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Lockeia gigantus ichnosp. nov. in the Lacustrine Deposits of the Early Cretaceous Jinju Formation, Southern Coast of Korea

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남해안 전기 백악기 진주층의 호성 퇴적층에서 산출된 *Lockeia gigantus* ichnosp. nov.

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Abstract: About 450 specimens of *Lockeia* were discovered from the lacustrine siltstone of the Early Cretaceous Jinju Formation of Jin Island, southern coast of Korea. They are very elongated, seed-shaped *Lockeia* characterized by a large size, mostly 60-70 mm long and 15-20 mm wide. They are characteristically sharp longitudinal furrow bounded by steeply inclined both margins, elevated marginal rims and sharp pointed both longitudinal furrow ends. This trace fossil is herein described as *Lockeia gigantus* ichnosp. nov. *Plicatounio*, a freshwater bivalve which does not occur occurs occasionally within *Lockeia gigantus* is regarded as the most-likely producer of this resting trace fossil. This new trace fossil represents the largest *Lockeia* ever known and the first record of *Lockeia* from the Cretaceous non-marine deposits in the world. This fossil also represents an unusual example of resting trace fossil (*Lockeia*) associated with a possible producer (bivalve *Plicatounio*) lived in community in the shallow lacustrine environment.

Keywords: *Lockeia gigantus* ichnosp. nov., *Plicatounio*, non-marine, Jinju Formation, Cretaceous, Korea

요 약: 남해안의 경남 진도에 분포하는 전기 백악기 진주층의 호성 실트암에서 약 450여 개의 생흔 화석 *Lockeia*가 발견되었다. 이 생흔 화석들은 상당히 길쭉한 씨앗 모양이며, 대부분 길이가 60-70 mm, 폭이 15-20 mm이다. 그들은 특징적으로 날카로운 세로 고랑이 양쪽 가장자리에서 급하게 경사진 부분과 접하며, 주변부는 융기되어 있고, 세로 고랑의 양쪽 끝부분은 뾰족하다. 이 생흔 화석은 신종인 *Lockeia gigantus* ichnosp. nov.로 기재한다. *Lockeia gigantus*와 함께 드물게 발견되는 담수 이매패류인 *Plicatounio*는 이 휴식 생흔 화석의 가장 유력한 생성자로 판단된다. 이 신종 생흔 화석은 현재까지 알려진 *Lockeia* 중에서 가장 크고 백악기 육성 퇴적층에서 세계적으로 처음 보고된 *Lockeia*이다. 이 화석은 또한 얕은 호수 환경의 생물 군집에서 살았던 생흔 화석 생성자 (이매패류인 *Plicatounio*)와 관련된 휴식 생흔 화석의 특이한 예이다.

주요어: *Lockeia gigantus* ichnosp. nov., *Plicatounio*, 비해성, 진주층, 백악기, 한국

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 *Lockeia* was originally interpreted as an alga (James, 1879), it is now considered to be a resting

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trace of burrowing pelecypods (e.g. Seilacher, 1953; Osgood, 1970; Häntzschel, 1975; Vossler and Pemberton, 1988). *Lockeia* has received considerable attention in interpreting the life history, ecology, and ethology of bivalves (e.g. Eagar et al., 1983).

As shown in Table 1, there are numerous occurrences of *Lockeia* from fluvial to deep marine deposits from the Precambrian to Cretaceous age in North America (USA and Canada), Europe (U.K., Germany, Poland, and Switzerland), and Asia (Saudi Arabia, Tibet, and Korea). However, few analyses on its mode of formation exist.

Eight ichnospecies of *Lockeia, L. siliquaria* James, 1879, *L. amygdaloides* Seilacher, 1953, *L. ornatus* Bandel, 1967, *L. czarnockii* Karazewski, 1974, *L. elongatus* Yang, 1984, *L. avalonensis* Fillion and Pickerill, 1990, *L. cordata* Rindsberg, 1994, and *L. triangulichnus* Kim, 1994, are recognized in the current literature. *L. ornatus* characterized by its surface ornamentation (Bandel, 1967) and *L. czarnockii*, characterized by its large size and drop-shaped form (Pienkowski, 1985) have been reported only from their type localities. *L. elongatus* is smooth, characteristically thin and elongate (Yang, 1984). *L. avalonensis* is a spherical, sub-ovate, squat *Lockeia* with an evenly rounded surface (Fillion and Pickerill, 1990). *L. triangulichnus* is a triangular trace resembling a small pyramid (Kim, 1994). *Lockeia 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; Kim, 1994). *L. cordata* is a heart-shaped to a arrowhead-shaped *Lockeia* with nearly smooth surface (Rindsberg, 1994).

Most *Lockeia* populations consist of clusters of individual traces belonging to the same ichnospecies (e.g. James, 1879; Seilacher, 1953; Osgood, 1970). A unique population including a new trace fossil with numerous and diverse forms of *Lockeia* including *L. siliquaria, L. amygdaloides,* and *L. triangulichnus* was reported in Yeongweol, Korea (Kim, 1994).

The purpose of this paper is to describe a new species of *Lockeia, L. gigantus* ichnosp. nov. unusually associated with bivalves from the Cretaceous non-marine deposits of Korea. Like a very common situation in ichnology, there has been considerable debates on the producing animal of *Lockeia*. Although bivalves have been generally regarded as probable producers of some forms of *Lockeia*, bivalves associated with *Lockeia* have rarely been reported.

Geologic Setting

The Cretaceous Gyeongsang Supergroup occurs within the Gyeongsang Basin and several small basins (Haenam, Neungju, Jinan, Kyokpo, Yongdong, Kongju, and Eumsung). The Gyeongsang Basin, the largest sedimentary basin of Korea, is located in the south-eastern part of the Korean Peninsula.

The Gyeongsang Supergroup is divided into the Sindong, Hayang, and Yucheon groups. The first two groups consist mainly of thick siliciclastic sequences of alluvial, fluvial and lacustrine sediments, and the Yucheon Group characterized by the dominance of volcanic rocks (Chang, 1975; Fig. 1). The Sindong Group is confined to the western margin of the Gyeongsang Basin with general trends to the NNE (Nagdong Trough, 2,000 to 3,000 m thick). The Sindong Group consists of the Nagdong, Hasandong, and Jinju formations, generally showing a fining-upward trend and three facies associations characterized as alluvial fan fringe, fluvial system, and shallow lake (Choi, 1986a, 1986b, 1986c). The source areas of the Sindong sediments have been revealed to WNW of the basin by paleocurrent analysis (Chang and Kim, 1968; Cheong and Kim, 1996). The occurrence of calcisol and vertisol indicates that climates during the Sindong deposition were arid to semi-arid (Paik and Lee, 1994, 1998; Paik and Kim, 1995). Abundant plant fossils collected from the Nagdong Formation were correlated from the floras of the Cretaceous Tetori Group in Japan (Tateiwa, 1925, 1929). The Sindong molluscan faunas have been studied extensively and all are assigned to non-marine taxa

Table 1. Record of *Lockeia* (or *Pelecypodichnus*)

Author(s)	Geologic Age	Strata	Environment	Locality	Width/Length	Remarks
Crimes et al., 1981	Eocene	Gurnigel Flysch	deep-sea fan	Switzerland	8/15	*P. siliquaria*
Crimes, 1977	Paleocene	Jaizkibel	deep-sea sand fan	Spain	(25)/(45)	*Pelecypodichnus*
Vossler and Pemberton, 1988	L. Cretaceous	Cardium Fm	offshore	Alberta, Canada		*Lockeia*
Kamola, 1984	L. Cretaceous	Blackhawk Fm	lagoon	Utah, USA		*Pelecypodichnus*
MacEachern et al., 1998	E. Cretaceous	Viking Fm	marginal marine	Alberta, Canada		*Lockeia*
MacEachern et al., 1994	E. Cretaceous	Viking Fm	estuary	Alberta, Canada		*Lockeia*
MacEachern et al., 1999a	E. Cretaceous	Viking Fm	lagoon to open marine shelf	Alberta, Canada		*Lockeia*
MacEachern et al., 1999b	E. Cretaceous	Viking Fm	marginal marine	Alberta, Canada		*Lockeia*
MacEachern et al., 1999c	E. Cretaceous	Viking Fm	marginal marine	Alberta, Canada		*Lockeia*
Wincierz, 1973	E. Jurassic	Mesozoic Hills	intertidal	Germany	(10)/(20)	*P. amygdaloides*
Piekowski, 1985	E. Jurassic	Skłoby Fm	brackish marine	Poland	8/20	*P. amygdaloides*
Piekowski, 1991	E. Jurassic	Helsingborg Member	lacustrine	Sweden	(13)/(18)	*P.* sp.
Seilacher, 1953	Jurassic	Donzdorfer Sandstone	shallow marine	Germany	(5)/(10)	*P. amygdaloides*
Wright and Benton, 1987	L. Triassic	Westbury Fm	non-marine	England	4-5/5-12	*Pelecypodichnus*
Bromley and Asgaard, 1979	Triassic	Fleming Fjord Fm	lake and fluvial	Greenland	6.5/15	*P. amygdaloides*
Rindsberg, 1994	L. Carboniferous	Hartselle Sandstone	shelf	Alabama, USA	0.7-3.5/2.1-8 14(26)/23(48)	*L. siliquaria* *L. cordata*
Maples and Suttner, 1990	L. Carboniferous	Fountain Fm	shoreface	Colorado, USA	1-3/3-7	*L.* sp.
Bandel, 1967	L. Carboniferous	Stranger Fm	littoral	Kansas, USA	(8)/(15)	*P. ornatus*
Archer and Maples, 1984	L. Carboniferous	Granerous Sh	nearshore-offshore	Kansas, USA		*Pelecypodichnus*
Hakes, 1976	L. Carboniferous	Tecunseh Sh, Kanwaka Sh, Stanton Ls	shallow marine to fresh water	Kansas, USA	1-3/2-10	*Lockeia*
Hakes, 1985	L. Carboniferous	Lawrence Fm, Stanton Ls	freshwater-brackish water	Kansas, USA	1.5/4	*Pelecypodichnus*
Miller, 1984	L. Carboniferous	Fentress Fm, Rockcastle Cg	back barrier	Tennessee, USA	(3)/(7)	*Pelecypodichnus*
Hardy, 1970	L. Carboniferous	Lower Mt. Mine		England		*Pelecypodichnus*

Table 1. Continued

Author(s)	Geologic Age	Strata	Environment	Locality	Width/Length	Remarks
Eagar, 1971	L. Carboniferous	Haslingden Flags	delta	England		*Pelecypodichnus*
Eagar et al., 1983	L. Carboniferous	Kinderscout Grit	bay	England	2.5-8/4-17	*Pelecypodichnus*
Eagar et al., 1985	L. Carboniferous	Silesian rocks	delta	England	(5)/(10)	*P. amygdaloides*
Chamberlain, 1971	L. Carboniferous	Atoka Fm	littoral	Oklahoma, USA	(9)/(20)	*L. siliquaria*
Chamberlain, 1978	L. Carboniferous	Atoka Fm	estuarine-nearshore	Oklahoma, USA	(9)/(20)	*Pelecypodichnus*
Chaplin, 1980	E. Carboniferous	Borden Fm	coastal	Kentucky, USA		*Lockeia*
Chaplin, 1982	E. Carboniferous	Borden Fm	delta front	Kentucky, USA	(4)/(8)	*Lockeia*
Bjerstedt, 1987	E. Carboniferous	Price Fm	nearshore	Virginia, Pennsylvania, and Maryland, USA	<8/<20	*Pelecypodichnus*
Bjerstedt, 1988	E. Carboniferous	Price Fm	delta plain	Virginia, USA	<4/<10	*Pelecypodichnus*
Thoms and Berg, 1985	Devonian	Catskill Fm	fluvial	Eastern USA	7.5-10/10-20	*bivalve trace fossil*
Gong and Liu, 1993	Devonian	Zhifang Fm	neritic	Xingjiang, China		*Pelecypodichnus*
Costa and Muniz, 1979	Devonian	Inaj Fm	littoral-offshore	Brazil	5/10-15	*Lockeia* sp.
James, 1879	Silurian	Cincinnati Group	shallow marine	Ohio, USA	<1/3-13	*L. siliquaria*
Yang, 1984	Silurian		shallow marine	Hubei, China	10/35	*P. elongatus*
Fillion and Pickerill, 1990	L. Cambrian? -Ordovician	Bell Island and Wabana Group	delta-offshore tidal flat-lagoon	Newfoundland, Canada	4.5/7 2-4/6.5-18	*L. avalonensis* *L. siliquaria*
El-Khayal and Romano, 1988	E. Ordovician	Saq Fm	offshore	Saudi Arabia	4-6/<10(13)	*P.* cf. *siliquaria*
Osgood, 1970	Ordovician	Latonia Fm	shallow marine	Utah, USA	3/12	*L. siliquaria*
Kim, 1994	Ordovician	Yeongheung Fm	lagoon-offshore	Korea	2.3-6.2/6.5-12.5 3/10 4/8	*L. amygdaloides* *L. siliquaria* *L. triangulichnus*
Pickerill, 1977	Ordovician	Upper Cwm Rhiwath Siltstones	inshore-offshore	Wales	7/27	*L. siliquaria*
Narbonne and Aitken, 1990	Ediacaran	Blue Flower Fm	deep-sea fan	Mackenzie Mt., NW Canada	2.7/5.2	*Lockeia* isp.

	Geological Age	Gyeongsang Basin	
Gyeongsang Supergroup	Campanian	Youcheon Group	Volcanic Rocks
	Albian	Hayang Group	Jindong Formation
			Haman Formation
			Silla Conglomerate
	Aptian		Chilgok Formation
	Barremian	Sindong Group	Jinju Formation
			Hasandong Formation
	Hauterivian		Nagdong Formation

Fig. 1. Stratigraphy of the Gyeongsang Supergroup (after Chang, 1987).

(Yang, 1974, 1975, 1976, 1978a, 1978b, 1979, 1982). In addition, charophytes and non-marine ostracodes were also recovered from the Nagdong and Jinju formations, respectively (Choi, 1989, 1990). The age of the Sindong Group has been determined as Aptian to Albian by molluscan faunas (Yang, 1982) and as Hauterivian to Barremian by palynomorphs (Choi, 1985, 1989; Yi et al., 1994).

The Hayang Group overlies the Sindong Group in the western part of the Gyeongsang Basin and directly overlies pre-Cretaceous rocks in the northern part of the Gyeongsang Basin. This group (1,000 to 5,000 m in thickness) was deposited through subsiding and eastward expansion of the basin. It is composed of shale, sandstone interbedded with marlstone and conglomerate, and partly volcanic rocks extruded within the sedimentary basin. The paleocurrent directions indicate that dominant source areas were in the northwest and the east, somewhere in the vicinity of the present East Sea (Chang, 1988; Chang et al., 1990). During the sedimentation of the Hayang Group, the basin was strongly controlled by WNW-trending growth faults, which divided the basement into smaller crustal segments such as the Milyang, Euiseong, and Yeongyang blocks. Therefore, under the influence of these syndepositional movements, the Hayang Group has different stratigraphic sequences from block to block (Chang, 1975, 1977).

The Hayang Group was deposited mainly in fluvio-lacustrine environments more than alluvial plains, an inference supported by abundant channel beds in association with floodplain sediments (Choi, 1986a). However, poorly sorted coarse grains of clastic rocks and prevalent reddish rock color suggest rather purely fluvial environments sometimes. The Hayang climate was generally arid to semi-arid judging from the occurrence of calcrete, rhizolith (Paik and Chun, 1993), and abundant pollen from *Corollina* and *Ephedripites* combined with scarcity of fern spores (Choi, 1985; Yi et al., 1993).

Since 40 specimens of plant fossils were reported from the Geoncheonri Formation and correlated with the Monobegawa Group and the Gyliak Series (Late Jurassic to Early Cretaceous) in Japan (Tateiwa, 1925, 1929), Hayang plant fossils have been recovered from the Geoncheonri, Daegu, and Iljik formations (Choi, 1989, 1990). Angiosperm pollens such as *Retimonocolpites*, *Clavatipollenties*, and *Tricolpites* from the Geoncheonri and Iljik formations suggest that the Hayang Group is Aptian to early Albian in age (Choi, 1985, 1989; Yi et al., 1994).

The Yucheon Group (2,000 to 3,000 m thick), unconformably overlying the Hayang Group, consists of volcanic and associated sedimentary rocks. No fossils are known so far from the Yucheon Group and its ^{40}K / ^{40}Ar radiometric age is 83 Ma (Doh and Kim, 1994).

The Jin Island, the fossil locality of *Lockeia*, is located in the Hallyo Haesang National Park of the southern coast of the Korean Peninsula. The fossil site is located about 5 km west from the dinosaur track site (Lockley et al., 2006), world-famous Deogmyeongri of Sacheon City. The Jin Island is small, up to about 500 m in north-south length, and located in Bitori, Seopo-myeon, Sacheon City (Fig. 2). The fossil locality is placed at 128° 58' 26" E, N 34° 57' 34" in the southwest of the island.

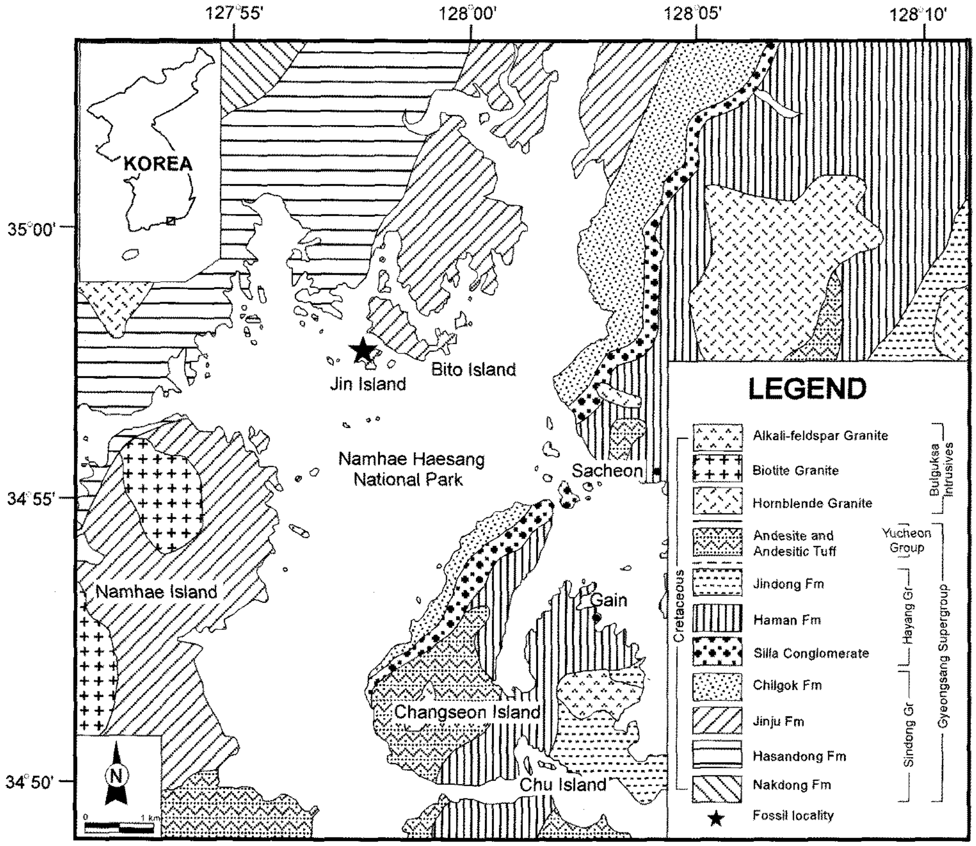

Fig. 2. Geologic map showing fossil locality (asterisk) (Kim et al., 1998 and Choi et al., 2002).

In the Jin Island, non-marine mollusks such as *Trigonioides*, *Plicatounio*, and *Viviparus*, theropod and sauropod tracks, and diverse types of stromatolites were observed from the Jinju Formation. In the fossil locality of the Jin Island, the lower part of the Jinju Formation predominately composed of mudstone infrequently intercalated with thin fine-grained sandstone. Strike and dip of fossil-bearing sandstone bed, probably deposited in the lacustrine margin environment, are N30°E and 20°SE.

Occurrence of *Lockeia*

Over 450 specimens of *Lockeia* are observed on the bedding surface in an area with about 500 cm in maximum length and 242 cm in maximum width (Fig. 3). Thus, fossil-bearing bed is about 6 m^2 in area and density of *Lockeia* is about 82/m^2. Assuming that the length of *Lockeia gigantus* is approximately five times those of currently well-known *Lockeia* (Fig. 4), it appears that the density of *Lockeia gigantus* specimens is regarded to be very high. It appears highly probable that these trace fossils were produced by communities of bivalves.

All specimens of *Lockeia* were measured and plotted in length-width diagram (Table 2, Fig. 3). The length of *Lockeia* is highly variable, ranges between 18 mm and 100 mm and about 50 mm in average. The width changes from 4 mm to 33 mm and about 13 mm in average. As shown is Fig. 4, it would appear that these are different size classes, perhaps representing cohorts of different ages, as the similar cases to the *Pelecypodichnus* from the uppermost Triassic rocks of Staffordshire of England (Wright and Benton, 1987). There may be eight size classes represented here, with modes correspond to 18-28, 29-34, 35-44, 45-57, 58-

Table 2. Measurement of length (L), width (W), and orientation (O) of *Lockeia* specimens from the Jinju Formation

No	L (mm)	W (mm)	O (°)	No	L (mm)	W (mm)	O (°)	No	L (mm)	W (mm)	O (°)	No	L (mm)	W (mm)	O (°)
1	49	13	85	56	71	10	-30	111	42	15	19	166	41	11	7
2	58	20	85	57	39	15	70	112	61	9	16	167	32	9	-7
3	65	15	-70	58	60	12	-40	113	53	8	-69	168	61	12	-26
4	51	13	80	59	50	9	-35	114	59	11	18	169	52	8	-59
5	45	10	-80	60	45	15	27	115	45	13	43	170	62	14	11
6	48	9	53	61	50	11	-35	116	54	12	16	171	21	11	64
7	45	11	68	62	40	11	80	117	55	19	55	172	41	13	78
8	50	15	-28	63	40	10	60	118	44	11	53	173	52	21	-60
9	59	15	4	64	39	12	20	119	52	10	21	174	32	12	23
10	45	12	21	65	55	9	90	120	43	15	65	175	43	11	79
11	40	11	76	66	54	15	12	121	51	12	40	176	43	18	73
12	52	15	54	67	50	12	-10	122	42	9	81	177	42	11	24
13	40	12	70	68	22	8	50	123	33	11	29	178	24	7	43
14	52	5	-15	69	35	10	-57	124	41	12	79	179	41	9	-68
15	68	12	-35	70	43	9	15	125	43	8	31	180	42	10	28
16	47	13	56	71	47	10	-30	126	59	5	-53	181	42	15	-36
17	23	8	-75	72	38	9	44	127	32	11	-80	182	51	12	4
18	48	13	75	73	45	9	-70	128	31	6	-23	183	41	22	29
19	45	15	-71	74	20	5	25	129	42	8	70	184	32	12	27
20	30	8	-65	75	18	5	-45	130	39	11	-89	185	41	11	90
21	63	20	30	76	41	8	90	131	51	9	16	186	32	5	-73
22	42	12	15	77	38	8	0	132	32	12	56	187	31	11	38
23	22	5	-80	78	60	8	-25	133	62	11	-31	188	34	10	44
24	37	10	5	79	68	9	-47	134	31	9	68	189	42	11	26
25	40	9	-75	80	49	12	-67	135	42	11	29	190	24	16	73
26	45	9	-50	81	40	8	-35	136	31	8	-75	191	51	12	25
27	73	10	-60	82	40	12	-70	137	41	7	-38	192	61	11	-19
28	60	15	63	83	33	9	90	138	40	11	-89	193	31	9	-11
29	35	8	24	84	28	7	-88	139	41	10	36	194	42	11	18
30	55	19	-81	85	30	8	-88	140	35	11	69	195	41	11	-68
31	27	7	15	86	47	8	-53	141	41	9	4	196	53	10	-73
32	51	9	-34	87	40	12	23	142	43	10	78	197	42	11	-78
33	49	9	-84	88	47	10	0	143	51	11	-17	198	21	8	-86
34	45	13	82	89	25	9	60	144	42	22	47	199	23	7	-87
35	31	8	-75	90	25	8	-10	145	61	15	-14	200	71	8	-45
36	38	12	-38	91	30	13	62	146	53	10	5	201	39	9	-34
37	40	10	-15	92	40	10	35	147	61	15	-19	202	31	8	-90
38	45	8	23	93	59	8	82	148	25	12	82	203	59	11	-27
39	38	7	-75	94	38	10	-8	149	82	13	-39	204	29	9	0
40	56	15	78	95	45	9	-36	150	62	9	-18	205	45	12	-2
41	49	10	90	96	40	9	54	151	31	11	9	206	24	11	64
42	51	15	80	97	49	10	-20	152	42	11	-16	207	21	5	-13
43	48	10	57	98	48	10	23	153	41	7	-40	208	34	10	29
44	47	9	-53	99	32	9	38	154	73	12	-41	209	62	9	84
45	45	12	50	100	50	9	-65	155	32	11	21	210	33	10	52
46	49	8	25	101	45	15	70	156	42	4	-49	211	48	8	-44
47	28	8	56	102	42	9	15	157	52	11	-6	212	38	9	54
48	25	7	30	103	35	8	-78	158	51	11	-62	213	21	11	-87
49	38	10	40	104	35	10	43	159	41	12	10	214	53	18	82
50	34	9	0	105	40	10	48	160	49	11	0	215	47	9	-23
51	48	8	-20	106	31	9	72	161	38	11	51	216	31	11	-3
52	45	9	80	107	29	7	-86	162	32	9	-41	217	42	11	81
53	50	18	90	108	38	8	80	163	21	4	37	218	35	12	32
54	29	13	-70	109	49	8	-23	164	31	11	69	219	21	7	26
55	60	25	55	110	41	9	71	165	39	8	-22	220	24	9	62

Table 2. Continued

No	L (mm)	W (mm)	O (°)	No	L (mm)	W (mm)	O (°)	No	L (mm)	W (mm)	O (°)	No	L (mm)	W (mm)	O (°)
221	42	9	24	279	43	18	52	337	50	25	70	395	50	15	55
222	41	11	71	280	47	8	-2	338	45	10	80	396	80	15	15
223	38	10	-88	281	39	15	-86	339	45	8	55	397	60	15	-37
224	41	11	15	282	42	15	-88	340	70	20	45	398	50	10	-10
225	72	11	-43	283	56	12	8	341	50	8	90	399	40	5	-35
226	70	25	9	284	62	15	43	342	60	10	40	400	60	10	-77
227	40	11	-76	285	52	25	53	343	55	10	-65	401	45	10	90
228	45	12	-74	286	30	9	-70	344	75	20	38	402	45	15	90
229	35	8	-76	287	40	9	10	345	60	10	12	403	50	15	-25
230	40	9	-78	288	30	8	-66	346	100	20	-10	404	50	15	-52
231	35	9	10	289	30	8	12	347	65	10	0	405	75	15	-28
232	38	10	11	290	30	8	-72	348	60	10	0	406	50	20	54
233	35	10	90	291	35	10	59	349	70	10	0	407	55	15	-58
234	67	10	-47	292	30	7	-27	350	55	15	82	408	60	20	-72
235	58	17	68	293	45	7	-32	351	80	15	0	409	65	15	-10
236	50	10	14	294	42	10	12	352	70	20	22	410	50	20	74
237	42	16	61	295	25	8	13	353	90	15	15	411	45	25	43
238	35	9	68	296	40	15	33	354	65	10	5	412	65	20	0
239	52	14	-54	297	42	15	85	355	60	20	10	413	55	20	-82
240	66	10	-55	298	49	8	-4	356	45	15	8	414	40	15	-72
241	78	21	-24	299	31	10	37	357	45	15	40	415	60	15	-68
242	51	15	-90	300	40	8	-44	358	70	25	-80	416	65	10	-36
243	50	12	64	301	34	8	-36	359	60	20	50	417	45	20	40
244	43	12	-82	302	35	11	66	360	50	20	70	418	55	10	0
245	51	12	-87	303	55	18	66	361	60	15	20	419	50	10	32
246	45	15	60	304	63	15	-27	362	70	20	90	420	40	20	28
247	58	11	73	305	90	23	5	363	50	20	78	421	55	15	49
248	62	14	-13	306	45	9	29	364	45	15	62	422	50	15	0
249	55	25	27	307	48	15	-82	365	40	10	-15	423	40	10	65
250	38	9	7	308	49	12	-74	366	60	25	38	424	40	5	40
251	65	19	-8	309	49	14	-88	367	45	10	85	425	50	10	28
252	45	15	19	310	31	15	-90	368	45	15	68	426	60	15	-62
253	61	25	28	311	40	12	43	369	70	15	90	427	45	10	-5
254	58	17	-56	312	49	15	90	370	40	20	58	428	50	15	-30
255	37	15	40	313	42	9	22	371	90	30	-47	429	40	10	60
256	40	18	-62	314	50	12	90	372	70	20	-5	430	40	10	70
257	58	10	-57	315	60	12	-65	373	30	15	45	431	45	15	30
258	50	15	-85	316	49	10	90	374	60	15	27	432	45	20	62
259	38	10	-83	317	50	12	90	375	60	20	27	433	40	15	56
260	45	9	-66	318	40	12	68	376	60	20	48	434	55	25	55
261	50	10	-43	319	70	20	36	377	60	20	-88	435	45	10	88
262	77	16	-43	320	50	20	46	378	65	26	0	436	45	20	42
263	40	7	45	321	40	10	64	379	50	25	25	437	40	20	40
264	38	12	81	322	50	15	75	380	65	20	47	438	40	10	40
265	59	10	-28	323	60	20	57	381	55	20	38	439	50	15	75
266	65	11	-35	324	50	10	90	382	60	15	12	440	45	15	90
267	52	15	-18	325	70	12	90	383	70	15	-45	441	35	15	90
268	37	9	75	326	50	10	90	384	50	20	55	442	30	10	62
269	48	12	-73	327	70	12	70	385	60	30	25	443	60	10	0
270	35	8	38	328	70	20	-65	386	75	25	0	444	40	10	50
271	32	9	53	329	60	20	38	387	65	15	-13	445	35	10	35
272	42	10	84	330	70	25	-72	388	65	15	-28	446	50	15	75
273	39	9	84	331	60	25	58	389	30	20	46	447	40	10	70
274	41	15	27	332	70	30	-85	390	60	15	-8	448	45	10	12
275	30	8	41	333	60	15	90	391	50	10	90	449	20	10	50
276	51	16	75	334	60	15	20	392	50	20	62	450	35	10	-60
277	62	9	-58	335	70	20	0	393	50	10	33				
278	48	8	-52	336	80	10	20	394	40	5	90				

※ Note: Zero degree in orientation represents north. (-) represents west.

Fig. 3. Drawing of *Lockeia* on the bedding surface.

64, 65-74, 75-83, and 91-100 mm. Fig. 4 also shows the length/width of *Lockeia* previously reported by others showing the measured data for comparing *Lockeia gigantus* which is remarkably larger in size.

The specimens show preferred orientation faintly though it varies from place to place (Fig. 5). NNE-SWW and NEE-SWW trending orientations are most predominate, however, NW-SW orientation is also conspicuous. Orientations may be related to either a feeding and resting behavior or a more stable posture, like their analogues in modern and ancient streams and rivers (Pryor, 1967; Eagar et al., 1983). The relationship between preferred orientation and lake shoreline appears to be not ruled out, though sedimentary features indicating paleocurrent are not observed.

All of *Lockeia* specimens are preserved as concave epirelief on the fine-grained sandstone bed. Many of them are characterized by symmetrical, seed-like to almond-shaped forms commonly with a sharp longitudinal furrow and elevated marginal rims (Fig. 6), like plow-up ridges observed in modern environment (Pryor, 1967).

Systematic Description

Lockeia gigantus ichnosp. nov.
Fig. 6

Type material: Holotype (Fig. 6D) KNUE 060701, paratypes (Fig. 6B, E) KNUE 060702, 060703, same horizon and same locality as holotype. Silicon rubber mold are housed in the Paleontological Collections of Department of Earth Science Education, Korea National University of Education (KNUE).

Other material: about five hundreds specimens in the field at fossil locality.

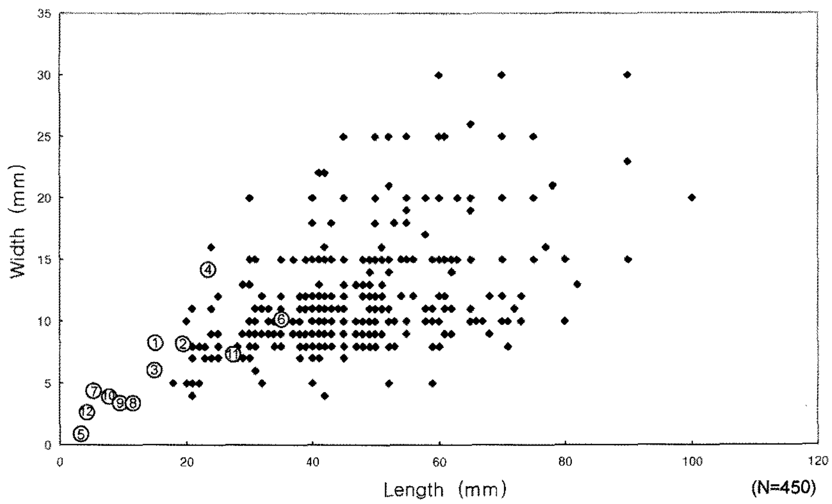

Fig. 4. Length/width diagram of *Lockeia* specimens (N=450) from the Jinju Formation and *Lockeia* or *Pelecypodichnus* previously reported by others (numbered as 1 to 12). 1: *Pelecypodichnus siliquaria* (Crimes et al., 1981), 2: *P. amygdaloides* (Pienkowski, 1985), 3: *P. amygdaloides* (Bromley and Asgaard, 1979) 4: *L. cordata* (Rindsberg, 1994), 5: *P.* (Hakes, 1985), 6: *P. elongatus* (Yang, 1984), 7: *L. avalonensis* (Fillion and Pickerill, 1990), 8: *L. siliquaria* (Osgood, 1970), 9: *L. siliquaria* (Kim, 1994), 10: *L. triangulichnus* (Kim, 1994), 11: *L. siliquaria* (Pickerill, 1977), 12: *L.* isp. (Narbonne and Aitken, 1990)

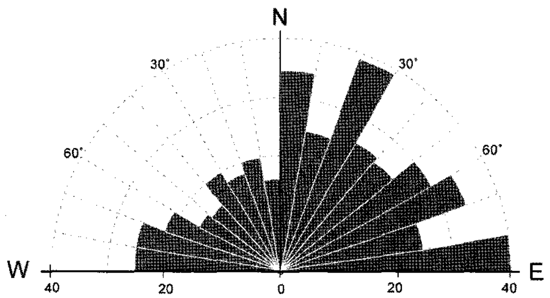

Fig. 5. Orientation of *Lockeia* specimens from the Jinju Formation. Numbers (0, 20, and 40) indicate number of specimens measured.

Derivation of name: After giant, large-sized *Lockeia*.

Occurrence: lower part of the Early Cretaceous Jinju Formation, Jin Island, Bitori, Seopo-myeon, Sacheon City, Korea.

Diagnosis: Large, seed-like to almond-shaped *Lockeia* with length up to 70 mm and width up to 30 mm, preserved as concave epirelief. Longitudinal furrows or grooves commonly developed in the center along the midline of oblong body, which is V- to U-shaped in cross section and sided by elevated marginal rims commonly developed in both sides.

Description: Specimens of *Lockeia gigantus* ichnosp. nov. are preserved as concave epirelief on the 15 cm thick fine-grained sandstone intercalated within thick mudstone. They are typically symmetrical seed-like to almond-shaped, tapering at both ends to a sharp point. Well preserved specimens possess a sharp longitudinal furrow or groove (about 1.5 mm thick) along the elongate body which is V- to U-shaped in transverse section. Many specimens show marginal rims (about 10 mm wide and 5 mm high) elevated at both sides of oblong body. Length ranges between 30 to 70 mm (mostly 40 to 50 mm), width varies from 10 to 30 mm (mostly 10 to 2 mm), and depth is up to about 7 mm.

Remarks: Since *Lockeia* James, 1879, the senior synonym of *Pelecypodichnus*, introduced as an ichnogenus of small almond-shaped oblong bodies tapering to sharp and obtuse points at both ends (Hntzschel, 1975). Although eight ichnospecies of *Lockeia* were erected, neither type material nor diagnosis and measured data were provided for

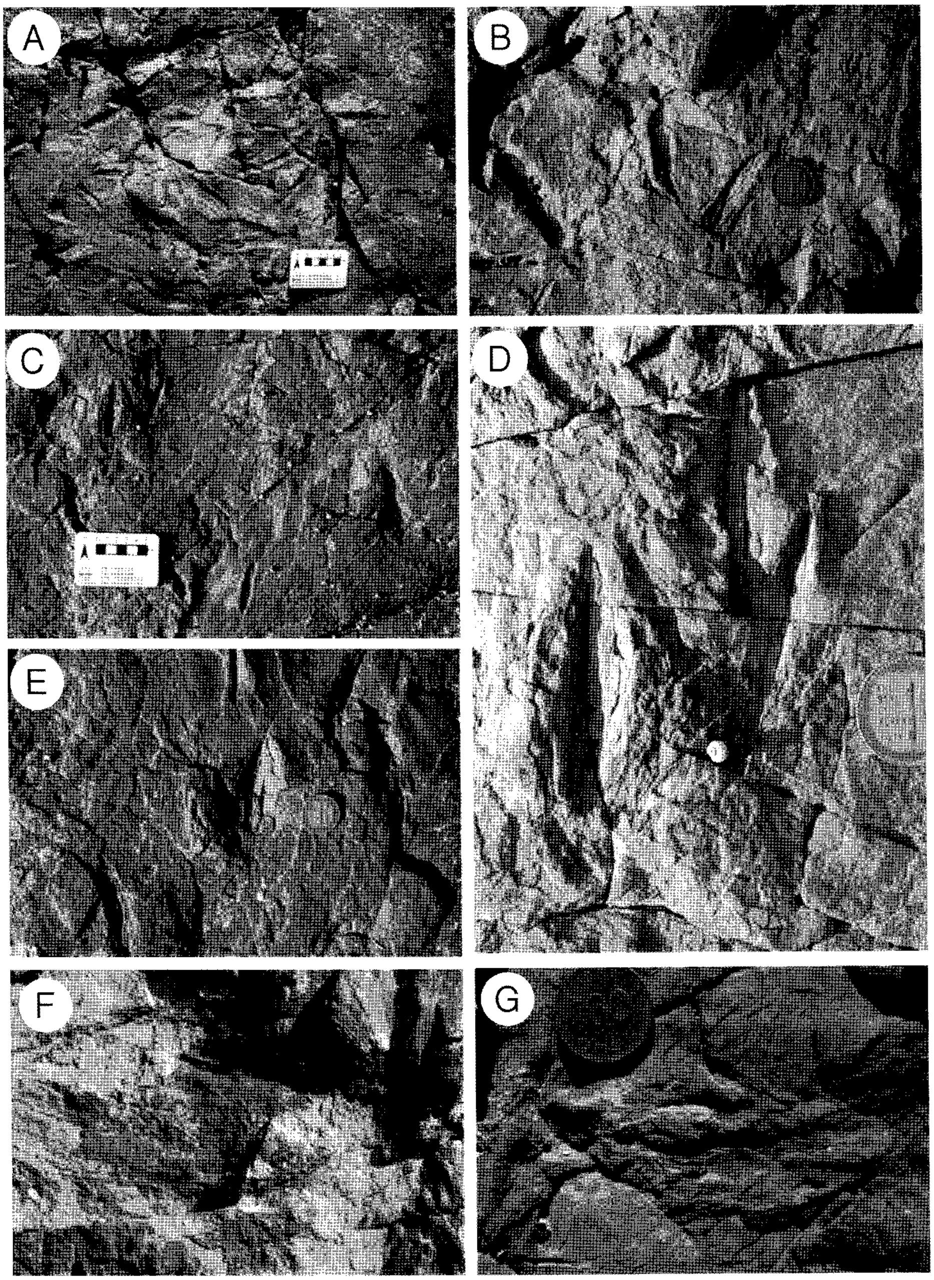

Fig. 6. Outcrop view of *Lockeia gigantus* (A~E) and a possible trace maker, *Plicatounio* sp. preserved *in situ* (F~G).

systematic study on new ichnospecies of *Lockeia*. Whether described features of *Lockeia czarnockii* (Pienkowski, 1985) do or do not fall into diagnostic features of *Lockeia* is also regarded to be questionable in its validity for a new ichnospecies. *Lockeia ornatus* (Bandel, 1967) described from the Pennsylvanian sandstones of Kansas is a questionable ribbed from that may, in fact, belong to *Walcottia* Miller and Dyer 1878 (Fillion and Pickerill, 1990).

Specimens herein assigned to *Lockeia gigantus* have essential features corresponding to diagnosis of ichnogenus *Lockeia*. However, its comparison with currently known ichnospecies is not easy because of its characteristic morphology clearly distinguished from them. As the name of ichnospecies shows, *Lockeia gigantus* is the largest, gigantic *Lockeia* with length up to 70 mm. Most of *Lockeia* species previously reported are small in size; 10 mm (maximum size of holotype of *L. amygdaloides* (Seilacher, 1953), 13 mm (maximum of paratype materials of *L. siliquaria* (Osgood, 1970), 13 mm (El-Khayal and Romano, 1988), 14 mm (Kim, 1994), 15 mm (Crimes et al., 1981), 20 mm (Chamberlain, 1971), and 27 mm (Pickerill, 1977). *Lockeia gigantus* is clearly distinguished from other ichnospecies of *Lockeia* by its large dimension, about three times the largest *Lockeia* ever described, though only size difference is regarded to be insufficient for erection of a new ichnospecies.

The general outline of *Lockeia gigantus* with seed-like to almond-shaped forms tapering at both ends resemble that of *Lockeia siliquaria* and *L. amygdaloides* except the size difference. However, *Lockeia gigantus* is also characterized by prominent longitudinal furrow or groove, V- or U-shaped form in the transverse section, and marginal rims laterally developed at both sides (Fig. 6).

Discussion

Except very rare cases where trace fossils occurred with trace maker, it is very hard to interpret exactly the trace maker only from the trace fossils. Mutual exclusive preservation of trace fossils and trace makers is a very common cases in ichnology.

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 surface ornamentation in each form may be related with the original trace maker and later environmental and diagenetic changes. Some forms with nearly concentric fine ribs or growth lines which may represent the surface ornamentation of original shells may partly be related with the slightly upward or downward movement of animals in response to environmental changes. The longitudinal furrows are considered to be structures representing ventral and lateral commissure of shells, like *Pelecypodichnus* from the Carboniferous strata of England (Eagar et al., 1983).

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 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 is 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.

Most forms show tapering at one end or at both ends which is known as one of diagnosis of *Lockeia* (James, 1879). These tapering ends are supposed to represent the ventral or lateral commissure of shells. The tapering ends of a few specimens are curved 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 orientation, i.e. anterior obliquely down and posterior obliquely up, of shells, whereas tapering at both ends in the specimens from the Jinju Formation may be related with nearly horizontal orientation, i.e. ventral down and dorsal up, of shells.

Hardy (1970), Eagar (1971, 1974), Hudson (1980), Eagar et al. (1983, 1985), Thoms and Berg (1985), and Wright and Benton (1987) recognized the bivalves *Carbonicola, Neomiodon, Archanodon,* and *Eotrapezium* as likely producers of some forms of *Lockeia* from the Carboniferous of England, the Jurassic of Scotland, the Devonian of the eastern USA, and the Triassic of England, respectively.

Over 450 specimens of *Lockeia* are occasionally associated with a bivalve *Plicatounio,* the most-likely producers of them (Fig. 6F). *Plicatounio* is one of the most common bivalves frequently reported from the Early Cretaceous Jinju Formation in the Gyeongsang Basin which has well known as one of the most significant dinosaur track sites in the world (e.g. Yang, 1979; Lockley et al., 2006). *Plicatounio* is a medium sized (about 50 mm in length), elongated elliptical to depressed triangular non-siphonate non-marine bivalve lived on muddy sand in the shallow water. It is characterized by the distinct radial ribs on the surface and the marginal crenation on the inner side of the shell (Suzuk, 1943). Therefore, *Lockeia gigantus* provides some clue for interpretation of fossil behavior (making communities, resting and shallow burrowing) of *Plicatounio* as the most-likely producer of *L. gigantus*.

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