Conservation Studies of Korean Stone Heritages

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Abstract: In Republic of Korea, a peninsula country located at the eastern region of the Asian continent, is mostly composed of granite and gneiss. The southern Korean peninsula stated approximately 7,000 tangible cultural heritages. Of these, the number of stone heritages are 1,882 (26.8%), showing a diverse types such as stone pagoda (25.8%), stone Buddha statues (23.5%), stone monuments (18.1%), petroglyph, dolmen, fossils and etc. Igneous rock accounts for the highest portion of the stone used for establishing Korean stone heritages, forming approximately 84% of state-designated cultural properties. Among these, granite was used most often, 68.2%, followed by diorite for 8.2%, and sandstone, granite gneiss, tuff, slate, marble, and limestone at less than 4% each. Furthermore, values of the Korean stone heritages are discussed as well as various attempts for conservation of the original forms of these heritages. It is generally known that the weathering and damage degrees of stone heritage are strongly affected by temperature and precipitation. The most Korean stone heritages are corresponded to areas of middle to high weathering according to topography and annual average temperature and precipitation of Korea. Therefore, examination of environmental control methods are required for conservation considering the importance of stone heritages exposed to the outside conditions, and monitoring and management systems should be established for stable conservation in the long term.

1 INTRODUCTION

Republic of Korea, a peninsula country located at the eastern region of the Asian continent, has mountains covering approximately 70% of its entire territory and four distinct seasons (Fig. 1a). Traditional religions practiced here are Buddhism and Confucianism, which have had a considerable influence on cultural development, thought and behavior in the ancient Korean kingdoms and states. After the modern era, Christianity and Catholicism were introduced in Korea from the West. The first state of the Korean peninsula was Gojoseon (BC 2333 to BC 108), followed by the Three Kingdoms Period (Goguryeo, Baekje and Silla; BC 57 to 675), Unified Silla (676 to 935) and Balhae (698 to 926). Goryeo (918 to 1392) and Joseon (1392 to 1910) Dynasty followed in the middle and middle to modern periods, respectively. Through the colonial period from 1910 to 1945, Korea achieved independence, whereas North and South were divided based on the 38th parallel. In 1948, Republic of Korea was formally established.

More than half of the Korean peninsula is composed of granite and granite gneiss. The former was mainly intruded during the Triassic, Jurassic and Cretaceous periods, whereas the latter was mostly metamor-phosed due to granitization of sedimentary rock during the Pre-Cambrian eons (Fig. 1b). These rocks were exposed to the surface of the earth due to diastrophism during several periods, and uplift and denudation phenomena of the Korean peninsula generated from the beginning of the Tertiary period, thereby distributing the sedimentary rock on the gneiss (Cheong et al., 2013). This geological distribution of the Korean peninsula is closely related to selection of materials for establishing stone heritages as well as construction techniques.

The National Research Institute of Cultural Heritage in Korea (2011) stated that approximately 7,000 tangible cultural properties exist in Korea including national treasures, tangible cultural properties of cities and provinces, and cultural property materials. Of these, the number of stone heritages is 1,882 (26.8%), showing a diverse composition range from petroglyphs and dolmens during the prehistoric ages to stone pagodas, stone Buddha statues, stone monuments, rock-carved Buddha statues, stone stupa, and flagpole supports during the historical period. In particular, stone pagodas (25.8%), stone Buddha statues (23.5%) and stone monuments (18.1%) account for the highest portions of the existing stone heritages (Fig. 1c).

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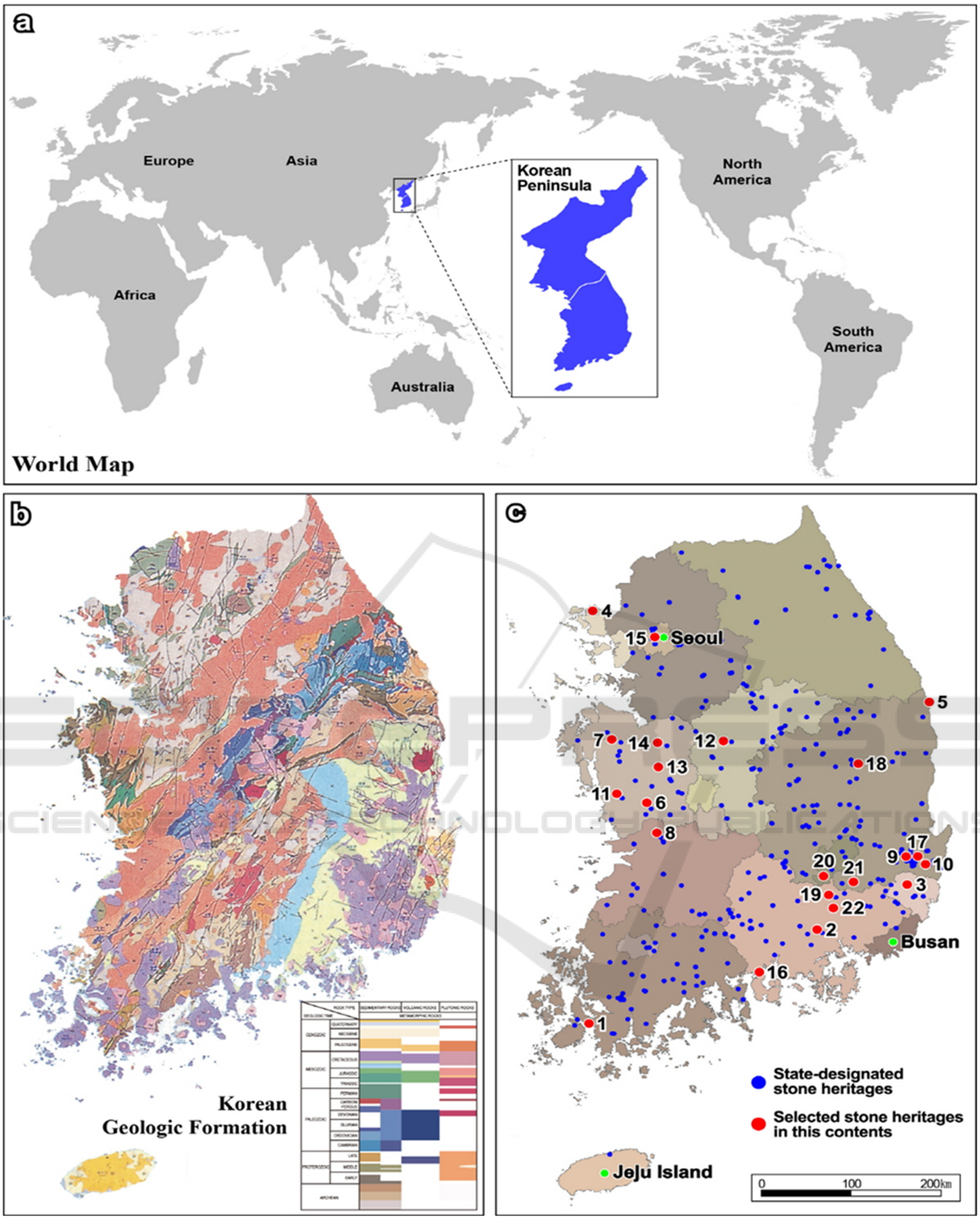

Figure 1: (a) Location of Korean peninsula. (b) Korean geological map. (c) Distribution map of representative Korean stone heritages (Lee and Chun, 2013). 1; Dinosaur footprint fossil sites in Uhang-ri, Haenam. 2; Dinosaur trackways in Daechi-ri, Haman. 3; Bangudae petroglyphs in Ulju. 4; Dolmen in Bugeun-ri, Ganghwa. 5; Silla Stele in Bongpyeong-ri, Uljin. 6; Five-story Stone Pagoda in Jeongrimsaji Temple Site, Buyeo. 7; Rock-carved Buddha Triad in Yonghyeon-ri, Seosan. 8; Stone Pagoda in Mireuksaji Temple Site, Iksan. 9; Chemseongdae in Gyeongju. 10; Dabo Pagoda and Three-story Stone Pagoda of Bulguksa Temple. 11; Five-story Stone Pagoda of the Seongjusaji Temple Site in Boryeong. 12; Rock-carved Buddha Statues of the Namharisaji Temple Site in Jeungpyeong. 13; Stone Standing Maitreya Statue of the Gwanchoksa Temple in Nonsan. 14; Five-story Stone Pagoda of the Magoksa Temple in Gongju. 15; Seoul City Wall. 16; Tombstone of Chungmugong Yi at the Chungryeolsa Shrine in Namhae. 17; Gyeongju Seokbinggo. 18; Andong Seokbinggo. 19; Changnyeong Seokbinggo. 20; Hyeonpung Seokbinggo. 21; Cheongdo Seokbinggo. 22; Yeongsan Seokbinggo.

In this study, representative cultural properties were selected according to type and material among Korean stone heritages established during the geologic, prehistoric and historical ages. Based on the results of previous studies, each of the selected stone heritages is briefly described in terms of historical value, lithological characteristics, stone provenance, deterioration state, non-destructive diagnosis and conservation treatment. Furthermore, globally outstanding characteristics and values of the Korean stone heritages are discussed as well as various attempts for preserving the original forms of these heritages.

2 STONE HERITAGES OF GEOLOGICAL AND PREHISTORIC AGES

2.1. Dinosaur Footprint Fossils of Uhang-ri and Daechi-ri

Korea is globally renowned as an excavation site for dinosaur footprint fossils, which are observed more frequently than skeleton fossils and have been unearthed in more than 20 regions. Main dinosaur footprint fossil sites are shale-rich lacustrine sedimentary rocks of various sub-basins such as the Cretaceous Gyeongsang Basin (Huh et al., 2003). Dinosaur footprint fossils of ornithopods are found most frequently although those of theropods and sauropods are also observed. Representative dinosaur footprint fossils are as follows.

Large (Fig. 2a) and extra-large dinosaur footprint fossils (Fig. 2b) in Uhang-ri, Haenam, mainly consist of black shale (Fig. 2c); only extra-large dinosaur footprint fossils in the open air are composed of tuffaceous sandstone that includes quartz and albite phenocrysts with rhyolite-rich matrix. Notable physical damage to these footprint fossils are cracks, delamination, fracture zone, and re-damage by repair materials; that of chemical damage is efflorescence (thenardite, Na2SO4) generated along the current trace of water that flowed into fossil sites. Moreover, the results of physical characteristics analysis of the fossil sites using measurement of ultrasonic velocity indicate that the fossils in these sites are highly weathered (Yoo et al., 2012).

Dinosaur trackways in Daechi-ri, Haman, were found in shale with purple and grayish-green strata (Fig. 2d), consist of two ornithopod trackways with an average depth of 29 mm and one sauropod trackway with an average depth of 30 mm for manus and 35 mm for pes (Fig. 2e). However, these fossils underwent severe physical damage by cracks due to relocation more than twice after the first excavation in 1993 in addition to inappropriate conservation treatment and secondary deterioration by plaster repair materials, thereby requiring for comprehensive improvement.

Thus, in 2008, scientific conservation treatment was performed to remove previous repair materials, which included cleaning and desalination through an impregnation method, preliminary joining using a three-dimensional drawing, fabrication of a fiberglass-reinforced plastic (FRP) mold on the floor surface, joining and filling of cracks and missing parts, application of anti-swelling agents and consolidating (Fig. 2f). Detailed investigation and scientific conservation treatment of dinosaur trackways greatly contributed to establishing a customized conservation system (Lee et al., 2012).

2.2. Bangudae Petroglyphs

Petroglyphs are paintings or patterns carved on the rock surfaces by using sharp parts of hard stones or metal tools. These images serve as valuable materials to represent the contemporary aesthetic consciousness of ancestors, such as life, religion and philosophy, who lived before the invention of writing systems in the prehistoric age. Such artwork is a universal cultural phenomenon; approximately 400,000 petroglyphs are widely distributed across approximately 120 countries worldwide. Of these, 14 petroglyphs have been designated as World Heritage. At present, approximately 20 petroglyphs exist in Korea. In particular, petroglyphs in Cheonjeon-ri and Bangudae in Deagok-ri, Ulju, are included on the tentative lists (2010) of UNESCO World Heritages.

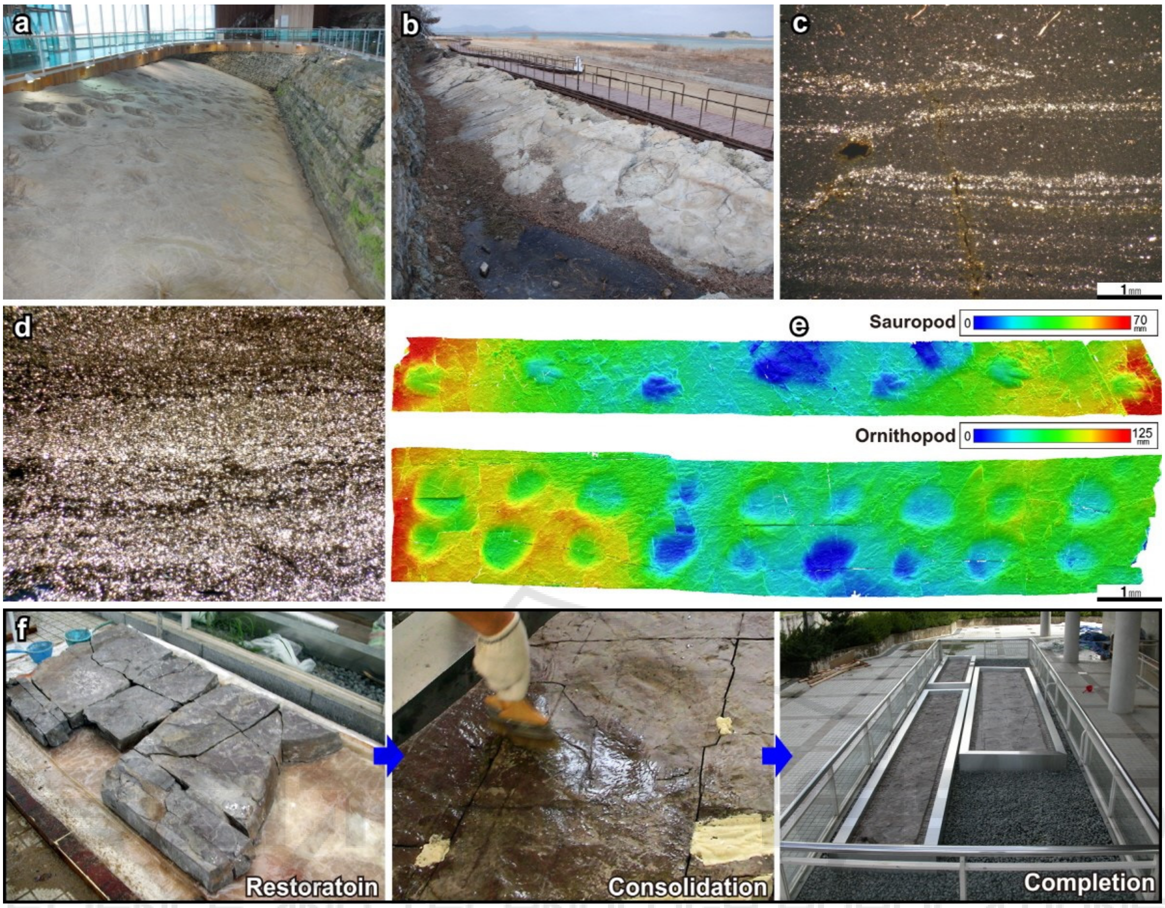

Figure 1: Photographs showing the large (a) and extra-large dinosaur (b) footprint fossils in Uhang-ri, Haenam. (c) Black shale composing of the large dinosaur footprint fossils. The shale lamination by accumulated clay and quartz (d), surface depth modelling (e) and conservation treatments (f) of the dinosaur trackways in Daechi-ri, Haman. (Lee *et al.*, 2012; Yoo *et al.*, 2012).

Among them, Korea National Treasure No. 285, the Bangudae petroglyphs in Daegok-ri, Ulju, represent first stone painting in Korea, and are regarded as the most sophisticated relic to reflect life of prehistoric people. In these petroglyphs, diverse objects of expression such as whales, tigers, deer, boar, turtles, ships, nets, harpoons, people and simply human faces are more implicitly carved than those in other remains (Fig. 3a). In particular, eight types of whales and complex religious paintings related to whaling are main expressions representing the traditions of the whaling culture (Cultural Heritage Administration of Korea, 2012).

However, the Bangudae petroglyphs are repeatedly flooded and exposed for four to eight months per year due to the Sayeon Dam constructed in 1965, six years before the discovery of these rock carvings. As a result, dark green hornfelsified shale, rock properties of the petroglyph, forms a weathered layer with an average porosity of 25% at a certain depth from the surface, thereby showing differences in mineral and chemical compositions compared with the fresh surface with an average porosity of 0.4% (Fig. 3b). The result of deterioration degree evaluation indicates that approximately 23.8% of the main rock surface areas were damaged (Fig. 3c) and the lower areas of the petroglyphs have weaker physical properties than those of the upper areas (Lee et al., 2012). As such, Ulsan City and many researchers including those with the Cultural Heritage Administration of Korea are seeking a scheme of permanently conserving the Bangudae petroglyphs.

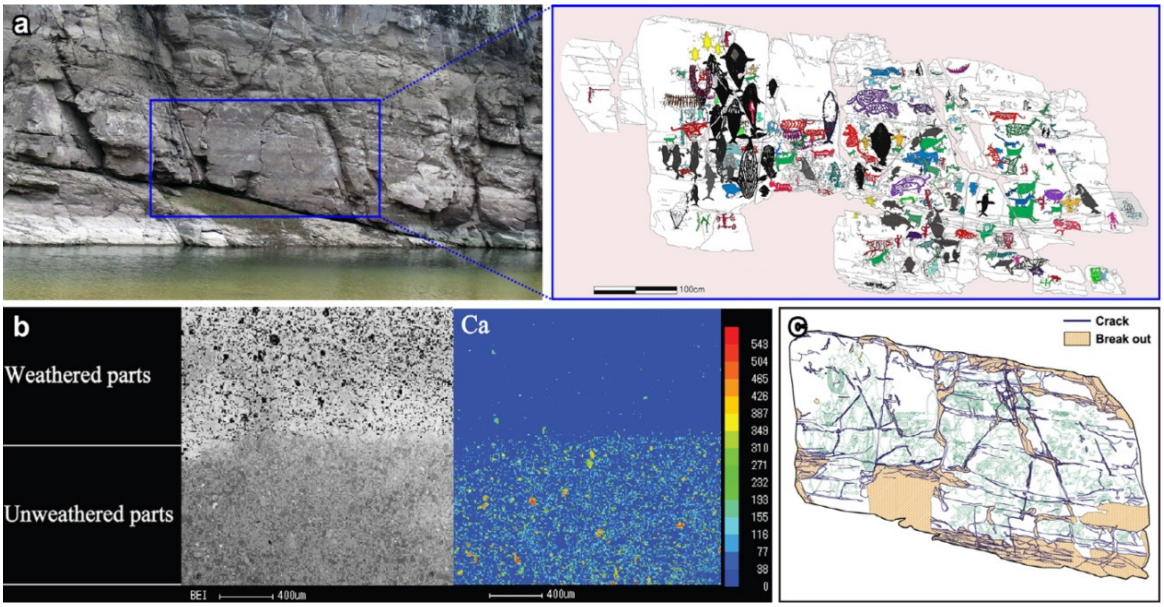

Figure 3: General view and occurrence (a), EPMA result of the weathered and unweathered parts (b), and deterioration map (c) of the Bangudae petroglyphs in Ulju. (Cultural Heritage Administration of Korea, 2012; Lee et al., 2012).

3 STONE HERITAGES OF HISTORICAL AGE

3.1 Five-story Stone Pagoda in Jeongrimsaji Temple Site, Buyeo (estimated the 6th to 7th century)

The Five-story Stone Pagoda in Jeongrimsaji Temple Site, Buyeo (National Treasure No. 9), a valuable pagoda constructed during the Baekje Kingdom, has distinct historical and artistic values in that its original form is well maintained, except for the upper part (Fig. 4a). In particular, this stone pagoda effectively expresses the beauty of a simple and vibrant stone tower by eschewing the complexities of wooden structures. It is 8.92 m in height and consists of 149 members. With regard to style, its basement part is significantly lower than its body part.

The pagoda’s rock material is porphyritic biotite granodiorite and contains pegmatite veinlets, basic xenoliths, and is consistently developed porphyritic texture of plagioclase (Fig. 4b, 4c). The results of provenance interpretation confirmed that Ong-nyeobong Peak, which is located 15 km to 20 km from Jeongrimsa Temple, and Mt. Hwa have same mineralogical and geochemical characteristics with those of this pagoda. In particular, ancient quarrying traces were observed at many outcrops in this region, thereby supporting the hypothesis that this region could have been used to supply the stone (Fig. 4d). Thus, the stone required for establishing this pagoda is likely to have been supplied to Buyeo through the Geum River from Ganggyeong Port (Fig. 4e, 4f) (Lee et al., 2007).

3.2 Rock-carved Buddha Triad in Yonghyeon-ri, Seosan (estimated the 6th to 7th century)

The Rock-carved Buddha Triad in Yonghyeon-ri, Seosan (National Treasure No. 84) is a representative Buddha statue of the Baekje Kingdom constructed in a rocky cliff of a gorge in Gaya Mountain; Pensive Bodhisattva and Standing Bodhisattva are carved on both sides of Standing Buddha (Fig. 5a). This Buddha triad statue has been considered as the greatest contemporary masterpiece because of its refined carving style and unique triad composition. It is a valuable cultural heritage that indicates contemporary Buddhist culture and interchange relations such as the spread of Buddha style from China and India based on geopolitical location (Moon, 1999; Park, 2005). The Buddha triad statue is carved on a rock slope consisting of light gray medium-grained biotite granite, and it shows low slope stability because rock blocks of different sizes and shapes are formed across the entire sides due to development of irregular discontinuities (Lee et al., 2010).

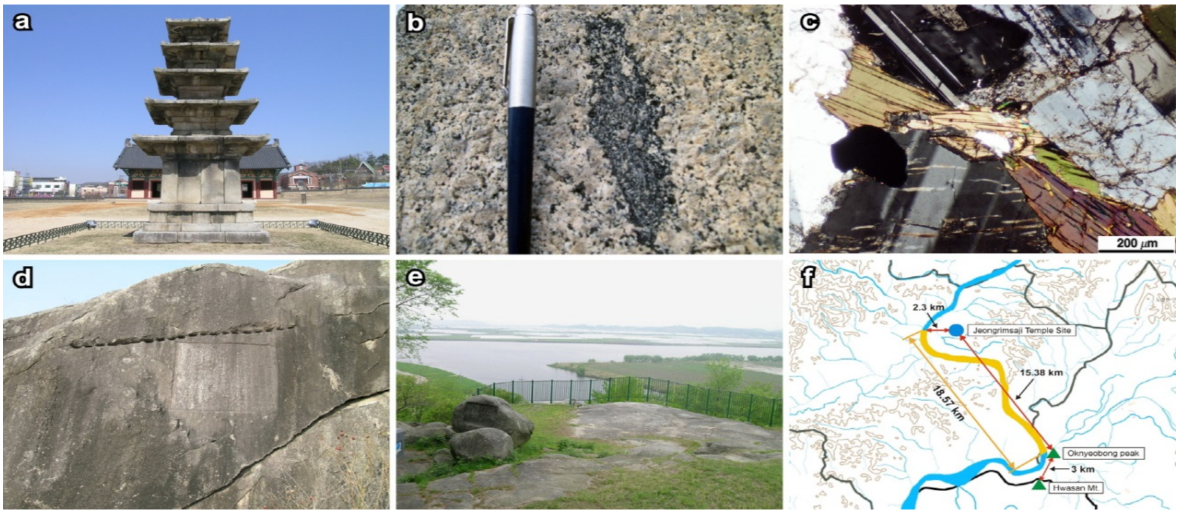

Figure 4: (a) Field occurrence of the Five-story Stone Pagoda in the Jeongrimsaji Temple Site. (b) Porphyritic granodiorite containing pegmatite veinlets and basic xenoliths. (c) Mineral assemblage of plagioclase with albite twin, biotite altered partly into chlorite, quartz and sphene. (d) Photographs showing the ancient quarrying trace from outcrop in the Oknyeobong Peak. (e) Geum River nearby the Oknyeobong Peak. (f) A map showing the distance of movement of rock properties between the stone pagoda, Oknyeobong Peak and the Mt. Hwa. (Lee et al., 2007).

In addition, since an enclosed traditional wooden shelter was installed to protect this Buddha triad statue from the atmospheric environment in 1965, internal leakage problems have occurred continually (Fig. 5b). In particular, limitations in the shelter's protective function owing to damage have resulted in deteriorations to this statue by condensation, dust deposition, and efflorescence. Moreover, visitors have been inconvenienced due to a narrow observing space in the protective canopy and insufficient lighting. Consequently, to improve conservation and the viewing conditions, the walls of the shelter were partly disassembled in 2006 (Fig. 5c), and the shelter was completely dismantled in 2007 (Fig. 5d). After demolishing the shelter, conservation treatment and maintenance of the surrounding environment were performed in 2008; currently, the Buddha triad statue is exposed to the external environment with no protecting structure (Lee et al., 2014).

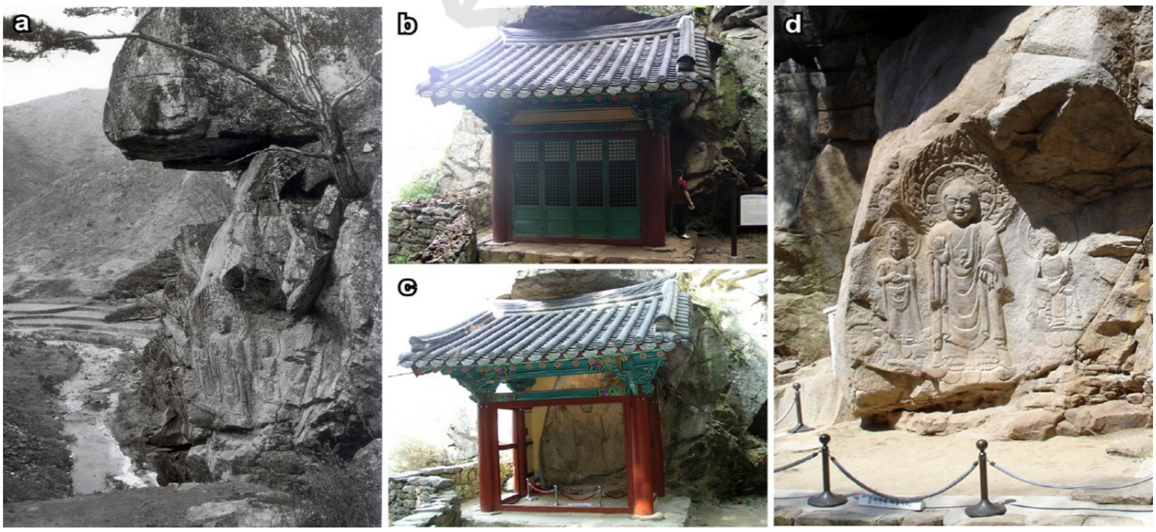

Figure 5: (a) Field occurrences (1959) of the Rock-carved Buddha Triad. (b) Enclosed traditional wooden shelter of Buddha statue. (c) Semi-opening shelter partly disassembled the door and both walls. (d) The current state completely demolished the shelter. (Lee et al., 2010).

3.3 Stone Pagoda in Mireuksaji Temple Site, Iksan (the 7th century)

Mireuksa Temple is the greatest Buddhist temple of Baekje Kingdom established by King Mu (600 to 641), the 30th King of the Baekje. Three pagodas and three main buildings are divided by corridors to form respective areas (Fig. 6a). The middle area is estimated to be a wooden pagoda site, and the eastern pagoda was restored to nine stories in 1992. The current Mireuksaji Stone Pagoda (National Treasure No. 11) is a western pagoda located in the west area; more than half has been destroyed except from the basement to part of the sixth story (Fig. 6b). The stone embankment was reinforced up to the first story based on the west side, and the upper part was covered by concrete for repair in 1915 (Fig. 6c). In January 2009, the Buddhist reliquary was excavated at the first-story center pillar stone of the stone pagoda. Inscription of the Gihae year (639) confirmed in the golden sarira enrichment record show the construction period of the west pagoda and identify the main founders and characteristics of the Mireuksa Temple (National Research Institute of Cultural Heritage in Korea; NRICH, 2013).

In 1998, a safety diagnosis results reported that the structural stability of the stone pagoda was low, and it was determined in 1999 to execute deconstruction and repair. Since October 2001, deconstruction, restoration, and maintenance have been performed by the NRICH. Thus far, deconstruction of the pagoda has been completed except for the basement. During the processes of deconstruction and excavation investment, detailed data were collected through research in various fields such as conservation science (Fig. 6d), construction (Fig. 6e, 6f), archaeology, and art history, and repair works for restoration (Fig. 6g) are currently being performed (NRICH, 2014). The members of this stone pagoda are composed of biotite granite, the same rock type as that occurring near Mt. Mireuk, and quarrying traces are scattered throughout the mountain area (Yang et al., 2000). Furthermore, the deterioration degree of the stone pagoda members was evaluated, and method for original restoration and selection of replacement stone were examined (Lee et al., 2009; Kim et al., 2011).

3.4 Cheomseongdae in Gyeongju (the 7th century)

Cheomseongdae in Gyeongju (National Treasure No. 31) is an astronomical observation structure constructed during the reign of Queen Sunduk (AD 647), the 27th ruler of Silla Kingdom, and is the largest existing observatory in Asia (Fig. 7a). For stone, alkali-feldspar granite (63%) was used for the basement, the upper cylindrical body part, and a top part of Cheomseongdae (Fig. 7b); micrographic granite (27%) was used for the lower cylindrical body part (Fig. 7c). However, since the two rock types have similar mineralogical and geochemical characteristics, they are considered to have been generated from same granitic magma (Fig. 7d). It was verified that these rocks originated from Mt. Nam at the south of Cheomseongdae in which many ancient quarrying traces are found.

Results of precise non-destructive diagnosis indicate that structural problems such as cracks and missing part occur mainly at the lower part of Cheomseongdae, whereas the upper part was damaged mostly by surface weathering such as blistering, scaling, and granular disintegration (Fig. 7e). It was also determined that the surface was mainly contaminated by darkening (37.3%) and biological colonization (58.0%). In particular, the darkening contaminants include microorganisms, clay minerals, dust and micro soil particles, which combined to form a thick layer that also led to discoloration after iron-oxidizing substances degraded from minerals, and consecutive applications of plaster were added. Regarding physical properties of rock used in Cheomseongdae, it was determined through the ultrasonic velocity measurement that the rocks were moderately weathered stage on average (Jo et al., 2010).

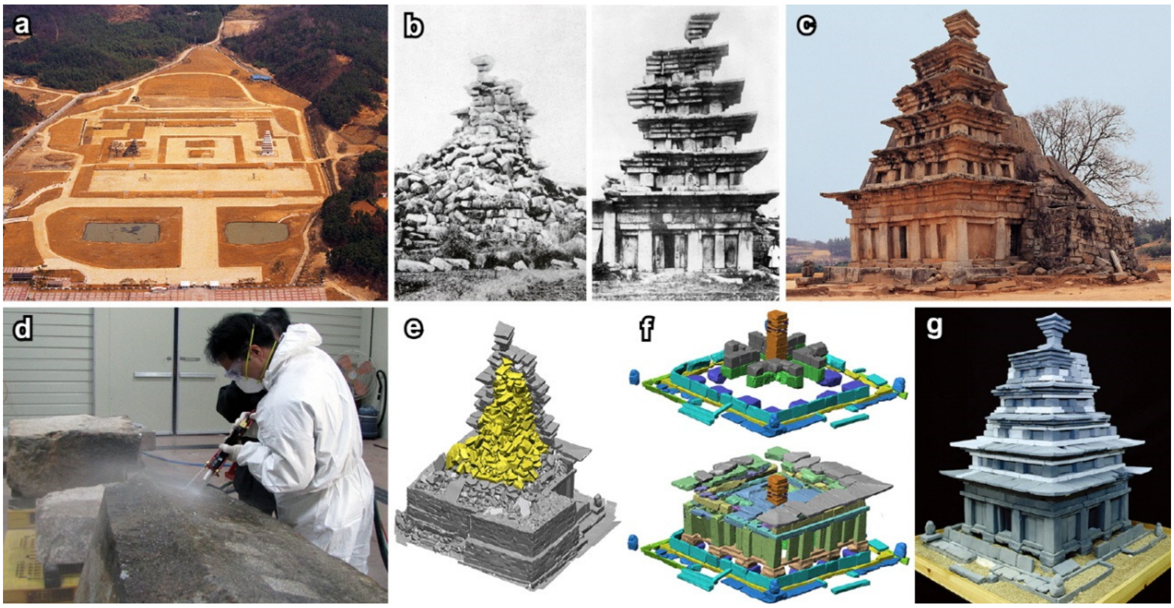

Figure 6: (a) Aerial photograph of the Mireuksaji Temple site in Iksan. (b) Western and eastern views of the Mireuksaji stone pagoda before and after reconstruction in the 1910s. (c) A recent (1990s) view from the northeastern side. (d) Steam cleaning to remove the surface contaminants. (e) Three-dimensional modeling to apply restoration and conservation treatment of the stone pagoda. (f) Virtual assembling of the basement part using three-dimensional simulation. (g) Three-dimensional model and restoration idea of the stone pagoda. (Lee et al., 2009; NRICH, 2013).

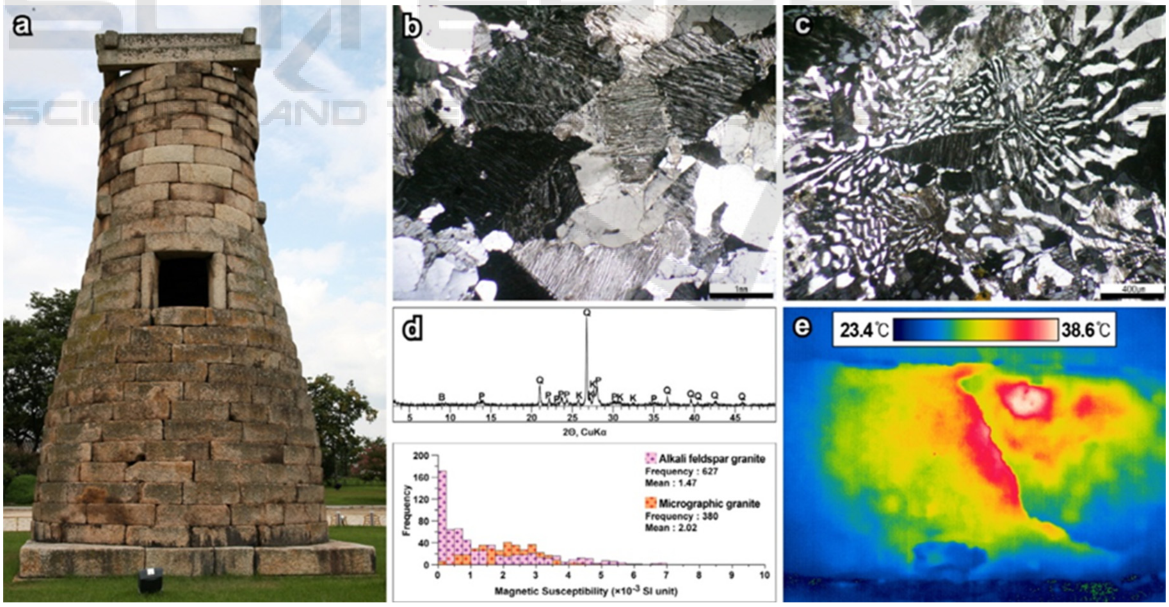

Figure 7: (A) Field Occurrence of Cheomseongdae. Polarizing Microscope Images of Alkali-Feldspar Granite (B) and Micrographic Granite (C). (D) X-Ray Diffraction Pattern and Magnetic Susceptibilities of Component Stones. (E) Infrared Thermographic Image on the Blistering. (Jo Et Al., 2010).

3.5 Dabo Pagoda and Three-story Stone Pagoda of Bulguksa Temple (the 8th century)

Bulguksa Temple in Gyeongju was built in the 10th year (751) of the reign of King Gyeongdeok of Unified Silla Kingdom. The Dabo Pagoda (National Treasure No. 20), representative of special pagodas, is located at the fontal east of main Buddhist hall, and the Three-story Stone Pagoda (National Treasure No. 21), representative of general pagodas, is at the west. It is easily observed that the latter, with a height of 10.8 m, is a three-story pagoda established on two-story basement, whereas the number of stories of the Dabo Pagoda, with a height of 10.3 m, is un-determined. Equigranular medium-grained alkali-feldspar granite in which small druse is developed was used in the two stone pagodas; rocks for other parts are mixed (Lee et al., 2005).

In 1925, the Dabo Pagoda was comprehensively deconstructed for repair, and its lower quadrangular banister of the second story and upper part were repaired in 1972. Nevertheless, due to inappropriate drainage at the second-story banister, the first-story support structure was damaged by weathering. Since repair was urgently needed, the NRICH performed conservation treatments in December 2008. Specifically, after preliminary investigation including the processes of three-dimensional scanning and making a deterioration map of the stone pagoda, eight members in poor condition were replaced by partially disassembling the quadrangular banister of the second story, octagonal banister, and upper part(Fig 8a, 8b).

Moreover, conservation treatments were performed on crack and blistering parts, and by removing concrete and cement mortar at joints and performing cleaning, the conservation process was completed in December 2009 (NRICH, 2011). Parts of the Three-story Stone Pagoda damaged during an attempted robbery case in 1966 were partially repaired. In December 2010, crack 1.32 m length and 5 mm in maximum width were confirmed in the cover stone on the northeastern upper basement through regular safety inspection. As a result, deconstruction and repair measures are being performed and are due to be completed in 2014.

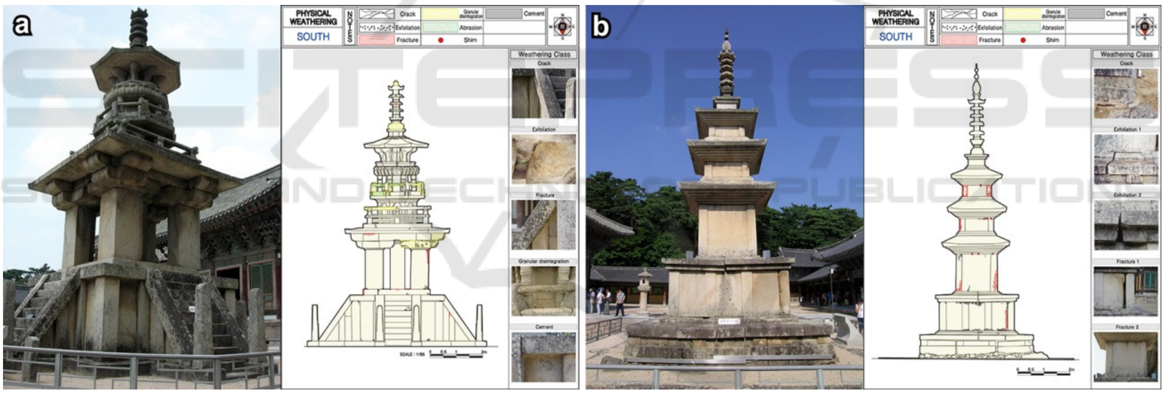

Figure 8: Field Occurrences and Deterioration Maps of the Dabo Pagoda (A) and the Three-Story Pagoda (B) in Bulguksa Temple. (Lee, 2007).

3.6 Stone Standing Maitreya Statue of the Gwanchoksa Temple in Nonsan (estimated the 10th to 11th century)

At a height of approximately 18 m, the Stone Standing Maitreya Statue of the Gwanchoksa Temple (Treasure No. 218) is the largest stone statue of Buddha in Korea (Fig. 9a). It is located on a slightly inclined outcrop of granodiorite against a backdrop of Mt. Banya (Fig. 9b). Overall, this Buddha's feet are carved in natural bedrock without a pedestal, whereas the upper and lower body and both arms are composed of large stones to establish a complete statue. A cylindrical high crown appears on the head, expressing baldachin that has the square Gat shape of a traditional Korean hat. On the face, which is comparatively larger than the body, the eyes, nose, and mouth are adjusted to completely fill the entire face, thus enabling the face to overcome a flat image and have a strong impression. The Buddha's linear eyes appear very sharp; the pupils, composed of black shale, realistically express the image of the stone sculpture (Fig. 9c).

This standing stone Maitreya statue had been physically weathered by blistering and scaling, and secondary contaminants and deposits are scattered around it (Fig. 9d). Moreover, a collapse risk of the host rock due to development of discontinuities is present, and a high amount of crustose lichens covers the statue; fungi, algae, and bryophytes are also present (Yun *et al.*, 2006). As such, to protect this statue from contamination by lichens, blistering, and cracks, conservation treatments were conducted in 2007 based on preliminary investigation with regard to conservation science. Overall processes were performed in the order of dry and wet cleaning, joining of cracks, and reinforcement of missing parts using replacement rock; maintenance of surrounding environments was also conducted.

3.7 Five-story Stone Pagoda of the Magoksa Temple in Gongju (estimated the 13th century)

The Five-story Stone Pagoda of the Magoksa Temple in Gongju (Treasure No. 799) is a representative cultural heritage of the late Goryeo Dynasty and was constructed under the influence of Lamaism (Fig. 10a). On the second-story body part of this pagoda, the mystic Buddhas of the Four Directions are embossed, whereas the upper part consists of a Lamaistic-style Pungmadong, which is unique in that it is found only at the existing White Pagoda of the Miaoying Temple in Beijing, China, and at the pagoda of the Magoksa Temple. This stone pagoda is composed mainly of dark gray fine-grained quartz diorite. The second-story body part and dew tray consist of granodiorite, and the basement, which was replaced during deconstruction and restoration works in 1970, is composed of biotite granite (Fig. 10b). The texture and color of biotite granite differ completely from those of quartz diorite, which is the main rock used, thereby leading to a sense of substantial heterogeneity in appearance (Jo *et al.*, 2012).

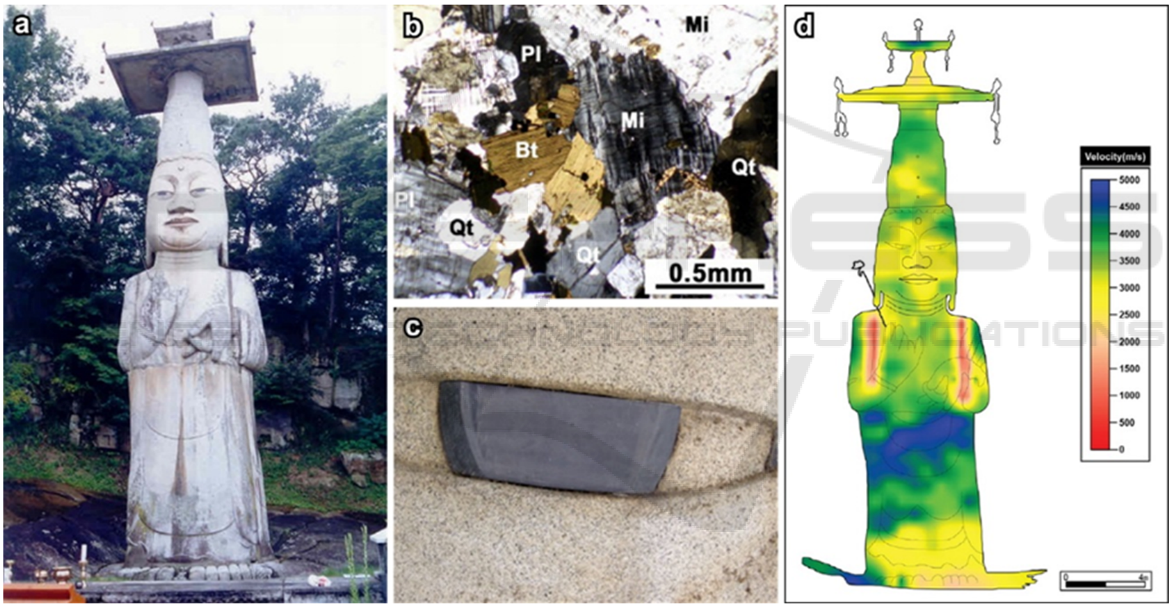

Figure 9: (a) Frontal view of the stone standing Maitreya statue of Gwanchoksa Temple in Nonsan. (b) Granodiorite composed of quartz, plagioclase, microcline and biotite. (c) Slate consisting of pupil part. (d) Two-dimensional modeling using ultrasonic velocity.

This stone pagoda is highly unstable due to a comprehensively low gradual decrease rate and because its northern part was substantially damaged when the Daegwangbojeon Hall was set on fire in 1782. Thus, it has lost most of its original form. In addition, constant deformation occurred even after deconstruction and restoration of this pagoda in the 1970s, thus resulting in missing part, cracks, blistering, and scaling of original rock and repair materials, which could be easily observed by the naked eye (Jo and Lee, 2014). Hence, precise safety diagnosis including ground exploration and behavioral monitoring was performed in 2006; deterioration degree evaluation, three-dimensional scanning and monitoring were done in 2008 (Fig. 10c); and infrared thermographic analysis and investigation using an endoscope were conducted in 2012 (Fig. 10d). Based on the results, scientific conservation treatments have been performed to maintain the original form of this pagoda.

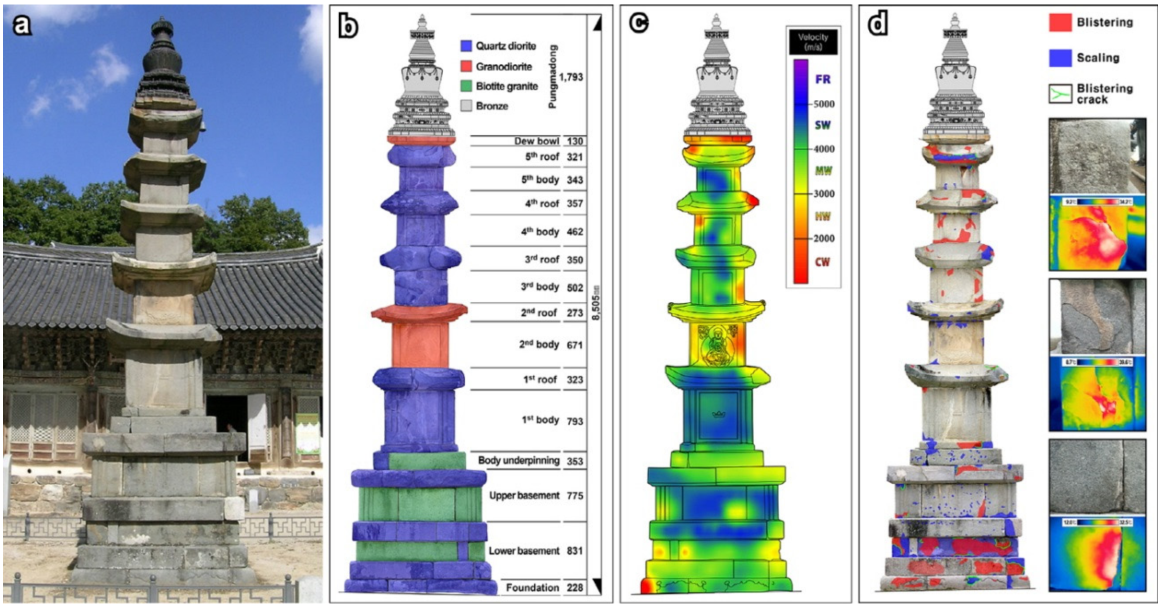

Figure 10: (a) Current appearance of the Magoksa Temple stone pagoda. (b) Lithological map of the stone pagoda. (c) Contour two-dimensional map by projecting the ultrasonic velocity of the stone pagoda. (d) Digital photographs and thermographic images of representative blistering zones and blistering map of the stone pagoda. (Jo *et al.*, 2012; Jo and Lee, 2014).

3.8 Seoul City Wall (after the 14th century)

The Seoul City Wall (Historic Site No. 10), at approximately 18.1 km, was constructed to protect Hanyang (now Seoul), the capital in the Joseon Dynasty (Fig. 11a). Since the beginning of its construction in the fifth year of King Taejo (1396) (Fig. 11b), its original form has been well maintained through extensive restoration measures performed during the reigns of King Sejong (1397–1450) and King Sukjong (1661–1720) (Fig. 11c). However, when trams were introduced as a new transportation mode during the Japanese colonial era, the city walls were heavily damaged. Even after Korean independence, rapid industrialization led to frequent damage to the walls. Fortunately, after the 1970s, the Seoul City Wall was gradually restored to its original form as repairing project of the walls to promote national pride. Furthermore, it has been recently listed on the tentative UNESCO World Heritage List (2012), achieving magnificent results.

Based on the results of previous studies, pinkish granite (approximately 80%), leucocratic granite (approximately 5%), gneiss (approximately 3%), and dark red granite (approximately 2%) were mainly used for constructing the Soul City Wall (Fig. 11d), whereas small amounts of fine-grained granite and aplite were also added (Lee *et al.*, 2013). The various material characteristics are closely related to geological characteristics of the rocks adjacent to the City Wall rather than other rocks intended for use by the technician in charge of its construction. This occurred because the City Wall reflects the political intention of Joseon Dynasty, in which a large amount of stone was required just after the national foundation, unlike other heritages such as the Angkor of Cambodia for which stone was supplied from a long distance (Uchida and Shimoda, 2013).

In particular, these features are verified in that rock properties of the early Joseon period was mainly supplied from inner four mountains adjacent to the City Wall, whereas a large amount of construction stone was supplied from a fixed quarry outside the City Wall after the middle Joseon period (Fig. 11e). Thus, material authenticity of the Seoul City Wall can be identified by examining the diversity of material distribution and changes in provenacne according to period and location. These criteria are also expected to be applied as basic data for selecting the same rock for future restoration (Lee *et al.*, 2013).

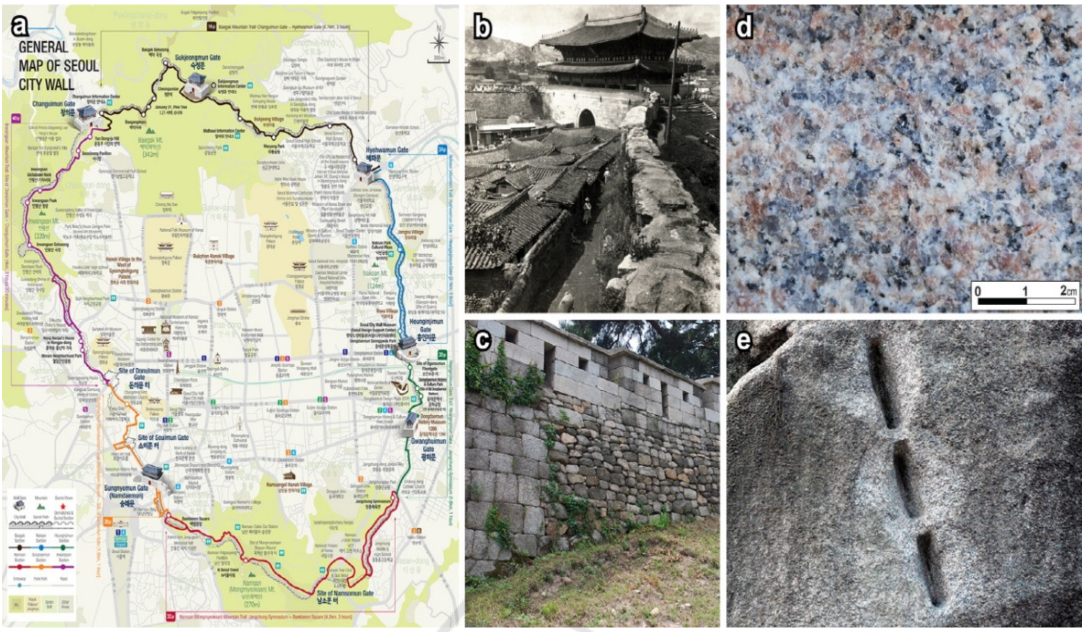

Figure 11: (a) General map of Seoul City Wall published by Seoul Metropolitan Government (2014). (b) Photograph of Sungnyemun Gate and its vicinity in early 1904 (Photographer : George Rose; Collection of Cha Sang-sun, head of Stereoscope). (c) Different techniques used to construct the wall during the reigns of King Sejong and King Sukjong. (d) Pinkish granite used as the main rock material for Seoul City Wall. (e) Ancient quarrying trace found in places for provenance investigation. (Lee *et al.*, 2013).

3.9 Seokbinggo (Stone Ice Storage) (the 18th century)

Seokbinggo is Stone Ice Storage to store ice collected in winter to be used in summer. At present, a total of six Seokbinggo structures, Treasure Nos. 66, 305, 310, 673, and 323 and Historical Site No. 169, are located in Gyeongju, Andong, Changnyeong, Hyeonpung, Cheongdo, and Yeongsan of South Korea, respectively (Fig. 12a). All of these structures were built in the late Joseon Dynasty and have been maintained thus far. Seokbinggo can keep ice collected in winter until summer because the selected locations utilize the natural environment, and the insulation design is effective. Thus, they are regarded as a Korean heritage of integrated scientific technology.

For effective ice-storage, the Seokbinggo has an arch structure in a semi-basement. Scientific design and construction were applied by establishing appropriate location environments, underground space, installing vents, drains, and narrow entrances. In particular, the arch structure transfers loads of the upper part to the lower part to maintain durability and maximize the internal capacity (Fig. 12b). For efficiency of these structures, granite was selected as the construction material (Fig. 12c). Thus, the Seokbinggo structures are valuable cultural heritages in that the applied scientific and technological principles reflect the scientific excellence and creativity of Korean ancestors (Fig. 12d). Furthermore, it is anticipated that these techniques can be applied in low-energy industries and can be used to establish an eco-friendly conservational environment system for cultural heritages (Kim and Lee, 2013).

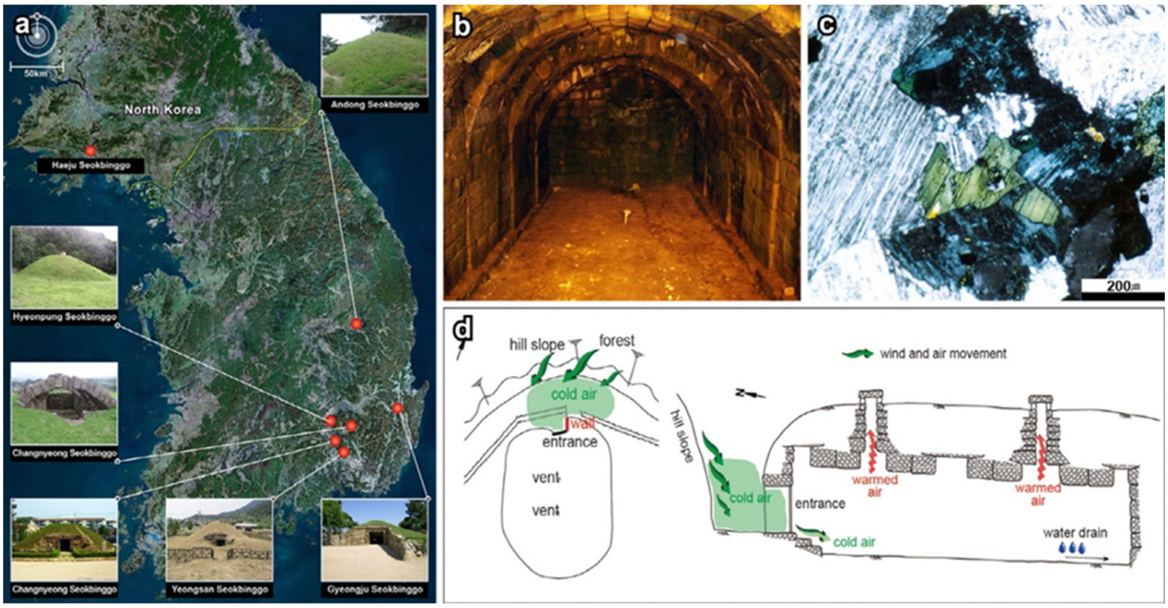

Figure 12: (a) Locations of Seokbinggo in Korean peninsula. (b) Arched interior structure of the Gyeongju Seokbinggo. (c) Polarizing microscopic image of alkali feldspar granite. (d) Schematic diagram of natural cooling effect of the Hyeonpung Seokbinggo. (Kim and Lee, 2013).

4 CONCLUSION

In this study, dinosaur footprint fossils distributed in the Cretaceous sedimentary rocks of the Mesozoic era in Korea were introduced along with a brief description of Korean stone heritages and petroglyphs, and dolmens in the prehistoric age were examined. Moreover, the Silla Stele in Bongpyeong-ri and Cheomseongdae in Gyeongju of Silla Kingdom during the period of the Three Kingdoms (BC 57 to 676) and the Five-story Stone Pagoda of the Jeongnimsaji Temple Site, Rock-carved Triad Buddha in Yonghyeon-ri, and Stone Pagoda in Mireuksaji Temple Site of Baekje Kingdom (BC 18 to 666) were discussed.

For stone heritages of Unified Silla Kingdom (676 to 935), the Dabo Pagoda and Three-story Stone Pagoda of the Bulguk Temple and the Five-Story Stone Pagoda of the Seongjusaji Temple site were presented. For stone heritages of the Goryeo Dynasty (918 to 1392), the Rock-carved Buddha Statues of the Namharisaji Temple Site, Stone Standing Maitreya Statue of the Gwanchoksa Temple, and Five-Story Stone Pagoda of the Magoksa Temple were investigated. Finally, for the stone heritages of the Joseon Dynasty (1392 to 1910), the Seoul City Wall, Tombstone of Chungmugong Yi at the Chungryeolsa Shrine and Seokbinggo were described.

Igneous rock accounts for the highest portion of the rock used for establishing Korean stone heritages, forming approximately 84% of state-designated cultural properties. Categorization results according to rock types indicate that granite was used most often, 68.2% in 397 cases, followed by diorite, 8.2% in 48 cases, and sandstone, granite gneiss, tuff, slate, marble, and limestone at less than 4% each.

Examination of the stone heritages introduced in this study indicates that clastic mud sedimentary rock is used as a parent rock in dinosaur footprint fossils and petroglyphs and that tuff, granite, and gneiss are mainly used in dolmens. In addition, for the Tombstone of Chungmugong Yi at the Chungryeolsa Shrine, sandstone distributed near the area of its placement was used.

On the contrary, despite different periods and styles, granite was used in the Silla monument in Bongpyeong, Cheomseongdae in Gyeongju, Five-story Stone Pagoda of Jeongnimsaji Temple site, Rock-carved Triad Buddha in Yonghyeon-ri, Stone Pagoda in Mireuksaji Temple Site, Dabo Pagoda and Three-story Stone Pagoda of the Bulguk Temple, Five-story Stone Pagoda of the Seongjusaji Temple site, Rock-carved Buddha Statues of the Namharisaji Temple Site, Stone Standing Maitreya Statue of the Gwanchoksa Temple, Five-Story Stone Pagoda of the Magoksa Temple, the Seoul City Wall and Seokbinggo. With regard to stone supply, rock distributed in regions of each cultural heritage was used, whereas the petrological characteristics and types of granite vary. In addition, in the Seoul City Wall and Seokbinggo requiring a large amount of rock, small amounts of metamorphic and sedimentary rocks were also used.

It is generally known that the weathering and damage degrees of stone heritages are strongly affected by temperature and precipitation. Although the average Korean temperature is 14°C, the temperature increases to more than 35°C in summer and decreases below -10°C owing to four distinct seasons. The annual average precipitation of Korea is nearly 1,300 mm, although it greatly differs according to regions; rain events are generally concentrated in summer. Lee and Chun (2013) reported the distribution of stone heritages according to topography and annual average temperature and precipitation of Korea, indicating that most Korean stone heritages are corresponded to areas of middle to high weathering. Therefore, examination of environmental control methods is required for conservation considering the importance of stone heritages exposed to the outside conditions, and monitoring and management systems should be established for stable conservation in the long term.

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