Proposals for Future Conservation Actions

Testing of Stone and Masonry Conservation Techniques and Materials

From the condition assessment of the Hieroglyphic Stairway, it has been concluded that two main types of conservation treatments would be appropriate in the future. One is repointing between Stairway blocks with mortar, and the other is the cleaning and stabilization of carved block surfaces (**Fig. 95**). These two treatments were the focus of the field trials and the laboratory testing that were carried out.

Because it is important that future treatments be sustainable, the criteria for selecting the treatment methods to be tested are the availability and cost of the materials and the equipment needed to carry them out. Therefore, the first step in developing treatment proposals was determining what is available locally.

Figure 95 Block 408, step 43. Previous consolidation treatments, biological growth, and loss of repointing mortar can be seen.

Treatment Materials Procurement

Mortar Materials and Tools

Sand

The Copán River, which runs immediately south and east of the main Acropolis of Copán, has been the traditional source of aggregates for restoration and maintenance work at the site. The use of sand from the Copán River presents the obvious advantages of proximity and no cost; however, there is no consistency in the grain-size distribution of the aggregate from one batch to another because of seasonal and locational changes. Consequently, sand vendors who sell more consistently graded sands were sought. The closest sources are situated just outside San Pedro Sula, on the road to Copán, where several vendors (including INDECO) process sands from the Chamelecón River. The main advantage of the processed sands is the consistency of the product, which should be considered against the cost of purchasing sand and transporting it to Copán.

Simple particle-size distribution analyses were performed on a number of samples of different grades of sand from the Copán River and Chamelecón River vendors. Two different batches of Copán River sand were selected for use to be mixed together in equal parts for the treatment trials: a fine sand (*arenilla*) and a coarser one (*arena colada*). For the *arena colada*, its larger grains (>5 mm) were first sieved out. Both sands were dried before use, without previous washing. The mixture of the two Copán sand samples produced a particle size distribution that is similar to that of the purchased Chamelecón River sand, and one that is comparable to industry standards (**Figure 96**).

Stone powder

To provide the needed smaller aggregate for the mortar mixes, as well as to influence the color of the mortar, stone powder was also used in the mortar mixes. The same green volcanic stone that was used as the Hieroglyphic Stairway building material is still quarried in the Copán Valley today. This stone was crushed by hand, and the fraction of grains larger than 2 mm was sieved out to create stone powder. Yellow Copán tuff stone powder, which was found at IHAH's Centro Regional de Investigaciones

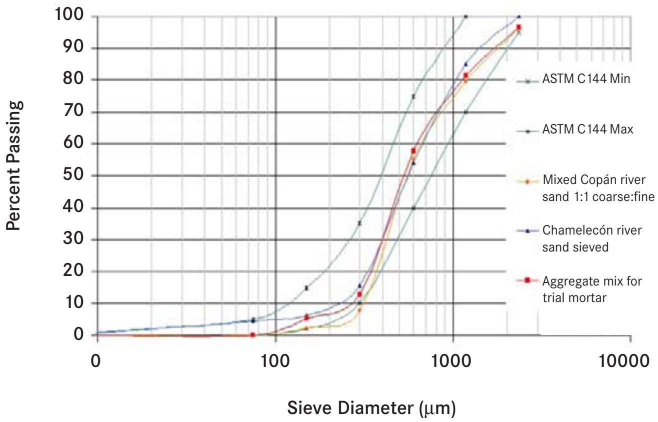


Figure 96 Particle size distribution of the mixed Copán river sand, the aggregate mix used for the treatment trials, the Chamelecón River sand (INDECO), and the ASTM (C144-99) standard.

Figure 97 Powdered lime hydrate ready for bagging (foreground) and discarded, unburnt lime (background), Chiquilas, Honduras.

Arqueológicos (CRIA), was also used. The yellow stone had been crushed mechanically in bulk in San Pedro Sula some years ago by IHAH; the location of the stone crushing operations could not be found.

Lime

Lime is another traditional material used at Copán. The source of lime closest to Copán is the village of Llanatillos, in the hills north of the Copán Valley. Quicklime from Llanatillos was purchased and later slaked and sieved in preparation for treatment trials and testing. Chiquilas, a village an hour away from Copán on the road to San Pedro Sula, is a major lime center with more than a dozen kilns, all wood fired, which use limestone from two local quarries (**Fig. 97**). Quicklime is available from a number of vendors, and two major commercial brands of hydrated lime can be found in Chiquilas: Honducal and 5 Estrellas (also known as Super Estrellas). No quality control can be expected from any of the local sources of lime.

Samples of lime putty obtained from quicklime from Llanatillos and Chiquilas, and 5 Estrellas hydrated lime from Chiquilas, were analyzed by X-ray diffraction (XRD). Results show that all lime putties contain calcite, but the Chiquilas limes contain considerably more than the Llanatillos one. Lower calcite content will result in better binding properties and better plasticity for the lime. Particle size analysis was performed on the two putties from quicklime, and they show similar particle size distribution, with a maximum at 3–4 µm. The Llanatillos lime is slightly richer in smaller particles (ca. 35% of 2 µm subfraction, in comparison to 20% for the Chiquilas lime), which has a positive effect on the plasticity and can be the result of the lower degree of carbonation.

Both lower calcite content and higher content of smaller particles make the tested batch of Llanatillos lime putty a better lime than the tested ones from Chiquilas, and consequently, it was used for most of the treatment trials.

Other limes were used in some of the trials, such as a ten-year-old Chiquilas lime putty that is stored in one of the Copán archaeological tunnels, but they were not tested in the laboratory.

No sources of local or imported hydraulic lime could be located in Honduras.

Pozzolanic additives

Because hydraulic lime is not available in Honduras, the availability of pozzolanic additives was researched. Pozzolanic additives are materials which, by themselves, possess little or no hydraulic properties (ability to set partially or entirely under water) but which can react chemically with lime in the presence of water and create a faster, harder set. A number of materials, both natural and man-made, are potentially pozzolanic, such as volcanic ash and earth, and bricks fired under or around 850°C and containing certain clay types (see the English Heritage Smeaton Project [Teutonico et al. 1994]).

A number of local materials were tested for pozzolanicity. They include several types of tierra blanca from different locations in Honduras, and a number of tiles and bricks from cottage brick making operations that use wood-fired kilns in the Copán area. At a regional scale, a tierra blanca from El Salvador and a pumice from Guatemala, which was available in Copán, were also tested.

Samples were reacted with lime milk in test tubes; pure water was used as reference. Calcium hydroxide (pure lime) will react with the pozzolana present in the sample to form colloidal calcium aluminosilicate hydrates. The increase in volume of the settled material after seven days gives a qualitative indication of the degree of pozzolanicity (Cowper 1927, 46–50). Sample descriptions and assessments of their pozzolanicity are presented in **Table 15**.

Several materials showed significant pozzolanicity: tierra blanca from El Salvador (a volcanic tephra with a high content of pumice), pumice from Guatemala, and a fired clay tile obtained from Copán Ruinas (**Fig. 98**). These materials should be considered if pozzolanic additives are required in the future—especially the pumice, if it continues to be available locally.

Mortar tools and equipment

Many specialized mortar mixing tools and equipment were not found in Honduras, including pan mixers, pointing keys, spatulas, rubber buckets, and sieves. Although most of this specialized equipment was imported, mortar treatments can nonetheless be carried out with only local materials and tools, such as mason's trowels and metal buckets.

Table 15 Results of the pozzolanicity test.

Sample		***Degree of pozzolanicity*** − = none + = mild reaction ++ = strong reaction
Tierra blanca	Llanatillos (near Copán Ruinas) white type 1	+
Tierra blanca	Llanatillos (near Copán Ruinas) white type 2	+
Tierra blanca	Llanatillos (near Copán Ruinas) gray type	−
Tierra blanca	Bario San Pedrito (in Copán Ruinas)	+
Tierra blanca	Jacaleapa (southwest of Tegucigalpa)	−
Tierra blanca	San Salvador	++
Brick	Quimistán (Ladrillo Rafon, brick maker)	+
Brick	Florida (outside La Entrada)	+
Brick	Los Planes (near Santa Rita)	−
Brick	Copán Ruinas	+
Tile	Copán Ruinas	++
Pumice	Guatemala	++

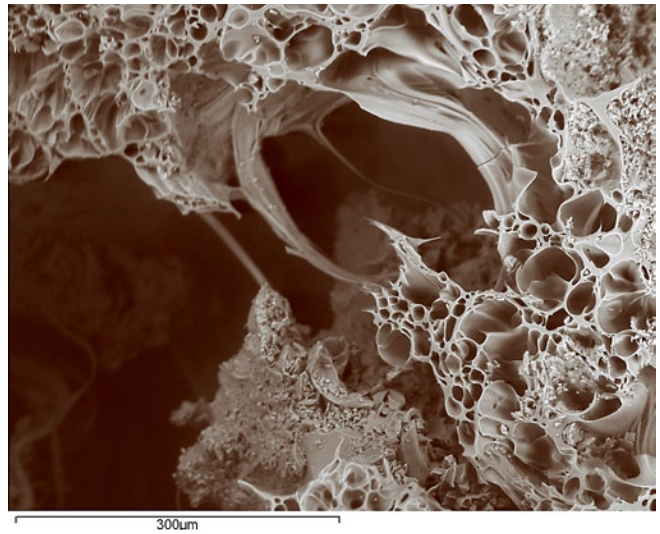


Figure 98 ESEM image of pumice from Guatemala, showing high-surface-area volcanic glass.

Surface Treatment Materials and Tools

Surface treatments can be divided into three main operations: general cleaning, reduction/removal of previous interventions, and stabilization. Each requires a different set of materials and equipment.

General cleaning

This operation generally requires that a soft bristle brush be used first, for dry cleaning. Then water, applied by brush or spray, is used. Finally, if needed, the last step is mechanical cleaning with a soft toothbrush and water. All of this equipment is available locally, except for hand-pump pressure sprayers. For one trial, a 4% v/v solution of the non-ionic surfactant Triton XL-80N (Dow Chemical Co.) in water was tried as a cleaning solution, although it had to be imported.

Reduction/removal of previous treatments

Reduction/removal of previous treatments carried out on the Stairway with acrylic or polyvinyl acetate–based resins requires chemical solvents. Some solvents, including acetone and distilled water, are found locally in pharmacies and hardware stores, although other basic solvents, such as toluene, are not available for retail purchase in western Honduras but can be found from wholesalers in San Pedro Sula (Transmerquim and Honduchem).

All basic tools and materials for reduction/removal of previous treatments (scalpels, brushes, cotton swabs, etc.) can be found in San Pedro Sula. However, specialized foam swabs (VWR brand and Texwipe), which were found to be extremely effective and efficient during the trials, are not available locally but could easily be imported at low cost because they weigh very little. Various poultice media mixed with solvents, such as paper pulp and attapulgite clay, were imported and employed during surface treatments, but local substitutes could probably be found.

Stabilization

In addition to the mortar materials previously described, pigments are needed to obtain proper color matching of lime-based edgings to the various colors of the Stairway stone. The pigments used during the treatment trials were brought from the United States (Kremer pigments, Germany). However, a few pigments, including a green (probably chrome oxide) and several ochres, were found in large San Pedro Sula hardware stores; they are all probably imported from Mexico. Fine spatulas for edging repairs and fills were not found in Honduras but could be forged by a local blacksmith. Grouting equipment, such as syringes and needles, is available.

Certain adhesives and consolidants have been used for treatment on site for many years, and they were also used during the treatment trials. They include the acrylic resin Paraloid B-72 and the aqueous acrylic emulsion Rhoplex (Primal) AC-33 (both manufactured by Rohm and Haas), which have been obtained from Mexico in the past.

Colloidal silica products Ludox HS-40 and Syton X-30 (both manufactured by DuPont) were employed during the trials, but they are not available locally.

Treatment Testing

Repointing Mortars

Preparation

Before carrying out in situ mortar trials, different mortar mixes were prepared and placed in locally made wooden molds (**Fig. 99**) (Martin 2001). Two sets of these samples were left on site for use in a comparative exposure trial, one set under the shelter, the other outside, at the top of the pyramid structure.

Figure 99 Preparation of the trial mortars for laboratory testing.

Six other sets (half cubes, half prisms) were brought back to the GCI for testing.

Mortar mixes were made on site in December 2001 to test a range of locally available materials. The two binders tested were a recently slaked quicklime from Llanatillos, and a bagged, hydrated lime (5 Estrellas brand from Chiquilas), made into putty by the addition of water before use. Both limes were screen-sieved. The aggregates used were mixed coarse and fine Copán River sand samples, and crushed green Copán stone powder. Following particle-size distribution analysis results, the large grains (>5 mm) of the two sands were screened out, then the sands were mixed together in equal parts to make "mixed Copán sand." Stone powder (10% v/v) was added to increase the proportion of the lower fraction (aggregates passing 600 μm) of the resulting mix. This aggregate mix (4.5 : 4.5 : 1 fine sand: coarse sand:stone powder) was used for all samples. Two different binder-aggregate ratio mortars were tested–namely, 1:2.5 and 1:3. The only other material used in the trial mixes was a metakaolin (trade name, Metastar 501), which was added in slurry form to two of the mixes as a pozzolanic additive. Metakaolin is a highly pozzolanic and reactive material, created by the calcination of kaolin at a moderately high temperature (650°C–850°C). This material was imported.

The five mortar mixes tested were:

LP1 1 Llanatillos lime putty: 2.5 mixed Copán sand

LP2 1 Llanatillos lime putty: 2.5 mixed Copán sand + 10% Metastar

LP3 1 Llanatillos lime putty: 3 mixed Copán sand

HLP1 1 "5 Estrellas" hydrated lime putty: 2.5 mixed Copán sand

HLP2 1 "5 Estrellas" hydrated lime putty: 2.5 mixed Copán sand + 10% Metastar

All mortars were mixed by hand on a flat board and then rammed in a bucket before being placed in the molds. The mortars were covered with damp burlap and placed for six weeks in a tunnel at the base of the Stairway to keep them humid. At the end of this period, six cubes and prisms were sent to the GCI for analysis (**Fig. 100**).

Analysis

After curing for more than six months, the mortar prisms were tested in the laboratory. The physicomechanical properties determined for repointing mortar formulations included measurements of compressive strength (DIN EN 1015-11, 1999), static modulus of elasticity, capillary water uptake and penetration coefficient (W- and B-value, respectively) (DIN 52617), ultrasonic velocity, porosity Hirschwald coefficient (RILEM II.1), and bulk density. The principal properties of the tested mortars are displayed in **Table 16**.

The results show values in the typical range of lime-based mortars: bulk density (1788–1881 kg/m^3), porosity (12.9%–16.8%), capillarity (W-value, 6.3–9.6 kg/m$^2\sqrt{h}$, B-value,

Figure 100 Cube and prism molds of trial mortars before curing.

3.7–6.1 cm/√h), combined with high Hirschwald coefficients (88%–93%), which indicate low freeze-thaw and salt crystallization resistance. Compressive strength values are also in the typical range (1.8–2.8 N/mm²), as lime mortars can reach compressive strengths of greater than 1 N/mm² within 28 days. The measured ultrasonic velocities (1.6–1.9 km/s) correlate well with the compressive strength.

The compressive strength has not considerably increased with the addition of Metastar for the lime putty mortars (from 1.9 to 2.5 N/mm²) and has actually decreased for the hydrate lime mortars (from 2.8 to 2.1 N/mm²). The mortars containing Metastar have a very low modulus of elasticity, which is particularly surprising. An explanation for this unusual behavior might be that considerable amounts of the pozzolanic additive could not react with calcium hydrate (pure lime) because of a lack of water. Hence, in such a case, the additive remains in the mortar like a fine aggregate and performs in a manner similar to that of kaolin, in that it reduces the modulus of elasticity. This interpretation is supported by the low increase in strength and ultrasonic velocity.

Table 16 Properties of the trial repointing mortar mixes.

Property	***LP1***	***LP2***	***LP3***	***HLP1***	***HLP2***
Compressive strength (N/mm²)	1.9	2.5	1.8	2.8	2.1
Modulus of elasticity E_{stat} (kN/mm²)	3.1	0.3	3.6	3.2	0.3
Capillary water uptake coefficient W (kg/m²√h)	9.4	8.6	9.6	6.3	8.4
Capillary water penetration coefficient B (cm/√h)	5.8	4.0	6.1	3.7	6.0
Ultrasonic velocity (km/s)	1.6	1.9	1.7	1.9	1.9
Porosity accessible to water (%)	13.7	15.6	14.2	12.9	16.8
Hirschwald coefficient (%)	90	92	89	88	93
Bulk density (kg/m³)	1860	1788	1840	1881	1800

The standard requirements for the compatibility of repointing mortars are that most mortar parameters should have similar or lower values in comparison to those of the adjacent stone. The compressive strength of the mortar is very low in comparison to that of the stone substrate, and water storage and transport behaviors are quite different as well. However, these differences are not detrimental, as the repointing mortar plays a very limited structural role in the reconstructed Stairway, and the Stairway is protected from the rain by a shelter. Consequently, all the tested mortar mixes can be considered suitable for use in repointing the sheltered Stairway.

On-site exposure tests

The samples left on site, both under the shelter and exposed at the top of the Stairway, have been visually assessed on a regular basis since 2001 (**Figs. 101, 102**). After two years, both sets of mortars were found to be in good condition, with no loss and no internal shrinkage cracks—just space between the wooden mold and the edge of the mortar samples due to shrinkage of the wood. The samples left under the shelter showed no change after two years. The exposed samples exhibit slightly eroded, rough surfaces due to rainwater erosion, and one sample has black algae on its surface.

Four additional mortar mixes were prepared in February 2003 to test the addition of pumice from Guatemala as a pozzolanic additive, as well as the use of additional Honduran limes (1992 Chiquilas lime putty and 2002 Chiquilas lime putty) and sands (INDECO Chamelecón sand). These four mixes were placed in wooden molds and left under the tarp. The mortar mix with the added pumice was also placed between two nonsculpted stones from the pile next to the Stairway environmental monitoring station. A year later, the exposed repointing mortar trial with pumice is in good condition, despite the presence of a vertical crack, which formed immediately after placement, and areas of slight erosion from rainwater (**Fig. 103**). The sample of the same mix left under the shelter was unchanged, but the surface of the three other mortar samples had become rough, in contrast to the still-smooth surface of the pumice admixture mortar. Given the protection of the shelter, the apparent erosion of these three samples is difficult to explain.

Surface Treatments

Laboratory testing of surface treatments was not carried out because conditions of deteriorated flaking stone and previous treatments cannot be replicated accurately in a laboratory. Therefore, surface treatment trials depended entirely on field testing on selected Stairway blocks.

In Situ Treatment Trials

Choice of Trial Blocks

A number of stone blocks of the Hieroglyphic Stairway were chosen for in situ treatment trials. The selection took into consideration different criteria: the blocks chosen presented

Figure 101 Lime-based mortar trial samples made in December 2001, shown after two and a half years of sheltered exposure on the Stairway. August 2004.

Figure 102 Lime-based mortar trial samples made in December 2001, shown after three years of unsheltered exposure at the top of the Stairway. December 2004.

Figure 103 Lime-based mortar mix with added pumice, made in February 2003, shown after ten months of unsheltered exposure at the top of the Stairway. December 2003.

different conditions, in particular various amounts of previous treatments and different colors, and required different types of treatment (surface cleaning, surface treatment, mortar repointing). Finally, blocks located in different parts of the Stairway were chosen, although there was a preference for selecting blocks from the upper half of the Stairway, so that the results would not be too visually evident to future visitors. **Figure 104** shows the location of the treatment trial blocks on the Stairway.

Three blocks were chosen for full treatment–that is, mortar removal and repointing, and full surface treatment. The blocks were chosen because they presented deteriorated pointing mortar, but without very deep empty joints, which would require lengthier intervention. One buff block (block 488) presented a very small amount of previous treatments and a stable surface, whereas two green blocks (406 and 407) exhibited evidence of a substantial amount of previous treatments.

Three blocks were chosen for partial surface treatment, and only some of their glyphs were treated. Blocks 576 and 578 were chosen because they were among the blocks that had been the most treated in the past. Their deteriorated surfaces displayed detachment, flaking, and disaggregation and presented significant color variations over small surfaces. These two blocks could be considered as worst-case scenarios in terms of future treatment. Light green Block 513 was also chosen for partial surface treatment because of its color and the quantity of previous surface treatments.

Two blocks were chosen to test cleaning treatments, both of them presenting very few previous interventions and stable surfaces. One green block (463), with a band of microbiological colonization in the upper half, was chosen to test the removal of microorganisms in selected areas. One light green block (197) was chosen for a test of cleaning stone without microorganisms.

Finally, one block, 71, a control block chosen for monitoring condition, was not initially selected for treatment trials, but loss of some surface flakes in 2003 prompted treatments. Subsequently it was decided to fully treat the block. Block 409, a control block that was not selected for treatment trials, also received some very localized treatment after the loss of a previously reattached stone fragment. The same is true for block 463, on which fallen fragments were reattached during the trial period.

Mortar Removal and Repointing

In situ trials of mortar removal and repointing were carried out in January 2003 in two locations on the Stairway, around blocks 406–407 and around block 488, using mortar mixes similar to the ones tested in the laboratory. Reconstruction mortar was removed with hammer and chisel to a depth approximately equivalent to the width of the joints, and it was therefore not necessarily completely removed. Mortar removal in these two new areas confirmed what had been observed in the past: that, depending on the location on the Stairway, the pointing mortars can be difficult or easy to remove. In addition, once the surface

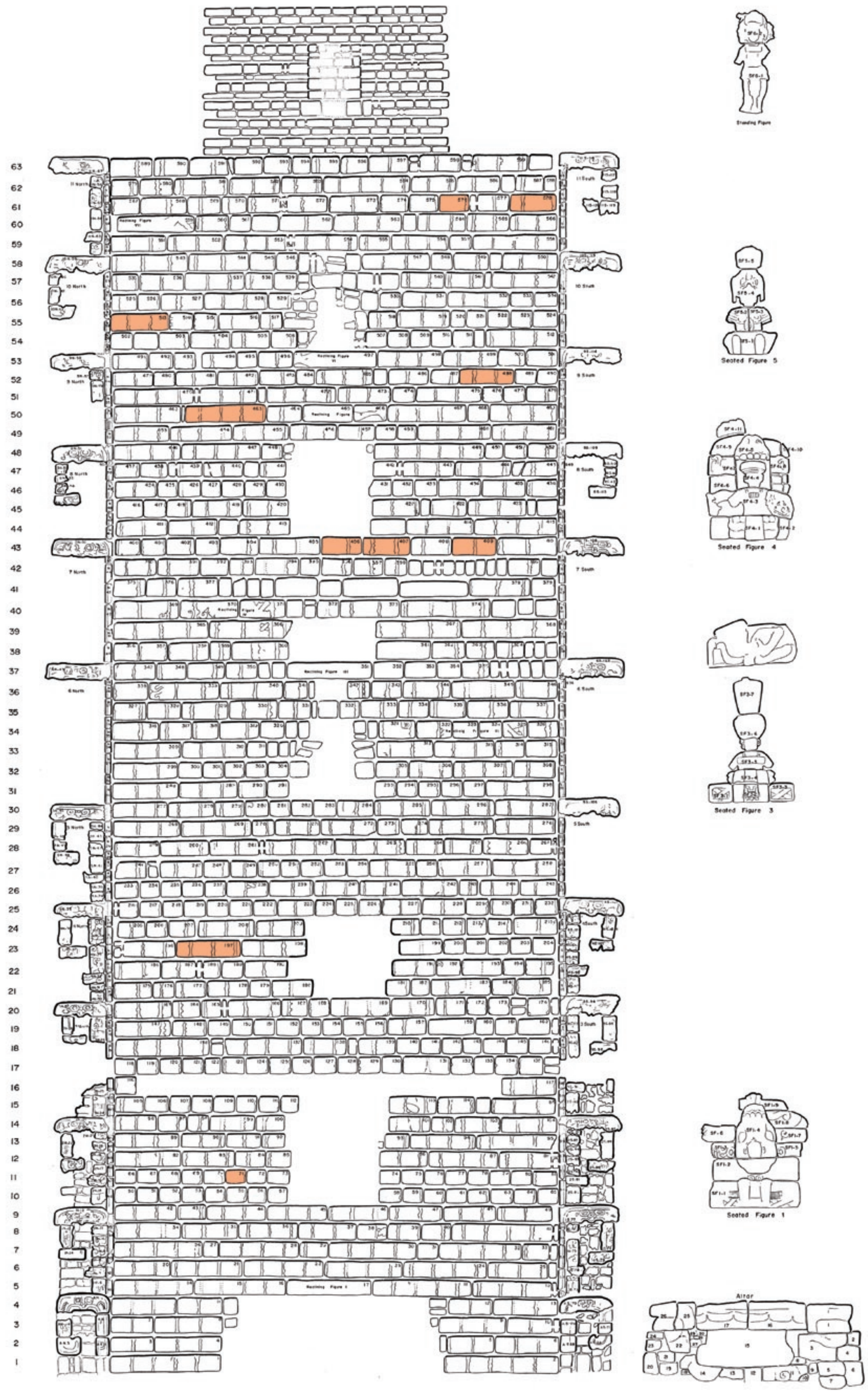


Figure 104 Locations of the treatment trial blocks (in orange) on the Hieroglyphic Stairway.

layer of mortar is removed, one finds areas where voids exist around the block, as well as areas where these joints have been filled with cement mortar and stone chinkers.

The joints were then filled with mortar to slightly below the surface level of the block, and, when large voids were present, stone chinkers were inserted. The mortar was compacted with pointing keys and surface-finished the same day or the following day with sprayed water and a sponge. To keep the mortar damp overnight, it was covered with wet cotton. The mortar mix ratio used around blocks 406–407 was 1:2.7 Llanatillos lime putty:aggregates (4.5:4.5:1 fine Copán sand: coarse Copán sand:fine Copán green stone powder). The repointing mortar used around block 488 was a similar mix, but with a much higher proportion of Copán stone powder (1:1 mixed Copán sand:Copán stone powder, instead of the earlier 9:1) (**Figs. 105a, b**). The higher ratio of stone powder to sand was chosen for aesthetic reasons, in an attempt to match the surface color of the blocks. The increased proportion of stone powder in the 488 repointing mortar produced a much lighter color, closer to the buff appearance of some of the blocks; however, the pinkish gray color of the repointing mortar of 406–407 is a better match for many of the existing cementitious repointing mortars (**Figs. 106a, b**).

The morning after application, the mortars already displayed considerable firmness, with only a few cracks in the larger surface areas, which were closed with a pointing key. The mortar that had not been surface-finished the same day proved to be more difficult to scrape back and sponge off the following day.

More than two years later, the two repointing mortar tests of blocks 406–407 and 488 were in good, unchanged condition. Either of these mortars, made with locally available materials and without any synthetic additives, could be used on the Stairway with adequate results, both functionally and aesthetically.

It should be pointed out, however, that the performance requirements that the Stairway repointing mortars need to fulfill are less demanding than those of most repointing mortars, because they play a very limited structural role, as the blocks rest on a modern support stairway, and because the shelter protects the mortar from direct rainfall.

Figures 105a and b Treatment trial block 488, step 52, before (a) and after (b) mortar removal and repointing.

Surface treatments

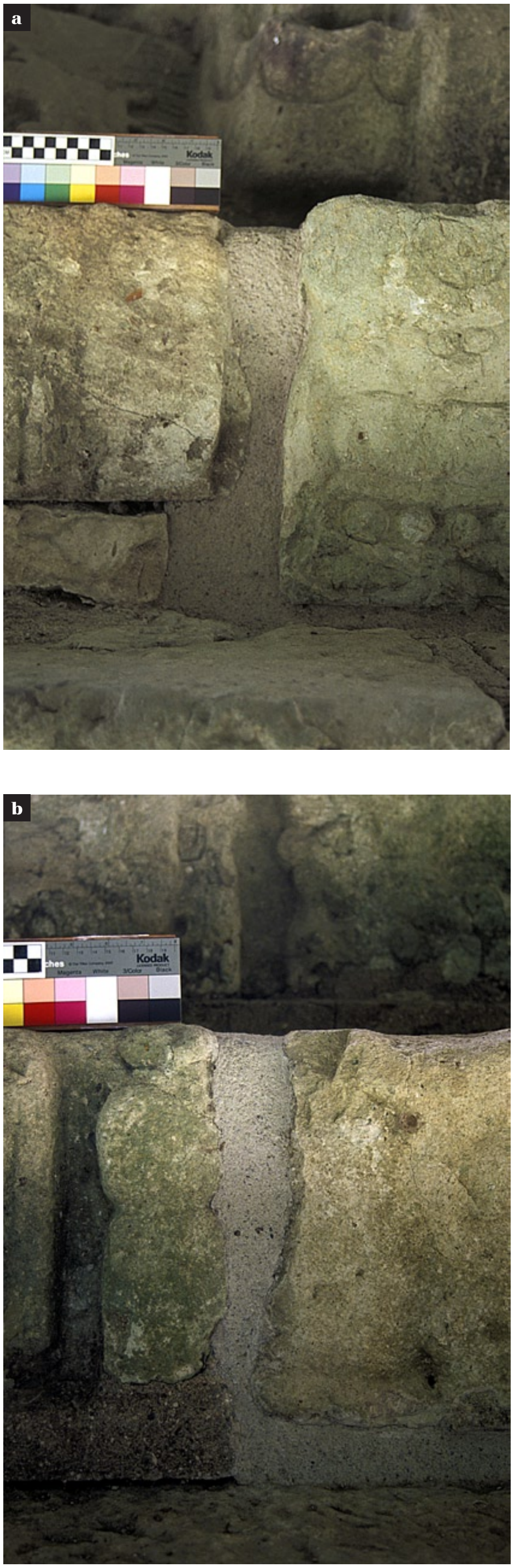
The surface treatment trials were carried out over various campaigns in 2001–2003, during which the following treatment procedure was developed, and all phases of it were tested.

Cleaning

Initial treatment trials provided evidence that general preliminary cleaning of block surfaces was needed in order for subsequent treatments to be carried out effectively and efficiently. General cleaning greatly improved the ability to see the parts of the surface that were previously treated and the parts that had not been, as well as the parts that were subject to microbiological growth. In all cases, cleaning was a necessary precursor to stabilization treatments, where they were required.

The first cleaning tests aimed at determining if cleaning prior to executing stabilization treatments would result in any loss of surface. Water was first applied by swab, and when this did not result in loss of surface, water spray and toothbrushing were tried (**Fig. 107**). For most surfaces this method was safe and effective, although in some more deteriorated areas of the surfaces (usually those treated previously), the use of the toothbrush was potentially too aggressive. A trial of a detergent additive (4% v/v Triton XL-80N) with water was also undertaken, but this addition did not considerably improve the cleaning operation, so it was not continued in subsequent treatment trials.

Blocks of different colors were chosen for cleaning trials to determine the aesthetic results of cleaning–namely, whether buff-colored blocks exhibited different results from water cleaning than did green ones. Cleaning trials of different blocks showed that dramatic changes can be obtained with very rapid cleaning operations on blocks that have not previously undergone treatments (**Fig. 108**). The removal of surface deposits of dust and spiderwebs reveals the variety of colors of the stone utilized for the Stairway, which, however, would not have been visible originally, because lime plaster was applied to the surfaces in the Maya period.



Figures 106a and b Comparison of two trial mortars for repointing: for block 406, step 43, the mortar was chosen to match the existing joint mortar (a); for block 488, step 52, the mortar was chosen to blend in with the variety of block colors (b).

Figure 107 Treatment trial block 463, step 50, glyphs F and G, shown after the cleaning of glyph F (on the left) with water and a light toothbrushing; glyph G (on the right) has not been cleaned.

Reattachment of surface fragments

The observed loss of a 2-cm-thick fragment of the surface of block 409 prompted a trial of re-attaching fallen fragments. Because the fragment had been re-attached previously with an unknown adhesive, this event also presented an opportunity to test different poultice media for the removal of adhesive from sound stone surfaces. Paper pulp, attapulgite clay, and a 1:1 mixture of the two were tested; they were mixed with acetone and applied to the inner surface of the fallen fragment. While all three effectively removed the adhesive, the best result appeared to come from the mixture of the clay and paper. Although both of the materials were imported, similar local equivalents of a lower quality could probably be found.

Once the adhesive had been removed from the join surfaces of the fragment and the block, a trial reattachment was carried out. It was done with Paraloid B-72 at 40% in acetone. Paraloid B-72 was chosen because of its local availability and because under the shelter the stone surface temperatures only very rarely exceed 40°C (the glass transition temperature of Paraloid B-72). In addition, the moderate size of the fragment did not require a stronger adhesive than Paraloid B-72. Smaller stones were wedged under the fragment to hold it in place

Figure 108 Treatment trial block 197, step 23, shown after cleaning with water and a light toothbrushing.

Figure 109 Reduction of previous treatments from a stone surface with acetone applied by a cotton swab.

during the setting of the adhesive. The next day the fragment was firmly re-attached; it has remained in place over a year.

Previous treatment reduction

After general cleaning trials with water and toothbrushing, or with water and swabbing (depending on the surface conditions), the reduction or removal of previous consolidation treatments was tested. Treatment reduction was considered advisable for two reasons: to enable stabilization treatment where needed, and to improve the legibility of the carved surfaces and the general aesthetic appearance of the blocks. The previously used surface consolidation materials, which have darkened considerably over time, and the generally poor execution of the treatments have made many of the carved surfaces unrecognizable today.

Different solvents and application techniques, including poulticing and swabbing, were tested to reduce the amount of material previously applied to the surfaces. While various poultice materials were tested, poulticing was considered inappropriate for the majority of stabilized surfaces because of the potential that flaking surfaces would be removed along with the poultice.

The preferred method, which affords greater control, is swabbing. After attempts at cotton swab reduction of previous treatments (**Fig. 109**), various types and sizes of synthetic foam swabs were used. These proved to be far more effective because of their capacity to hold the solvent in greater quantity and over a longer period of time. Unfortunately, these types of swabs were not found to be available in Honduras, but they were considered essential to realistic treatment times and could be easily imported or ordered from Web sites at a modest cost. The few solvents available in western Honduras were tested, and acetone was found to be the preferable option, because of its capacity to solubilize Paraloid B-72 used for previous treatments, as well as because of its widespread availability and its lower toxicity for the user.

The use of acetone and synthetic swabs was successful in removing Paraloid B-72 from the stone surface and, consequently, in removing any superficial darkening. However, previously treated surfaces maintained some water-repellent behavior due to the remains of Paraloid B-72 just under the surface. In some areas, where the surface was extremely friable or flaking, even careful swabbing with acetone produced some very limited loss of material, but this was considered acceptable in relation to the improved overall surface conditions obtained.

When reduction of previous edging repairs did not threaten the stability of the flakes, they were fully removed, while in other cases, they were only trimmed back. Some edging repairs were found to be considerably more soluble in acetone than others and much easier to remove. These repairs were most likely carried out with Paraloid B-72 acrylic resin because of its greater solubility, while the repairs that were more difficult to solubilize were probably done with Mowilith 30 polyvinyl acetate. Removal of the latter required more mechanical action with a scalpel. Fourier transform infrared spectroscopy (FTIR) analysis confirmed the hypothesis (see "Analyses of Materials").

The reduction/removal of previous treatments produced very dramatic changes in the visual appearance of the stone surfaces. The darkening of both types of materials over time could be reversed by removing them from the surfaces, so that the natural color of the stone is revealed, and, more important, the carved details are as visible as before the past treatments (**Fig. 110**).

Stabilization

The reduction or removal of previous stabilization/consolidation treatments often left the surfaces fragile and vulnerable to further loss; therefore, it was necessary to carry out stabilization treatments immediately after previous treatment reduction, in order to prevent loss.

Two principal stabilization treatments were tested and employed on block surfaces: grouting to fill voids behind detached surfaces and larger flakes inaccessible to normal solid mortar (**Fig. 111**), and repairing edges with mortar to fill, close, and protect the open edges of detached areas and flakes (**Fig. 112**). Most of the flaking surfaces had been previously treated and were held in place with edgings, without the void behind being filled, leaving them vulnerable to loss if subjected to physical impact. Grouting of surface flakes was therefore considered particularly important to fill such voids, in order to provide support and help re-adhere the flakes to the sound stone behind.

Two main types of materials for grouting and edging were assessed. Lime-based treatments were tested because lime is the most easily obtained traditional binder material. It is stable and reversible. Colloidal silica–based treatments were

Figure 110 Stone surface shown after reduction of darkened consolidant (on the left); the procedure has not been performed on the right side.

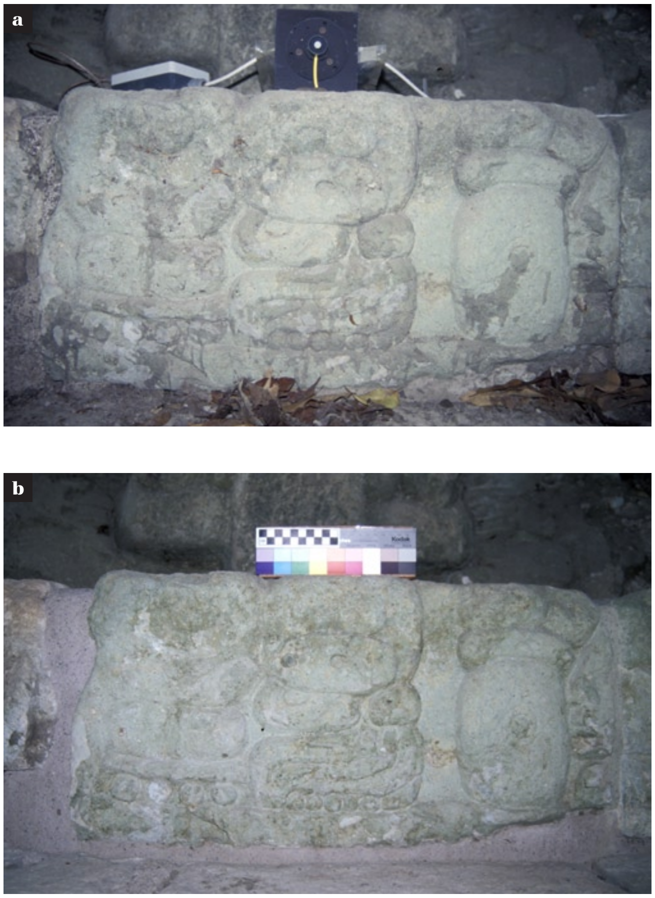
Figure 111 Grouting of a detached area of block 71, step 11, with a lime-based liquid mortar.

also tried as an alternative, because of its chemical compatibility with the volcanic tuff. Colloidal silica was also chosen because of the ease of use and importation, since it is water-based rather than solvent-based.

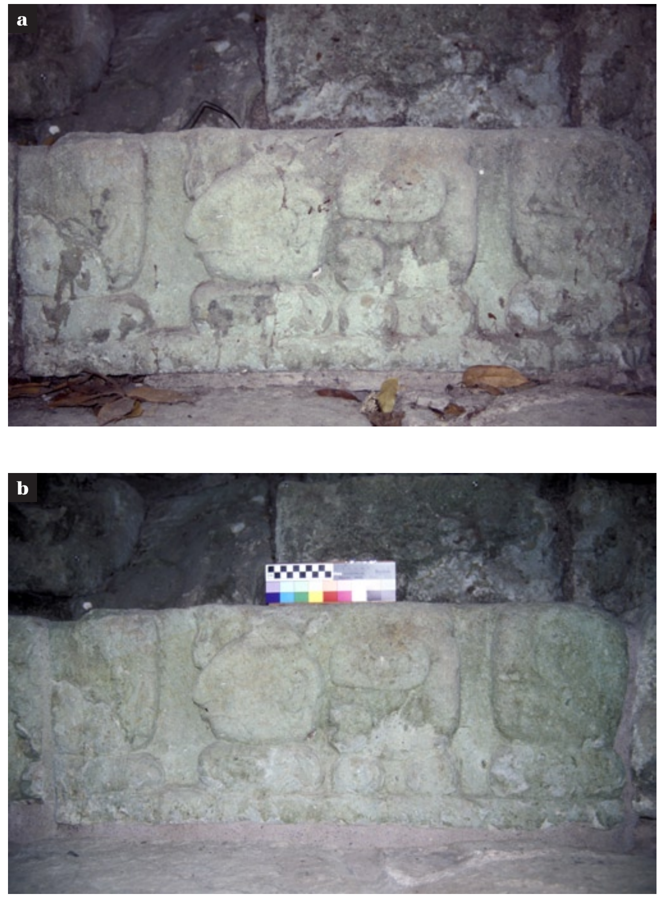
New edging repairs of stone flakes using lime putty, Copán stone powder (both green and yellow), and mixed Copán sands were tested and found to be well adapted. However, they were generally too light in tone after drying, because of the whitening effect of the lime. Neither an increase in stone powder content in the aggregate mix (up to 1:1.5 sand:stone powder) nor a lowering of the proportion of the lime (down to 1:5) in the mix significantly improved the color match to most stones. Only the addition of dry pigments produced satisfactory color matches between the lime-based edgings and the stone surfaces. A number of Kremer pigments used at different concentrations (from 0.5% to 10% v/v) were tested. Relative proportions of the aggregates were also tested, and it was found that the pigments can only influence the color of the dry mortar if the aggregate mix contains more of the stone powder than of the dark Copán mixed sand. The final base mix was 1:1:2 lime putty:Copán mixed sand:Copán stone powder. The maximum aggregate size, the color of the Copán stone powder, and the type and concentration of pigments remain variables to be selected, depending on the required width of the edging and the local color of the stone surface (**Figs. 113a, b, 114a, b**).

Lime-based grouts were tested and found to be successful, even when surfaces of the flakes had previously

Figure 112 Edging flakes on block 578, step 61, with a lime-based mortar.



Figures 113a and b Treatment trial block 406, step 43, before (a) and after (b) treatment. There is an improvement in readability of surfaces after reduction of darkened consolidant from previous treatments and stabilization with edging repairs and with fills of lime-based mortars, colored with pigments to match the stone.



Figures 114a and b Treatment trial block 407, step 43, before (a) and after (b) treatment. There is an improvement in readability of surfaces after reduction of darkened consolidant from previous treatments and stabilization with edging repairs and with fills of lime-based mortars, colored with pigments to match the stone.

been consolidated with Paraloid B-72. It was sometimes difficult to achieve penetration of the grout when a mixture of Paraloid B-72 and soil was found behind the flakes. Flushing the void with acetone prior to grouting helped to resolve this problem, but in these cases, adhesion of the grout to the stone surfaces remains problematic.

Grouting of flakes with a mix of colloidal silica (Syton X-30), stone powder, and Copán mixed sand, with the addition of fumed silica to help keep the aggregates in suspension, was also tried. After grouting, the detached areas sounded solid, and the stone flakes no longer moved when tapped; however, the flow of the grout proved to be more difficult to control. Syton-based edging repairs were also tested and found to be successful, but they became very hard after drying. For both grouting and edging repairs, it was felt that the Syton-based materials were very hard and more brittle than the stone itself, and, therefore, that they would be less preferable for general use throughout the Stairway.

In a few specific cases, where small stone flakes were too unstable to be edged directly, the aqueous acrylic emulsion Rhoplex AC-33 (30% v/v in water) was used to obtain some adhesion of the flake to the sound stone below prior to edging. In some cases, Rhoplex AC-33 was also used with success where very fine detachment had occurred and penetration with lime-based grouts was difficult.

Surface consolidation

There is a very small percentage of blocks that present disaggregation or powdering surfaces that could benefit from surface consolidation treatments to prevent further loss. Limewater was not considered a viable option for treating such surfaces, because it would constitute a nontransparent shelter coat and would consequently alter the surface appearance of the stone excessively. A colloidal silica (Syton X-30) was tested for use as a surface consolidant on parts of uncarved, modern blocks of the reconstructed upper Stairway steps. After general water cleaning and then drying, the product was applied by brush in two different dilutions, 1:1 and 1:2 in distilled water. The more dilute solution appeared to offer better penetration of the surface, while both have provided more stable surface conditions and no visible change of color after a year (**Figs. 115a–c**).

Conclusions

Mortar Repointing

The treatment trials of mortar removal have shown that in some areas of the Stairway, the cementitious mortar can be very difficult to remove, while in others it is very soft and easy to remove with small hammers and chisels. The repointing trials have shown that with local lime, sand, and stone powder, 1:3 lime:aggregate mortars have performed well and can be used successfully to fill areas of missing mortar between Stairway blocks or to repoint the entire Stairway, if this is considered preferable. Adjustments to the type and mixture of aggregates can modify the color of the mortar to give a better match with existing mortars, if the repointing is carried out only where mortar is lacking. If a complete repointing is to be carried out, the type and mix of aggregates can be modified to achieve a good neutral color to fit in visually among the different colors of the stone blocks themselves. The space between the blocks to be filled will vary, and in cases of deep voids, small fragments of stone or brick can be embedded in the mortar and the mortar laid in more than one application over several days to ensure proper setting. Pumice obtained from Guatemala was used successfully as a mortar ingredient, and it could be used in the future if a slightly hydraulic mortar is preferred or required.

Surface Treatments

Tests have shown that cleaning with small amounts of water and the gentle and careful use of a toothbrush can significantly improve the appearance and visibility of the carved surfaces without loss of material. It is a necessary first step for the treatment of blocks with previous surface consolidation treatments that are to be reduced or removed.

Surface stabilization trials have shown that inorganic materials, in particular lime, can be used to grout and edge areas of flaking and detachment and to fill cracks and areas of loss. They are preferable to the use of acrylic or polyvinyl acetate resins such as Paraloid B-72 and Mowilith 30, which have been used on the Stairway in the past. Lime is considered a more appropriate material for stone stabilization, especially outdoors, because it is more similar to the stone itself in terms of its mechanical properties. Although in badly deteriorated areas, where a material with more adhesive qualities may be required, an acrylic resin emulsion could be used in conjunction with the lime-based treatment.

A major obstacle to re-treatment of stabilized surfaces with lime is the presence of acrylic resin on the surface, which prevents the penetration or attachment of the lime. For this reason, as much of the resin as possible should be removed from the surface by solvent applications. This was done most successfully by the use of acetone and synthetic foam swabs. The treatment trials have shown that reduction/removal of previous treatments can be carried out safely with only very limited risk of material loss in the most severely deteriorated areas. The reduction/removal of previous treatments is also considered advisable because the previously consolidated

Figures 115a–c Uncarved block 68-2e, from the reconstructed upper steps, before treatment (a), after water cleaning of the left two-thirds (b), and eight months after the application by brush of Syton X-30 in distilled water (c) (left of tape, concentration 1:1; right of tape, 1:2).

Figure 116 Treatment trial block 578, step 61. Glyph Q, on the left, is shown after reduction of previous treatments and new stabilization treatments; glyph R, on the right, shows the darkening over time of previous stabilization treatments.

surfaces have darkened, in many cases making the reading of the carving much more difficult (**Fig. 116**). Many previously treated flaking and detached surfaces, while being held in place by the resin, still have hollows behind the surface flakes. The condition of these surfaces can be improved substantially by grouting in voids behind the surface with lime or other material, thereby making them less susceptible to loss due to mechanical impact.

Colloidal silica–based treatments have been shown to be a possible alternative to lime-based treatments, as well as an improvement over the previous acrylic resin–based methods. However, the colloidal silica products are not available in Honduras, a circumstance that makes their continued use in Copán problematic. These treatments are irreversible, and from trial experience, they appear to be hard and excessively brittle in comparison to the stone itself. For these reasons, lime-based treatments are preferable for the future maintenance of the Stairway. However, colloidal silica–based treatments may provide the best option for surface consolidation of areas of disaggregation or powdering, where edging and grouting treatments are not useful.

Re-adhesion of small fallen fragments was carried out only with Paraloid B-72, without other adhesives being tested, because Paraloid B-72 is locally available and easily reversible. Surface temperature readings on the Stairway over the past two years indicate that there is little risk of the Paraloid B-72 softening from elevated temperatures.

The surface treatment trials have shown in general that the amount of conservation treatment work now required per block—if we consider full treatment, rather than just emergency stabilization—is related largely to the extent of previous treatments on the surface of the block. In order to estimate the treatment work required for the entire Stairway, an attempt was made to quantify the extent of previous treatments for each block, using a four-point scale (**Figure 117**). This quantity survey was used as the basis for the treatment time estimates presented in the following section.

Technical Conservation Proposals and Options

Analysis of the archival and published information on the Stairway, in conjunction with an assessment of Stairway conditions during the past five years, has led to the conclusion that the Stairway is currently overall in stable condition. As discussed in "Assessment of Current Conditions," the Stairway is structurally sound at present, and the stability of the immediate environment under the shelter is largely responsible for the generally stable condition of the stone.

Large cracks both within and between blocks of stone have been shown through photographic comparisons to have formed decades ago and are substantially unchanged since then, as a structural equilibrium has been reached since the reconstruction was carried out in the 1930s. Much attention has been drawn to the gradual loss of carved Hieroglyphic Stairway surfaces in recent decades. And although photographic documentation has confirmed that the surfaces of some blocks on the Stairway have deteriorated rapidly since their excavation over one hundred years ago, currently there is equilibrium between the stone and the environment, and this state has significantly slowed down the rate of surface deterioration. This equilibrium is a result of the shelter, which, since 1987, maintains consistently dry and warm conditions throughout the year by blocking rainwater, direct sunlight, and condensation formation, thereby preventing wetting and drying, as well as excessive cooling and heating condition changes. It is these normal exterior environmental changes that cause the contraction and expansion (shrinking and swelling) of stone surfaces which, when repeated many times, are thought to be the main cause of the microcracking and flaking of some Stairway block surfaces. More obvious visually is how rain and sun exposure leads to the growth of microorganisms, such as lichens and algae, on stone surfaces, which contribute to surface deterioration. These growths are almost totally absent from the Stairway at present, thanks to the shelter. It is therefore unnecessary to remove the monument to a museum setting to ensure the future preservation of the Stairway and its carved surfaces.

Some small, limited loss of Stairway block surfaces has occurred during the past five years, but in most cases this has been attributable to mechanical damage caused by walking on the Stairway, despite the fact that regular visitors to the site have not been allowed access on the Stairway since the 1970s. The infrequent and exceptional instances of access on the Stairway by authorized personnel continue to have a negative impact on block surfaces, but this cause can be addressed without resorting to the removal of the Stairway from its original location. To maintain the current stable conditions of the Stairway in situ, two key, basic preventive measures must be continued: first, direct access on the Stairway needs to be limited to the absolute minimum; and second, a protective shelter needs to be in place. In addition, there are a number of remedial conservation treatments that could be undertaken to improve current surface conditions. Both the preventive

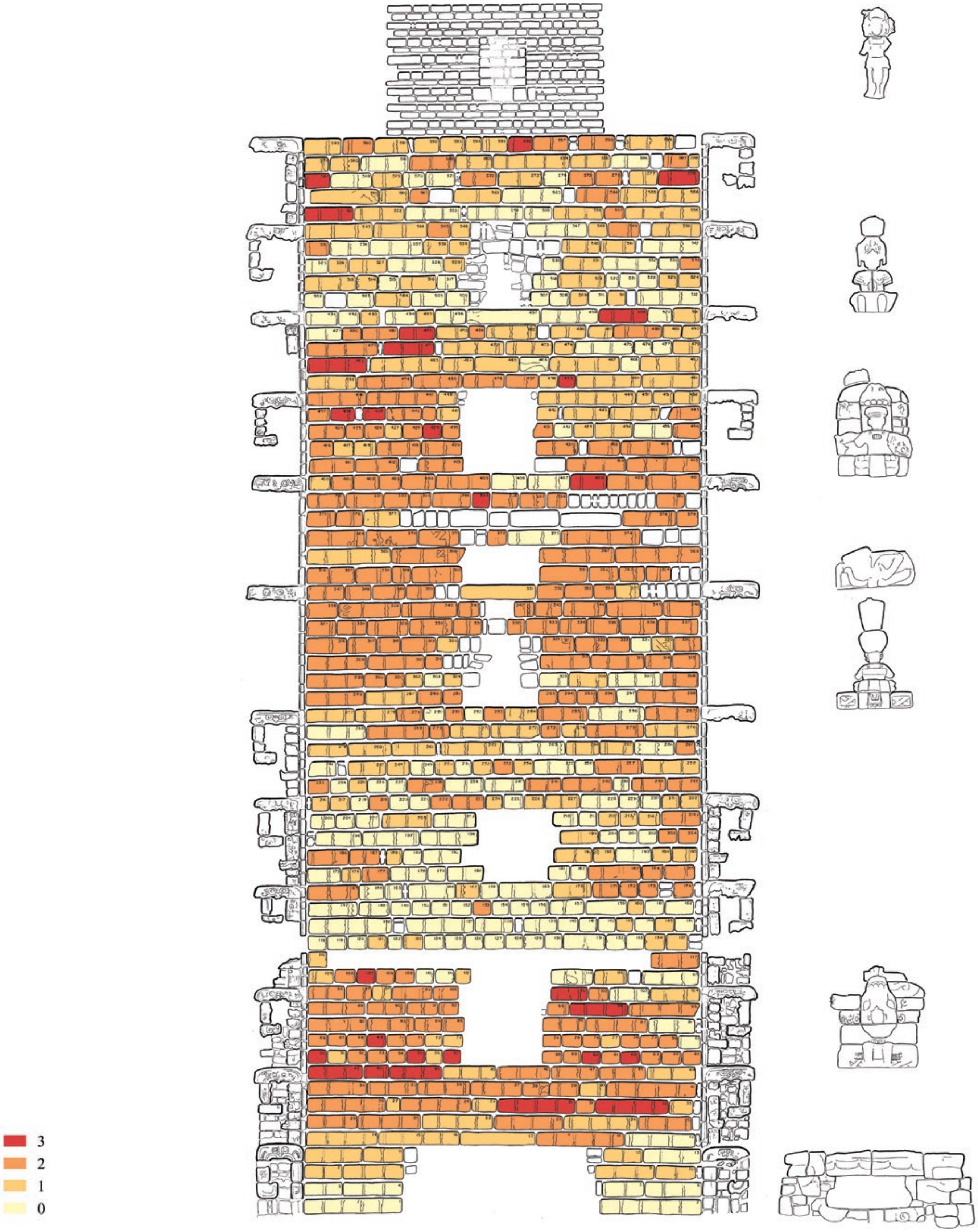


Figure 117 The extent of Stairway riser surfaces that have undergone surface consoilidation treatments in the past. Treatment levels of individual blocks are designated on a scale from 0 to 3, with 3 indicating the greatest level of treatment.

Figure 118 Current Stairway access across the south balustrade provided by steps at several points on the reconstructed terraces to the south of the Stairway. 2004.

Figure 119 Access steps leading to a bridge across the south balustrade.

Figure 120 Metal screening leaf barrier to the north of the Stairway, with wasp's nest.

measures and the remedial treatments are presented below, and options for each are proposed.

Preventive Measures

Minimizing Access to the Stairway

Access on the Stairway is at present not allowed to the public; however, it would be beneficial if access were further restricted to only selected, trained maintenance personnel working for the Instituto Hondureño de Antropología e Historia (IHAH), who are well aware of and sensitive to the fragile nature of some of the stone surfaces. These few people should dress appropriately to minimize accidental damage when on the Stairway by removing their shoes and by avoiding wearing loose, wide trousers. To minimize walking up and down the Stairway by project members, a wooden access stairway parallel to the stone Stairway on the north was constructed in 2000. This stairway was replaced by a more permanent means of access along the south side of the Stairway in 2004. Currently, three metal bridges span the width of the balustrade at different locations, providing lateral access to the Stairway (**Figs. 118, 119**). These access points should be used by those few staff with authorization to enter onto the Stairway for maintenance purposes. In the future, if a major conservation project is carried out on the Stairway and more people will require access, the number of access points should be augmented.

In the past, maintenance of the Stairway has included regular removal of wind-blown leaves from the Stairway. This has been one of the primary reasons in the past for site personnel to access the Stairway. In the interest of limiting this type of access as much as possible in the future, different ways of preventing the leaves from falling onto the Stairway were considered. Since removal of the source of the leaves (i.e., the nearby trees) is not an acceptable option because of the negative impact such a step would have on the value of the site as a natural park, erecting a leaf barrier next to the Stairway was considered. A trial metal screening barrier was erected to the north of the Stairway, where the prevailing winds originate, to test its feasibility (**Fig. 120**). Because of the partial coverage of the space between the pyramid and the tarpaulin shelter, as well as the fact that the south side of the Stairway was not fitted with a leaf barrier at all, some leaves did continue to accumulate on the Stairway, but in a much-reduced quantity (**Fig. 121**). Clearly, installing the barrier to a greater height and on both sides of the Stairway would be more effective, and using a more flexible netting material should prevent the building of nests by wasps in the barrier. Such a barrier should reduce the need for access to the Stairway for leaf removal by trained personnel, but would have an impact on visitor perception of the monument.

Another aspect of ordinary cleaning maintenance that was temporarily suspended on the Stairway during the project was the removal of cobwebs, which accumulate on stone surfaces throughout the site (**Figs. 122, 123**). While there is no way to prevent the formation of cobwebs, their periodic removal on the Stairway should be carried out only by trained personnel and performed together with leaf removal a few times a year.

Figure 121 Accumulation of leaves on the south side of the bottom portion of the Stairway.

Small, soft bristle brushes should be used with care to minimize contact with the stone to the degree possible.

Animal Intrusion Prevention

Burrowing animals, such as skunks, which make their nests in the Stairway, have had a negative impact on its conservation. There is no clear evidence of damage to block surfaces due to animal activity, but many instances of animals removing mortar between blocks in their attempts to find a nest under or behind the blocks have been recorded (**Fig. 124**). Animal nesting in the Stairway should be discouraged as much as possible by filling all existing gaps between blocks with mortar and by preventing the accumulation of leaves on the steps, which provide animal nesting material.

The current shelter design, with a minimal interior support system, effectively prevents birds and bats from perching or nesting within the shelter, thereby almost preventing the accumulation of guano on Stairway surfaces. However, a small amount of guano has been observed on the Seated Figures of the Stairway that provide attractive perches (**Fig. 125**). A number of bird-perching prevention systems are

Figure 122 Spiderwebs and leaves on the steps of the Stairway.

Figure 123 IHAH staff member using a brush to remove spiderwebs from a stela.

Figure 124 Area of mortar loss between blocks caused by burrowing animals.

Figure 125 A Seated Figure used by birds as a perch. Guano can be seen on the carved surface.

available commercially, but perhaps the simplest one consists of thin metal spikes placed in the preferred perching area. If several of these were installed where needed on the horizontal surfaces of the Seated Figures, the disfiguring and damaging accumulation of guano in these areas could be prevented.

Sheltering the Stairway from Rainwater and Solar Radiation

A crucial factor for ensuring the stable condition of the Stairway in the future is the continued presence of a protective shelter. As the environmental data have shown, the current shelter–through its almost complete exclusion of rainwater and direct sunlight (while at the same time it allows air circulation)–provides sufficiently stable environmental conditions to prevent most deterioration to the Stairway. However, there are modifications that could be carried out to the shelter to improve its protective function, as well as other changes that could improve the visibility and presentation of the Stairway. Alternatively, consideration could be given to constructing a different type of shelter that would be more permanent than the current one, which was conceived originally as a shelter for just the rainy season.

Modifications to the existing shelter

Since the shelter was first installed in 1985, modifications to it have been made to improve its protective function. Primarily, the length of the tarpaulin has been extended so that it covers more of the upper part of the pyramid (**Figs. 126, 127a, b**), and as a consequence, rainwater no longer collects above the Stairway. During this project, modifications to the shelter have already been proposed informally, and some have been carried out, such as improvements to the lateral anchoring of the tarpaulin so that it remains more taut and less prone to tear in high winds (**Figs. 128, 129**). The following additional modifications could be employed to improve the current performance of the shelter:

Figure 126 The top of the Stairway pyramid. The tarpaulin extends beyond the platform above the Stairway.

Figures 127a and b The shelter of the Hieroglyphic Stairway in 1992, with coverage that stops short of the top of the pyramid (a); a replacement tarpaulin, in place in 2001, offers greater coverage of the top of the pyramid (b).

Figure 128 Shelter in 1998, with previous system of lateral supports.

Figure 129 Shelter in 2003, with a modified lateral support system that keeps the tarpaulin taut.

Figure 130 Shelter in 2000; note the proximity of the tarpaulin to the top of the Stairway.

1. *Extend lateral coverage of the tarp.* Currently, wind and rain from the north have been observed to cause the wetting of stone surfaces near the bottom of the Stairway, where the tarpaulin is at the greatest height above the Stairway.

2. *Reinstall or replace the central cable support.* The increasing frequency of the removal and reinstallation of the tarpaulin has caused the existing center cable support at the top of the Stairway to deflect downward. As a result, the tarpaulin moves increasingly closer to the top of the Stairway (**Fig. 130**), and it touches stone surfaces during high winds. The proximity of the tarpaulin to the top of the Stairway reduces air circulation and increases air temperature in this part of the Stairway (see "Environmental Monitoring"); however, it increases stone surface temperatures only slightly, so it does not seem to be a significant factor in stone deterioration. As a temporary solution, a small metal cable has been attached to the top of the support in order to pull it back to vertical (**Fig. 131**). If the cable support is reinstalled or replaced, it should be done in such a way that the height of the tarpaulin above the top of the Stairway is increased.

3. *Replace the missing cable covers.* Originally the tarpaulin fabric was protected from friction with the steel cables by tubes surrounding the cables, which are now absent in most

Figure 131 The central shelter cable support. Additional cable on the left keeps the support vertical.

Figure 132 The shelter, which was installed in February 2001, with a tear caused by high winds in 2003, in the same location where the tarpaulin was previously repaired.

Figure 133 View from the Plaza, as the public sees the Hieroglyphic Stairway. The visibility of the upper portion is poor because of the contrast between the bright sky and the dimly lit upper part of the Stairway.

places. Installation of new cable covers would help increase the useful life of the tarpaulin.

4. *Improve the quality and durability of the tarpaulin.* Experience has shown that the tarpaulin has needed replacement with increasing frequency since the shelter was first installed in 1985 (**Fig. 132**). Explanations could be that the quality of the tarpaulin canvas has declined over the years or that the quality of the impermeable treatment applied to it has declined. In the future, better-quality or better-treated canvas should be used, so that the tarp lasts longer than the current two to three years. Alternatively, a lighter, more resistant synthetic material, like those used to make sails, could be used in place of the cotton canvas. This step would entail a substantial increase in cost, however, and would probably require sourcing outside the country.

5. *Improve natural lighting underneath the shelter.* Currently the visibility of the upper part of the Stairway from the ground under the tarpaulin is poor because of the strong contrast between the dimly lit upper part of the Stairway and the bright sky visible at the top of the pyramid (**Fig. 133**). Assuming that the current dark canvas continues to be used in the future, this contrast in illumination could be reduced and, consequently, viewing of the upper part of the Stairway could be improved. This could be achieved by installing a fabric or netting covering along the top of the pyramid to block the skylight between the top of the pyramid and the top of the tarp. A trial covering with a locally available dark netting was installed in part of this location to verify the effect (**Fig. 134**). This experiment indicated that a similar yet complete covering would significantly improve the visibility of the top of the Stairway when viewed from below. This final proposed modification to the current shelter addresses the presentation of the Stairway, rather than its conservation, but it is included here nonetheless, because it can significantly impact the visitor experience of the Stairway.

New shelter design

Rather than modify the existing shelter as proposed above, a second option would be to design and construct a new shelter to provide, as the current shelter does, the basic, required parameters of a dry, shaded, stable environment. Any new design should incorporate the positive aspects of the current shelter (low cost, low tech, easily reversible), while improving on its weaknesses (nondurable covering, lateral exposure to rain and leaves, poor visibility of entire Stairway). In the interest of long-term sustainability, a new shelter should ideally be made of simple, cost-effective materials that are not difficult to acquire, replace, or maintain. As part of this project, a consultant architect formulated several alternative conceptual designs for the Stairway shelter (see Appendix G), which could provide a starting point for interdisciplinary discussion on future shelter characteristics and alternative design solutions, should this be the chosen option.

Figure 134 Trial placement of dark netting at the top of the Stairway in order to reduce visual contrast and improve the visibility of the Stairway from the Plaza.

Figure 135 Area of increased biological growth near the Stairway, where rainwater flows toward it.

Figure 136 Accumulation of rainwater at the base of the Stairway during a heavy rainstorm.

Improvement of Existing Drainage

Whether the existing shelter is modified or a new one is designed and constructed in the future, rainwater drainage should be addressed in the immediate area of the Stairway. Currently, rainwater on the pyramid slope north of the Stairway flows in part toward the Stairway, causing microorganisms and plants to grow in its vicinity and creating unstable moisture conditions for stone surfaces in the adjacent part of the Stairway (**Fig. 135**). The surface of the pyramid should be modified slightly by the addition of mortar and small stones in localized areas where rainwater is being channeled toward the Stairway, so that it flows directly down the slope instead.

During very heavy rain, it has been observed that water collects in the Plaza and floods the area in front of the Stairway under the tarpaulin (**Fig. 136**). Drainage of the Plaza at the Stairway end should be improved to prevent occasional flooding, by altering the present grade so that water flows away from the base of the Stairway. Alternatively, a more effective barrier of stone and mortar could be constructed along the line of the current single-stone perimeter separating the Plaza grass from the dirt area under the shelter, in order to redirect the water shed by the tarp and the pyramid away from the base of the Stairway.

Monitoring and Maintenance of Tunnels within the Pyramid

Two independent structural assessments produced by consulting engineers concurred that there is no active structural deterioration of the Hieroglyphic Stairway, but there are locations that should be monitored in the future to determine if structural problems are developing. Some of those locations are the excavated tunnels underneath or near the Stairway, which are a potential cause of structural instability. The tunnel directly under the Stairway is, however, deep within the pyramid, and it did not exhibit any cracks in the rubble masonry (**Fig. 137**). A program of maintenance should be developed for the tunnels on a case-by-case basis. Structural stabilization could be carried out in some tunnels, for example, by the construction of masonry arches at certain points; others could be backfilled where access is not required. In those tunnels that it is deemed necessary to keep open, regular inspections should be carried out to detect any future collapse of material.

Stairway Crack Monitoring

Similarly, the structural cracks visible on the Stairway surface that have been determined not to be active (see “Structural Assessment”) should be regularly inspected and monitored to determine if any structural movement takes place in the future. Regular photographic monitoring could be undertaken where cracks are present, or crack monitoring devices could be installed and inspected regularly. In particular, there are several cracks in the Stairway balustrades that should be regularly monitored (**Figs. 138, 139**).

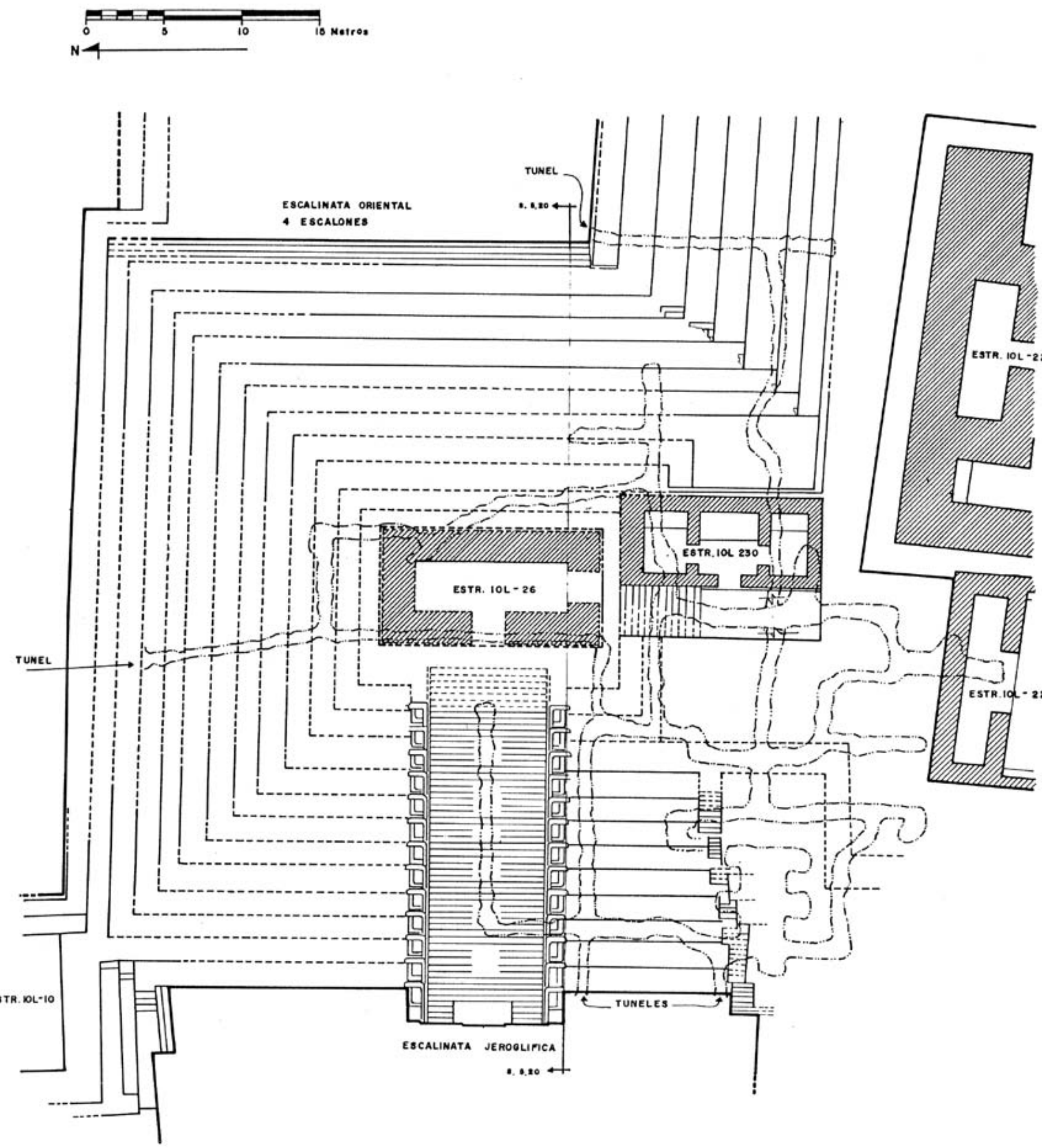


Figure 137 Plan of the tunnel system underneath Structure 26.

Figure 138 An old crack between the north balustrade and steps 54–58.

Figure 139 A crack within north balustrade blocks N38 and N39.

Figure 140 An in situ block (step 10, block 53) tread surface seen from above; the parallel cracks are behind the carved block face.

Remedial Conservation Treatments

In addition to the measures or interventions that could be performed to prevent future deterioration of the Stairway, the following proposals and options concern treatments on the stone of the Stairway which aim to remedy or improve conditions, so that the Stairway is better conserved and presented in situ. The Stairway has already undergone a long history of remedial interventions since its reconstruction in the late 1930s, beginning in the 1970s with biocide treatments (see "History of Interventions"). Subsequent surface stabilization treatments were carried out on Stairway blocks and sculptures for decades, as part of intermittent maintenance by local personnel to repair and prevent surface loss. Treatments generally include edging repairs of surface flakes of stone, as well as infiltration of liquid adhesive in voids behind detached and flaking surfaces. These treatments, considerable in number and extent, have a strong impact on the type and extent of future treatment options. Structural stabilization treatments of individual blocks–such as the grouting of cracks within blocks, the pinning of fragments, and the re-laying of blocks on a new mortar bedding–have been virtually absent in the past. Such structural stabilization treatments have not been needed because the Stairway, except for the first fifteen in situ steps, rests on a new foundation built during the reconstruction of the 1930s.

Structural Stabilization of Stone Blocks and Seated Figures

There are only a few carved blocks near the bottom of the Stairway which contain structural cracks running through the block, parallel to its face (**Fig. 140**). As long as these blocks are not regularly walked upon or exposed to rainwater, there is no threat of eventual detachment of their faces and no immediate need to pin or otherwise stabilize them. Several blocks of Seated Figures were pinned together as part of the reconstruction of the 1930s, but there is no sign of these structural interventions requiring repair or replacement.

Surface Stabilization of Stone Blocks and Seated Figures

While the amount of surface loss has decreased dramatically since the construction of the protective shelter in 1985, numerous stabilization treatments have been carried out by IHAH personnel since then. Since this project began six years ago, some localized and occasional loss of surface material has been observed. Despite being previously treated, many surfaces are fragile enough to fall off if they are subjected to mechanical impact, such as from a passing foot. The current condition of the stone surfaces (many of which have been previously treated) suggests two basic options for remedial surface treatments.

The first option is to stabilize only those surfaces in most imminent danger of loss from flaking and detachment. The other option is to carry out a comprehensive cleaning and surface stabilization program for the Stairway, which addresses both aesthetic problems (**Fig. 141**) and stabilization problems (**Fig. 142**). There have been many poorly or incompletely

Figure 141 Glyph A, block 513, step 55, with darkened surfaces caused by previous consolidation treatments.

Figure 142 Block 71, step 11, with flaking and detached surfaces that require stabilization.

executed stabilization treatments in the past, and there are previously untreated areas that would benefit from treatment today. The two different options–limited or comprehensive stabilization–require very different amounts of time to carry out, but they essentially use the same treatment methodology and materials.

A complete conservation treatment requires more time because of the need to reduce or remove the previous treatments and then to re-treat the areas requiring stabilization. It is important to remove as much as possible of the previous stabilization treatments for aesthetic reasons, because they have darkened and become very evident over time; at present, they negatively affect the readability of the carved surfaces. Reduction of the previous treatments is important in some cases for conservation reasons as well, because the presence of adhesive materials (consolidants) used in the past for surface stabilization makes re-treatment of areas very difficult to accomplish. Treatment trials have shown that partial removal of the consolidant can allow the introduction of new filling material behind detached surfaces, a process that can result in a more stable condition. Considerable care, however, needs to be taken during the process of reducing or removing the consolidant from certain localized surfaces, because loss of small amounts of stone surface can occur.

Surface cleaning

If the chosen option is that of a complete conservation treatment, cleaning operations should generally precede surface stabilization treatments. Cleaning should begin with the removal of dust and spiderwebs with gentle brushing with small, soft bristle brushes. Adherent dirt and microorganisms should be removed using fine-spray applications of water and gentle brushing with a soft toothbrush; close attention must be paid to avoid brush contact with the more fragile flaking surfaces. The final cleaning operation involves the reduction or removal of previous excess applications of acrylic or vinyl consolidants (Paraloid B-72 or Mowilith 30) where they are present on stone surfaces. This step can be done with acetone, applied preferably with absorbent and efficient synthetic swabs, or with ordinary cotton swabs.

Treatment of previous edging repairs

After the surface cleaning operations, the decision must be made as to whether or not to reduce or remove the previous edging repairs of flaking surfaces made of the same consolidants (Paraloid B-72 or Mowilith 30) mixed with stone powder. During the treatment trials, these repairs were removed with solvent (acetone) applications and a scalpel, then replaced with a different material. The replacements were made primarily for aesthetic reasons, because the previous repairs were very evident, as they frequently differed in color and surface appearance from the adjacent stone. However, if the edging repairs do not affect the legibility of the carving and they still function well to keep a flaking surface in place, it is not advised to remove them; they can, however, be reduced to improve the overall aesthetic appearance.

Stabilization of flaking and detached surfaces

In areas of detachment and flaking, there are basically two possible stabilization treatments: edging repairs to help re-adhere the edges of flakes to the surrounding sound surface and to close openings in the surface, and small-scale grouting (infiltration or injection of liquid mortar) to fill voids behind flakes and help re-adhere them to the sound stone behind the voids. Where the surface detachment is sufficient to permit entry of the grout, grouting should precede edging repair.

All treatments on the Stairway in the 1980s and 1990s were basically the same: infiltration of consolidant behind flakes and edging repairs of the flakes. The materials used in the past for these treatments (Paraloid B-72 and Mowilith 30) have generally functioned well, but they have darkened considerably over time, since they have attracted dirt. For this reason, during the trials, two alternative materials were tested, with positive results (see "Testing of Stone and Masonry Conservation Techniques and Materials"). Both are inorganic and thus more stable than the previous organic consolidants, yet they are

Figure 143 Block 407, step 41, after a trial treatment in which the color of the edging and fill mortar was matched to the stone surface by the addition of mineral pigments to the lime mortar (at the left).

far less adhesive. Lime was tested as an alternative binder for edging repairs and grouting because of its local availability, low cost, reversibility, and stability. Colloidal silica (Syton X-30 and Ludox HS-40) was also tested as an alternative binder for edging repairs and grouts because of its chemical compatibility with the Copán stone and because of its ease of use in relation to other synthetic materials, particularly solvent-based ones. Both materials performed adequately in the field trials, but for reasons of sustainability, and because the lime is sufficiently resistant under the protection of a shelter, lime-based edgings and grouts are recommended for future surface stabilization treatments. The use of lime will necessitate the use of pigments for edging repairs, however, as the color of the repairs made with lime and local aggregates alone will be too different from the adjacent stone. Because the Stairway has a variety of stone colors, the needed pigments will be varied as well. Tests in the field have defined the best pigment mixtures to match several different colored blocks (**Fig. 143**).

Stabilization methodology

The edging repair should be carried out with small metal sculpture or mortar spatulas, and the lime mortar should be applied as far as possible behind the flake after the area has been wetted with water. Any remaining excess mortar on the surrounding stone surface should be removed; then the surface of the mortar should be sponged off, leaving a slightly rough surface just below the level of the surrounding stone. The edging repair should be kept moist for as long as possible by being covered with damp cotton wool and kitchen cling film, in order to prevent rapid drying and cracking of the mortar.

For surface grouting repairs, given the small dimensions of the voids behind areas of detachment and flaking, it will be necessary to use very finely sieved aggregates and to apply the grout by syringe, being careful to clean the void prior to the grouting with either water or a mixture of water and ethanol to remove dirt and dust (**Fig. 144**). If the area has been previously treated with a consolidant, then it would be advisable to flush the void with acetone in order to reduce the amount of consolidant in it and allow more grout to fill it. While these two operations are often performed in tandem, in general, edging will follow grouting

Surface consolidation

Edging repairs and grouting treatments are capable of stabilizing flaking and detached surfaces, the most common type of surface deterioration on the Stairway. However, there are localized areas of a few blocks where the surface is disaggregated or powdery. In this case, lime is not an appropriate consolidation material because it is not transparent and would alter the color of the stone surface. Instead, consolidation of powdery surfaces was tested with brush applications of colloidal silica after cleaning with water and toothbrushing, with satisfactory results. Although the cleaning operation removed some of the powdery surface of the stone, the treatment left the surface unchanged in appearance and solid to the touch after six months.

Repointing and Mortar Repairs

Closely connected to the treatment of Stairway block surfaces is the treatment of the joints between the blocks and between the steps. During the Stairway reconstruction in the 1930s, mortar was applied to these areas to fill the gaps, but the mortar served no real structural function, as the weight of the blocks is generally supported by the modern foundation stairway and the small leveling stones underneath. Some of the joints have been

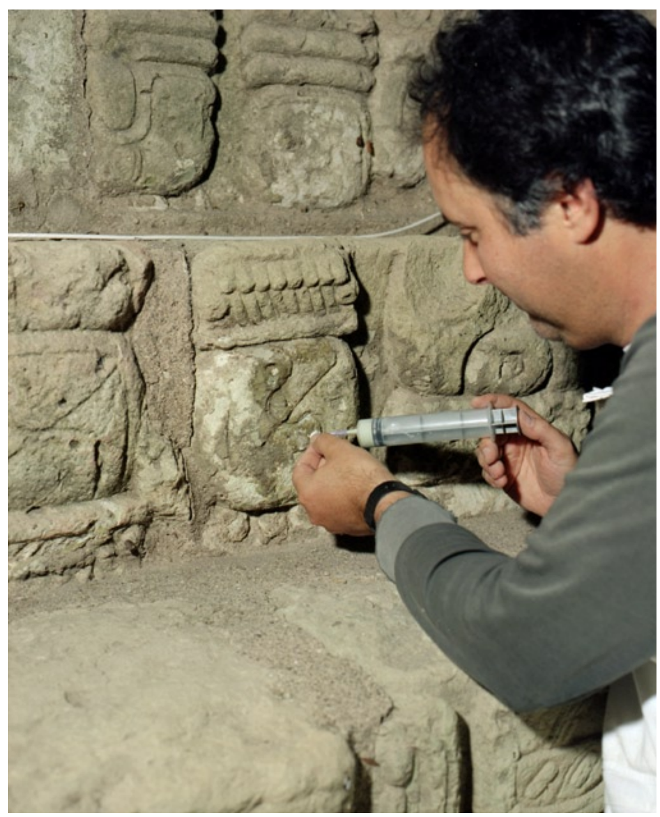


Figure 144 The microgrouting of a flaking surface of treatment trial block 578, step 61.

Figure 145 A view of step 42, in the foreground, shows missing repointing mortar (right) and previous repointing, where mortar covers edges of the blocks (left).

filled again or repointed in more recent decades with various types of mortar, which are recognizable under close examination. At present there are joints lacking mortar–a situation partly caused by burrowing animals. To prevent the entrance of nesting animals and debris between the blocks, as well as to improve the presentation of the Stairway, the areas currently lacking mortar should be filled with lime mortar and small stones as bulk fillers.

As with the question of surface treatments of blocks, there are two options regarding repointing of the Stairway. One option is to carry out the minimum required–namely, filling areas of mortar loss. However, since different mortars have already been employed in the Stairway, and since some of the mortar fillings are poorly executed and cover the edges of blocks in some cases (**Fig. 145**), consideration could also be given to a program to reduce or remove all mortar between the blocks and to repoint the entire Stairway. The rationale for such a program would be essentially an aesthetic one–to improve and regularize the overall appearance of the Stairway. The existing mortars, although mostly cementitious, do not pose a threat of deterioration to the adjacent blocks.

When considering the option of repointing the entire Stairway, it is also important to consider the effect that removing the mortar may have on the adjacent stone. Based on the trial mortar removals, it was found that some of the mortars are quite hard and difficult to remove by hammer and chisel. There is a risk of small losses of stone near the block edge during the removal operation. Therefore, if this treatment option is chosen, the removal of the mortar, as with the surface treatments, should be carried out by trained personnel. Hammers and chisels of various sizes should be used for this operation, and the mortar should be broken into small fragments before it is removed manually. It is not necessary to remove all of the existing mortar if it continues to great depth and is difficult to break up and extract. An inch or two below the surface of the block would be sufficient to allow it to be covered over with a new repointing mortar.

Repointing materials

Two different mortar mixes for repointing were placed on the Stairway as trials, one more similar in appearance to the majority of the existing mortar fills. This mortar mix would be appropriate if only existing losses were to be filled. If, instead, the entire Stairway were to be repointed, then a different-colored mortar could be used, one that would blend in well with the variety of existing block colors, so that it is less evident when viewed from a distance. The second mortar mix was aimed at satisfying this aesthetic criterion in case the second option is chosen. Both of the mortars placed on the Stairway as trials (see "Testing of Stone and Masonry Conservation Techniques and Materials") were lime mortars made of locally available quicklime and aggregates (river sand and stone powder only). For these mortars the proportions of aggregates were varied slightly, while a basic ratio of 1:3 lime:aggregate was maintained. Both laboratory analysis and the field trials have shown that the mortars are sufficiently strong and resistant for use in a non-load-bearing situation and in a protected environment, where rainwater erosion and micro-biological growth are not present.

Repointing methodology

Prior to the application of mortar to the area to be repointed, all dirt, leaves, and debris should be removed with a paintbrush or with air suction, if available. The sides of the adjacent blocks should then be thoroughly wetted to remove residual dirt and to aid in the adherence of the mortar.

The lime mortar should be applied with a mason's trowel and spatula or repointing key as deeply as possible between the blocks. Depending on the depth of the void, clean and wet fragments of stone or brick should be inserted as chinkers along with the mortar. The mortar can be applied over several days, if the void is deep, to allow proper setting. It should be applied until it is just below the level of the edge of the adjacent stone and then compacted as much as possible. Soon after, the surface of the mortar should be cleaned of lime with a sponge and water spray, to expose the aggregates and roughen the surface. The mortar should then be prevented from drying quickly by covering it with a damp cloth or burlap to prevent shrinkage cracks and to ensure proper setting (**Fig. 146**).

Inspection of existing mortar platform and removal of cement lip above step 63

In addition to the repointing of the Stairway, another mortar removal and repair operation is proposed for the platform above step 63 (**Fig. 147**). Several blocks of the top step have been observed to be actively deteriorating, yet no documentation has been found regarding the type of mortars used to construct the platform immediately behind these blocks. Therefore, it is proposed to remove the top layer of mortar near the top step, in order to inspect the mortar layer below. If cementitious mortar underneath is found to be in contact with the back of the top step blocks, it would be beneficial to remove the cement mortar. Lime mortar should then be used to rebuild the platform, and a gentle slope should be constructed down to the sides, so that occasional rainwater does not collect above the Stairway.

The lip of cement running across the top of Step 63 was applied many years ago in order to prevent rainwater from collecting on the platform and running down the Stairway (earlier versions of the tarpaulin did not extend across the entire platform). Now that the tarpaulin has been modified to prevent rainwater from collecting in that location, the lip no longer serves a function. The presence of the cement applied directly

Figure 146 Repointing of treatment trial block 407, step 43 (left), and missing mortar under the adjacent block (right).

Figure 147 View of the mortar platform and cement lip above the last step of the reconstructed Stairway, looking south.

on the top of the last step could also be contributing to the surface deterioration that can be seen on selected blocks of the top step. It is recommended that the cement lip be removed carefully by hammer and chisel.

Estimate of Time Required for Remedial Treatments to the Stairway

The treatment trials carried out during the project provided the experience needed to develop time estimates for the two different levels of treatments: (1) the minimum required treatment, and (2) the complete treatment of the entire Stairway.

Surface stabilization

- Emergency treatment of selected areas: 72 workweeks for one person
- Complete surface treatment of all stone blocks: 357 workweeks for one person

Repointing and mortar repairs

- Filling areas of mortar loss: 4 workweeks for one person
- Complete mortar reduction/removal and repointing of all Stairway joints: 45 workweeks for one person.

The workweek calculated is eight hours per day, five days per week. The work does not include the time required to prepare the mortar materials but, rather, only their application.

Implementation Proposal

These estimates show that the proposed remedial conservation work of the Stairway requires a significant amount of skilled labor, especially if the option of complete treatment is chosen over that of minimum treatment. The Stairway is, of course, only one of many monuments at Copán requiring maintenance treatments, and some of these monuments, such as the Jaguar Stairway in the East Court, will pose the added problem as well of having been treated frequently in the past. The materials and equipment for carrying out monument maintenance at Copán are not costly, as the bulk of them–lime and aggregates–can be obtained locally at little expense, but a trained workforce dedicated to this task needs to be employed.

To meet the monument conservation needs of the Stairway, as well as those of the site as a whole, IHAH could develop a small team of four or five trained conservation technicians working under the guidance of a trained professional conservator. The sole responsibility of this group would be to monitor conditions, carry out preventive measures and remedial treatments as needed, and document the maintenance work. In this way, the minimum treatment option at the Stairway could be carried out in approximately four months. This team would then move on to maintain other monuments at the site, and possibly at other sites in the region, throughout the year.

If the complete treatment option is chosen for the Stairway, then the same team could undertake such a project over a longer period of time. Given the great amount of work needed for complete treatment of the Stairway, it would be advantageous to have a larger group of workers, including skilled masons who could be employed in the repointing exclusively, while the surface treatments are left to the more specialized conservation technicians. For practical reasons, the repointing of the Stairway should be done before the surface treatments, although precautions should be taken to prevent the most fragile surfaces from impact during the operation.
A significant amount of time will be needed to prepare the lime and aggregates in advance, to secure a source of water, and to otherwise prepare the Stairway for repointing. A movable work platform will need to be designed and installed, so that, as much as possible, sections of the Stairway are protected during the work as it proceeds from the top of the Stairway to the bottom.

If IHAH employs skilled masons and conservation technicians in other parts of the country, they could be transferred to Copán to join the few trained local staff and external people for the duration of the complete Stairway conservation treatment. If IHAH does not have such skilled personnel (and in the case that the complete treatment option is chosen), then it must either contract the conservation work or wait until the required personnel have been hired.

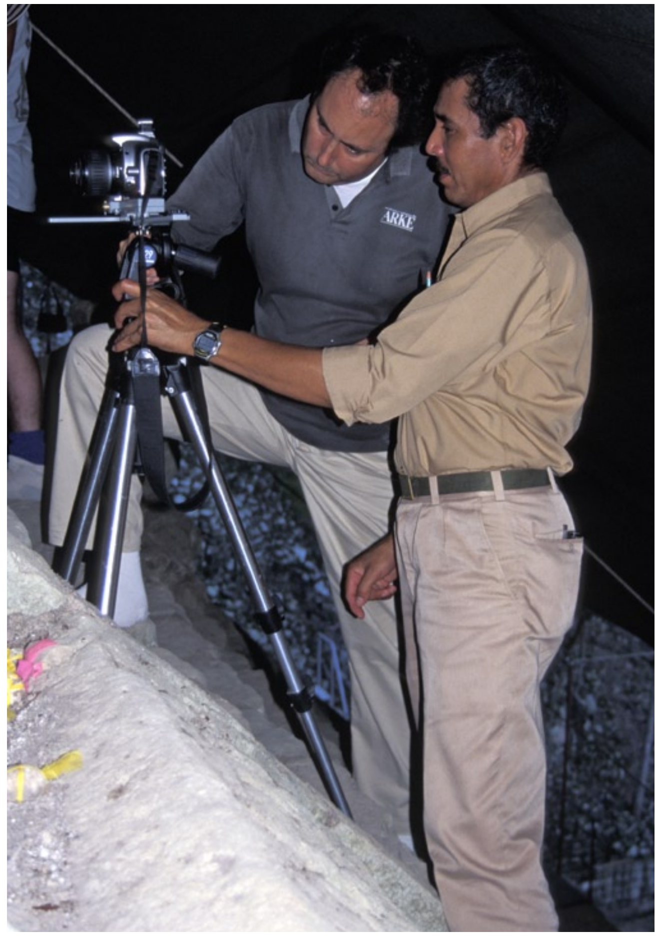


Figure 148 GCI and IHAH staff practicing the protocol for photographic monitoring of control block condition.

In either case, to ensure the sustainability of continuous maintenance activity on sites in the future, a training program for site conservation technicians should be developed within the country, while potential IHAH conservators, as well as funding for professional conservation training overseas, are identified. Professional training of a conservator can take from two to four years, depending on the type of program and studies chosen. Technician training should take a minimum of four months of classroom instruction and supervised practical work, followed by independent work to be reviewed by the instructors. In this way, IHAH will build its own capacities to conserve the monuments and sites in its care.

Unless IHAH has done so recently, it would be important as a first step to identify the conservation resources it presently has in terms of personnel throughout the country, as well as identify its needs for additional personnel—masons, conservation technicians, or conservators. It could then develop a strategy for obtaining the conservation staffing and funding to address the needs not only for the Stairway and Copán but for sites, monuments, and historic buildings throughout the country.

Monitoring of Stairway Conditions

All of the proposed conservation interventions discussed above, whether preventive or remedial, will require future monitoring and maintenance to ensure that they continue to function properly. A maintenance regime or program for each Copán monument should be established. It should consist of inspections at regular intervals to monitor the condition of the monument; then, as conditions require, a program should be designed for repair or treatment. The frequency and timing of the inspections should depend on the rate of deterioration observed over time, as well as on the time of year when damage is more likely to occur because of climatic factors. However, possible inspection intervals are suggested below, to be verified over time.

In the case of the Hieroglyphic Stairway, there are a wide range of regular monitoring and maintenance activities that should be carried out, assuming that the current conditions persist:

- During or immediately after heavy rainstorms, monitor the flow of water off the shelter and down the slope of the pyramid, to determine that the Stairway is remaining dry and that rainwater is not collecting under the tarpaulin at the base of the pyramid.
- Remove leaf and spiderweb accumulations on the Stairway and check on animal burrowing activity (in the middle and end of the leaf-falling season, October–January).
- Monitor the condition of the tarpaulin and its support and anchoring system, to prevent damage in the form of tears in the fabric; monitor contact between the Stairway and the tarpaulin (every three months, in particular before the beginning of the rainy season).
- Monitor structural cracks in the Stairway and document their dimension and orientation photographically, with or without the aid of crack-monitoring equipment (before and after the rainy season, May–December).
- Monitor the condition of the tunnels within the pyramid to determine if any new cracks and collapses have occurred (before and after the rainy season, May–December).
- Conduct a rapid condition survey of all blocks for evidence of deterioration of both the stone and previous repairs, as well as identify losses; use the elevation drawing of the Stairway to document the location of deterioration phenomena; write inspection observations in a notebook (every six months). This task should take one person two days to carry out. If remedial treatments are needed, they should be planned and executed in response to their urgency; they should be documented graphically and photographically.
- Conduct a detailed condition survey of selected control blocks, following the glossary of conditions used during the project; conduct photographic monitoring of the same blocks following the methodology established during the project, using analog equipment and, if desired, digital equipment (every year) (see Appendix H) (**Fig. 148**). The documentation, both graphic and photographic, should be labeled, compiled, and stored at IHAH's Centro Regional de Investigaciones Arqueológicas (CRIA) for future reference. This task should take two to three weeks to carry out. A few IHAH personnel have already received training in this type of monitoring, and the photographic equipment, both analog and digital, that is needed to carry it out has been provided.

The inspections should be carried out by trained and skilled conservation technicians, and, ideally, by professionals, including those staff of IHAH who have been involved in carrying out treatments or interventions in the past, as detailed documentation on past interventions is usually lacking. Several IHAH employees and external project personnel have already received some experience and training during this project. They have been involved in condition survey and treatment documentation, as well as in executing treatment and maintenance techniques. These individuals could form the core of a future maintenance team for all of the monuments of Copán. IHAH should also identify other potential local conservation technicians and provide them with the specialized skills to care for the monuments of the site, thereby providing the most important means for achieving the Stairway's long-term conservation—the human resources suited to and prepared for the task.