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Korean Hypogean Malacofauna: First Record in Asia of Troglobitic *Zospeum*-like Snails (Pulmonata, Ellobioidea, Carychiidae)

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한국의 동굴 연체동물 상: *Zospeum*속 진동굴성 육산패류 (유폐아강, 대추고둥상과, 양귀비고둥과)의 아시아 지역 최초 보고

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ABSTRACT

Korean hypogean malacofauna is reviewed. Shell morphology of troglobitic carychiids from the Nodong Cave is studied in comparison with that of epigenous *Carychium* species from the Southern Russian Far East. Based on ecology, shell shape and protoconch sculpture the Nodong Cave snails are excluded from the genus *Carychium* and regarded as the "*Zospeum*" sp. It is revealed, that in contrast with European *Zospeum* teleoconch of the Korean "*Zospeum*" sp. like protoconch is finely pitted. The record of the "*Zospeum*" sp. for the first time represents a range extension of the genus to Asia, with disjunctive distribution, because in Europe its range is restricted to the Pyrenees, the Cantabrian Mountains, and the eastern Dinaric Alps.

Key words : Korean mollusks, *Carychium*, Shell morphology, Protoconch, Teleoconch

INTRODUCTION

Subterranean habitats worldwide are developed mainly in limestone areas and are inhabited by several hundred mollusk species belonging to troglophiles and troglobites. True troglobites as obligate cavernicoles prefers dark, inner areas of caves. Troglophiles inhabit not only caves, but other hypogean cool, dark and moist microhabitats (deep soil, ground water, small voids, deep crack in the rock etc.). In the worldwide fauna most terrestrial hypogean species are pulmonates, whereas aquatic species are primarily prosobranchs and a few are bivalves. In tropical and subtropical areas most terrestrial cave snails usually belong to the Prosobranchia, while in the Western Palearctic these are mainly pulmonates. Korean caves, located between those regions, are inhabited by one prosobranch and one pulmonate troglobite species.

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The limestone in Korean Peninsula is well developed within the Ordovician carbonate rocks. It is estimated that there could be more than 1,000 caves (Woo *et al.*, 2001).

Most of them are concentrated in the eastern-central region of the peninsula. Caves are one of the most peculiar terrestrial ecosystems. Lack of light is the greatest determining factor for all subterranean life. This distinctive fauna, adapted to darkness, is known in South Korea from 36 caves and 4 wells (sinkholes) (Kim *et al.*, 2004).

Korean hypogean malacofauna is represented by both troglophiles and true troglobites, which are very rare and not often found in the peninsula. Ecologically epigenous trogloxenes in Zonitidae, Subulinidae, Euconulidae, Strobilopsidae, and Streptaxidae inhabit entrance areas of Korean caves. Besides these, other epigean mollusks might be found occasionally in caves in accumulations of debris and mud carried out with surface detritus through water circulation.

As opposed to trogloxenes which occur in various caves throughout South Korea, hypogean mollusks are restricted to

Gangweon Province, where the largest limestone caves are located. In this area only four caves are known to be dwelled by depauperate subterranean malacofauna represented by five species. Three troglophiles (freshwater mollusks) and two troglobites (one terrestrial and one amphibious species) are recorded in Hwanseon, Baengnyong, Dongdae, and Nodong caves.

Hwanseon Cave is situated on a mountainside in Dae-ri district at an elevation of approximately 800 meters. It is reported to be about 6.2 km long, but many speleologists still believe that the cave may be longer than 10 km (Exodus DMS, 2010). The cave is dwelled by two mollusks-cavernicoles (Kwon *et al.*, 2001; Kim *et al.*, 2004). The first is troglobite *Cavernacmella coreana* Kwon et Lee, 1991 closely related to the Japanese cavernicole *C. kuzuuensis* (Suzuki, 1937). While belonging to the aquatic family Assimineidae, these troglobitic species live in terrestrial habitats in surroundings with high humidity. The second species is troglophilic snail *Bithynella coreana* Kwon, 1993, belonging to the freshwater family Hydrobiidae (Kim *et al.*, 2004).

Baengnyong Cave, in Pyeong-chang County, is about 1.1 km long and has three branches. Its entrance is located 15 m above a stream with cliffs on both sides of the cave entrance (Exodus DMS, 2010). Baengnyong Cave contains a strongly flowing stream. The troglophilic bivalve *Limnoperna coreana* Park et Choi, 2008 (Mytilidae) has been found in this stream about 50 m inside the cave mouth (Park and Choi, 2008).

Dongdae Cave is only 210 meters long and has a very small entrance (Exodus DMS, 2010). The cave provides a habitat for the troglophilic hydrobiid *Akiyoshia coreana* Kwon, 1993 (Kwon *et al.*, 1993; Kim *et al.*, 2004).

Nodong Cave is located in Danyang, a city surrounded by mountains. It is believed to have been formed about 500 million years ago, and its deepest area about 600 m long (Exodus DMS, 2010). This is one of the largest potholes in Asia. When it is rains a huge waterfall forms inside the cave. The central part is divided into five branch caves. The first section of the main cave is the only part that lets in sunlight, and the rest of the cave is dark because of this narrow entrance. Nodong Cave is famous for its rare species of animals and plants (Exodus DMS, 2010; Show Caves, 2011). In 2000 in the dark zone of Nodong Cave, living tiny land snails were collected by Dr. J.-S. Lee from the muddy walls, near piles of limestone fragments. These mollusks provisionally identified as *Carychium* sp. (Kwon *et al.*, 2001; Lee and Min, 2002; Min *et al.*, 2004), in its shell shape and ecology are closer to exclusively troglobitic *Zospeum* Bourguignat, 1856 than *Carychium* Müller, 1774 (Prozorova *et al.*, 2010), which normally lives in external habitats. To make a more precise taxonomic identification of the Nodong Cave carychiids, the present study was conducted.

MATERIALS AND METHODS

Dry shells of 106 specimens of troglobitic carychiids "*Zospeum*" sp., collected by Dr. J.-S. Lee in the Nodong Cave in 13 January 2000 and kept at the Min Molluscan Research Institute in Seoul were examined conchologically. For comparison 15 specimens of ecologically epigenous *Carychium pessimum* Pilsbry, 1902 from the Southern Russian Far East were studied as well in Institute of Biology and Soil Science FEB RAS, Vladivostok. An overall examination of shell morphology was made using a MBS-10 binocular microscope with scales equipped by camera. A detailed examination was carried out using Scanning Electron Microscope EVO-40 (Zeiss).

RESULTS AND DISCUSSION

Korean "*Zospeum*" sp., like the European representatives of the genus, has squat, conic-ovate shells nearly 2 mm long, which are white, fragile, transparent, and not sculptured (Fig. 1). The Nodong Cave snails have only one parietal denticle (lamella), whereas European *Zospeum* have one to two lamellae or no trace of any teeth or lamellae in the aperture (Gittenberger, 1980). Protoconch of the "*Zospeum*" sp. is not clearly distinct from

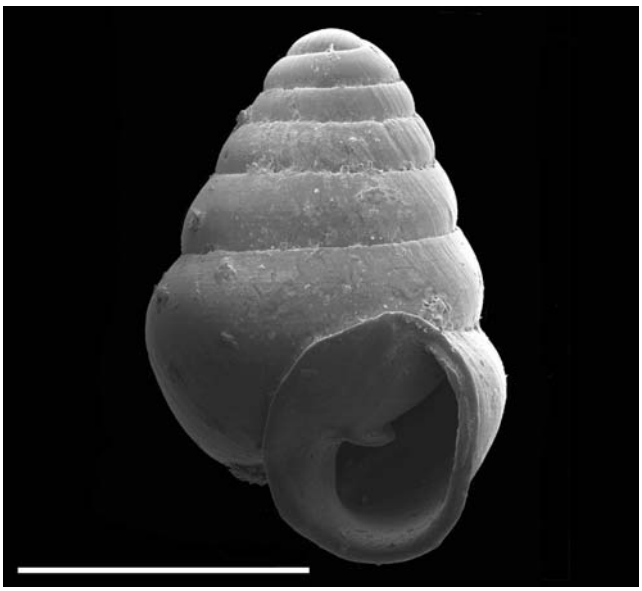

Fig. 1. "*Zospeum*" sp. from the Nodong Cave, South Korea. Scale bar=1 mm.

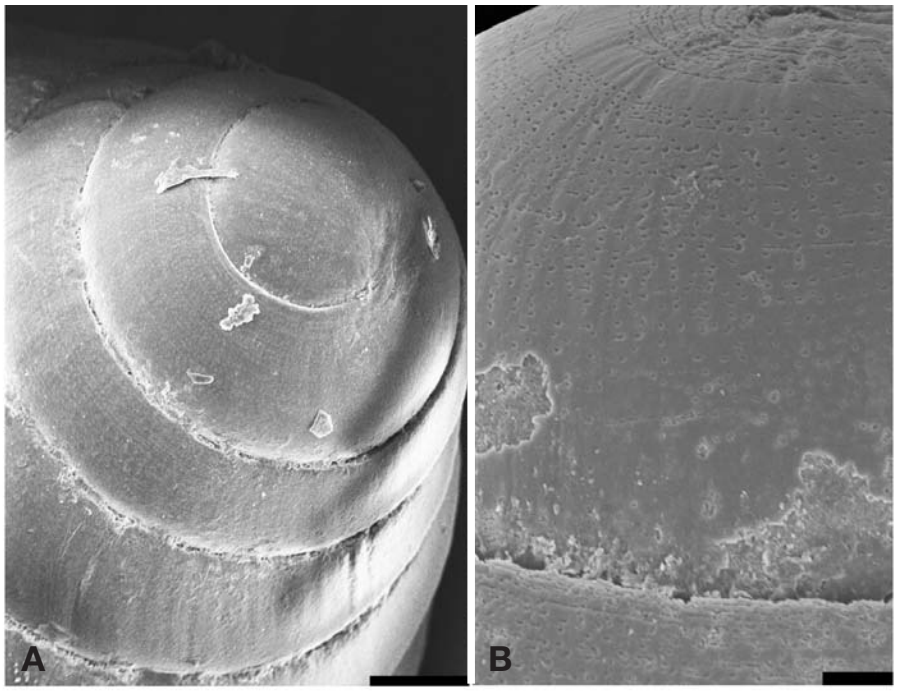

Fig. 2. Protoconch of "*Zospeum*" sp. from the Nodong Cave, South Korea: A. common view; B. protoconch microsculpture. Scale bar=20 μm.

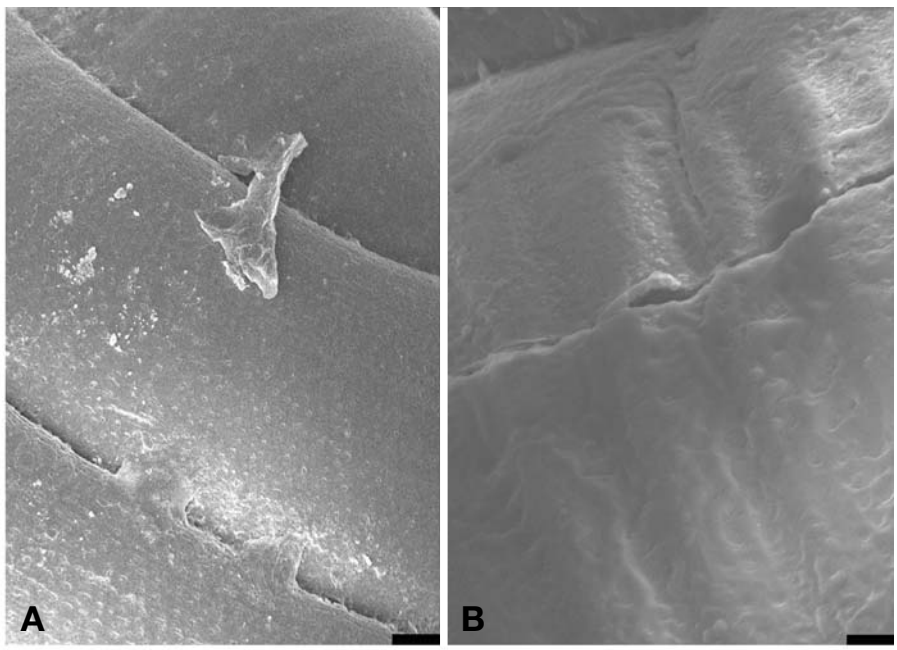

Fig. 3. Teleoconch microsculpture of two Carychiidae species: A. troglobitic "*Zospeum*" sp. from the Nodong Cave, South Korea; B. epigenous *Carychium pessimum* Pilsbry, 1902, from the Southern Russian Far East. Scale bars: A=20 μm; B=100 μm.

teleoconch and nearly smooth (Fig. 2A), but under high magnification irregular spiral rows of pores or pits 1 micron in diameter are visible (Fig. 2B). In some areas pits conjugate and show visibility of spiral grooves (Fig. 2B). Concentric pitting firstly recorded for the Korean "*Zospeum*" sp. (Prozorova *et al.*, 2010) microsculpture, to the recent time is reported as well for some European species of *Zospeum* and *Carychium* as structurally consistent carychiid feature (Jochum, 2011).

The teleoconch of "*Zospeum*" sp. is covered by very weak, irregular growth striae. Under magnification a spiral structure

like that on the protoconch becomes visible, but the spirally-arranged series of one micron pits are joined more closely, and the spiral grooves are more distinct, regular, and crowded than those on the protoconch (Fig. 3A). In contrast with "*Zospeum*" sp. adult whorls of *C. pessimum*, under a magnification of 100x, are granulated; under more than 200x magnification a malleated structure is visible (Fig. 3B).

Besides the evident resemblance, there is probably a difference in shell microsculpture between European and Asian *Zospeum*. Teleoconch of the Korean "*Zospeum*" sp. like protoconch is nearly smooth, but finely pitted (Fig. 3A). No pits are visible on teleoconch surface of European *Zospeum* (Adrienne Jochum, personal communication).

So, based on ecology, shell shape and protoconch sculpture we exclude the Nodong Cave snails from the genus *Carychium*, which normally lives in external habitats, with the exception of the North American *C. stygium* Call, 1897 found only in karst caves of central Tennessee and Kentucky (Jochum, 2011). Korean troglobitic carychiids are closely related with the European genus *Zospeum*. The record in Korea *Zospeum*-like mollusks represents a range extension of the genus to Asia, with disjunctive distribution, because in Europe its range is restricted to karst caves in the Pyrenees, the Cantabrian Mountains, and the eastern Dinaric Alps (Slapnik and Ozimec, 2004; Weigand *et al.*, 2010).

A further study shell and soft body morphology of the Korean "*Zospeum*" sp. is needed for correct taxonomic classification. Some differences in shell microsculpture of Korean cave carychiids will probably cause both European *Zospeum* and "*Zospeum*" sp. to be regarded as close but separate genera. A new genus may be described when preserved specimens can be studied. Unfortunately, as Nodong Cave is now closed for restoration, future efforts should be focused on obtaining living snails in order to examine their internal anatomy.

The discovery of a new species comprising an Asian disjunctive distribution of hypogean carychiids demonstrates that the cave malacofauna of the Korean Peninsula is probably more varied than previously believed. At present, only five species of hypogean malacofauna are recorded in South Korea. Nevertheless, it is known that many snail species prefer small voids with a relatively high humidity and high levels of carbon dioxide, and only occasionally wander into larger caves where they may be more easily observed. Most limestone formations are riddled with such small voids, even when larger caves are not present. These factors are indications of the potential richness of the Korean hypogean malacofauna which therefore merits further study.

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