SUMMARY
The consolidation of weathered tuff material is problematical in most cases due to their unusual pore size distribution. For the case of the Rano Raraku tuff of Easter Island under study, the distribution shows a trimodal pattern. The problem arises because the smallest capillary pores are not reached by the liquid, gel-forming consolidants, such as silicate esters, which mainly fills the larger capillary pores. Thus, the weakened area around the smallest capillary pores is not reinforced. Furthermore, the enormous rates of hygric swelling observed for this material contribute to curtail the durability of this type of consolidation treatment.

This study tested commercially available and modified silicate esters, as well as newly developed anti-swelling agents on Rano Raraku tuff samples taken from the quarry and from broken moai (statues). Treated and untreated specimens were studied by SEM and their pore size distribution and specific surfaces determined. Their hygroscopicity, hygric dilation and their drill resistance were also measured. Both treated and untreated specimens were then subjected to artificial weathering, simulating an exaggerated Easter Island sub-tropical climate, and the studies and aforementioned measurements repeated. The results obtained are discussed and the possible durability of the treatments assessed.

1. INTRODUCTION

1.1 Background Information

Over the summer of 1986-87 the first conservation treatment to be applied to one of the several hundred monumental statues on Easter Island was carried out. The treatment, considered a first test application, was applied to the statue at Ahu Hanga Kio'e. This ahu, or ceremonial platform, had been restored and the moai re-erected on it by William Mulloy in 1972 [1]. The moai was set on to the base slab by a cement mortar which was also used to place the head back onto the shoulders. The ahu is located on the promontory by the Hanga Kio'e bay (hanga means bay) on the west coast to the north of the urban center of Hangaroa. The statue is only meters away from the sea and has suffered much deterioration due to its marine exposure.

The treatment, consisting of an in-depth consolidation with subsequent surface hydrophobization, was carried out by the Centro Nacional de Conservación y Restauración of Chile with the assistance and support of Wacker Chemie, GmbH. Both the consolidant and the water repellent were modified from the usual commercial formulation by the use of a less volatile solvent. These changes were introduced specifically in the formulation for application on the island which is windy and warm (maximum average summer temperature oscillates around 26°C) to avoid undue evaporation. The consolidant used was a modified Wacker OH which included a fungicide. This was applied at the beginning of December 1986, and about two month later (February 1987) the water-repellent, a modified Wacker 090 S, was sprayed on. More details about the treatment can be found elsewhere [2,3,4].
The original project had considered the treatment of three statues [5], however, concerns regarding
the stability of the consolidant in the special climate of the island limited the test to this one treatment
[6]. It was considered that the frequent, short rain events followed by sunshine, i.e., an accelerated
wet-dry cycling, could solubilize part of the consolidant deposited and cover the statue with an
unsightly white deposit. So far this effect has not been noticeable on the statue, which however, has
already a white silica deposit at its base partly attributable to the silica deposit that formed when the
statue had been lying on its "belly" before the restoration.

1.2 Experimental Design
The present study aims to test the use of two newly developed conservation products, a modified
consolidant and an in-depth protective agent. Both products address the problem of the hygric
dilation which can be considered one of the main contributing factors to the deterioration of volcanic
tuffs [7, 8].
The modified stone consolidant forms an elastic silica gel film with water-repellent properties. The
elasticity of the matrix should prevent any irreversible movements between the grains from hygric
and thermal loads leading to increased durability of the treatment. The in-depth protective agent is a
surfactant capable of reducing the large hygric swelling of the material without changing its
mechanical and hygric transport parameters.
The effectiveness of the treatments was determined by comparing the tests results obtained from
treated and untreated material. Different tests were performed to evaluate various properties, in
some cases, new test procedures had to be developed to take into account the complex and
inhomogeneous structure of the stone.
The durability of the treatments was estimated from comparison between the tests results of treated
samples before and after artificial ageing. The artificial weathering system used a combination of
moisture and temperature conditions reflecting the actual climate conditions on the island.

2. EXPERIMENTAL PROCEDURES AND RESULTS

2.1 Material Description
The volcanic tuff from Easter Island used for this study can be visually divided into coarse and fine
grained. For each type, samples were obtained from two sources. The first one was the Rano
Raraku quarry, from which most of the moai on the island were carved, and the second corresponded
to moai fragments broken from statues of the Tongariki ahu which was destroyed by a tsunami in
1960. These last samples were obtained in 1992 during the reconstruction of this ahu. It should be
noted that even the quarry samples are weathered since they were taken from the surface of the top
of the volcano and selected to match the visual characteristics of the Tongariki samples.
The two varieties investigated, the fine-grained with dense structure and the coarse-grained with
clasts of 1 cm or more in diameter, can be classified as a typical lapilli tuff with a clast/ground mass
ratio of approximately 1:1. The ground mass consists of a glassy matrix with plagioclase,
clinopyroxene, olivine and flaky limonite as mineral components. No significant differences in the
petrographic composition of the two varieties mentioned, regardless of their source, were observed
[9].
Due to the high fragility of the material and the lack of large pieces it was not possible to cut the
samples into regular shaped specimens of equal size. Thus, only a few prism-shaped samples of
some 1 to 3 cm could be obtained by careful cutting.

2.1.1 Tests on Untreated Material
The hygric dilation or swelling and the corresponding weight increase (moisture sorption isotherm)
have been determined in equilibrium conditions at increasing relative humidities and ending by water
immersion of the samples for 48 hours. The results obtained are illustrated in Figure 1 for the fine-
grained material of both quarry and moai samples, where the top portion shows the hygric dilation and the bottom curve the sorption isotherm.

It can be seen that the degree of dilation exhibited by the fine-grained material is very large. It reaches values of 1000 µm/m, i.e., 1 mm/m when exposed to relative humidities over 80%, and of more than 2 mm/m when in contact with liquid water. Both samples show similar behaviour except when immersed in liquid water: the moai sample absorbs more than the quarry one. This difference can be explained by the high number of large capillary pores \( (r > 4 \, \mu m) \) in the moai sample. This is illustrated in Figures 2a and 2b, which shows the pore size distribution of the quarry and moai samples as determined by mercury porosimetry.

The degree of hygric dilation of the coarse-grained material, both from the quarry and the moai, is only half as large as that of the fine-grained material. However, the amounts of liquid water absorbed are in the same order as for the fine-grained material. The pore size distribution of the coarse-grained material (not shown) follows the same tri-modal distribution of the fine-grained material for both quarry and moai samples, respectively.

Since the small sizes of the samples precluded the traditional flexural strength determination or testing of other mechanical parameters, the strength was evaluated through drill resistance \( (d.r.) \) plots. These are obtained by plotting the drill rate (depth per unit time) over the time required to drill a 3-mm diameter hole at constant pressure and energy supply. As reported previously [10], laboratory tests demonstrated that the slope of the drill resistance \( (d.r.s.) \) plots relates to the flexural strength of the material through an empirical function \( [thv/7, \text{ where } th = \arctan (d.r.s)] \), with a precision of about ± 1 MPa. The empirical function is plotted vs. drill depth [mm]. Useful results were only obtained from the fine-grained materials, since the coarse-grained ones did not yield homogeneous drill resistance plots. Figures 3a and b present the depth profiles obtained for the fine-grained material of both quarry and moai sample, respectively. The lower mechanical strength of the moai sample can be attributed to their past eventful history.

2.2 Applied Treatments and Test Results

2.2.1 Fine-grained material

Due to the high degree of hygric dilation suffered by the fine-grained material, some of these samples were treated with an aqueous solution of a bifunctional surfactant BDAC (butyl di-ammonium chloride) which has been known to reduce the degree of swelling of various materials without changing their hydric transport properties [11, 12]. This action is based on the preferential bonding between the surfactant to the surfaces of reactive minerals thus preventing their hydration in the presence of water, cause of the swelling.

The tenside was applied by capillary uptake of a 50% v/v solution until saturation and then immersed in the solution for one hour to assure maximum uptake. The amount absorbed ranged from 6.5% to 7.3% w/w for the quarry samples and about twice as much for the moai samples (14.1% to 15.4% w/w).

After treatment, the hygric dilation and sorption isotherm were measured again. The result is shown in Figure 4 which compares the treated to the untreated material. While the hygric dilation is reduced significantly, the liquid water absorption remains unaffected confirming that the capillary pore spaces remain open.

2.2.2 Coarse-grained material

The coarse-grained material was consolidated with a modified ethyl silicate consolidant (WOH-DEXDMS, commercial Wacker OH mixed with prepolymerized di-methyl siloxane) at a 50% v/v concentration in ethanol. The DEXDMS bonds as linear segments into the gel network during the condensation reaction thus introducing elastic properties into the film as well as giving it water-repellency. For comparison, some samples were treated with commercially available ethyl silicate (WOH, Wacker OH) at a 50% v/v concentration in ethanol. The dilution in ethanol, which reduces the hydrolysis speed, was intended to allow the consolidating agent to be absorbed for a longer period of
time, thus improving the absorption in the mesopore region. The samples were stored at 20°C and 65% RH for four weeks prior to the treatment, which was carried out by the previously described method of total absorption, and for ten weeks after it. This ensured that the amount of moisture in the stone was constant and sufficient for the hydrolysis reaction of the ethyl silicate which is the first step in the gel formation. The amount of consolidant absorbed is reported in Table I.

Table I. Amount of consolidant absorbed by the coarse-grained volcanic tuff of the moai and quarry samples.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Consolidant</th>
<th>Amount Absorbed [% w/w]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarry</td>
<td>WOH</td>
<td>10.6 %</td>
</tr>
<tr>
<td></td>
<td>WOH-DEXDMS</td>
<td>9.0 - 11.7 %</td>
</tr>
<tr>
<td>Moai</td>
<td>WOH</td>
<td>9.2 %</td>
</tr>
<tr>
<td></td>
<td>WOH-DEXDMS</td>
<td>5.8 - 8.8 %</td>
</tr>
</tbody>
</table>

After two months, the polymerization reaction was considered essentially complete, and the hygric dilation curves were measured again for samples treated with WOH-DEXDMS. These showed a slight increase in swelling, more noticeable for the quarry sample, occurring at 35% RH and corresponding to sorption phenomena within the smaller pores (< 0.01 µm).

The sorption isotherms were measured for all treated samples and showed some significant changes. Figure 5 illustrates the curves obtained for the treated moai samples and, for comparison, includes the absorption range of the untreated material. It can be seen that the sample treated with WOH leads to an increased water vapour absorption for regions of high relative humidity (RH% > 70%). This can be explained as a function of the extra micropores introduced by the cracking of the rigid gel formed. In the modified product, the elastic gel film prevents this occurrence and even shows a decrease in the slope of the curve for the region of liquid water absorption, especially for the case of the quarry samples (not illustrated) which could be attributed to the water-repellent nature of the consolidating material.

The difference in pore size distributions between the treated and untreated material for the moai samples is shown in Figures 6a and 6b, for treatments with WOH and WOH-DEXDMS, respectively. For the WOH treatment a decrease in the number of the large capillary pores (r > 4 µm) and an increase in the number of micropores (r < 0.1 µm) can be observed. The latter can account for the increased water vapour absorption at higher relative humidities (see Fig. 5). The elastified consolidant only reduced the number capillary pores thus contributing in part to the reduced liquid water uptake (see Fig. 5).

2.3 Artificial Weathering

Some treated, as well as untreated, samples were subjected to artificial ageing in a climate chamber. The combination of temperature and moisture changes was chosen to simulate actual climate conditions on the island characterized by frequent, and mostly short, rain events. Each cycle exposed the samples to 11 hours at 40°C/18%RH and 1 hour total immersion in liquid water (20°C). The artificial ageing was carried out for 300 days corresponding to 600 cycles.

The mass loss was monitored by weighing and it was found that this was less than 1% w/w in all cases, regardless of whether the samples had been treated or not.

2.3.1 Fine-grained material

The drill resistance measurements on the untreated quarry material and that treated with the BDAC surfactant showed a significant difference. As can be seen in Figure 7, the former shows an important decrease in strength in the outermost 1 to 1.5 mm (see Figure 3 for comparison) which is not as apparent in the treated material. This can be attributed to the reduction of hygric swelling
induced by the treatment which decreased the stress applied to the material during hygric load changes.

The pore size distribution for the untreated moai material after weathering is shown in Figure 8a. Comparison with Figure 2b (unweathered sample) shows that the artificial ageing reduced the relative number of larger capillary pores while increasing significantly the number of smaller capillary pores (r = 0.1 - 4 µm). The increase of latter can be interpreted as a loosening of the lapilli from the surrounding matrix, which has been observed by SEM examination. This effect is not apparent in the treated and weathered sample (Figure 8b).

2.3.2 Coarse-grained material
The pore size distribution obtained after artificial ageing of untreated material depends on the source of the sample. For the case of the quarry samples, a significant increase occurs in the capillary pore region with a reduction in the smaller pores, as can be seen in Figure 9a which shows the difference pore size distribution resulting from the artificial weathering. For the case of the moai samples, Figure 9b, a reduction of the larger capillary pore region is apparent with an increase of the smaller capillary pores after artificial ageing.

This apparently contradictory behaviour could be explained by considering the total weathering history of the samples. In a first moment, the pores of the glassy matrix are affected, while continued weathering will also affect the embedded lapilli [13]. The mechanism can be thought of as a first step which increases the number of larger capillary pores due to dissolution phenomena of the vitreous matrix induced by the water present in the pores. This would explain the increased number of larger capillary pores found in both the original moai samples and the artificially weathered quarry sample. A second step corresponds to the re-deposition of the dissolved glassy material within these pores, transport to the surface being reduced by previous deposition (see below) thus reducing the number of larger capillary pores while increasing that of smaller capillaries. The prolonged contact with water will facilitate the weathering of the more resistant lapilli embedded in the glassy matrix.

This theory appears to be confirmed by the observation that a white-yellowish efflorescence appeared on the surface of most of the artificially weathered samples. It was more profuse on the moai samples in particular, as would be expected from the above theory, and for the fine-grained material as compared to the coarse-grained material. Both treated and untreated specimens showed this occurrence. The efflorescence was an acid-insoluble, amorphous material, presumably amorphous silica dissolved from the glassy matrix such as observed in situ on the statues on Easter Island and identified as opal [14].

Due to the limited amount of material, only the pore size distribution of samples treated with WOH-DEXDMS was measured after artificial ageing. No significant changes occurred in either the quarry or the moai samples.

3. POROSIMETRY RESULTS AND DISCUSSION

From the above mentioned experimental results it can be seen that the pore size distribution of the material will contribute significantly to determine both the weathering mechanism and the distribution of the protective agent within that network.

Table II reports the number of pores within each different pore size group: micropores (r = 0.0019-0.1 µm); small capillaries (r = 0.1-4 µm); and, large capillary pores (r > 4 µm); for all the examined samples. The table also includes the specific surface calculated from Hg-porosimetry and from BET N₂ adsorption data. The latter is, for most of the samples, consistently larger indicating the presence of pores smaller than 2 nm, henceforth referred to as submicropores. Artificial ageing reduces this difference significantly in nearly half of the samples, Wu-Fq, Wt1-Fq and Wu-Cm, following the expected weathering behaviour of volcanic tufts [15]. However, the coarse-grained quarry material
increased the difference upon artificial ageing and even upon treatment. This could explain the increased hygric expansion observed for this material at low relative humidities (35 %RH).

All untreated and unweathered moai samples show a higher number of capillary pores than the equivalent quarry ones, as would be expected from their more eventful history. As previously discussed, weathering first increases the percentage of capillary pores (through dissolution) but subsequently reduces them (through silica deposition), if the weathering process is continued. It would appear that the threshold for the preponderance of this latter reaction is reached when the capillary porosity accounts for over 20% of the total porosity.

While samples treated with the commercial product (WOH) show a reduction of both the larger and smaller capillary pores and a slight increase of the micropores, treatment with the modified WOH-DEXDMS results in an even trimodal distribution, shown in Figure 10, i.e., each range accounts for approximately one third of the total porosity, regardless of the original pore size distribution of the samples. However, the weathering pattern of these treated samples will follow that of the untreated stone. Weathering of these treated samples does not appear to affect the number of submicropores.

Table II Changes in porosity and pore size distribution for the fine-grained and coarse-grained material upon artificial weathering and/or treatment.

<table>
<thead>
<tr>
<th>Mat. (N)</th>
<th>Mat. (W)</th>
<th>Micropores $r = 0.002-0.1 \mu$ [V-%]</th>
<th>Smaller Capillaries $r = 0.1-4.0 \mu$ [V-%]</th>
<th>Larger Capillaries $r &gt; 4.0 \mu$ [V-%]</th>
<th>Total Poros. [V-%] (Hg)</th>
<th>Specif. Surface [m²/g] (Hg)</th>
<th>Specif. Surface [m²/g] (BET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nu-Fq</td>
<td>16.11</td>
<td>7.84</td>
<td>20.56</td>
<td>44.52</td>
<td>48.23</td>
<td>63.28</td>
<td></td>
</tr>
<tr>
<td>Wu-Fq</td>
<td>19.02</td>
<td>8.89</td>
<td>6.24</td>
<td>34.15</td>
<td>57.24</td>
<td>57.63</td>
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<tr>
<td>Wu1-Fq</td>
<td>17.85</td>
<td>7.26</td>
<td>9.11</td>
<td>34.22</td>
<td>54.87</td>
<td>59.70</td>
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<tr>
<td>Nu-Fm</td>
<td>15.47</td>
<td>5.26</td>
<td>24.14</td>
<td>44.88</td>
<td>45.93</td>
<td>58.31</td>
<td></td>
</tr>
<tr>
<td>Wu-Fm</td>
<td>14.28</td>
<td>14.25</td>
<td>10.29</td>
<td>38.81</td>
<td>33.48</td>
<td>44.65</td>
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<tr>
<td>Wu1-Fm</td>
<td>15.17</td>
<td>7.23</td>
<td>24.66</td>
<td>47.05</td>
<td>38.33</td>
<td>47.66</td>
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<tr>
<td>Nu-Cq</td>
<td>18.66</td>
<td>10.66</td>
<td>12.73</td>
<td>42.04</td>
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<tr>
<td>Wu-Cq</td>
<td>16.08</td>
<td>7.37</td>
<td>21.68</td>
<td>45.13</td>
<td>50.13</td>
<td>72.42</td>
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<tr>
<td>Nt2-Cq</td>
<td>12.87</td>
<td>12.10</td>
<td>14.94</td>
<td>39.91</td>
<td>43.94</td>
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<tr>
<td>Wu2-Cq</td>
<td>14.90</td>
<td>9.07</td>
<td>17.30</td>
<td>41.28</td>
<td>48.95</td>
<td>77.51</td>
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<tr>
<td>Nu-Cm</td>
<td>12.11</td>
<td>9.91</td>
<td>26.66</td>
<td>48.68</td>
<td>38.18</td>
<td>61.33</td>
<td></td>
</tr>
<tr>
<td>Wu-Cm</td>
<td>13.11</td>
<td>14.61</td>
<td>11.59</td>
<td>39.31</td>
<td>41.64</td>
<td>43.76</td>
<td></td>
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<tr>
<td>Nt2-Cm</td>
<td>12.92</td>
<td>12.11</td>
<td>13.97</td>
<td>39.00</td>
<td>39.79</td>
<td>51.72</td>
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<tr>
<td>Wu2-Cm</td>
<td>11.74</td>
<td>12.60</td>
<td>11.83</td>
<td>36.18</td>
<td>35.66</td>
<td>51.22</td>
<td></td>
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<tr>
<td>Nt3-Cm</td>
<td>13.77</td>
<td>7.30</td>
<td>18.37</td>
<td>39.43</td>
<td>48.05</td>
<td>62.02</td>
<td></td>
</tr>
</tbody>
</table>

where:
- N = not artificially weathered
- W = artificially weathered
- u = untreated
- F = fine-grained material
- C = coarse-grained material
- q = quarry samples
- m = moai samples
- t1= treatment with BDAC surfactant
- t2= treatment with WOH-DEXDMS consolidant
- t3= treatment with WOH
4. CONCLUSIONS

The changes in porosity observed for Rano Raraku tuff weathered to different degrees, as well as those induced by artificial ageing, suggest a multi-step weathering mechanism that begins with a dissolution of the glassy matrix followed by a redeposition of silica, on the surface and within the pores. Such a complex scenario, developing within this extremely heterogeneous material, makes ascertaining the most adequate treatment a difficult problem.

The modified silicate ester treatment tested in this study builds on previous experiences obtained with the commercial product [16, 17, 18]. It was found that the application of this elastified and slightly water repellent product resulted in an even tri-modal distribution of pore sizes (Fig. 10) which decreased the overall water uptake (Fig. 5). The slight changes in pore size distribution observed upon artificial ageing appear to confirm that the velocity of the dissolution step in the weathering mechanism is reduced. However, the hygric dilation was slightly enhanced by this treatment and the appearance of amorphous silica deposits on the surface upon artificial ageing indicated that the deterioration problem was not completely eliminated.

Treatment with the anti-swelling surfactant reduced both the hygric and hydric dilation and prevented the loss of mechanical resistance upon artificial ageing. Surface deposits were also observed to occur after ageing.

It is to be expected that combining both treatments would improve the overall performance. First the application of anti-swelling surfactant would reduce hygric/hydric dilation and the associated mechanical stresses. The subsequent treatment with the elastified water-repellent silicate ester would consolidate the weakened structure, while reducing the uptake of water in both liquid and vapour phase. Previous experiences with such double treatments have proven successful for clay-rich sandstones [19].

The problem of the formation of surface deposits, produced by the dissolution of the vitreous matrix upon weathering, is still to be addressed. It should be considered that treatments depositing amorphous silica within the pore space might possibly enhance this phenomenon. The ideal treatment would therefore have a third step for the stabilization of the glass/silica phases.

From the above it is clear that although some advances have been made in the elucidation of the deterioration mechanism and possible counter-measures, the in-situ conservation of the monumental statues of Easter Island requires further studies to assure that the applied treatments will provide long-term stabilization of the tuff without secondary effects.

ACKNOWLEDGEMENTS

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REFERENCES


Figure 1
Hygroscopic dilation curve for fine-grained tuff of both quarry and moai samples. The bottom curve shows the moisture sorption isotherm for both materials.

Drill Resistance Measurement
Easter Island Tuff Samples 13.02.96

Figure 2a and 2b
Pore radius distribution of the fine-grained tuff for the quarry sample (2a) and the moai sample (2b). Note the larger number of capillary pores for the latter.

Drill Resistance Measurement
Easter Island Tuff Samples 13.02.96

Figure 3a and 3b
Drill resistance plots of the fine-grained tuff for quarry samples (3a) and moai samples (3b). Note the lower mechanical strength of the latter.
Figure 4 (upper left)
The top curve is the hygric dilation for fine-grained tuff of moai samples, before and after treatment with the bifunctional surfactant BDAC. Note the reduction in swelling exhibited by the treated material. Note also that the moisture sorption isotherm curve, bottom, is not affected by the treatment.

Figure 5 (upper right)
Moisture sorption isotherm for coarse-grained tuff of moai samples treated with WOH and WOH-DEXDMS. For comparison the absorption range of the untreated material is indicated. Note the increased water vapour absorption of the WOH-treated sample for relative humidities above 70% RH. The water-repellency of the WOH-DEXDMS treatment is evidenced by the reduced liquid water absorption.

Figure 6a and 6b
Difference pore radius distribution between untreated and treated moais samples of coarse-grained tuff. The treatments were with WOH for fig. 6a, and modified WOH-DEXDMS for fig. 6b.
Drill Resistance Measurement
Easter Island Tuff Samples 13.02.96

Drill Resistance Measurement
Easter Island Tuff Samples 13.02.96

Figure 7a and 7b
Drill resistance plots of the artificially weathered fine-grained tuff from untreated (7a) and treated (7b) quarry samples. Note the loss in mechanical strength of the outermost 1.5 mm of the untreated sample. The sample treated with the bifunctional surfactant, BDAC, did not show this effect.

Pore radius distribution
Gr. 1 II/3-4
Total porosity: 38.81 Vol.-%

Figure 8a and 8b
Pore radius distribution of the artificially weathered fine-grained tuff, for untreated maoi samples (8a) and treated with the bifunctional surfactant, BDAC, (8b). Note the reduction in capillary pores and increase of mesopores upon weathering of the untreated sample (see Fig. 2b).

This effect is not evident for the treated sample.
Figure 9a and 9b
Difference pore radius distribution between unweathered and weathered samples of coarse-grained tuff from quarry samples (9a) and moai samples (9b). In the first there is an increase in the larger capillary pores, while the second shows a decrease of the same which can be hypothetically explained by the postulated weathering mechanism.

Figure 10:
Pore radius distribution of the coarse-grained quarry sample treated with the modified silicate ester (WOH-DEXDMS). Note the even tri-modal distribution of the pore radii.