

Occurrence of *Lockeia* from the Yeongheung Formation (Middle Ordovician), Yeongweol, Korea

강원도 영월지역에 분포하는 영흥층에서 생존화석 *Lockeia*의 산출

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Abstract : Diverse forms of *Lockeia* are abundantly preserved in the dolomitic mudstone of the Middle Ordovician Yeongheung Formation, Yeongweol, Korea. On the basis of general morphology, five forms of *Lockeia* are recognized in the material from the Yeongheung Formation. *L. siliquaria* is a thin, seed-like form, and tapered at both ends. *L. amygdaloides* is a relatively plump, almond-shaped form, and tapered at one end and the other end is obtusely pointed or somewhat rounded. *L. triangulichnus* nov. ichnosp. is a small triangular form with three ridges from apex, resembling a pyramid, preserved in convex hyporelief and concave epirelief. *L. ichnosp. 1* is a pear-shaped form and *L. ichnosp. 2* is an irregular form. Usually populations of *Lockeia* are monospecific and this occurrence is unique. The characteristic features of *Lockeia*, such as length, width, surface ornamentation, symmetry, convexity and tapering, seem to be related to the orientation and burrowing depth of shells, degree of sediment erosion, and possibly with the later environmental and diagenetic change, as well as original shape and behavior of trace makers. *Lockeia* is interpreted as a resting trace of a burrowing bivalve which may be oriented horizontally, obliquely and vertically.

Key Words : Occurrence, *Lockeia*, Yeongheung Formation

요 약

중기 오오도비스기 영흥층의 고회질 이암에는 다양한 생존화석 *Lockeia*가 잘 보존되어 있음이 확인되었다. 일반적인 형태에 근거하여, 영흥층의 *Lockeia*는 5가지 형태로 구분되며 이들은 *L. siliquaria*, *L. amygdaloides*, *L. triangulichnus* nov. ichnosp., 그리고 *L. ichnosp. 1*과 *L. ichnosp. 2*로 기재되었다. *L. siliquaria*는 얇고 씨앗 모양의 형태를 가지고 있으며 양끝에서 가늘어진다. *L. amygdaloides*는 상대적으로 볼록하며 아몬드 모양을 하고 있고, 한쪽 끝은 뾰족하나 다른 한쪽 끝은 뿔뿔하거나 약간 둥글다. *L. triangulichnus* nov. ichnosp.는 작은 삼각형 모양의 정점으로부터 3개의 능선이 있는 피라미드를 닮았으며, 볼록 저면요철 및 오목 표면요철로 보존되어 있다. *L. ichnosp. 1*은 서양배 모양을 하고 있으며, *L. ichnosp. 2*는 불규칙한 모양을 하고 있다. 산출된 *Lockeia*의 여러 형태적 특징을 고려해 볼 때 길이, 폭, 표면 장식, 대칭성, 볼록한 정도, 및 끝 부분의 뾰족한 정도와 같은 *Lockeia*의 특징적인 형태는 패각의 배열 방향과 버로우의 깊이, 퇴적물의 침식 정도와 깊은 관계가 있는 것으로 보이며, 부분적으로 생존생성 생물들의 원래 모양과 행동뿐만 아니라 후기의 환경 및 속성 작용의 변화와도 관계가 있을 것으로 생각된다. 주로 수직 배열의 기원으로 생각되었던 종전의 해석과는 달리 *Lockeia*는 퇴적물내에서 수평, 수직 또는 비스듬히 자리잡은 굴착하는 이매패류들의 휴식생흔으로 생각된다. 영흥층에서 산출된 이들 표본들은 최초의 다양한 *Lockeia* 생존화석종을 나타내며, 고회질 이암으로부터는 최고의 기록에 해당한다.

주요어 : 산출, *Lockeia*, 영흥층

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INTRODUCTION

Lockeia James 1879, the senior synonym of *Pelecypodichnus* Seilacher, 1953, has been known as an ichnogenus of small almond - shaped oblong bodies preserved in convex hyporelief, tapering to sharp and obtuse points at both ends (Häntzschel, 1975). Although it was originally interpreted as an alga (James, 1879), and later it was once regarded as "ovarian capsules" of graptolites, it is now considered as a resting trace of burrowing pelecypods (e.g. Seilacher, 1953; Osgood, 1970; Häntzschel, 1975; Vosler and Pemberton, 1988). *Lockeia* has received a considerable attention in life history, ecology and ethology of bivalves (e.g. Eagar *et al.*, 1983).

There are numerous occurrences of *Lockeia* from fluvial to deep marine deposits of Precambrian to Cretaceous in North America (U.S.A. and Canada), Europe (U.K., Germany, Poland, and Switzerland), and Asia (Saudi Arabia and Tibet). However, few analyses exist in which the trace fossil morphology has been interpreted in its mode of formation.

Six ichnospecies of *Lockeia* (*L. siliquaria* James 1879; *L. amygdaloides* (Seilacher, 1953); *L. ornatus* Bandel 1967; and *L. czarnockii* (Karaszewski, 1974); *L. elongata* Yang, 1984; and *L. avalonensis* Fillion and Pickerill, 1990) are recognized in the current literature. *L. ornatus* which is characterized by its surface ornamentation (Bandel, 1967) and *L. czarnockii* which is characterized by its big size and drop-shaped forms (Pienkowski, 1985) were reported only once from their type localities. *L. elongata* is smooth, characteristically thin and elongate (Yang, 1984). *L. avalonensis* is spherical, sub-ovate, squat *Lockeia*, with an evenly rounded surface (Fillion and Pickerill, 1990). *L. siliquaria* and *L. amygdaloides* are well known from Early Ordovician to Cretaceous strata (e.g. Seilacher, 1953; Pickerill, 1977; Bromley and Asgaard, 1979; Crimes *et al.* 1981; Pienkowski, 1985; Fillion and Pickerill, 1990).

However, morphological distinctions between *L. siliquaria* and *L. amygdaloides* are not clear or rarely cited in the current literature (e.g. Seilacher, 1953). It is, therefore, necessary to review taxonomically

the ichnospecies of *Lockeia*. Most reported previously *Lockeia* populations (e.g. James, 1879; Seilacher, 1953; Osgood, 1970) consist of clusters of individual traces belonging to the same ichnospecies. A unique population including diverse forms of *Lockeia* occurs in Yeongweol, Kangweondo, Korea.

The purpose of this study is to report the unique occurrence of *Lockeia*, to interpret the mode of formation of *Lockeia*, and to describe five ichnospecies of *Lockeia*, *L. siliquaria*, *L. amygdaloides*, *L. triangulichnus* nov. ichnosp., *L.* ichnosp. 1 and *L.* ichnosp. 2, which are excellently preserved in the Yeongheung Formation, Korea. These specimens represent the earliest occurrence of diverse ichnospecies of *Lockeia*, and the oldest record of this ichnogenus from dolomitic mudstone.

GEOLOGIC SETTING AND FOSSIL LOCALITY

The Cambro - Ordovician sedimentary rocks, the Choseon Supergroup, are widely distributed in Yeongweol, Korea. They consist of the Sambangsan, Machari, Wagok, Mungok and Yeongheung Formations in ascending order. Kobayashi (1966) compiled a list of over 100 species of macroinvertebrate fossils, such as trilobites, brachiopods, gastropods, hyolithids, cirripedians(?), machaeridias, cystoidea and graptozoan, and established 11 biostratigraphic zones in the Choseon Supergroup of Yeongweol area. Although many fragments of bivalves occur from the Yeongheung Formation (Woo, 1992 personal communication), the fossil bivalves, which are known as a trace maker of *Lockeia*, are not described yet. Recently 14 ichnospecies of trace fossils were reported from the Yeongheung Formation (Kim *et al.*, 1992).

The Yeongheung Formation consists mainly of dark grey dolomitic limestone and grey to bluish grey limestone intercalated in places with several thin beds of shale and argillite. Recent sedimentological study shows that the Yeongheung sediments were deposited in a shallow lagoon to offshore environment (Yoo, 1991).

Kobayashi (1966) correlated the Yeongheung Formation with the Toufangian Series of the Middle Ordovician on the basis of the trilobite *Basiliella*, orthids and actinoceratoids which are uncommon in the formation. On the basis of 29 species of conodonts microfossils discovered from the Yeongheung Formation, the formation is considered to be Middle Ordovician (Lee, 1979).

All of the specimens considered in this paper were collected from the middle part of the Yeongheung Formation. The fossil locality is on the east side of a small meandering creek, 200 m downstream point from the old Namgyo bridge, Omandong, approximately 7 km NNE from Mungok, Yeongweol ($128^{\circ} 26'10''$ E, $37^{\circ} 15'20''$ N) (Fig. 1).

Exposures of the Yeongheung Formation at this locality are excellent, with grey dolomitic limestone beds, 12 m in thickness. The specimens were collected from the middle of the upper fine grained parts which show in places wave ripple marks and mud cracks.

OCCURRENCE OF *Lockeia*

The numerous specimens are preserved on the calcareous mudstone which is overlain by the dolomitic mudstone with wave - ripple marks and is underlain by the laminated to flaser bedded dolomite. The thickness of the calcareous mudstone is 6 mm in the ripple trough and 2 mm in the ripple crest.

On the polished slabs which are vertically sectioned through the counterpart, i.e. convex and concave, specimens do not show any disturbed structures in the underlying and overlying sediments. This fact indicates that they are the imprint - filled trace fossils.

The specimens show preferred orientation (Fig. 2). Most of forms are oriented in the same direction of wave motion which is inferred from the ripple marks. Some types, especially triangular - and pear - shaped forms, however, are oriented in perpendicular to the inferred wave motion. Such orientations may be related with strategy of trace - making animals for more efficient food - gathering or more sta-

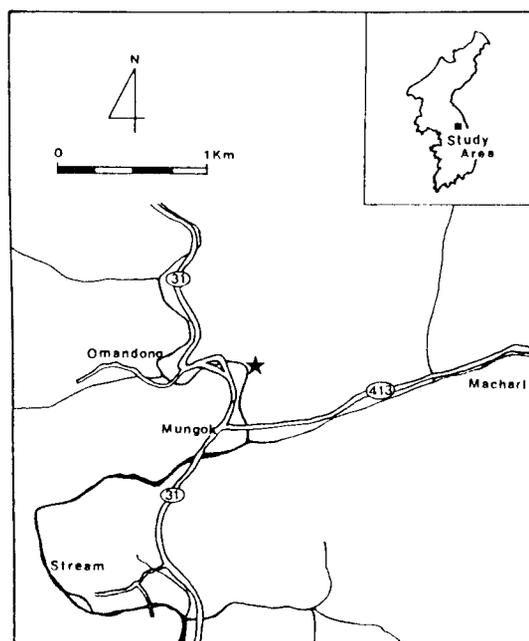


Fig. 1. Map showing trace fossil locality (asterisk mark).

ble posture in the hydrodynamic environments.

The specimens from the Yeongheung Formation can be grouped into five forms on the basis of surface ornamentation, symmetry, convexity, tapering and size. They are seed - like, almond, triangular-, pear - shaped, and irregular forms (Fig. 3).

The seed - like forms (Fig. 3 - A) are thin and tapered at both ends. These forms are crested or smooth in the surface, longitudinally symmetrical to asymmetrical or sigmoidal in shape.

The almond - shaped forms (Fig. 3 - B) are relatively plump and oval in shape. They are tapered only at one end and the other end is more or less rounded or obtusely pointed.

The triangular forms (Fig. 3 - C) are virtually pyramid - like. Many forms are elongated triangles in plan view. They are characterized by three crests from the pyramid apex which is located toward in relatively short side. Some forms are sharply pointed or tapered at one end.

The pear - shaped forms (Fig. 3 - D) are the longest forms among other ones. They are tapered at one end. The tapered parts of these forms ac-



Fig. 2. Occurrence of *Lockeia*, showing preferred orientation.

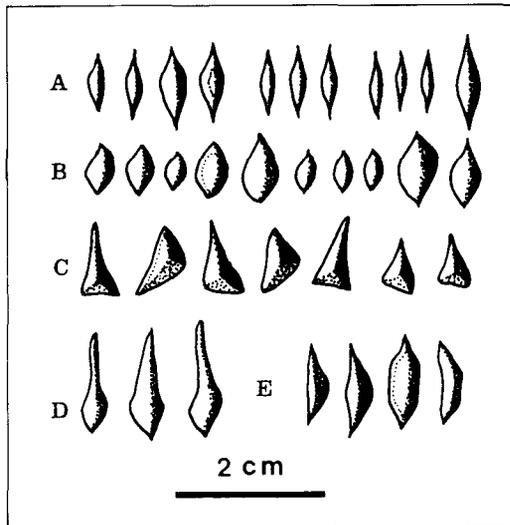


Fig. 3. Various forms of *Lockeia* from the Yeongheung Formation. A; seed-like forms, *L. siliquaria*, B; almond-shaped forms, *L. amygdaloides*, C; triangular forms, *L. triangulichnus*, nov. ichnosp., D; pear-shaped forms, E; irregular forms.

count for about more than two thirds of their whole length.

The irregular forms (Fig. 3 - E) represent diverse forms which can not assigned to any types described

above. They may consist of possibly real irregular forms and apparent irregular forms which may probably be produced by superimposing or connecting with two or more forms.

INTERPRETATION OF *Lockeia*

Morphological Characteristics

The surface ornamentation in each forms may be related with the original trace maker and later environmental and diagenetic changes. Smooth surface may reflect possibly the smooth shell forms or later change of original ornamentation. Some forms show nearly concentric fine ribs or growth lines which may represent the surface ornamentation of original shells or may partly be related with the slightly upward or downward movement of animals in response to environmental changes. The crests of some forms are considered to be structures representing ventral and lateral commissure of shells.

The longitudinal symmetry of most forms may represent the symmetry between the equivalves of pelecypod. But some specimens show slightly asymmetry in longitudinal section which seems to be

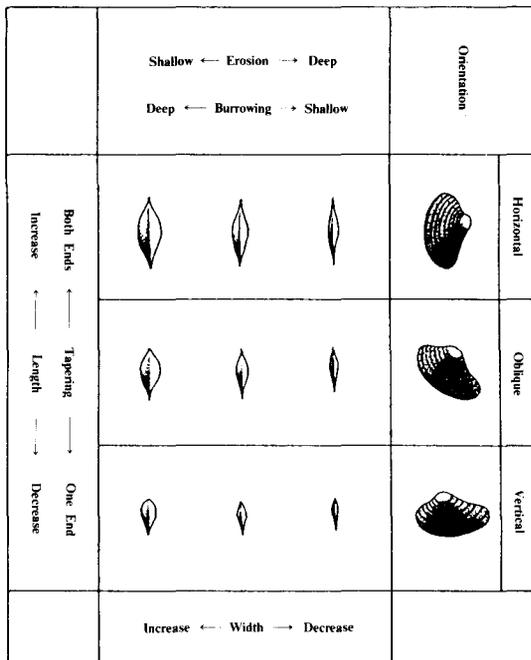


Fig. 4. Relationship between forms of *Lockeia* and orientation, erosion and burrowing depth. Length and tapering of *Lockeia* are related with shell orientation, and width of *Lockeia* is related with erosion and burrowing depth.

related with oblique orientation of shells to sediment surface.

All of the forms are generally biconvex in outline. The wide range of convexity of forms from strongly biconvex to slightly biconvex, are noted. The convexity, as well as overall shape, of forms may undoubtedly represent that of shells. But even within the same shells, they seem to be related with the burrowing depth of shell below the sediment surface and degree of sediment erosion. The more biconvex forms are considered to be produced in deeper burrowing of shells or more slight erosion of sediments (Fig. 4).

Most forms show tapering at one end or at both ends which is known as one of diagnoses of *Lockeia*. These tapering ends are supposed to represent the ventral or lateral commissure of shells. The tapering ends of a few specimens are sigmoidal in shape which seems to be related to slight change of shell position.

Thus, the tapering of one end or both ends is considered to represent the orientation of shells; tapering only at one end may be related with oblique to vertical orientation i.e. anterior down and posterior up, of shells, whereas tapering at both ends may be related with nearly horizontal orientation, i.e. ventral down and dorsal up, of shells (Fig. 4).

Types of Forms

According to Seilacher (1953), diagnosis of *Lockeia* (*Pelecypodichnus*) is: "Ruhespuren in der Form hochkant stehender Mandeln". Osgood (1970) also gave similar interpretation of *L. siliquaria*; vertical orientation of antero - posterior axis of pelecypod.

The Yeongheung specimens, as previously mentioned, show so nearly complete preservation of various and numerous forms that it is possible to interpret the formation of *Lockeia*. The morphological features of the *Lockeia* may be related with original shell shape, orientation of shells, burrowing depth of shells and degree of sediment erosion. The relationship between the morphology and these characteristic parameters are briefly shown in Fig. 4. As orientations of a certain shell are changed from horizontal through oblique to vertical ones, the corresponding features are changed from tapering at both ends to tapering at one end, become more bilateral - asymmetrical, and thus decrease the length of forms. All of these features vary undoubtedly with the original shape of shells. Even within the same orientation of shells, the morphological features vary with the burrowing depth of the shells and degree of sediment erosion. As the shells burrow more deeply and the sediment erosion becomes more slightly, the corresponding features are changed from thin to plump and thus increase the width of forms. Also it is not necessary to say that these forms vary undoubtedly with the original shell shape.

The morphological features according to the orientation of shells of probably different forms are shown in Fig. 5. The seed - like forms seem to be

Orientation		Horizontal	Oblique	Vertical
Forms	Seed-like			
	Almond			
	Triangular			
	Pear-shaped			

Fig. 5. Relationship between shell orientation and forms of *Lockeia*. Dark areas represent range and relative abundance in the Yeongheung Formation.

mainly related with the horizontal to oblique orientation. The almond and pear-shaped forms may be related with oblique to vertical orientation and the triangular forms are probably related mainly with the vertical orientation of shells.

Mode of Formation

On the basis of occurrence, one of the possible reconstruction of *Lockeia* from the Yeongheung Formation is shown in Fig. 6. Many small pelecypods probably burrowed into the wave-ripple surface of dolomitic mud (Fig. 6 - A). Most of forms with horizontal and oblique orientation are aligned in parallel with the wave direction, while the other forms with vertical and oblique orientation are aligned in perpendicular to the wave direction. These different orientation may be represented by different animals of different strategy in response to wave action. Subsequent erosion of dolomitic mud results only corresponding concave imprints of shells on the bedding plane (Fig. 6 - B). This erosive action seems to be too rapid to allow the animal to penetrate deep into the underlying sediments and seems not to be too intense to rework all of this imprints. Following deposition of dolomitic sediments on the erosive surface fills the concave imprints and thus results corresponding convex hyporelief and concave epirelief (Fig. 6 - C).

The previous interpretation of *Lockeia*, a resting trace of small burrowing pelecypod with vertical orientation of antero-posterior axis (cf. Seilacher, 1953; Osgood, 1970, p.311, Fig. 6), is included in this interpretation as one end member.

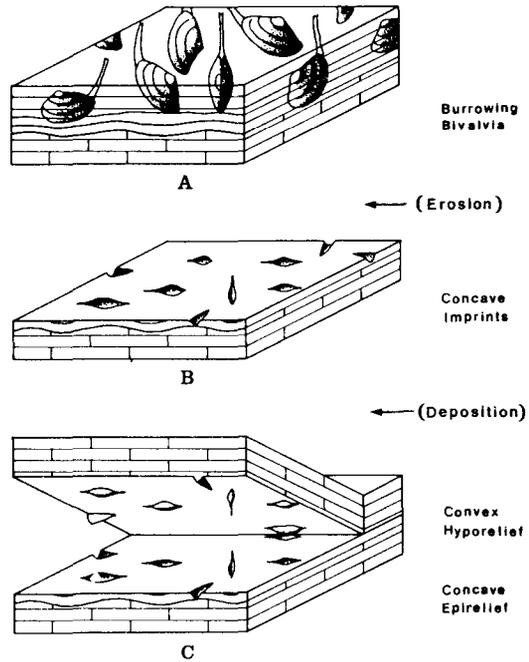


Fig. 6. Interpretation of *Lockeia*. Reconstruction showing the origin of specimens from the Yeongheung Formation. A; variously oriented bivalves burrow through rippled mud and nick the adjacent sediments with their ventral or anterior portion of the valves, B; subaqueous erosion strips away the mud down to a few millimeter above the mud-underlying dolomite interface, and results concave imprints, C; following deposition of dolomitic sand filled the ovoid imprints result concave epirelief and convex hyporelief of *Lockeia*.

SYSTEMATIC ICHNOLOGY

Ichnogenus *Lockeia* James, 1879

***Lockeia siliquaria* James, 1879**

Fig. 3 - A, 7 - A

Lockeia siliquaria James, 1879, p.17; Osgood, 1970, p.308, Pl.57, fig.7, Pl.59, fig.7; Chamberlain, 1971, p.219, Pl. 29, fig.1; Pickerill, 1977, p.8, Pl.2 - a; Crimes et al., 1981, p.965, Pl.1, fig.5 - 7; Fillion and Pickerill, 1990, p.39, Pl.8, fig.3, Pl.9, figs.6 - 8.

Diagnosis—Elongated, convex fossil sea-plants, rounding and tapering to sharp or obtuse points, seed-like in appearance, with or without slight lo-

ngitudinal depressions, attached to the surface of rocks (James, 1879).

Occurrence—Middle part of the Yeongheung Formation, Omandong, Mungokri, Yeongweolgun, Kangweondo, Korea.

Material—Numerous specimens are deposited in the Paleontological Collections of Department of Earth Sciences, Korea National University of Education (KNUE).

Description—Small seed-like oblong bodies preserved in convex hyporelief and concave epirelief; tapering to sharp and obtuse points at both ends; surface smooth or longitudinally crested, very rarely one furrow along the longitudinal line of body; mostly symmetrical although a few forms asymmetrical; length varying from 5 to 22 mm (average about 10 mm), width ranged from 1.8 to 7 mm (average about 3 mm), height ranged from 0.3 to 1.3 mm, strongly aligned (Fig. 2).

Remarks—The specimens are bilateral symmetry or asymmetry, longitudinally sharp crested or smooth. The length and width of the *Lockeia* has been known as 13 mm (maximum), 4-6 mm (El-Khayal and Romano, 1988), 27 mm (maximum), 7 mm (maximum) (Pickerill, 1977), 3-20 mm, 5 mm (Chamberlain, 1971) and 15 mm (maximum), 8 mm (maximum) (Crimes *et al.*, 1981) respectably.

The specimens are very similar to *Lockeia siliquaria* from the Late Ordovician Latonia Formation of the type locality, the bank of the Ohio River at Ludlow, Kentucky, although Osgood (1970) states the width to be only from 1-2 mm. These specimens show high population density and strong alignment which are also similar to those of Osgood (1970).

L. siliquaria has been temporally or provisionally identified as *L. cf. siliquaria* from shallow marine sandstone of the Early Ordovician Saq Formation, Buraydah, Saudi Arabia (El-khayal and Romano, 1988). *L. siliquaria* has been known from shallow marine siltstones of the Late Ordovician Upper Cwn Rhiwarth Siltstone, Wales, U.K. (Pickerill, 1977), the sandstones of the Carboniferous Atoka Formation, Oklahoma, U.S.A. (Chamberlain, 1971) and Creta-

ceous Gurnigel Flysch, Switzerland (Crimes *et al.*, 1981).

***Lockeia amygdaloides* (Seilacher, 1953)**

Fig. 3 - B, 7 - B

Pelecypodichnus amygdaloides Seilacher, 1953, Pl. 10, fig. 1; Pl. 12, fig. 1, 2; Wincierz, 1973, Pl. 7, fig. 1; Bromley and Asgaard, 1979, fig. 5A-C, 20 C; Pienkowski, 1985, Pl. 1, fig. E.

Diagnosis—Resting traces with the form of highly standing almonds. Their originators are molluscs living in sand (Seilacher, 1953).

Occurrence—Middle part of the Yeongheung Formation, Omandong, Mungokri, Yeongweolgun, Kangweondo, Korea.

Material—Many specimens are deposited in the Paleontological Collections of Department of Earth Sciences, KNUE.

Description—Small almond-shaped ovoidal traces preserved in convex hyporelief and concave epirelief; tapering to sharp point at one end and the other end more obtuse point or somewhat round; surface smooth or longitudinally crested; some forms rhomboidal in shape, more or less straight-sided in outline; mostly symmetrical except tapering points in some specimens; length 6.5-12.5 mm, width 2.3-6.2 mm.; markedly aligned.

Remarks—Although ichnogenus *Lockeia* and ichnospecies *L. siliquaria* were originally introduced by James (1879), he did not illustrate any figures, and he did not designate the type material. Unfortunately, his holotype was also lost (Osgood, 1970).

James (1879) did not mention the diagnosis of *L. siliquaria* as well as that of ichnogenus *Lockeia*. Although Seilacher (1953) briefly noted the diagnosis and description of *L. amygdaloides*, it is difficult to differentiate between *L. siliquaria* and *L. amygdaloides* on the basis of original description of *L. siliquaria* and diagnosis and description of *L. amygdaloides*. Both are the most commonly referred in previous papers. However, it is not difficult to divide them into two on the basis of paratype material of *L. siliquaria* (Osgood, 1970, Pl. 57, fig. 7) and holo-

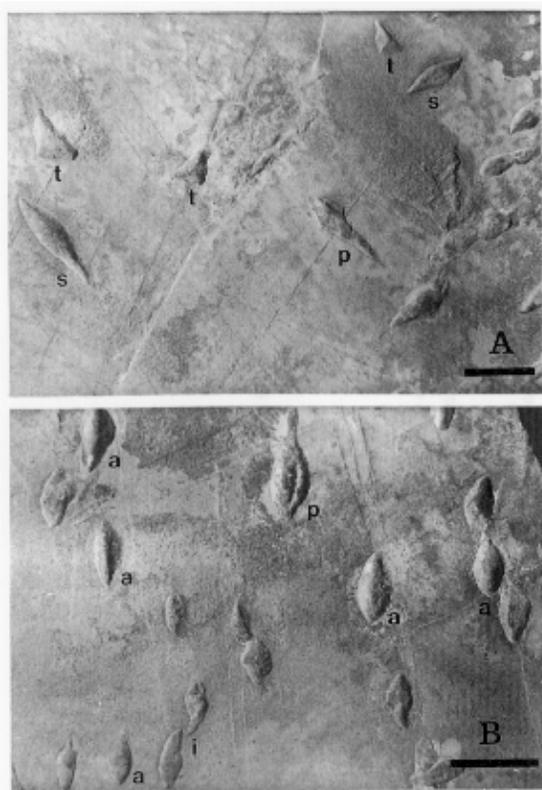


Fig. 7. Specimens of *Lockeia* from the Yeongheung Formation. A; *L. siliquaria* (s), *L. triangulichnus* (t), pear - shaped forms (p) of *L. sp.*, B; *L. amygdaloides* (a), pear - shaped forms (p) and irregular forms (i) of *L. sp.*, scale bar 1 cm.

type material of *L. amygdaloides* (Seilacher, 1953, Pl.10, Fig. 1, Pl.12, Fig. 1,2). One of the possible criteria used for ichnospecific differentiation between them is the form ratio, i.e., length/width ratio of form. The form ratios of the type specimens and Yeongheung specimens of *L. siliquaria* and *L. amygdaloides* are shown in Fig. 8. The form ratio of *L. siliquaria* is higher than that of *L. amygdaloides* though they are highly overlapped.

James (1879) originally described *Lockeia* and *L. siliquaria* as seed - like forms. Seilacher (1953) originally described *L. (Pelecypodichnus) amygdaloides* as almond - shaped forms. Most of subsequent authors illustrated specimens of *L. siliquaria* as well as *Lockeia amygdaloides* as (highly - standing) almond forms (e.g., Osgood, 1970; Häntzschel, 1975). The pre-

sent authors, however, think that it is taxonomically reasonable to follow the original description of *L. siliquaria* as seed - like forms and the original diagnosis of *L. amygdaloides* as almond - shaped forms. Although an almond is undoubtedly also one type of seed, seed - like forms of *L. siliquaria* are thin and tapered at both ends (James, 1879; Osgood, 1970, Pl. 57, Fig. 7) and almond - shaped forms of *L. amygdaloides* are relatively plump ovoid, and tapered only at one end and the other end is obtusely pointed or somewhat rounded (Seilacher, 1953, Pl. 10, Fig. 1, Pl. 12, Fig. 1.2).

***Lockeia triangulichnus* nov. ichnosp.**

Fig. 3 - C, 7 - A

Type material—Holotype (Fig. 7 - A, upper left) KNUE 920601, upper part of Yeongheung Formation, uppermost part of the Omandong section, Omandong, Yeongweol, Korea. Paratypes (Fig. 7 - A, center and upper right) KNUE 920602, 920603, same horizon and same locality as holotype. All material are deposited in the Paleontological Collections of Department of Earth Sciences, KNUE.

Derivatio nominis—After *tri*, Latin, three, *angulus*, Latin, angle, corner and *ichnos*, Greek, trace.

Occurrence—Upper part of the Middle Ordovician Yeongheung Formation, Omandong, Mungokri, Yeongweolgun, Kangweondo, Korea

Diagnosis—Small triangular forms with three ridges from apex, resembling triangular pyramid, preserved as convex hyporelief and concave epirelief.

Description—Type specimens resemble large based triangular pyramid with low height, preserved in convex hyporelief on the dolomite and concave epirelief on the dolomitic mudstone; based triangle 8, 8, 4 mm sides and height less than 3 mm; three sided faces smooth; three distinct ridges from the apex located toward short side from center, reach to three corners.

Remarks—With only a cursory glance, these materials seem to be pseudocasts of evaporite minerals, but on close analysis the mudstone which contains these materials does not show any structures which

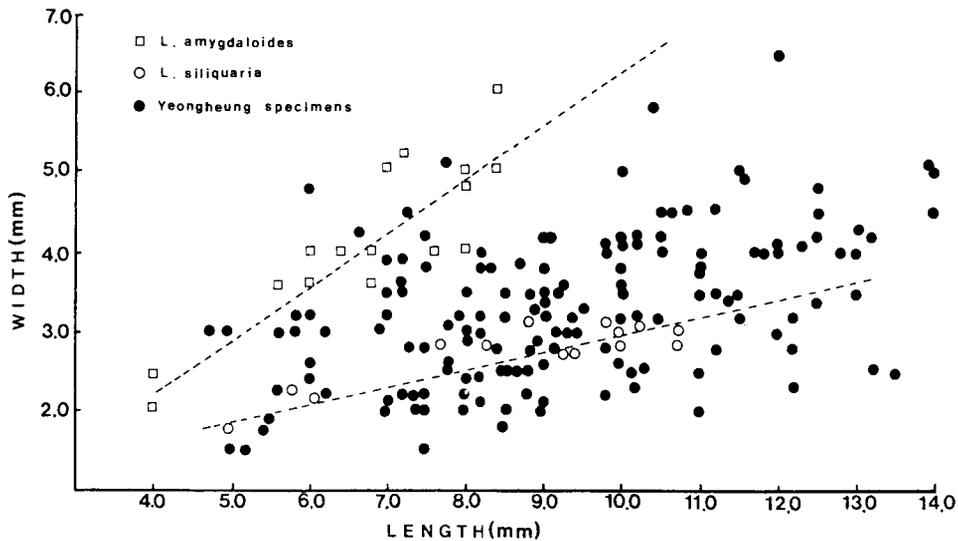


Fig. 8. Plot of length versus width of *Lockeia*: open squares for holotype materials of *L. amygdaloides* (Seilacher, 1953); open circles for paratype materials of *L. siliquaria* (Osgood, 1970); and solid circles for specimens from the Yeongheung Formation. Regression line from the holotype materials of *L. amygdaloides* is, $y=0.71x+1.0$, and that from the paratype materials of *L. siliquaria* is, $y=0.28x+0.8$

are related with subaerial dessication. The numerous *Lockeia*, which have commonly been recorded in subaqueous marine environment, preserved on the same bedding plane suggest that these materials are not pseudocast of evaporite minerals.

Some criteria which may lead one to consider a biogenic origin (cf. Ekdale *et al.*, 1984) include nearly uniform size and shape of these material on the bedding surfaces of numerous *Lockeia*. They are oriented mostly perpendicular to wave direction which is inferred from the wave ripple marks. These materials seem to be burrowing traces of molluscs which may orient in vertical posture; i.e. anterior down and posterior up, and may have triangular or axe-like shape in cross section of shell (Fig. 6).

Each trace fossil which represents possibly same behavioral pattern of similar animals should have the same name of ichnogenus. Therefore, it is reasonable to name these materials as *Lockeia* although the triangular shape of these specimens does not fit into the revised diagnosis of this ichnogenus by Osgood (1970). The several specimens of this peculiar shape which are well preserved may be enough to erect a new ichnospecies, *L. triangulichnus*.

Lockeia ichnosp. 1

Fig. 3 - D, 7 - A

Occurrence—Middle part of the Yeongheung Formation, Omandong, Mungokri, Yeongweolgun, Kangweondo, Korea.

Material—Five specimens are deposited in the Paleontological Collections of Department of Earth Sciences, KNUE.

Description—Pear-shaped forms, tapering very long at one end, about two thirds to three fourths of whole length; length 18 to 24 mm, width up to about 5 mm.

Remarks—Pear-shaped forms which are characteristically long tapering, seem to represent the original thin-shelled shape of animal or more possibly the long ventral extension of foot. The specimens are mostly aligned nearly perpendicular to wave motion, although most of other forms are oriented in parallel to that. This suggests that it is different behavioral response of trace making animal to wave motion from the most of other forms.

Lockeia ichnosp. 2

Fig. 3 - E, 7 - B

Occurrence—Middle part of the Yeongheung Formation, Omandong, Mungokri, Yeongweolgun, Kangweondo, Korea.

Material—Ten specimens are deposited in the Paleontological Collections of Department of Earth Sciences, KNUE.

Description—Irregular forms, asymmetrical, tapering at both ends; length up to 21 mm, width up to 4 mm. Preserved in concave epirelief and convex hyporelief.

Remarks—The irregular forms may consist of real irregular forms which seem to be related with superimposing of animals behaviors and of apparent irregular forms which seem to be produced by superimposing or connecting with two or more forms.

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REFERENCES

- Bandel, K., 1967, Trace fossils from two upper Pennsylvanian sandstones in Kansas. Univ. Kansas Paleont. Contrib., Paper 18, 1 - 13.
- Bromley, R., and Asgaard, U., 1979, Triassic fresh water ichnocoenoses from Carlsberg Fjord, East Greenland. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 28, 39-80.
- Chamberlain, C. K., 1971, Morphology and ethology of trace fossils from the Ouachita Mountains, southeast Oklahoma. *Jour. Paleont.*, 45, 29 - 32.
- Crimes, T. P., Goldring, R., Homewood, P., Van Stuijvenberg, J., and Winkler, W., 1981, Trace fossil assemblages of deep - sea fan deposits, Gurnigel and Schlieren flysch (Cretaceous - Eocene), Switzerland. *Ecol. Geol. Helvet.*, 74, 953 - 995.
- Eagar, R. M. C., Okolo, S. A., and Walters, G. E., 1983, Trace fossils as evidence in the evolution of Carbonicola. *Proc. Yorkshire Geol. Soc.*, 44, 283 - 303.
- Ekdale, A. A., Bromley, R. G., and Pemberton, S. G., 1984, Ichnology, The Use of Trace Fossils in Sedimentology and Stratigraphy. *Soc. Econ. Paleont. Min.*, 317p.
- El-Khayal, A. A., and Romano, M., 1988, A revision of the upper part of the Saq Formation and Hanadir Shale (Lower Ordovician) of Saudi Arabia. *Geol. Magaz.*, 125, 161 - 174.
- Fillion, D. and Pickerill, R. K., 1990, Ichnology of the Upper Cambrian (?) to Lower Ordovician Bell Island Formation and Wabana groups of eastern Newfoundland, Canada, *Palaeontogr. Canad.* No.7, 119p.
- GICTR (Geological Investigation Corps of Taebaegsan Region), 1962, Geologic map of Yeongweol.
- Häntzschel, W., 1975, Trace fossils and problematica. In Teichert, C. (ed.), *Treatise on Invertebrate Paleontology, Part W, Miscellanea, Supplement 1.* Geol. Soc. Am. Univ. Kansas Press, 1 - 269.
- James, U. P., 1879, Description of new species of fossils and remarks on some others, from the Lower and Upper Silurian rocks of Ohio. *The Paleontologists*, 3, 17 - 24.
- Karaszewski, W., 1974, A new trace fossil from the Lower Jurassic of the Holy Cross Mountains. *Bull. Acad. Polon. Sci., Ser. Sci. de la Terre*, 22, 157 - 160.
- Kim, J. Y., Seo, Y. S., and Park, S. I., 1992, Trace fossils from the Middle Ordovician Yeongheung Formation, Yeongweol, Korea. *Korean Jour. Earth Science*, 13, 313 - 326.
- Kobayashi, T., 1966, The Cambro - Ordovician formations and faunas of South Korea. Part X, Stratigraphy of Chosen Group in Korea and South Manchuria and its relation to the Cambro - Ordovician formations of other areas. Section A. The Chosen Group of South Korea. *Jour. Fac. Sci., Univ. Tokyo, Sec. II*, 16, 1 - 84.
- Lee, H. Y., 1979, A study on biostratigraphy and bioprovince of the Middle Ordovician conodonts from South Korea with special reference to the conodonts from the Yeongheung Formation. *Jour. Geol. Soc. Korea*, 15, 121 - 150.
- Osgood, R. G., 1970, Trace fossils of the Cincinnati Area. *Palaeontogr. Am.*, 6, 281 - 444.
- Pickerill, R.G., 1977, Trace fossils from the Upper Ordovician (Caradoc) of the Berwyn Hills, Central Wales. *Geol. Jour.* 12, 1 - 16.
- Pienkowski, G., 1985, Early Liassic trace fossil assemblages from the Holy Cross Mountains, Poland: their distribution in continental and marginal marine envi-

- ronments. In Curran, H. A. (ed.), *Biogenic Structures: Their Use in Interpreting Depositional Environments*. Soc. Econ. Paleont. Min. Spec. Pub. 35, 37 - 51.
- Seilacher, A., 1953, *Studien zur Palichnologie II. Die fossilen Ruhespuren (Cubichnia)*. Neues Jahrb. Geol. Paleont., Abhandl., 98, 87 - 124.
- Vossler, S. M., and Pemberton, S. G., 1988, *Ichnology of the Cardium Formation (Pembina Oilfield): implications for depositional and sequence stratigraphic interpretations*. In James, D. P., and Leckie, D. A. (eds.), *Sequences, Stratigraphy, Sedimentology: Surface and Subsurface*. Canad. Soc. Petrol. Geol., Memoir 15, 237 - 254.
- Wincierz, J., 1973, *Kustensedimente und Ichnofauna aus dem oberem Hettangium von Mackendorf (Niedersachsen)*. Neues Jahrb. Geol. Paleont. Abhandl., 98, 104 - 141.
- Yang, S., 1984, *Silurian trace fossils from the Yangzi Gorges and their significance to depositional environments*. Acta Palaeont. Sinica, 23, 705 - 714.
- Yoo, C. M., 1991, *Depositional environments of the Yeongheung Formation (Middle Ordovician)*. Master Thesis, Seoul National University, 119p.

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