

## Three new vermetid gastropod species from Guam

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**Abstract**—Three new species from the gastropod family Vermetidae are described. *Serpulorbis hadfieldi* n. sp. has two distinct color forms, dark brown and tannish-white. The average feeding tube diameter is about 4.2 mm. This species form colonies of up to five adults or occurs singly in the moat area of the reef flat. *S. hadfieldi* is only found on the central east coast of Guam. The second species, *Petalconchus apakadikike* n. sp., is white in color, with a feeding tube ranging from about 1.5 to 2.5 mm in diameter, and is found in areas exposed to strong wave action and current on rimmed terraces and on the reef front. *P. apakadikike* form colonies of up to 20 individuals with adults separated by millimeters or occurs singly, and is only found on the western and south-western coasts of Guam. The third species, *Petalconchus lilandikike* n. sp., is dark purple, the feeding tube ranges from about 0.9 to 1.8 mm in diameter, and is also found in areas exposed to strong flow. *P. lilandikike* form compact colonies on the east coast of Guam, or occurs singly in the central to southern area on the east and west coast of the island.

### Introduction

The marine gastropods of the family Vermetidae are a unique group characterized by an uncoiled shell that is attached permanently to a hard substratum (Hadfield 1970). Given this sedentary life style, vermetids have evolved unique reproductive behavior, juvenile ontogeny, and feeding strategies. Males are aphyllid and produce pelagic spermatophores (Scheuwimmer 1979). Females capture the spermatophore in their mucous net, transfer it to the mouth, and via a biting action, eject the sperm packet into the mantle cavity; fertilization occurs in the pallial oviduct (Scheuwimmer 1979). The sperm packet contains two types of sperm; typical (eupyrene) that contains DNA and atypical (apyrene) with no DNA that nourishes the typical sperm until fertilization takes place (Scheuwimmer 1979). Females brood egg capsules in the mantle cavity freely or attach them to the inner dorsal shell (Morton 1965, Hadfield 1972). A few species of vermetids release pelagic larvae that metamorphose in the water column, while for most species metamorphosis takes place prior to hatching (Morton 1965, Hadfield et al. 1972, Miloslavich & Penchaszadeh 1992).

Crawling juveniles locate suitable substratum and settle on their right side; the teloconch grows at a right angle to the protoconch and attaches to the substratum (Keen 1961, Morton 1965). Settlement and attachment occur within 24 hours of hatching if a suitable substratum is available or they may delay attachment for several days in the absence of a suitable settlement surface (Hughes 1978). Morphological changes of the head and foot, to the adult feeding form, occur within two days after attachment (Hughes 1978, Calvo et al. 1998). Two types of feeding strategies are known to occur in the Vermetidae; mucus net and ctenidium filtering (Keen 1961, Morton 1965, Hughes & Lewis 1974, Schiaparelli & Cattaneo-veitti 1999, Schiaparelli et al. 2006). Mucous net feeding is predominately observed in areas of high water flow, while ctenidium filtering occurs mainly in areas of calm water; in many cases a single species will display both feeding mechanisms (Hughes & Lewis 1974, Schiaparelli & Cattaneo-veitti 1999, Schiaparelli et al. 2006). Many vermetids produce temporary feeding tubes that can be broken and re-molded by the animal, leaving a characteristic feeding tube scar at the point of breakage, to grow around obstacles thus enhancing successful competition for substrata space (Keen 1961, Hughes & Lewis 1974, Schiaparelli & Cattaneo-veitti 1999, Schiaparelli et al. 2006).

Adult vermetids are found in a variety of distinctive coastal habitats (Keen 1961, Hadfield et al. 1972, Safriel 1975, Hughes 1993, Schiaparelli 1995, Antonioli et al. 1999, Schiaparelli et al. 2006). In Guam, Mariana Islands (Western Pacific), vermetids are distributed along the intertidal shoreline, across the reef flat, and down the reef front. Ocean conditions in their Guam habitat range from areas of strong current and wave action to the relative calm reef flat moat area.

When describing new species of the marine gastropod family Vermetidae, conchology alone is often insufficient to make a diagnosis, as shell morphology is often variable depending on the substrate where the animal is attached and epibiont cover may obscure the shell sculpture. Adult animal coloration and morphology, operculum and protoconch design, brooding style, habitat, geographic locations, and to some extent variation in internal anatomy such as ctenidium morphology, are often more reliable indicators (Morton 1951, Keen 1961, Morton 1965, Scheuwimmer & Nishiwaki 1982, Hughes 1993, Schiaparelli 1996, Schiaparelli & Métivier 2000).

Presently, there are twelve vermetid species identified from Guam (see below); three are described here as new to science. Descriptions of shell morphology, operculum, head and foot coloration and external morphology, ctenidium and radula morphology, protoconch size and shape, brood protection and early ontogeny, habitat, comparisons, etymology, and taxonomy are provided.

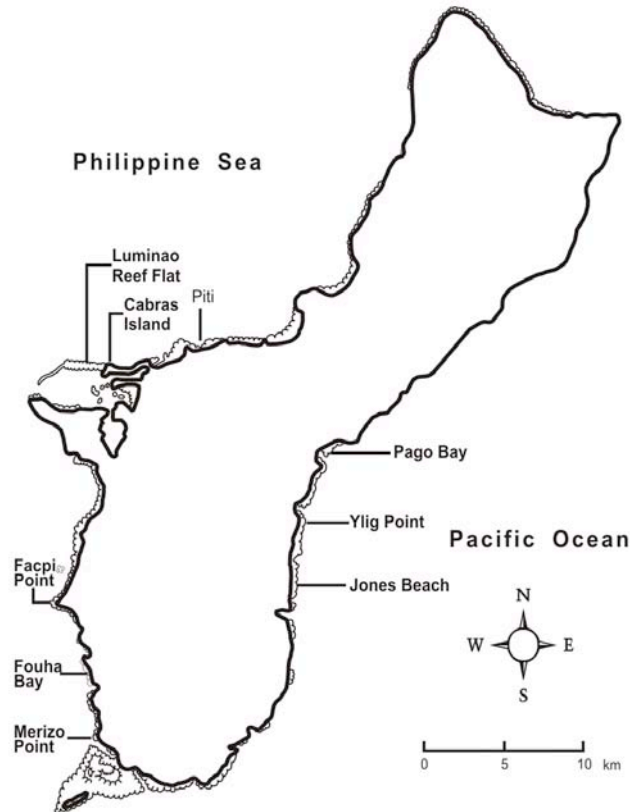


Figure 1. Map of Guam depicting collection and observation sites.

### Methods and Materials

All specimens were collected from central to southern Guam (Figure 1). Samples were taken using a hammer and chisel to break off pieces of substratum where the vermetids were imbedded. Specimens of *Serpulorbis hadfieldi* n. sp. were collected from the reef-flat moat of Pago Bay on the east coast of Guam (Figure 2A). Specimens of *Petalconchus apakadikike* n. sp. were taken from the reef front of the Merizo Point in southwestern Guam (Figure 2B) and from the rimmed terrace at Cabras Island on the west coast of Guam (Figure 2C). Samples of *Petalconchus lilandikike* n. sp. were taken from the rimmed terraces at Pago Bay (Figure 2D) and from the Ylig Point reef-flat ridges (Figure 2E) on the east coast of Guam.

The habitats of the two *Petalconchus* species occur in areas that are often extremely dangerous for collection. Samples taken from Ylig Point were collected at extreme low tide because at high tide the substrata is submerged and there is an extremely strong current. The Pago Bay rimmed terraces and Cabras

Island rimmed terraces are also extremely dangerous at high tide because there is a strong tidal surge that can reach heights of over 2 meters above the substrata. Samples from Merizo Point reef front were taken during calm days, as the surf there can be hazardous when high. Pago Bay reef flat is generally always accessible.

All specimens were kept in a flow-through seawater table until preservation. Several samples of each species were placed in 10-liter tubs filled with seawater and provided with aeration. Juveniles released in these tubs were collected for measurement and then photographed. Adult specimens were relaxed with 8% MgCl<sub>2</sub> isotonic to seawater and removed from their shells for photographing.

Type specimens were relaxed in MgCl<sub>2</sub> prior to preservation. Specimens were fixed in 10% formalin in seawater and preserved in 80% ethanol or fixed and preserved in 95% ethanol.

Ctenidium were observed by dissecting open the mantle wall and viewed using a dissecting microscope. Sections were excised and mounted on slides for photography. Samples from each species were photographed using a Leica DM LB2 compound microscope at 40x power and the ProgRes™ C12 Plus digital microscope camera. The photographs were then traced on to transparent acetate paper, scanned to a JPEG file, and retraced using CorelDRAW® 12.

From a few specimens, radula and opercula were excised, cleaned of soft tissue by brief treatment with 3% sodium hypochlorite followed by a tap-water rinse, and mounted on slides for microscopy. Opercula were photographed using a Leica DM LB2 compound microscope at 40x power and the ProgRes™ C12 Plus digital microscope camera. Morphological terms follow Morton (1965). Paired t-tests were performed using Stat View (Statview for Windows, SAS Institute Ins. © 1992-1998 Version 5.0) to determine if there were significant differences in maximum aperture diameter between sites for the two *Petalocochus* species.

### Systematic Account

Genus *Serpulorbis* Sassi 1827

Subgenus *Serpulorbis s. s.* (Keen, 1961)

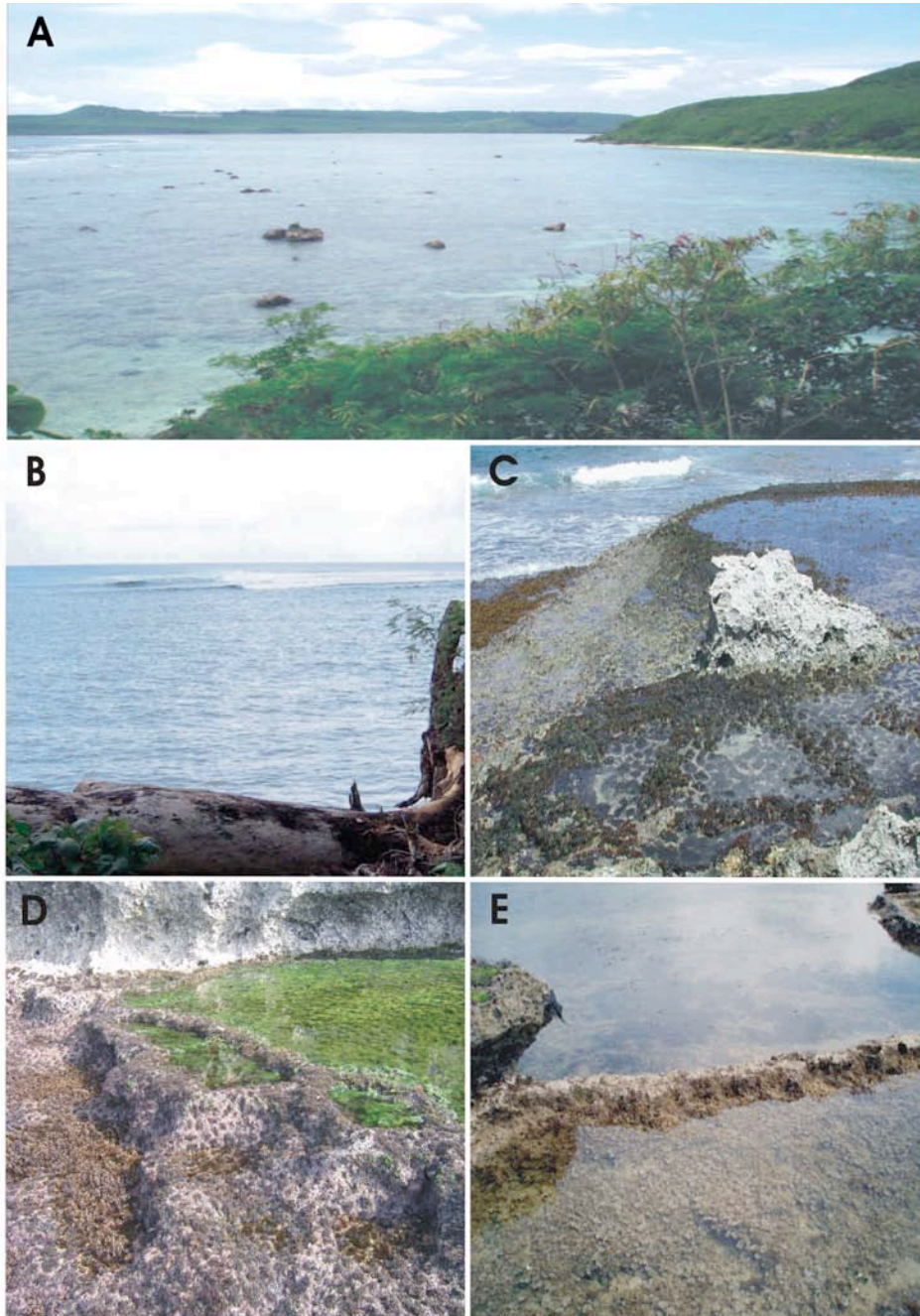
#### *Serpulorbis hadfieldi* n. sp.

**Type Material:** Holotype: U. S. National Museum of Natural History (Smithsonian Institution), Washington D.C., USNM 1096658.

**Type location:** Pago Bay, Guam, latitude 144° 47' 50.22" E and longitude 13° 25' 39.85" N (WGS 1984), inner reef flat by outer edge of moat, imbedded in the coral *Pocillopora damicornis*. Specimen collected May 15, 2003 by Walter C. Kelly III.

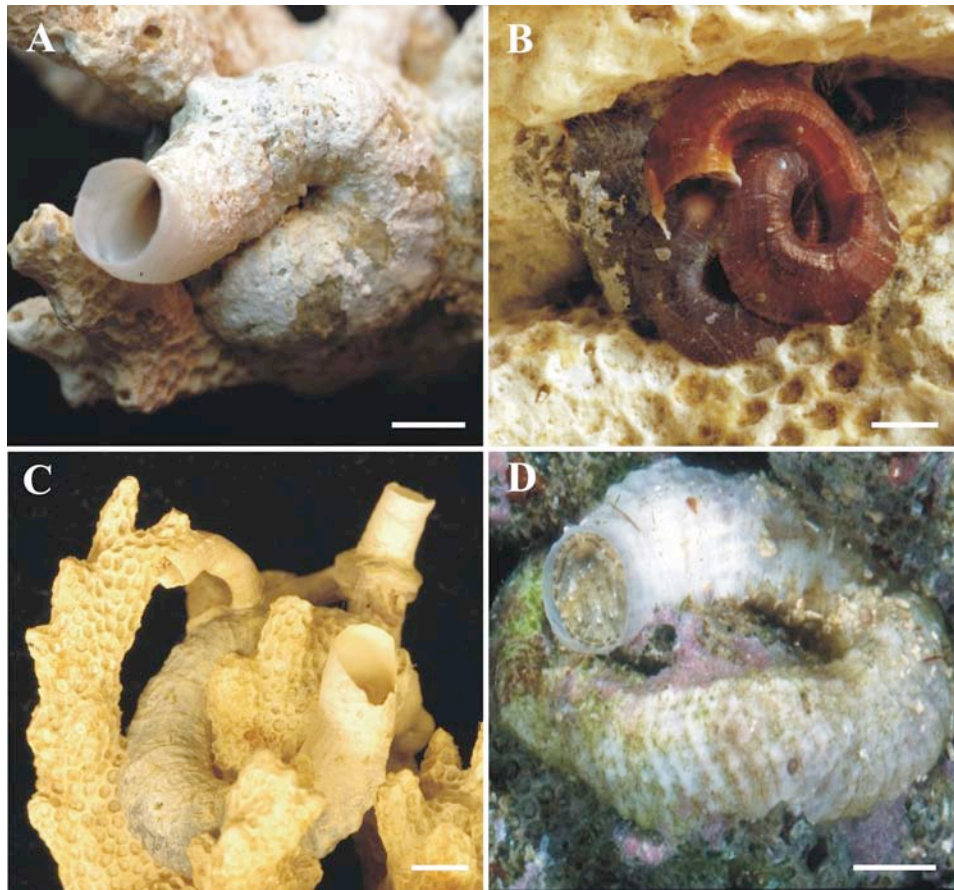
**Paratypes:** U. S. National Museum of Natural History (Smithsonian Institution) (USNM 1096659–1096662); Museum of Natural History, University of Florida

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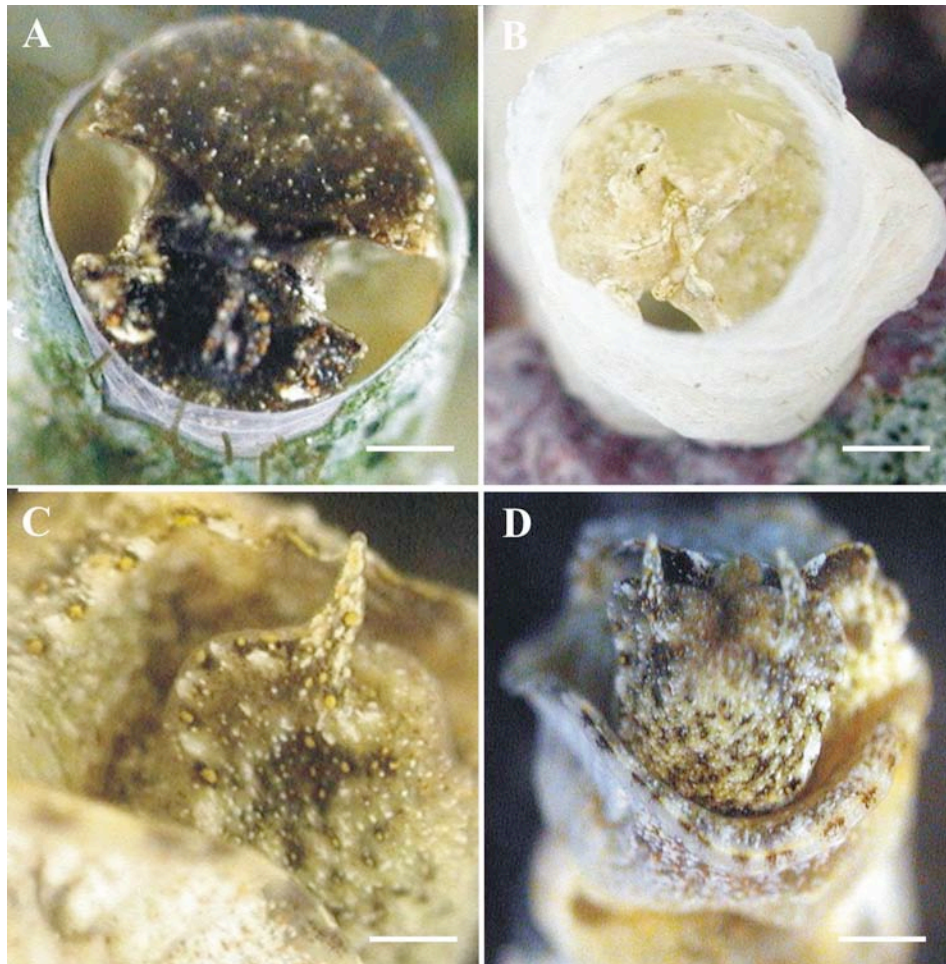
**Figure 2.** A. Pago Bay reef flat moat at middle tide, B. Merizo Point reef flat with 4 to 6 foot surf breaking on the reef crest, C. Cabras Island rimmed terrace at low tide, D. Pago Bay rimmed terrace at low tide, E. Ylig Point fault line ridge at low tide.





**Figure 3.** **A.** *Serpularia hadfieldi* n. sp. holotype shell growing in the coral *Pocillopora damicornis* (Scale bar = 4 mm), **B.** Juvenile attached to back side of holotype (Scale bar = 1 mm), **C.** Colony of three adults (Scale bar = 3 mm), **D.** Tannish-white colored adult on flat substratum (Scale bar = 4 mm).

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**Figure 4.** **A.** *Serpulorbis hadfieldi* n. sp. brown type (Scale bar = 1 mm), **B.** Tannish-white type (Scale bar = 1 mm), **C.** Close up of cephalic tentacle (Scale bar = 0.5 mm), **D.** Mesopodium, neck area, and mantle rim (Scale bar = 1 mm).

(UF 310732); Muséum nationale d'Histoire Naturelle, Paris (MNHN 9671–9674); Bernice P. Bishop Museum, Honolulu (BPBM 269453–269455).

**Holotype:** The holotype is an adult with a white outer shell growing among the branches of the coral *Pocillopora damicornis*, a juvenile is attached on the opposite side of the shell that has a deep red-brown colored shell (Figure 3 A & B). The shell attaches on the apical portion, coils on its self, and then follows the contour of the coral branches. Aperture diameter is 4.5 mm; length of shell is 2.4 cm, and the width at the widest point 1.2 cm. The shell with preserved animal inside it is deposited in the U. S. National Museum of Natural History (Smithsonian Institution), Washington D. C., USA.

**Shell:** The aperture diameter of the adult feeding tube averages  $4.2 \pm 0.6$  mm (range 3.1 mm to 5.2 mm,  $n = 20$ ). The early shell tube coils on itself, characteristic of *Serpulorbis*, then grows among the branches of coral (Figure 3C) or may continue to coil loosely if on flat substratum (Figure 3D). New growth of the shell feeding tube is thin, smooth and white, with only light horizontal growth rings. Older shells are thicker and often covered in fine sandy material cemented into the shell and or the red crustose coralline algae *Hydrolithon reinboldii* (Figure 3A). The early telococonch tube aperture is more oval and concave on the surface conforming to the substratum (Figure 3B); older feeding tube is generally round (Figure 3A, C, and D). The inner shell is shiny, white in the area of the feeding tube, and mostly dark brown to purple to the posterior. The dark color of the inner shell shows through giving the older outer shell a dark appearance in some individuals (Figure 3C). Feeding tube scars occur at irregular intervals.

**Operculum:** Present only in the emergent juvenile as a transparent concave disk attached to the metapodium. The operculum is lost in the adult form.

**Animal:** The metapodium (foot) pad is in the shape of a flat, wide cone with either deep brown or tannish-white ground color (Figure 4A & B). The surface has distinctly raised cone-shaped tubercles, colored with symmetrical black and yellow pigment rings, and few orange speckles. The sides of the metapodium are muscular and extensible; the lateral ridge has alternating light and dark pigment bands (Figure 4A & B). The propodial pad (remnant of juvenile propodium and opening of the adult petal mucus gland) is bulbous and similar in color to the metapodium, except for a band of lighter colored pigment that encircles it. The pedal tentacles extend laterally from the propodial pad and are long and extensible, with light and dark pigment spots, and a few orange speckles. The mesopodium (head area) is similar to the metapodium in color. The cephalic tentacles form broad flanges at their base that taper to a distal point, when extended they are about three-fourths the length of the petal tentacles. The cephalic tentacles are similar in color to the mesopodium, with distinct cone shaped tubercles colored with symmetrical black and yellow pigment rings on the edges of the flange; the tips may have abundant yellow pigment (Figure 4C). A darkly pigmented eye lays posterior lateral to the base of each cephalic tentacle.

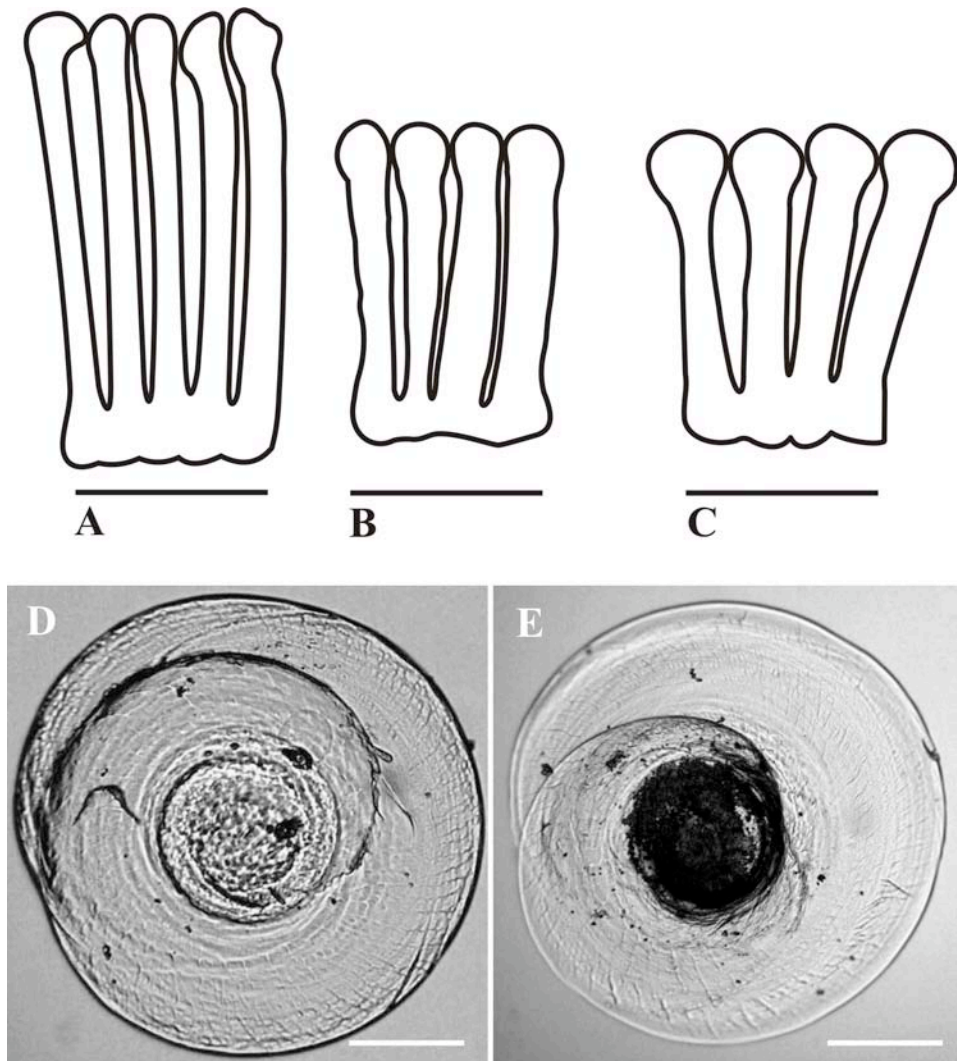


Table 1. Diagnostic characteristics among the species of *Serpulorbis* reviewed.

Species	Shell aperture diam. mm	Shell color	Protoconch dimensions mm, Number of whorls	Foot color	Head color	Development, Hatching stage	Brooding style	Radula median tooth	Habitat	Reference, Location
<i>Serpulorbis variabilis</i> Hadfield & Kay 1972	7 – 9	White	0.2 x 0.1 1.5 whorls	Variable orange, red, brown	Variable orange, red, brown	Indirect Veliger	Egg capsule attached to shell	*	Inter tidal bench, rimmed terrace, reef front	Hadfield et al.1972 Hawaii
<i>Serpulorbis imbricatus</i> Dunker 1860	9-12	Yellowish-brown to purple-brown	0.7 x 0.4 2.5 whorls	Dark brown	Brown with yellow flecks	Indirect Veliger	Egg capsule attached to shell	Equi-lateral triangle	Intertidal rocky shore, subtidal to 10 m	Scheuwimmer & Nishiwaki 1982 Japan, Korea, Taiwan, China
<i>Serpulorbis daidai</i> Scheuwimmer & Nishiwaki 1982	10.0	Light reddish-brown to cream	0.6 x 0.5 2.5 whorls	Orange	Orange with central black spot	Direct Juvenile	Egg capsule attached to shell	Elongate triangle	Intertidal to subtidal rocky shoreline	Scheuwimmer and Nishiwaki 1982 Japan
<i>Serpulorbis medusae</i> Pilsbry 1891	10.0	Yellowish to reddish-brown	0.7 x 0.4 2.5 whorls	Red	Red	Direct Juvenile	Egg capsule attached to shell	Elongate triangle	Attached to rocks, to 100 m	Scheuwimmer & Nishiwaki 1982 Japan

<i>Serpulorbis natalensis</i> Mörch 1862	5-6.5	*	1.0 length *	Bright white, orange-red, dark brown	Bright white, orange-red, dark brown	Direct Juvenile	Egg capsule attached to shell	*	Attached beneath substrata, reef flat	Hughes 1978 South Africa
<i>Serpulorbis zelandicus</i> Quoy & Gaimard 1834	8-10	Yellow-brown	* *	Orange-red, light-brown, yellowish, deep chocolate red	Orange-red, light-brown, yellowish, deep chocolate red	Direct Juvenile	Egg capsule attached to shell	Twice as wide as long	Exposed rocks, reef fringe	Morton 1951 New Zealand
<i>Serpulorbis aotearoicus</i> Morton 1951	8-10	Dark brown to purplish-brown	* 2.0 whorls	Black	Black	Direct Juvenile	Egg capsule attached to shell	Elongate triangle	Under boulders, exposed rocks, reef fringe	Morton 1951 New Zealand
<i>Serpulorbis (Serpulorbis) Sipho</i> Lamarck 1818	10	Light brown	* *	Black, yellowish fawn	Black, yellowish fawn	*	*	*	Upper surface of stones, inner reef flat	Hughes 1993 Rottneest Island, W. Australia
<i>Serpulorbis arenaria</i> Linnaeus 1767	12	Yellowish-brown to white	* *	Dark-red with yellow or white spots	Dark-red with yellow or white spots	*	*	*	Rocky subtidal zone to 18 meters	Schiaparelli 1996 Ligurian Sea
<i>Serpulorbis hadfieldi</i> n. sp.	4.2	White	0.66 x 0.54 2.5 whorls	Tannish-white to deep brown	Tannish-white to deep brown	Direct Juvenile	Egg capsule attached to shell	Equilateral triangle	Reef flat moat	this paper Guam

\* = Data unavailable.



**Figure 5.** Ctenidia: **A.** *Serpulorbis hadfieldi* n. sp., **B.** *Petalconchus apakadikike* n. sp., **C.** *Petalconchus lilandikike* n. sp (Scale bars = 1 mm). Opercula: **D.** *Petalconchus apakadikike* n. sp., **E.** *Petalconchus lilandikike* n. sp. (Scale bars = 1 mm).

The buccal area is colored similarly to the mesopodium. The ventral neck area of the mesopodium (posterior to the buccal area that extends to the mantle rim) is the color of the mesopodium and is covered in distinct, cone-shaped tubercles, colored with symmetrical black and yellow pigment rings, and few orange speckles (Figure 4D). The mantle margin is marked similarly to the metapodial rim with alternating bands of light and dark pigment (Figure 4D). The pallial and abdominal regions show the color of the internal organs. The columellar muscle is long allowing the animal deep retreat into the shell.

**Ctenidium:** The monopectinate ctenidium extends about the length of the mantle cavity and comprises long filaments, with slightly club shaped tips (Figure 5A). The well-developed petal tentacles and bulbous propodial pad indicate mucus-net feeding as the dominant form, which is commonly observed in the field and laboratory; the long ctenidium suggests filter feeding is also probable.

**Radula:** The radula of *Serpulorbis hadfieldi* n. sp. is typical of the family Vermetidae, taenioglossate, with one median tooth, a pair of lateral teeth, and two pair of marginal teeth. In *S. hadfieldi* n. sp. the central plate of the median tooth is trapezoid shaped; the median tooth is the shape of an equilateral triangle.

**Protoconch:** Protoconchs average  $0.66 \pm 0.02$  mm (range 0.62 mm to 0.68 mm,  $n = 20$ ) in length and  $0.54 \pm 0.02$  mm (range 0.51 mm to 0.57 mm,  $n = 20$ ) in width across the second whorl. Protoconchs are barrel-shaped and are 2.5 whorls at hatching. The shell is transparent, with yellowish spots on the second whorl; the surface is smooth (Figure 6A).

**Brood protection and early ontogeny:** Ovoid egg capsules are brooded in the mantle cavity suspended from stalks attached to the inner shell (Figure 6B). A slit in the dorsal mantle wall accommodates these stalked egg capsules. Observations show females brood an average of  $10 \pm 1.5$  egg capsules at one time (range 7 to 12,  $n = 20$ ). Mature egg capsules average  $3.0 \pm 0.1$  mm (range 2.8 mm to 3.1 mm,  $n = 20$ ) in length and  $1.5 \pm 0.1$  mm (range 1.3 to 1.7 mm,  $n = 20$ ) in width. There is an average of  $30 \pm 6.9$  juveniles per egg capsule (range 16 to 39,  $n = 20$ ). Development is direct and metamorphosis occurs prior to hatching. The tissue of post-hatching, crawling juvenile is mostly transparent to milky white except for maroon stripes by the eyes that extend posterior. White pigment spots are found on the otherwise transparent cephalic tentacles. Two distinct white spots on the propodium mark the openings of the pedal mucous gland (Figure 6A). Juvenile attachment occurs within 24 hours of hatching if suitable substratum is present or may be delayed for several days until the internal yolk supplies run out and attachment becomes obligate to any available substratum.

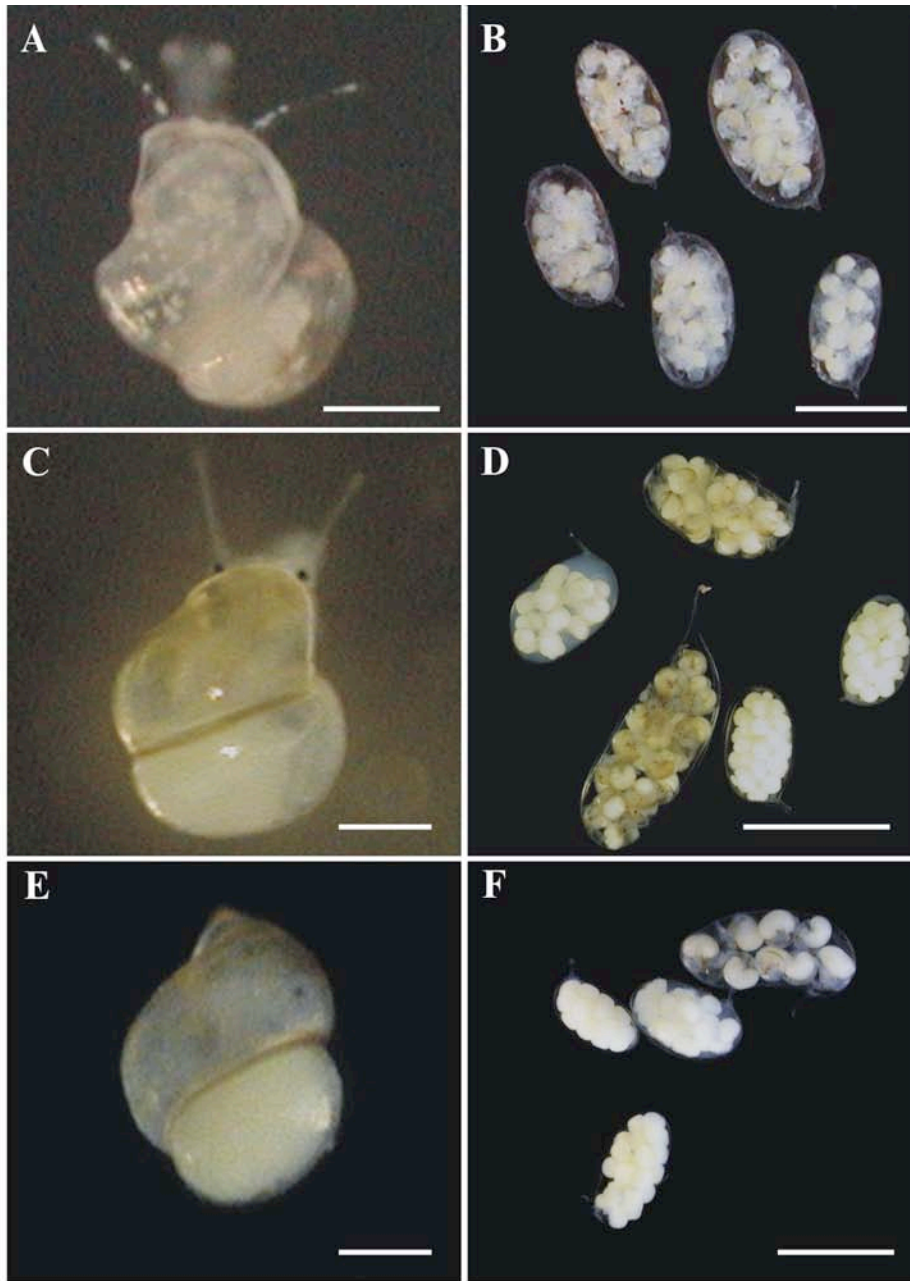
**Habitat:** *Serpulorbis hadfieldi* n. sp. inhabits the reef-flat moat that is often under a high-suspended particle load, at depths of 1 to 2 meters in areas of low wave energy and moderate current. This species has not been observed in areas subjected to subareal exposure from low tide. Adults are found in live branching coral, such as *Pocillopora damicornis*, on dead spots on massive corals such as *Porities lutea*, on sediment free hard pavement, and occasionally on boulders and reef rubble. Adults may form small colonies up to five or be solitary. *Serpulorbis hadfieldi* n. sp. has been observed only on the east coast of Guam, from Pago Bay to Jones Beach.

**Comparisons:** *Serpulorbis variabilis* (Hadfield & Kay 1972) from Hawaii, also found in Guam (Smith 2003) is larger than *S. hadfieldi* n. sp. with an aperture diameter of 7 - 9 mm. *Serpulorbis variabilis* adults occur solitarily or forms loose colonies spaced by decimeters to meters, and are found in areas of

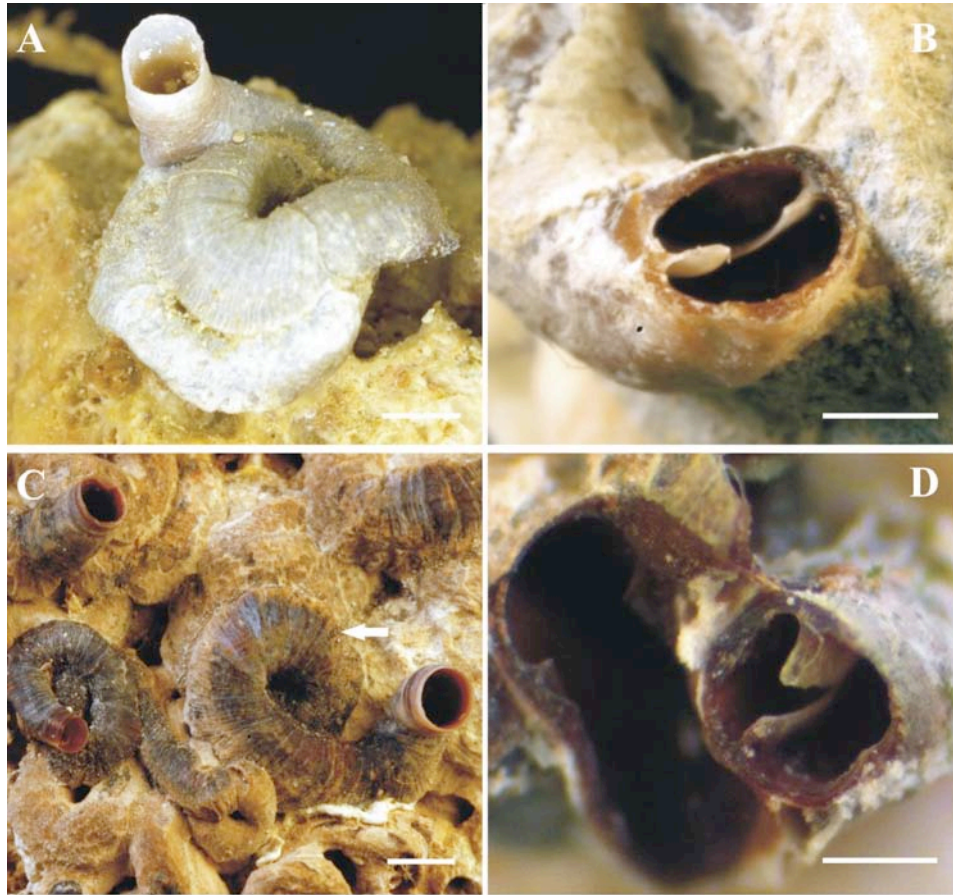
high wave energy, such as the reef crest, rimmed terraces, and in areas of strong current along intertidal benches such as Cabras Island, Guam and Diamond Head Beach on Oahu, Hawaii (personal observation). The coloration of the head and foot area is variable with colors ranging from orange, yellow, bright red, to brown. Larval development is indirect. *Serpulorbis imbricatus* (Dunker 1860) is found in Japan, Korea, Taiwan, and China (Scheuwimmer & Nishiwaki 1982). The adult tube aperture is 9 to 12 mm and the adult head and foot coloration is brown. The habitat of *S. imbricatus* is along the rocky intertidal shore to subtidal at a depth of 10 m on rocky substratum. Development is indirect. *Serpulorbis daidai* (Scheuwimmer & Nishiwaki 1982) is found in Japan. The adult tube aperture is 10 mm and the adult head and foot coloration is orange. The habitat of *S. daidai* is from the lower intertidal to the upper subtidal rocky shoreline. Protoconch size is 0.6 by 0.5 mm. *Serpulorbis medusae* (Pilsbry 1891) is found also in Japan (Scheuwimmer & Nishiwaki 1982). The aperture is larger than that of *S. hadfieldi* n. sp. at 10 mm, and the adult head and foot coloration is red. The habitat of *S. medusae* occurs mostly at subtidal depths of 40 to 100 m on rocky or shell and gravel rubble, although it has been occasionally observed the lower intertidal rocky substrata and to a depth of 14 m. Only one protoconch was observed and was said to be similar to that of *S. imbricatus*. *Serpulorbis natalensis* (Mörch, 1862) from South Africa is slightly larger at 5 to 6.5 mm wide across the head (Hughes 1978). The coloration of the head and foot is bright orange or a darker brownish-red. The protoconch is larger in *S. natalensis*, 0.7 to 1.4 mm long, and the shell has a light brown tint. *Serpulorbis natalensis* is found in calm water attached beneath substrata and is most common within the first few meters below mean low water in areas of high turbidity (Hughes 1978). *Serpulorbis zelandicus* (Quoy & Gaimard 1834), from New Zealand is found on exposed rocks on the reef fringe, has an orange-red to deep chocolate-red ground color, and is larger, with a tube aperture 8 to 10 mm in diameter (Morton 1951). *Serpulorbis aotearoicus* (Morton 1951), also from New Zealand, is found under boulders or on exposed rocks on the reef fringe, the adult head and foot are colored black. Juveniles hatch at two whorls. *Serpulorbis (Serpulorbis) siphon* (Lamarck 1818) from Western Australia are mostly a black ground color, a few specimens have a yellowish fawn color (Hughes 1993). The feeding tube diameter is about 10 mm. They form aggregates subtidally on the upper surface of stones in inner reef flat at Rottnest Island, Western Australia. *Serpulorbis arenaria* (Linnaeus 1767) from the Ligurian Sea has an average feeding tube aperture diameter of 12 mm; the shell is yellowish-brown to whitish (Schiaparelli 1995). The sculpture of the shell has very small granules that form parallel striae. The adult coloration is dark-red, with yellow or white spots on all anterior parts of the body and of the mantle. They are found attached to boulders to a depth of 18 meters (Schiaparelli 1995). Table 1 provides comparison of shell, animal, and developmental characters for all of the species of *Serpulorbis* cited.

**Etymology:** This species is named for Dr. Michael G. Hadfield, of the University of Hawaii, who conducted observations of the Guam vermetid fauna

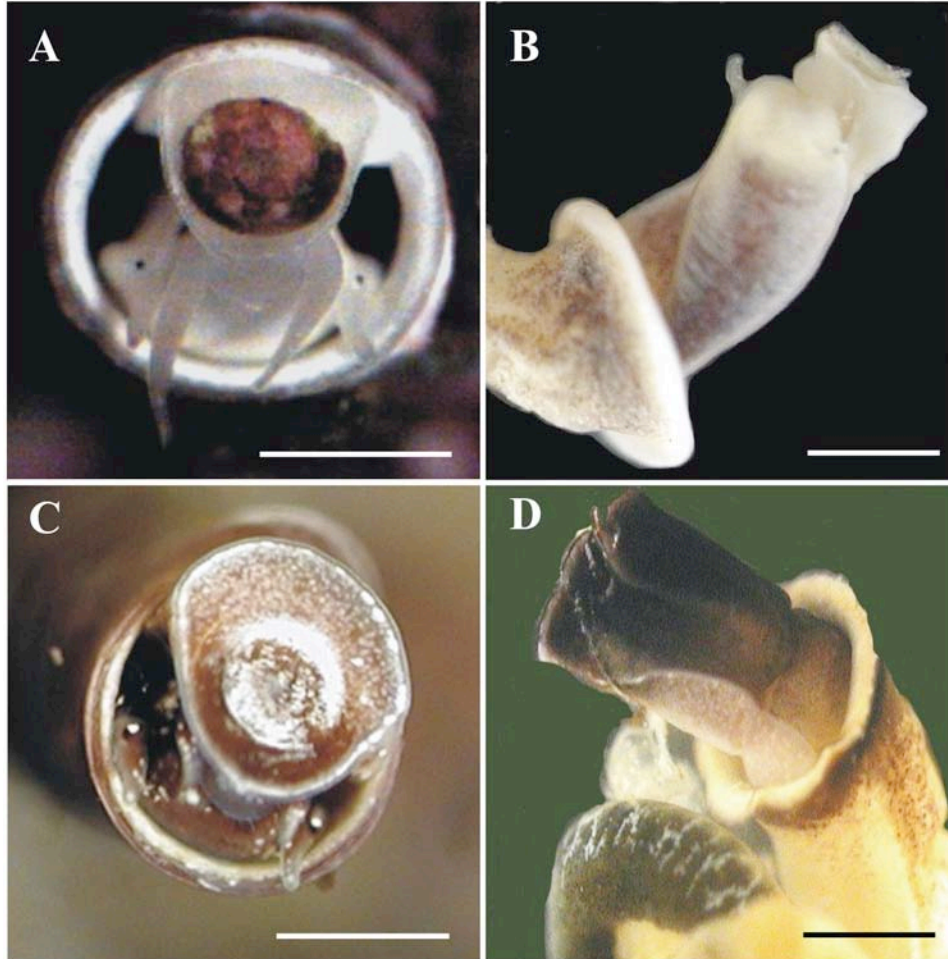




**Figure 6.** Juveniles and Egg Capsules: **A.** *Serpulorbis hadfieldi* n. sp. juvenile (Scale bar = 0.25 mm), **B.** *S. hadfieldi* n. sp. egg capsules (Scale bar = 1.5 mm), **C.** *Petalconchus apakadikike* n. sp. juvenile (Scale bar = 0.2 mm), **D.** *P. apakadikike* n. sp. egg capsules (Scale bar = 2 mm), **E.** *Petalconchus lilandikike* n. sp. juvenile (Scale bar = 0.2 mm), **F.** *P. lilandikike* n. sp. egg capsules (Scale bar = 1 mm).

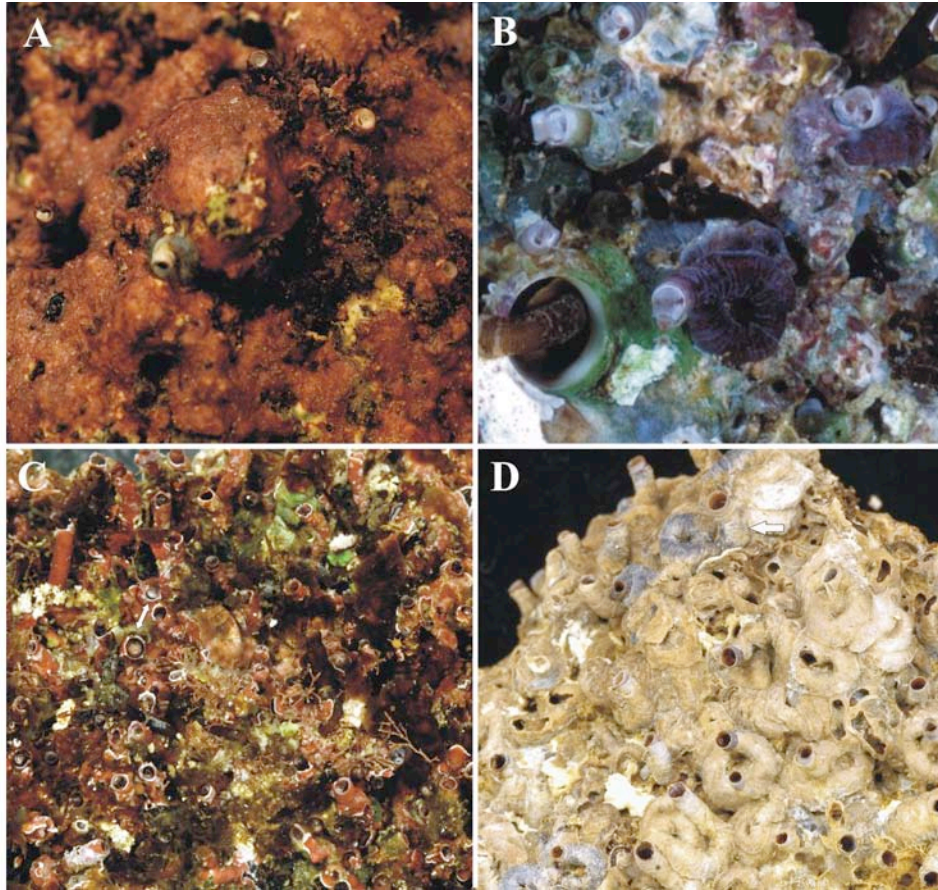


**Figure 7.** **A.** *Petaloconchus apakadikike* n. sp. holotype shell (Scale bar = 2 mm), **B.** *P. apakadikike* n. sp. paired internal lamellae (Scale bar = 0.5 mm), **C.** *Petaloconchus lilandikike* n. sp. arrow points to holotype shell (Scale bar = 2 mm), **D.** *P. lilandikike* n. sp. paired internal lamellae. (Scale bar = 0.5mm).



**Figure 8.** **A.** *Petalconchus apakadikike* n. sp., from Cabras Island rimmed terrace, metapodium and tentacles (Scale bar = 0.75 mm), **B.** *Petalconchus apakadikike* n. sp. adult without shell (Scale bar = 0.75 mm), **C.** *Petalconchus lilandikike* n. sp., from Pago Bay, rimmed terrace, metapodium and tentacles (Scale bar = 0.5 mm), **D.** *Petalconchus lilandikike* n. sp. adult without shell. (Scale bar = 0.5 mm).





**Figure 9.** **A.** *Petaloconchus apakadikike* n. sp., section of aggregate at Merizo Point reef front, five adults and one juvenile, **B.** *P. apakadikike* n. sp. aggregate of five adults at Cabras Island rimmed terraces, **C.** *Petaloconchus lilandikike* n. sp. aggregate at Pago Bay rimmed terraces, mixed with several *Dendropoma meroclista* (double arrow points to two *D. meroclista* adults), **D.** *P. lilandikike* n. sp. monospecific aggregate at Ylig Point fault line ridge, arrow points to holotype.

in 1980, and who has contributed much to the present knowledge of vermetid biology.

**Taxonomy:** *Serpulorbis hadfieldi* n. sp. is placed in the genus *Serpulorbis* because of the lack of adult operculum, as discussed by Keen (1961). This species is placed in subgenus *Serpulorbis s. s.* because of a lack of coiling pattern in the adult form and a tendency for colonial forms, as discussed by Keen (1961).

Genus *Petalochonchus* Lea, 1843  
Subgenus *Petalochonchus s. s.* (Keen 1961)

***Petalochonchus apakadikike* n. sp.**

**Type material:** Holotype: U. S. National Museum of Natural History (Smithsonian Institution), Washington D.C. (USNM 1096663).

**Type location:** Cabras Island, Guam, latitude 144°38'54.0" E and longitude 13°27' 56.9" N (WGS 1984), in a rimmed terrace on the edge of a narrow reef flat. Specimen collected November 21, 2003 by Walter C. Kelly III.

**Paratypes:** U. S. National Museum of Natural History (Smithsonian Institution) (USNM 1096664–1096668); Museum of Natural History, University of Florida (UF 310734); Muséum nationale d'Histoire Naturelle, Paris (MNHN 9675-9679); Bernice P. Bishop Museum, Honolulu (BPBM 269456–269460).

**Holotype:** The holotype is a single shell, in a small colony, attached to the hard substratum from Cabras Island (Figure 7A). The feeding tube aperture diameter is 1.5 mm, length of the shell is 8 mm, and the width at the widest point is 9 mm. The shell coils on its self then grows erect. Red crustose coralline algae cover the early whorls. The shell, with preserved animal inside, is deposited in the U. S. National Museum of Natural History (Smithsonian Institution), Washington D. C., USA.

**Shell:** The aperture diameter of the feeding tube of *Petalochonchus apakadikike* n. sp. varies significantly ( $t = -9.418$ ,  $df = 19$ ,  $p < .0001$ ) between Merizo Point reef front and Cabras Island. At Merizo Point reef front the aperture diameter averages  $2.5 \pm 0.2$  mm (range 2.3 mm to 2.8 mm,  $n = 20$ ) and at Cabras Island it averages  $1.5 \pm 0.3$  mm (range 1.0 mm to 2.0 mm,  $n = 20$ ). The shell is typical of *Petalochonchus*, the early tube coils along the substratum, then complete one or two coils on its self before becoming emergent above the substratum. The emergent shell is somewhat thin and white, with fine horizontal growth rings. The older shell is thicker and white in color, with growth rings more prominent and is frequently encrusted with red crustose coralline algae *Hydrolithon reinboldii*. The inner shell is white in new growth and dark brown to purple in older shell. The dark inner shell color shows through in the older shell giving the outer shell a dark appearance (Figure 7A). Early whorls have paired internal shell lamellae that do not meet in the center (Figure 7B). Feeding tube scars occur at irregular intervals.

**Operculum:** The concaved operculum forms a shallow transparent dish



with a slightly raised distal flange, spiral lamina of several volutions, and a small mamilla on the petal surface that is the attachment point to the metapodium (Figure 5D). The operculum is less than half the aperture diameter and covers about two-thirds of the metapodial surface (Figure 8A). The operculum to aperture diameter ratio is about  $4.3 \pm 0.05$ ,  $n = 20$ .

**Animal:** The metapodium pad is milky-white with an irregular band of dense white pigment encircling the rim (Figure 8A). The dorsal aspect of the metapodium, just posterior to the metapodium pad bears a golden colored shield shaped pigment area enlaced with white fluorescent horizontal stripes that tapers as it approaches the mantle rim. The propodial pad is milky-white in color and bulbous. The pedal tentacles emerge distally from the propodial pad; they are long, extensible, and milky-white in color with white pigment spots (Figure 8A). The metapodium bears a distinct ridge on the distal lateral edges that leads into the mantle cavity. This ridge begins milky-white in color and becomes light purple as it enters the mantle cavity. The mesopodium is milky-white in color. The distal lateral area of the dorsal mesopodium neck also bears a distinct ridge that leads into the mantle cavity. This ridge becomes light purple as it enters the mantle cavity (Figure 8B). The cephalic tentacles emerge laterally from the buccal area as long slender rods and are transparent with white pigment spots and are about two-thirds the length of the petal tentacles (Figure 8A). The eyes appear as black spots posterior lateral to the bases of the cephalic tentacles. The buccal area is milky-white in color. The ventral neck area is smooth, has a light rose to purple color, and this color extends into the mantle cavity (Figure 8B). The mantle rim is dense white; just posterior to this there is a wide band of pigment that is flecked heavily with reddish-brown to purple pigment that widens ventrally, then tapers and fades to a milky-white color (Figure 8B). The rest of the pallial and abdominal region shows the color of the internal organs. The columellar muscle is long allowing the animal deep retreat into the tube.

**Ctenidium:** The ctenidium extends about three fourths of the mantle cavity and comprises of stubby filaments with a slightly club shaped tip (Figure 5B). The well-developed petal tentacles and bulbous propodial pad indicate mucus-net feeding as the dominant form, which is commonly observed in the field and laboratory. The moderate sized ctenidium suggests that filter feeding is possible.

**Radula:** The radula of *Petalococonchus apakadikike* n. sp. is typical of the *Petalococonchus* genus. The central plate is rectangular; the median tooth is the shape of an isosceles triangle with three pairs of striations laterally. There is a pair of lateral teeth and two pairs of marginal teeth.

**Protoconch:** The protoconch averages  $0.66 \pm 0.01$  mm (range 0.62 mm to 0.67 mm,  $n = 20$ ) in length and  $0.44 \pm 0.01$  mm (range 0.43 mm to 0.48 mm,  $n = 20$ ) in width, is barrel shaped, and has two-and-a-half whorls at hatching. The protoconch is transparent with the second whorl a light amber color. The suture between the first and second whorl is a dark reddish-brown color (Figure 6C).

**Brood protection and early ontogeny:** Ovoid egg capsules are brooded in the mantle cavity, suspended from a stalk attached to the inner shell (Figure 6D).

Table 2. Diagnostic characteristics among the *Petaloconchus* species reviewed.

Species	Shell Aper- -ture diam. mm	Shell color, Internal lamellae	Protoconch dimensions mm, Number of whorls	Foot color	Head color	Develop- ment, Hatching stage	Brooding style	Radula median tooth	Habitat	Reference, Location
<i>Petaloconchus keenae</i> Hadfield & Kay 1972	4.0	Red- brown Present	0.7 x 0.45 2.5 whorls	Rusty red with yellow pigment	Rusty red with yellow pigment	Direct Juvenile	Egg capsule attached to shell	Isosceles triangle	Coral, pavement, reef rubble, reef flat and reef front	Hadfield et al. 1972 Hawaii
<i>Petaloconchus montereyensis</i> Dall 1919	1.6 Mont . 2.0 SJI	* Present	1.1 Mont. 1.45 SJI 2.5 whorls	Black- orange Brown- orange	Black- orange Brown- orange	Direct Juvenile	Egg capsule attached to shell	*	Intertidal rocks	Hadfield 1970, 1989 California, Washing- ton
<i>Petaloconchus myrakeenae</i> Absalão & Rios 1987	*	Dark brown black- purple Present	* *	Black	Black	*	*	Isosceles triangle	Intertidal rocks	Absalão & Rios 1987 Brazil
<i>Petaloconchus (Macrophragma) glomeratus</i> Linnaeus 1758	1.5	Light brown Single Lamella	* *	*	*	*	*	*	Rocky intertidal zone	Schiaparelli 1996 Ligurian Sea

Kelly: Three new vermetids from Guam

<i>Petalococonchus (Macrophragma) caperatus</i> Tate & May 1900	<1.0	White, pink to amber *	* 2.5 whorls	Colorless, pinkish red and white spots	Colorless, pinkish red and white spots	*	*	Isosceles triangle	Under stones, inner reef flat	Hughes 1993 Rottnest Island. Western Australia
Hadfield's vermetid Strathmann & Strathmann 2006	1.0	Red-brown Not present	0.4 x 0.3 3.0 whorls	Rose to dark maroon	Rose to dark maroon	Direct Juvenile	Egg capsule attached to shell	Isosceles triangle	Under side of coral, rocks, intertidal	Strathmann & Strathmann 2006 Hawaii
<i>Petalococonchus apakadikike</i> n. sp.	2.5 Merizo 1.5 Cabras	White Present	0.66 x 0.44 2.5 whorls	White	White, light purple	Direct Juvenile	Egg capsule attached to shell	Isosceles triangle	Rimmed terrace, reef front	This paper Guam
<i>Petalococonchus lilandikike</i> n. sp.	0.9 Pago 1.8 Ylig	Dark purple Present	0.65 x 0.43 2.5 whorls	Dark purple	Dark purple	Direct Juvenile	Egg capsule attached to shell	Isosceles triangle	Rimmed terrace, reef flat ridges	This paper Guam

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Mont. = Monterey Bay, California. SJI = San Juan Island, Washington. \* = Data unavailable

A slit in the dorsal mantle wall accommodates these stalked egg capsules. Observations show that females brood an average of  $8.2 \pm 1.6$  egg capsules (5 to 10,  $n = 20$ ) at one time. Mature egg capsules average  $2.3 \text{ mm} \pm 0.3$  in length (range 1.9 mm to 3.5 mm) and  $1.1 \text{ mm} \pm 0.08$  in width (range 0.95 mm to 1.4 mm,  $n = 20$ ) and contain an average of  $10.15 \pm 1.4$  pre-hatchling juveniles (range 8 to 12,  $n = 20$ ); the largest capsule observed was 3.5 mm by 1.4 mm and contained 19 juveniles (Figure 6D). Larval development is direct and metamorphosis occurs prior to hatching. The juvenile tissue coloration is milky white with the black eye spots standing out. Juvenile attachment occurs within 24 hours of hatching if suitable substratum is present or may be delayed for several days until the internal yolk supplies run out and attachment becomes obligate to any available substratum.

**Habitat:** Adult *Petaloconchus apakadikike* n. sp. form colonies up to about 20 animals, with individuals separated by millimeters to centimeters, on the Merizo Point reef front (Figure 9A), such colonies are separated by meters. On the rimmed terraces at Cabras Island, *P. apakadikike* n. sp. forms colonies of about five adults separated by millimeters; such colonies are separated by centimeters, and are continuous along the rim of the terraces (Figure 9B). The substratum at each of these sites is heavily incrustated with red crustose coralline algae. *Petaloconchus apakadikike* n. sp. is also found singly on the intertidal benches and boulders at Piti, in the intertidal Holocene limestone outcrops at Facpi Point, on the Merizo Point reef flat, and on the reef flat at Fouha Bay. This species has not been observed on the east coast of Guam. The habitat of *P. apakadikike* n. sp. is in areas of strong wave action and current. At the Cabras Island rimmed terrace, Facpi Point, and Piti, they are exposed during low tides; colonies at the Merizo Point reef front have not been observed exposed to low tide.

**Comparisons:** *Petaloconchus keenae* (Hadfield & Kay 1972) is found in Guam (Smith 2003) imbedded in corals, on boulders, and on pavements on the reef flat and down the reef front. *Petaloconchus keenae* is sometimes found on the same substratum as of *P. apakadikike* n. sp. The tube aperture diameter of *P. keenae* is larger at 3 to 4 mm. The coloration of the head and foot of *P. keenae* is a rusty red with ample yellow pigment. Egg capsules, larva, and juvenile morphology are similar to *P. apakadikike* n. sp. *Petaloconchus montereyensis* (Dall 1919) occur from central California to Washington State in gregarious colonies on the rocky intertidal area (Hadfield 1970, 1989). The tube aperture diameter varies significantly between the two areas, about 2.0 mm at San Juan Island, Washington and 1.6 mm at Monterey Bay, California (Hadfield 1989). Juvenile length at hatching also varies, 1.45 mm at San Juan Island and 1.18 mm at Monterey Bay, significant variation in *P. apakadikike* juvenile length is not observed in Guam. One juvenile is hatched per egg capsule. The color of the adult head and foot are black or brown with orange specialia (Hadfield 1970). *Petaloconchus myrakeenae* (Absalão & Rios 1987) is found on intertidal rocks and on mollusk shells in coastal Brazil. The shell coloration is chocolate brown

with three main longitudinal ribs. The head and foot are black. Brooding style and juvenile morphology are not presently known. One shell of *Petalococonchus* (*Macrophragma*) *glomeratus* (Linnaeus 1758) was found in the rocky intertidal zone of the Ligurian Sea, the feeding tube diameter was 1.5 mm (Schiaparelli 1996). Only one internal lamina was observed. The color of the shell was brown. *Petalococonchus* (*Macrophragma*) *caperatus* (Tate & May, 1900), from Rottneest Island, Western Australia has an feeding tube diameter less than 1 mm and is found abundantly on the under side of stones on the inner reef flat (Hughes 1996). The shell color ranged from transparent white, pink to amber. The protoconch had 2.5 bulbous whorls. The operculum had raised spiral lamina. The animals are colorless in white shells and those in pink or amber shells had pinkish red and white spots. Hadfield's vermetid (Strathmann & Strathmann 2006) identified in Hawaii and also found in Guam (personal observation 2003); is found on dead spots of branching coral or coral rubble that is at least partially encrusted with red crustose coralline algae. The tube aperture of Hadfield's vermetid, at a diameter of about 0.9 mm, is smaller than that of *P. apakadikike* n. sp. The coloration of the head and foot of Hadfield's vermetid ranges from rose to dark maroon. The juvenile protoconch, at an average of 0.44 mm long and 0.29 mm wide is smaller, is more cone shaped, and three whorls at hatching. No internal lamellae have been observed in this species. The habitat of *Petalococonchus lilandikike* n. sp. is similar to *P. apakadikike* n. sp. with respect to high wave energy habitat but different in other ways. *Petalococonchus lilandikike* n. sp. is found along the east coast of Guam in dense colonies on the Pago Bay rimmed terraces and on ridges at Ylig Pont reef flat, and occurs singly in the central to southern areas of the island. The tube aperture of *P. lilandikike* n. sp. is smaller at about 0.9 to 1.8 mm. The head and foot of *P. lilandikike* n. sp. is dark purple in color. Egg capsule, larva, and juvenile morphology are similar. Protoconch and ctenidium morphology are characteristically different between the two species. Table 2 provides comparison of shell, animal, and developmental characters for all of the species of *Petalococonchus* cited.

**Etymology:** The species name *apakadikike* is from the Chamorro language, in which it is correctly spelled á'paka' dikike'. The name á'paka' dikike' translates as "small white one".

**Taxonomy:** *Petalococonchus apakadikike* n. sp. is placed in the genus *Petalococonchus* because of the relative size of its operculum and the occurrence of internal shell lamellae, as discussed by Keen (1961). This species is placed in subgenus *Petalococonchus s. s.* because of adult coiling pattern, as discussed by Keen (1961).

Genus *Petalococonchus* Lea, 1843

Subgenus *Petalococonchus s. s.* (Keen 1961)

***Petalococonchus lilandikike* n. sp.**

**Type material:** Holotype: U. S. National Museum of Natural History (Smithsonian Institution) (USNM 1096669).



**Type location:** Ylig Point, Guam, latitude 144° 46' 37.65" E and longitude 13° 23' 16"E (WGS 1984) on reef flat ridges by Holocene peninsula. Specimen collected October 17, 2003 by Walter C. Kelly III.

**Paratypes:** U. S. National Museum of Natural History (Smithsonian Institution) (USNM 1096670–1096675); Museum of Natural History, University of Florida (UF 310733); Muséum nationale d'Histoire Naturelle, Paris (MNHN 9680–9685); Bernice P. Bishop Museum, Honolulu (BPBM 269461–269466).

**Holotype:** The holotype is a single shell, in a gregarious colony, attached to the hard substratum from the Ylig Point fault line ridge (Figure 7C). The feeding tube aperture diameter is 1.8 mm, the length is 1 cm, and the width at the widest point is 6 mm. The shell completes two coils on its self then grows erect. Crustose coralline algae covers the early whorls, new growth is light purple. The shell, with preserved animal inside, is deposited in the U. S. National Museum of Natural History (Smithsonian Institution), Washington D. C.

**Shell:** The aperture diameter of the feeding tube of *Petaloconchus lilandikike* n. sp. varies significantly ( $t = -28.325$ ,  $df = 19$ ,  $p < 0.001$ ) between Pago Bay rimmed terraces and Ylig Point reef-flat ridges. At the Pago Bay rimmed terrace, the mean aperture diameter is  $0.9 \pm 0.08$  mm (range 0.79 mm to 1.1 mm,  $n = 20$ ) and at the Ylig Point reef flat, the aperture averages is  $1.83 \pm 0.01$  mm (range 1.81 mm to 1.85 mm,  $n = 20$ ). Early tubes coil along the substratum, then complete one or two coils on its self before becoming emergent above the substrata (Figure 7C). The emergent tube is round, thin with fine horizontal growth rings, and light purple in color. The older shell is thicker and dark purple in color with growth rings more prominent, and frequently encrusted with red crustose coralline algae. The internal shell is shiny and dark purple to black in color. Early whorls have paired internal shell lamellae that do not meet in the center (Figure 7D). Feeding tube scars occur at irregular intervals.

**Operculum:** The operculum is thin, concave, and transparent with a distinct lateral flange and may have slightly raised spiral lamina (Figure 5E). A small mamilla is present on the petal surface of the operculum. The distinctive coloration of the metapodium shows through (Figure 8C). The operculum covers about two-thirds of the surface of the metapodium and is less than one-half the diameter of the adult tube aperture. The aperture to operculum ratio is about  $4.0 \pm 0.08$ ,  $n = 20$ .

**Animal:** The metapodium is a dark purple ground color. On the surface of the metapodium the pedal mucous gland is seen as a distinctive white ring around the dark purple center that is the attachment site of the petal mamilla of the operculum (Figure 8C). The metapodium is extensible and the rim is encircled with distinctive white pigment (Figure 8C). The dorsal aspect of the metapodium just posterior to the metapodium pad bears a deep purple shield inlaid with blue-green, horizontal fluorescent stripes that tapers as it approaches the mantle rim. The ridges on the distal lateral edges of the metapodium extend back into the mantle cavity (Figure 8D). These ridges are dark purple and bear a narrow row of yellow spots. The bulbous propodial pad is transparent with a bluish tint over a

dark purple ground color. The pedal tentacles are long, extensible, and colored dark purple with a light whitish-strip along the length of the lateral sides. The mesopodium is deep purple in color with white pigment spots (Figure 8D). The distal lateral ridges of the mesopodium bear two rows of dense yellow dots that fade as they extend back into the mantle cavity. Cephalic tentacles are about two-thirds the length of the cephalic tentacles and dark purple in color with dense white pigment at the tips (Figure 8C). The eyes appear as black spots posterior lateral to the bases of the cephalic tentacles. At the bases of these tentacles, behind the eyes, the pigment is less dense and is lighter purple in color. The buccal area is predominately a dark purple ground color, with a few white spots. The ventral neck area of the mesopodium is smooth, dark purple in color with few white speckles, more so on lateral edges, and this color lightens slightly as it enters into the mantle cavity (Figure 8D). The mantle rim is light yellow. Just posterior to the mantle rim, a band of maroon pigment forms a crest dorsally that reduces to a band ventrally (Figure 8D). The pallial and abdominal regions are the colors of the internal organs. The columellar muscle is long allowing the animal deep retreat into the tube.

**Ctenidium:** The ctenidium of *Petaloconchus lilandikike* extends about three fourths of the mantle cavity and comprises of stubby club shaped filaments, the club shaped tip portion is more pronounced than in *P. apakadikike* n. sp. (Figure 5C). The well-developed petal tentacles, bulbous propodial pad and moderate sized ctenidium indicate mucus-net feeding as the dominant form, which is commonly observed in the field and laboratory. The moderate sized ctenidium also suggests that filter feeding is also possible.

**Radula:** The central plate is rectangular, and the median tooth is the shape of an isosceles triangle with three pairs of striations laterally. There are a pair of lateral teeth and two pairs of marginal teeth.

**Protoconch:** At hatching, the protoconch average  $0.65 \pm 0.01$  mm in length (range 0.62 mm to 0.67 mm,  $n = 20$ ) and  $0.43 \pm 0.02$  mm (range 0.38 mm to 0.47 mm,  $n = 20$ ) in width. The protoconch is bulbous with the second whorl is slightly larger than the first, of two-and-a-half whorls at hatching, and it is transparent with a dark red-brown suture (Figure 6E).

**Brood protection and early ontogeny:** Ovoid egg capsules are brooded in the mantle cavity, suspended from stalks attached to the dorsal inner shell (Figure 6F). The slit mantle accommodates these stalked egg capsules. Observations indicate that females brood an average of  $10 \pm 3.6$  egg capsules (range 5 to 14,  $n = 20$ ) at a time. Mature egg capsules average about  $2.0 \pm 0.15$  mm (range 1.8 to 2.3 mm,  $n = 20$ ) in length and about  $1.0 \pm 0.1$  mm in width (range 0.9 to 1.3,  $n = 20$ ) and contain an average of  $9.25 \pm 2.0$  pre-hatchling juveniles (range 8 to 16,  $n = 20$ ). Larval development is direct and metamorphosis occurs prior to hatching. The juvenile tissue coloration is milky white, and the black eye spots stand out. Juvenile attachment occurs within 24 hours of hatching if suitable substratum is present or the may be delay for several days until the internal yolk supplies run out and attachment becomes obligate to any available substratum.

**Habitat:** *Petaloconchus lilandikike* n. sp. forms colonies up to about six adults per square centimeter, segregated within millimeters of other species, or mixed with other species on rimmed terraces at Pago Bay (Figure 9C) and along the reef crest south to Jones Beach in areas of strong wave action and current that is exposed during low tide. At Ylig Point, they form dense monospecific colonies of about five adults per square centimeter along the fault line ridge (Figure 9D) and on reef flat ridges in an area of strong current that is exposed during extreme low tide. In other areas, such as Merizo Point reef flat, Fouha reef flat, Luminao reef flat, and Cabras Island, they are solitary or mixed with other species.

**Comparisons:** *Petaloconchus keenae* (Hadfield & Kay 1972) identified in Hawaii, also occurs in Guam (Smith 2003) and is found imbedded in corals, on boulders, and on pavements on the reef flat and down the reef front in. *Petaloconchus keenae* has not been observed on the same substratum as *P. lilandikike* n. sp. at the Pago Bay rimmed terraces or on the ridges at Ylig Point. The tube aperture diameter, at 3 to 4 mm, of *P. keenae* is larger than that of *P. lilandikike* n. sp. The coloration of the head and foot of *P. keenae* is a rusty red with ample yellow pigment. Egg capsules, larva, and juvenile morphology are similar. *Petaloconchus montereyensis* (Dall 1919) occur from central California to Washington State in gregarious colonies along the rocky intertidal area (Hadfield 1970, 1989). The gregarious colonies of *P. montereyensis* are similar to *P. lilandikike* n. sp., though denser at 12 animals per square centimeter (Hadfield 1989). The color of the adult head and foot is black or brown with orange specialia (Hadfield 1970). The tube aperture diameter varies significantly between the two areas, about 2.0 mm at San Juan Island, Washington and 1.6 mm at Monterey Bay, California. Juvenile length at hatching also varies, 1.45 mm at San Juan Island and 1.18 mm at Monterey Bay (Hadfield 1989), significant variation in *P. lilandikike* juvenile length is not observed in Guam. One juvenile is hatched per egg capsule. *Petaloconchus myrakeenae* (Absalão and Rios 1987) is found on intertidal rocks and on mollusk shells in coastal Brazil. The shell coloration is chocolate brown with three main longitudinal ribs. The head and foot are a black color. Brooding style and juvenile morphology are presently unknown. One shell of *Petaloconchus (Macrophragma) glomeratus* (Linnaeus 1758) was found in the rocky intertidal zone of the Ligurian Sea the feeding tube diameter was 1.5 mm (Schiaparelli 1996). Only one internal lamina was observed. The color of the shell was brown. *Petaloconchus (Macrophragma) caperatus* (Tate & May, 1900), from Rottnest Island, Western Australia has a feeding tube diameter less than 1 mm and is found abundantly on the under side of stones on the inner reef flat (Hughes 1993). The shell color ranged from transparent white, pink to amber. The protoconch has 2.5 bulbous whorls. The operculum has raised spiral lamina. The animal is colorless in white shells and those in pink or amber shells have pinkish red and white spots. Hadfield's vermetid (Strathmann and Strathmann 2006) identified in Hawaii also occurs in Guam (personal observation, 2003) and is found attached to coralline algae

encrusted spots on coral in areas of moderate current. The tube aperture of Hadfield's vermetid diameter is about 0.9 mm. The coloration of the head and foot ranges from rose to dark maroon. The juvenile protoconch, at an average of 0.44 mm long and 0.29 mm wide, is more cone shaped and three whorls at hatching. Internal shell lamellae have not been observed in this species. *Petalococonchus apakadikike* n. sp. is found along the west and south coasts of Guam from the Piti intertidal area to the reef front at Merizo Point reef flat. The diameter of the tube aperture is larger than that of *P. lilandikike* n. sp. at about 2.0 mm. The head and foot of *P. apakadikike* n. sp. are white in color. Egg capsule, larva, and juvenile morphology are similar. Protoconch and ctenidium morphology are characteristically different between the two species. Table 2 provides comparison of shell, animal, and developmental characters for all of the species of *Petalococonchus* cited.

**Etymology:** The species name *lilandikike* is from the Chamorro language and is correctly spelled li'lan dikike'. The name li'lan dikike' translates as "small purple one".

**Taxonomy:** *Petalococonchus lilandikike* n. sp. is placed in the genus *Petalococonchus* because of its operculum size and occurrence of internal shell lamellae, as discussed by Keen (1961). This species is placed in the sub genus *Petalococonchus s. s.* because of adult coiling pattern, as discussed by Keen (1961).

## Discussion

Operculum, brooding style, protoconch morphology, and radula morphology are highly conserved in the family Vermetidae, and are genus and species specific as well (Morton 1965). The basic characteristics that distinguish these three new species from others in their genera are coloration of the adult animal's soft tissue, habitat, adult size, and slight variation in protoconch morphology and ctenidium morphology between the two *Petalococonchus* species. A major distinguishing characteristic of *Serpulorbis hadfieldi* n. sp. is habitat and geographic distribution as *S. hadfieldi* n. sp. occur in the reef-flat moat, in areas of moderate current, and are only observed on the central east coast of Guam. There is variability of the adult tube aperture diameter in *S. hadfieldi* n. sp., this variation is consistent throughout their range, and appears to be due to differences in the age of the adult. There is also variability in shell coiling pattern that is apparently due to the substratum where they attach. There are two ground color morphs of these vermetids, rich brown and tannish-white, and these colors are characteristic of this species. This theme of distinct habitat, adult size, and animal coloration is apparent for both *Petalococonchus* species. They occur in distinct areas of strong wave action and current, are of a small size, and are distinctly different in coloration. Both species are abundant on rimmed terraces with *P. apakadikike* n. sp. also found on the reef crest and *P. lilandikike* n. sp. found on ridges on the reef flat. These habitats are distinctive and characteristic of these *Petalococonchus* species. There is little variation of shell coiling pattern for either of the *Petalococonchus* species and this may be attributed to the

substratum where they are attached. Each species attaches on the surface of hard substratum where there is little or no obstruction to warrant variation in coiling pattern. The main obstruction is other shell tubes on the substratum and the individual animals just make minor feeding tube changes to avoid these obstacles. Occasionally sea weed cover increases greatly at Pago Bay and Cabras Island rimmed terraces; this results in temporary elongation of the feeding tube but does not appear to effect coiling pattern. Adult coloration is characteristically different between these two species. The subtle variation that occurs in protoconch shape and ctenidium filament morphology further distinguishes the two *Petaloconchus* species as distinct from each other. Habitat, adult size, coloration of adult tissue, and morphological variation between the *Petaloconchus* species, clearly set these three new species as distinct and unique from any others reviewed, and clearly indicate them as newly described in the family Vermetidae.

For field identification, these three new species are distinct and identified easily as different from other vermetids found on Guam. The only other *Serpulorbis* species observed on Guam is *S. variabilis* (Smith 2003) which is found in areas of high wave energy or strong current. Most of the *Dendropoma* species found on Guam are not easily mistaken for any of the three new species. *Dendropoma gregaria* (Smith 2003), *D. platypus* (Smith 2003), *D. maxima* (Smith 2003), *D. psarocephala* and *D. rhysoconcha* (personal observation 2003) are all distinct as to size, operculum design, and habitat. *Dendropoma meroclista* (Smith 2003) may be mistaken as *P. lilandikike* n. sp. because of its proximity of habitat, tube size and shell color; however, the operculum of *D. meroclista* is a distinct white calcareous dome (Figure 9C) and the shell aperture is often closed to a narrow slit. *Petaloconchus keenae* (Smith 2003) is larger than the other *Petaloconchus* species, has a reddish-brown ground color, and generally occurs in calmer water. Hadfield's vermetid described by Strathmann & Strathmann (2006) in Hawaii and recently identified on Guam (personal observation 2003), is not often found in the same area as the two new *Petaloconchus* species; it is found more often on coral branches along with *S. hadfieldi* n. sp. or on crustose coralline algae encrusted coral rubble generally in calm water. There are no apparent internal lamellae in the shell of Hadfield's vermetid.

Tube aperture diameter varies in both of the *Petaloconchus* species at different sites. These variations in aperture diameter are obvious when observed in the field and prove to be significantly different when analyzed statistically. Tube aperture diameters also vary in *Petaloconchus montereyensis* between Monterey Bay, California and San Juan Island, Washington State (Hadfield 1989). In this case, size variation is attributed to differences in water temperature between the two sites; as in colder water, marine invertebrates tend to grow larger (Hadfield 1989). In Guam, the habitats of the two new *Petaloconchus* species vary distinctively between the different observation sites. The smaller members of each species are mostly found on high wave energy rimmed terraces that are regularly subjected to low tide exposure as at Pago Bay and Cabras

Island. The larger species are mostly found on either reef flat ridges that are exposed to swift current during tidal change and periodically exposed during extreme low tides at Ylig Point or the reef crest at Merizo Point that is submerged and exposed to breaking waves and strong current. It would seem that ocean conditions, habitat type, and dry exposure time may result in a difference of available nutrients, hence differences in adult size in the different habitats, more data is needed in this respect.

Recently surveys were conducted of vermetid fauna in a number of Pacific Ocean islands including Okinawa, Singapore, Yap, Palau, Chuuk, Pohnpei, Kosrae, Majuro, American Samoa, Johnston Island, and the Hawaiian Islands. Though at times observations were somewhat limited, the three new species were not observed at any of these localities (A. Faucci personal communication, March 2005). One observation made was that the type of reef flats, apparently specific to the three new species found on Guam, were not seen in these survey areas (A. Faucci personal communication, March 2005). Reef flats and rimmed terraces similar to those found on Guam are common in the islands of Rota and Tinian, located to the north of Guam (Smith personal communication, March 2005). Further surveys of islands, in the general geological region, with habitats similar to those found on Guam, need to be conducted before confirming that these new species are unique to Guam.

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