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Materials and Microclimatic Characteristics of Dinosaur Footprint Sites in Uiseong and Haenam Area, Korea

Ji Hyun Yoo and Chan Hee Lee*

Department of Cultural Heritage Conservation Science, Kongju National University, Gongju, 314-701, Korea;
jhyoo@kongju.ac.kr, chanlee@kongju.ac.kr

Abstract

The dinosaur footprint fossil sites at Uiseong Jeori and Haenam Uhangri are representative Natural Heritage sites in Korea. This study was performed to analyze the materials and microclimatic characteristics of these fossil sites to enable long-term conservation. The material characteristics of fossil sites showed that the host rocks of these areas were composed of vulnerable sedimentary rocks by weathering. We were also conducted focusing on the microclimate environments within the protective structures of the fossil sites. There is an open protective structure at Uiseong Jeori, which delivers adequate ventilation but is vulnerable to frost weathering in winter. Therefore, it is considered necessary to extend the drain at the back of the protective structure for the site. In contrast, enclosed protective structures with air conditioning were built at Haenam Uhangri. However, although it is possible to control the internal microclimate therein, condensation occurs frequently as a result of microclimatic differences in the interior structure, and thus additional measures are required.

Keywords: Dinosaur, Footprint Tracks, Material Characteristics, Microclimate, Protective Structure

1. Introduction

Fossils are the remains or traces of organisms from the remote past, and as such, they provide important data relating to ancient environments and the origins of life. Dinosaur footprints are a type of trace fossil, and provide considerable information about dinosaurs and their life habits. In addition, the footprints are able to tell us about the paleo-environment. For example, geopetal structures, sediments originating in particular settings, original physical properties of sedimentary deposits, and stratigraphic zonation and correlation are indicated by the occurrence of dinosaur tracks[1].

In Korea, the first dinosaur fossil was discovered in 1972. Since then, a large number of dinosaur footprint fossil sites have been excavated in the southern coastal area of Korea[2]. Among these, the dinosaur footprint fossil sites in the areas of Uiseong Jeori and Haenam Uhangri are representative natural heritages, and have been designated as natural monuments No. 373 and No. 394, respectively, for academic values. These sites contain large-scale footprints of ornithopods, sauropods, and theropods, which have provided abundant information about the paleoenvironment and extinct organisms.

However, with the passage of time, the original shape of the fossils has been partly destroyed by various types of physicochemical and biological damage, such as cataclasis, and the rocks have been discolored. In addition, groundwater has flowed into the fossil sites at Uiseong Jeori and Haenam Uhangri, thereby eroding the property of the rocks, and weathering at these sites has been accelerated. Despite the persistent damage to the fossils, most dinosaur footprint fossil studies have focused solely on paleontology and the paleoenvironment, and only a few studies related to the preservation of the fossils have been conducted recently[3]. Thus, scientific study is undoubtedly required to conserve these fossil sites.

**Author for correspondence*

In this study, we aim to determine the material and microclimatic characteristics of the fossil sites so as to suggest ways to reduce the damage occurring at these sites. In doing so, we investigated the material characteristics of fossil rocks as basic data elements. In addition, we conducted a detailed investigation into how the microclimate affects the weathering of rocks. The results are considered to be important in gaining an understanding of weathering factors at fossil sites, and to establish conservation plans for the future.

2. Current States and Methodology

2.1 Current States

The fossil site at Uiseong Jeori was discovered in 1988 during the road construction, and is located in mudstone and sandstone of the Sagok Formation from Jeori, Geumseong-myeon, Uiseong-gun, Gyeongsangbuk-do (Figure 1A). After excavation, more than (approximately) 300 dinosaur footprints were found in four stratigraphic horizons, and among these are 12 trackways of sauropods, 10 trackways of ornithopods, and 1 trackway of a theropod (Figure 1B)[4].

Thus, this fossil site was designated as a natural monument to all dinosaur footprint fossils because of the high density of footprints. A few years later, a protective structure was built on the fossil site, and conservation treatment was then conducted in 2003. The main theme of the treatments was to paint the footprints and to use cement work to distinguish between fossils and matrix. However, this work received fierce criticism because the original shape of the fossils was severely destroyed, and cleaning treatment of the paint was therefore carried out in 2012.

The fossil sites at Haenam Uhangri are located in shale and sandstone of the Uhangri Formation from Uhangri, Hwangsan-myeon, Haenam-gun, Jeollanam-do (Figure 1A). This site was originally located on the southern coast of Haenam Bay, and thereafter became a riverside site after the construction of a sea dike. Haenam Uhangri comprises many fossil sites, and here we focus on three of these important sites that have enclosed protective structures. A total of 263 ornithopod footprints have been unearthed in the fossil sites under the No. 1 protective structure, and there is a high density of these footprints, which have distinct shapes that are mostly rounded or oval morphologies of ornithopods (Figure 1C).

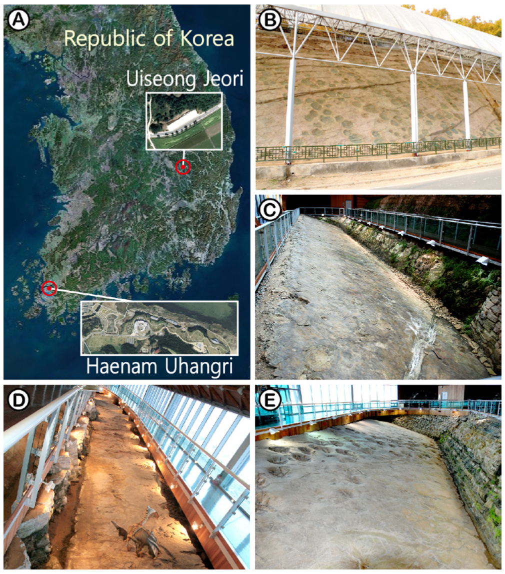

Figure 1. Location and foreground of research area. (A) Location map of the fossil sites. (B) Footprints fossil site of Uiseong Jeori. (C to E) Footprints fossil site of Haenam Uhangri. C; Fossil site of the No. 1, D; Fossil site of the No. 2, E; Fossil site of the No. 3.

In addition, footprints of bipedal and quadrupedal dinosaurs have been found. Pterosaur footprints have been found at the fossil sites under the No. 2 protective structure, in addition to petrified wood and ostracoda (Figure 1D). When the tracks were excavated they were considered to be the longest pterosaur trackways in the world, and were thus important for interpreting the ecosystems of the pterosaurs. The fossil site under the No. 3 protective structure is of an enormous scale (with a length of 45 m and width of 9 m). Deep and distinct footprints occur at this site (Figure 1E), and in a recent study these were interpreted as being undertracks made by bipedal sauropods while walking on the ground[5].

2.2 Methodology

Polarization microscope analysis was carried out in order to determine the rock characteristics at the fossil sites. Samples collected from exfoliated rock fragments were observed using a Nikon Eclipse E600W with an automatic counter. X-ray diffraction (XRD) was conducted to identify minerals forming the rocks of the fossil sites. A D/Max- Ⅱ B (Rigaku) was used, with an X-ray of Cu Kα with 40 kV and 100 mA.

The microclimatic analysis of fossil sites was carried out using a large number of data loggers that were installed on the indoor and outdoor walls of the protective structures to monitor the influence of the protective structure. The types of data loggers used in Uiseong Jeori were HOBO U30 Station and HOBO Pro v2, and Testo 175-H2 and Testo 177-H1 (with a wall surface temperature probe) were used at Haenam Uhangri. The logging interval occurred hourly. In addition, an Automatic Weather System (AWS) and statistical climate data from the National Climate Data Service System (NCDSS) were used to analyze the local climate[6]. The climate data obtained by these methods were subdivided and schematized to understand the tendencies.

3. Results

3.1 Materials

3.1.1 Uiseong Jeori Site

To examine the petrological and mineralogical characteristics of the site at Uiseong Jeori, we collected exfoliated rock fragments from the area, produced thin sections, and conducted polarization microscope analysis. Observations showed that the site was generally composed of sandstone and mudstone. The sandstone part of the structure was arkose sandstone with a poor sorting grade (Figure 2A). In the microcrystalline matrix, mostly quartz grains of various sorting grades were found to be distributed. Minerals other than quartz grains were mica, plagioclase, and alkali feldspar, which showed the same compositional characteristics as sandstone.

Mudstone was obtained in only one part of the site, and showed a fine textured matrix with a calcareous composition (Figure 2B). In general, like the sandstone it was found to be composed of mica, plagioclase, alkali feldspar, and quartz grains, with the additional presence of calcite. We also observed a layer of light yellow clay along the fissure in the mudstone matrix, which had been altered from the black clay layer. This was presumably due to the reaction of the rock to underground water or a hydrothermal solution and to discoloration from metasomatism[7].

X-ray diffraction analysis was also conducted on the rocks. Based on this analysis, we were able to confirm the results obtained from polarization microscope analysis, and thereby identified the rock-forming minerals to be mica, plagioclase, alkali feldspar, and quartz grains for the sandstone, and mica, plagioclase, alkali feldspar, quartz grains, and calcite for the mudstone (Figure 2C).

3.1.2 Haenam Uhangri Site

The rock in the No. 1 site is comprised of mudstone with a micro-crystalline matrix composed of quartz, calcite, and plagioclase phenocrysts (Figure 3A). Rock in the No. 2 site consists of black shale with a foliated structure (Figure 3B), and rock in the No. 3 site is black shale with alternating layers of colored and black shale (Figure 3C, 3D). Additionally, the X-ray diffraction analysis showed same results obtained from polarization microscope analysis (Figure 3E).

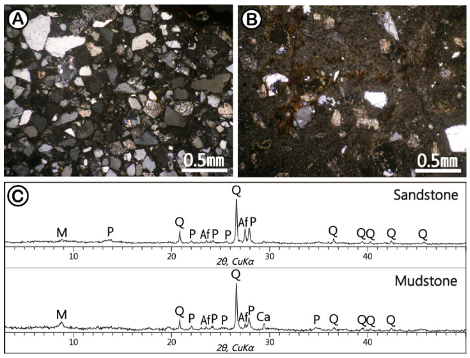

Figure 2. Material characteristics of the fossil site in Uiseong Jeori area. (A) Photomicrograph of the sandstone. (B) Photomicrograph of the mudstone. (C) X-ray diffraction patterns of the host rocks. M; mica, P; plagioclase, Q; quartz, Af; alkali feldspar, Ca; calcite.

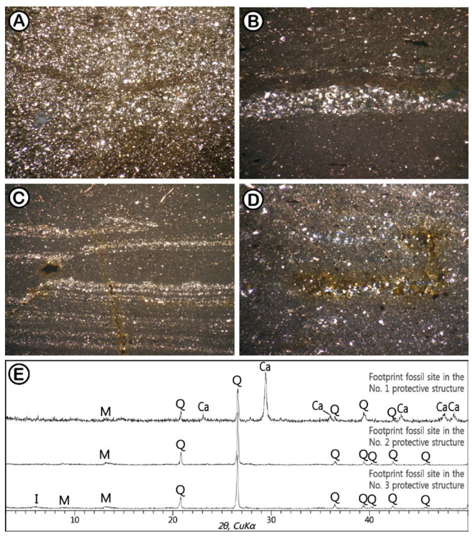

Figure 3. Material characteristics of the fossil site in Haenam Uhangri area. (A) Photomicrograph of the mudstone in the No. 1 site. (B) Photomicrograph of the shale in the No. 2 site. (C, D) Photomicrograph of the shale in the No. 3 site. (E) X-ray diffraction patterns of the host rocks. I; illite, M; mica, Q; quartz, Ca; calcite.

3.2 Microclimatic Characteristics

3.2.1 Uiseong Jeori Site

We analyzed the microclimate of the studied fossil sites to interpret the effect of environment factors. According to the relationship between the climate and the type of weathering by Fookes[8], the climate of Uiseong is classified as having three types of decomposition: strong decomposition, moderate decomposition, and moderate decomposition with frost action (Figure 4).

In order to find out how the protective structure of dinosaur foot print fossil site in the region of Jeori, Uiseong influences the microclimate, the investigator arranged and analyzed environmental data from the site collected between May 2013 and March 2014. As a result of data analysis, it was found that the internal and external temperatures of the fossil site were almost the same, with a very high correlation coefficient between both the temperatures. The reason for this is attributed to the protective structure installed at this site, which is an open type, and has a superior ventilation capacity compared to that of the enclosed type of protective structure. This open-type structure lacks the ability to isolate the environment from external influences, so it is difficult to control the internal space in certain temperature and humidity conditions (Figure 5A, 5B).

However, it is not considered possible to install an enclosed-type structure at the site of Jeori at Uiseong, because of the adjacent road, and the narrow land area of the site. As shown in Figure 5A, the lowest temperature

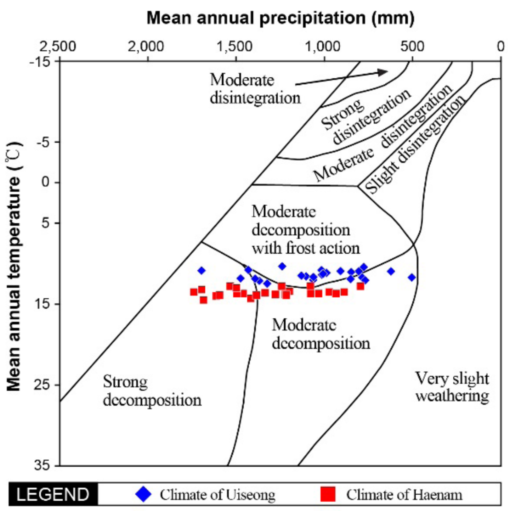

Figure 4. Diagram showing climate-weathering of the Uiseong and Haenam area (from 1990 through 2013).

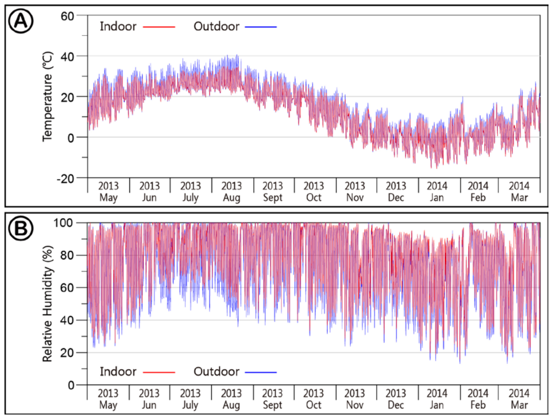

Figure 5. Comparison with indoor and outdoor temperature (A) and relative humidity (B) of the fossil site in the Uiseong area.

within the internal space of the protective structure is almost the same as that of the external space, but the highest temperature of the internal space tends to be about 3 °C higher than that of the external environment. Such a difference between highest temperatures is considered to be related to the blocking effect of the sun's direct rays, which occurs in the summer when the average temperatures are high.

The highest relative humidity of the internal space in the protective structure was almost the same as that of the external space, but the lowest relative humidity of the internal space in the structure was somewhat higher. It is considered that these differences are caused by the influence of ground water flowing into the fossil site after rainfall, and the abmodality of highest relative humidity between both spaces was more significant in summer, illustrating the urgent need for countermeasures against intrusion of underground water.

In consideration of the difference of approximately 3°C between the outside and inside spaces, it can easily be expected that the temperature at the fossil site in November would drop below zero. Therefore, if water flows into the area after rain or snowfall during winter, the water could potentially cause physical damage to the rocks, and substantially accelerate weathering. In the case of the occurrence of frost weathering, it is extremely probable that the rocks at the fossil site would be exfoliated, or in more serious cases the fossil site could develop into a cataclasis zone.

In order to evaluate the wind's influence on the fossil site, the investigator examined the direction and velocity of the wind in the internal space of the site. As a result, it was found that the prevailing wind blows towards the fossil site advances from the front and right of the site. The highest wind velocity and the average wind velocity were found to be only 4.64 m/s and 0.43 m/s, respectively, and it could therefore be considered that the influence of the wind on the fossil site may be not significant. This could be related to the fossil site being located below a mountain slope within a basin.

3.2.2 Haenam Uhangri Site

To understand the influence of climate on the fossil site in the Haenam area, the investigator applied the diagram of climate weathering proposed by Fookes[8] to the climate of the Haenam area. This weathering diagram classifies the weathering fields depending on the climate, and relates the annual average temperature and average precipitation to categories of strong decomposition, moderate decomposition, and moderate decomposition with frost action.

As a result of applying this diagram to the annual average temperature and average precipitation in the Haenam area for the period from 1990 to 2013, the area was found to be classified as both a moderate decomposition field and a strong decomposition field (Figure 4). This indicates that because Haenam is located on the southern Korean peninsula and is adjacent to the sea, it has a climate that is warm all year round with copious precipitation, and therefore the fossil sites in their natural condition are at a high risk of weathering.

In order to recognize the annual environmental characteristics of the fossil site, the investigator compiled graphs of the daily average temperature and daily average relative humidity for the period from January 1st, 2010 to May 28th, 2011, and analyzed the changes apparent within such graphs (Figure 6A, 6B). To evaluate the microclimate conditions of the internal space of the protective structure and the external space, the investigator also compiled graphs that corresponded with the environmental data attained in the internal space, and to Haenam area's temperature and relative humidity data, which were provided by the Meteorological Administration of Korea.

It is evident from the graphs that the temperature of the internal space within the protective structure has higher values than the external space. The temperature differences between the internal and external spaces are seen to be distinctive in winter but not in summer, and the patterns of variation are repeated each year. However, the temperatures of the internal and external spaces produce similar figures over the whole distribution of the charts, which implies that they were closely related to each other.

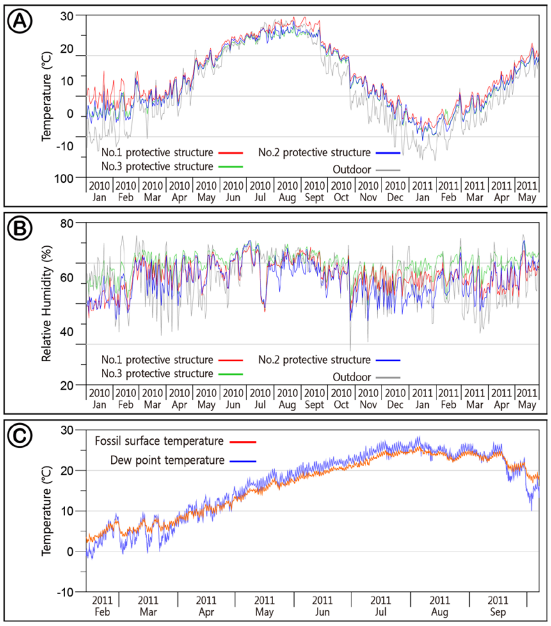

Figure 6. Microclimatic analysis results of the fossil sites in the Haenam area. (A, B) Comparison with in and outdoor temperature and relative humidity. (C) Dew point and fossil surface temperature in the No. 3 site.

To verify this hypothesis, the investigator compiled graphs of temperature measured per hour, both within the internal space of the protective structure and in the external space, and calculated the trend line and coefficients of determination. As a result of calculations, it was evident that the coefficients of determination of both temperatures were 0.88; thereby implying that the temperatures of both spaces are in close correlation. It has been reported that the temperature difference between the internal space of a building and the external space is smaller when the building has an effective ventilation system[9], and it can therefore be interpreted that the No. 3 site has high ventilation effectiveness. The reason that the temperature difference between the internal space of the protective structure and the external space is largest in winter is considered to be related to the air-conditioning equipment in operation in the internal space of protective structure, and therefore the internal temperature of the No. 3 site does not drop below zero even in winter, in contrast with the external space. This therefore effectively prevents any risk of damage to the fossil site from a freeze-thaw action.

The distribution characteristics for relative humidity of the internal and external spaces were somewhat different from those of temperature. Upon investigation, it was observed that the humidity of the external space showed a larger deviation than that within the internal space. In addition, the humidity of the internal space showed slightly different ranges between the different spaces within the protective structure in comparison to those of temperature, and this humidity difference between internal and external space was most significant during dry winters, but was smallest in summer when a highly humid environment was created. It is of note that the fossils span a wide area, and therefore the protective structure covering the fossils is huge. This implies that the temperature and the humidity can vary depending on the location of the measurements recorded, even within the protective structure.

Condensation in the form of dew occurs on the surface of rocks within the No. 3 site, and this accelerates the physicochemical weathering of the site and induces plant growth. To identify the cause of this phenomenon, the investigator measured the temperature at the surface of the fossil site using a temperature and humidity logger (Testo 177-H1), and measured the temperature of connected points through a surface temperature probe. Analysis of results comparing temperature data collected via this process and the temperature at dew point of the internal space showed that mostly the surface temperature of the rock was distributed in a lower range than that of the temperature at dew point (Figure 6C). It is considered that this difference may be a cause of the serious dew condensation on the surface of the fossil site.

In order to gather the differences in temperature and humidity between the surface of the fossil site and the upper view way, the investigator comparatively analyzed the environmental data obtained from the temperature and humidity logger that was attached to a wall at a height of approximately 2 m from the view way in the Dinosaur Museum, and the temperature and humidity logger installed near the surface of the fossil site. According to the results of a comparative analysis, it was found that the temperature at the surface of the No. 3 site showed no significant difference to that of the internal space of the protective structure, but the relative humidity of the surface of the fossil site in the No. 3 showed significantly higher values than those of the internal space of the structure. This shows that the humidity difference accelerates condensation.

Such a difference is related to the structural characteristics of the protective structure. As the fossil site is located in a position that is relatively lower than the view way, the air flow at the site is minimal. Ventilation does not occur adequately, and therefore vapor is created when the groundwater that flows backwards and cannot escape is evaporated. Due to this structural problem, the highly elevated relative humidity at the surface of the fossil site, together with the low temperature at the surface, contributes to creating condensation in the form of dew. This condensation is then not fully evaporated, but remains on the surface of rocks and causes physicochemical weathering and promotes the growth of plants.

Preventative measures are in place to stop the influence of groundwater that flows into the site, in the form of drains and drainage pumps under the site and inside the protective structure. However, although there is air-conditioning equipment in place, this does not achieve an efficient, balanced, air-conditioning function. In addition, no equipment is in place to control the microclimate environment on the surface of the fossil site, and therefore this environment within the protective structure is closely related to the external weather environment. It is considered that if the air-conditioning equipment in the protective structure was operated in accordance with the external weather conditions, a suitable microclimate environment would be attained which would conserve the site.

4. Discussion and Conclusions

From the analysis of material characteristics at the fossil sites, it was found that the sites at Uiseong and Haenam are composed of sedimentary rocks vulnerable to the weathering. The site at Uiseong was found to be composed of sandstone, and therefore exfoliation and fragmentation are actively developed at this site. Once cataclasis occurs and breaks the rock into small fragments, it is difficult to recover the lost fragments and restore the original shape. It was therefore considered necessary to investigate the cause of the occurrence, in order to prevent cataclasis. The causes of cataclasis were found to be mainly attributed to intricate cracks developing within the rock, the rock expanding and contracting due to moisture. It is therefore considered that the cracks should be filled via filling work, and that the inflow of groundwater should be blocked.

In relation to the results of microclimatic analysis, both the fossil sites at Uiseong Jeori and Haenam Uhangri were classified as having strong decomposition and moderate decomposition, and it is therefore highly possible that rocks will be damaged in the outdoor environment. Although the fossil sites targeted in this study are surrounded by protective structures, the results of analysis of the microclimates of the internal and external spaces showed that the microclimates of both spaces had a very close correlation. In particular, at Uiseong where an open-type protective structure is installed, it was found that there is not adequate control of the internal environment, and therefore the risk of frost weathering in winter is very possible. In addition, the inflow of groundwater from the back of the fossil site promotes frost weathering and plant growth. Hence, it is necessary to firstly block the inflow of water by expanding the drainage equipment, and then to reduce the weathering at the fossil site by performing consolidation treatment on the rocks.

At Haenam, the internal temperatures of each of the protective structures are distributed above zero almost all of the time except for during a few periods, and therefore the possibility of frost weathering of rocks therein is considered to be very low. However, although frost weathering has not yet occurred, the influence of moisture may accelerate weathering of rocks. It is considered that further analysis of the influence of moisture should be performed. This is particularly relevant in the internal space of the No. 3 site, where condensation occurs in the form of dew, and where there is efflorescence over the entire surface of the site. These phenomena are created by moisture conditions in the internal space. It is considered that the internal environment of the protective structure should be kept at a low humidity by means of effective air-conditioning equipment, and that the inflow of groundwater should be blocked by the installation of additional drainage pumps.

5. References

1. Thulborn T. Dinosaur tracks. Chapman and Hall, pp. 33–36; 1990.
2. Huh M, Park J. Dinosaurs in Korea. The 11th Sysmposium on Mesozoic Terrestrial Ecosystems (Abstracts). 2012 Aug; pp. 89–92.
3. Yoo JH, Lee CH, Eo EI. Evaluation of deterioration diagnosis and conservation environments of the large and the giant dinosaur footprint fossils in Haenam Uhangri, Korea. J Geolog Soc Korea. 2012; 48(4):325–340.
4. The Geological Society of Korea. A report on the natural monuments (fossil, rock) and the dinosaur footprint fossils. The Geological Society of Korea. p.203; 1992.
5. Song JY. Reinterpretation of unusual Uhangri dinosaur tracks from the view of functional morphology. J Paleontol Soc Korea. 2010; 26(2):95–105.
6. Available From: www.kma.go.kr.
7. Jeong GY, Kim SJ. Applied mineralogy for the conservation of dinosaur tracks in the Goseong interchange area. J Mineralog Soc Korea. 2004; 17:189–199.
8. Fookes PG, Dearman WR, Franklin JA. Some engineering aspects of rock weathering with field examples from Dartmoor and elsewhere. Quart J Engin Geol Hydrogeol. 1971; 4:139–185.
9. Frederick KT, Mikko H, Matti P, Jaan P, Imbi V, Väino P et al. Microclimate and ventilation in Estonian and finnish dairy buildings. Energy Buildin. 2008; 40:1194–1201.