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Two New Species of *Bathymodiolus* (Bivalvia: Mytilidae) from Methane Seeps on the Kuroshima Knoll off the Yaeyama Islands, Southwestern Japan

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Abstract: Two new species of *Bathymodiolus, B. hirtus* n. sp. and *B. securiformis* n. sp., are described. They inhabit bathyal chemosynthetic environments around methane seeps on the Kuroshima Knoll, off the Yaeyama Islands, southwestern Japan. *B. hirtus* n. sp. is characterized by having anteriorly situated umbones and a distinctly hirsute shell surface. *B. securiformis* n. sp. has an elongate shell with a short and low anterior part, a high and expanded posterior part, and a deep ventral concavity. Some anatomical characters also separate these new species from hitherto known species.

Keywords: *Bathymodiolus*, new species, Kuroshima Knoll, methane seeps, Yaeyama Islands

Introduction

Since the genus *Bathymodiolus* was introduced with *B. thermophilus* Kenk & Wilson, 1985 from the Galapagos Rift at a depth of 2495 m as the type species, more than a dozen species have been described from World Oceans:

Southwest Pacific:

B. brevior Cosel, Métivier & Hashimoto, 1994 from the North Fiji Basin and the Lau Basin, Fiji Back Arc, 1750-2750 m.

B. elongatus Cosel, Métivier & Hashimoto, 1994 from the North Fiji Basin, 2765 m.

B. tangaroa Cosel & Marshall, 2003 from off southwestern North Island, New Zealand, 920-1205 m.

Northwest Pacific:

B. platifrons Hashimoto & Okutani, 1994 from Sagami Bay, the Iheya Ridge and the Izena Caldron of the Okinawa Trough, 1170-1410 m.

B. japonica Hashimoto & Okutani, 1994 from Sagami Bay and the Minami-Ensei Knoll of the Okinawa Trough, 705-1170 m.

B. aduloides Hashimoto & Okutani, 1994 from Sagami Bay and the Minami-Ensei Knoll of the Okinawa Trough, 679-1389 m.

B. septemdierum Hashimoto & Okutani, 1994 from Suiyo and Mokuyo Sea Mounts in the Ogasawara Trough, 1256-1367 m.

Indian Ocean:

B. marisindicus Hashimoto, 2001 from Kairei Field, Rodriguez Triple Junction, 2420-2450 m.

Atlantic:

B. puteoserpentis Cosel, Métivier & Hashimoto, 1994 from the Snake Pit Area, the Mid-Atlantic Ridge, 3478-3515 m.

B. sp. (aff. *puteoserpentis*) Cosel, Comtet & Krylova, 1999 from the Logatchev Hydrothermal

Field, Mid-Atlantic Ridge, 2930-3063 m.

B. boomerang Cosel & Olu, 1998 from the southern end of the Barbados Accretionary Prism, 1700-1950 m.

B. heckerae Turner, Gustafson, Lutz & Vrijenhoek, 1999 from the West Florida Escarpment in the Gulf of Mexico, 3243-3314 m.

B. brooksi Gustafson, Turner, Lutz & Vrijenhoek, 1999 from Alaminos Canyon, 2222-2340 m, and the West Florida Escarpment, 3270-3314 m in the Gulf of Mexico.

B. childressi Gustafson, Turner, Lutz & Vrijenhoek, 1999 from the Louisiana Continental Slope, 546-737 m, and Alminos Canyon, 2222 m in the Gulf of Mexico.

B. azoricus Cosel, Comtet & Krylova, 1999 from Azores Triple Junction, the Mid-Atlantic Ridge, 866 m.

B. mauritanicus Cosel, 2002 from off Banc d'Arguin, Mauritania, 1200 m.

During a series of geological and biological investigations on the Kuroshima Knoll, off the Yaeyama Islands with the manned submersible *Shinkai 2000*, and the ROV *Dolphin 3K* (Fujikura *et al.*, 2003), two more unnamed mussels were discovered around methane seeps in bathyal depths. They have been provisionally called "short-type" and "long-type" by the scientists concerned with ecological and biochemical studies on these mussels (*e.g.* Fujikura *et al.*, 2003; Shintaku *et al.*, 2003; Sato-Okoshi, 2003). Taxonomic descriptions are thus urgently required in order to avoid future confusion in treating these taxa.

Materials

All of the *Bathymodiolus* specimens were collected from the Kuroshima Knoll off the Yaeyama Islands (Fig. 1) with the scoop samplers of the *Shinkai 2000* and the ROV *Dolphin 3K*. The date, locality, and depths for the present material are as follows:

Shinkai 2000:
Dive 1355 (June 1, 2002) : 24°07.80′ N, 124°11.57′ E, 641 m
Dive 1356 (June 2, 2002) : 24°07.81′ N, 124°11.54′ E, 637 m
Dive 1370 (June 30, 2002) : 24°07.83′ N, 124°11.54′ E, 640 m
ROV *Dolphin 3K*:
Dive 555 (May 21, 2002) : 24°07.82′ N, 124°11.54′ E, 642 m
Dive 558 (May 22, 2002) : 24°07.82′ N, 124°11.37′ E , 644 m

Thirty-seven specimens of *Bathymodiolus platifrons* collected from Hatoma Knoll (*Shinkai 2000* Dives 1352 and 1358) were used for biometrical comparison (Fig. 6).

Abbreviations used in the text: JAMSTEC – Japan Marine Science & Technology Center; NSMT – National Science Museum Tokyo; SH – Shell height; SL – Shell length; SW – Shell width; UMUT – University Museum, University of Tokyo.

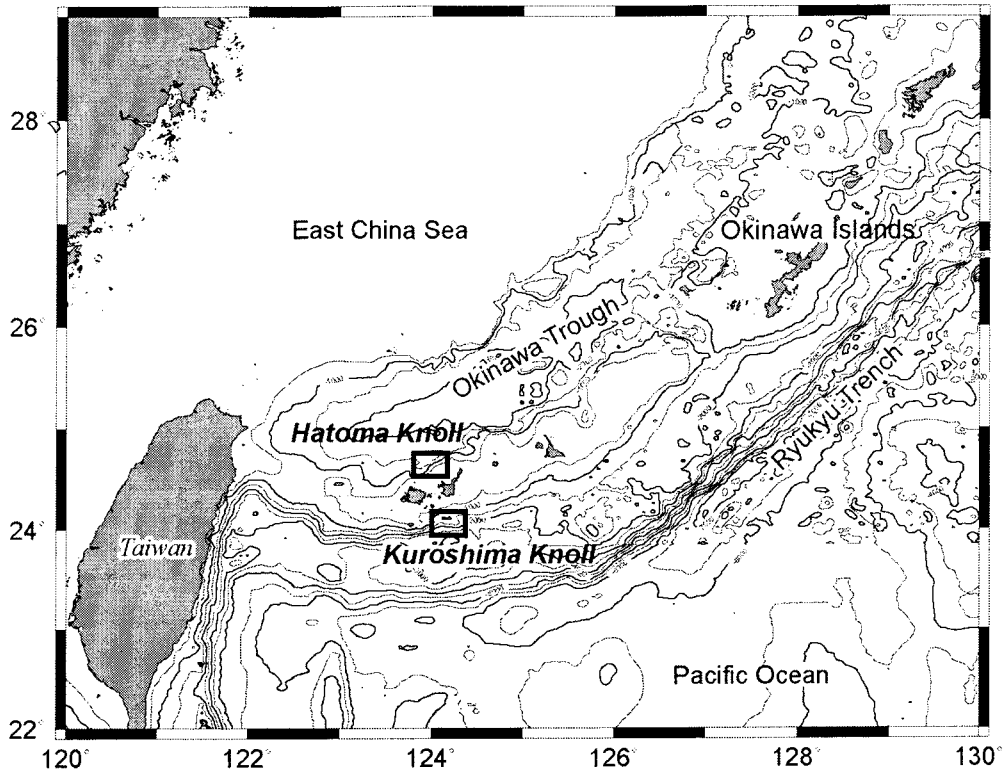

Fig. 1. Collecting locality (Kuroshima Knoll, off the Yaeyama Islands).

Taxonomy

Family Mytilidae

Bathymodiolus hirtus n. sp.

(Figs. 2, 3, 4A, B, E, F, 5, 8A, B)

Materials examined: More than 150 specimens from a methane seep site at Kuroshima Knoll, off the Yaeyama Islands (*Shinkai 2000* Dives 1355, 1356, 1370, and ROV *Dolphin 3K* Dives 555, 558) from depths between 637 m and 644 m.

Diagnosis: Shell short, modioliform with umbo situated a little behind or level with anterior tip. Periostracum light to dark brown and hirsute in posterior area. Hairs long, but sparse in young specimens.

Description: Shell thick, solid, short modioliform, inflated, equivalve and inequilateral (Fig. 2). Shell height increasing posteriorly exhibiting somewhat trapezoid outline with height/length ratio 0.44-0.58, and width/length ratio 0.36-0.46. Dorsal margin straight, ventral margin weakly concave. Umboes low, situated very slightly behind anterior tip of shell, but in some specimens level with anterior tip. A blunt and rounded ridge running from umbo to postero-ventral corner, rather acute initially, but becoming flush posteriorly. Shell surface opaque or pinkish, and roughened with commarginal growth lines, covered by pale brown to dark brown, or even blackish periostracum, which is occasionally eroded, particularly around the umbonal region. Surface hirsute. Hairs triangular, remaining only on posterior region in grown specimens (Fig.

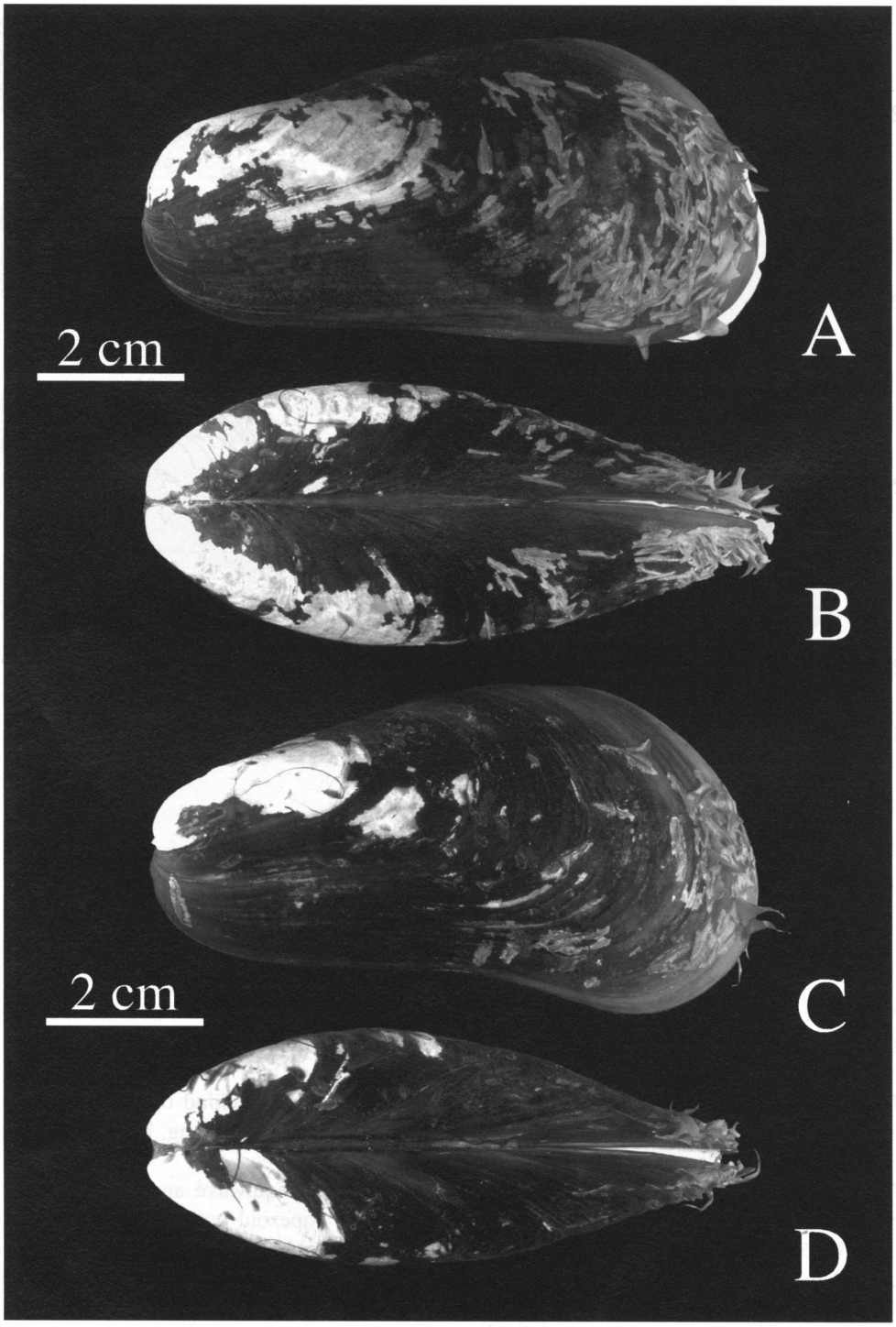

Fig. 2. *Bathymodiolus hirtus* n. sp. **A-B.** Holotype, UMUT-RM 28472 (81.2 × 41.2 × 33.9 mm). **C-D.** Paratype #1, UMUT-RM 28473 (76.8 × 40.1 × 30.5 mm).

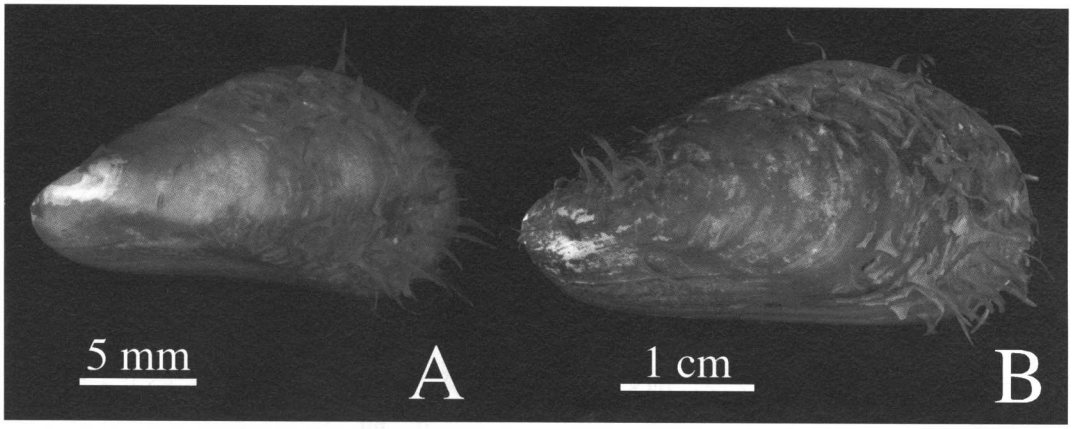

Fig. 3. *Bathymodiolus hirtus* n. sp. **A.** 18.5 × 10.3 × 8.0 mm (UMUT-RM 28474). **B.** 38.7 × 20.7 × 16.3 mm (UMUT-RM 28475).

4F); long, sparse, but present on entire shell surface in young specimens (Figs. 3, 4E).

Internal surface of shell white with weak iridescence. Hinge plate slightly thickened, but totally edentulous. Ligament extends from below umbo almost to halfway point of dorsal margin. Anterior adductor muscle scar spindle-shaped, located in low (ventralward) position at antero-ventral corner. Posterior adductor scar oval with anterior elongation from fusion with scar of posterior byssal-pedal retractor. Pallial line unbroken (Fig. 4A).

Animal milky white. Ctenidia large, rather thin, fragile, extending to four-fifths of shell length, about half of shell height (ct in Fig. 4B). Outer and inner demibranchs almost equal in size and length. Mantle lobe (ml) separated from the position of anterior adductor (aa) to the postero-ventral corner, smooth and lacking frills (Fig. 8A). Valvular siphonal membrane (vm) short, thin with no papilla. Foot (f) cylindrical. Foot-byssus retractor complex with moderate anterior byssal-pedal retractor (ar) attached within umbonal cavity well posterior to umbo. Posterior pedal retractor (pr) and anterior portion of byssal-pedal retractor (apr) attached below posterior end of ligament (li). Attachment of posterior portion of byssal-pedal retractor (ppr) elongated, reaching anterior rim of posterior adductor muscle (pa). Labial palps (lp) triangular in shape, the posterior rami large with smooth surface, while anterior rami vestigial. Gut straight.

Juvenile shell (Fig. 5): The smallest specimen available for the present study measured 2.2 mm in shell length. Prodissoconch I circular and well demarcated from prodissoconch II. Dorsal hinge carrying about 20 taxodont teeth on posterior arc, and only six on anterior arc below prodissoconch I. Tooth-bearing part of anterior arc quadrate, protruding slightly.

***Measurements (in mm) of selected type specimens*:**

Type	Registration number	Dive	Shell length	Shell height	Shell width
Holotype	UMUT-RM 28472	*Shinkai 2000* Dive 1356	81.2	41.7	33.9
Paratype #1	UMUT-RM 28473	*Dolphin 3K* Dive 558	76.8	40.1	30.5
Paratype #2	NSMT-Mo 73554	*Shinkai 2000* Dive 1356	68.9	34.8	29.1
Paratype #3	NSMT-Mo 73555	*Shinkai 2000* Dive 1356	58.5	29.7	27.8
Paratype #4	NSMT-Mo 73556	*Shinkai 2000* Dive 1356	58.5	30.4	25.8

Measurements of all other paratypes are incorporated in Fig. 6.

Etymology: The Latin *hirtus* means 'hairy' or 'shaggy', for the byssal hairs on the periostracum.

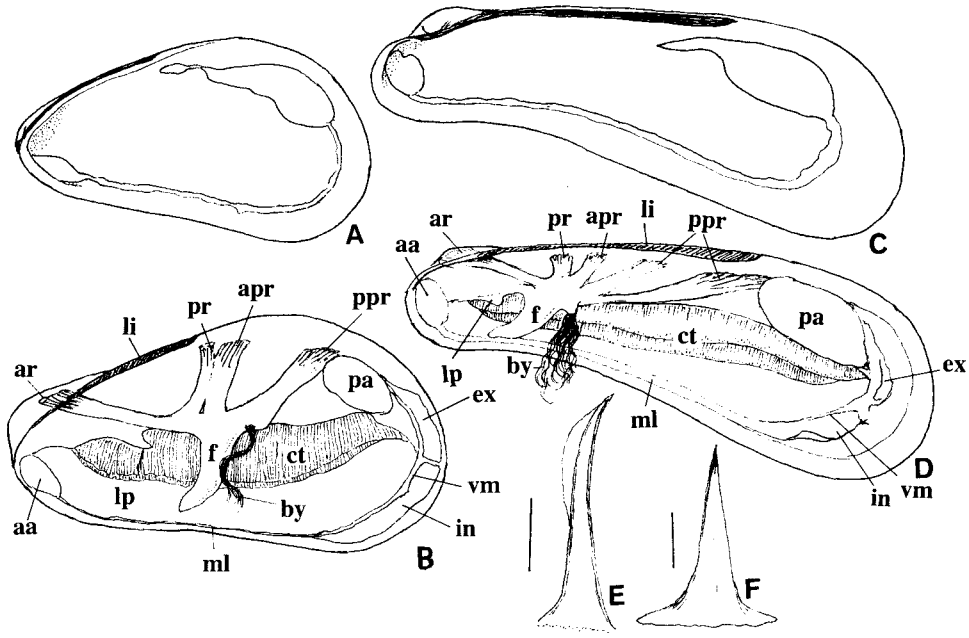

Fig. 4. A-B, E-F. *Bathymodiolus hirtus* n. sp. **A.** internal surface. **B.** musculature system. **E.** byssal hair (SL 64.2 mm). **F.** byssal hair (SL 22.1 mm). **C-D.** *Bathymodiolus securiformis* n. sp. C, internal surface; D, musculature system. Abbreviations: aa - anterior adductor muscle, apr - anterior portion of posterior byssal-pedal retractor, ar - anterior byssal-pedal retractor, by - byssus, ct - ctenidium, ex - exhalent siphon, f - foot, in - inhalent siphon, li - ligament, lp - labial palp, ml - mantle lobe, pa - posterior adductor muscle, ppr - posterior portion of posterior byssal-pedal retractor, pr - posterior pedal retractor, vm - valvular siphonal membrane.

Remarks: The present species is characterized by its hairy, shaggy appearance. Some young specimens (Fig. 3) recall intertidal hairy mytilids, such as *Modiolus* spp. According to Bottjer & Carter (1980) and Ockelmann (1983), these hairs are not of true periostracal origin, but should be called "byssal hairs". Kenk & Wilson (1985) stated that young specimens, larger than 2 cm in shell length, of *B. thermophilus* also have "periostracal hairs of byssal origin". Individual hairs in small specimens (around 2 cm in shell length) are long and flat, with a latero-distal "fin" (Fig. 4E). However, hairs in grown specimens are short, flat and triangular without the "fin", and are arranged roughly commarginally along the growth lines.

The present species is closest to *B. platifrons* Hashimoto & Okutani, 1994, which is one of the commonest elements of bathyal chemosynthesis-based communities of both cold seeps in Sagami Bay and hydrothermal vents in the Okinawa Trough, particularly in its possession of terminally situated umboes. The shell proportions, such as shell height and shell width relative to shell length, do not show any significant difference between these two species (Fig. 6), though *B. platifrons* grows larger in size than *B. hirtus* n. sp. *B. platifrons* has a shining, smooth periostracum, with no hairs. The muscle scars are similar to each other. However, the posterior pedal retractor muscle in *B. platifrons* is widely divergent, and valvular siphonal membrane is papillated. *B. platifrons* lives a little deeper (1170-1410 m) than the present new species, and both are consistently allopatric at the Kuroshima Knoll site.

Other species with superficial resemblance, particularly in its possession of terminal umboes, is *Bathymodiolus childressi* Gustafson, Turner, Lutz & Vrijenhoek, 1998 from the Louisiana Continental Slope, 546-737 m, in the Gulf of Mexico. The shell proportions (SH/SL = 0.45-0.53

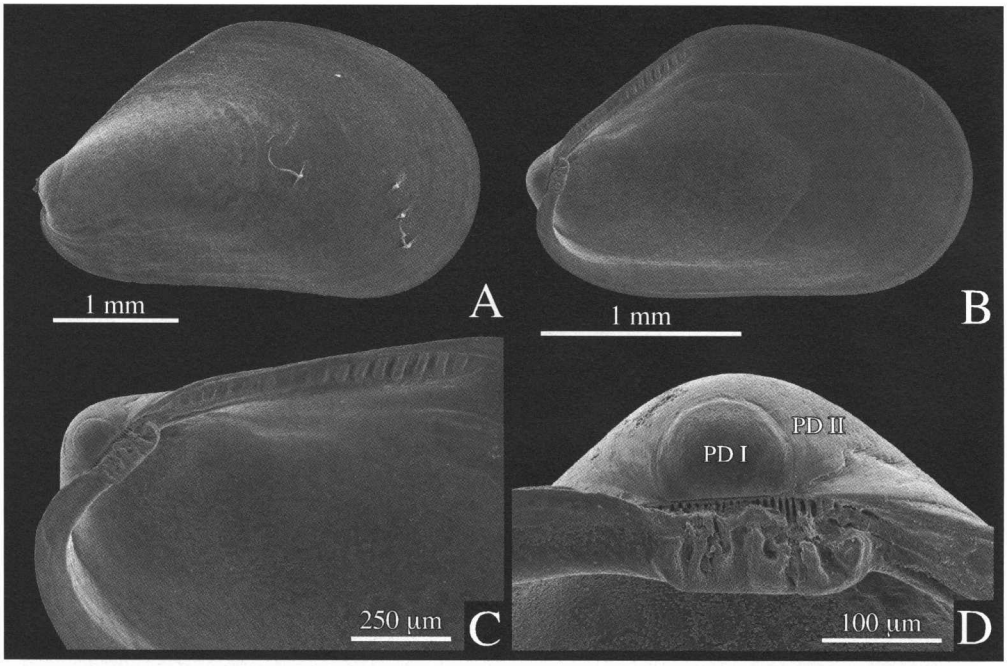

Fig. 5. *Bathymodiolus hirtus* n. sp., juvenile shells (*Dolphin 3K* Dive 554). **A.** UMUT-RM 28476. **B-D.** UMUT-RM 28477. PDI - prodissoconch I, PDII - prodissoconch II.

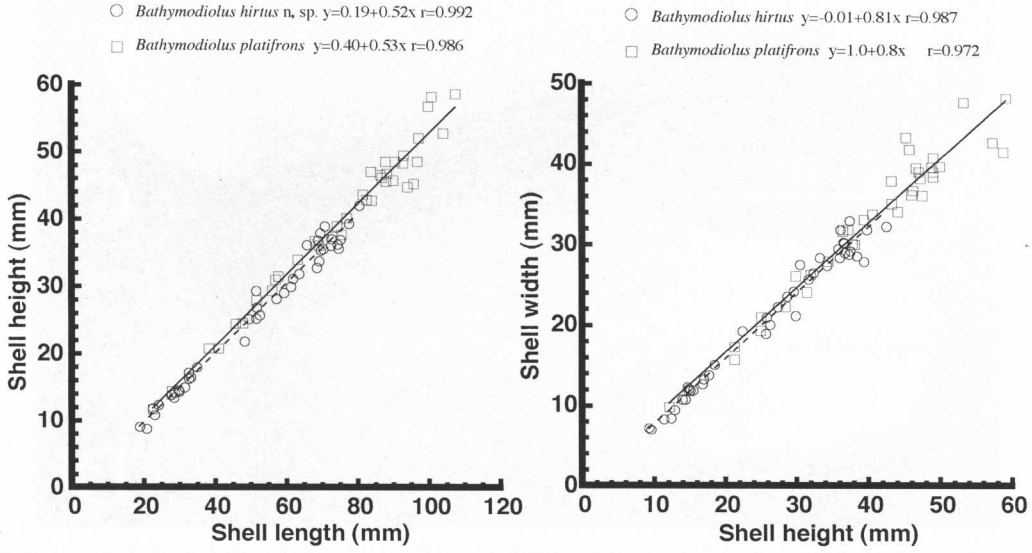

Fig. 6. SL-SH and SL-SW relationships between *Bathymodiolus hirtus* n.sp. (41 specimens from *Dolphin 3K* Dive 554) and *B. platifrons* (37 specimens from the Hatoma Knoll: *Shinkai 2000* Dives 1352 & 1358).

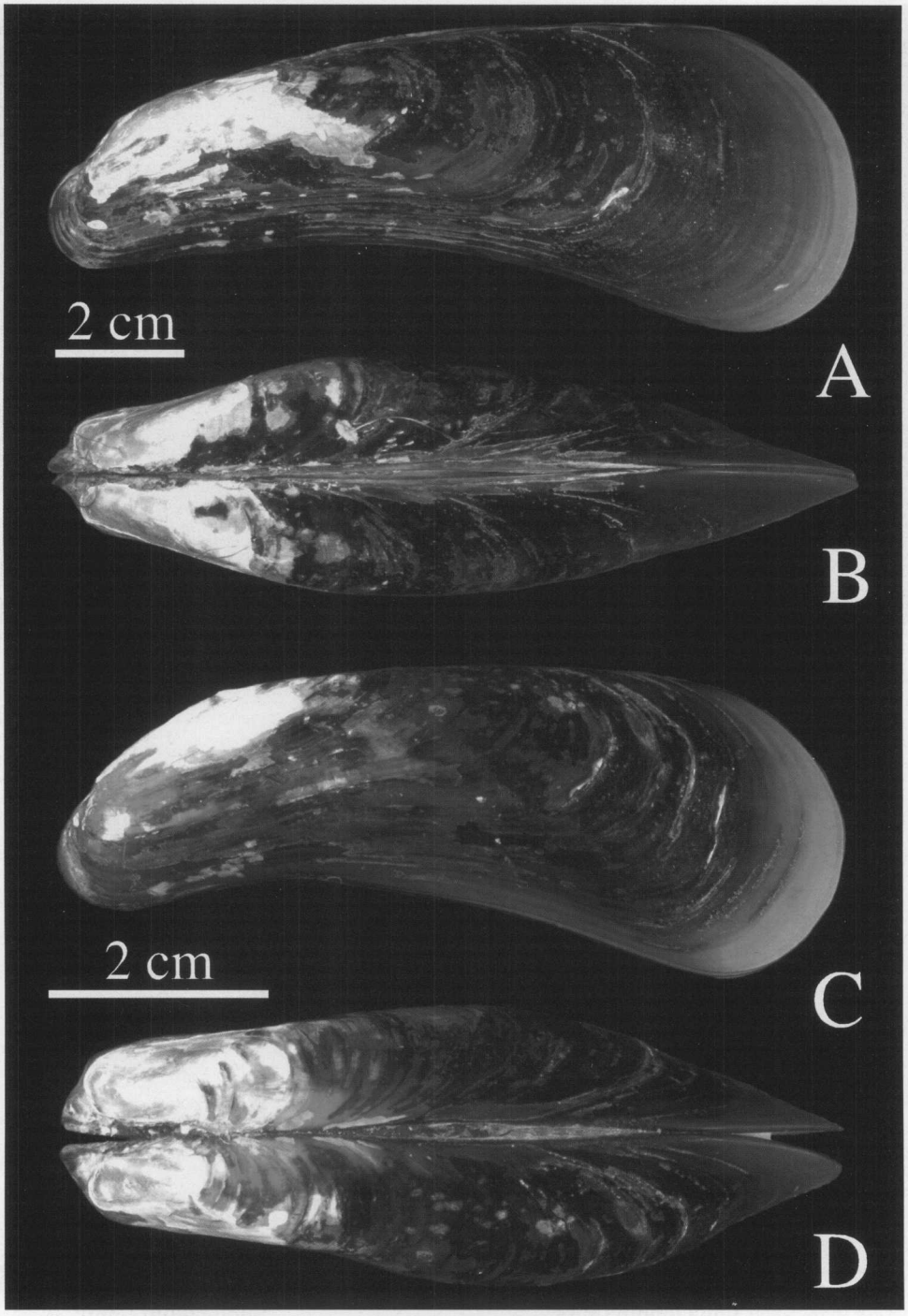

Fig. 7. *Bathymodiolus securiformis* n. sp. **A-B.** Holotype, UMUT-RM 28478 (130.1 × 49.3 × 37.5 mm). **C-D.** Paratype # 1, UMUT-RM 28479 (72.6 × 26.4 × 24.6 mm).

in *B. childressi)* are not significantly different from those of the present new species (0.44-0.58), but *B. childressi* has no hairs. *B. childressi* also differs from the present new species in the configuration of the foot-byssal retractor complex (see Fig. 13 in Gustafson *et al.*, 1998). The posterior pedal retractors are subdivided into six muscle bundles in *B. childressi*, while those in the present new species are not. The anterior pedal retractors in *B. childressi* are thin and small, and arising from antero-dorsal portion of the foot mass, while those in *B. hirtus* n. sp. are rather thick and arinse from a more anterior point in the foot mass, with the attachment point located well behind the central umbonal cavity. The locality of *B. childressi* (Gulf of Mexico) is far distant isolated from that of the present new species (Okinawa, Northwest Pacific).

Another species with terminal umboes is *Bathymodiolus mauritanicus* Cosel, 2002, recently described from off Mauritania. Cosel (2002) established a "*B. childressi*-group" to which the present new species belongs. *B. hirtus* n. sp., differs from *B. mauritanicus* in having byssal hairs through all growth stages.

The outline and external characters of Prodissoconch I and early Prodissoconch II are not much different among *Bathymodiolus* species (Cosel *et al.*, 1994, 1999). However, the juvenile hinge structure exhibits intraspecific differences. The central hinge plate with denticles of *B. childressi* is not protruding, unlike that of the present new species. The juvenile dentition may be a new character that is useful for separating *Bathymodiolus* species.

Distribution: Around the bathyal methane seeps on the Kuroshima Knoll, off the Yaeyama Islands, Okinawa, at depths around 600 m.

***Bathymodiolus securiformis* n. sp.**

(Figs. 4C, D, 7C, D, 8, 9)

Material examined: More than 100 specimens from a methane seep site at Kuroshima Knoll, off the Yaeyama Islands (*Shinkai 2000* Dives 1355, 1356, 1370, and ROV *Dolphin 3K* Dive 444) from depths between 637 m and 642 m.

Diagnosis: Shell long, modioliform, with low umbo situated 10-20% posteriorly from anterior margin. Anterior portion short and low, but becoming wider and higher posteriorly, with widest point at or a little behind middle. Ventral margin pronouncedly concave. Periostracum smooth, not hirsute, dark olive in young specimens, but almost black in adults.

Description: Shell thick, solid, elongate modioliform, inflated, equivalve and markedly inequilateral (Fig. 7). Umboes low, frequently eroded and exhibiting pearly layer, situated 10 to 20% posteriorly from anterior tip of shell. Anterior portion of shell low and narrow, but shell becoming higher and wider posteriorly, with widest point at middle or slightly behind. Anterior margin round. Ventral margin first ascending in anterior part, but distinctly concave at middle, then descending to roundly expanded posterior margin. A weak postero-dorsal angle present in young specimens, but round and smooth in fully grown specimens. Ventral concavity tending to become pronounced with growth, and degree of concavity varying by specimen. Postero-dorsal margin weakly convex. General profile axe-shaped with height/length ratio 0.32-0.43, and width/length ratio 0.26-0.35. Widest point situated around middle. A round blunt ridge apparent initially, running from umbo to postero-ventral corner, but becoming obsolete towards end. Shell surface covered by blackish, shining periostracum, bearing rough commarginal lines. Periostracum usually varnished black, but occasionally dark brownish or greenish, even yellowish, particularly around posterior margin, varying by specimen in accordance with growth. Fine and rather indistinct radial sculpture occasionally present in ventral area.

Internal surface of shell dull white with weak pearly luster. Hinge plate thin, edentulous.

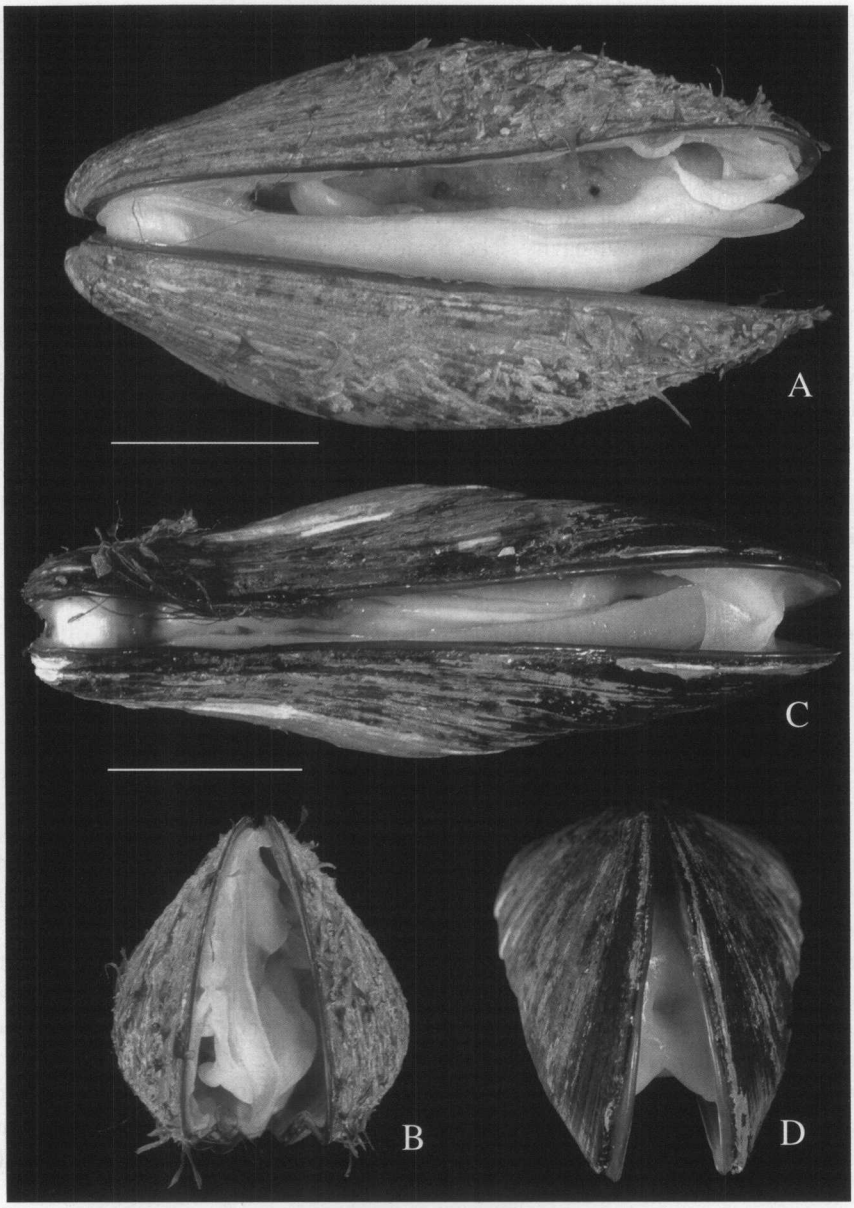

Fig. 8. A-B. *Bathymodiolus hirtus* n. sp. Ventral and posterior views, JAMSTEC 051042 (64.3 × 31.9 × 28.0 mm). **C-D.** *Bathymodiolus securiformis* n. sp. Ventral and posterior views, JAMSTEC 0949137 (101.0 × 39.1 × 38.0 mm). Scale bar = 2 cm.

Ligament thick, long, extending to two-thirds of posterior dorsal margin. Nymphal area rigid. Anterior adductor muscle scar round, situated below antero-dorsal margin of shell, anterior to umbo. Posterior adductor muscle scar oval, fusing with scar of posterior portion of posterior byssal-pedal retractor. Pallial line entire (Fig. 4C).

Animal opaque white. Ctenidia thick, long, extending from position of labial palps to posterior end of mantle cavity (ct in Fig. 4D). Mantle lobe thick, smooth (ml) with non-papillated valvular siphonal membrane (vm). Labial palps triangular, but very small (lp).

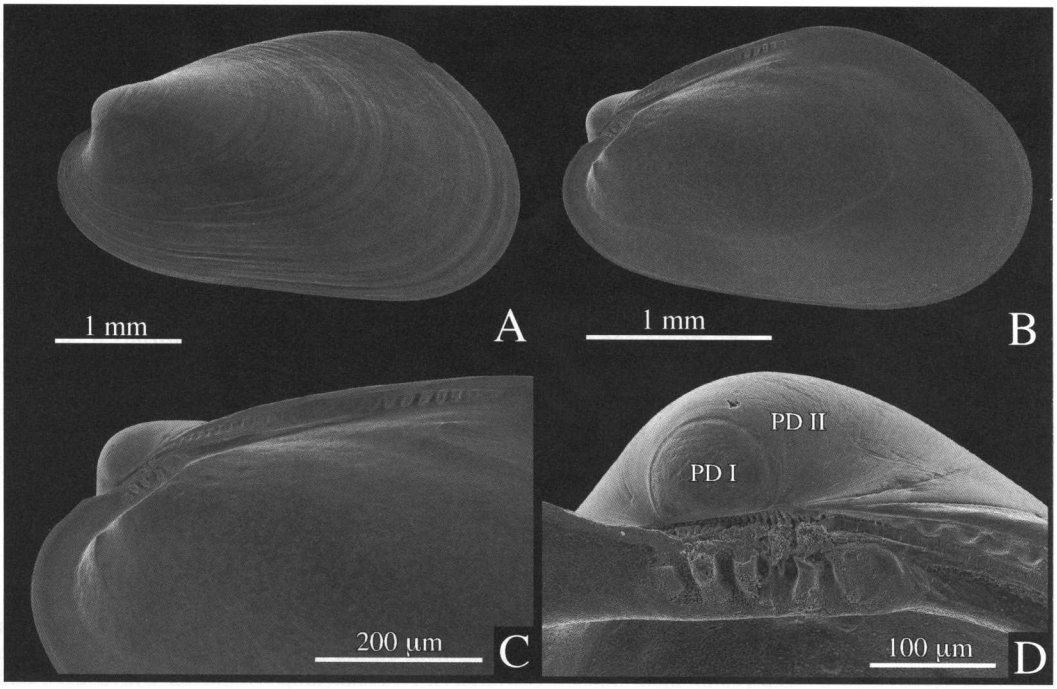

Fig. 9. *Bathymodiolus securiformis* n. sp., juvenile specimen (3K Dive 558). **A.** UMUT-RM 28480. **B-D.** UMUT-RM 28481. PDI: prodissoconch I, PDII: prodissoconch II.

Foot-byssus retractor complex composed of long anterior byssal-pedal retractor (ar) attached just below umbo in umbonal cavity, short posterior pedal retractor (pr), moderate anterior portion of posterior byssal-pedal retractor (apr), both under midpoint of ligament (li), and bifurcated posterior portion of posterior byssal-pedal retractor (ppr): posterior ramus located in front of posterior adductor muscle (pa), while anterior ramus situated at mid-point between anterior portion of posterior byssal-pedal retractor and posterior ramus of posterior portion of posterior byssal-pedal retractor.

Juvenile shell (Fig. 8): The smallest specimen available for the present study measured 2.5 mm in shell length. General profile of shell and position of umbo like those of adults, but juvenile shell proportionally higher (or shorter) than adult shell. Posterior arc of hinge plate, which carries taxodont teeth, overlying anterior arc, bearing six vertical teeth beneath circular prodissoconch I.

***Measurements (in mm) of selected type specimens*:**

Type	Registration number	Dive	Shell length	Shell height	Shell width
Holotype	UMUT-RM 28478	*Dolphin 3K* Dive 558	130.1	49.3	37.5
Paratype #1	UMUT-RM 28479	*Shinkai 2000* Dive1355	72.6	26.4	24.6
Paratype #2	NSMT-Mo 73557	*Shinkai 2000* Dive1355	135.1	43.3	39.1
Paratype #3	NSMT-Mo 73558	*Dolphin 3K* Dive 355	112.7	41.0	32.7
Paratype #4	NSMT-Mo 73559	*Dolphin 3K* Dive 355	98.9	42.3	32.0

Etymology: The Latin *securis* means an axe, *-formis* form or shape. The outline of the shell recalls a hand-axe.

Remarks: The configuration of the foot-byssus retractor complex in *B. securiformis* n. sp. may be characterized by the position of the anterior byssal-pedal retractor in the central umbonal cavity, as well as by the bifurcated posterior portion of the posterior byssal-pedal retractor and particularly its strong posterior ramus.

A sole species among the known taxa in this genus, *B. tangaroa* Cosel & Marshall, 2003, may be closest to the new species in shell profile, except for concavity in the ventral margin. The length/height ratio in the New Zealand species is 2.5-3.2, while that in *B. securiformis* n. sp. is 2.32-3.13. An apparent difference may be the presence of more divergent byssal-pedal retractors in *B. tangaroa* than *B. securiformis* n. sp.

Another species from the Atlantic, *B. boomerang* Cosel & Olu, 1998, grows much larger in size (36 cm in shell length), and possesses a longer anterior part than in *B. securiformis* n. sp. The young specimens of *B. boomerang* have a straight or even convex ventral margin. The locality of *B. boomerang* is the southern end of the Barbados Accretionary Prism, Western Atlantic, 1700-1950 m in depth, far away from the locality of the present new species.

B. securiformis n. sp. seems to be close to the *B. heckerae*-group in the Atlantic established by Cosel (2002).

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黒島海丘のメタン噴出域に産するシンカイヒバリガイ属の2新種

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要　約

八重山諸島沖の黒島海丘のメタン噴出孔付近の水深600 m付近に棲むシンカイヒバリガイ属の2種はこれまでshort-typeとlong-typeと仮称されてきたが，それらを精査した結果，いずれも未記載種であることが明らかとなった。

Bathymodiolus hirtus n. sp. クロシマシンカイヒバリガイ（新種・新称）

殻頂が前方に寄り，前縁とほとんど同レベルにあるところは，ヘイトウシンカイヒバリガイ*B. platifrons*と概形が極めてよく似ているが，殻表には毛状の装飾があり，若い個体などは一見，潮間帯のヒバリガイを彷彿とさせる。殻長8 cm。

Bathymodiolus securiformis n. sp. テオノシンカイヒバリガイ（新種・新称）

殻は長く，前域は極めて低いが，後域は広がる。腹縁は著しく凹みブーメランか手斧を思わせる。殻表は黒っぽく，殻皮に毛はない。殻長13 cm。