Material and Deterioration Characteristic Analysis for Inscribed Stones of Naksan Mountain Area of the Hanyangdoseong(Seoul City Wall), Korea

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ABSTRACT The Inscribed stones of Hanyangdoseong has been weathered for a long time because of external environment and living organisms. To establish a long-term conservation-management strategy for the inscription stones, the material characteristics of the inscription stones of Naksan Mountain Area were identified, and its deterioration state was diagnosed. Consequently, it was confirmed that the Inscription stones of Naksan Mountain Area mainly comprised coarse-to medium-grained pinkish granite and biotite granite, and, in part, comprised reddish granite, quartz porphyry, and aplite. Presently, the Inscription stones of Naksan Mountain Area, Hanyangdoseong, is undergoing a considerable decrease in physical properties because of physical, chemical, and biological weathering. Moreover, it has been confirmed that the type of damage, such as blistering, soiling, and discolouration, on the surface shows a significantly high deterioration rate, and that conservation treatment might be required in future. In addition, because the possibility of damage recurrence is high even after the treatment, the conservation state must be regularly monitored.

Key Words Hanyangdoseong, Inscribed stones, Deterioration grade, Soiling, Conservation management

1. INTRODUCTION

Hanyangdoseong, the Seoul city wall(Historic site No. 10) was built around the time of the relocation of the capital of the Joseon dynasty(1392–1910) from Gaegyeong(present-day Gaeseong) to Hanyang(present-day Seoul). The wall, which was originally composed of earthen and stone sections, required approximately 120,000 man-days of labor until its completion in February 1396(the 5th year of King Taejo's reign). In 1422(the 3rd year of King Sejong's reign), the earthen sections were replaced with stone ones, while partial repairs were performed during the reigns of Kings Gwanghae and Gojong. The above-mentioned construction-related data can be found in various documents, and hundreds carvings

on the wall also reveal information regarding the building of the Hanyangdoseong(Seoul Metropolitan Government, 2015).

The number of Inscribed stones was 288. In addition, the contents of the Inscribed stones comprise the following: section mark that indicates the built-up section, head of the county, officer, and workers. Therefore, they act as a significant source of evidence for proving the authenticity of world heritage. Although research on the Inscribed stones of Hanyangdoseong has been conducted many times, most of them have been conducted on the basis of its readings and forms(Oda, 1931; Min, 2008; Park, 2008; Seoul Metropolitan Government, 2009; 2015; Seoul Museum of History, 2012; Moon, 2014). However, the Inscribed stones of Hanyangdoseong has been weathered for a long time because

of external environment and living organisms. In addition, because of the large area it is spread on, it is difficult to systematically investigate stone characteristics and perform conservation management.

The precise diagnosis of stone cultural heritages, such as the Inscribed stones of Naksan Mountain Area, requires considerable time and manpower, thereby presenting a practical limit to performing effective and continuous periodic monitoring. In this study, the first scientific investigation of the Inscribed stones of Naksan Mountain Area, including the deterioration assessment and deterioration type of 100 Inscribed stones there, was simplified, and the corresponding results were comprehensively analyzed. The deterioration characteristics were examined, and a conservation plan was suggested. These results will be used as basic data to establish the methodology of conservation-science research and establish long-term conservation-management plan.

2. METHODS

The materials and deterioration characteristics of the stones were analyzed to systematically investigate the Inscribed stones of Naksan Mountain Area. First, visual observation, magnetic susceptibility measurement, and mineralogy analysis were performed to understand the petrological characteristics of the Inscribed stones of Naksan Mountain Area. The visual observation briefly described the structure and particle size of the constituent rocks, and magnetic susceptibility was measured to confirm the homogeneity of the rocks. The magnetic-susceptibility-measuring instrument used was ZH Instruments(CZE)' SM30 model with the measurement limit of 10^{-5} SI units. The magnetic susceptibility intensity was expressed in 10^{-3} SI units.

The samples, which dropped naturally because of weathering, were collected from the surroundings and subjected to mineralogical analysis. To investigate the semi-quantitative mineral composition and relative content of the constituent stones, thin sections were fabricated and observed under a polarizing microscope(LV100NPOL, Nikon, JPN). The X-ray diffraction analysis(Empyrean, Malvern Panalytical, NLD) was performed to precisely identify the relative frequency distribution of minerals, crystal structure and secondary minerals. The X-ray used as the

target was Cu K α , and the acceleration voltage of the anode and current of the filament were 40 kV and 100 mA, respectively.

To easily and quickly record the deterioration characteristics of the Inscribed stones of Naksan Mountain Area, Hanyangdoseong, a deterioration record table was prepared. For the record table, the basic survey items were determined by using both the general method for making a record of the deterioration of stone cultural heritages(The Korean Society of Conservation Science for Cultural Heritage, 2001) and the glossary of the types of stone-based cultural property deterioration published by ICOMOS (ICOMOS-ISCS, 2008). The main types of deterioration were first identified and, subsequently, the deterioration-type check items were set.

In addition, ultrasonic measurement(Pundit Lab, Proceq, CHE) and infrared thermography(ThermaCAM, SC660, FLIR, DEU) were performed to determine the physical deterioration of the rocks. Moreover, hyperspectral image analysis and environmental-impact assessment were performed to identify the biological damage state of the Inscribed stones of Naksan Mountain Area. Along with investigating the deterioration type, physical deterioration grade, discoloration, and biological deterioration grade were subdivided into 5 grades for the damage-level assessment; however, the total number of deterioration grades was curtailed to 3 for performing quick and easy judgment(Kim *et al.*, 2013). Accordingly, an appropriate method for long-term conservation of the Inscribed stones of Naksan Mountain Area was suggested.

3. CURRENT AND CONDITIONS

Hanyangdoseong, which surrounded Seoul, was built as the capital city of the Joseon dynasty, and when the Joseon dynasty was established, it was moved from Gaekyeong to Hanyang. The city wall was renovated several times because it was built along the Baekak(Bukaksan Mountain), Nakta(Naksan Mountain), Mokkeok(Namsan Mountain), and Inwangsan Mountain. The city-wall castle has four main gates and four auxiliary gates. The four main gates are the Heunginjimun Gate in the east, Donuimun Gate in the west, Sungnyemun Gate in the south, and Sukjeongmun Gate in the north. The four auxiliary gates are the Honghwamun Gate

in the northeast, Gwanghuimun Gate in the southeast, Changuimun Gate in the northwest, and Sodeokmun Gate in the southwest.

In 1422(the 3rd year of King Sejong's reign), the earthen sections were replaced with stone ones, while partial repairs were performed during the reigns of the Kings Gwanghae, Hyojong, Hyeonjong, Sukjong, Jeogjo, Sunjo, Heonjong, Cholljong, and Gojong. However, during the Japanese colonial period, many city gates and walls were destroyed under the pretext of urban planning, and many were destroyed during the Korean War. Although Hanyangdoseong

has been repaired several times, it is possible to distinguish the contraction time because of the different methods of building and the shape of the stones. Such contents can be found in literatures, such as Joseonwangjosillok(*Annals of the Joseon dynasty*), Seungejongwomilgi(*Diaries of the Royal Secretariat*), and in the inscription on the wall.

A total of the 288 Inscribed stones include 46 in the inner part of the castle, 229 in the outer part of the castle, and 13 in the section where the rock and the wall except the wall collapsed(Table 1). The Inscribed stones of Hanyangdoseong is divided into Areas 1-15, starting from the top of the

Table 1. Status of the Inscribed stones of Hanyangdoseong by period(Seoul Metropolitan Government, 2015)

Reign (King)	Taejo	Sejong	Gwanghae	Hyojong	Sukjong	Jeongjo	Sunjo	Heonjong	Cheoljong	Gojong	Unclear	Total
Number	29	118	1	1	23	2	38	4	2	1	69	288
Share (%)	10.1	41.0	0.3	0.3	8.0	0.7	13.2	1.4	0.7	0.3	24.0	100.0

Figure 1. Current state of the Inscribed stones of Naksan Mountain Area, Hanyangdoseong; (A) Location and area status, (B) Soiling, (C) Blistering, (D) Plants.

Table 2. Status of the Inscribed stones of Naksan Mountain Area

Reign (King)	Area 4	Area 5	Area 6	Total
Sejong	6	41	9	56
Sukjong	-	1	16	17
Unclear	4	16	7	27
Total	10	58	32	100

Baekak Mountain, the base of the King-Taejo period of Hanyangdoseong(Figure 1A)(Seoul Metropolitan Government, 2015). A total of 100 Inscribed stones in the Naksan Mountain Area of this survey are all inscribed between the 1st and 5th stages of the surface.

The periods of the Inscribed stones in Naksan Mountain Area were divided into the contents and the shape of the walls. The most frequent period is 56 Inscribed stones of the King-Sejong period, 27 of which are unclear and 17 of the King-Sukjong period. According to the zone, there are 10 Inscribed stones in Area 4, 58 in Area 5, and 32 in Area 6. Notably, the Inscribed stones of the King-Sejong period have the highest number in Area 5(Table 2). Presently, the Inscribed stones of Naksan Mountain Area, Hanyangdoseong, has undergone significant weathering because of external environment and organisms for a long time(Figure 1B~1D).

4. MATERIAL CHARACTERISTICS

4.1. Petrographic characteristics and magnetic susceptibility

The Inscribed stones of Naksan Mountain Area, Hanyangdoseong, mainly comprises coarse-to medium-grained pinkish granite and biotite granite, and partly comprises reddish granite, quartz porphyry, and aplite(Figure 2). The pinkish granite is difficult to identify the surface of the rock by dust, organisms, etc., but it mostly comprises coarse-to medium-grained quartz, alkali feldspar, plagioclase, and biotite. Notably, biotite granite is also significantly discolored, and dark color is pale brown to yellowish brown because of light gray or weathering(Figure 2A, 2B). Reddish granite has the same basic characteristics as that of pinkish granite, but the alkaline feldspar is more reddish and, therefore, visually distinguished(Figure 2C). In some cases, yellowish of brown quartz porphyry and aplite are observed (Figure 2D, 2E).

The magnetic susceptibility measurements of the Inscribed stones of Naksan Mountain Area, Hanyangdoseong, showed that the considerable granularity of pinkish granite ranged from 1.34 to $7.79(\times 10^{-3})$ SI units) with the average value of 4.04(Figure 2G). The magnetic susceptibility of biotite granite and reddish granite was 0.06–6.61, thereby indicating that the distribution of magnetite that controls the magnetic susceptibility value in granite is considerably heterogeneous. The characteristics of the magnetic-susceptibility distribution of the Inscribed stones of Naksan Mountain Area, Hanyangdoseong, have been reported to occur in granite mountains such as Namsan Mountain, Buaksan Mountain, Naksan Mountain, and Bukhansan Mountain around Seoul(Jo *et al.*, 2012; Jo and Lee, 2015).

4.2. Mineralogy characteristics

To investigate the mineral composition, texture, and altered minerals due to the weathering of granite, polarized microscope analysis was performed on the specimens, and powder samples were prepared for performing X-ray diffraction analysis. Consequently, it was observed that the pinkish granite comprised coarse-to medium-grained quartz, microcline, plagioclase, biotite, and minor minerals such as muscovite, chlorite, and opaque minerals(Figure 3A). Most of quartz is morphology and microcracks are developed inside the particles and small crystal dolomite or shaped plagioclase is symbiotic and seritization. In addition, biotite is chlorinated along the boundary or cleavage of the particles, thereby indicating that the rocks are currently undergoing weathering(Figure 3B).

Biotite granite is well observed undulatory extinction and direct extinction of quartz and contains fine grains such as muscovite inside the particle, and the plagioclase shows a zonal structure(Figure 3C, 3D). Reddish granite was more orthoclase and microcline are perthite than pinkish granite, and biotite had mostly brown interference color(Figure 3E).

Figure 2. Lithological characteristics of the Inscribed stones of Naksan Mountain Area; (A) Pinkish granite, (B) Biotite granite, (C) Reddish granite, (D) Quartz porphyry, (E) Aplite, (F) Percentage of each rock type, (G) Magnetic susceptibility.

Figure 3. Mineralogical characteristics of the Inscribed stones of Naksan Mountain Area; (A, B) Pinkish granite, (C, D) Biotite granite, (E) Reddish granite, (F) Aplite, (G) X-ray diffraction analysis results.

Aplite comprised fine-to medium-grained quartz, feldspar, and fine mica, and it had a granular structure(Figure 3F). The X-ray diffraction results revealed that quartz, alkali feldspar, plagioclase, and mica coarse minerals were commonly identified in all the samples. All the diffraction peaks that indicated the relative content among minerals showed similar composition trends; however, plagioclase was observed to be somewhat higher in pinkish granite(Figure 3G).

5. DETERIORATION CHARACTERISTIC ANALYSIS

5.1. Deterioration status

Prior to performing the efficient comprehensive survey of the Inscribed stones of Naksan Mountain Area, Hanyangdoseong, the deterioration types were classified and identified via the visual inspection of the area. To understand the overall conservation status of the Inscribed stones, a conservation- management survey report was prepared, and detailed check items were set by considering the deterioration type of the Inscribed stones of Naksan Mountain Area by using the general deterioration diagnosis record table of stone cultural heritages(The Korean Society of Conservation Science for Cultural Heritage, 2001).

The deterioration types that appear in the Inscribed stones

of Naksan Mountain Area are classified as cracks and deformation, detachment, material loss, discoloration, deposits, and biological contamination(Figure 4). The deterioration type, called crack and deformation, was ascribed to physical weathering, was subdivided into cracks and deformations. The deterioration type of detachment was subdivided into delamination, blistering, disintegration, and fragmentation. The material loss type was subdivided into mechanical damage, erosion, pitting, perforation, alveolization, and coving. The surface discoloration deterioration type, which is ascribed to chemical weathering, was subdivided into discoloration, efflorescence, and patina. The deterioration type of deposit was subdivided into crust, concretion, deposit, and soiling. The biological contamination deterioration type was subdivided into alga, lichen, moss, and plant (ICOMOS-ISCS, 2008).

The determination of the deterioration type is based on precise observation; however, if performing visual judgment is difficult in the case of physical weathering, discoloration, and biological damage, the surface analysis is performed using an infrared thermal imaging camera, scanning electron microscope, and hyperspectral image analysis(Figure 4). Other than investigating the deterioration types, each deterioration type was subdivided from Grade 1 to 5 to determine the degree of deterioration(Table 3)(Brown, 1981). The most prevalent physical weathering of the Inscribed

Figure 4. Deterioration status of the Inscribed stones of Naksan Mountain Area.

Table 3. Criteria of deterioration degree for the Inscribed stones of Naksan Mountain Area

Grade	Crack	Detachment	Material loss	Discoloration and deposit	Biological colonization	Ultrasonic velocity (m/s)	Criteria (Brown, 1981)
1	Very weak	Very weak	Very weak	0-20%	0-20%	>4,063	No visible sign of rock-material weathering
2	Weak	Weak	Weak	21-40%	21-40%	3,250-4,063	Discoloration indicates the weathering of rock material and discontinuity surface
3	Moderately	Moderately	Moderately	41-60%	41-60%	2,438-3,250	Less than half of the rock material is decomposed and disintegrated into soil
4	Strong	Strong	Strong	61-80%	61-80%	1,625-2,438	More than half of the rock material is decomposed and disintegrated into soil
5	Very strong	Very strong	Very strong	81-100%	81-100%	<1,625	All the rock material is decomposed and disintegrated into soil. The original mass structure is still significantly intact

stones of Naksan Mountain Area was crack, particularly, hair cracks, which showed a high frequency of occurrence. The highest frequency of the occurrence of discoloration and deposit types in the Inscribed stones of Naksan Mountain Area was attributed to dust soiling and coloration. In addition, biological contamination tends to be locally distributed, except for some Inscribed stones.

5.2. Deterioration map

On the basis of the above-mentioned damage conditions, a primary deterioration map was constructed during the outdoor survey. Subsequently, a corrected and supplemented secondary deterioration map was constructed by correcting and supplementing the primary map via reconfirmation and reading by using photo data in the laboratory. The deterioration map was prepared for the deterioration patterns induced by physical factors, and the chemical-and biological-deterioration rates were calculated using the hyperspectral image. Hyperspectral imaging is a spectroscopic method that is used to classify light into more than 200 bands at tens of nanometers. Clustering and classifying the spectral characteristics of each damaged image in the image obtained from the measurement yields the number of pixels in the damaged region(Chun *et al.*, 2015).

The deterioration types that appear in the Inscribed stones of Naksan Mountain Area include fracture, hair cracks,

blistering, crumbling, chipping, and roughening(Figure 5A). Most cracks were hair cracks, which were 431 in total. The most frequent cracks were found in Area 5. Particularly, there are 10 stones in which 10 or more hair cracks occurred, and in some stones hair cracks up to 19 were observed.

Blistering and crumbling occurred in the absence of 81 and 85, in addition, it is confirmed in the absence of chipping 16 and roughening 11. Among these, 16 had more than 10% occurrences of expansion and detachment compared with the member area, and 4 had more than 20%. Crumbling mostly appeared at the corners and occurred in less than 20% cases, except for some parts. Chipping occurred in less than 10% in all but Area 5, and unevenness showed more than 50% damage in some parts of Area 5(Figure 5C).

As a result of hyperspectral image analysis(Figure 5B), the major damage in the Inscribed stones of Naksan Mountain Area occurred in the Inscribed stones of 56 and 97 because of dust soiling and coloration. Particularly, soiling occurred in all areas except Area 4. The deterioration rate of soiling was 50%, and the most frequent occurrence is absent, but Inscribed stones, which has occurred more than 80%, has 14 and needs proper conservation management. In the case of coloration, both the number of occurrences(56) and deterioration rate were lower than those in the case of soiling; however, the incidence rate was more than 80% for 4 Inscribed stones in Area 6.

Among all the areas, the deterioration rate due to soiling

was the most significant for Area 5. The coloration was observed to be most significant in Area 6. However, the biological damage of the Inscribed stones was considerably low in most areas except for Areas 4 and 5, and it is confirmed that the damage occurred mainly in Area 4. In summary, soiling and coloration are the most significant

deterioration types in the Inscribed stones of Naksan Mountain Area. However, in part, the issues associated with blistering and crumbling also require long-term conservation management.

Figure 5. Deterioration maps and rates of the Inscribed stones of Naksan Mountain Area; (A) Physical deterioration maps, (B) Chemical and biological deterioration maps, (C) Deterioration rates.

5.3. Ultrasonic measurements

Various methods exist for quantitatively measuring the physical properties of rocks. The methods include uniaxial compressive strength measurement, specific gravity and porosity measurement, and rebound hardness measurement. However, if the test subject is a cultural heritage, a non-destructive method must be used. Ultrasonic measurement has been widely used for evaluating the properties of stone cultural heritages by using non-destructive methods, as it has excellent on-site portability and stability, and it leaves no trace after performing measurement. To calculate the material-weathering grade, there exists a method that is based on the ultrasonic velocity of fresh rocks. The stone of Hanyangdoseong is the Seoul granite from Namsan

Mountain, Inwangsan Mountain, Buaksan Mountain, Naksan Mountain, among others(Jo and Lee, 2015). Because quarrying is difficult in the aforementioned areas, the weathering grades are calculated on the basis of the ultrasonic velocity measured on the fresh stones of Yangju granite near Seoul(National Research Institute of Cultural Heritage, 2012).

By calculating the weathering grade for 100 Inscribed stones in the survey, it was confirmed that Grade 1 was 1%, Grade 2 11%, Grade 3 31%, Grade 4 53%, and Grade 5 4%(Table 4). Analyzing the share of weathering grades according to the types of rocks that constitute the Inscribed stones, pinkish granite has 59% of Grade 4, 38% of Grade 3, 8% of Grade 2, 3% of Grade 5, and 2% of Grade 1. In addition, quartz porphyry had 100% of Grade 2; aplite had 100% of Grade 4; and reddish granite had 100% of Grade 3.

Table 4. Coefficient of weathering, and weathering grade according to ultrasonic velocity

Weathering grade	Coefficient of weathering(k)	Ultrasonic velocity($\frac{m}{s}$)	Number	Rate(%)	
Grade 1	Fresh	>0.0	>4,063	1	1
Grade 2	Slightly weathered	0.0-0.2	3,250-4,063	11	11
Grade 3	Moderately weathered	0.2-0.4	2,438-3,250	31	31
Grade 4	Highly weathered	0.4-0.6	1,625-2,438	53	53
Grade 5	Completely weathered	0.6-1.0	<1,625	4	4

Figure 6. Share of the weathering grade according to rock type of the Inscribed stones of Naksan Mountain Area.

100% of Grade 4; reddish granite had 50% each of Grades 3 and 4; biotite granite had 43% of Grade 4, 37% Grade 3, 14% Grade 2, and 6% Grade 5(Figure 6). Notably, long-term conservation management seems to require intensive conservation management for the stones of Grades 4 and 5.

5.4. Deterioration Assessment

In the Inscribed stones of Naksan Mountain Area, Hanyangdoseong, various deterioration types occurred in combination. Therefore, to establish a long-term conservation plan for each inscribed stone, the damages of the stones, as well as the result of classification and frequency of the occurrence of damages, must be identified. To quantitatively identify the physical, chemical, and biological damages identified in each stone, the damages were classified into 5 stages. In addition, for performing the efficient management of the Inscribed stones of Naksan Mountain Area, a comprehensive management grade of 3 was assigned to determine the urgent need for the conservation management for all stones(Table 5).

Analyzing the share of Inscribed stones that resulted in detailed deterioration types, it is confirmed that hair cracks(87%) for crack and deformation, crushing(91%) for detachment, abrasion(98%) for material loss, soiling(97%) for discoloration and deposit, and plants(34%) received the largest share of biological contamination. In addition, the highest incidence of deterioration type was abrasion(98%), followed by soiling(97%), crumbling(91%), hair cracks and blistering(87%), and discoloration(56%). Accordingly, it is interpreted that these are major damages to the Inscribed stones.

After calculating the grade occupancy rate of the deterioration type of the Inscribed stones, it was confirmed that crack and deformation were 11% in Grade 1, 64% in Grade 2, 24% in Grade 3, 1% in Grade 4, and 0% in Grade 5. Detachment was calculated as 0% in Grade 1, 43% in Grade 2, 50% in Grade 3, 5% in Grade 4, and 2% in Grade 5. Material loss was calculated as 2% in Grade 1, 80% in Grade 2, 18% in Grade 3, and 0% in both Grades 4 and 5. Discoloration and deposit were calculated as 3% in Grade 1, 8% in Grade 2, 15% in Grade 3, 27% in Grade 4, and 47% in Grade 5. Last, biological contamination was calculated as 96% in Grade 1, 2% in Grade 2, 1% in both Grades 3 and 4, and 0% in Grade 5. The proportion of Grade 5, which indicates the most considerable deterioration status, was highest in the deterioration type of discoloration and deposit; however, detachment was the most obvious among physical-deterioration types(Figure 7).

In addition, as a result of examining the deterioration degree by the area where the Inscribed stones of Naksan Mountain Area is located, the regions with the highest share of Grades 4 and 5, both of which are two of the most significant deterioration grades, were observed in Area 6 as crack and deformation, Area 4 as detachment, and material loss does not difference. Discoloration and deposit were observed in Area 6 and biological contamination in Area 4 (Table 6). According to the distribution patterns of deterioration grades by area, Area 4 is relatively better than Areas 5 and 6; however, the difference is not significant.

The results showed that the major damages occurring in the Inscribed stones of Naksan Mountain Area Hanyangdoseong, ranged from the most frequent physical damages to detachment, material loss, and crack and

Table 5. Criteria of comprehensive degree for the Inscribed stones of Naksan Mountain Area

Grade		Criteria
1	Maintain	None or slight deterioration. Single physical-deterioration form observed. Conservation intervention is not urgently considered. None or slight discoloration due to organic and inorganic contaminants. Surface coverage of contaminants is less than 20%.
2	Monitoring	Moderate deterioration. Multiple deteriorations interacted; for example, a set of crack and break-out, or crack and exfoliation. Although conservation intervention is not urgent, short-term monitoring is required. Moderate discoloration due to organic and inorganic contaminants. Surface coverage of contaminants between 20 and 50%.
3	Conservation treatment	Intensive deterioration. Multiple deterioration observed, resulting in material disintegration in short period. Conservation intervention is urgently needed. Intensive discoloration due to organic and inorganic contaminants. Surface coverage more than 50%.

Figure 7. Comparison of the number of stones by deterioration types in the Inscribed stones of Naksan Mountain Area.

Table 6. Deterioration grades by weathering forms and areas of the Inscribed stones of Naksan Mountain Area

Weathering forms	Area	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Total
Crack and deformation	4	0	8	2	0	0	10
	5	7	35	16	0	0	58
	6	4	21	6	1	0	32
	Total	11	64	24	1	0	100
Detachment	4	0	6	3	1	0	10
	5	0	29	26	2	1	58
	6	0	8	21	2	1	32
	Total	0	43	50	5	2	100
Material loss	4	2	7	1	0	0	10
	5	0	44	14	0	0	58
	6	0	29	3	0	0	32
	Total	2	80	18	0	0	100
Discoloration and deposit	4	3	2	2	3	0	10
	5	0	4	12	19	23	58
	6	0	2	1	5	24	32
	Total	3	8	15	27	47	100
Biological contamination	4	7	1	1	1	0	10
	5	57	1	0	0	0	58
	6	32	0	0	0	0	32
	Total	96	2	1	1	0	100

Table 7. Comprehensive management grade for each zone of the Inscribed stones of Naksan Mountain Area

	Grade	Area 4	Area 5	Area 6	Total
1	Maintain	-	-	-	-
2	Monitoring	8	19	11	38
3	Conservation treatment	2	39	21	62
	Total	10	58	32	100

deformation. Notably, discoloration and deposit comprised significant soiling and coloration. In addition, after calculating the deterioration of the Inscribed stones of Naksan Mountain Area, Hanyangdoseong, as a comprehensive management grade, there was no regular management member with Grade 1. The emphasis management member at grade 2 is 38, and the intensity management member at grade 3 is 62(Table 7).

6. DISCUSSION AND CONCLUSION

It is confirmed that the physical properties of the Inscribed stones of Naksan Mountain Area are significantly reduced because of physical-, chemical-, and biological-damage factors, as the stones have been outdoors for hundreds of years and weathered because of physical, chemical, biological, and structural factors. The deterioration-assessment results showed that a significant number of the Inscribed stones exhibited surface damage and low physical properties. After analyzing the meteorological environment of Seoul for the past 30 years(1981–2010) in the region where Hanyangdoseong is located, the average temperature in winter was below freezing, the average number of snowing days approximately 25 days, and the average number of frost days was approximately 66 days. The Inscribed stones of Naksan Mountain Area were damaged because of the pressure generated by the freezing-thawing of incoming water in the form of snow and frost.

In addition, soiling(black) observed in most Inscribed stones is attributed to black pollutants, i.e., dust and carbon, generated because of the industrialization since the 1960s. In the Inscribed stones, the rock-color change occurred because of Fe being eluted via chemical reaction with water and deposited on the surface, thereby resulting in discoloration. The repair records of Hanyangdoseong show that ash was

used several times as a repair material. Accordingly, the surface of the Inscribed stones might have damaged because of both the pressure generated during the elution of the ash and the recrystallization of salt.

Although biological contamination is relatively good, algae, lichens, and moss can weather rocks via biochemical action. In addition, some of the members of the Inscribed stones are hard to withstand the upper parts because of the rock-strength weakening due to hair cracks, scaling, crumbling, and surface contaminants. Especially, some members have previously been soiled to the extent that only the hand is broken, thereby making it difficult to perform any conservation treatment.

On the basis of the results of this study, the deterioration types, such as blistering, soiling, and coloration on the surface of the Inscribed stones of Naksan Mountain Area, have been shown to be significantly intense and, accordingly, conservation treatment is required in future. In addition, there exists a high possibility of damage reoccurrence even after treatment, thereby necessitating the regular monitoring of the conservation status.

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