

Discovery of an overlooked Helicarionid land snail (Helicarionidae: Durgellinae) from northeastern Thailand, with description of a new genus and new species, and note on radula morphology and genital system

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Abstract. *Aenigmatoconcha clivicola*, new genus and new species, was described from a limestone hill in Loei Province, northeastern Thailand. Morphological features of the shell, genital system, and radula were examined and compared with *Sophina calias* and *S. schistostellis* from Southeastern Myanmar, and *Chalepotaxis infantilis* from Southern China. It differs from all previously described *Sophina* species due to its more flattened and depressed, thin glossy shell, and its soft parts possessing broad right and left mantle shell lobes. The radula comprises approximately 20–25 transverse V-shaped rows of teeth; each row having 17–137 unicuspis spatulate teeth. The genital system lacks an amatorial organ and has a very large cylindrical penis without a penial sheath.

Key words. *Sophina*, *Chalepotaxis*, *Aenigmatoconcha*, V-shaped rows of teeth, amatorial organ, limestone dweller

INTRODUCTION

Sophina Benson, 1860, is a genus of pulmonate land snail described from southeastern Myanmar. The genus was initially proposed as the distinct “southern Burmese section of the Naninoid group: Section *Sophina*” due to its peculiar formation of a columellar lip and horizontal spiral keel at the umbilicus (Benson, 1859b), and subsequently elevated to generic level (Benson, 1860). Based on the unique shell morphology, external body and radula pattern, Blandford & Godwin-Austen (1908) proposed *Sophina* as the type genus of the subfamily Sophininae. However, the classification of this taxon remains uncertain, and recently, Bouchet & Rocroi (2005) synonymised Sophininae with Durgellinae (Table 1). Currently the genus *Sophina* Benson, 1860, comprises six nominal taxa: *Sophina calias*, *S. schistostellis*, *S. discoidalis*, *S. conjungens*, *S. forabilis*, and *S. forabilis bensonii*, which are all found in southeastern Myanmar (Table 2) (Blandford & Godwin-Austen, 1908).

The empty shells of *Sophina* are very similar to those of *Sarika* Godwin-Austen, 1907, and consequently they are usually misidentified as *Sarika* or *Macrochlamys* Benson, 1832. From October 2012 to October 2014, some limestone hills in Loei Province were surveyed (Fig. 1), and living

and empty shells of land snails with a strongly depressed dextral shell and animals possessing broad right and left shell lobes were discovered (Fig. 2). Tammuangpak et al. (2012) first reported this taxon as Helicarionidae *gen. indet.* It was subsequently reported as *Sophina* sp. based on its unique v-shaped transverse rows of radular teeth (Tammuangpak, 2016). Based on the checklists of pulmonate landsnails of Thailand (Panha, 1996), the terrestrial molluscs of Thailand (Hemmen & Hemmen, 2001) and molluscan fauna of Thailand (Nabhitabhata, 2009), Tammuangpak’s discovery would be the first record of this genus in Thailand. However its genital system without amatorial organ and the shape and length of the penis, epiphallus and gametolytic sac is different from all known species in the genus *Sophina* Benson, 1859. These distinct characters support the recognition of these snails as a new genus and new species of the helicarionid subfamily Durgellinae.

MATERIAL & METHODS

Specimens were collected from Phu Pha Lom limestone area during the rainy seasons from October 2012 to October 2014. Live specimens were drowned in water for 24 hours, then fixed and preserved in 70% ethanol to facilitate examination of their genital system and radula. Adult shells (n=736) were used to determine the whorl number. Shell height (SH) and shell width (SW) were measured using Vernier calipers. Radula were extracted from five adult snails (n=5) and examined under a scanning electron microscope (JEOL, JSM-5410LV) at the Central Laboratory, Faculty of Science, Mahasarakham University. The radula shape and teeth formula were observed and recorded. 15 adult snails were dissected to examine the genital system. Specimens examined were deposited in the Natural History

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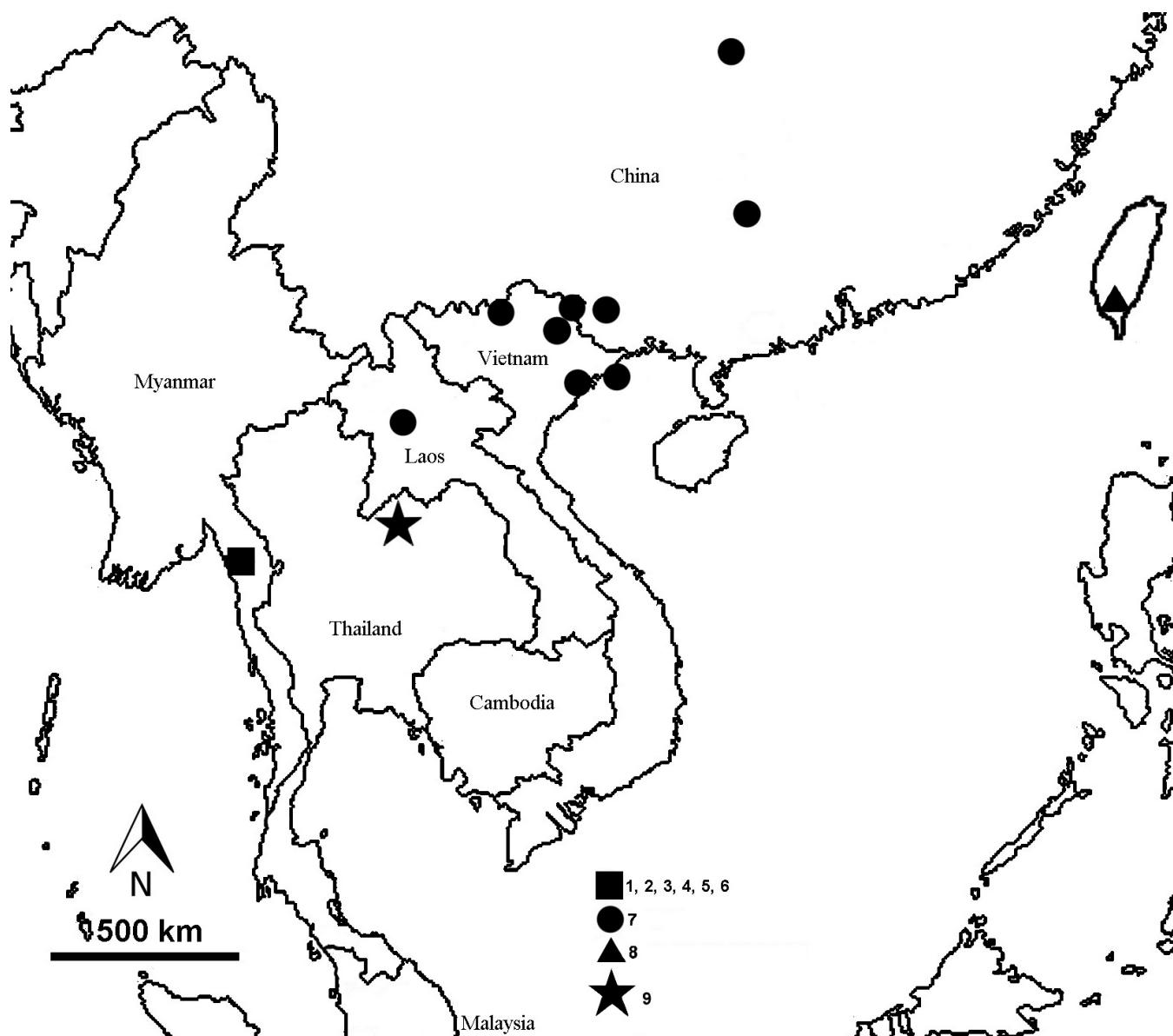


Fig. 1. Map of Thailand and surrounding area showing the type locality of *Aenigmatoconcha clivicola*, new genus and new species, from Phu Pha Lom, Mueang District, Loei Province (star); type localities of six other nominal species of *Sophina* in Moulmein (square); localities of *Chalepotaxis infantilis* (circle); and localities of *Chalepotaxis spadix* (triangle) (numbers correspond to species in Table 2).

Museum, Mahasarakham University (NHMSU); Zoological Reference Collection of the Lee Kong Chian Natural History Museum, National University of Singapore (ZRC); Natural History Museum of Loei Rajabhat University, Loei Province (NHLRU); and Thailand Natural History Museum (THNHM).

SYSTEMATICS

According to Bouchet & Rocroi (2005), the systematic classification of the new genus and new species is listed as follows:

Superfamily Helicarionoidea Bourguignat, 1877

Family Helicarionidae Bourguignat, 1877

Subfamily Durgellinae Godwin-Austen, 1888

Tribe Durgellini Godwin-Austen, 1888

Aenigmatoconcha, new genus

Type species. *Aenigmatoconcha clivicola*, new species.

Diagnosis. The radula possesses similar unicuspids spatulate teeth arranged in V-shaped rows. The genitalia lack an amatorial organ and possess a large, stout penis and slender elongate epiphallus.

Etymology. “*Aenigma*” from the Latin word meaning something obscure, a riddle or mystery, and “*concha*” from the Latin word meaning snail or shell.

Remarks. The radula and genital organs form the unique characters distinguishing *Aenigmatoconcha*, new genus, from other morphologically close helicarionid genera.

Table 1. Classification of *Sophina* Benson, 1860, and *Chalepotaxis* Ancey, 1887.

Authors	Taxa			
	Family	Subfamily	Tribe	Genus
Blanford & Godwin-Austen (1908)	Zonitidae	Sophininae	-	<i>Sophina</i>
Schileyko (2003)	Ariophantidae	Ariophantinae	Satiellini	<i>Sophina</i>
Bouchet & Rocroi (2005)	Helicarionidae	Durgellinae	Durgellini	<i>Sophina</i>
Páll-Gergely et al. (2016)	Helicarionidae	-	-	<i>Chalepotaxis</i>

Table 2. Reported distribution of *Sophina*, *Chalepotaxis*, and *Aenigmatoconcha* species.

Reference: 1 = Benson (1859a); 2 = Benson (1859b); 3 = Benson (1860); 4 = Stoliczka (1871); 5 = Blanford & Godwin-Austen (1908); 6 = Schileyko (2011); and 7 = Páll-Gergely et al., (2016)

No.	Taxa	Localities	References
1	<i>S. forabilis</i> (Benson, 1859a)	Phie-Than Valley, Tenassarim Caves in limestone hills at Damotha, near Moulmein, Myanmar	1, 3, 4, 5
2	<i>S. forabilis</i> , var <i>bensonii</i> Godwin-Austen, 1908	Damotha, near Moulmein, Myanmar	5
3	<i>S. calias</i> (Benson, 1859b)	Near Moulmein, Myanmar. Limestone hills to east and south of Moulmein at the Farm Caves and Tavoy, Myanmar	2, 3, 4, 5
4	<i>S. schistostelis</i> (Benson, 1859b)	Near Moulmein, Myanmar	2, 4, 5
5	<i>S. discoidalis</i> Stoliczka, 1871	Limestone hills of the Farm Caves on Attaran River and South of Moulmein, Myanmar	4, 5
6	<i>S. conjungens</i> Stoliczka, 1871	South of Moulmein, Myanmar	4, 5
7	<i>C. infantilis</i> (Gredler, 1881)	Hupei, Guang Xi, and Hunan, Southern China Ha Giang, Ha Lang, Quang Uyen, Lang Son, Hải Phong, Dě Ma Phuc, Ke Bao and Krieu islands, Northern Vietnam Luang Prabang, Laos	6, 7
8	<i>C. spadix</i> (Schmacker & Boettner, 1891)	Taiwan	7
9	<i>A. clivicola</i> , new species	Phu Pha Lom, Loei, Thailand	This study

Table 3. Comparison of shells of *Sophina*, *Chalepotaxis*, and *Aenigmatoconcha* species.

	Shell: Shape	Shell height	Shell width	Whorls	Umbilicus	Ventral spiral striation
<i>S. calias</i>	Dispersedly orbiculate	4–6 mm	9–15 mm	5	Narrow	Absent
<i>S. schistostelis</i>	Globosely depressed	8.5 mm	16 mm	4½–5½	Narrow	Absent
<i>S. discoidalis</i>	Depressed subdiscoid	4.5 mm	10.5 mm	5–5½	Wide	Absent
<i>S. conjungens</i>	Globosely orbiculate	5 mm	12 mm	5	Slightly wide	Absent
<i>S. forabilis</i>	Semiglobosely conoid	4 mm	8–9 mm	5½–6	Wide	Absent
<i>S. f. bensonii</i>	Globosely conoid	4 mm	7.5 mm	5¼–5½	Slightly wide	Absent
<i>C. infantilis</i>	Depressed conical	4–5 mm	6–7 mm	6	Narrow	—
<i>A. clivicola</i> , new species	Flattened to depressed	7.69–9.89 mm	15.40–18.62 mm	5¼–5½	Slightly wide	Absent

Aenigmatoconcha differs from *Sophina* (*S. calias* and *S. schistostelis*) by the absence of an amatorial organ and the gametolytic sac with three distinct portions, including thick wall, robust tube at proximal portion and slender tube at middle portion leading to bulbous and thin walled head of distal portion. The penis is also larger and stouter than in *S. calias* and *S. schistostelis* (Table 4 and Fig. 5). *Aenigmatoconcha* has more characters in common with *Chalepotaxis*, including a radula with V-shaped rows of teeth, the absence of an amatorial organ and three distinct portions of gametolytic sac (Páll-Gergely et al., 2016), but it differs in shell characters, radula teeth without smaller upper part, and short and stout penis without penial sheath.

***Aenigmatoconcha clivicola*, new species**

Figs. 2–5; Tables 2–4

Helicarionidae gen. *indet.*: Tanmuangpak et al., 2012: 18–24.
Sophina sp.: Tanmuangpak. 2016: 93–94.

Type material. Holotype: NHMSU-0013 (Fig. 3) (SH 9.6 mm, SW 16.9 mm), Phu Pha Lom Limestone Hill in Mueang District, Loei Province, Northeastern Thailand, coll. K. Tanmuangpak, November 2012. Paratypes: NHMSU-0014 (genital system and radula, Figs. 4–5), NHLRU-0006 (one specimen in 70% ethanol and one shell), ZRC.MOL.9413 (one shell), THNHM-IV-18003 (one shell), same locality as holotype, coll. K. Tanmuangpak, November 2012–May 2014.

Etymology. The specific epithet “*clivicola*” comes from two Latin words: “*clivus*”, meaning sloping side of hill, and “*-cola*”, meaning dweller.

Diagnosis. As for genus above.

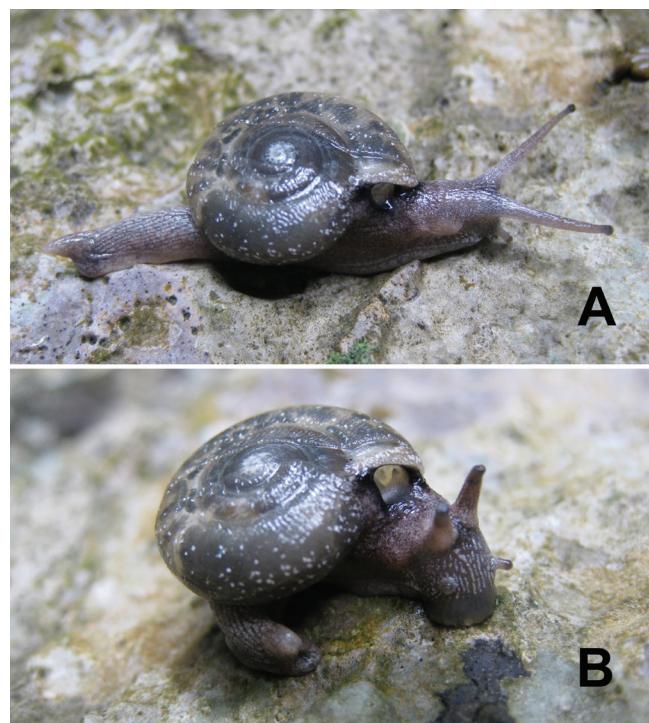


Fig. 2. *Aenigmatoconcha clivicola*, new species, in natural habitat. A, living snail; B, foraging behavior. Photographs: Kitti Tanmuangpak.



Fig. 3. *Aenigmatoconcha clivicola*, new species, holotype (NHMSU-0013).

Description. Shell (Fig. 3, Table 3): Dextral, flattened and depressed, umbilicus narrow and deep; 7.69–9.89 mm height, 15.40–18.62 mm width; whorls 5½–5½, thin, glossy, slightly convex. Last whorl not descending in front, rounded at periphery. Colour pale brown and glass-like when fresh. Aperture large, ovately lunate, moderately oblique, with simple margin.

Body (Fig. 2): Animal pale to dark brown, with broad right and left transparent shell lobes with many small white patches of pigmentation. Foot dark brown; sole tripartite, caudal foss and caudal horn well developed.

Radula (Fig. 4, Table 4): Subovate, comprises 25 transverse v-shaped rows of teeth; 17–137 teeth in each row. Central teeth meet at sharp angles in the middle line; all teeth unicuspis, spatulate.

Genital system (Fig. 5): Genital organs chiefly occupy the anterior part of the body. Albumen gland (ag) of moderate size, slightly thickened, yellowish in colour, hermaphroditic duct (hd) tube slender, uterus (ut) very long, thick. Vas deferens (vd) a long and slender tube, entering apically to epiphallus. Epiphallus (e) a long slender tube, ephiphalllic flagellum (ef) absent. Epiphalllic retractor caecum (erc) shorter and thicker than epiphallus. Penis (p) short and stout, peanut-shaped. Gametolytic sac (gs) comprises three parts: gland with pointed appendage at distal end, slender tube at the middle and robust tube at the base. Vagina globose, yellowish colour. Free oviduct, long cylindrical, distal part short, orange colour. Amatorial organ absent.

Remarks. All six known taxa of the genus *Sophina*, namely *S. calias*, *S. schistostelis*, *S. discoidalis*, *S. conjungens*, and *S. forabilis*, are from eastern Myanmar (Blanford & Godwin-Austen, 1908). Most species are known only from their shell morphology, and the external body, genital system and radula have been studied in only *S. calias* and *S. schistostelis* by Stoliczka (1871) and Blanford & Godwin-Austen (1908), respectively. A comparison with *S. calias* (Benson, 1859a) from Tenasserim Province, eastern Myanmar reveals that while their shell morphology and radula pattern are similar,

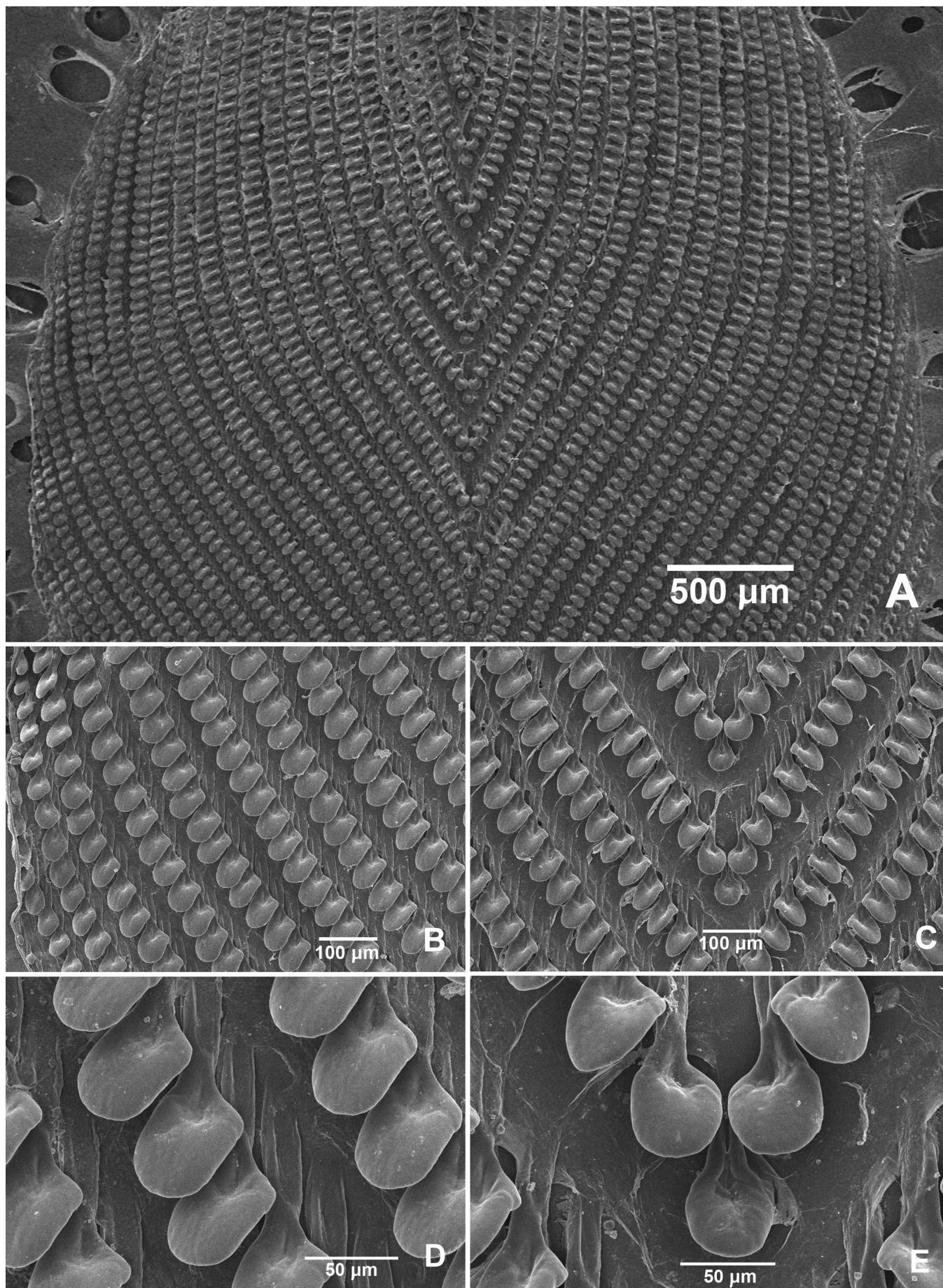


Fig. 4. *Aenigmatoconcha clivicola*, new species, radula of paratype (NHMSU-0014). A, whole radula; B, close up view of left side of radula; C, close up view of central part of radula; D, close up view of left latero-marginal teeth; E, close up view of central and first lateral teeth.

Table 4. Comparison of known genital system and radula of *Sophrina*, *Chalaeptaxis*, and *Enigmatoconcha* species. Characters in brackets were used by Stolizcka (1871), Blanford & Godwin-Austen (1908), and Pall-Gergely et al. (2016).

Characters	<i>S. callosa</i>	<i>S. schistostelis</i>	<i>C. infantilis</i>	<i>A. clivicola</i> , new species
Radula:				
Number of rows	35–50	-	21	25
Number of teeth in each row	80–100	-	49	17–137
Teeth morphology—lower part	Unicuspid pyramidal	-	Unicuspid fan-shape	Unicuspid spatulate
Teeth morphology—upper part	Absent	-	Present	Absent
Genital system:				
Amatorial organ	Slightly stout cylindrical	Slightly stout cylindrical	Absent	Absent
Penis	Long cylindrical	Long cylindrical	Very long	Large & stout
Penial sheath	Absent	Absent	Present	Absent
Epiphallus	Shorter than penis	Shorter than penis	Distal part very short; proximal part short cylindrical	Distal part long slender tube equal to penis length, proximal part short cylindrical
Epiphalllic flagellum	Absent	Absent	Absent	Absent
Epiphalllic retractor caecum (appendage)	Long pointed appendage	Short appendage	Equal to the distal part of epiphallus	Shorter than distal part of epiphallus
Gametolytic sac (spermatheca, receptaculum seminis, bursa copulatrix)	Globular gland attached to very slightly twisted string	Globular gland attached to twisted string	Elongated gland attached to short stalk, on thickened base	Globalular gland with pointed appendage at distal end, attached to thick string, proximal part slightly swollen
Gametolytic sac position	Connected to proximal part of vagina	Connected close to genital opening	Connected at the same origin with vagina and penis	Connected to distal part of vagina

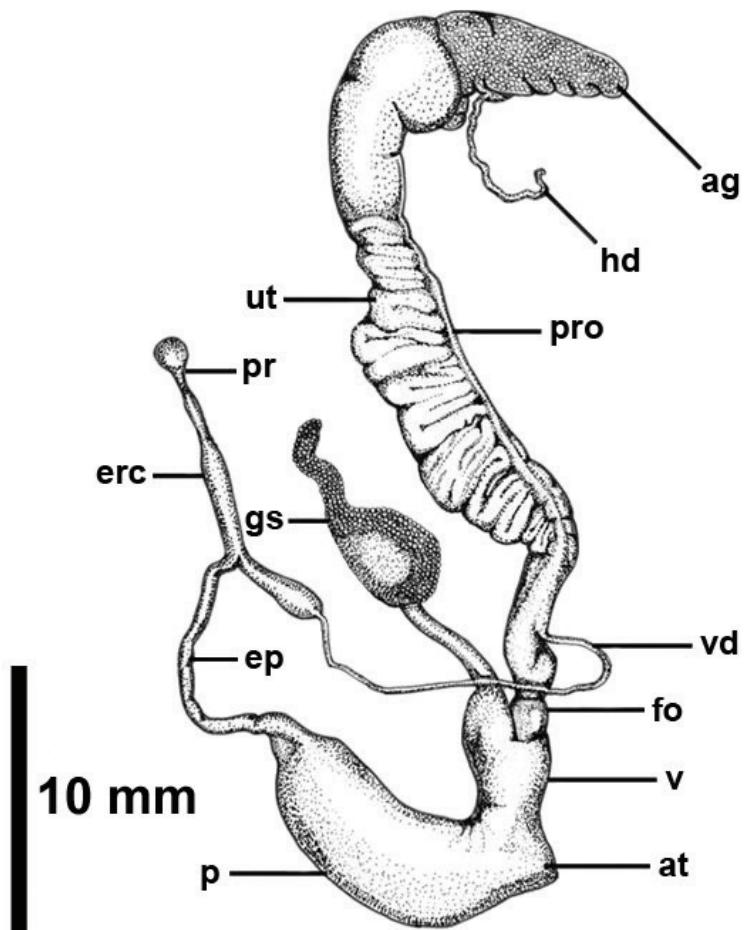


Fig. 5. *Aenigmatoconcha clivicola*, new species, genital system of paratype (NHMSU-0014) and schematic drawing. Abbreviations: ag, albumen gland; at, atrium; ep, epiphallus; erc, epiphalllic retractor caecum; fo, free oviduct; gs, gametolytic sac; hd, hermaphroditic duct; p, penis; pr, penial retractor; pro, prostate gland; ut, uterus; v, vagina; vd, vas deferens. Photograph and illustration: Kitti Tanmuangpak.

their genital systems are different as explained under the remarks of the new genus description.

DISCUSSION

The genital organ of *Aenigmatoconcha*, new genus, shows great similarity to that of *Sophina* and *Chalepotaxis*. The genital system of *Sophina* was first examined in *S. calias* by Stolizcka (1871), but Blanford & Godwin-Austen (1908) suggested that Stolizcka's figure and description were based on genital organs that were not fully developed. Mature specimens of *S. schistostelis* were dissected and examined by Blanford & Godwin-Austen (1908). *Aenigmatoconcha* and *Chalepotaxis* differ from *Sophina* by the absence of an amatorial organ and presence of a gametolytic sac with three portions. Meanwhile, *Aenigmatoconcha* differs from *Chalepotaxis* by its large stout penis without a penial sheath.

All six known species of *Sophina* were only found in limestone areas, or more specifically the Moulmein Limestone Hills, in eastern Myanmar, while *Aenigmatoconcha clivicola*, new genus and new species, was discovered only in Phu Pha Lom limestone hill in Loei Province. This indicates that *Aenigmatoconcha clivicola* and *Sophina* are possibly obligate limestone dwellers. Members of both genera bear a

small, flattened and depressed shell, which may be adapted for hiding and aestivating in limestone crevices during the dry season, and the similarities in shell shape in some of the limestone species, such as *Aenigmatoconcha*, *Sophina*, *Chalepotaxis*, and *Sarika*, could be due to convergent evolution. Similarities in both the V-shaped rows and cusp morphology of teeth on the radula among *Aenigmatoconcha*, *Sophina*, and *Chalepotaxis* are assumed to be due to similar feeding habits. For example, members of some subfamilies in the unrelated family Clausiliidae show similar radula morphology to *Chalepotaxis* in the family Helicarionidae (see Páll-Gergely et al., 2016), which suggest that similarities in radula morphology are due to feeding habit and food type rather than to a shared ancestry.

Based on the recorded distribution of all described nominal species of *Sophina*, *Chalepotaxis*, and *Aenigmatoconcha*, the genera are distributed in three disjunct geographical ranges. *Sophina* is distributed only around the limestone hills in Moulmein, eastern Myanmar; *Aenigmatoconcha* is found only in the limestone hills of Loei Province, approximately 500 km from Eastern Myanmar, whereas *Chalepotaxis* was collected from Taiwan, southernmost part of China, northern Laos and northern Vietnam. Due to the disjunct distributions of these three helicarionid genera that possess V-shaped

rows of teeth on the radula, it might be hypothesised that these genera arose from allopatric speciation. However, *Sophina*, *Aenigmatoconcha*, and *Sarika* are probably more wide ranging than previously recorded because their empty shells can be confused and misidentified as *Sarika*. This conforms to the opinion of Benson (1860), who suggested that shells of *Sophina* spp. may have been overlooked, and that they may be distributed in the Malay peninsula (Malaysia, Southern Thailand, Southern Myanmar), Siam (Thailand, Laos, Cambodia) and probably Cochin China (Southernmost Vietnam around the Mekong Delta). Further studies are needed to confirm this hypothesis. Nevertheless, recent discoveries of three new land snail species from Phu Pha Lom limestone area (Tumpeesuwan & Tumpeesuwan, 2014; Tanmuangpak et al., 2015; Tanmuangpak et al., 2017) confirm that the area is very important for biodiversity conservation.

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