Notes on Freshwater Coated Grains of the Hengchun Peninsula

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Abstract. This research focuses on the geographical distribution and occurrence of freshwater coated grains on the Hengchun Peninsula. Field surveys showed that coated grains were mainly distributed in areas with spring water seepage in Siangjiao Bay and the Gongyuan Road Reservoir, and a small amount has developed at Fongchuisha. Most coated grains were well-rounded with a smooth surface. However, those which had grown in the catchment sedimentation sink of the Gongyuan Road Reservoir site are unique. Each has a peculiar outer layer composed of short dense branching protrusions. The results of rock thin section and electron microscope inspections showed that the formation of these two types of coated grains is by intermittent rolling and the growth of microorganisms on the top of the grain. Their quite different appearances may reflect the relative stability of the growth substrates.

Key words: spring water, coated grains, oncoid, freshwater carbonates, Hengchun Peninsula

INTRODUCTION

The term "coated grains" was proposed by Wolf (1960) as a substitute for Folk's (1959) "oölites" to include other concentrically formed materials. Later studies showed that different types of coated grains may be formed or grown in various environments (Peryt 1983). As a general term, coated grains include the so-called ooids, oncoids, pisoids, cyanoids, vadoids, rhodoids, etc.

In 1998, freshwater carbonate coated grains were first noted at Fongchuisha, Kenting National Park (Locality 1 in Fig. 1). This discovery was associated with a field survey of microbialites on the east coast of the Hengchun Peninsula (Wang *et al*. 1998a, b). However, as the development was limited to the bank of a narrow roadside ditch (<20 x 200 cm), further study was suspended. Subsequent research was re-started in 2016, with observation of a large amount of pebble-sized spring water carbonate coated grains in Siangjiao Bay (Locality 2 in Fig. 1) and Gongyuan Road Reservoir (Locality 3 in Fig. 1), both sites of which were investigated by Dr. Yuh-Wen Chiu.

Records of carbonates in the Hengchun Peninsula can be traced back quite early (Kleinwaeckter 1883). The majority of follow-up

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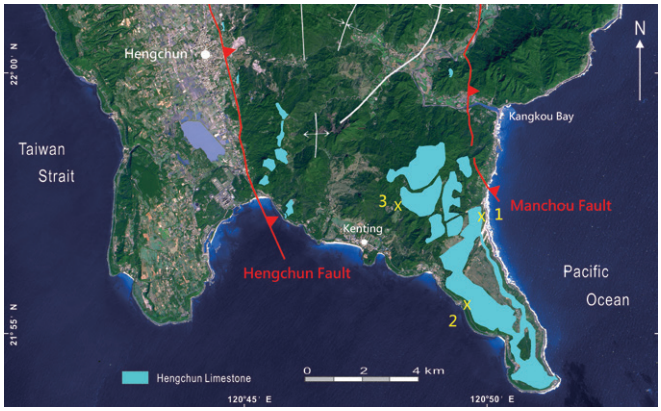

Fig. 1. A mosaic of Spot 5 satellite image of the southern Hengchun Peninsula. Image shows major structural units and the geographic distributions of the Hengchun Limestone within the region bounded by the Hengchun Fault and Manchou Fault (from Chen *et al*. 2005). Localities of the studied coated grains are marked by yellow Xs. Locality 1, Fongchuisha; 2, Siangjiao Bay; 3, Gongyuan Road Reservoir. Permission was granted to use the satellite images from the Center for Space and Remote Sensing Research, National Central University, Taoyuan, Taiwan.

studies focused on marine Pleistocene Hengchun Limestone and Holocene Raised Coral Reef, with the purposes of exploring the stratigraphy, fossils, carbonate sedimentology, meteoric diagenesis, age dating, neotectonics, etc. (see review by Gong and Wang 2007, and references therein). A few studies were performed on microbial carbonates deposited in the coastal brackish-water environment of Fongchuisha (Wang *et al*. 1998a, b).

MATERIALS AND METHODS

According to the phenomenon that most spring water seeps from the base of the Hengchun Limestone, in 2019, we conducted a field survey on the southern part of the Hengchun Peninsula, focusing on the area east of the Hengchun Fault and west of the Manzhou Fault where the most extensive Hengchun Limestone outcrop exists. The survey results showed that the most abundant freshwater coated grains on the Hengchun Peninsula were located in Siangjiao Bay and Gongyuan Road Reservoir sites. Both were selected as major research locations for revealing the growth mode or process of these carbonate coated grains.

This study on spring water coated grains included geological, invertebrate zoological, and microbiological surveys. Among them, the geological investigation focused on the occurrence, mineralogy, and microtextures of the coated grains. The vast majority of specimens obtained were hand-collected.

Bulk mineralogy of coated grains was determined by x-ray diffraction (XRD) analyses of powdered samples using a Rigaku Diffractometer with Cu Kα radiation (1°/min) located at the National Museum of Natural Science (NMNS; Taichung, Taiwan). Interiors of coated grains were revealed by x-radiography at the National Museum of Marine Biology and Aquarium (Pingtung, Taiwan). Dry samples for thin section preparation were impregnated with dyed epoxy resin under a vacuum. We used Sigma Coomassie Brilliant Blue G to dye the resin in order to differentiate the porosity and cement under microscopic examination. Standard rock thin sections of coated grains were prepared at the NMNS.

All samples collected from the field were briefly cleaned with fresh water and air-dried in a working hood for at least 2 weeks. When collected specimens were air-dried at room temperature, the color slowly changed from the original blue-green to purple. This phenomenon has been observed on those modern microbialite specimens collected from the eastern coast of Hengchun Peninsula. It was suspected that these specimens were another type of microbialite. Surfaces with a purplish color of three coated grains were broken off for scanning electron microscope (SEM) examination.

At the Gongyuan Road Reservoir site, a YSI Pro Plus Multiparameter Water Quality Instrument was used to measure the temperature and pH of spring water at the outlet of the catchment sedimentation sink.

RESULTS AND DISCUSSION

Occurrences of Coated Grains

Abundant coated grain growth was seen in the spring water ditch (Plate 1, Fig. B) and catchment sedimentation sink (Plate 1, Fig. E). Most of the water environment was shaded by dense vegetation (Plate 1, Figs. B, E). Most coated grains in the water were blue-green on the top

(Plate 1, Figs. F-H). The sizes of the coated grains observed in spring water were often smaller than 2.5 cm in diameter, excepting those grown around fallen twigs in the catchment sedimentation sink of the Gongyuan Road Reservoir site. Some larger or even cobble-sized (64~256 mm in diameter) coated grains, and blocks of cemented coated grain aggregates (Plate 1, Fig. C) were collected from ditch sides and fish pond dredged materials (Plate 1, Fig. D). The largest size of a single coated grain collected from Siangjiao Bay was 20 x 16 x 11 cm.

Results of water quality measurements showed that the water temperature was stable all year, while the pH values changed slightly among data (Table 1).

Most coated grains were well-rounded with a smooth surface. However, those which had grown in the catchment sedimentation sink of the Gongyuan Road Reservoir site were unique. Each had a peculiar outer layer composed of short dense branching protrusions (Plate 2, Fig. E).

Compositions and Microtextures of Coated Grains

Results of the XRD analyses showed that carbonates of coated grains were all composed of low-Mg calcite (Table 2, *n*=8).

Appearances of the coated grains observed in the study area can be roughly divided into two types, which are designated as types 1 and 2 in this article. Type 1 coated grains are smooth in appearance (Plate 1, Figs. D, F), while type 2 has many branching protrusions on the outermost surface (Plate 2, Fig. E). Type 1 coated grains were rather common in the study area, excluding the catchment sedimentation sink of the Gongyuan Road Reservoir site. The distribution of type 2 is just the opposite.

Several well-rounded type 1 coated grains were cut in half to show the concentric layers and a central nucleus (Plate 2, Fig. A). These layers consisted of alternating porous branching protrusions and densely lamellated calcite (Plate

Table 1 Water quality measurement results at the Gongyuan Road Reservoir site

Day	Time	Temperature (℃)	pH
2019/02/21	16:00	25.2	6.78
2019/04/26	10:00	25.2	7.55
2019/06/30	06:49	25.3	7.40
2019/08/29	14:00	25.4	7.70
2019/10/19	14:40	25.3	8.00
2020/01/07	15:00	25.1	8.28
2020/03/27	15:00	25.2	8.28

Table 2 Carbonate mineralogy of coated grains (**SGB**, Siangjiao Bay site; **GYR**, spring water catchment sedimentation sink, Gongyuan Road Reservoir site; **LMC**, low-magnesium calcite; diam., diameter)

Sample number	Occurrence	Location	Mineralogy
M-01	well-rounded, with a smooth surface (diam. 7 mm)	**SGB**	**LMC**
M-02	well-rounded, with a smooth surface (diam. 7 mm)	**SGB**	**LMC**
M-03	well-rounded, with short, dense branching protrusions in the outer layer (diam. 9 mm)	**GYR**	**LMC**
M-04	well-rounded. with short, dense branching protrusions in the outer layer (diam. 9 mm)	**GYR**	**LMC**
M-05	rounded, carbonate coating on a small fallen plant twig (diam. X length = 7 X 11 mm)	**GYR**	**LMC**
M-06	Sheet-like, carbonate coating on a fallen leaf	**GYR**	**LMC**
M-07	carbonate coating on a long fallen plant twig (diam. X length = 30 X 350 mm)	**GYR**	**LMC**
M-08	carbonate coating on a long fallen plant twig (diam. X length = 25 X 250 mm)	**GYR**	**LMC**

Table 3. List of species in the field survey results from February to November 2019 (**SGB**, Siangjiao Bay site; **GYR**, spring water catchment sedimentation sink, Gongyuan Road Reservoir site; **V**, present; —, absent)

Specific name	SGB	GYR
Phylum Arthropoda		
Class Malacostraca		
Order Decapoda		
Family Palaemonidae		
Macrobrachium austral Guerin-Meneville, 1838	**V**	—
Macrobrachium lar Fabricius, 1798	**V**	**V**
Macrobrachium latimanus Von Martens, 1868	**V**	—
Family Atyidae		
Caridina typus H. Milne Edwards, 1837	**V**	—
Neocaridina fonticulata Shih, Cai & Chiu, 2019	—	**V**
Family Potamidae		
Candidiopotamon rathbuni (De Man, 1914)	**V**	**V**
Geothelphusa albogilva Shy, Ng & Yu, 1994	**V**	—
Geothelphusa ferruginea Shy, Ng & Yu, 1994	—	**V**
Sesarmops impressum (H. Milne Edwards, 1837)	**V**	—
Family Varunidae		
Varuna litterata (Fabricius, 1798)	**V**	—
Family Gecarcinidae		
Cardisoma hirtipes (Dana, 1851)	**V**	—
Phylum Mollusca		
Class Gastropoda		
Family Thiaridae		
Melanoides tuberculate Muller, 1774	—	**V**
*Stenomelania plicari*a (Born, 1778)	**V**	**V**
Tarebia granifera (Lamarck, 1822)	**V**	—
*Thiara scabra scab*ra (Muller, 1774)	**V**	—
Family Ampullariidae		
Pomacea canaliculate (Lamarck, 1819)	**V**	—

Remarks:
Elevations measured at the spring water ditch bottom (above mean sea-level):
at BNB were 14.5~10.4 m and at KPR were 150.8~147.0 m.

2, Fig. B). In order to reveal the microtextures of those dense laminae, rock thin sections were etched by 1.5% hydrochloric acid for about 15 s. Under high-magnification inspection, it was seen that there were actually many filaments in the transparent lamella, and the thin boundary of lamellae was composed of filaments associated with fine-grained calcite (Plate 2, Fig. C). We proposed that this was probably caused by adhesion of microcrystalline calcite crystals to the mucilaginous sheath of cyanobacteria. Nuclei of type 1 coated grains included scleractinian coral fragments (Plate 2, Figs. A-1a, b), limestone lithoclasts (Plate 2, Figs. A-2a, b), dead freshwater snail shells (Plate 2, Fig. D), etc. The top surface of a type 1 coated grain was also selected for SEM examination. It showed that all of the cyanobacterial filaments were coated with fine-grained calcite (Plate 2, Fig. H).

Three short branching protrusions were broken off from the surface of a type 2 coated grain (as shown in Plate 2, Fig. E) for SEM observations. Results (Plate 2, Figs. F, G) show that the development of this type of coated grain was closely related to the growth of cyanobacterial filaments. In addition, patches of diatoms, including *Achnanthes rupestoide*, *Amphora libyca*, *Lemnicola exigua*, *Lemnicola rostellata*, and *Nitzschia frustulum,* were observed growing on depressions of these branching protrusions. Some extracellular mucus coatings associated with the diatoms were also observed. As to whether the growth of diatoms and adhesion of the extracellular mucus coatings were also related to the formation of type 2 coated grains was left to subsequent research. Five rock thin sections of type 2 coated grains showed a similar texture to the porous branching protrusions

lamellae of type 1.

Judging by the round appearance, concentrically lamellate internal texture, and active growth of filamentous cyanobacteria, intermittent rolling should be the most important mechanism in the formation of both types of coated grains. These coated grains probably were produced by mechanical turning or rolling, exposed new surfaces to microbial growth.

In contrast to type 2 coated grains trapped in the sedimentation sink, type 1 grains grew in a more-unstable environment. Because the study area is located in the southern part of the Hengchun Peninsula with a tropical climate, alternations of porous branching protrusions and densely lamellated calcite are likely to be a result of significant change in spring water flux or the occurrence of heavy rainfall. Perhaps the carbonates of these coated grains can be used as potential materials for exploring past climate change.

In the spring water of the study area, many freshwater gastropods, shrimps, and crabs (Plate 3, Figs. A-H) were observed moving on or around the coated grains. Determining whether the activities of these invertebrates can cause the rolling of the coated particles still needs further observation.

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PLATE 1.

A. Field occurrence of coated grains at Fongchuisha (locality 1 of Fig. 1). This photo was taken on April 23, 1998.

B. The source of spring water at the Siangjiao Bay site (locality 2 of Fig. 1).

C. Rock blocks (arrow) composed of coated grains observed at the ditch side at the Siangjiao Bay site. Picture taken 70 m downstream of the spring source. PVC water pipe with a diameter of 10 cm for scale.

D. A cormorant standing on a pile of well-rounded coated grains dredged from a small fish pond at the Siangjiao Bay site.

E-H. The Gongyuan Road Reservoir site (locality 3 of Fig. 1).

E. Spring water running to the catchment sedimentation sink through a cement drainage ditch.

F. Photograph showing the occurrence of coated grains in a small depression with flowing water. The sizes of coated grains are similar to those of figure G.

G. Occurrence of coated grains on the ground surface at the side of the ditch, which was wetted by spring water. Coin diameter = 2.6 cm.

H. Occurrence of coated grains in the spring water catchment sedimentation sink.

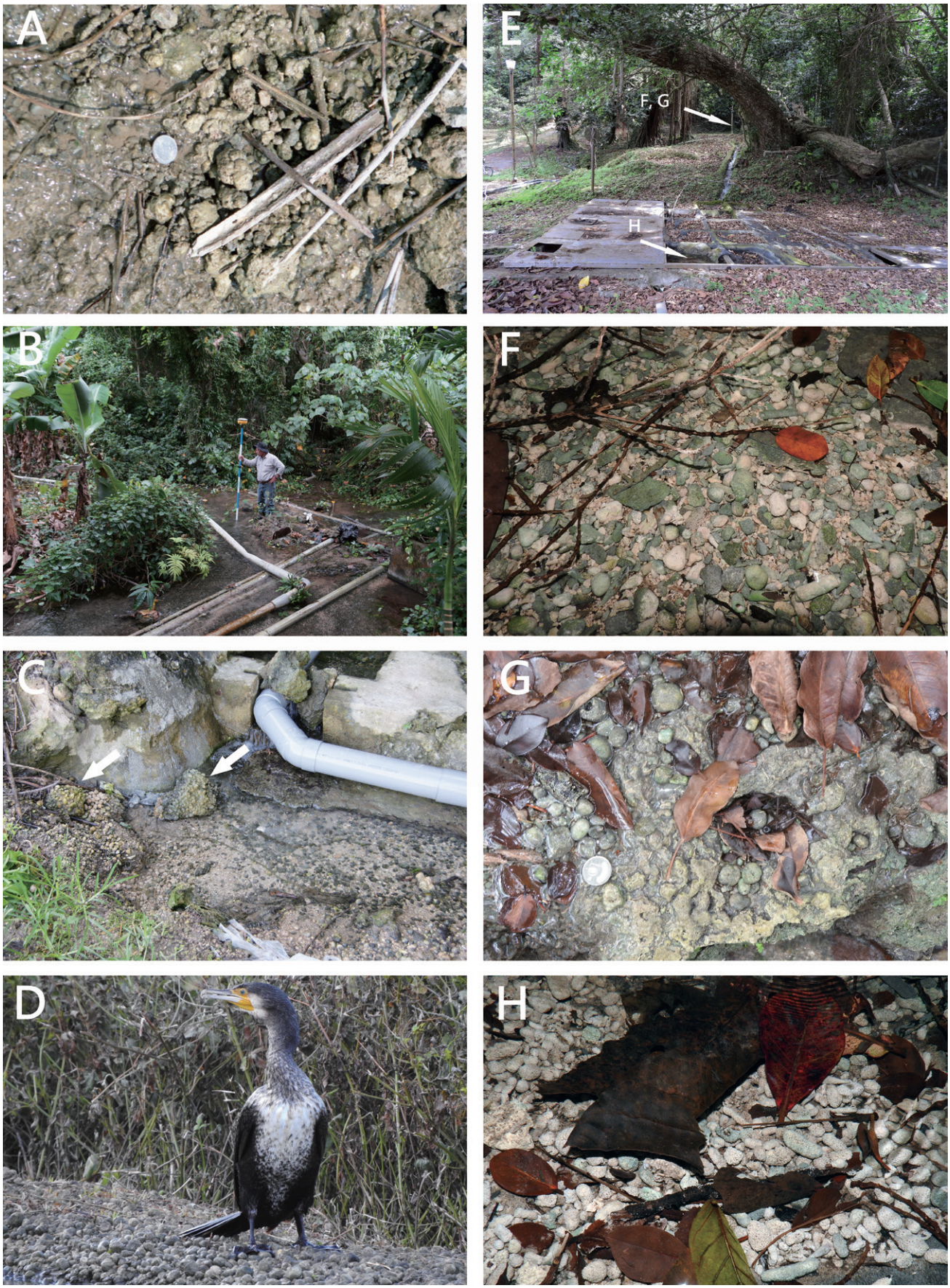
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PLATE 2.

A-D. Coated grains collected from the Siangjiao Bay site.

A. Two ellipsoidal coated grains were cat in half through the center, revealing the inner textures of concentrically stacked laminae and a central nucleus. The core of sample A-1 is a dendroid coral fragment, and the core of sample A-2 is limestone debris.

B. Cross-polarized light photograph of sample A-1 rock thin section. The growth process of this particle can be roughly divided into three stages as shown in pictures S-1 to S-3.

C. Transmitted light microphotograph of sample A-1 rock thin section, showing intergrowth of cyanobacterial filaments in the sparry calcite layer. The dark curved belt (arrow) at the base of this picture consisted of cyanobacterial filaments and fine-grained calcite. The blue filaments are not cyanobacteria but casts of dyed epoxy resin.

D. X-Radiograph image showing that the growth nucleus of this coated grain was a freshwater snail. This sample was collected from a small spring water ditch 400m northwest of locality 2 of Fig. 1.

E-G. Coated grains collected from the spring water catchment sedimentation sink, Gongyuan Road Reservoir site.

E. Three branching protrusions (in the arrowed red circle) of a type2 coated grain were broken off for SEM photography. Insert upper-right image is the cross-polarized light photograph of an ellipsoidal coated grain rock thin section, revealing inner textures of branching protrusions. The large central cavity of this coated grain was originally a small twig which served as a nucleus for coated grain growth. Scale bar length = 1 cm.

F. Top view of one branching protrusion, showing dried cyanobacterial filaments and clusters of calcite crystal growth.

G. Side view of one branching protrusion, showing intergrowth cyanobacterial filaments and a diatom frustule (arrow).

H. Top view of the smooth surface of a type1 coated grain. This was collected from the ground surface adjacent to the spring source of the Gongyuan Road Reservoir site. All cyanobacterial filaments were coated with fine-grained calcite. Compare this occurrence to that shown in Fig. F of this plate.

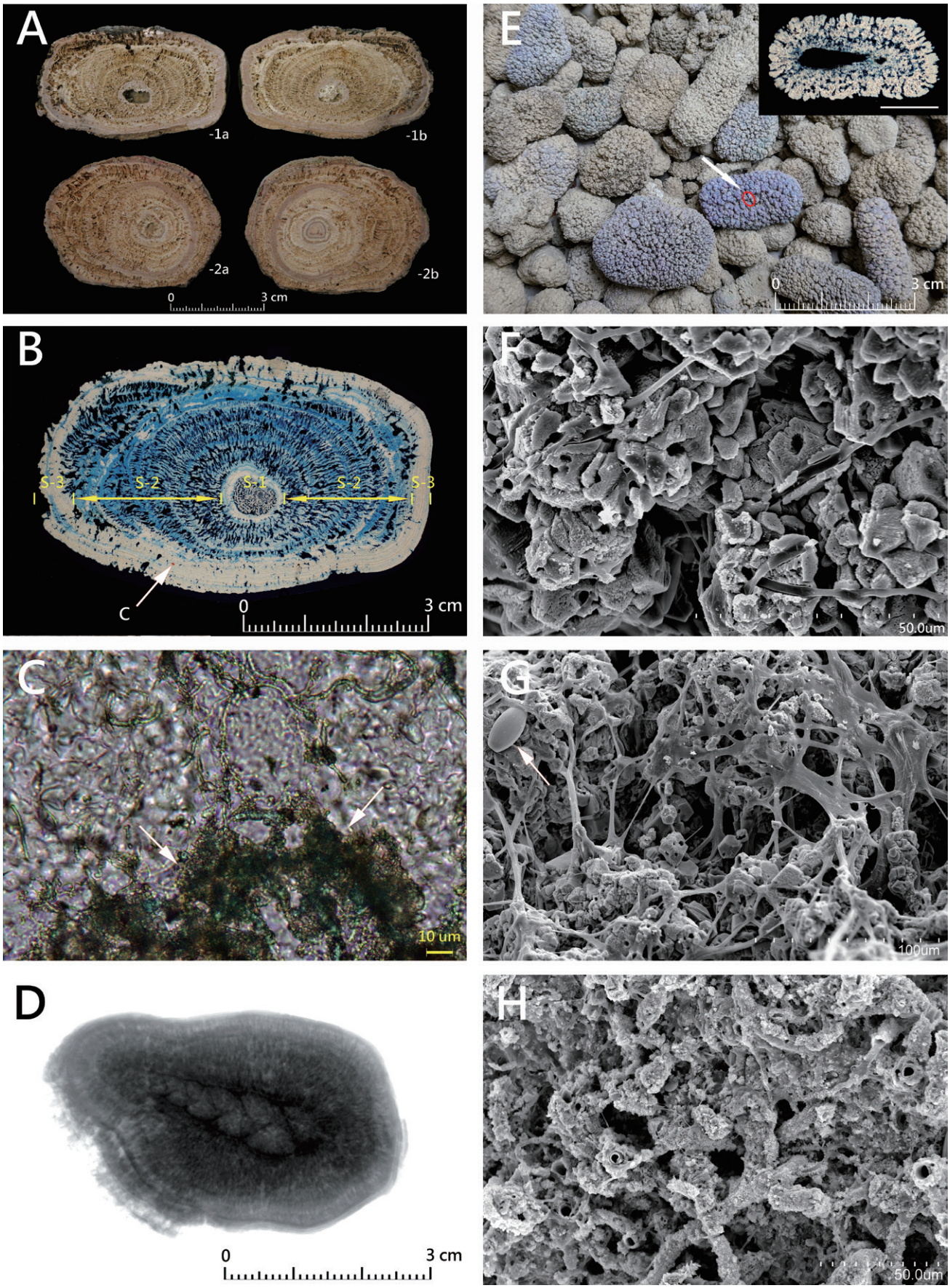
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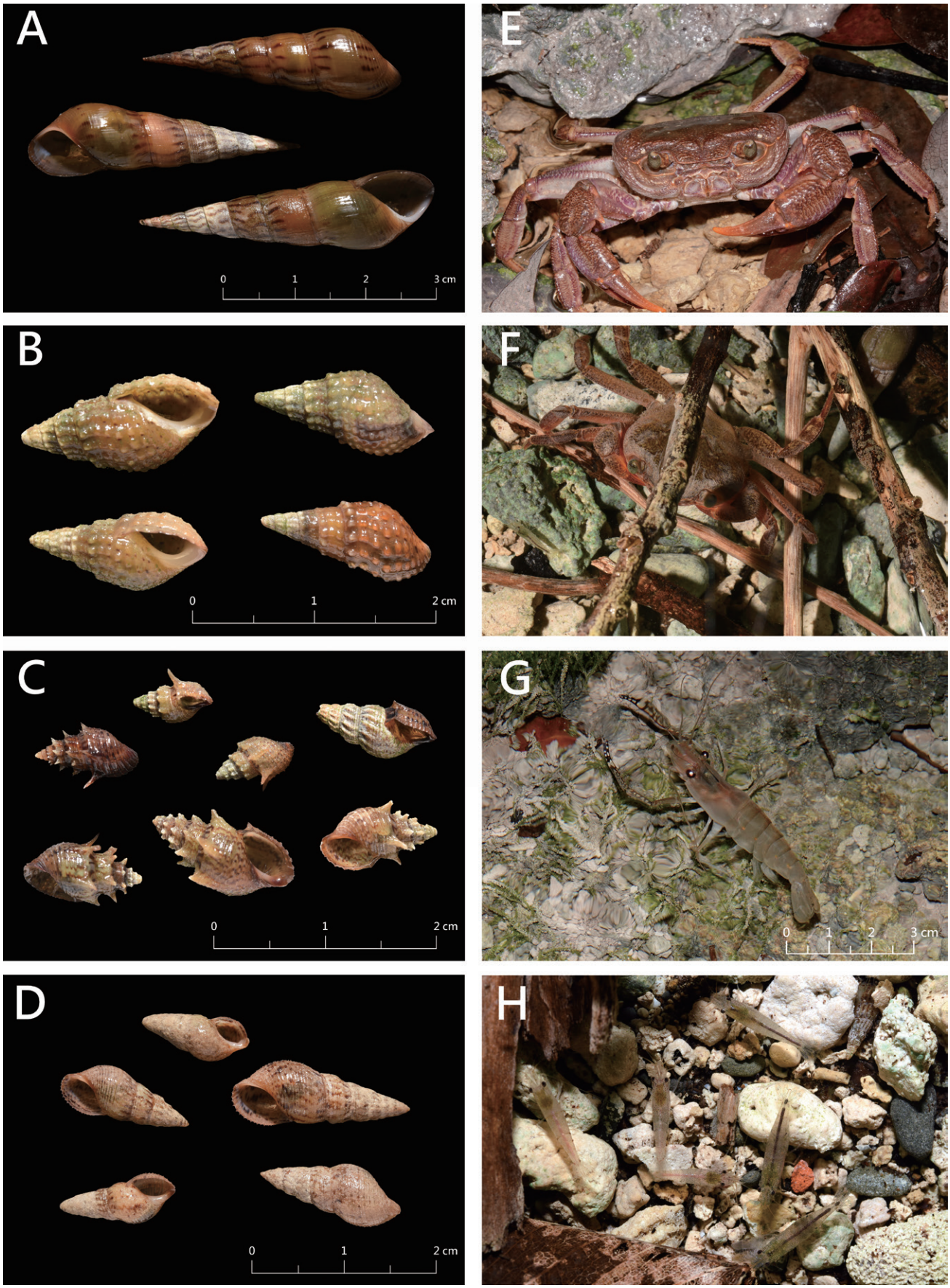
PLATE 3.

Invertebrates observed in spring water where grains were collected from Siangjiao Bay (SGB) and the Gongyuan Road Reservoir (GYR) sites. **A.** *Stenomelania plicaria* (Born, 1778) (SGB); **B.** *Tarebia granifera* (Lamarck, 1822) (SGB); **C.** *Thiara scabra scabra* (Muller, 1774) (SGB); **D.** *Melanoides tuberculate* (Müller, 1774) (GYR); **E.** *Candidiopotamon rathbuni* (De Man, 1914) (GYR) (carapace width = 4.5 cm); **F.** *Geothelphusa ferruginea* Shy, Ng & Yu, 1994 (GYR) (carapace width = 3.5 cm); **G.** *Macrobrachium lar* Fabricius, 1798 (GYR) **H.** *Neocaridina fonticulata* Shih, Cai & Chiu, 2019 (GYR) (body length = 11 mm).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恆春半島淡水包殼粒簡記

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本研究聚焦於恆春半島淡水包殼粒的地理分布與產狀。經由野外調查結果，顯示包殼粒主要分布於香蕉灣湧泉與墾丁公園路湧泉樣區，少量發育於風吹砂蓄水池旁地面。大部分的包殼粒爲外表平滑的圓球狀，但在墾丁公園路湧泉匯集沉澱池中，則發育另一種表面具有密集分支狀突起的包殼粒。經由岩石薄片與電子顯微鏡檢視結果，顯示這兩種包殼粒的形成，均與間歇性滾動及微生物生長有關；而其相當不同的外表形態與內部微細結構組成，則可能反映其生長環境底質的相對穩定程度。

關鍵詞：湧泉，包殼粒，核形石，淡水碳酸鹽，恆春半島