Japanese ones, belonged to a single species *Orbitolina lenticularis* (Blumenbach). His classification concept was followed in the Japanese literature for a long time (e.g., Ujiié and Kusukawa 1968; Matsumaru 1971, 1973), though this concept was not accepted worldwide. The specimens from Japan are often missing embryonic apparatus due to strong abrasion in high energy depositional environments and biomineral neomorphism (e.g., Ujiié and Kusukawa 1968). Thus the identifications have not been based on detailed structures and the size of embryonic apparatus, but rather on other features such as the form of the test (e.g., Matsumaru et al. 1976; Salnikov and Tikhomolov 1987). Finally Iba et al. (2005) successfully analysed orbitolinid species from northern Hokkaido as *Orbitolina* (*Mesorbitolina*) gr. *parva* Douglass–*texana* Roemer, following the classification scheme of Schroeder (1975, 1979).

More recently, several taxonomic studies of orbitolinids from the Northwest Pacific have been published (e.g., Matsumaru 2005; Matsumaru et al. 2005, 2007; Iba and Sano 2006;



TEXT-FIGURE 1

Map of orbitolinid localities in the Cretaceous of the Northwest Pacific region.

Matsumaru and Furusawa 2007), although problems with these studies include: 1) some identifications are still based on test shapes, and not on the structure and size of the embryo; 2) several genera and species are mentioned, but not described nor figured; and 3) the stratigraphy of the orbitolinid localities was not accounted for. Recently, Cherchi and Schroeder (2009) reviewed some of the taxonomic problems in these studies, and also pointed out that Early Aptian *Praeorbitolina* gr. *cormyi* Schroeder–wienandsi Schroeder and possibly *Palorbitolina lenticularis* (Blumenbach) probably represent the oldest orbitolinid records in the Northwest Pacific. There are, however, orbitolinids from Hauterivian and Barremian in the Northwest Pacific. Early Albian orbitolinid specimens with an embryonic apparatus, which represents the last record in the Northwest Pacific, have been discovered. This paper brings together all available information of the orbitolinid records in the Northwest Pacific and attempts a coherent picture of their taxonomy and spatiotemporal distribution.

## ORBITOLINID-BEARING STRATA IN THE NORTHWEST PACIFIC

The orbitolinid-bearing strata are widely distributed along the Northwest Pacific margin. Remains of orbitolinids are abundant in 1) shallow-marine calcareous sandstones and conglomerates (e.g., Ujiie and Kusukawa 1968; Iba and Hirauchi 2009), and 2) small-scale shallow-marine carbonates. These are not of

accreted sea-mount origin, but were deposited in continental-margin settings with abundant terrigenous clastics (e.g., Sano 1995). Orbitolinids generally co-occur with other typical Tethyan biota such as rudists and hermatypic corals (Iba and Sano 2006, 2007; Iba and Hirauchi 2009).

Field surveys and literature studies confirm the presence of orbitolinids in ten formations exposed at eight localities (text-figure 1 and table 1): Loc. 1—The Ishido Formation (Late Hauterivian–Barremian) in the Sanchu area of the Kanto Mountains, central Honshu Island. Loc. 2—The Lower Hanoura Formation (Early Barremian) of the Monobegawa Group in the Hanoura area, Shikoku Island. Loc. 3—The Lower Member of the Hibihara Formation (Early Aptian) of the Monobegawa Group in the Hibihara area, Shikoku Island. Loc. 4—The Takaoka Formation (Early Aptian ?) in the Koma area, central Honshu Island. Loc. 5—The limestone olistoliths intercalated in the Kirigishiyama Olistostrome Member (Aptian) of the Shuparogawa Formation of the Yezo Group in the Yubari Mountains, central Hokkaido Island. Loc. 6—The Kamiji Formation (Late Aptian–Albian) of the Yezo Group in the Nakagawa area, northern Hokkaido Island. Loc. 7—The Tanohata (Late Aptian) and Hiraiga (Late Aptian–Early Albian) formations of the Miyako Group in the Rikuchu area, northern Honshu Island. Loc. 8—Ai Formation of the Yezo Group (Early Albian ?) in southern Sakhalin Island, Russian Far East. Occurrences from the Taiwan Island, which have not been confirmed by Matsumaru and Furusawa (2005) and Matsumaru et al. (2005), are excluded from the present discussion. Occurrences from the submerged seamounts now located in the Northwest Pacific (e.g., the Daiichi Kashima seamount; Shiba 1988; Masse and Shiba 2010) have also been excluded, because their paleogeographic position in the Cretaceous was different from Northwest Pacific. The ages of all orbitolinid localities in the Northwest Pacific, in which specimens preserving embryonic apparatus were recovered, are reviewed below.

## Sanchu (Loc. 1)

In the Outer Zone of Southwest Japan, both non-marine and shallow marine strata were deposited alternatively during the Early Cretaceous (e.g., Matsukawa and Obata 1992). The Ishido (Loc. 1) and Lower Hanoura (Loc. 2) formations are usually considered as almost coeval strata (Tashiro 1985; Matsukawa and Obata 1992; Ishida et al. 1992, 1996). Although the occurrence of orbitolinids from the Sanchu area in the Kanto Mountains (Loc. 1) has been reported frequently since Takei (1963), Matsumaru et al. (2005) were the first to report *Palorbitolina lenticularis* from two localities of the Ishido Formation: one is a calcareous sandstone of the lowermost part of the Ishido Formation at Otchi, the other a spongiomorphoid coral and algal limestone of the upper part of the Ishido Formation at Yaegoya. The orbitolinid specimens with embryo were reported only from the Yaegoya locality. Iba and Hirauchi (2009) recently showed that orbitolinids occur with Tethyan-type mollusks in the calcareous sandstone and carbonate of the lowermost part of the Ishido Formation at Otchi, which is same locality that was mentioned by Matsumaru et al. (2005). Since the fossiliferous limestones (“Torinosu-type limestone”) were recognized only in the upper part of the Ishido Formation according to the description of Takei et al. (1977), the locality of Matsumaru et al. (2005) at Yaegoya probably belongs to the upper part of the Ishido Formation.

TABLE 1  
Orbitolinid records in the Northwest Pacific.

Locality	Strata	Geological Age	Orbitolinid species
Sanchu, central Honshu	lowermost part of the Ishido Fm.	L. Hauterivian	orbitolinid
	Upper part of the Ishido Fm.	Barremian	" <i>Palorbitolina lenticularis</i> "
Hanoura, Shikoku	Lower Hanoura Fm. of the Monobegawa Gp	E. Barremian	"? <i>Palorbitolina lenticularis</i> "
Hibihara, Shikoku	Lower member of the Hibihara Fm. of the Monobegawa Gp.	E. Aptian	orbitolinid
Koma, central Honshu	Takaoka Fm.	E. Aptian (?)	orbitolinid
Yubari Mountains, central Hokkaido	Shuparogawa Fm. of the Yezo Gp.	late E. Aptian - L. Aptian	<i>Praeorbitolina</i> cf. <i>wienandsi</i>
			<i>Mesorbitolina parva</i>
			<i>Mesorbitolina texana</i>
Nakagawa, northern Hokkaido	Kamiji Fm. of the Yezo Gp.	L. Aptian	<i>Mesorbitolina parva</i>
Rikuchu, northern Honshu	Tanohata Fm. of the Miyako Gp.	L. Aptian	orbitolinid
	Hiraiga Fm. of the Miyako Gp.	L. Aptian - late E. Albian	<i>Mesorbitolina parva</i>
southern Sakhalin	Ai Formation of the Yezo Gp.	Early Albian (?)	orbitolinid

Abundant ammonites have been recovered from the Ishido Formation, suggesting a Late Hauterivian–Barremian age (Obata et al. 1984; Matsumoto et al. 1985; Matsukawa 1988). The orbitolinid-bearing horizon at Otchi is very close to the basal part of the Ishido Formation (Iba and Hirauchi 2009). Since specimens of *Simbirkites* (*Milanowskia*) sp. were recovered from the lowermost part of the Ishido Formation (Matsukawa 1983, fig. 6; Matsukawa et al. 2007, fig. 7), the age of the orbitolinids at Otchi can be considered as Late Hauterivian. Recent finds of ammonites from the upper part of the Sebayashi Formation, which directly overlies the Ishido Formation, clearly indicate an Barremian age (Terabe and Matsuoka 2009; Matsukawa and Tomishima 2009). Thus the age of the orbitolinids at Yaegoya should be considered as the Barremian.

It should be noted that Sashida et al. (1992) considered the age of the "Torinosu-type limestone" in the upper Ishido Formation to be the early Aptian based on poorly preserved planktonic foraminiferal specimens recovered from the limestones themselves. These authors referred solely to Caron (1985) in constructing their planktonic foraminiferal biochronology. However, since the work of Banner and Desai (1988), significant accumulation of knowledge has been made regarding the taxonomy of Aptian or older planktonic foraminifera (Coccioni and Premoli Silva 1994; Boudagher-Fadel et al. 1997; Verga and Premoli Silva 2003). Now the identifications of *Globuligerina hoterivica* (Subbotina), *Hedbergella planispira* (Tappan), and *Globigerinelloides* aff. *blowi* (Bolli) by Sashida et al. (1992, fig. 3) are obsolete (Ando, personal communication, 2010). Matsumaru et al. (2005) considered the age of Sanchu orbitolinids as Early Aptian (Bedoulian) based on the above-mentioned planktonic foraminiferal study and the occurrences of *Palorbitolina lenticularis* and *Iraqia simplex* Henson. However, *Iraqia simplex* has not been described nor figured.

#### Hanoura (Loc. 2)

"*Orbitolina shikokuensis* Yabe and Hanzawa" was recovered from a thin ooid-rich limestone bed of the Lower Hanoura Formation. The shales of this formation are characterized by *Shasticrioceras nipponicum* (ammonite) and *Archaeodictyomitra pseudoscalaris* (radiolarians) assemblages (Ishida et al. 1996). The *Shasticrioceras nipponicum* assemblage consists of *Crioceratites* (*Paracrioceras*) *asiaticum* Matsumoto, *Heteroceras* (*Argvethites*) sp., *Pulchellia* sp. cf. *ishidoensis* Yabe and Shimizu, *Shasticrioceras nipponicum* Matsumoto (Ishida et al. 1996), and probably indicates an Early Barremian age (Matsukawa and Obata 1993). The occurrence of Hanoura specimen with embryo, which belongs to *Orbitolina lenticularis* form group I *sensu* Hofker (1963), was briefly mentioned in the postscript of Matsumaru (1971). Matsumaru (1973, pl. 22–127 (Cr-12)–10) figured a single specimen with an embryonic apparatus from this locality as *Orbitolina lenticularis* similar to the Early Aptian form from Aude, France. Matsumaru et al. (2005) include the orbitolinid of Matsumaru (1971) from this locality in the synonym list of *Palorbitolina lenticularis*. Cherchi and Schroeder (2009) point out that its embryonic apparatus could be identical with *Palorbitolina lenticularis*, and concluded an Early Aptian age. Cherchi and Schroeder (2009), however, misunderstood that it was recovered from Hokkaido. Their age discussion of the orbitolinid-bearing carbonates in Hokkaido based on *Palorbitolina lenticularis* needs revision.

#### Yubari Mountains (Loc. 5)

The occurrence of Japanese orbitolinids was first reported from the Yubari Mountains, central Hokkaido (Yabe 1901), and two species were described later (Yabe and Hanzawa 1926). Matsumaru (1971) described *Orbitolina lenticularis* form group II *sensu* Hofker (1963) from this locality. Matsumaru (1973) discussed *Orbitolina lenticularis* from this locality is similar to the



Late Aptian form from Aude, France. *O. lenticularis* and a Late Aptian–Early Albian age of *O. lenticularis* form group II had been the basis for the study of the Yezo Group until several years ago (e.g., Sano 1995; Takashima et al. 2004). Matsumaru and colleagues later revised its classification as *Palorbitolina lenticularis* in the synonym list of Matsumaru et al. (2005), and reconsidered the age of orbitolinid-bearing limestones as Early Aptian, based on their identification of orbitolinid species (Matsumaru 2005; Matsumaru and Furusawa 2007; Matsumaru et al. 2007). Iba and Sano (2006) considered its age as Late Aptian, based on the occurrences of *Mesorbitolina parva* (Douglass). In this paper, *Mesorbitolina* Schroeder was used as genus name, according to recent literatures (Schroeder et al. 2002, 2010; Cherchi and Schroeder 2004).

The shallow-marine carbonates of the Yezo Group that contain orbitolinids have long been called “*Orbitolina* limestones” (e.g., Matsumoto 1942, 1951). A recent revision of the stratigraphy of the Yezo Group revealed that “*Orbitolina* limestones” are re-deposited limestone olistoliths intercalated in the Kirigishiyama Olistostrome Member of the Shuparogawa Formation of the lower part of the Yezo Group (Sano 1995; Takashima et al. 1997, 2004; Takashima and Nishi 1999). The orbitolinid-bearing limestones of “the Shimanoshita Mudstone of the Lower Yezo Group” in Matsumaru (1971, 1973, 2005), Matsumaru et al. (2007) and Matsumaru and Furusawa (2007), where *Praeorbitolinoides japonica* Matsumaru, *Mesorbitolina parva*, *M. libanica* (Henson), *M. minuta* (Douglass), *Palorbitolina lenticularis*, “*Paleodictyoconus conica* Matsumaru n. sp.” were recovered, are the same as those of the Kirigishiyama Olistostrome Member in Iba and Sano (2006, 2007), where *M. parva* was described. Ando and Kakegawa (2007) supposed that the Aptian–Albian boundary existed in the lower part of the Kasamori-zawa Member of the Shuparogawa Formation, which directly overlies the Kirigishiyama Olistostrome Member. The age of the orbitolinid-bearing limestones should thus be of Late Aptian age or earlier.

#### Nakagawa (Loc. 6)

*Mesorbitolina parva* was recovered from the limestone pebbles in the conglomerate of the Kamiji Formation, the lowermost part of the Yezo Group in the Nakagawa area, northern Hokkaido (Iba et al. 2005; Iba and Sano 2006). Occurrence of the Late Aptian ammonite, *Parahoplites colossus* Matsumoto from the K<sub>j</sub> 2 Member of the Kamiji Formation, which lies above the limestone clast-bearing conglomerate, indicates the upper limit of the age of the orbitolinid-bearing limestone is Late Aptian. Because of the stratigraphic range of *M. parva*, it may be that the source carbonate sediments were deposited originally in the shallower parts of the Late Aptian Yezo forearc basin.

#### Rikuchu (Loc. 7)

The Rikuchu area is the one of classic localities for Japanese orbitolinid studies (Yabe and Yehara 1913), from where three species were described by Yabe and Hanzawa (1926). Ammonite biozones of Late Aptian–Early Albian age have been established for the Miyako Group (Obata 1967; Hanai et al. 1968; Obata and Futakami 1992 and references therein). Orbitolinid tests are very abundant in the relatively pure calcareous sandstone to grainstone facies of the Tanohata and Hiraiga formations, called the “*Orbitolina* facies” (Hanai et al. 1968). However, they are usually abraded and no embryonic apparatus has been reported (Ujiié and Kusukawa 1968; Matsumaru and

Furusawa 2005). Recently, the present authors discovered specimens of *Mesorbitolina parva* with embryonic apparatus from the upper part of Hiraiga Formation (Early Albian: *Douvilleicerias mammillatum* Zone) in the Tanohata area. This finding is mentioned below.

### HOW MANY ORBITOLINID SPECIES DID EXIST IN THE NORTHWEST PACIFIC?

Orbitolinid specimens with embryonic apparatus have been recovered from five localities (Locs. 1, 2, 5, 6, and 7) so far. Japanese orbitolinids have been assigned in the past to over ten “species” following the concept of Schroeder (1975, 1979). Some of these “species” have not been described nor figured at present, and are excluded from this study. Cherchi and Schroeder (2009) had already discussed the classification problems of some of these taxa including the new genus and species *Praeorbitolinoides japonica* Matsumaru. Systematic assignments of all these specimens whose systematic position can be discussed based on embryonic apparatus, are reviewed in the context of revised stratigraphic and age data.

#### *Eopalorbitolina*–*Palorbitolina* group

*Palorbitolina lenticularis* is the most common and stratigraphically important orbitolinid foraminifer, which is known worldwide for the Late Barremian–early Late Aptian (e.g., Schroeder 1963; Husinec 2001). *Eopalorbitolina pertenuis*–*Palorbitolinoides hedini* evolutionary lineage, where *Palorbitolina* belongs, was established by Schroeder et al. (2002) and reviewed in detail in Schroeder et al. (2010).

The specimen of “*Orbitolina lenticularis*” from the Lower Hanoura Formation (Loc. 2: Early Barremian) in Matsumaru (1973, pl. 22–127 (Cr-12)–10) is very blurred, but indicates the presence of protoconch similar to that of *Palorbitolina* (text-figure 2a). However, the centric/eccentric position of embryonic apparatus and the shape of perieembryonic zone, which are the important characters to distinguish between *Eopalorbitolina* Schroeder and *Palorbitolina* Schroeder, cannot be recognized. In addition, its Early Barremian age is remarkably older than the stratigraphic range of *Palorbitolina* in Schroeder et al. (2010). Thus, although Cherchi and Schroeder (2009) suggested that its embryonic apparatus could be identical with that of *Palorbitolina lenticularis*, the Hanoura specimen is identified as “*?Palorbitolina lenticularis*” in this paper. *Palorbitolina lenticularis* from the upper part of the Ishido Formation at Yaegoya (Loc. 1: Barremian) in Matsumaru et al. (2005, pl. 1, figs. 1 and 3), clearly belongs to the *Eopalorbitolina*–*Palorbitolina* group, as Cherchi and Schroeder (2009) suggested (text-figure 2b). Nearly centric position of embryonic apparatus, and status of development of perieembryonic chamber and alveolar layer in the uppermost part of embryonic apparatus suggest its assignment to primitive form of *Palorbitolina lenticularis* in Schroeder et al. (2010). However, as original figure caption in Matsumaru et al. (2005) indicated, this specimen is sub-axial to slightly oblique section, and thus detailed study of its embryonic apparatus is difficult. The Yaegoya specimen is tentatively identified as “*Palorbitolina lenticularis*” here.

Matsumaru (2005) and Matsumaru and Furusawa (2007) figured *Palorbitolina lenticularis* from central Hokkaido (Loc. 5). Matsumaru’s specimen (2005, pl. 1, fig.2) is poorly preserved and does not show any diagnostically important structural details of the embryonic apparatus. Furthermore, Matsumaru and Furusawa’s specimen (2007, pl. 2, fig. 4) does not preserve any

embryonic structures, and their identification was based on comparison of test shape and form ratio. Thus there is no confirmed record of Aptian *Palorbitolina lenticularis* in Hokkaido at present. Well-oriented sections are necessary to determine the classification of *Eopalorbitolina*–*Palorbitolina* group in the Northwest Pacific.

### *Praeorbitolina*

Cherchi and Schroeder (2009) re-examined the specimens of *Praeorbitolinoides japonica* (text-figures 2c–e) from central Hokkaido (Loc. 5) and concluded that *Praeorbitolinoides* Matsumaru is a junior synonym of *Praeorbitolina* Schroeder. In addition to their discussion, our own observation reveals that the sub-embryonic zone (“periembryonic chamber”) is not subdivided by partitions into chamberlets (text-figures 2c–e). Partitions in the sub-embryonic zone, which are one of the most important characters of *Praeorbitolinoides*, do not exist, and the sub-embryonic zone represents a cup-like shape, embracing the protoconch (text-figures 2d–e). Our observations strongly support Cherchi and Schroeder (2009)’s re-identification.

At present, *Praeorbitolina* comprises two species: *P. cormyi* and *P. wienandsi*. *P. wienandsi* has a larger deuteroconch and a more developed sub-embryonic zone than *P. cormyi* (the average diameters of deuteroconch: 0.08 and 0.13 mm for *P. cormyi* and *P. wienandsi*, respectively) (Schroeder 1964; Cherchi and Schroeder 2009). Based on the diameter of the deuteroconch (0.12 mm) and the morphology of sub-embryonic zone, Cherchi and Schroeder (2009) suggested that *Praeorbitolinoides japonica* is a transitional form between *P. cormyi* and *P. wienandsi*. However, based on the relatively large size of the deuteroconch and its developed cup-shape sub-embryonic zone (text-figures 2d–e), the specimen of Matsumaru (2005) can be considered more similar to *P. wienandsi* than to *P. cormyi*. Thus we identify this specimen as *P. cf. wienandsi* in this paper. Important features of *P. wienandsi* include several partitions in the sub-embryonic zone that cannot be observed in Matsumaru’s specimen because of poor preservation.

### *Mesorbitolina*

The existence of *Mesorbitolina*s in the Northwest Pacific was first reported by Iba et al. (2005) from the Yezo Group in northern Hokkaido (Loc. 6), as *Orbitolina* (*Mesorbitolina*) gr. *parva*–*texana*. Subsequently, Iba and Sano (2006) described the specimen from Iba et al. (2005) and new specimens from the central Hokkaido (Loc. 5) as *O. (M.) parva* (text-figures 2f–g). After these papers, Matsumaru and Furusawa (2007) described *Mesorbitolina parva*, *M. libanica*, and *M. minuta* from central Hokkaido (Loc. 5) (text-figure 2i) based on Moullade and Saint-Marc (1975). *M. libanica* and *M. minuta* are now regarded as synonyms of *M. texana* (Schroeder and Neumann, 1985). Cherchi and Schroeder (2009) also pointed out that “*Paleodictyoconus conica* Matsumaru n. sp.” in Matsumaru and Furusawa (2007) has the typical feature of *Mesorbitolina*s: three parts of embryonic apparatus (deuteroconch, protoconch, and sub-embryonic zone). Our observation on the holotype of this species (Matsumaru and Furusawa 2007, pl. 2, fig. 3) revealed that 1) the small globular protoconch is 0.08 mm in diameter, 2) the poorly-preserved deuteroconch is approximately 0.20 mm in diameter, and 3) several partitions can be observed in the cup-like shaped sub-embryonic zone. These lines of evidence indicate that “*Paleodictyoconus conica*” can be assigned to *M. parva*.

Recently, the specimens of *M. parva* have been discovered from the upper part of Hiraiga Formation (Early Albian) of the Miyako Group (Loc. 7) (text-figure 2h). This is the first record of the specimens with embryonic apparatus from this locality. In summary, *M. parva* and *M. texana* occurred in the Northwest Pacific.

### DISCUSSION AND CONCLUSIONS

Orbitolinids occur almost continuously in the Northwest Pacific from the Late Hauterivian to the Early Albian. The earliest occurrence is at present the un-identified specimens from the lowermost part of the Ishido Formation in the Sanchu area (Loc. 1), providing a Late Hauterivian age, which is much older than a previously expected Early Aptian age (Cherchi and Schroeder 2009). “*Palorbitolina lenticularis*” occurs in the Hanoura area (Loc. 2; Early Barremian) and “*Palorbitolina lenticularis*” in the Sanchu area (Loc. 1; Barremian). Three species (*Praeorbitolina cf. wienandsi*, *Mesorbitolina parva*, and *M. texana*) from the limestone olistoliths of the Shuparogawa Formation in the Yubari Mountains, central Hokkaido (Loc. 5) are confirmed in this study. *Praeorbitolina* indicates a late Early Aptian age, and *M. parva*–*texana* group the Late Aptian–Albian (Cherchi and Schroeder 2009; Schroeder et al. 2010). Since a Late Aptian age is supposed for the olistostrome bed, the age of the orbitolinid-bearing limestones should be of Late Aptian age or earlier. The orbitolinid-bearing carbonates of the Yubari Mountains are thus supposed to late Early to Late Aptian age. *M. parva* of the northern Hokkaido (Loc. 6) has a Late Aptian age as suggested by Iba et al. (2005) and Iba and Sano (2006). Youngest orbitolinid occurrences (*M. parva*: Early Albian, *Douvilleiceras mammillatum* zone) are known from the upper part of Hiraiga Formation in the Rikuchu area (Loc. 7).

No orbitolinids have been recorded later than Early Albian from the Northwest Pacific, though *M. parva*, *M. texana* and their descendants still flourished in the Middle Albian–Cenomanian of the Tethys. This orbitolinid demise is therefore interpreted as a local extinction in the Northwest Pacific. Recently, Iba and Sano (2007) summarized the Cretaceous records of carbonate platform biota (e.g., rudist and hermatypic corals) in the Northwest Pacific, and described their stepwise demise during the latest Aptian–Middle Albian. The final demise of orbitolinids occurred at the Early to Middle Albian transition. Iba and Sano (2007, 2008) explained this bio-event by means of a vicariance event, which led to separation of the North Pacific Realm from the Tethyan Realm. This hypothesis can explain the absence of orbitolinids throughout the post-Early Albian Cretaceous in the Northwest Pacific.

The occurrence of four orbitolinid species (“*Palorbitolina lenticularis*”, *Praeorbitolina cf. wienandsi*, *Mesorbitolina parva*, and *M. texana*) is confirmed for the Northwest Pacific (text-figure 2). These species except “*Palorbitolina lenticularis*” belong to the widespread *Praeorbitolina cormyi*–*M. aperta* lineage. Records of Dictyoconinae have not been confirmed. Masse (1992) recognized infralittoral and consequently a low latitudinal distribution of the Dictyoconinae compared with circalittoral and more widely distributed Orbitolininae. Masse (1992) also pointed out that the intramesogean provincialism of the Dictyoconinae at the generic and species level is very pronounced, while that of the Orbitolininae is weak. Dictyoconinae were recovered with the *Mesorbitolina*s from the Late Aptian–Albian shallow marine carbonates of the MIT and Takuyo-daisan Guyots in ODP Expedition 144 (Arnaud

Vanneau and Premoli Silva 1995). Thus the absence of the Dictyoconinae and the dominance of Mesorbitolinas in the Northwest Pacific possibly provide a clue for the recognition of provincialism or difference in paleoceanographic conditions in the Early Cretaceous Pacific.

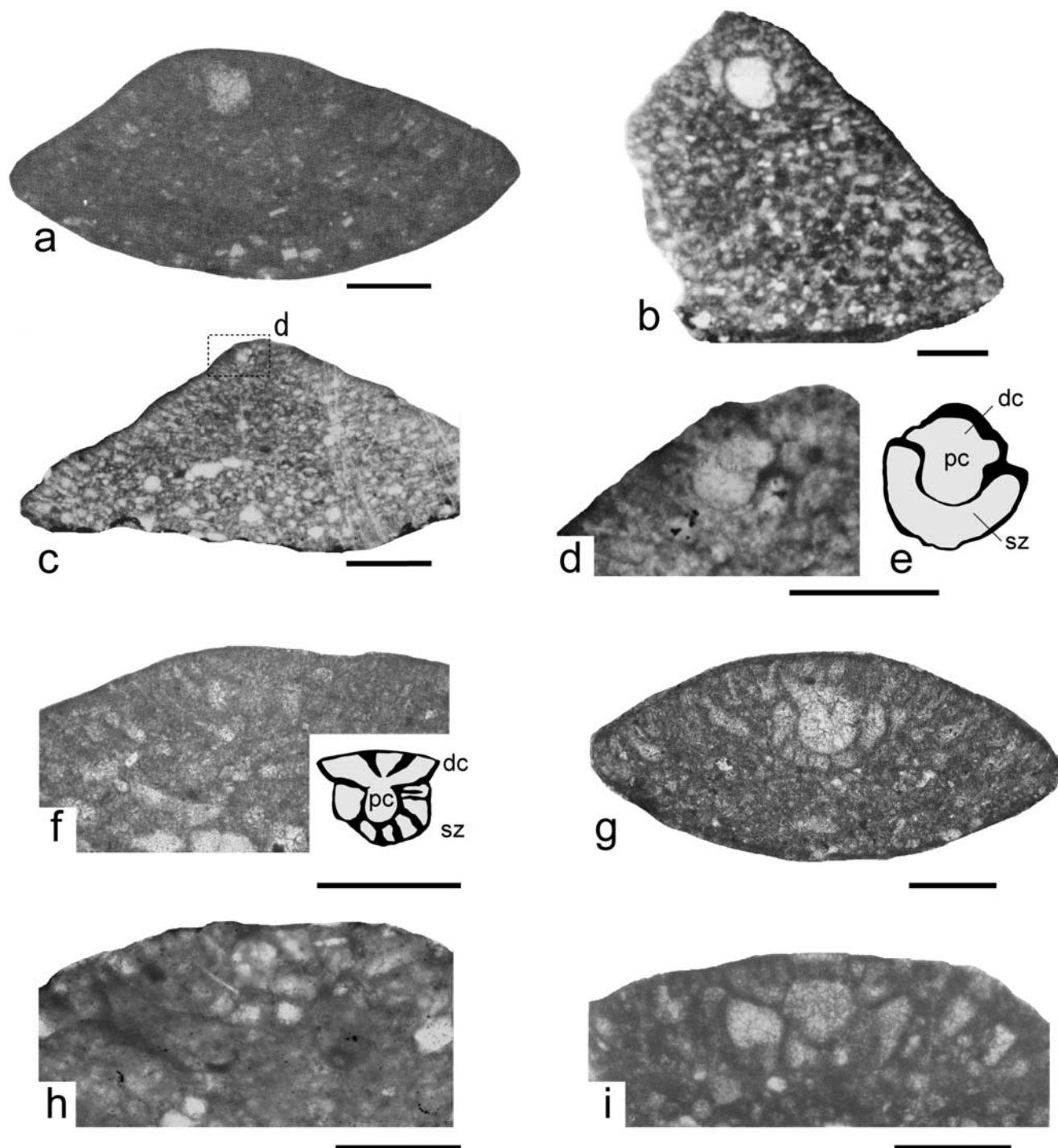
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TEXT-FIGURE 2

Orbitolinid foraminifera from the Cretaceous of the Northwest Pacific. Axial section through megalospheric embryonic apparatus and its drawings. a. “*Palorbitolina lenticularis* (Blumenbach)” (Loc. 2). From Matsumaru (1973, plate 22–127(Cr-12)–10). b. “*Palorbitolina lenticularis*” (Loc. 1). From Matsumaru et al. (2005, plate 1, fig. 1). c–e. *Praeorbitolina* cf. *wienandsi* Schroeder (Loc. 5). From Matsumaru (2005, pl. 1, figs. 1a, c). f–h. *Mesorbitolina parva* (Douglass). f, g, and h from Loc. 5, 6, and 7, respectively. f and g from Iba and Sano (2006, figs. 1b, c) and Iba and Sano (2006, fig. 3a), respectively. h. new collection from Loc. 7 (UMUT MF 30645; the University Museum, the University of Tokyo). i. *Mesorbitolina texana* (Roemer) (Loc. 5). From Matsumaru and Furusawa (2007, pl. 1, fig. 6). dc: deuteroconch, pc: protoconch, sz: sub-embryonic zone. Scale bars are 0.2mm for a–b, d–i, and 0.5mm for c.

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