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New Findings of the Planktonic Foraminifer *Leupoldina cabri* (Sigal, 1952) from the Sorachi Group of Hokkaido, Japan and Its Bearing on the Cretaceous Chronology of Northwestern Pacific Marine Strata

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Abstract *Leupoldina cabri* (Sigal) has a very unique outer morphology that makes it one of the most easily identifiable species among the Cretaceous planktonic foraminifers. The species is also very short-ranging, with its occurrence being restricted to the mid-Aptian interval of the Lower Cretaceous System. Despite its wide geographic distribution in the Atlantic and European realms, the species has not been recorded from the broad Pacific region until its discovery in 1999 from northern California. *L. cabri* was recovered from a short stratigraphic interval of siliciclastic sequences that brackets the boundary between the Sorachi and Yezo Groups in the axial zone of central Hokkaido, the northernmost island of Japan. The present report of *L. cabri* from the northwestern Pacific serves to confirm a wide geographic distribution of this species in the early Cretaceous ocean and enables to unequivocally identify the mid-Aptian interval in the Hokkaido sequence. With the recognition of *L. cabri* in the Hokkaido sequence, a possible "Livello Selli interval", detected by a parallel, independent carbon isotope study undertaken on the same sequence, can be confirmed to be time-correlative with the actual Selli Level observed in the Mediterranean type region. This confirmation clearly establishes that the ocean-wide shoaling event of oxygen-deficient waters, called the "Oceanic Anoxic Event (OAE)," had also taken place in the Pacific region during the correlative time period of Aptian age.

Key words: Cretaceous chronology, planktonic foraminifers, oceanic anoxic event, foraminiferal biogeography, Hokkaido of northern Japan.

Introduction

Leupoldina cabri (Sigal) is one of the most distinct species among all the planktonic foraminifers of Cretaceous age. Its distinct and somewhat bizarre outer morphology results from the stellate test made of planispirally coiled, four to five, trigonally shaped end chambers. When specimens are fully developed, each of the last few end chambers may take a trihedron shape from which two or more bulb-like extensions protrude (for example, see Longoria, 1969, pl. 2, figs. 6–8; Premoli Silva *et al.*,

1999, p. 1, figs. 5–6). In terms of the stratigraphic distribution, this species is extremely short-ranging occurring only in the upper one-third of the lower Aptian Stage of the Lower Cretaceous System, when two-fold subdivision of the type Aptian as proposed by Bralower *et al.* (1995) is adopted.

One of the most complete marine Cretaceous siliciclastic sequences in the Pacific realm is exposed along river valleys dissecting both eastern and western slopes of the Ashibetsu-dake-Yubari-dake Mountain Range that forms the axial zone of central Hokkaido, the northernmost island of Japan. Abundant occurrences of ammonites and inoceramids have provided well-defined biostratigraphic age constraints for these strata, particularly for the Upper Cretaceous part of the sequence. For the lower part, however, calcareous fossils are sparse and well-defined chronologies are as yet to be fully developed. We present here the first record of Tethyan planktonic foraminiferal species of *Leupoldina cabri* (Sigal) in the northwestern Pacific region, which provides an unequivocal criterion in recognizing a time-correlative interval with the mid-Aptian Age in Europe.

Geologic Setting of the Hokkaido Sequence

Although a complex framework of geology, composed of such varying lithologies as metamorphic rocks, ophiolites, accreted deep-sea sediments, and forearc basin sediments, characterizes the relatively narrow axial zone of Hokkaido, the area of study exposes an uninterrupted sequence of marine Cretaceous siliciclastic sediments along deeply incised river valleys on the western slope of the Nakatengu-dake-Ashibetsu-dake Mountain Range (Fig. 1). Sedimentary strata exposed in the area are traditionally classified into two groups, the lower Sorachi and the upper Yezo Group (Kiminami *et al.*, 1986).

The Sorachi Group is composed of basal green rocks including pillow lavas and the overlying volcanic and volcaniclastic rocks which are topped by tuffaceous mudstone. Kito (1987) and Taketani and Kanie (1992) described radiolarian faunas of the Sorachi Group and showed them to be of Late Jurassic (Tithonian) to Early Cretaceous age. No calcareous fossils have been recorded from the Sorachi Group until the present discovery of *Leupoldina cabri*-associated planktonic foraminifers from its uppermost part.

The Yezo Group conformably overlies the Sorachi Group and consists of terrigenous siliciclastic sediments which were transported into forearc basins as turbidites. These turbidites are in places interbedded with hemipelagic mudstone. A prominent olistostrome unit, containing shallow-water *Orbitolina-Praecaprotina*-bearing limestone olistoliths is intercalated within the lower part of the Yezo Group. The geology and planktonic foraminiferal biostratigraphy of the Yezo Group developed in the area immediately south of the present area of study were described in detail by Takashima *et al.* (1997). The main sequence of the Yezo Group yields diverse assemblages of

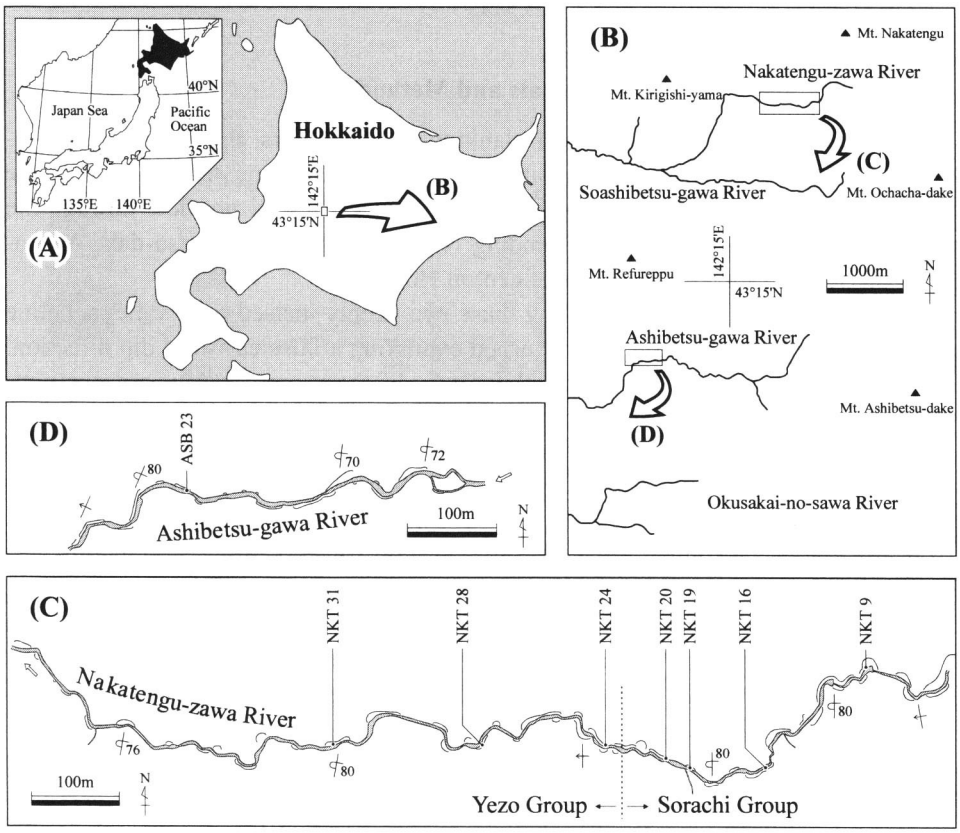

Fig. 1. Index maps, increasing details in scales, showing the sites in Hokkaido, Japan, where specimens of *Leupoldina cabri* (Sigal) were recovered. A, map of Hokkaido with indication of the Ashibetsu area. B, two studied sections, along the Nakatengu-zawa and Ashibetsu-gawa Rivers, in the Ashibetsu area. C, plan map of the Nakatengu-zawa River section showing outcrops of strata and sampling localities for foraminiferal analyses. D, plan map of the Ashibetsu gawa River section showing the ASB 23 sample site.

planktonic foraminifers assignable to zones ranging from the "*Globigerina*" *kugleri* to *Helvetoglobotruncana helvetica*. These zones characterize a late Aptian to Turonian interval of the Cretaceous Period.

Interestingly, Kimura *et al.* (1994) presented a view that the green rocks of the Sorachi Group were diffusive rocks emplaced over a Late Jurassic oceanic plateau once situated in the equatorial region of the Panthalassa Ocean. They postulated the accretion of this "Sorachi Plateau" to the region of northern Japan at about 110 Ma after its rapid northwestward migration through the western Pacific since 140 Ma. Gradstein *et al.*(1995) assigned the lower Aptian Stage to the early portion of Magnetic Chron C34N. On this basis, the range of *Leupoldina cabri* can be approximated

to a time period between 117 and 118.5 Ma.

Materials and Methods

Leupoldina cabri and associated planktonic foraminifers, discussed in the present paper, come from two sedimentary sections exposed along river valleys of the Nakatengu-zawa and Ashibetsu-gawa Rivers (Fig. 1). These rivers flow through the western slope of the meridionally trending Nakatengu-dake–Ashibetsu-dake Mountain Range that forms the axial zone of central Hokkaido.

Sedimentary strata exposed along these two deeply incised river valleys incline at an angle of ca. 80° and are all overturned exhibiting a false eastward dip direction. Sedimentary columns exposed along the course of these river valleys are diagrammatically illustrated in Fig. 2. Sediment samples for microfossil analyses were always collected from a mudstone layer forming the top portion of a given turbidite bed. Aliquots of the same mudstone samples were subjected to $\delta\ ^{13}C$ analyses, whose results will be published elsewhere.

Throughout the studied sequences, clastic sediments are strongly indurated as a result of tectonic deformation. In order to extract planktonic foraminiferal specimens, therefore, mudstones had to be treated with three separate chemical rock maceration methods. First, rocks were disaggregated with the method utilizing Glauber's salt (Kirchner, 1958). Partially disaggregated rock fragments with this method were then treated with a petroleum solvent, Varsol or Naphtha (Saito, 1985, p. 622). Finally, any remaining, undissolved rock residues were subjected to the sodium tetraphenylborate fossil extraction method as described by Hanken (1979) and Yasuda *et al.* (1985).

Such chemically processed recovery of planktonic foraminifers from the Hokkaido Cretaceous samples is thought to be quite fortuitous, and as such any one of recovered assemblages holds a strongly skewed image of the species composition of the original, live faunas in the Cretaceous ocean. Therefore, no abundance data are presented for any of the identified species in the distribution chart (Fig. 2).

Faunal References

In the two examined sections, *Leupoldina cabri* occurs in association with seven species of planktonic foraminifers. Their stratigraphic distribution relative to lithologies observed in each of the sections is shown in Fig. 2. Since the systematic paleontology of most of these species has amply been treated elsewhere in recent literature, only faunal references are given herein with the exception of *L. cabri*. Publication names cited only in the "Faunal references" are not re-captured in the references section at the end of this paper.

Gubkinella graysonensis (Tappan)=*Globigerina graysonensis* Tappan, 1940.

Globigerinelloides maridalensis (Bolli)=*Planomalina maridalensis* Bolli, 1959.

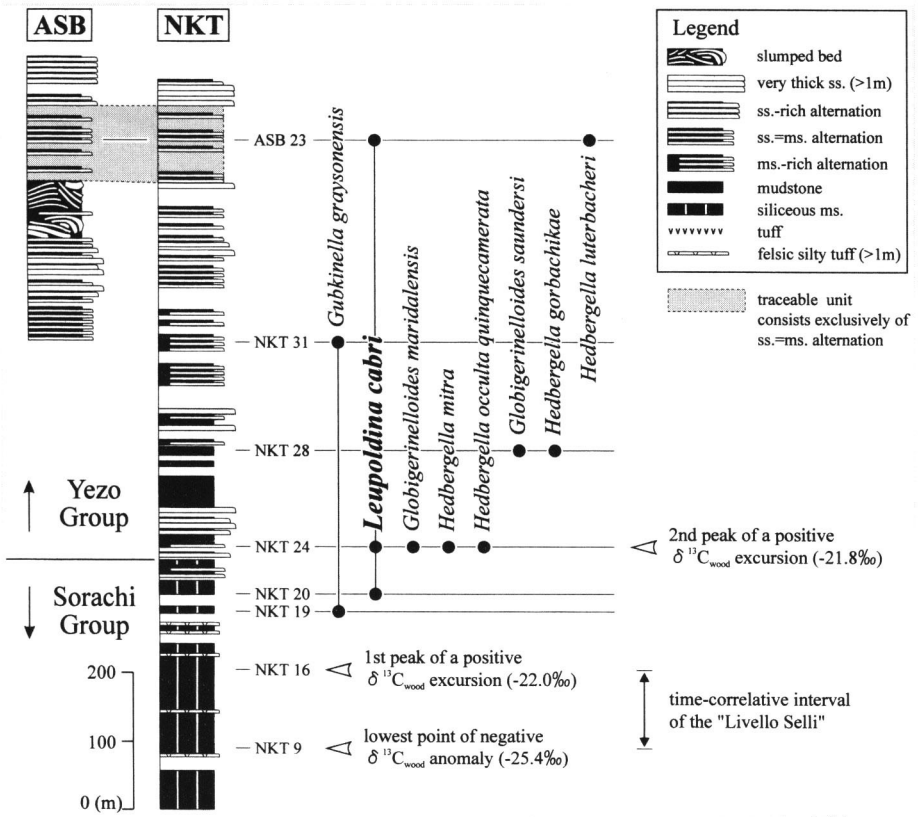

Fig. 2. Stratigraphic distribution of planktonic foraminiferal species across the boundary between the Sorachi Group and the conformably overlying Yezo Group in the Ashibetsu area. ASB: Ashibetsu-gawa section. NKT: Nakatengu-zawa section. These two sections are correlated with each other by recognizing as a point of reference the ca. 100 m-thick depositional unit composed exclusively of normally alternating beds of sandstone and mudstone [shaded horizon in the figure's upper left corner]. Small dots next to foraminiferal species names denote the occurrence of said species in a given assemblage. Position of the measured flex points of $\delta\ ^{13}C_{wood}$ curve (Ando *et al.*, 2000), that are correlative with the standard Tethyan $\delta\ ^{13}C_{carbonate}$ curve of Early Aptian age (e.g. Weissert *et al.*, 1998), is also shown to provide evaluation points for the chronology suggested by planktonic foraminifers.

Globigerinelloides saundersi (Bolli)=*Planomalina saundersi* Bolli, 1959.

Hedbergella gorbachikae Longoria, 1969.

Hedbergella occulta quinquecamerata (Banner and Desai)=*Blefuscuiana occulta* (Longoria) subsp. *quinquecamerata* Banner and Desai, 1988.

Hedbergella mitra (Banner and Desai)=*Blefuscuiana mitra* Banner and Desai, 1988

Hedbergella luterbacheri Longoria, 1969.

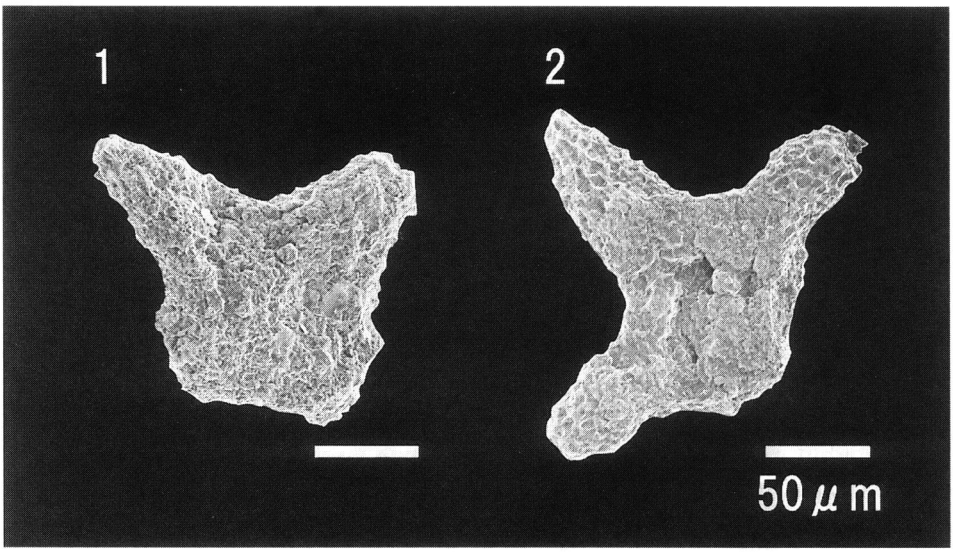

Fig. 3. *Leupoldina cabri* (Sigal). 1, side view of a specimen with four chambers per whorl; tips of three elongated chambers broken off; from Sample NKT 24. 2, side view of another specimen with four chambers per whorl; tip of one elongated chamber broken off; from Sample ASB 23. Scale bars equal 50 μm.

Taxonomic Note

Genus *Leupoldina* Bolli, 1957

The genus *Leupoldina* is characterized in having a planispiral, biumbilicate test exhibiting semi-evolute to completely involute coiling and often bearing two or more bulb-shaped chamber extensions (protuberances) in some or all of the chambers in the last whorl.

Leupoldina cabri (Sigal, 1952)

Fig. 3.

Schackoina cabri Sigal, 1952, pp. 20–21, fig. 18.
Leupoldina cabri (Sigal). Longoria, 1969, p. 90, pl. 2, figs. 1–12.
Leupoldina gr. *cabri* (Sigal). Banner and Desai, 1988, pp. 176, 178, pl. 10, figs. 1–8.
Leupoldina cabri (Sigal). Sliter, 1999, pl. 3, figs. 1–2.
Leupoldina cabri (Sigal). Premoli Silva *et al.*, 1999, pl. 1, figs. 5–6; pl. 3, figs. 8–9.

Remarks. Four to five, sub-trigonally shaped chambers forming the planispirally coiled last whorl are giving rise to the characteristic stellate periphery of the species. Also, chambers of the last whorl often tend to become radially elongated and tapered distally. In addition, well-preserved specimens are known to have two am-

poullae, or bulb-like extensions on the last two chambers forming the last whorl. The unique, stellate peripheral silhouette of this species, created by the combined effect of both the chamber shape and their arrangement in the last whorl, makes this species to be one of the most easily identifiable among the Cretaceous planktonic foraminifers.

Because our *Leupoldina cabri* specimens are recovered from strongly tectonized sedimentary strata, all the specimens appear to be laterally flattened to the point of somewhat overly exaggeration of its characteristic stellate periphery. The tubular to bulbose chambers so characteristic of this species are, however, clearly visible on our specimens (see particularly the specimen shown in Fig. 3-2).

Discussion

In spite of its easily identifiable morphology and its abundance in the Atlantic and European realms, *Leupoldina cabri* had not been recognized from the entire Pacific Ocean basin and the surrounding land areas until its discovery in 1999 from northern California by Sliter. The present report of *L. cabri* from Hokkaido of northern Japan constitutes the first discovery of this species from the western Pacific region and should greatly aid a global correlation of marine Cretaceous sediments, particularly between the Tethyan and Pacific realms.

Magniez-Jannin (1998) observed that planktonic foraminifers with radially elongated chambers, such as those including *L. cabri*, appeared in the Early Cretaceous in coincidence with or following the deposition of organic-rich sediments in the past ocean, suggesting that the elongation of chambers in these foraminifers was an adaptive response to low oxygen content in surface waters. Premoli Silva *et al.* (1999), in their study of the marly Cismon section of northern Italy that intercalates a prominent black, organic-rich interval called the "Selli Level", concluded that species of *Leupoldina* inhabited water levels poor in oxygen and proliferated only when oxygen-deficient waters shoaled as in the case of an active upwelling regime.

The junior author (A. Ando) of the present paper undertook carbon isotope analyses of bulk sediments collected from the same sections in which *L. cabri* was discovered (Ando *et al.*, 2000). Microscopic observations of selected kerogen samples contained in these sediments indicate that sedimentary organic matters were the kind composed exclusively of detrital woody materials. The resultant $\delta\ ^{13}C_{wood}$ curve is closely comparable with the $\delta\ ^{13}C_{carbonate}$ reference curves of Aptian age derived from Tethyan pelagic limestone sections (e.g. Weissert *et al.*, 1998). A remarkable positive shift of $\delta\ ^{13}C_{wood}$ values (from −25.4‰ to −22.0‰) was identified and this stratigraphic interval was interpreted to be the "Selli Level" in the northwestern Pacific realm. Major deflection points of the $\delta\ ^{13}C_{wood}$ curve are indicated in Fig. 2, although detailed discussions of this isotope study will be presented elsewhere.

The Selli Level in the Tethyan realm lies within the lower half of the *L. cabri* Zone (Premoli Silva *et al.*, 1999). The present discovery of *L. cabri* in close associa-

tion with this interpreted "Selli Level" is not only important in that it provides an independent biochronological constraint on the isotopic curve, but also it strongly reinforces the previous notion that such a major episode of organic carbon accumulation and preservation was indeed a global event in the Early Cretaceous, also similarly taking place in the northwestern Pacific Ocean.

The Selli Level, with similar lithological features (black, organic carbon-rich shales alternated with radiolarian-rich laminated horizon), has been documented in the same stratigraphic position in such distant regions as the Franciscan Terranes in California (Sliter, 1999), several drilled sites in the Pacific including Magellan and Shatsky Rises and Manihiki Plateau (Sliter, 1989), drilled sites in the North and South Atlantic including Bay of Biscay, Bermuda basin, Galicia Bank, Angola basin, and Falkland Plateau, and Exmouth Plateau in the Indian Ocean (Bralower *et al.*, 1994).

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