Four Gods: Weathered Stone Relief at Lung-Shan Temple, Lu-Kang, Taiwan

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Abstract
This paper discusses stone relief images of four gods preserved as a Grade 1 National Monument at Lung Shan Temple, Lu Kang, Taiwan R.O.C. The weathering of these four stone relief’s is severe due to loss of mineral compositions, formation of a weathered shell and stripped scales. When observed with a polarizing microscope, the thin weathered shell section was found to exhibit fiord shaped voids; When observed with a stereo microscope, the weathered shell was found to exhibit salt crystals on the weathered shell and void surfaces. SEM microscopy presented continuous mineral particle stripping. XRD examination showed that the gypsum exhibited salt crystals in the weathered shell. The results from this study will serve as a reference for subsequent preservation and conservation of stone cultural artifacts.

Keywords: andesite; stone relief; weathering

Introduction
As a symbol of the conventional culture, the conventional buildings in Taiwan fall within the Southern traditional Chinese building style and are similar to those characterized by traditional Northern Chinese buildings. Buildings in Taiwan have developed a branch of form with local influence thanks to a number of factors, namely, weather impacts, material limitations, different living style, and Feng-Shui (風水) and taboos. With

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process in the natural environment takes place at any time. Stripped of several centimeters from the rocks in the natural world would not affect the form of the rock; however, stripped of few millimeters in case of a stone relief, the cost of its surface characteristics.

Ranging from granite and basalt from Fukein (福建) in China, and local andesite featuring significant variances in physical properties, composition minerals, and chemical ingredients, the source of stone materials used in the ancient buildings in Taiwan varies depending on the time of construction. Listed as a Grade 1 National Monument for conservation, the Lung-Shang Temple (龍山寺) at Lu-Kang (鹿港), built in 1786 on a site facing the west, has many exquisite wooden sculptures, stone relief’s, brick relief’s, cut and sticks (剪黏), Koji pottery (交趾陶) and other decorative items preserved today after several expansions and maintenance works. Severe damage was caused to the Lung-Shan Temple by a major earthquake (magnitude 7.2) striking Taiwan in 1999. The repair work has become a main event in the filed of historical site conservation. The stone relief’s of the four gods on the Lung-Shan Temple wall, also known as the Five-Gate Hall (五門) (Fig. 1) was reinstated in improvement work done in 1928. This was seen to have no major damage from the introduction of Lung-Shan Temple published in 1989. The four stone relief’s represent “favorable weather” on both sides of the Five-Gate Hall were seriously weathered, having lost their original visage, according to a survey made in September 2002 (Fig. 2).

Methods

This study focuses on the “Shun” stone relief (meaning “timely”). This relief was the most severely damaged due to weathering. Weathered shells were analyzed with instruments during the site survey with fresh andesite sample as a reference to determine the composition and structure of the rock. The differences between the fresh andesite and weathered shell is discussed.

A polarizing microscope from Leitz Ortholux pol-BK was used to observe thin sections of the weathered shell at thicknesses of approximately 0.03 mm. A Leica Wild M8 stereo microscope, connected to an external KODAK 760 6-million pixel digital camera, were also used. Scanning Election Microscopy (SEM) images of the weathered shell were take with a field-emission scanning electron microscope (Hitachi, S-4100. X-ray diffraction (XRD) measurements were made with a Philips PW3020 vertical type goniometer. Cu Kα radiation (λ=0.154186nm) was used for the XRD measurements. The high voltage was set to 40 kV with 30 mA current. Step-scanned data were collected in the 3-65 range. ° 2θ.

Results and Discussion

Site Survey

According to the site survey, the stone relief was
carved from andesite, a type of igneous rock, referred to as “Kwen Ying Shan Stone” (鶴音山石) in Taiwan. This is one of the materials generally used for stone relief on local temple walls. After several site observations, three types of weathered stone relief, pore, weathered shell and strip were found in the of four god images. Little of the mineral was corroded and falling off to form pores. The surface of the stone relief held its integrity (Fig. 3). The surface was coated with non-permeable layer during maintenance performed during 1985-1989. Water vaporized into the pores failed to escape through the protection layer and accumulated, allowing the solvable scale to crystallize in the pores. This resulted in increased pore pressure that reduced the effective stress. Tension was created in turn that separated grains on the surface layer from those in the rock layer below to form a weathered shell (Fig. 4). This weathered shell was stripped by further weathering (Fig. 5). The “Shun” stone relief was observed using thin sections from the upper left corner (A), forehead (B) and face (C) in September 2002. The weathered shell was stripped off in subsequent observations during February 2004 (Fig. 6).

Polarizing Microscope
A polarizing microscope was used to observe thin sections of the weathered shell on the Shun image. The weathered shell is essentially comprised of phenocryst, matrix and fiord shaped voids (Fig. 7). The phenocryst includes Feldspar and Hornblende; with a cleavage also observed (Fig. 8). Fiord shaped voids (Fig. 9) and cleavage were also found in the fresh andesite during observation of the polished andesite film (Fig.10). By comparing Figs. 7 and 9, the voids in the weathered shell are larger than those in the fresh andesite, indicating that as the matrix was gradually stripped off of the andesite, the phenocryst falls when losing the support from the matrix. This further exaggerates the voids in the andesite. When putting Figs. 8 and 10 together, cleavage takes place in the minerals along the crystal aspect where a weaker link exists. Upon subjected to external force, the mineral cracks where the cleavage is presented. When cracks develop into a line, the mineral is stripped off to expand the voids due to weathering. So far this weathering is from nature characterized by cavities, i.e., the first weathering phenomenon found with the stone relief in this study.
Stereo Microscope

When observed with the stereo microscope, many pores were found on the surface of the weathered shell (Fig. 11). Mineral crystals present on the surface and in the pores (Fig. 12) define the second weathering phenomenon, or chemical weathering. During this stage, salts get crystallized in the voids on the surface and grains from the surface of the stone relief are separated from layers below to form a weathered shell away from the deeper course of the stone relief. Voids on the fresh polished andesite sample were found smaller than those on the weathered shells on the stone relief, showing that the andesite voids will gradually expand when weathered (Fig. 13). Phenocryst and matrix composition including Feldspar and Hornblende can be clearly observed (Fig. 14). As illustrated, should the Hornblende matrix be gradually stripped off, the Hornblende will also falls off, in a cycle that causes the voids to grow larger.
SEM
SEM showed that the weathered shell surface was found covered with crystallized salts and a few mineral particles covered by crystallized scales separated from the weathered shell (Fig. 15) indicating that mineral particles continued to be stripped off even after weathered shell formation on the stone surface.

X-ray Measurements
The powder pattern and data from the weathered shell and andesite were determined using XRD. The powder pattern (Fig. 16) showed that the weathered shell contained Feldspar, Quartz, Hornblende, Pyroxene, Cristobalite and Gypsum. The andesite powder pattern (Fig. 17) showed that the andesite contained Feldspar, Pyroxene, Mica, Hornblende, Quartz, and Cristobalite. By comparison, the salt crystallization found on the surface and in the voids related to gypsum (CaSO₄ · 2H₂O). Gypsum is not one of the andesite composites. It is recommended that the gypsum be treated through maintenance on the four gods stone relief on the walls of Lung-Shan Temple.

Conclusions
The improper use of materials in several repair works on the stone relief done in the past is the primary cause for the severe weathering attacking the stone relief. Scientific approaches to assess the materials used in constructing these monuments is recommended. Determination of cause of the damage must be conducted before prescribing preservation materials has seldom been performed in the preservation and conservation of ancient relics in Taiwan. This ignorance only helps accelerate the damage to these ancient relics.

The weathering phenomena found in the four gods on the walls of Lung-Shan Temple at Lu-kang were analyzed using field survey, polarizing microscopy, stereo microscopy, SEM and XRD. The conclusions are summarized as follows:
1. This study provides a summary and investigation method using precision instruments to measure and assess the extent of damage to stone relief due to weathering.
2. The stone relief in this study has lost its original visage due to combined physical and chemical...
weathering processes.

3. An improper protective coating had a significant impact upon the stone relief by subjecting it to increased weathering.

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