

Evaluation of Inorganic and Organic Contaminants on the Surface of the Bunhwangsa Temple Stone Pagoda, Korea

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1. Introduction

The stone pagoda of the Bunhwangsa temple located in Gyeongju, Republic of Korea was nominated for Korean National Treasure No. 30 on December 1962. The pagoda body is presently only 3-story, and made piling small brick-shaped rocks. It is oldest one among those in Shilla Kingdom with precious relics. Though made of stone, this pagoda was constructed to resemble brick pagodas. It was built in 634 year during the reign of Queen Seondeok, the same year the temple, Bunhwangsa, was founded. The pagoda was reconstruction by the Japanese in 1915, at which time a Sarira case was found between the second and third stories.

In Korea, most of stone cultural heritage have been damaged severely by weathering, and there are many cases in which the original rock structure and composition have not been preserved. The geological and petrological deterioration characteristics of stone cultural heritages, as well as research on weathering and contamination, require much future research. Present studies have undertaken to evaluate mechanical, chemical and biological weathering at the Bunhwangsa temple stone pagoda on the basis of petrological and mineralogical characteristics. This research examines the deterioration factors which affect mechanical, chemical, mineralogical and biological weathering away of the this stone pagoda. This data can be quantitatively utilized for conservation research of other stone cultural heritages.

2. Mode of Occurrences

There are lots of kinds rocks in building the brick-shaped stone pagoda of the Bunhwangsa temple. The overall observation tells the damages by air pollutants are serious (Fig. 1A). The northeast parts show the much advanced state of turning white, while the southeast parts are heavily cracked in the materials (Fig. 1B). The general environment of the pagoda's site is fine, but the pagoda is exposed to tourists directly with no shelters for it.

Key words: Bunhwangsa Stone Pagoda, Weathering, Pollutants, Biodeterioration

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The host rocks of brick-shaped stone pagoda in the Bunhwangsa temple are lots of kinds andesitic rocks, which has gone through mechanical and chemical weathering. The stylobate, the tabernacle in all the four directions, and the rock of the stone statues are most granite. The stone lion standing in the southeast and northeast side are alkali granite, while that in the southwest and northwest lithic tuff. The body and roof stone of the pagoda are in a relatively stable condition of weathering and damage except for the abrasion and cracks of the corners.

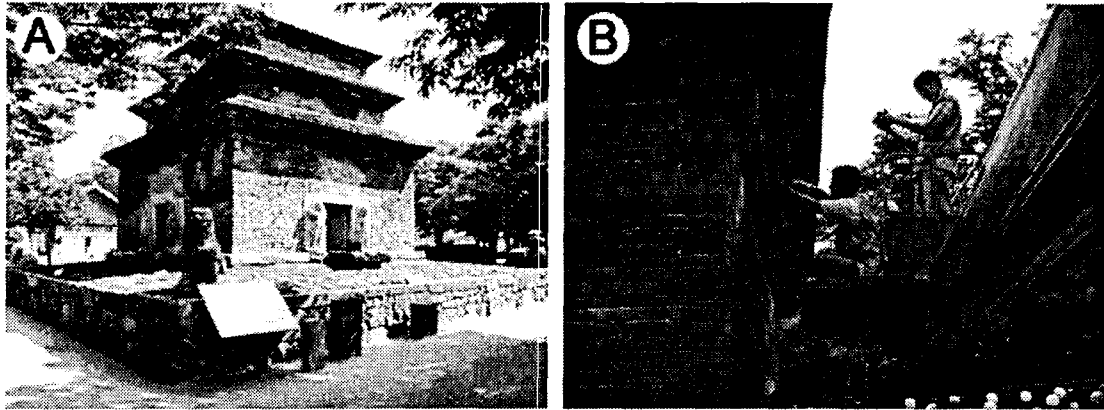


Fig 1. Southwestern views of the stone pagoda in the Bunhwangsa temple (A). Detail survey and sample collections from the northern side using crane car (B).

The pagoda roof-forming rocks suffer from more symptoms, however, including multiple peel-offs, exfoliation, decomposition like onion peels, cracks forming round lines, and falling off stone pieces. The rocks of brick-shaped pagoda body are in a relatively stable condition of weathering and damage except for the abrasion and cracks of the corners. The stylobate-forming rock is heavily contaminated by lichens and mosses with the often marks of inorganic contamination by secondary hydrates that are dark black or yellowish brown.

3. Deterioration and Contamination

The central part of the east stylobate has been sinking down, while that of the 1st floor west stylobate is protruded nesting a line of cracks. Accordingly, the inside of the tabernacle is always humid with the constant introduction of rainwater. There are even gray precipitates looking like stalactites between the rocks of the body (Fig. 2A). Their major minerals are calcite, gypsum and clay minerals. The contaminants are mostly evident in the northeast parts, in particular, the first and second story in the east side and the body parts in the north side are the most serious. The surface of the body is always humid with the constant introduction of water after the rain (Fig 2B).

The rocks of the stylobate are undergoing various symptoms of abrasion of the corners, falling off, granular decomposition, peel-off, exfoliation and cracks. Almost all the feldspar constituting pagoda stone has changed to clay minerals, and biotite has

been replaced by chlorite and iron hydroxides. Secondary inorganic contamination is also serious. Stone pieces discolored by yellowish brown iron oxyhydroxides and dark black manganese precipitates were found everywhere along a rainwater drainage path (Fig. 2C). Dark brown contaminants were also left around iron plates inserted into a gap of blocks and around the drain path as well.

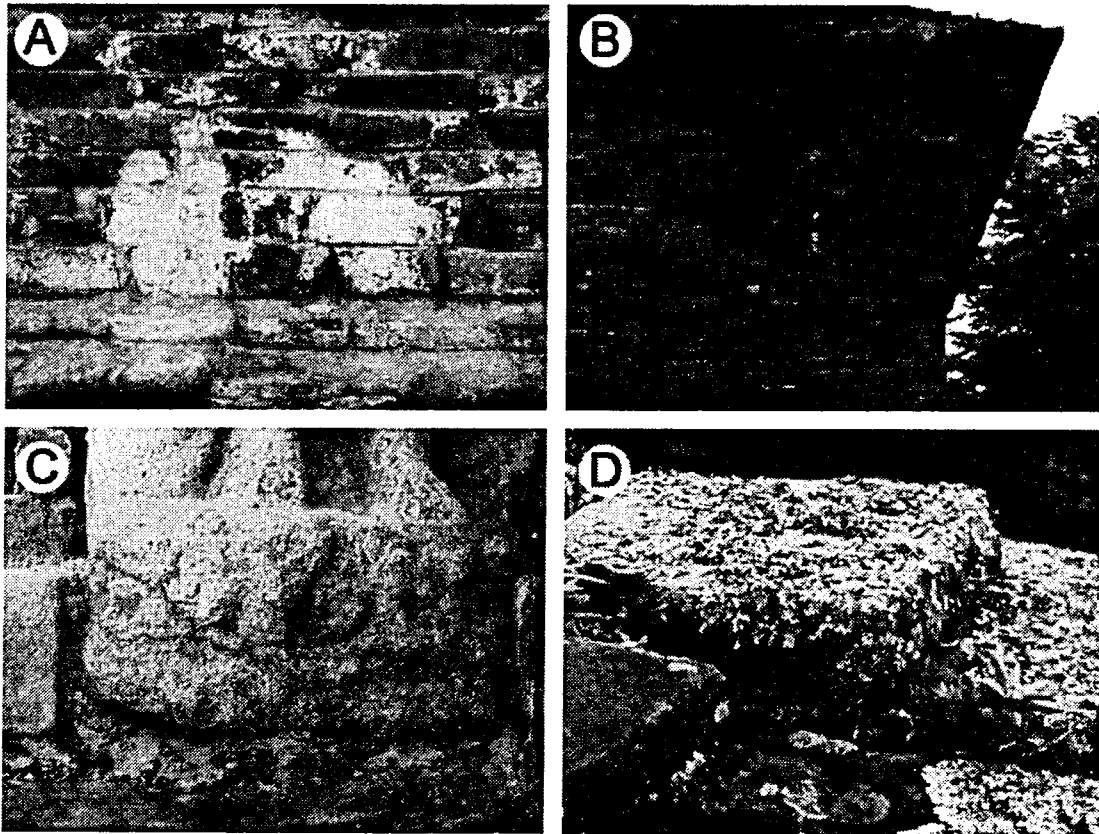


Fig 2. Grey precipitates coated cement mortar composed of calcite, gypsum and clay minerals (A). Eastern pagoda body is soak in rain water through the fractures (B). Surface of basement granitic rocks are variable deteriorated by mechanical and chemical weathering (C). The 3rd roof rocks are whole covered leafy lichen and some weeds grown into the rock blocks (D).

The body constituting rocks of the pagoda are in a good condition despite the partial invasion of lichens and mosses. Those pagoda roof rock, however, are dominated by the thriving foliose type lichens, mosses, and higher plants. In particular, there are higher plants (e.g. *Selaginella involvens* and dandelions) taking root actively between the brick stones and cement mortar filling the gap between bricks (Fig 2D). The northwestern side shows relatively more serious damages by the vegetation with the dense population of plants such as hair mosses. It's also easy to see spider's webs and ant's nests all over the pagoda.

The fillers between the concrete and stone materials where rain drops in the stylobate are seriously damaged by the invasion of higher plants. Each of the stone lion

is heavily contaminated by lichens (dark black, light green and light gray), leafy lichens, mosses (hair mosses), algae and bacteria (yellowish brown). Around the pagoda there grow higher plants. The surface weathering has deteriorated the functions of the stones and made the loss, falling off, and biological contamination even worse.

4. Conclusions

1. The stone pagoda of the Bunhwangsa temple is lots of kinds rocks in building the brick-shaped stone. The northeast parts show the much advanced state of turning white, while the southeast parts are heavily cracked in the materials. The major brick-shaped constituting material is andesites with the presence of other diverse rocks.

2. The brick-shaped body and pagoda roof stone are in a relatively stable condition of weathering and damage except for the abrasion and cracks of the corners. The pagoda body-forming rocks are in a good condition despite the partial invasion of lichens and mosses. Those pagoda roof rock, however, are dominated by the thriving leafy lichens, mosses, and higher plants.

3. The total 45 bio-species (2 bacteria, 9 algae, 12 lichen, 7 moss, 15 higher plant) on the epilithic plants were collected and identified on the surface of the stone pagoda. The coverage was more than 80 percent. The degree of inorganic contamination show very different states according to the rock types and situations.

4. The northwest side shows relatively more serious damages by the vegetation with the dense population of plants such as hair mosses. There are even light gray precipitates looking like stalactites between the rocks of the body. Their major minerals are calcite, gypsum and clay minerals.

5. The stylobate, the tabernacle and the rock of the stone statues are most granite. The stone forming the stylobate is heavily contaminated by lichens and mosses with the often marks of inorganic contamination by secondary hydrates that are dark black or yellowish brown. The fillers between the concrete and stone materials where rain drops in the stylobate are seriously damaged by the invasion of higher plants.

6. The stone lion standing in the southeast and northeast side are alkali granite, while that in the southwest and northwest lithic tuff. Each of the stone lion is heavily contaminated by lichens (foliose and crustose type), mosses, algae, and bacteria. There are the part of exfoliation and cracks are observed.

7. Thus it's urgent to come up with scientific restoration and preservation measures through clinical tests. The materials consisting of the tabernacles show the severe splits and distortion, which causes the structural instability. It's necessary to plan a comprehensive preservation project after a scrutiny.