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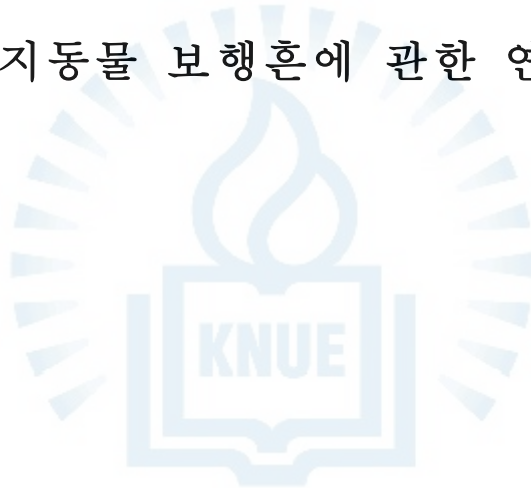
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A Thesis for the Degree of Master

Arthropod trackways from the Pleistocene
sediments of Jeju Island, Korea

제주도 플라이스토세 퇴적층에서 산출된
절지동물 보행흔에 관한 연구



Major in Earth Science Education
Graduate School of Korea National University of
Education

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February 2007

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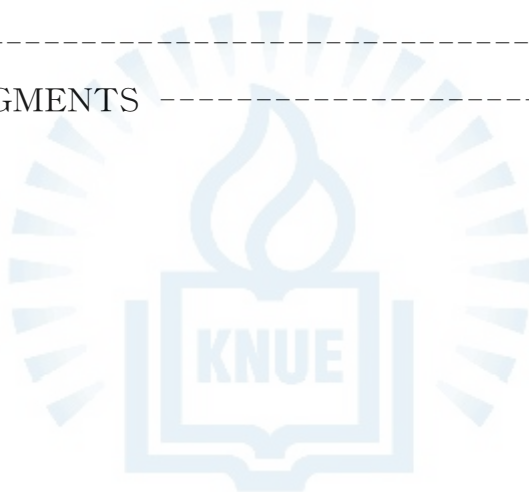
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ABSTRACT

Arthropod trackways from the Pleistocene sediments of Jeju Island, Korea

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Two types of arthropod trackways occurred from the Pleistocene sediments of Jeju Island, Korea where footprints of hominids and other vertebrates were recently reported, are described and interpreted. The living and fossil crab trackways are compared for understanding the paleobiological and paleoenvironmental significance of ichnofossils. The first one is an asymmetrical track without central groove marks and composed of series of three, four or five evenly-spaced elongated imprints about 5 mm in length. It is interpreted to have been formed by small crabs like *Ocypodidae* living in the modern shoreline environment. Second one is a symmetrical trackway with two grooves and track rows. Central parallel grooves are about 2~4 mm apart and continuous or

discontinuous and lateral track rows consists of bow-shaped imprints obliquely oriented. This trackway is somewhat similar in morphology to *Siskemia* and thought to be formed by arthropods resembling *Ligia exotica* which is commonly living in the modern shoreline environment and it drags a telson with two tail spines for two central grooves. Fossil arthropod trackways together with other trace fossils and sedimentological structures such as ripple marks and mud cracks indicate that the sediments were deposited in the shoreline environment.



※ A thesis submitted to the Committee of the Graduate School of Korea National University of Education in partial fulfillment of the requirements for the degree of Master of Education in February, 2007.

I . INTRODUCTION

Trace fossils are important for revealing the diversity and paleoenvironmental distribution of arthropods in the fossil record. Arthropod trackways and trails reveal important evidence of the locomotory capabilities of ancient arthropods, although only the imprints of the distal part of legs are usually preserved, thus limiting interpretation of the producer (Braddy and Briggs, 2002). Two types of arthropod trackways are occurred from the Pleistocene sediments of Jeju Island, Korea where footprints of hominid and other vertebrates were recently reported (Kim et al., 2004). However, despite the frequent observation that living crabs can burrow, walk, rest, and feed, there has been little detailed study of the walking trace they produce.

In this study area, well preserved and diverse trace fossils are abundantly found in outcrop along the coastal line and arthropod trackways discovered from the Hamori Formation of Jeju Island.

The purpose of this study is to describe two fossils arthropod trackways from the Pliestocene sediments, discuss their probable producers and behavior represented, and to interpret the depositional environments of the bearing strata, by comparing the living and fossil arthropod trackways for understanding the paleobiological and paleoenvironmental significance.

II. GEOLOGICAL SETTING

1. Study area and fossil localities

The sedimentary deposits distributed along the coastline of Sagaeri, Jeju Island are recently well known as a fossil locality of hominid footprints (Kim et al., 2004). It is composed of reworked tuffaceous sediments, about 2 m thick (Fig. 1). The sediments contain desiccation

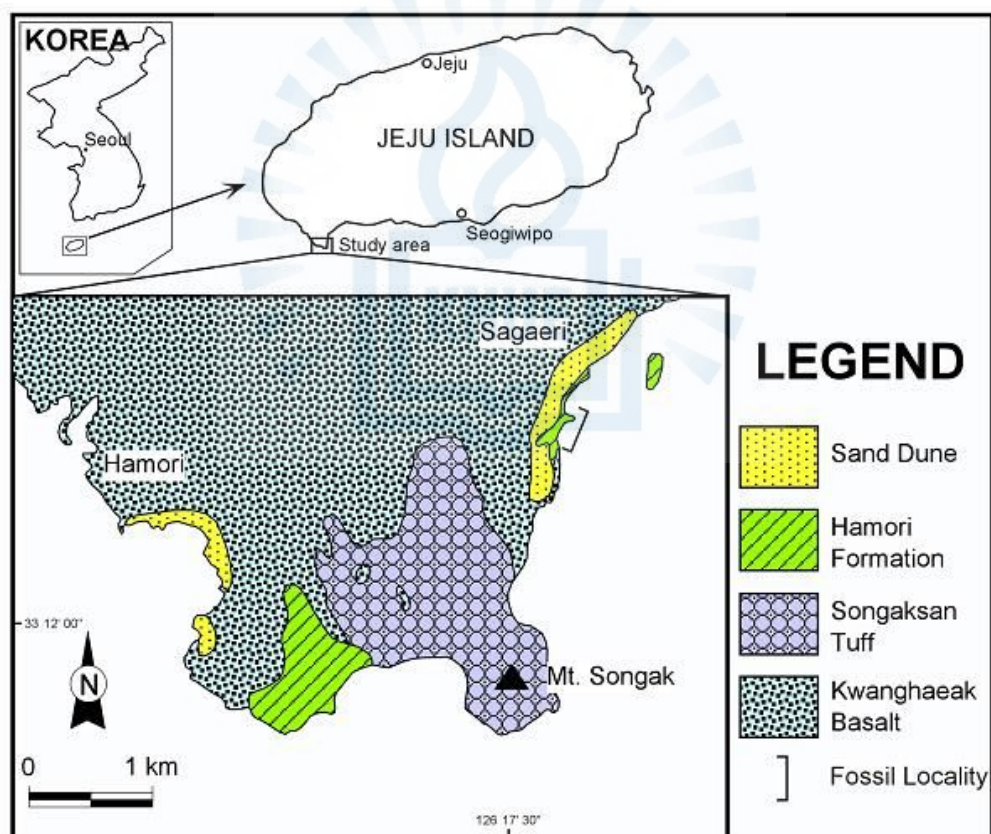


Figure 1. Geologic map showing the fossil locality (Park et. al., 2000).

cracks and ripple marks as well as numerous and diverse footprints of birds, artiodactyla, proboscideans, carnivores, and hominids, diverse invertebrate trace fossils, molluscas, crabs, and fissils plants which suggest the low energy shallow shoreline environment (Kim et al., 2004)

The Songaksan Tuff and Hamori Fomation, which are the youngest units on Jeju Island, occur in the southwestern margin of the island above an extensive and low-altitude, plateau-forming basalt lava. Another tuff rings/cones and a lava dome also occur along the coastal region (Shon et al., 2002).

Sohn et al. (2002) regarded that the age of the Hamori Formation is less than 4,000 yr B.P. by ^{14}C dating of the mollusks collected at the west coast of Mt. Songak and the Hamori Formation was formed during and after the eruption of the Songaksan Tuff (ST). Park et al. (2005) and Cho et al. (2005) regarded that ^{14}C data of humin fraction is the maximum age of the hominid Footprint-bearing Strata as $15,161 \pm 70$ yr B.P. and insisted that the age of the strata is from $6,800 \pm 300$ to $7,600 \pm 300$ yr B.P. by OSL. However, Pessenda et al. (2001) compared ^{14}C data of total soil organic matter, humin fraction, and charcoal in several soil profiles under natural vegetation from different locations, and thought that the humin fraction ages could be assumed as the minimum ages for carbon in soils.

On the basis of field observation, the geologic sequence, in ascending order, in the study area consists of the Kwanghaeak Basalt, unnamed strata, ST, Hamori Formation, and Dune Sand, on the west coast of Mt. Songak (kim et al., 2006). At the hominid footprint site, Sagaeri area in the northeast coast of Mt. Songak, the sequence is composed of the

Kwanghaeak Basalt, Footprint-bearing Strata, Beach Sand, and Dune Sand in ascending order (Kim et al., 2006). According to the designation that the Hamori Formation overlies the ST (Shon et al., 2002), age dating results (Park et al., 2005; see the review of Kim and Kim, 2006), and the geologic sequence observed in the field, the strata containing hominid footprints are not correlated with the Hamori Formation but the unnamed strata at the west coast of Mt. Songak (Kim et al., 2006), though the strata are shown as the Hamori Formation on the geologic map (Park et al., 2000). It seems, therefore, to be more reasonable that the geologic age of the Footprint-bearing Strata is thought to be around ca. 15,161 $\pm$ 70yr B.P. (Kim and Kim, 2006) according to the ^{14}C data of Park et al. (2005).

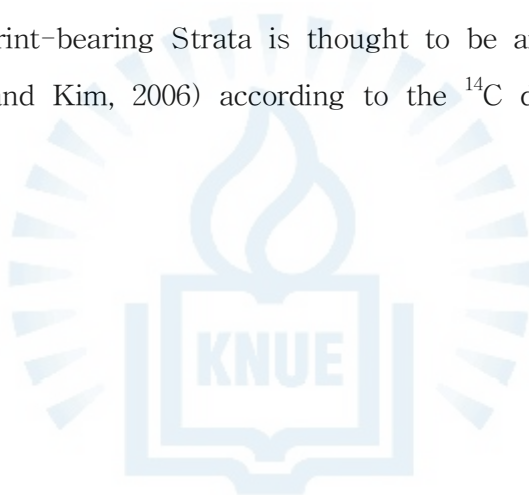




Figure 2. The outcrop view of the fossil locality.



Figure 2. continued.

2. Stratigraphy

The sedimentary facies of the Hamori Formation distributed in the west part of the Mt. Songak was recently analysed for interpretation of depositional environment (Sohn et al., 2002). According to them, this strata was deposited in a high-energy nearshore environment above a fair-weather wave base during and after the eruption of the ST. However, the Hamori Formation of the northeast coast of the Mt. Songak is mainly composed of basaltic granule conglomerate, basaltic pebbly sandstone, tuffaceous sandstone and mudstone. Diverse sedimentary structures including wave ripple marks, adhesion ripple marks, Runzelmarken, desiccation cracks, planar- and cross-stratification associated with footprints of humans, mammals, and aves, and invertebrate trace fossils observed in the measured section of the northeast coast of the Mt. Songak indicate low-energy shoreline environment, especially semi-closed lagoon or intertidal flat setting, existed at the time when the tracks were made (Kim et al., 2004).

The footprints bearing strata distributed in the Sagaeri area, east coast of Mt. Songak overly the Kwanghaeak Basalt and are overlain by Sand Dune. The measured section of the arthropod trackway bearing strata in the northeast coast shows stratigraphic distribution of the lithology, sedimentary structure, footprints of the humans, mammals and aves and invertebrate trace fossils (Fig. 4).

LEGEND

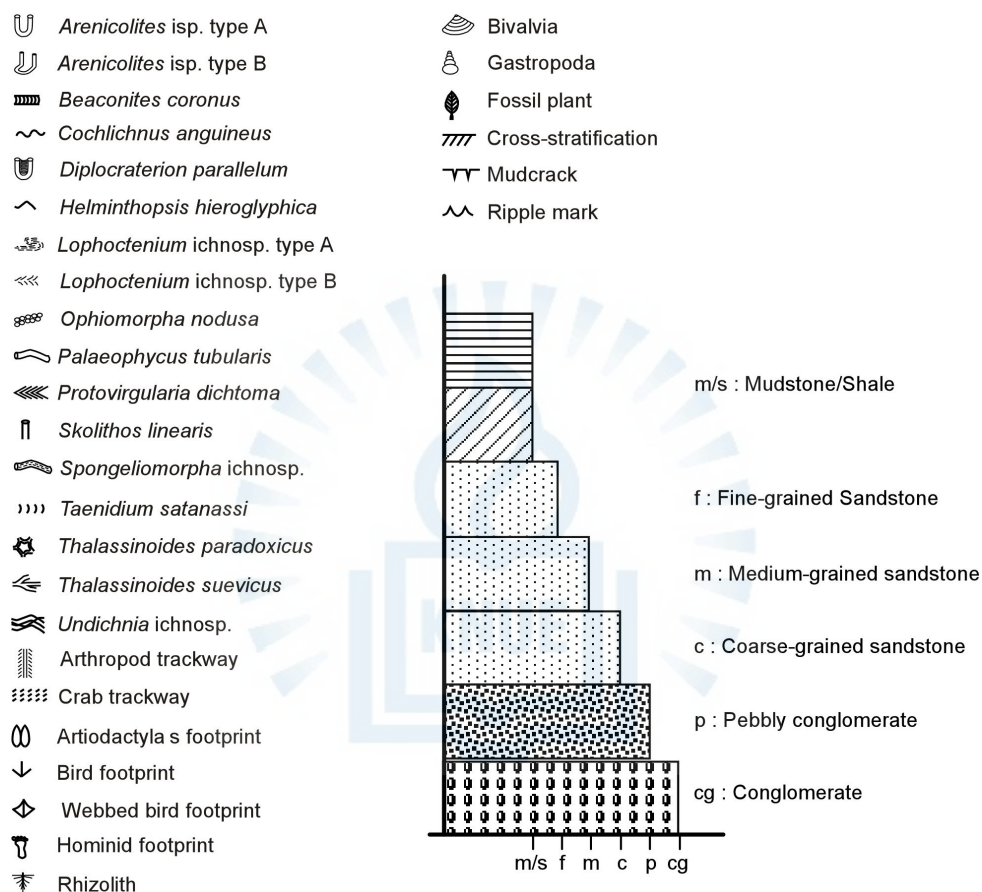


Figure 3. Symbols used in the measured section (Kim, 2004).

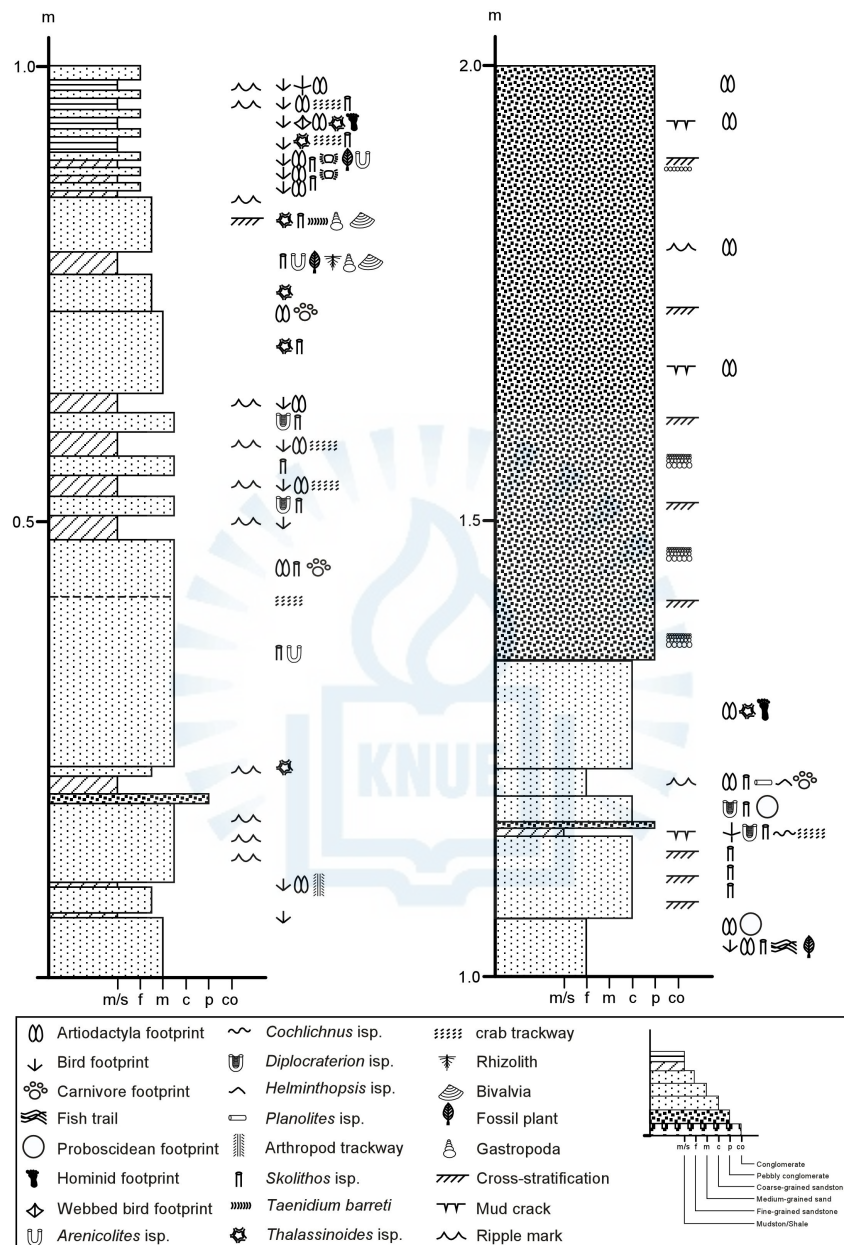


Figure 4. Measured section of the trackway bearing strata (Kim et al., 2004).

III. SEDIMENTARY CHARACTERISTIC

1. Sedimentary facies

The sedimentary facies of the Hamori Formation distributed in the northeast part of the Mt. Songak is mainly composed of basaltic granule conglomerate, basaltic pebbly sandstone, tuffaceous sandstone and mudstone (Kim et al., 2004).

Rocks of Footprint fossil place is composed basaltic rock, Songaksan tuff, sand dune layer from lower part. From this region the basalt in the area of most ranges widely with the bedrock and to the top the tuff and Hamo-ri flat are covering with the unconformity (nonconformity). The reworked deposits are composed of basaltic pebbly sandstone, basaltic tuffaceous sandstone and siltstone. Individual grains of basaltic sand and gravel in this formation are subangular to subrounded, compared with the generally angular grains in the primary tuff-ring deposits. The sandstones are also depleted in fine ash and enriched in quartz sand fragments of molluscan shells (Shon et al., 2002).

2. Depositional environments

The sedimentary characteristics suggest that the Hamori Formation was deposited in a low-energy nearshore environment and diverse vertebrate footprints and invertebrate trace fossils may indicate shallow shoreline environment (Kim et al., 2004).

Arthropods are currently abundant and diverse in many environments.

and they also need a warm climate. Arthropod trails occur occasionally in fine-grained, usually argillaceous sand- and siltstones. Only in a very few cases, however, has it been possible to determine the animal that made the impressions in the sediment. The fossilization potential of arthropods, however, is low. With the exception of trilobites, ostracods, and decapods, most arthropod exoskeletons are weakly construction and ecdysis (shedding of exoskeleton during life) introduces the problem of disarticulation and transportation. Therefore, preservation of most arthropods as body fossils requires exceptional circumstances such as rapid burial or anoxic conditions.

Arthropod trackways can also be valuable paleoenvironmental or paleoecological indicators, for example, a wet sediment trackway overprinted by a dry sediment trackway indicates a drying out sequence in the surrounding environment (Zang et al., 1998). The most abundant and diverse trace fossils were produced in the washover deposits of laminated to thin-bedded sandstone facies.

Based on grain size and primary sedimentary structures, several sedimentary facies are identified in the fossil locality of Hamori Formation. Mudstone/fine-grained sandstone facies is interpreted as tidal flat deposit and shale/fine-grained sandstone facies is thought to be deposit in the shallow lagoon subenvironment. Although the thickness of the bed in the fossil locality is thin, sedimentary facies represent subenvironments such as marsh, tidal flat, lagoon, washover, and beach face deposits of the barrier-lagoon depositional system.

IV. LIVING AND ANCIENT ARTHROPOD TRACKWAYS

As predominantly vagrant organisms equipped with appendage, arthropods produce a variety of walking, resting, burrowing, feeding and other trace that reveal information about their lifestyles and anatomy. A trackway is a series of imprints made by the walking appendages of an animal as it moves over a substrate. such a trackway can become preserved in the fossil record and as such is an example of a *trace fossil*, that is a sedimentary structure produced by the behaviour of organism. Other examples of trace fossils are preserved burrows and borings, as well as vertebrate trackways such as dinosaur footprints. Trails are formed when part of the organism is in continual contact with the sediment (Simpson, 1975). Hantzschel (1975) reported ichnogenera attributable to arthropods.

Trackway comprise a series of individual footprints that are produced as an organism moves across the surface of the sediment; a trackway is defined as a succession of individual marks (Keighley and Pickerill, 1998). All arthropods have a preferred gait but will change their gait patterns to suit the substrate they are walking on, whether they are walking sub-aerially or sub-aqueously etc (Briggs et al., 1979). Arthropod trails occur occasionally in fine-grained, usually argillaceous sand- and siltstones. only in a very few cases, however, has it been possible to determine the animal that made the impressions in the sediment (Hanken and Størmer, 1975).

1. Arthropod locomotion

Arthropods are a highly diverse group of invertebrates and use many forms of locomotion including walking, swimming and flying. We are concerned with their walking techniques as it is these which produce the fossilised trackways we see in the rock record. Depending on their life habits, arthropods will walk either sub-aerially, that is on terrestrial sediments, or sub-aqueously, or underwater; some species will do both (Braddy and Anderson, 1996).

The stride of arthropod can be thought of as the distance between successive footfalls of the same leg, and is made up of the propulsive backstroke (remotor), and the recovery forward stroke (promoter). Their locomotory mechanisms today represent different methods of achieving much the same fleetness. Arthropod is the only animal group that has bilateral symmetry, is segmented, and contains jointed appendages. The trace is readily interpreted as a resting or concealment imprint (Keighley and Pickerill, 1998). The relationships between the substrate, sedimentary environment, preservation of the trace fossils, the animal and its behaviour are examined in Pollard and Walker (1984).

2. Track cycle

Identification of repeat distance and interpretation of imprint series is essential for analysis of arthropod gait (e.g. Briggs et al., 1979). Recognition and interpretation of organization within track rows is

important both for description and for interpretation of trackway originators (Trewin, 1994).

The trail produced by an arthropod may be envisaged as a 'set' of footprints repeated at an interval determined by the distance between successive footfalls of the same appendage i. e. the stride length (Briggs et al., 1979). A track cycle is a unit sequence of tracks which is repeatedly reproduced to form a continuous length of trackway. Track cycle can be distinguished only where individual tracks are sufficiently characteristic to allow their differentiation. A Repeated Track Cycle is the sequence between two successive identical tracks; a Natural Track Cycle is the consecutive sequence of tracks left by the walking appendages when each, starting with the fore- or hind-most, has pivoted on the substrate once. The natural track cycles usually overlap, i.e. they tend to be longer than the repeated track cycles. of couses, in one trackway both natural and reprated cycles involve the same number of tracks (Anderson, 1975). Series usually represent a movement phase of the animal using all appendages once, but groups do not necessarily represent the same situation. Numbering of imprints within groups (Sadler, 1993) may aid description, but imprint numbers will not generally relate to leg numbers on an arthropod, and are unlikely to be in a regular order with respect to leg number. Generally, there will be an appropriate taxon for a trackway lacking recognized organization in groups or series, but when the organization becomes recognized the trackway would be elevated to another taxon (Pollard, 1985).

Measurement taken on the trackways (Table 1) follow those used by previous researchers. For the most part, these measurements are similar

to those used for vertebrate trackways, with modifications where needed for the anatomy of arthropods. Average stride length (pace) was measured from the center of one print to the center of corresponding print of the next set on the same side. Maximum width of the trackway (Track Width on Table. 1) was taken as the measurement between external tangents to the prints, parallel to the axis of the trackway.

Table 1. Measurement of fossil crab trackways of Jeju Island, Korea.

	Series length	Stride Length (Pace)	Track Width
A	32~37 mm	31~39 mm	22 mm
B	30~33 mm	26~29 mm	15 mm
C	19~20 mm	18~22 mm	26 mm
D	20~23 mm	19~23 mm	15 mm

V. SYSTEMATIC ICHNOLOGY

For the description of arthropod trackways we have followed, for the most part, the approach and terminology suggested by Trewin (1994).

Most of material mentioned in this study is housed with the Department of Earth Science, Korea National University of Education (KNUE), Cheongwon, Chunghbuk, Korea.

1. Crab trackways

Living crabs are common inhabitants of shallow subtidal, intertidal, and supratidal environments, and many crabs are capable of producing traces that can be preserved in the rock record (Frey et al., 1984). Many crabs undoubtedly produced domiciles that are preserved in shallow marine to quasimarine sediments and that should be useful in characterizing the depositional environment of the sediments (Frey et al., 1984). In addition to their preserved trackways, crabs may be represented in the ichnologic record by various bioturbate textures imparted to host sediments (Edwards and Frey, 1997; Katz, 1980). Crabs thus have considerable importance as geologic agents. Fossil trackways such as those remained by living crabs, although well-documented locally, have rarely received formal ichnogenus and ichnospecies names. Locomotion typically results in a trackway representing a single excrusion; in some instance, however, the path is used repeatedly.

2. Comparison living and ancient trackways

Living Crabs are divided into two major taxonomic groups; the Anomura-hermit crabs and their kin, and the Brachyura-or true crabs. Here, we are concerned mainly with brachyurans. Living benthic crabs and their trackways are abundant in numerous sedimentary environment, from terrestrial clastics to shoaling marine carbonates. Because prominent crab trackways generally are most abundant in intertidal, supratidal, and terrestrial environments - facies having relatively low potential for preservation - fossil crab trackways are inherently less abundant in the rock record than other arthropod trackways made in low intertidal and subtidal environments (Frey et al., 1984).

Evidence for crabs as the tracemaker is circumstantial in most ancient setting; the strongest conclusions obviously are drawn when the fossil trackways closely resemble living crab trackways.

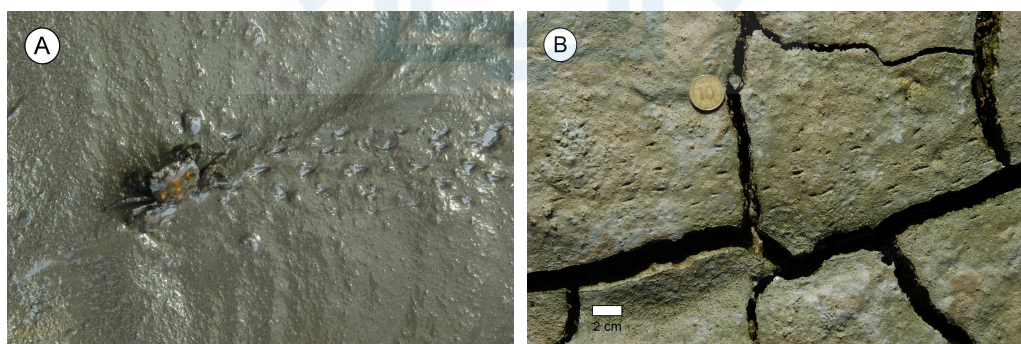


Figure 5. The morphology of fossil trackways similar to those produced by the living crab, *Ocypodidea*.

We are experimented with several invertebrate species to determine possible trail makers for the trackways, and the conditions under which these trackways might have been formed. The trackways produced by the small crab, *Ocypodidae* were consist in terms of morphology. The experimental tracks in wet mud tended to be bigger, deeper (Fig 5).

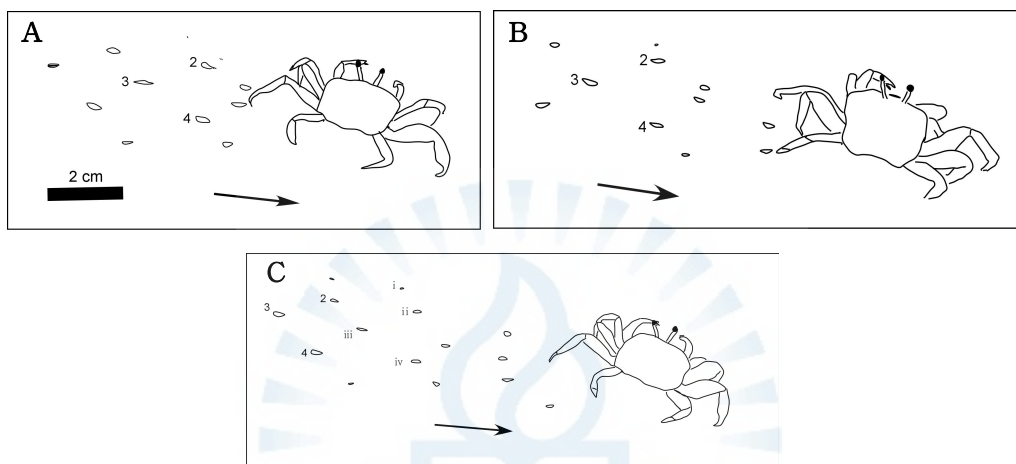


Figure 6. Trackway of living crab, *Ocypodidae*.

The three phase (A, B, C) illustrate one cycle of movement of the left working leg. The individual cycle are numbered. one with Arabic numbers, the other with Roman numbers.

Kingdom INVERTEBRATE

Phylum ARTHROPOD

Material : Two specimens collected (KNUE 040064, 65) and two silicon cast deposited at Dept. Earth Science, KNUE (KNUE 040066, 67).

Crab trackway Type A

Pl I , II, III. Fig. A, B.

Description : Trackway preserved in concave epirelief (Fig 7 a, b, c). Trackway, slightly curved, comprises series of imprint. Trackways are asymmetrical track without central groove marks and composed of series of three, four or five evenly-spaced elongated imprints about 5 mm length. The specimen is preserved in concave epirelief on a current rippled, ver-fine- grained sandstone. The highly distinctive shape described above means that only crabs could logically have produced it.

The generally imprint, 6 mm long by 1~2 mm wide, is round at one end (interpreted as posterior) and tapers to terminal striae at the other (anterior). Trackways contained two or three imprints per series on each. Additionally, experiments with the crabs *Ocypodidae* showed that trackways were produced in wet substrate and formed when the substrate was drier.

Remarks : These trackways are characterized by comparing a set of three or five imprints and must be formed by crab. The trackways are interpreted to have been formed by small crab like *Ocypodidae* living in the modern shoreline environment.

Crab trackway Type B

Pl IV, Fig. A

Description : Trackway preserved in convex hyporelief (Fig 7, d). Trackway, slightly curved, comprises series of imprint. Right imprint in

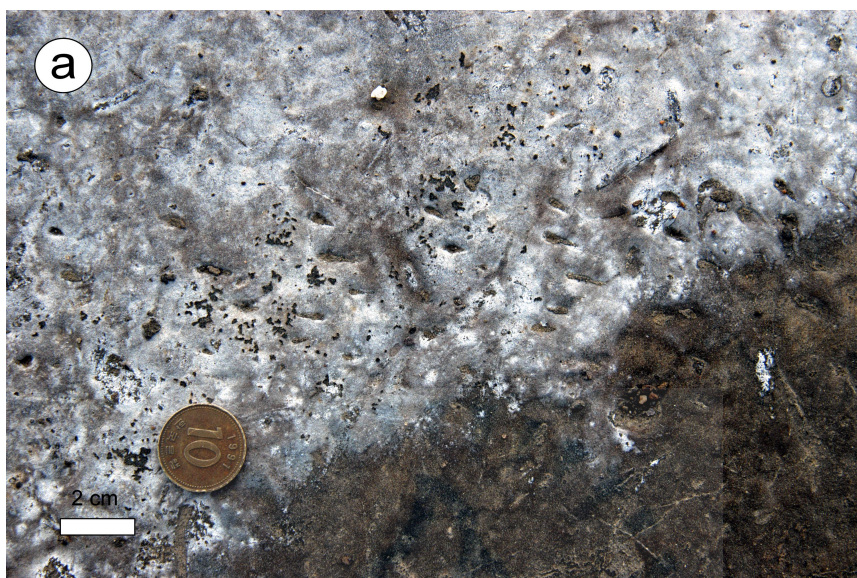


Figure 7. Fossil crab trackways. a, b, c : Type A, d : Type B



Figure 7. continued.

each imprint series is more slender than the other two imprints.

Distances between left imprint and central imprint and between right and central imprints in each imprint series are 6–8 mm and 4–6 mm respectively. This trackway is considered to be attributed to crab-like arthropod. Bivalves and gastropods, small crabs, rhizolith and plants assigned to *Magnolia* sp. are also found.

Remarks : The highly distinctive shape described above means that only an arthropod could logically have produced it. Tracks produced by crabs on the dry and wet mud. As the animal moves from dry to wet sand, the individual footprint become smaller and more sharply defined.

It is difficult to compare with previously known fossil arthropod traces. If better quality material were to be recovered, introduction of a new ichnogenus and ichnospecies would again be warranted, since we are unaware of any similar named trackways.

3. Comparison of arthropod trackway

A single organisms may produce a variety of traces depending upon the activity and different organisms may produce similar trace as a result of similar lifestyles or body construction, making it difficult to accurately identify the specific trace-maker.

We are experimented with several invertebrate species to determine possible trail makers for the trackways, and the conditions under which these trackways might have been formed (Fig. 8). The trackways produced by the *Ligia exotica* were consist in terms of morphology, and

closely resembled at least one species of genus *Siskemia*. The experimental tracks in dry sand tended to be bigger, deeper and with avalanche structures obscuring much of the detail, while those produced in damp sand were small and sharp. If the sand was too wet, it either balled up on the feet of the animal, or the animal left no imprint at all. If the sand was allowed to dry and a crust formed on the surface, the animals left no marks.

Ichnogenus *Siskemia* Smith, 1909

Type species : *Siskemia elegans* Smith, 1909

Diagnosis : Trackway consisting of parallel rows of grouped appendage imprints on either side of two parallel central grooves. The tracks consists of imprints arranged in series, trasversely or obliquely to the midline of the trackway (Walker, 1985).

Siskemia elegans Smith, 1909

Pl V, Fig. A, B

1909 *S. minor* Smith, p. 3, fig. 1.

1909 *S. bivia* Smith, p. 4, fig. 2.

1909 *S. laxa* Simith, p. 4, fig. 3.

1909 *S. elegans* Simith, p. 4, 42, plate 1.

1909 *S. cf. elegans* Pollard *et al.*, p. 82, fig. 13a.

1909 *S. elegans* Pollard and Walker, p. 572, plate 1, fig 3, 4.

Material : A silicon cast deposited at Dept. Earth Science, KNUE (KNUE 040063).

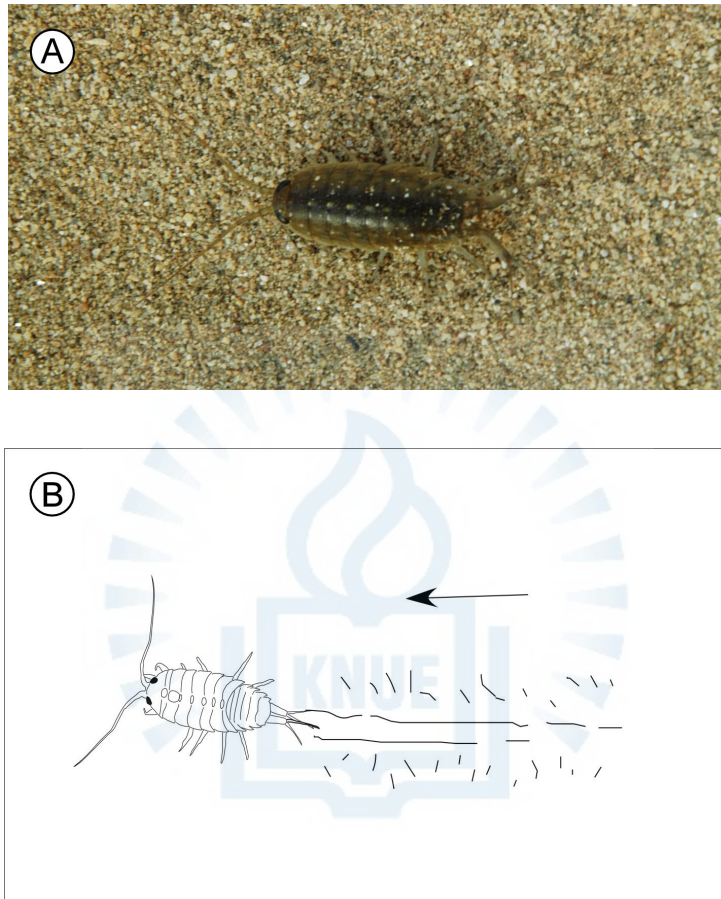


Figure 8. Suggested producer of the *S. elegans* trackway
 A : *Ligia exotica*, B : Sketch of trackway of *Ligia exotica*.
 C : *Ligia exotica* and its track, D : Sketch of C.

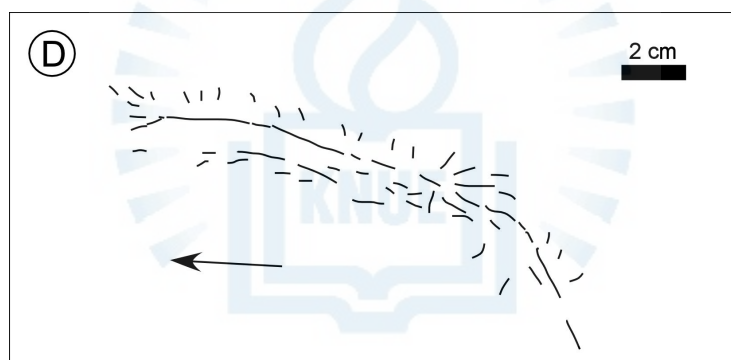


Figure 8. continued.

Description : Trackway is a symmetrical trackway with a central ridge two grooves and track rows. Central parallel grooves are about 2~4 mm apart and 180 mm in length and continuous and lateral track rows consists of bow-shaped imprints obliquely oriented. A median groove terminates at one end of the trackway, where it is more deeply impressed, but at the opposite end it is continuous into the trackway. Five striae radiate out on each side of the median groove and those arranged from the terminal end of the median groove are the best preserved. The same pattern is less well distinguished on the other side of the median groove. It is considered to mark the of the trackway, the organism having settled on the substrate at this location moving away (Fig. 8C). Median groove was where the organism rested its telson on the substrate and must be considered posterior. Additionally, experiments with the *Ligia exotica* showed that grooves were produced in wet substrate and trackways were formed when the substrate was drier. The number of imprints in a series is only one and make a nearly right angle with median groove. The imprints range from 3 to 4 mm in length and less than 1 mm in width. Preserved as convex epirelief.

Remarks : This trackway is somewhat similar in morphology to *Siskemia elegans* (Walker, 1985) thought to be formed by arthropods resembling *Ligia exotica* which is commonly living in the modern shoreline environment and drags a telson with two tail spines for two central grooves. However, *Siskemia elegans* (Smith, 1909) has double median grooves. This specimen shows the single keel-like median grooves.

VI. DISCUSSION

The following sections contain brief discussions about the traces, trace makers and their stratigraphic distribution in Jeju Island. All the repichnial trackways are discussed using the terminology of Trewin (1994).

Ancient depositional environments in which population of – might abound constitute a mixture of marginal-marine and quasimarine facies. Typical modern environments include the uppermost foreshore and backshore of beaches, dunes, washover fans, and supratidal flats. Marine conditions characterize the backshore during spring and storm tides, and also characterize washover fans and supratidal flats during storm surges. In contrast, maritime eolians conditions characterize dunes the backshore during neap tides, and washover fans and sipratidal flats during non-storm periods. Relatively few invertebrate tracemakers are tolerant of such stressful conditions (Dörjes and Hertweck, 1975); among marine or quasimarine species, only the amphibious crabs have succeeded in exploiting this highly variable coastal zone. Dörjes and Hertweck (1975) outlined a distinct division of the main shallow-water marine bottom environments located between the supratidal backshore and the edge of the continental shelf.

Because prominent crab trackways and arthropod trackways by *Ligia exotica* are most in intertidal, supratidal and shallow subtidal, fossil crab trackways are produced subenvironment such as marsh, tidal flat, lagoon and foreshore. Arthropod trackways by *Ligia exotica* thought to be deposit in backshore of beaches, dunes, and supratidal flat.

In the rock record, vertical sequences and associated physical sedimentary structures also are important in ichnological and environmental reconstructions.



VII. CONCLUSION

Two types of arthropod trackways from the Pleistocene sediments of Jeju Island, Korea are herein described and interpreted.

The type one fossils trackways are interpreted to have been formed by small crab like *Ocypodidae* living in the modern shoreline environment but it is difficult to compare with previously known fossil arthropod traces. The type two trackway is somewhat similar in morphology to *Siskemia* (Smith, 1909) thought to be formed by arthropods resembling *Ligia exotica* which is commonly living in the modern shoreline environment and drags a telson with two tail spines for two central grooves. Fossil arthropod trackways together with other trace fossils and sedimentological structures such as ripple mark and cracks indicate that the sediments were deposited in the shoreline environment.

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論 文 要 約

제주도 플라이스토세 퇴적층에서 산출된 절지동물 보행흔에 관한 연구

金 賢 起

韓國敎員大學校 大學院 地球科學敎育 專攻

(指導敎授 金 正 律)

최근 사람 발자국과 다른 척추동물 발자국이 보고된 제주도의 플라이스토세 퇴적층에서 두 가지 유형의 절지동물 보행열이 산출되었다. 생흔 화석의 고생물학적, 고환경적 중요성의 이해를 위하여 현생 계와 화석 계의 보행열을 비교하였다. 첫 번째는 가운데 홈 구조가 없고 약 5 mm 길이의 3~5개의 평평하고 길쭉한 imprint 시리즈로 구성되어 있다. 이것은 현재 해안 환경에서 서식하는 *Ocypodidae*같은 작은 계에 의해 형성된 것으로 해석된다. 두 번째는 두 개의 홈 구조와 지나간 자취 선이 있는 대칭인 보행열이다. 가운데의 평행한 홈 구조는 약 2~4 mm 떨어져있고, 연속적이거나 비연속적이며 양측에 비스듬히 기울어진 활모양의 자취 열이 있다. 이 보행열은 현재 해안환경에 일반적으로 살고 있는 갯강구와 비슷한 절지동물에 의해 형성된 것으로 여겨지며 형태학적으로 *Siskemia*와 유사하다. 가운데 홈 구조는 꼬리의 두 바늘 모양의 돌기를 끌며 만들어진 것이다. 연흔과 건열과 같은 퇴적 구조와 다른 생

흔 화석과 함께 화석 절지동물 보행열은 퇴적층이 해안환경에서 퇴적되었음을
지시한다.



(10급 명조체)

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PLATES

Explanation of the scale in the figures

- ◇ Ten won coin (bronze) is 23 mm in diameter
- ◇ Hundred won coin (silver) is 24 mm in diameter
- ◇ Five hundred won coin (silver) is 26 mm in diameter

PLATE I

Figure A. Crab trackway type A-a

Figure B. Sketch of crab trackway type A-a



PLATE I

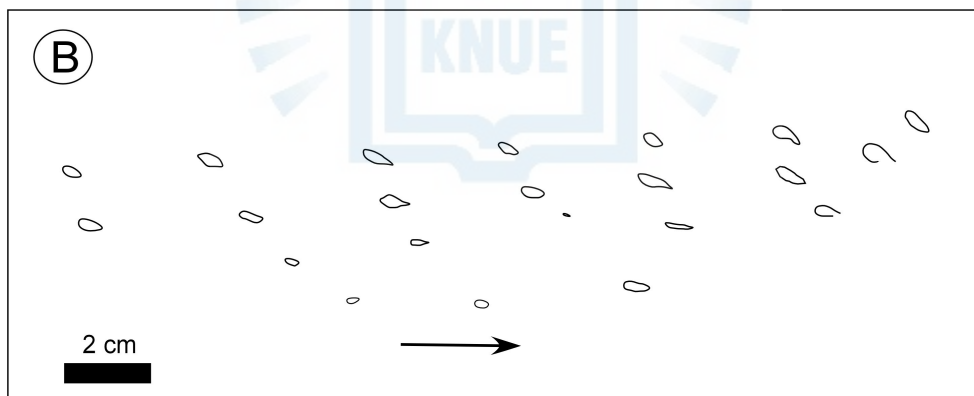
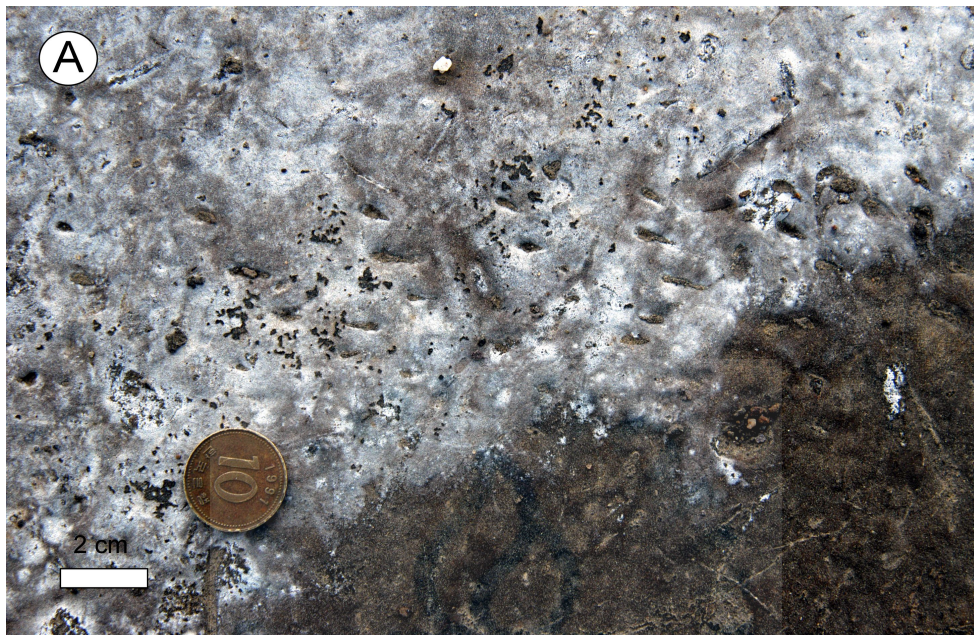


PLATE II

Figure A. Crab trackway type A-b

Figure B. Sketch of crab trackway type A-b



PLATE II

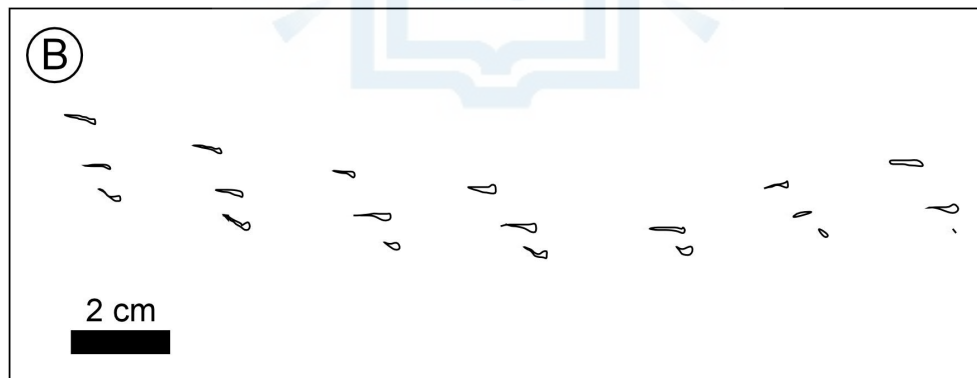
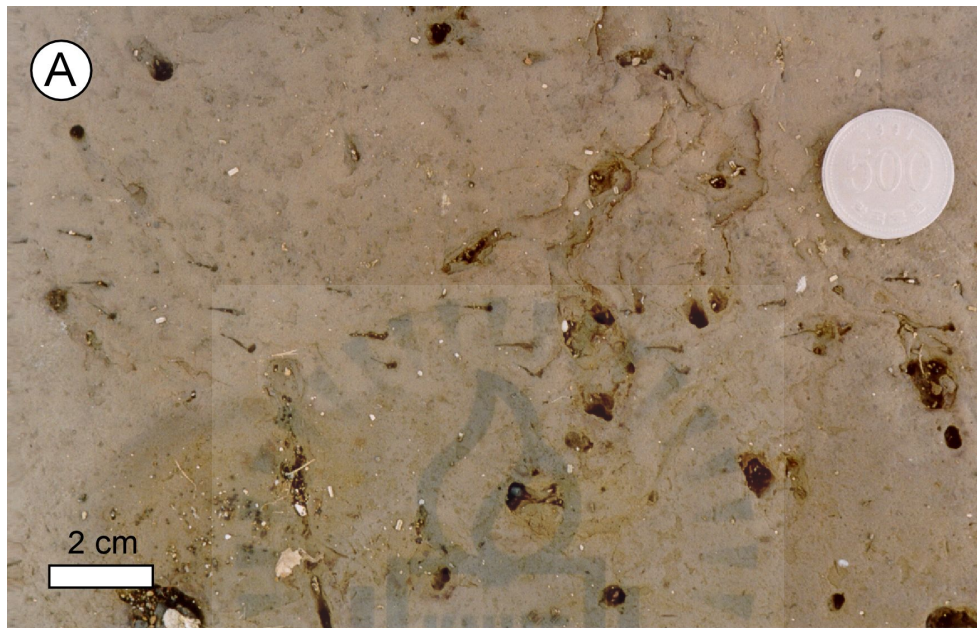


PLATE III

Figure A. Crab trackway type A-c

Figure B. Sketch of crab trackway type A-c



PLATE III

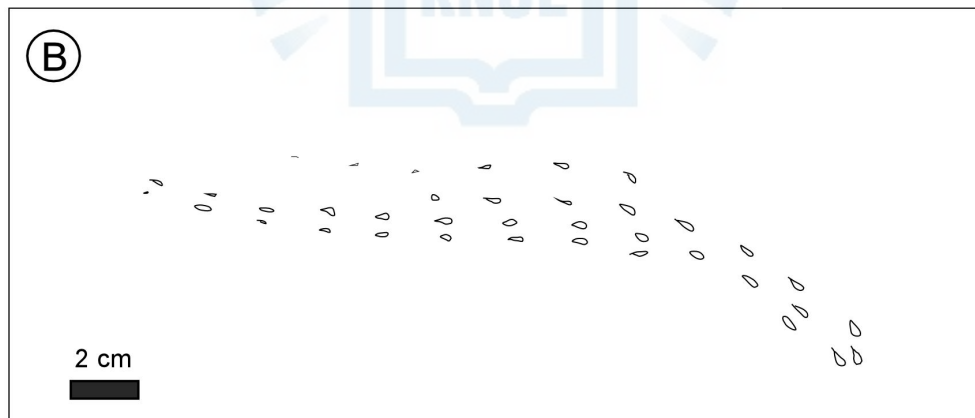


PLATE IV

Figure A. Crab trackway type B-d

Figure B. Sketch of crab trackway type B-d



PLATE IV

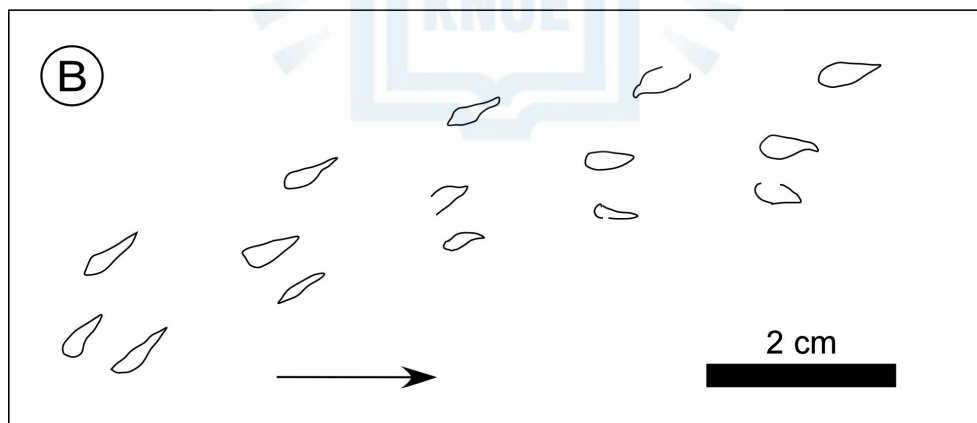


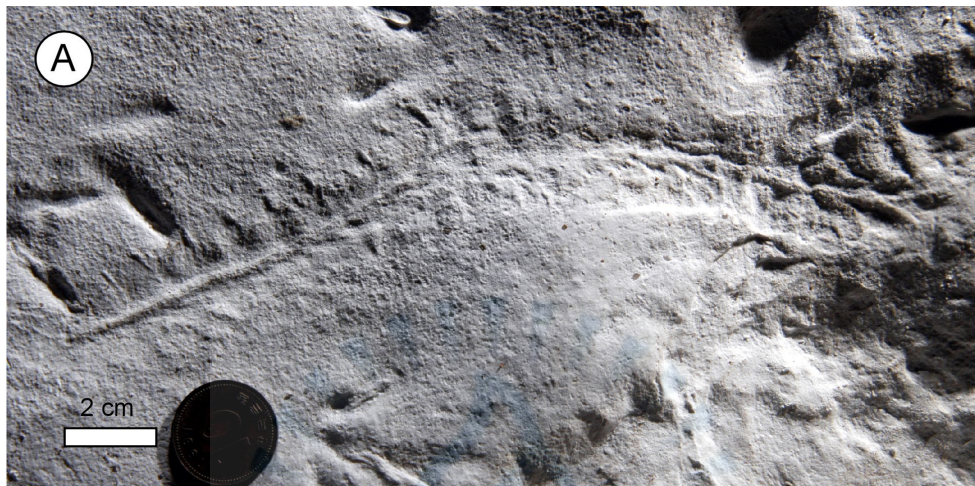
PLATE V

Figure A. Arthropod trackway : *Siskemia*

Figure B. Sketch of arthropod trackway : *Siskemia*



PLATE V



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