Paleontological Research, vol. 15, no. 2, pp. 79–84, June 30, 2011

doi:10.2517/1342-8144-15.2.079

A Tethyan bivalve, *Neithea* (Cretaceous pectinid) from northern California, and its biogeographic implications

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Received September 25, 2010; Revised manuscript accepted May 12, 2011

Abstract. The pectinid bivalve genus *Neithea* is an important indicator for understanding the Cretaceous biogeographic relationships between the Tethyan Realm and peripheral regions. However, its records in the Northeast Pacific have been scarce and *Neithea* (*Neithea*) *grandicosta* Gabb is the only known species from this area, though its stratigraphic range and morphology are poorly known. Recently collected specimens of *N.* (*N.*) *grandicosta* from the Hauterivian and Upper Aptian parts of the Budden Canyon Formation in northern California are described in detail. It is possible that the stratigraphic distribution of *Neithea* in the Northeast Pacific is also restricted to the Lower Cretaceous as it is in the Northwest Pacific. It can be considered that the demise of the Tethyan biota and following origination of endemic fauna in the post-Aptian Cretaceous occurred not only in the Northwest Pacific, but also in the Northeast Pacific. The stratigraphic distribution of the non-rudist Tethyan bivalves and other Tethyan biota in the Northeast Pacific is an important clue for understanding major mid-Cretaceous biogeographic changes in the entire North Pacific.

Key words: Biogeography, Budden Canyon Formation, Early Cretaceous, *Neithea*, North Pacific

Introduction

The mid-Cretaceous is a well documented greenhouse period of global importance during the Earth's history (e.g., Clarke and Jenkyns, 1999; Steuber *et al.*, 2005). The typical Tethyan biota, such as Mesogean biota *sensu* Masse (1992) (e.g., rudists, hermatypic corals, and orbitolinids) and "non-rudist Tethyan bivalves" *sensu* Dhondt (1992) (e.g., *Neithea*) prospered in the world's oceans during the Cretaceous, and are reliable indicators of the Cretaceous tropical marine environment and biotic realm (e.g., Dhondt, 1992; Masse, 1992; Iba and Sano, 2007a). A pectinid bivalve, *Neithea*, is one of the most important indicators for understanding the biogeographic relationships between the Tethyan Realm and peripheral regions during the Cretaceous period, because *Neithea* has a high potential for fossilization and occurred abundantly in the Tethyan Realm (e.g., Dhondt, 1973, 1981, 1985, 1992; Dhondt and Dieni, 1991, 1992; Andrade *et al.*, 2004). Recently Iba and Sano (2007a, 2008) elucidated the gradual demise of the Mesogean biota and *Neithea* in the Albian and its subsequent long-term absence through the Late Cretaceous in the Northwest Pacific. This enigmatic event in the Northwest Pacific has not been recorded in the Mediterranean, Caribbean, or indeed in any other regions of the Tethys Sea. After the demise of the Tethyan biota, mollusks in the Northwest Pacific became endemic during the late Albian–Cenomanian (Iba and Sano, 2007a). Iba and Sano (2007a, 2008) concluded that this local extinction of the Tethyan biota was a signal of a "vicariance event" and that the Northwest Pacific gradually separated from the Tethys Realm during the Albian.

Neithea has been reported also a number of times from the Northeast Pacific (e.g., Stewart, 1930; Anderson, 1938; Murphy, 1956), since Gabb (1869) first described a new species, *Neithea grandicosta*, still the only known species of the genus in this region, from the Cottonwood Creek, Shasta County, northern California. However, its precise horizon and stratigraphic range were uncertain. Furthermore, a revision of its systematic description is required, because the original description was based on only two incomplete right valves. Despite their potential paleobiogeographic importance, *Neithea* records in the Northeast Pacific have been dismissed for a long time. In the course of stratigraphic and paleontological studies of the Ono area, Shasta County

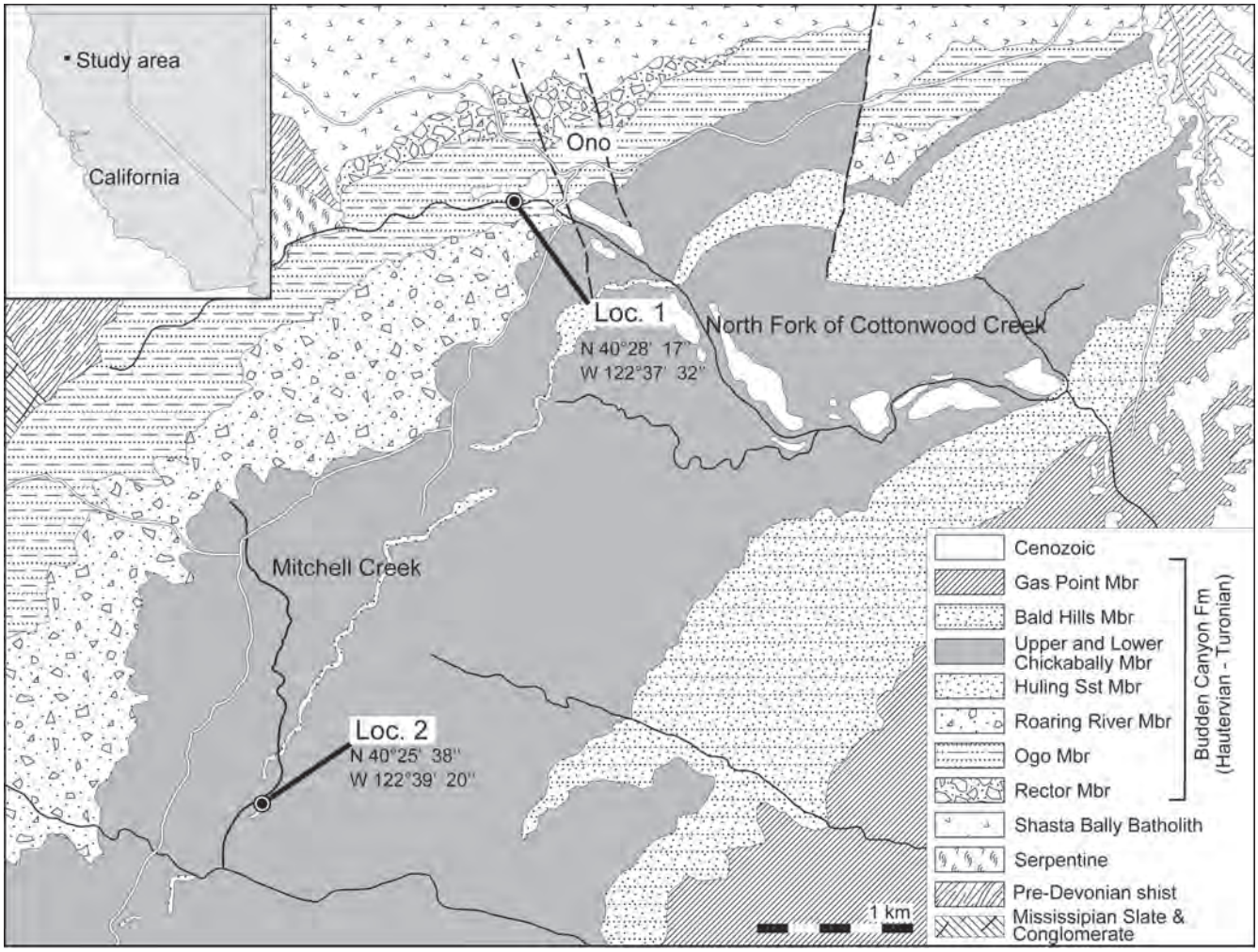

Figure 1. Locality map of *Neithea* (*Neithea*) *grandicosta* in the Ono area, northern California. *Neithea* (*Neithea*) *grandicosta* was recovered from two localities: Loc. 1 (North Fork of Cottonwood Creek, Ogo Member, Hauterivian) and Loc. 2 (Mitchell Creek, Huling Sandstone Member, Upper Aptian). Geological map modified from Murphy *et al.* (1969).

(e.g., Iba and Tanabe, 2007; Iba *et al.*, 2009), several new specimens of *Neithea grandicosta* were collected from the Hauterivian and Upper Aptian parts of the Great Valley Sequence. A detailed systematic description of *N. grandicosta* based on newly collected specimens and materials deposited in the California Academy of Sciences is provided in this paper. Comparison of the *Neithea* records in the Northeast Pacific with those in the Northwest Pacific is also made. The records of the Tethyan biota in the Northeast Pacific should further our understanding of the biogeography of the Pacific during the Cretaceous.

Geological setting

The Great Valley Sequence is widely exposed on the western side of the Sacramento Valley in northern California and is represented by an almost continuous Hauterivian to Turonian marine sequence called the Budden Canyon Formation. This formation has been the subject of many biostratigraphical and paleontological studies (e.g., Murphy and Rodda, 1996; Amédro and Robaszynski, 2005; Iba *et al.*, 2009), and has long been recognized as the most continuous and fossiliferous Cretaceous section in the Northeast Pacific margin. Murphy (1956) and Murphy *et al.* (1969) subdivided the Budden Canyon Formation into eight members; the Recter, Ogo, Roaring River, Lower Chickabally Mudstone, Huling Sandstone, Upper Chickabally Mudstone, Bald Hills, and Gas Point members, in ascending order (Figure 1). These members are essentially conformable, though the Upper Aptian Huling Sandstone Member unconformably overlies the Barremian Lower Chickabally Mudstone Member (Murphy *et al.*, 1969).

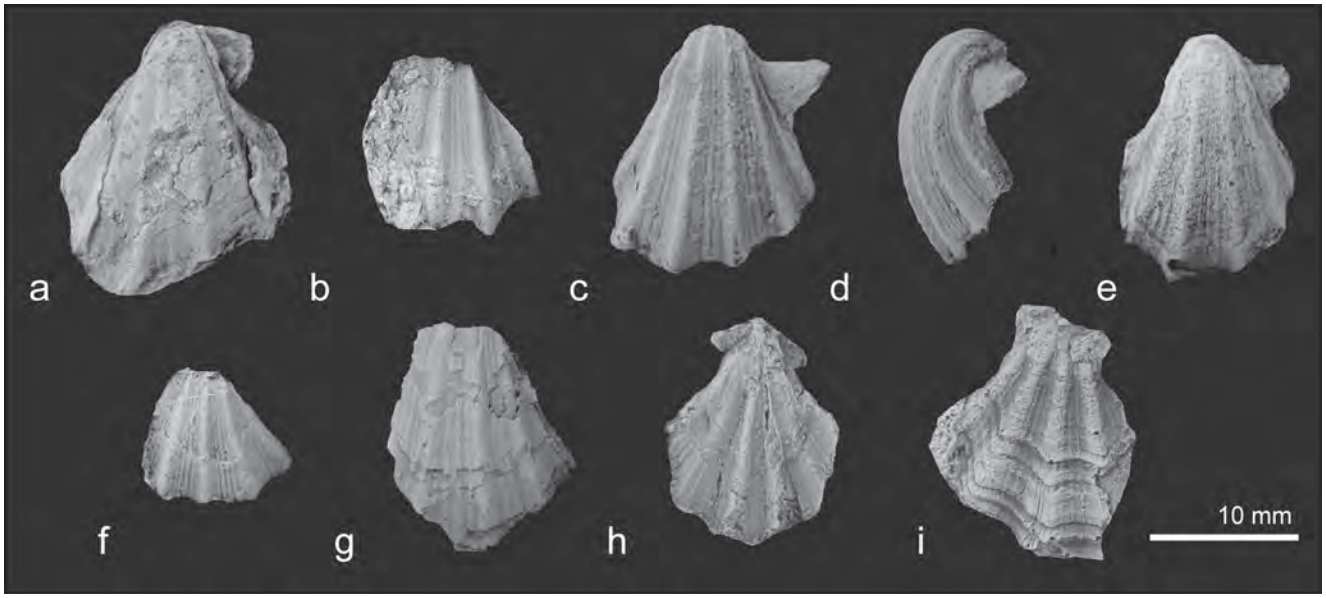

Figure 2. *Neithea* (*Neithea*) *grandicosta* from the Budden Canyon Formation, Ono area, northern California. a–g, right valve. d, lateral view. h–j, left valve. a, b, and h, j are from Loc. 1. c–g and i are from Loc. 2 (see Figure 1 for detailed locality). a–CASG 71185; b–CASG 71186; c–d–CASG 71190; e–CASG 71195; f–CASG 71191; g–CASG 71197; h–CASG 71188; i–CASG 71194.

Neithea grandicosta has been recently collected from two horizons exposed in the Ono area, Shasta County, northern California (Loc. 1 and 2 in Figure 1). Locality 1 is located along the North Fork of Cottonwood Creek, where the upper part of the Ogo Member is exposed. Medium- to coarse-grained tuffaceous sandstone containing abundant bivalves (e.g., *Pholadomya*) is exposed in this locality. The Ogo Member is correlated with the Hauterivian based on the occurrence of ammonoids such as *Simbirskites lecontei* and *Hertleinites aguila* (Murphy, 1956). Locality 2 is along the Mitchell Creek. We recovered *Neithea* specimens from the basal conglomerate of the lowermost part of the Huling Sandstone Member (Figure 1). This is the same locality where Anderson (1938) and Murphy (1956) reported the occurrence of *Neithea grandicosta*. The lower part of the Huling Sandstone Member is correlated with the Upper Aptian by the occurrences of ammonoids such as *Gabbioceras wintunius* and *Tropeum percostatum* (Murphy, 1956; Murphy *et al.*, 1969).

The type locality of *Neithea grandicosta* was only mentioned as the Cottonwood Creek, Shasta County in Gabb (1869) and Stewart (1930), though its precise position is uncertain. They mentioned that type specimens were collected from the "Shasta Group", whose age was assigned to the pre-Albian Early Cretaceous (Anderson, 1938), corresponding to parts of the Budden Canyon Formation in recent studies.

Systematic Paleontology

Family Pectinidae Rafinesque, 1815

Subfamily Neitheinae Sobetski, 1960
Genus *Neithea* Drouet, 1824
Subgenus *Neithea* Drouet, 1824

Remarks.—Stewart (1930) created the subgenus *Neitheops* with *Neithea grandicosta* as the type species on the basis of having unequal auricles and pronounced ribs. However, this opinion is not supported in later studies, such as Hayami (1965) and Dhondt (1973). Dhondt (1973) mentioned that it is impossible to separate *Neitheops* from *Neithea* on the basis of such characteristics; indeed, in one and the same species one can find specimens with unequal ribs and others with all their ribs perfectly equal, and concluded that the species classified by Stewart (1930) in *Neitheops* belong to *Neithea* s.s. Here we follow the interpretation of Hayami (1965) and Dhondt (1973).

Neithea (*Neithea*) *grandicosta* Gabb, 1869

Figure 2

Neithea grandicosta, Gabb, 1869, p. 200, 251, pl. 33, figs. 99, 99a
Neithea (*Neitheops*) *grandicosta*, Stewart, 1930, p. 116, pl.1, fig. 5.
Neithea grandicosta, Anderson, 1938, p. 110.

Original description.—Neithea grandicosta n. sp. by Gabb (1869): Shell minute, very inequivalve, equilateral, elongated; lower valve, sides tapering a little concavely; general contour of the base semicircular, with six prominent angles and concave interspaces. Surface marked by six very large, round, equidistant ribs, the interspaces carrying a small

Table 1. Dementions of selected specimens of *N* (*N.*) grandicosta.

Specimen number	Length (mm)	Height (mm)	L/H
CASG 71185 (R.V.)	12.6	16	0.787
CASG 71188 (L.V.)	12	15.2	0.789
CASG 71190 (R.V.)	12.2	15.0	0.813
CASG 71195 (R.V.)	11.2	14.6	0.767
CASG 71196 (R.V.)	9.5	12.5	0.76

rib, flanked on each side by one still smaller; in some cases the sides of the large ribs are faintly striate; crossing these ribs are minute, very regular lines of growth; ears very unequal, the right ear long and deeply emarginate.

Neithea (*Neitheops*) *grandicosta* Gabb by Stewart (1930): The six prominent radiating ribs extend to the ventral margin which is therefore sinuous. The central interspace, at least, has three minor radials, of which the central one is the widest. Fine concentric ribs cross the radial sculpture and are sinuous, evidently following the growth lines. The right ear or wing is not complete, but it is the anterior one, the specimen being a right valve. Length (incomplete) 9 mm; height, 12.4 mm; thickness, *ca*. 5 mm; no. 4435.

Remarks on type materials.—Gabb (1869) did not designate a holotype. Later Stewart (1930) designated as the lectotype (collection no. 4435) the better of the two specimens of Gabb's materials deposited in the Academy of Natural Sciences, Philadelphia, and figured it. He also mentioned that Gabb's original figure was a synthetograph of two specimens, and that the left side of the lectotype was slightly telescoped. Now the lectotype has been lost and only the paralectotype, which is a small poorly preserved inner mold specimen, remains in the collection at the Academy of Natural Sciences.

Materials.—13 specimens (CASG 71185–71197) from two localities in the Ono area, Shasta County, northern California. Three right valves and two left valves were recently collected by us from the Ogo Member (Hauterivian) in Loc. 1 of the North Fork of Cottonwood Creek. Three new specimens of right valves by this study and four right valves and one left valve by the "Cotton Wood Project" (Rodda and Murphy, 1987) were recovered from Loc. 2 in the lowermost part of the Huling Sandstone Member (late Aptian) in the Mitchell Creek. Specimens from Loc. 1 are fragmentary, and external shell surfaces are not well preserved. All specimens are deposited in the California Academy of Sciences, San Francisco (repository abbreviation: CASG).

Emended Diagnosis.—Small-sized *Neithea* species, with convex right valves and flattened left valves. Six primary ribs between each three weak ribs. Secondary ribs very weak, not high, flat-topped, comparatively narrow, nearly equal development. Left valve nearly flat, provided with six elevated and angular primary radials ribs.

Measurements.—see Table 1.

Description.—Right valve convex, incurved, higher than wide, with prominent umbo. Apical angle is about 60 degrees. Ornamentation varies depending on the preservation state. Six primary ribs are not high, but are relatively wide and clearly distinguished from secondary ribs, slightly curved outward. Each interval between primaries slightly concave. Secondary ribs generally three in number, very weak, low, flat-topped, comparatively narrow, and equally developed. Straight narrow groove between each of the secondaries. Secondaries cannot be observed on internal mold. Prominent concentric growth lines cross primary and secondary ribs and are observed on well preserved specimens. Auricle is not complete. Left valve is nearly flat, and higher than wide. Postero-dorsal margins are straight, forming an apical angle of about 80 degrees. Six primary ribs are elevated and angular with many radial ribs between each primary. Prominent concentric growth lines are visible on shell surface.

Comparison.—The present species is similar to *Neithea* (*Neithea*) *coquandi* (Peron, 1877) and *N*. (*N.*) *syriaca amanoi* Hayami, 1965 in the numbers of secondary ribs on the right valve and small-sized shell. *N*. (*N.*) *coquandi* is known from the Albian–Cenomanian of Angola, western Brazil, the Cenomanian of Algeria, Egypt, the Middle East, the Cenomanian–Turonian of France, the Turonian of Austria, and the Santonian of France, Algeria, Somalia, and the Middle East (Dhondt, 1973; Andrade *et al.*, 2004). *N*. (*N.*) *syriaca amanoi* is known from the Aptian–Albian of Japan (Hayami and Noda, 1977; Iba and Sano, 2008). *N*. (*N.*) *coquandi* is characterized by having three prominent unequal secondary ribs on the right valve and approximately 22 prominent ribs on the left valve (Dhondt, 1973, pl. 3, fig, 1b; Andrade *et al.*, 2004, fig. 4-3). The middle secondary rib is more strongly developed than the others (Dhondt, 1973). The present species differs from *N*. (*N.*) *coquandi* in having equal, low and flat-topped secondary ribs on the right valve, and six strong primary ribs on the left valve. *Neithea* (*N.*) *syriaca amanoi* is characterized by its small size, almost invariably three secondary ribs on the right valve, fine ribs (22–24 in number) on the left valve, almost smooth lateral areas, not strongly inflated right valve and nearly flat left valve without marginal digitations (Hayami and Noda, 1977). The present species differs from *N* (*N.*) *syriaca amanoi* by having an incurved right valve with weak and flat-topped secondary ribs and six strong primary ribs on the left valve. Another subspecies of *N*. (*N.*) *syriaca, N*. (*N.*) *syriaca syriaca* (Conrad, 1852) has four secondaries on the right valve and 26–28 ribs on the left valve (Hayami and Noda, 1977), and is distinct from the present species in number and morphology of ribs both on right and left valves.

Age.—Hauterivian–Late Aptian.

Distribution.— Ono area, Shasta County, northern California.

Discussion and conclusions

Recently Iba and Sano (2008) reviewed the stratigraphic distribution of *Neithea* in the Northwest Pacific region: There *Neithea* occurs from the Berriasian to the Late Albian, diversifying in the Late Aptian, then disappearing step-wisely in the Albian and never reappearing in the Late Cretaceous. This pattern is the reverse of the Albian–Cenomanian diversification of *Neithea* in the Mediterranean, which is consistent with the mid-Cretaceous global warming trend and sea-level rise (Iba and Sano, 2008). This unique record is concordant with almost simultaneous and similar local extinction event of the Mesogean biota in the Northwest Pacific (Iba and Sano, 2006, 2007a). In the post-Albian Cretaceous, the molluscan fauna in the Northwest Pacific region was characterized by many endemic species (e.g., Iba and Sano, 2007a). Thus Iba and Sano (2007a, 2008) concluded that the local extinction event of the Tethyan biota is one signal of a "vicariance event", which means that the Northwest Pacific was gradually separated from the Tethys Sea.

The present study reveals that the stratigraphic range of *Neithea* in northern California is at least from the Hauterivian to the Late Aptian. Specimens of *Neithea grandicosta* reported by Gabb (1869) and Steward (1930) from the "Shasta Group" are also most probably assigned to the pre-Albian Early Cretaceous (Anderson, 1938), though the precise horizons are uncertain. It should be noted that *Neithea* records from the Northeast Pacific are possibly restricted to the Early Cretaceous as well as those in the Northwest Pacific, though fossiliferous Upper Cretaceous strata are widely distributed in the Northeast Pacific margin, for example, in northern California and British Columbia. Moreover, Iba and Tanabe (2007) recognized that the ammonite fauna changed from the "Tethyan type" to an "endemic type" across the Aptian/Albian boundary in northern California. In the Upper Aptian of northern California, Tethyan-type ammonite genera comprised the Californian assemblage, but, in contrast, endemic-type ammonite genera comprised the assemblage in the Albian. It can be considered that the demise of the Tethyan biota and subsequent origination of endemic fauna in the post-Aptian Cretaceous occurred not only in the Northwest Pacific, but also in the Northeast Pacific.

Iba and Sano (2008) discussed the possibility that Albian "cool" conditions and changes in oceanic circulation/heat transport affected the demise of Tethyan biota and also restricted faunal connections between the Northwest Pacific and the Tethys. The Albian faunal change in the Northeast Pacific, here described, can be explained by the same mechanism. Furthermore, Iba and Sano (2007a, b) pointed out the possibility that the Albian demise of Tethyan biota can also be traced in the equatorial Pacific. In the Philippines, which was located in the western equatorial Pacific at that time, the carbonate platform biota disappeared in the latest Albian. Carbonate platforms and their biota recorded in some guyots in the central equatorial Pacific at that time, also disappeared in the latest Albian (Sager *et al.*, 1993; Iba and Sano, 2007b). It is possible that the Albian demise of the Tethyan biota occurred not only in the Northwest Pacific, but also in the whole of the equatorial–North Pacific, and can be explained by changes in oceanic circulation and temperature as a result of global perturbations. Additional studies of the temporal and geographical distribution of the non-rudist Tethyan bivalves and other Tethyan biota in the equatorial–North Pacific may give important clues for understanding the mid-Cretaceous major biogeographic changes in the whole Pacific.

Acknowledgments

We thank M. Murphy (UC Riverside), A. Kaim (Polish Academy of Science), R. Jenkins (Yokohama National Univ.), and A. Franklin (Redding) for help with our field work, and R. Wani (Yokohama National Univ.) and N. Mateer (California Institute for Energy and Environment) for critical reading of manuscript. Thanks are extended to J. F. DeMouthe (California Academy of Sciences) and Paul Callomon (Academy of Natural Sciences, Philadelphia) for help in observing fossil collections of their institutions. This research was financially supported by a JSPS Fellowship (no. 8119 for Y. Iba), and a JSPS Grant-in-Aid for Scientific Research (no. 14255001 for K. Tanabe).

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