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First columbellid species (Gastropoda: Buccinoidea) from deep-sea hydrothermal vents, discovered in Okinawa Trough, Japan

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The molluscan diversity of deep-sea chemosynthetic ecosystems in Japan has been in general well documented with about 80 described species, of which over half are gastropods (Sasaki *et al.* 2005; Fujikura *et al.* 2012; Sasaki *et al*. 2016). Recently, however, a number of novel hydrothermal vent sites were discovered in the area using multibeam echo-sounding (Nakamura *et al*. 2015), providing opportunities for new discoveries. As a part of ongoing studies documenting the biodiversity of such sites, we present the first record of Columbellidae from hydrothermal vents, with a new species recovered from Natsu and Aki sites, in the Iheya North hydrothermal field (for map and background on the vent field see Nakamura *et al*. 2015).

Columbellidae is a diverse family of caenogastropods in the superfamily Buccinoidea which include 70 genera and several hundred species (deMaintenon 2014; Araya *et al.* 2016), most of which inhabit shallow waters and carry distinct colour patterns. Generally, columbellids are small in size (mostly less than 20 mm although some large specimens exceed 40 mm) and are either active carnivores or scavengers (Squires 2015). More than 65 species are known from Japan alone (Okutani 2017), although the deep-water diversity of the family remains poorly understood with a number of unnamed species (Hasegawa 2009). The present new species is the first columbellid recorded not only from hydrothermal vent ecosystems in Okinawa Trough, but from global vent communities as a whole. Prior to the present study, the only columbellids reported from chemosynthetic ecosystems have been from whale-falls (Smith *et al*. 1989; Levin *et al.* 2002).

Material and methods

During the R/V KAIYO research cruise KY14-01, two newly detected hydrothermal vent sites named Natsu and Aki near the Iheya North field (Nakamura *et al*. 2015) were explored for the first time using the ROV HYPER-DOLPHIN equipped with a slurp gun for collection of biological samples. In the Natsu site, a bush of tubeworms (*Lamellibrachia* sp. and *Alaysia* sp.) was collected, and nine specimens of a columbellid gastropod were recovered from their washings. In Aki site, five specimens of the same columbellid were found in washings of *Bathymodiolus* mussels.

The columbellid specimens were measured for shell diameter (SD), shell height (SH), and height of last whorl (LW) using Vernier callipers to ±0.1 mm accuracy. The radula was dissected out under a microscope and the remaining tissue dissolved using 20% strength commercial bleach. Cleaned radula and protoconch were observed using a Hitachi TM3000 SEM. Phylogenetic reconstruction was carried out using a 618 bp alignment of the cytochrome *c* oxidase subunit I (COI) gene. In addition to the present columbellid species, other columbellid species with COI sequences available on GenBank and three additional caenogastropods were included. The vetigastropod *Turbo sazae* Fukuda, 2017 served as an outgroup. Sequencing and phylogenetic methods follow that of Chen *et al*. (2017). Type materials are deposited in the collections of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the National Science Museum, Tsukuba (NSMT) and the University Museum, the University of Tokyo (UMUT).

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Taxonomy

Clade CAENOGASTROPODA Cox, 1960

Superfamily BUCCINOIDEA Rafinesque, 1815

Family COLUMBELLIDAE Swainson, 1840

Genus *Astyris* H. Adams & A. Adams, 1853

Astyris thermophilus n. sp.

http://zoobank.org/urn:lsid:zoobank.org:act:43FA9CFA-3756-4CBC-9861-41FAF66397B9

Type specimens. Holotype (Fig. 1A–D) [SH 8.5 mm, SD 4.3 mm, LW 4.1 mm], UMUT RM32644. Paratypes. #1 (Fig. 1E) [SH 8.3 mm, SD 4.5 mm, LW 4.6 mm], NSMT Mo 78990. #2 (Fig. 1F) [SH 7.4 mm, SD 4.2 mm, LW 4.1 mm], periostracum removed with diluted bleach to reveal fine sculpture, operculum and radula removed for SEM, UMUT RM32645. #3 [SH 7.1 mm, SD 4.0 mm, LW 4.0 mm], NSMT Mo 78991. #4 [SH 7.7 mm, SD 4.1 mm, LW 4.3 mm], NSMT Mo 78992. #5 [SH 6.5 mm, SD 3.7 mm, LW 3.9 mm], JAMSTEC 1140053525. #6 [SH 3.0 mm, SD 1.7 mm, LW 1.6 mm], juvenile with intact protoconch, UMUT RM32646. All type specimens fixed and stored in 99% ethanol.

Type locality. Natsu hydrothermal vent site, Iheya North field, Okinawa Trough, Japan; 27°46.843'N, 126°54.024'E, 1074 m deep; 2014/Jan/24, collected by slurp gun, ROV HYPER-DOLPHIN Dive #1614, R/V KAIYO cruise KY14-01, principal scientist: Ken Takai.

Additional material examined. Two specimens from type locality, fixed and stored in 99 % ethanol, used for genetic barcoding (tissue dissolved). Five specimens, live collected, fixed and stored in 99% ethanol. Aki hydrothermal vent site, Iheya North field, Okinawa Trough, Japan; 27°46.130'N, 126°54.159'E, 1087 m deep; 2014/Jan/25, collected by slurp gun, ROV HYPER-DOLPHIN Dive #1614, R/V KAIYO cruise KY14-01, principal scientist: Ken Takai.

Etymology. From '*Thermós*' (Greek), warm or hot, and '*philíā*' (Greek), love or affection; combined to mean heat-loving, referring to its habitat in hydrothermal vent fields.

Japanese Name. '*Yomotsu-mugi-gai*', meaning 'mitrid from the underworld'.

Diagnosis. A moderate-sized (up to SH 8.5 mm) *Astyris* with rather tall-spired, uniformly white, thin, semi-transparent shell; smooth including base, except 25 to 30 very fine spiral striae. Columella lacking columellar fold. Periostracum thin, greyish brown. Protoconch paucispiral. Radula stenoglossate with acuspate centre plate, three sharp cusps on each lateral.

Description. Shell (Fig. 1A–F) moderate-sized for genus (up to SH 8.5 mm), rather tall-spired. Apex always decollate in adults, leaving at most three whorls remaining. Teleoconch thin, semi-transparent, uniformly white in colouration. Periostracum thin, greyish brown, earlier whorls slightly darker coloured. Often covered by further sulfide deposits. Teleoconch largely smooth except approximately 25 to 30 very fine, shallow, evenly spaced spiral striae present across entire whorl (see Fig. 1F), increasing in strength anteriorly towards siphonal canal. Striations on posterior half of shell usually too fine to detect when covered by periostracum. Whorls elevated, slowly expanding, slightly convex but not angulated. Suture distinct, shallowly constricted. Aperture entirely lacking dentition, semi-circular in shape, siphonate, approximately twice as tall as wide, posteriorly acuminate. Outer lip simple, not thickened, completely smooth on inside. Columella straight, simple, with slightly thickened callus. Siphonal canal short with weakly constricted but distinct siphonal notch. Protoconch (Fig. 1G) paucispiral, about 1.5 whorls, smooth, lacking velar sinus, sculpture or distinct growth lines. Transition edge between protoconch and teleoconch clearly marked by a varix. Suture of protoconch shallow, slightly higher than teleoconch.

Operculum (Fig. 1H) corneous, small, length about half of aperture height. Lamellate with lateral nucleus on right often eroded away.

Radula (Fig. 1I) stenoglossate, typical of columbellids with one lateral on each side separated by an acuspate centre plate instead of rachidian. Laterals sigmoid, well-supported, with three strong cusps. Two distal cusps sharper, longer, closer spaced compared to basal cusp. Centre plate rectangular, slightly wider posteriorly, without sculpture.

Distribution and ecology. Only known from Natsu and Aki sites of the Iheya North hydrothermal field (Nakamura *et al*. 2015), mid-Okinawa Trough, Japan. Found in tubeworm bushes attached on the tubes, presumably a predator of other animals inhabiting the same habitat or alternatively it may be ovophagous and feed on eggs of other animals.

Remarks. The present new species is assigned to genus *Astyris* as it matches well with the diagnosis for the genus given by McLean & Gosliner (1996), most notably by having a small, high-spired shell with smooth surface and a paucispiral protoconch (Garcia 2009). Of those species currently in *Astyris*, the new species most closely resembles *A. permodesta* (Dall, 1890) from methane seeps at Monterey Canyon and whale falls in California (Smith *et al*. 1989; Bennett *et al*. 1994) and *A. atacamensis* Araya, Catalán & Aliaga, 2016 from northern Chile. Although *A. permodesta* has been reported also from off Callao, Perú (Levin *et al.* 2002), this is likely in fact another record of *A. atacamensis* (Sellanes 2017). Both of these species are easily separable from *A. thermophilus* **n. sp.** as they have a thicker, broader

shell with wider aperture and less constricted siphonal canal, as well as having spiral grooves on the base. The pronounced columellar fold seen in *A. atacamensis* and the lirae inside the outer lip are also lacking in *A. thermophilus* **n. sp.** Until the discovery of *A. thermophilus* **n. sp.**, *Astyris permodesta* was the only other columbellid species known from deep-sea chemosynthetic ecosystems.

Astyris thermophilus **n. sp.** is conchologically similar to *Zemitrella cera* Okutani, 1964 from 1000–3000 m deep off Izu Islands, Japan (Okutani, 1964; 2017), but differs by having spiral striation across the entire teleoconch whorl (sculpture is only present on the base in *Z. cera*) and a slightly longer siphonal canal. As the protoconch of *Z. cera* is unknown, it is not transferred to *Astyris* at this point. Furthermore, the new species is also very similar to a yet undescribed species reported from deep-water trawls and dredges carried out in northern Pacific coast of Honshu, Japan (*Mitrella* sp. 1 *sensu* Hasegawa, 2009: figs. 162–166), but differs from that species in the spiral striae on the teleoconch being less distinct and that the columella is always straight. At this point we cannot entirely dismiss the possibility that *Mitrella* sp. 1 (*sensu* Hasegawa, 2009) may be conspecific with *Astyris thermophilus* **n. sp.** and the morphological differences may be due to environmental factors.

The phylogenetic reconstruction (Fig. 2) confirmed the placement of the present new species within Columbellidae. Its generic placement cannot be tested at present because sequences from other *Astyris* species were not available.

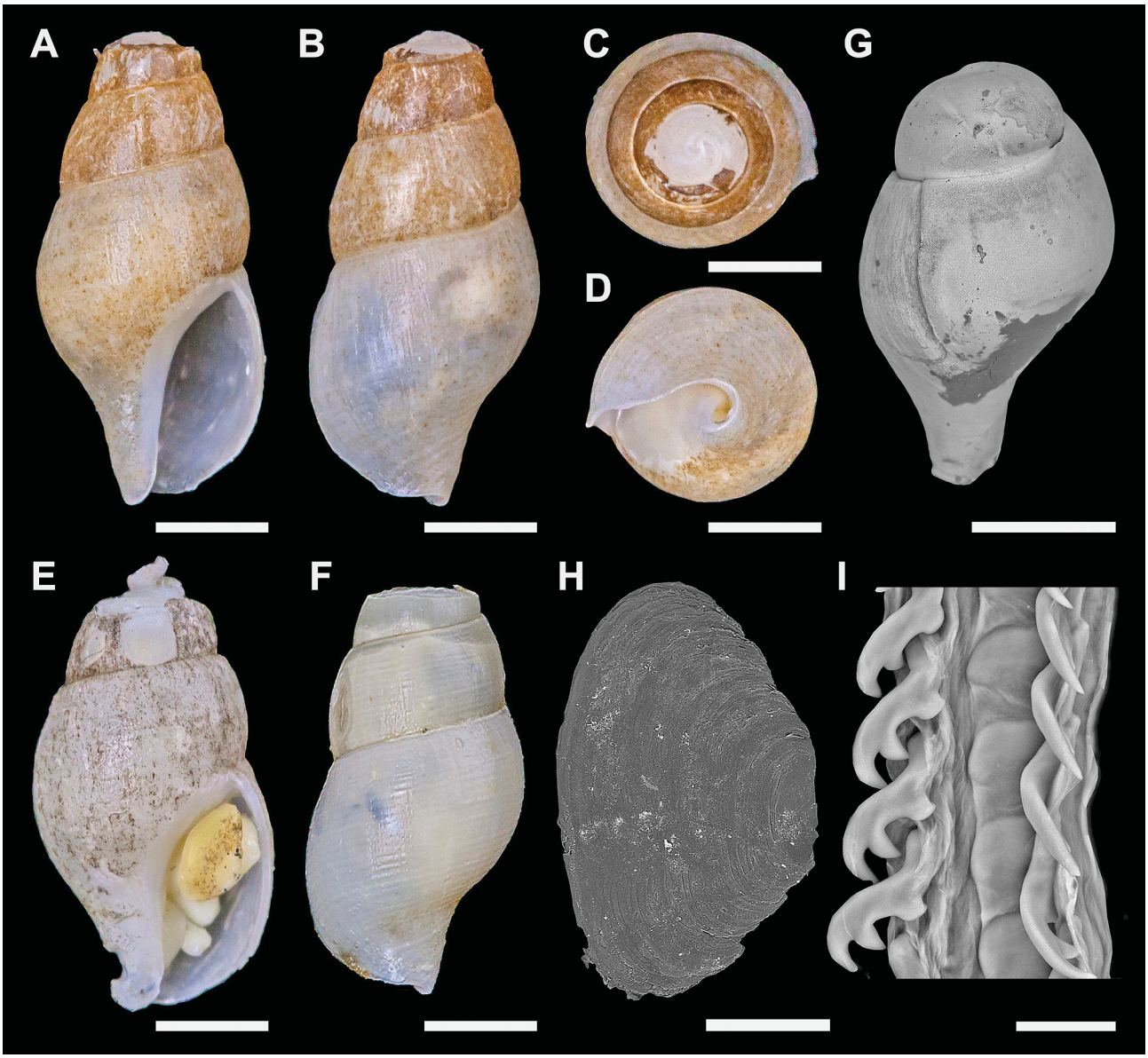

FIGURE 1. *Astyris thermophilus* **n. sp. A–D.** Holotype (UMUT RM32644). **E.** Paratype #1 (NSMT Mo 78990). **F.** Paratype #2 (UMUT RM32645), periostracum removed to show spiral striae. **G.** Protoconch of paratype #6, a juvenile specimen (UMUT RM 32646). **H.** Operculum of paratype #2 (UMUT RM32645). **I.** Radula of paratype #2, UMUT RM32645). Scale bars = 2 mm (**A–F**), 500 µm (**G, H**), 20 µm (**I**).

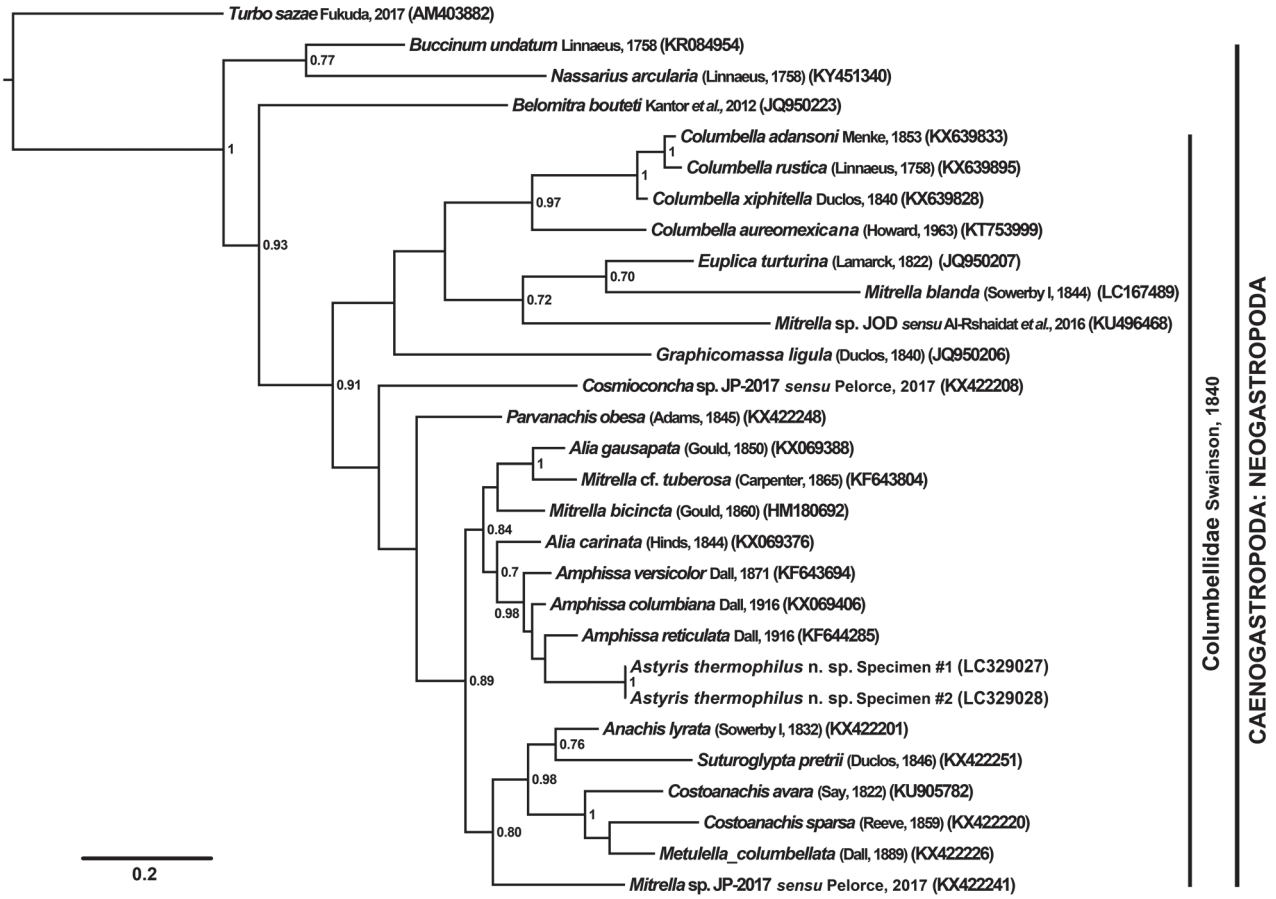

FIGURE 2. Phylogenetic reconstruction using the COI gene (618 bp) showing *Astyris thermophilus* **n. sp.** nested within Columbellidae. Node values indicate Bayesian posterior probability, those lower than 0.7 are omitted. The DDBJ/EMBL/GenBank accession numbers for each sequence used are shown inside brackets (LC329027 and LC329028 for the two sequenced specimens of *A. thermophilus* **n. sp.**).

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