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Trace Fossil *Protovirgularia* McCoy, 1850 from the Nonmarine Cretaceous Jinju Formation of the Sacheon area, Korea

Jeong-Yul Kim[1,*] · Kyung-Soo Kim[1] · Ron K. Pickerill[2]

[1]Department of Earth Science Education, Korea National University of Education, Cheongwon, Chungbuk 363-791, Korea

[2]Department of Geology, University of New Brunswick, Fredericton, New Brunswick E3B 5A3, Canada

경상남도 사천 지역의 백악기 진주층에서 산출된 비해성 *Protovirgularia* McCoy, 1850

김 정 률[1,*] · 김 경 수[1] · 로날드 피커릴[2]

[1]한국교원대학교 지구과학교육과, 363-791 충청북도 청원군 강내면 다락리 산 7

[2]뉴브런스윅대학교 지질학과, 프레데릭톤, 뉴브런스윅 E3B 5A3, 캐나다

요 약: 경상남도 사천 지역에 분포한 백악기 진주층의 비해성(非海成) 퇴적층에서 생흔화석 *Protovirgularia* McCoy, 1850를 보고한다. 이 지역의 진주층은 주로 호수 환경에서 퇴적된 회색의 이암과 셰일 및 세립질 사암으로 구성되어 있다. 이러한 *Protovirgularia*의 산출은 비해성 퇴적 환경에서 처음으로 보고되는 것이다.

주요어: 생흔화석, *Protovirgularia*, 비해성, 백악기, 진주층

Abstract: The ichnogenus *Protovirgularia* McCoy, 1850 is reported from nonmarine strata of the Cretaceous Jinju Formation of the Sacheon area, Korea. There, the Jinju Formation is composed mainly of fine-grained sandstone, grey to brownish grey mudstone, and shale which were deposited in a freshwater lacustrine environment. This occurrence represents the first formal recording of the ichnotaxon from Korea and the first, on a global basis, from a nonmarine depositional environment.

Key words: trace fossil, *Protovirgularia*, nonmarine, Cretaceous, Jinju Formation, Korea

INTRODUCTION

The ichnogenus *Protovirgularia* McCoy, 1850 is characterized by a small keel-like trail which is composed of an elevated median line and lateral wedge-shaped appendages alternating on both sides (Häntzschel, 1975). *Protovirgularia*, an enigmatic ichnotaxon, has been recorded and discussed by many authors for well over a century and has previously been interpreted as an octocoral (McCoy, 1850), a graptolite (Richter, 1853), and a structure produced by crabs (Gümbel, 1879), arthropods (Richter, 1941; Volk, 1961) and annelids (Richter, 1941; Claus, 1965). It was not until 1958 that Häntzschel (1958) convincingly established it as a trace fossil. More recently Seilacher and Seilacher (1994) further demonstrated that *Protovirgularia* was most likely produced by burrowing bivalves in, or crawling on, soft substrates.

Han and Pickerill (1994), based on a literature review, considered the nomenclatural history of the ichnotaxon and provided a detailed taxonomic evaluation of *Protovirgularia*. They recommended that three ichnospecies of *Protovirgularia*, namely, *P.*

* E-mail: kimjy@cc.knue.ac.kr

harknessi Lapworth, 1870, *P. nereitarum* (Richter, 1871), and *P. mongraensis* Chiplonkar and Badve, 1970, should be considered as junior synonyms of the type, *P. dichotoma* McCoy, 1850. In the same year, however, Seilacher and Seilacher (1994) also revised the taxonomy of *Protovirgularia* and proposed five ichnospecies, namely, *P. dichotoma, P. triangularis* (Macsotay, 1967), *P. tuberculata* (Williamson, 1887), *P. rugosa* (Miller and Dyer, 1878), and *P. longespicata* (Stefani, 1885). Subsequently, Uchman (1998) described seven ichnospecies of *Protovirgularia* from flysch deposits of the Polish Carpathians; i.e., *P. dichotoma, P. pennatus* (Eichwald, 1860), *P. rugosa, P. obliterata* (Ksiażkiewicz, 1977), *P. vagans* (Ksiażkiewicz, 1977), *P. ?longespicata*, and *P. dzulynskii* (Ksiażkiewicz, 1977).

Irrespective of these various ichnotaxonomic considerations, the ichnogenus *Protovirgularia* has previously been reported from several Paleozoic deep and, less commonly, Devonian to Carboniferous and Mesozoic shallow marine environments (Han and Pickerill, 1994). To our knowledge, there is no unequivocal formally reported nonmarine occurrences of *Protovirgularia*. Indeed the only possible previous recording is that by Buatois *et al.* (1996) from Jurassic turbidites of central China but as *Tuberculichnus vagans* Ksiażkiewicz, 1977, which Uchman (1998) reservedly included within *P. vagans*. The unique and exceptional recording herein is therefore undoubtedly significant with respect to paleoenvironmental changes of ichnotaxa throughout geologic time. The purpose of this paper is, therefore, to document the ichnogenus from an unequivocal nonmarine sequence. This recording also represents the first for the ichnotaxon from strata in Korea.

GEOLOGIC SETTING AND FOSSIL LOCALITY

The Cretaceous sedimentary strata in the southeastern part of Korea are referred to the Kyongsang Supergroup (Chang, 1975). This is composed exclusively of nonmarine epiclastic and volcaniclastic sediments which were deposited in various environments including alluvial fan, alluvial plain, fluvial, and lacustrine systems. The Kyongsang Supergroup has been divided, in ascending order, into the Sindong, Hayang, and Yucheon groups (Chang, 1975). A nonmarine origin of the sediments of the Kyongsang Supergroup has long been recognized from the occurrence of fossil plants (Yabe, 1905; Tateiwa, 1929), freshwater molluscs (Yang, 1975, 1978, 1979a, 1979b), dinosaur footprints (Yang, 1982, 1986; Lim *et al.*, 1989; Lim, 1990; Lockley *et al.*, 1992), pollen and spores (Choi, 1985), charophyta (Seo, 1985; Choi, 1987), and an absence of marine fossils. These fossils also indicate that the geologic age of the Sindong, Hayang, and Yucheon groups are Berriasian to Barremian, Aptian to Albian, and Cenomanian respectively (Chang, 1982).

The Sindong Group consists mainly of alluvial fan, floodplain, and lacustrine deposits. The Hayang Group comprises floodplain and lacustrine sediments intercalated with minor volcaniclastic sediments (Um *et al.*, 1983) and the overlying Yucheon Group of volcanic rocks.

The Sindong Group has been subdivided, primarily on the basis of variation in rock color, into, the Nakdong, Hasandong, and Jinju formations, in ascending order. The Hasandong Formation is a red bed sequence underlain by the non-red colored Nakdong Formation and overlain by the non-red colored Jinju Formation.

The Jinju Formation is widely and well-exposed in the study area, Gurangri, Jahaeri, and Gupyungri of Seopomyeon, Sacheon City, Kyongsangnamdo, southern coast of Korea (Fig. 1). The lower part of the Jinju Formation, well-exposed along the coast, is about 150 m thick and generally dips 10°SE. The formation is composed mainly of grey mudstones and shales interpreted as having been deposited in a marginal lacustrine environment, and intercalated sandstones

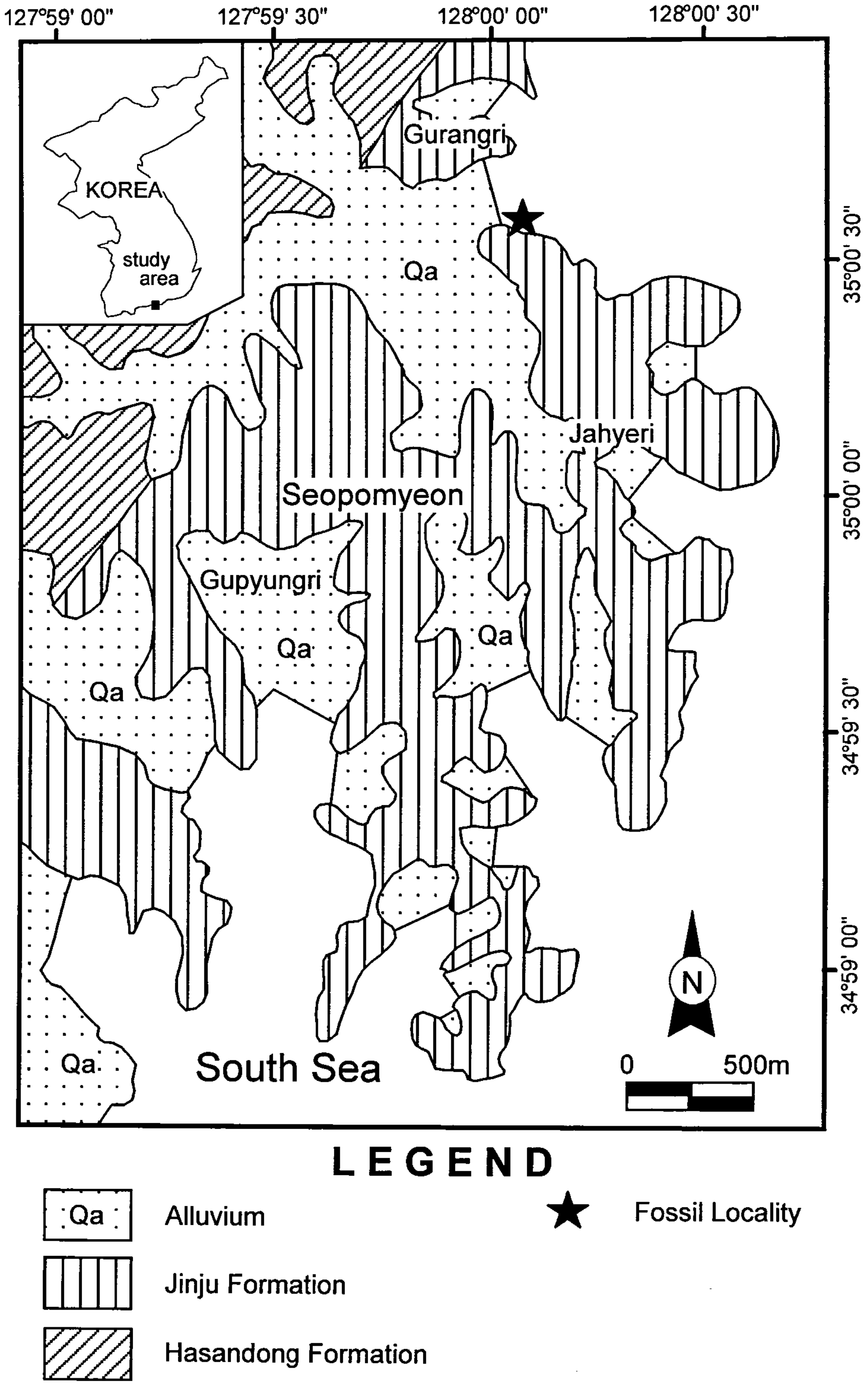

Fig. 1. Geologic map (Chang *et al.*, 1989; Chi *et al.*, 1983; Choi *et al.*, 1969; Kim *et al.*, 1965) and the fossil locality (asterisk) from where specimens of *Protovirgularia dichotoma* described herein were collected.

probably deposited in stream channels (Choi, 1981). Stromatolites, gastropods, esteria, and ostracods have previously been reported from the grey mudstones (Choi, 1981; Um *et al.*, 1983; Paik and Chun, 1993).

The locality exhibiting *Protovirgularia* is on the coast, approximately 500 m southeast of the village of Gurangri, Lat. 35°00′N., Long. 128°01′E (Fig. 1). All specimens were collected from a grey fine-grained sandstone bed, about 90 cm thick, which is covered by a thin film of dark grey mudstone (Fig. 2). Abundant trace fossils, including *Beaconites, Diplocraterion?, Palaeophycus, Planolites, Skolithos, Thalassinoides,* and arthropod trackways resembling *Diplichnites, Kouphichnium,* and *Protichnites* also occur in the same sequence. Freshwater gastropod and fish fossils also occur in the study area.

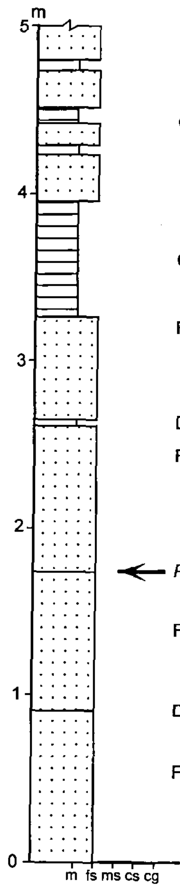

Fig. 2. Measured section showing the *Protovirgularia dichotoma* horizon in the lower part of the Jinju Formation exposed at the fossil locality in Fig. 1.

SYSTEMATIC ICHNOLOGY

Ichnogenus *Protovirgularia* McCoy, 1850

Type ichnospeices: *Protovirgularia dichotoma* McCoy, 1850

Diagnosis: Small, plaited, unbranched, keel-like trail, mostly straight or slightly curved, more rarely sinuous, consisting of a median line (ridge or furrow) with lateral, generally paired and bilaterally symmetrical, narrow wedge-shaped appendages (after Han and Pickerill, 1994).

Discussion: The history of the ichnotaxonomy and origin of the ichnogenus *Protovirgularia* have been discussed in detail, respectively, by Han and Pickerill (1994) and Seilacher and Seilacher (1994). Its relationship to morphologically similar ichnotaxa and its detailed ichnospecific taxonomy were more recently elegantly reviewed by Uchman (1998). It ranges in age from Arenig to Miocene (Uchman, 1998).

Protovirgularia dichotoma McCoy, 1850

Fig. 3A-C

Material: 25 specimens were collected from a grey fine-grained sandstone layer in the lower part of the Jinju Formation in Gurangri, Sacheon City, Korea. All specimens, including figured material (Fig. 3), are deposited in the Department of Earth Science Education, Korea National University of Education (KNUE), Cheongwon, Chungbuk, Korea.

Diagnosis: Unbranched, keel-like trail, typically, but not universally, with a median ridge or furrow from where paired, lateral, wedge-shaped appendages, commonly only a few mm in length, and of even or variable spacing, originate. Lateral appendages may be normal or at an acute angle to the median ridge or furrow (after Han and Pickerill, 1994).

Description: Specimens preserved in positive

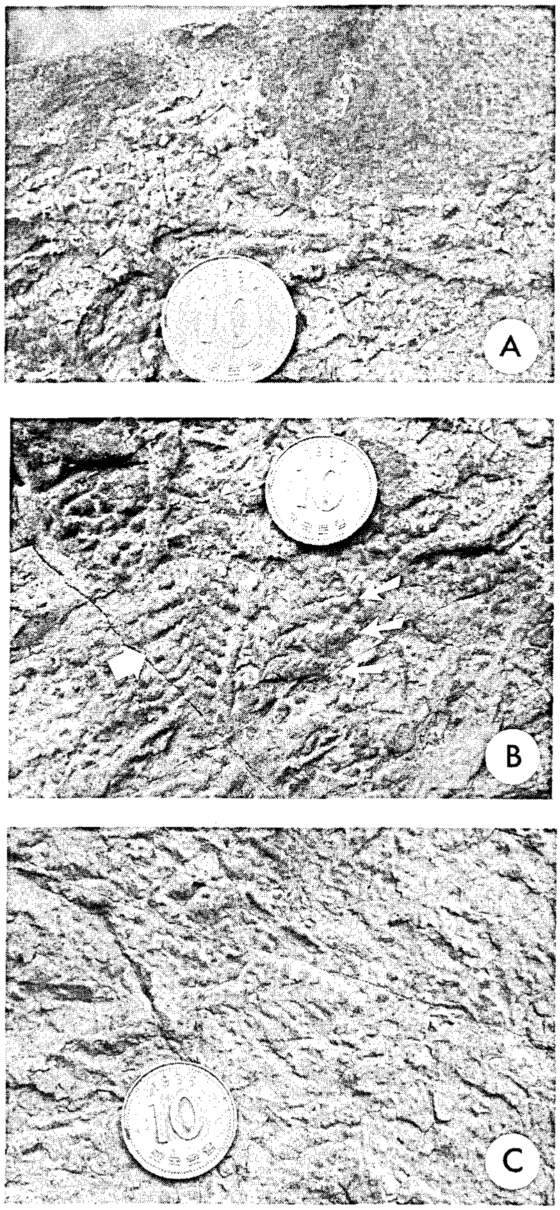

Fig. 3. *Protovirgularia dichotoma* from a grey fine-grained sandstone of the Cretaceous Jinju Formation. A. KNUE 00201 (above coin), B. KNUE 00202 (thick arrow) and KNUE 00203 (thin arrows), C. KNUE 00204 (above right of coin). Coin diameter is 2.3 cm.

epirelief on a grey fine-grained sandstone bed. Traces are straight or slightly curved. Length is variable, maximum observed up to approximately 80 mm (Fig. 3B), but mostly less than 30 mm. Width of traces is also quite variable, ranging from 5 to 20 mm. Width of median ridge, virtually constant in each specimen, ranges from 0.7 to 0.9 mm.

Lateral appendages are generally elongated, club-shaped forms with rounded terminations. Length of lateral appendages is quite variable ; their maximum length of these is 18 mm. Width of lateral appendages is nearly constant, ranging from 3.4 to 6.0 mm. Patterns of lateral appendage arrangement are alternate. V-angles of these are variable even in a single specimen, generally ranging from 60° to 120° (Fig. 3C). Thus, V-angles, as well as length and shape, of lateral appendages on one side or at any level are similar or dissimilar to those on the opposite side of the same or different levels. Distance between the adjacent lateral appendages on each side of the median ridge of a individual specimen is virtually constant, commonly between 1.0 and 2.0 mm (Fig. 3A, B). Number of lateral appendages of individual specimens varies from 10 to 30.

Remarks: Superficially, the material documented herein could potentially be confused with and interpreted as of plant origin. However, we prefer an ethologic interpretation based on the following observations. First, there is no evidence of carbonized material on the fine-grained sandstone layer. Second, the specimens are preserved in positive relief, a preservational style inconsistent with a plant origin at the scale of the preserved structures. Third, the bedding plane is also pervasively bioturbated by *Planolites* which is similarly preserved in positive relief and exhibits no difference in preservational style to the specimens described herein. We are confident, therefore, that the structures are ethologic in origin and, given their morphology, can confidently be assigned to *Protovirgularia*.

Following the two recent revisions of the ichnospecies of *Protovirgularia* conducted by Seilacher and Seilacher (1994) and more recently Uchman (1998) it is clear that several contrasting considerations must be undertaken prior to ichnospecific evaluation.

These include nature and density of the lateral chevron or appendage markings, size and development of the median ridge or furrow, depth and cross-sectional shape of individual traces, and presence or absence of papillae on individual chevrons. Given that several of these criteria most probably rely on taphonomic considerations and are, therefore, not exclusively taxonomic criteria per se, caution must be exercised in ichnospecific assignment. Indeed, of the two previously outlined nomenclatural schemes only four ichnospecies are common to both. Given the fact that these four ichnospecies have been recognized from various spatially and temporally unrelated sequences (see reviews in Seilacher and Seilacher, 1994; Uchman, 1998) we regard them as valid whereas the remainder require further evaluation.

The four ichnospecies are *P. pennatus* (regarded by Uchman (1998) as the senior synonym of *P. triangularis* as described by Seilacher and Seilacher (1994) – a conclusion supported herein), *P. longespicata, P. rugosa* and the type *P. dichotoma*. Of these, *P. pennatus* is deeply impressed with a carinate cross-section and faint, densely spaced lateral markings (Uchman, 1998). *P. longespicata* is a very large fodinichnial version of *Protovirgularia* with strong papillate chevrons and *P. rugosa* is a short cubichnial version distinguished by a chevroned escape burrow leading away from a smooth, *Lockeia*-like resting burrow (Seilacher and Seilacher, 1994). Finally, *P. dichotoma* is characterized by paired, typically short, wedge- or club-shaped appendages that may be oriented normally or at an acute angle to the median structure (Han and Pickerill, 1994; Uchman, 1998). Of the ichnospecies we consider to be valid, the Korean material therefore accords best to the latter and is confidently assigned as such.

McCoy (1850), subsequently reiterated by Häntzschel (1975), interpreted *P. dichotoma* to be dichotomously branched. However, Han and Pickerill (1994) believed that McCoy's types were falsely branched (*sensu* Bromley, 1990), interpreting the material as representing individual specimens that intersected each other. Hence they omitted the descriptor "branched" from their emended diagnosis of the ichnospecies. Interestingly, the actuopalaeontological experiments conducted by Seilacher and Seilacher (1994) demonstrated that because of its production by molluscs *Protovirgularia* could exhibit a radial form but that true branching was not feasible. In this context it is notable that several examples of the Korean material (e. g., Fig. 3B) appear to be branched though we regard this as equally fortuitous.

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