death of a moai

Easter Island statues: their nature, deterioration and conservation

a. elena charola

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Georgia Lee, Editor

Cover Illustration: Fallen *Moai* at a south coast *ahu* (Photo: G. Lee)
Drawing of *moai,* p.viii by Tom Scalise

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In Memoriam

Erika Kirchhoff Charola
Hertha Kirchhoff Probst

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Foreword: Pores for Thought

It is a pleasure and a privilege to write a preface for this short but extremely important study of the problems and potential solutions involved in trying to preserve the statues and rock art of Easter Island for future generations. The author, by far the leading expert on this topic, has opened my eyes, like those of an "activated" *moai*, to many factors which had not crossed my mind before. For example, it has not occurred to me that, ironically, it is predominantly the weather-resistant basalt statues which are now indoors in museums, while the far more vulnerable figures in red scoria remain in the open air. And I had never realized that the causes and sources of deterioration were so numerous and so varied. The *moai* have suffered cruelly—even their birth, the original quarrying, caused them stress, and they have been subject to endless harmful processes and episodes throughout their long lives—both natural and inflicted by humans. Most obvious is the damage caused by moving them around, erecting them, and then toppling them; but far more insidious is the gradual penetration of their pores by water and salt. The analogies to the life of a human being are abundant and manifest. You undergo a horrendous birth, life's a struggle and then you die, after long and undignified deterioration. As Elena Charola shows, ways are being sought to at least postpone the death of the *moai* and the rock art. They cannot and certainly will not survive for ever but, thanks to her efforts and those of others, present-day science is coming up with solutions—quite literally, sometimes—that may achieve a stay of execution. No doubt the next few decades will bring hitherto unimagined techniques for prolonging their existence, and this will be possible because of the dedication of the author and her colleagues in documenting and analyzing the precise nature of Easter Island's enormous problems. The *moai*—and all rapanuiphiles—owe them tremendous gratitude.

—**Paul G. Bahn**

Prologue

Easter Island holds a special fascination not found in other sites of the world. Its appeal is such that those who visit it desire to return. And to learn more of its extraordinary past in order to better understand its present and hopefully to contribute towards its future. Each of us will have a different objective in mind. This book results from the application of my professional experience to stone: the key material used in the creation of the island's monumental heritage.

It is the aim of this book to help us understand this material. And, for this purpose, the formation of the island itself is considered, including the nature of the resulting rocks and their weathering mechanisms. For those whose interest is sufficiently whetted to know more of the processes described, appendices are provided which include a basic introduction to the necessary geology.

The story of a "virtual" *moai* serves as the backdrop to follow the "life" of the stone from the moment it is carved into a *moai* until the statue, after a long life, is re-erected on a reconstructed *ahu*. The current understanding of means and methods to preserve this heritage are also discussed and the need for "preventive conservation" is emphasized. This is just the "technical" name for defining what the popular saying summarizes in "an ounce of prevention is worth a pound of cure."

The book is an acknowledgment of the help I received from Dr. Georgia Lee over the past decade since I had the opportunity of meeting her personally and is a means of thanking her for it. Her enthusiasm and love for this island has fired many to help in the study, the preservation, and the understanding of the Rapanui culture and its heritage.

I take this opportunity to thank my friends and colleagues Profs. G. Lombardi (Università "La Sapienza" di Roma); B. Fitzner and H.F. Forster (RTWH Aachen); J.Vouvé (Université de Bordeaux I), Drs. E. Wendler (Ludwig-Maximilians-Universität München) and Robert Koestler and Mark Wypyski (Metropolitan Museum of Art, NYC) who kindly read and corrected different technical sections of the book. Dr. Koestler, my oldest colleague, and my husband, Ruben Gianzone, also had the opportunity of reading the complete text at various stages.

I am grateful for their help and encouragement.

A. Elena Charola
Great Neck, NY, 1996

Figure 1. Vista from Vai Atare on the east side of Rano Kau, looking toward the north-east side of the island. Both Terevaka (left) and Poike (right) are visible in the distance. Many of Tongariki's subsidiary volcanoes in the center of the island can be seen (Photo: G. Lee)

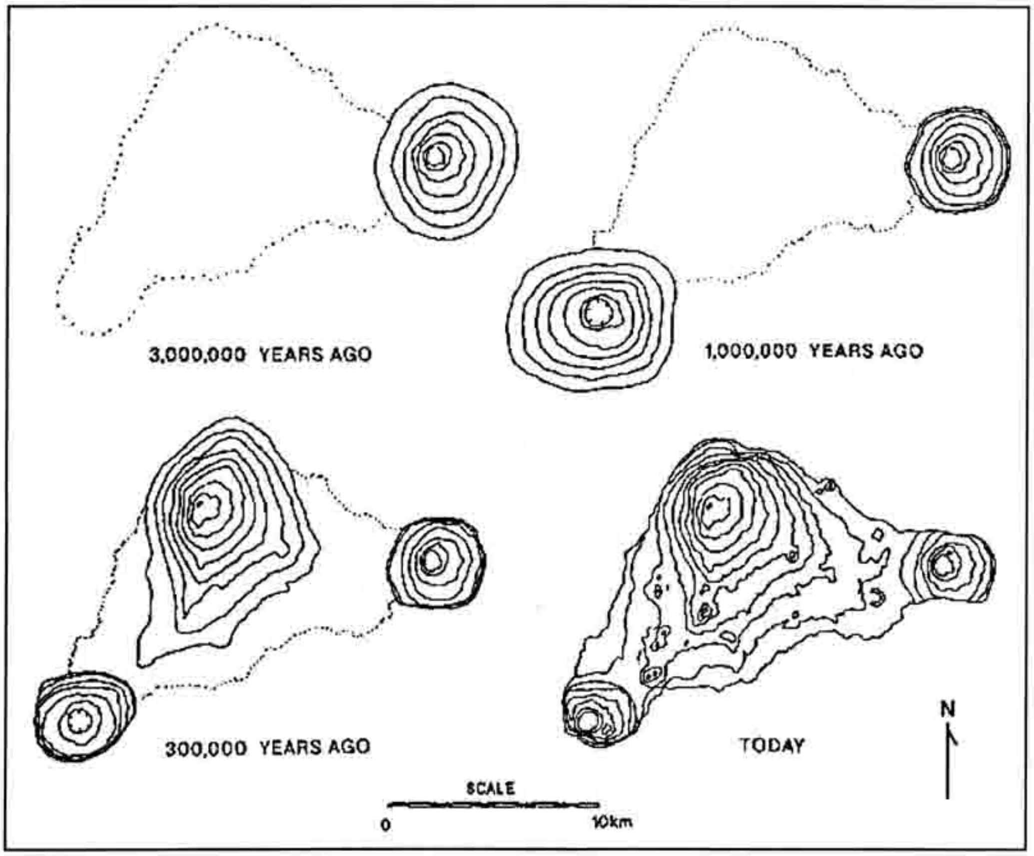

Figure 2. The volcanic stages in the formation of Easter Island (after Fischer and Love 1993)

An Island rises from the Sea

It must have been a terrifying spectacle! The sea churning wildly, foaming and roaring as the top of the volcano rose out of the waves spewing gases and rocks. Thus the first corner of what we call Easter Island was formed (fig. 2). This was the Poike volcano, dated to nearly three million years ago, now the eastern point of the island.

Two million years later, another volcano, Rano Kau, emerged to the southwest. For millenia these volcanoes were separated until, some three hundred thousand years ago, a third and larger volcano, Terevaka, arose to the north. The lava flows it generated linked the two older volcanoes and eventually formed the triangular shaped island we see today.

Figure 3. Rano Kau's dramatic crater and fresh water lake at the southwest corner of the island. Erosion of the crater rim is clearly visible in the center rear (Photo: G. Lee)

Jealous of this intrusion, the sea has been trying to eliminate the land by relentlessly thrusting its waves at it. The resulting erosion along the coastal cliffs is readily apparent. Poike, being the oldest volcano, has suffered the longest from this attack, its cliffs testifying to the continued wave action for over two and a half million years while the volcano stood isolated.

The south side of the volcano Rano Kau is also severely eroded, the sea threatening to break down the 200 meter high cliff separating it from the caldera (fig. 3), eager to accelerate the invasion that eventually will take place. Even the younger Terevaka has some eroded cliffs on its northern face.

This volcano, locally called Maunga Terevaka, is the highest on the island. It has a flattish summit, about 3 km in diameter, and is some 400 meters above sea level. On it, the highest point of the island (506 m) can be found. Terevaka slopes gently to the east and to the southeast towards the two older volcanoes.

Figure 4. A typical collapsed lava tube on the island. Some lava tubes run for miles (Photo: E. and D. Dvorak)

The history of this volcano, with its nearly one hundred parasitic craters, can be divided into three periods. The oldest one, responsible for Rano Raraku and Maunga Toatoa, produced lavas and broken rock fragments of aphyric basalt, i.e., basalt without visible large crystals.

The middle period produced porphyritic basalt which, covering the western half of the volcano, gave the present shape to Maunga Terevaka. This basalt was the source for the large stones, *ahu paenga*, used in the front walls of the central platform of *ahu* (altars), such as that at Ahu Naunau at Anakena. It also produced the Puna Pau scoria cone, characterized by its red welded scoria used in carving the top-knots, *pukao*, that decorate some of the island's statues.

Finally, the youngest volcanic episode, with Rano Aroi as the largest crater, produced great quantities of basaltic lava and formed many lava tubes. Examples of these are the caves, Ana Te Pahu and the Ana Kekenga, and numerous tunnels. They originated through the cooling and hardening of the exposed layers of flowing lava, the inside finally draining away and leaving the conduit free.

The lava tubes can be very long and can be branched. In some instances the roof may cave in (fig. 4), leaving open depressions. These often were used as natural *manavai*, garden enclosures. Plants grow well in these damper areas which also protect the plants from the winds. Some lava tunnels end at the edge of the sea, producing many caves (fig. 5). These sea level caves can be widened by the periodic intrusion of the waves. Ana Kai Tangata, located on the southwest coast at the foot of the Rano Kau and in the Mataveri area, was apparently used for ceremonial feasts associated with the birdman cult; it is decorated with rock paintings of sea birds. The name, which can be translated as "the cave where men eat" or "the cave where men are eaten," has led to the belief that cannibalism had been practiced.

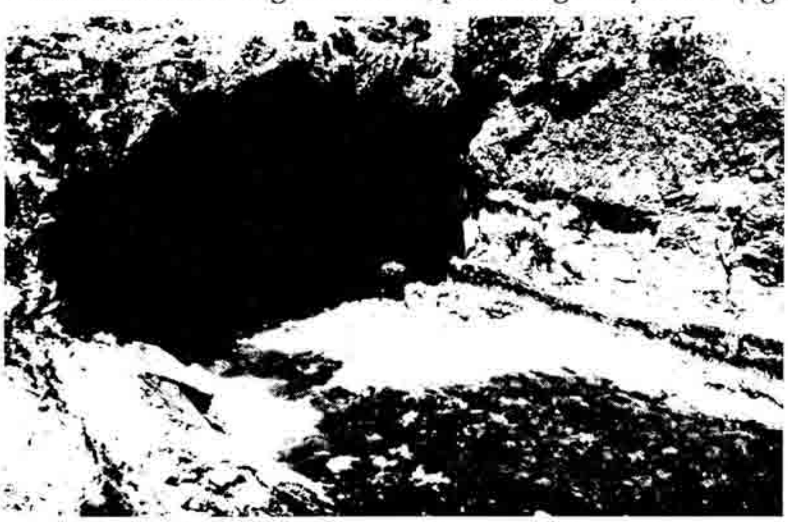

Figure 5. A lava tube that opens to the sea near Ana Kai Tangata (Photo: E. and D. Dvorak)

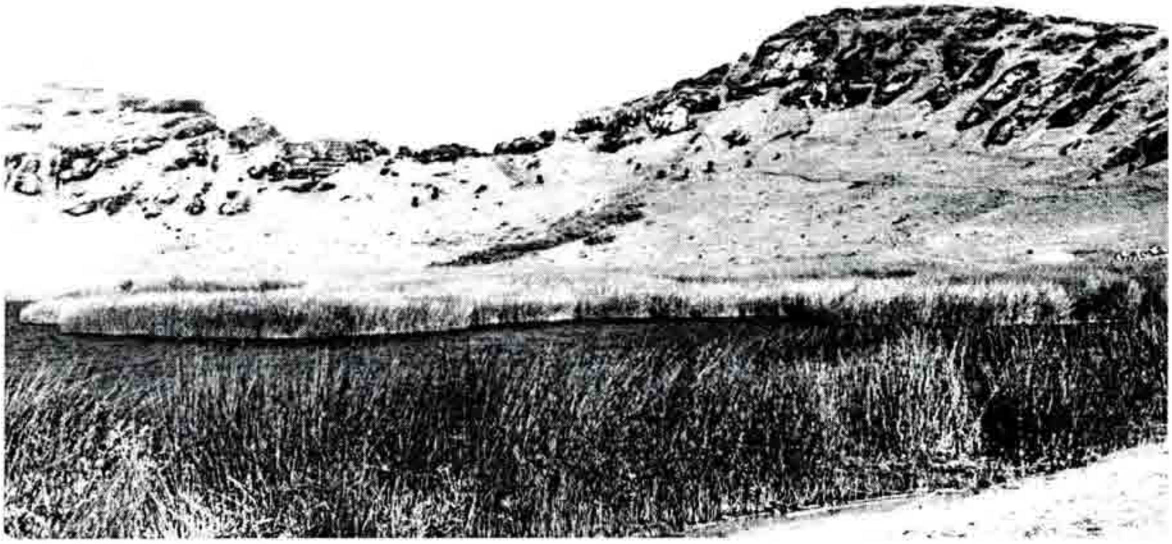

Figure 6. The southern inner slope of Rano Raraku crater: the lake, *totora* reeds and, in the distance, a number of *moai* can be seen as they were left in position for finishing (Photo: G. Lee)

The last large lava flow corresponding to the Maunga Terevaka flow occurred towards the southeast side and is estimated to have happened only 2,000 or 3,000 years ago. This rough and blocky lava flow, called *aa* lava, is found in the Rohio area and was emitted by a small cone called Maunga Hivahiva.

Both the Rano Raraku and the Rano Aroi craters, as their names indicate—*rano* means lake—have fresh-water lakes. The Rano Raraku lake (fig. 6) is approximately 650 m in diameter and some 12 meters deep, while that of Rano Aroi is only 200 m in diameter but is deeper, its actual depth is yet to be established. The hard basalt produced by Rano Aroi was later used for tools. The Rano Raraku crater is famous for being the quarry of the monolithic statues. These *moai* were carved out of the tuff on the southern slopes (inner and outer) of the crater. This tuff was apparently produced by another volcano, supposedly located to the southeast of the Rano Raraku, but later destroyed by marine erosion. Testimony of the presence of the sea in this area are the cliffs on the south-east side of Rano Raraku itself. The Rano Raraku volcano actually emitted red ash which, in part, covered the tuff, particularly on the north side of the crater.

The Rano Kau has a caldera formed by the collapse of the summit of the volcano, probably as a consequence of the last eruption which has been dated to some 180,000 years ago. The caldera is over 1 km in diameter and 200 to 250 m deep, its floor covered with a fresh-water lake of some ten meters in depth (fig.3). Over fifty lava flows of basalt interspersed with pyroclastics can be identified in the south cliffs, while thick flows of benmoreite lava form the eastern slopes. The latter have, in part, a platy jointing which allowed the extraction of the flagstones, *keho*, used in the construction of the village at 'Orongo. On the northeast slope a deposit of pumice corresponding to the last activity of the volcano, can be found. The three islets towards the southwest, Motu Nui, Motu 'Iti and Motu Kaokao, are the present day evidence of secondary eruption centers. Only on Motu 'Iti and in Maunga Orito, located to the northwest of Rano Kau, can obsidian be found.

Figure 7. View of Poike from the west looking across La Pérouse bay. The three trachytic domes can be seen on the upper left (Photo: G. Lee)

The oldest volcano, Poike, forms the conical peninsula at the northeast end of the island. It is about 370 m in height and has a dry crater that is approximately 150 m across, and now covered with an eucalyptus grove. It has a relatively simple history of successive basaltic lava flows, of which about 50 can be identified on its north cliffs. On the northeast side of the crater three domes of trachytic lava interrupt the smooth down-hill slope (fig. 7). On the west side, at about 100 m above the plain, the Poike Ditch cuts across the slope from north to south. This feature, first attributed to geological faulting, has been found to be modified by man. It was apparently used either for agricultural purposes or to accommodate large earth ovens, *umu*, for workers in that area. From this use the local legend that it played an important role in the conflict between the *Hanau Eepe*, the stout people, and the *Hanau Momoko*, the thin people, may have started. This is colorfully described by its local name, *Ko te Umu o te Hanau Eepe*, the oven where the stout men were cooked (*Hanau Eepe* was originally mis-translated as "long-ears").

No volcanic activity has been recorded since human habitation, around the 4th or 5th century A.D. Plants, however, had established themselves far earlier, at least 40,000 years ago as determined from pollen analyses carried out on cores taken from under the crater lakes. The imprints left in the lava by long-disappeared tree trunks attest to the several advances made by plants during the quiet periods between eruptions, followed by their burial under subsequent lava flows. Some examples of these can be seen on the cliffs along the upper west coast.

Basic Geological Appendix

It is currently believed that the outer layer of the earth, called lithosphere (from the Greek *lithos*, stone) is actually formed by about a dozen large plates, called tectonic plates (from the Greek *tektonikos*, constructive) that "float" on the relatively fluid silicate rock mantle above the Earth's dense iron core. The mantle can be considered relatively fluid (viscous) when taken in a geological time frame.

In the Pacific Ocean, as in most major water bodies, there are ridges at the boundaries between the plates that form its bottom. They are called spreading ridges because new ocean floor is generated as molten magma erupts from fissures and submarine volcanoes forming them. As the edges of the plates grow along the rift, they accommodate by sliding at the other end under another plate, a process called subduction, causing earthquakes and, eventually, the formation of mountain ranges.

A volcano is a vent or fissure through which molten magma, hot gases, and other fluids escape from the magma chamber to the surface. For oceanic volcanoes, magma is created by partial melting of the mantle, which in the upper region is largely composed of olivine-rich peridotite. Melting can occur due to increases in temperature or reduction in pressure, as displacement of and within the mantle takes place. The melt, referred to as primary basaltic magma, can be classified into two broad types: basic and silicic. Basic magmas are dark, heavy and dense. They predominate in mid-ocean and hot spot environments, and sometimes in subduction areas. Silicic magmas are paler in color, less dense but more viscous and explosive than basic magmas. They generally erupt in much smaller volumes, even in the subduction zones where they are most commonly generated (secondary magma).

The most common kind of mafic volcanic rock is basalt, a dark, fine-grained, sometimes glassy, basic igneous rock rich in ferro-magnesian minerals, pyroxene and olivine. Tholeiitic basalt is the most silicic type. With decreasing ferro-magnesian content, and as quartz content increases the rocks turn lighter in color grading into intermediate rocks, from andesites to dacites. Andesites containing more olivine are called hawaiites. With increasing quartz and feldspar content they turn into acid rocks, rhyolites, called silicic because they have over 10% free quartz, some of it present as phenocrysts (distinct crystals). As the amount of feldspar increases becoming the dominant mineral and quartz content decreases to less than 10% and no quartz phenocrysts are present, the resulting rocks are called trachytes. Benmoreites can be called the felsic equivalent of hawaiites (see diagram).

basic	*intermediate*		*acid*	*intermediate*
tholeiite				
basalt →	andesite →	dacite →	rhyolite →	trachyte
mugearite	hawaiite		benmoreite	
mafic	*mafic*	*felsic*	*felsic*	*felsic*

Simplified diagram of relevant volcanic rocks

Easter Island is the summit of a submarine volcanic complex located on the Nazca plate about 350 km east of the East Pacific Rise, the ridge that separates the Nazca from the Pacific plate (fig. 8). Submarine volcanoes, greatly outnumbering land volcanoes, form along fissures on the crests of the mid-ocean ridges or in isolated vents related to hotspots, giving rise to seamounts. These develop eventually into volcanic islands, such as Hawaii or the Azores. Whether Easter Island resulted from a hotspot is still under discussion.

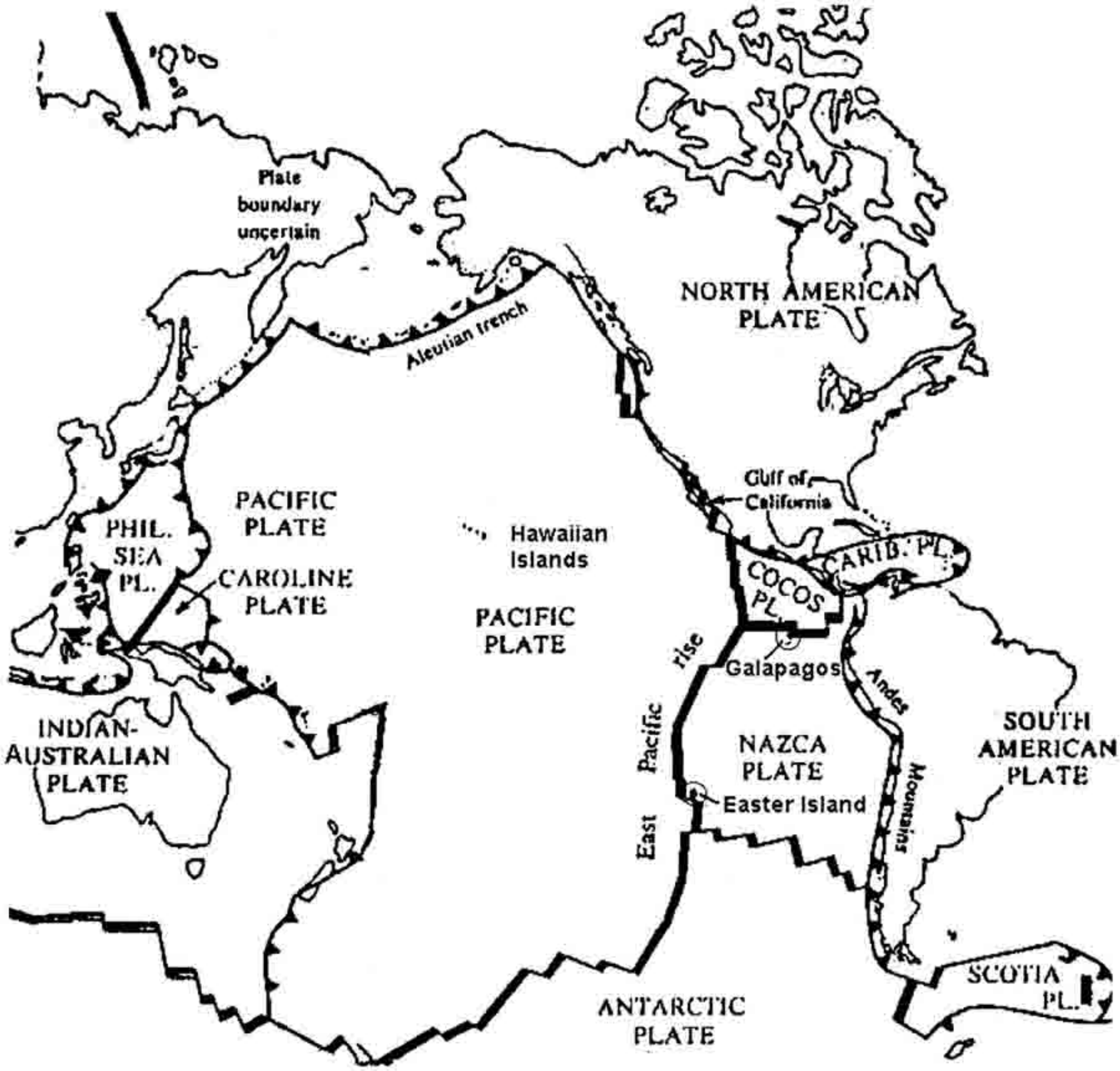

Figure 8. The tectonic plates in the Pacific region and the location of Easter Island on a plate boundary (after Clark and Dymond 1977)

The type of magma and conditions under which the eruption takes place will determine the type of material expelled. For example, if the magma has low viscosity, the gas escapes or forms bubbles in the resulting rock. If the eruption is sudden, it forms a froth solidifying quickly into a light, glassy rock, i.e., pumice. If the bubbles are coarser, the rock is called a scoria. If the pressure is very high, the expanding bubbles may shatter the glassy rock completely and the fluid mixture of gas and glass fragments can move very quickly as *nuées ardentes* or glowing avalanches. When these finally come to rest the glass fragments weld together, as for example the welded scoria of the Puna Pau crater (fig.9).

Figure 9. Cylindrical topknots of red scoria at the Puna Pau crater (Photo: G. Lee)

If the viscosity of the magma is higher the eruption is even more violent and then the rock shatters by the pressure of the expanding gas. This blows the rock fragments, pyroclasts, into the air. The pyroclasts (from the Greek *pyr*, fire, and *klastos*, broken) are classified according to their size, ranging from ash (< 2 mm), lapilli (2-64 mm), blocks (> 64 mm) and bombs, when they are rounded and show evidence of having been melted when they were ejected. When the volcanic ash consolidates over time it forms the volcanic tuff rock. If lapilli are present, it is called a lapilli tuff, such as that found at the Rano Raraku quarry.

Poike has been classified as a shield volcano where the symmetrical volcanic cone is mainly composed of layers of basaltic lava flows originating from clustered vents. Some fifty flows interlayered with *pahoehoe* lava, i.e., smooth and undulating lava flows, ranging in thickness from 1 to 5 m, can be seen in the sea-cliffs. They are formed by basalts and hawaiites, some strongly porphyritic with large plagioclase phenocrysts, others quite aphyric. The three domes on the north slope resulted from eruptions of trachytic lava, a more silicic and viscous material, that, unable to flow far from the fracture source, formed these rounded masses (see fig.7).

Rano Kau also has over fifty aphyric and porphyritic basalt flows interbedded with pyroclastics. The lower flows of tholeiitic basalts are covered by somma flows of hawaiites and benmoreites on the eastern rough slope. The pumice deposit on the northern slope makes it smoother and may represent the final eruption that resulted in the collapse of the summit and the formation of the caldera. The secondary centers are aligned on a northeast-southwest running fracture which erupted very viscous rhyolitic lava, as found in Maunga Orito and the three *motu* off the southwest end of the island. As noted, obsidian is restricted to these areas of the island.

Maunga Terevaka is a complex fissure volcano responsible for the greater part of the island. The main bulk of it, composed of basalt and hawaiite lava with little pyroclasts of aphyric basalt, was formed in the older period. During the middle period, a western fissure produced porphyritic basalt covering the western half of the summit and leaving some 14 aligned cinder cones, one of which is the present summit of Maunga Terevaka. The younger period produced great amounts of basaltic lava flows of both *aa* and *pahoehoe* type. The most recent *aa* lava flow of olivine basalt is found in the Rohio area. This is the area notable for its extensive lava tunnels. It should be mentioned that most of the secondary eruptive centers and fissures are aligned in a north-southwest direction, while the others follow a north-northeasterly direction. The summit of Maunga Terevaka falls in the intersection of these two lines.

The low-lying area in the southwest of the island, between Mataveri, Hangaroa, Maunga Toatoa and Vaihu is made up of benmoreite and mugearite flows. It has not been determined whether these lavas originated from the Terevaka or the Rano Kau. From a compositional point of view, some appear to belong to the latter, while the younger flows were emitted from Maunga Otu'u, a subsidiary of Terevaka (fig. 10).

Figure 10. Map of Easter Island showing main geological and archaeological features (after Baker 1993)

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10 death of a moai

A Statue is Born

From the last major lava flow of Maunga Terevaka, estimated to have occurred some two to three thousand years ago, about a millennium passed in which the island, not as yet inhabited, slowly developed and acquired its flora. Then people from other Polynesian islands, in their eastward spread across the South Pacific, arrived and established themselves on this "new" island. This has been estimated to have occurred about 400 A.D.

Another three centuries went by before the descendants of those first colonizers were ready to create large monolithic statues, *moai*, and place them on the *ahu*, "altars," in their ceremonial centers (fig. 11).

Figure 11. A typical statue, Ahu Ature Huke, Anakena (Photo by R. V. Gianzone)

The local legend explains how the shape of the *moai* developed. As told by Alfred Métraux it reads as follows:

The image carver lived in Hotu-iti where he made the first image called Tai-hare-atua. When the statue was finished, he did not find it pretty at all because it had no neck. He said to two men, "You go to Apina-nui and ask how they carve the neck of the images. When they tell it to you, come back."
The two went to Apina-nui. They saluted a man, and the man returned their greetings. The young men entered his house and they stayed there. The owner of the house lit the oven and put in it chicken and sweet potatoes. In the evening he opened the oven and invited the young men to eat. The owner sat at one side of the house and the young men at the other. They slept. One of the young men said, "This man does not ask questions." Next day the young men prepared to go. The owner of the house asked, "Where are you going?" "We came to see you in order to learn how to make the neck of images." He answered, "Just go on, the neck of the images is with you." The young men turned back and arrived at Ahu Ohau-para. They felt the need to urinate. The younger one went aside and urinated. He looked at his penis and said to the other, "Listen, it was true, the neck of the image is with us, here below." They returned and told the image carver the story. They set out to make other images. This time they made them well. From then on they always carved good statues.

The statue carvers, *tangata maori moai maea*, men expert in stone statues, were considered a privileged class and belonged to what might be called a guild of stone carvers. This special craft was transmitted from father to son. They worked on commission, chiefs and priests requesting the carving of statues to honor their ancestors, and were paid in food. Given the quantity of work in progress at the quarry, a Master Carver, *tangata honui maori*, was needed to organize and direct it.

Figure 12. A basalt *toki* (24 x 12 cm) (After Forment 1990)

For carving the statues they used stone picks (fig. 12), *toki,* made from hard basalt. They were also called *maea toki*, meaning stone for picks. The basalt for these tools was selected from many sources. Local tradition has is that it came from an area close to La Pérouse bay, but subsequent studies show that the

Figure 13.The outer slope of Rano Raraku showing the cavities from which statues were removed. Other statues stand on the slopes below the cliff where they awaited finishing (Photo: G. Lee)

harder material produced by the Rano Aroi volcano was used, as well as that found in the Mataveri area, or even taken directly from the large basalt inclusions found in the Rano Raraku tuff.

The Rano Raraku tuff is a relatively soft stone, easier to carve when it has been wetted. The *toki* were used to outline the figure in the quarry, in most cases lying on its back. Then the front and sides were cut out (fig. 14), and finally, the back was cut away from the both sides, leaving the back of the statue fastened to the rock by a central keel. This was cut out when the statue was ready to be lowered from the quarry. It has been estimated that it took twenty men at least one year to get the statue to this point. The statues were lowered by means of ropes into *ad hoc* pits dug at the foot of the quarry to receive them. Then the backs were finished and fine details, such as hands and ears, were carefully cut with smaller chisels, called *tingi.*

And then the statues were ready!

Local lore tells that the statues then "walked" to their destination, i.e., to the *ahu* of the *ure*, the tribe that commissioned it for its own ceremonial center. This legend has given archaeologists plenty to think about and devise a method of moving a statue in the upright position (figs 15 and 16). Several possibilities have been established, however, we will never know which one was used, or whether different methods were used for different terrain or if they changed as the years went by.

Once the statues were erected on their *ahu*, some of them received a *pukao*, top knot, carved out of red scoria from Puna Pau . And some even received eyes! For this purpose the eye sockets had to be carved out carefully to receive the white coral eyes with red scoria pupils that were fitted into them.

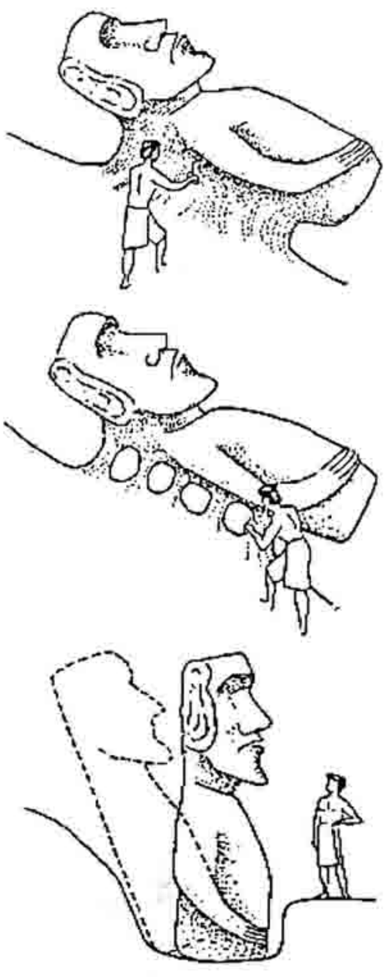

Figure 14. Three stages in the release of a *moai* from bedrock to its erection at the base of the quarry slope (After Bahn and Flenley 1992)

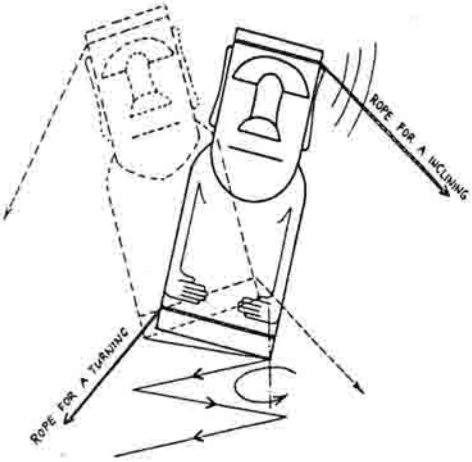

Figure 15. Walking the statue by tilting it back and forth (Drawing: Pavel)

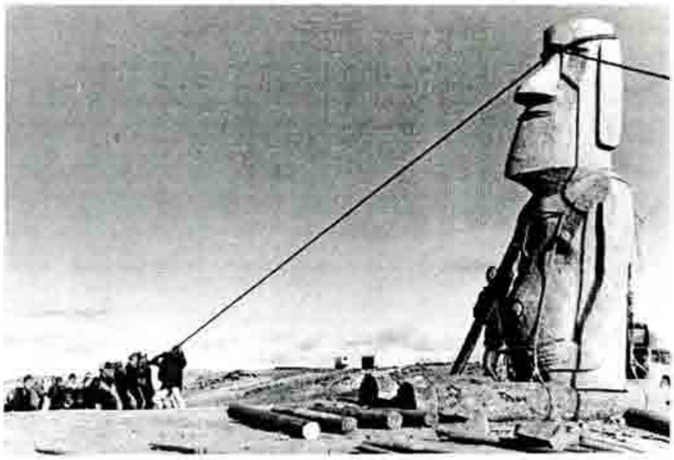

Figure 16. The experiment of C. Love showing a cement replica of a *moai* being pulled upright on rollers (Photo: Rocket Miner)

An original of such an eye was found during the excavation at Ahu Naunau at Anakena and can now be seen in the R. P. Sebastian Englert Museum on the island. At the time of the reconstruction of that *ahu*, copies of the eyes were made and installed in the statues. This raised severe criticism from the archaeological world and the eyes were removed. However, by popular demand, both of the local inhabitants and tourists, these are reinstalled for "occasions". To end the subsequent commerce that was established, the Council of Rapanui Elders decided to install a permanent set of eyes on one statue. This was done on the statue at Ahu Ko te Riku at Tahai, although no record indicates that this statue ever had eyes. Unfortunately the eyes were crudely made and cemented in place. It should also be mentioned that the *pukao* of this *moai* is a replica that was installed for documentation purposes at the time of the restoration of this *ahu* in 1978. However, the local population decided at the time that the statue should keep the *pukao* (fig. 17).

Figure 17. *Moai* at Ahu Ko te Riku with eyes and *pukao*. Both the eyes and the *pukao* are modern replicas (Photo: G. Lee)

The first ceremonial centers were established in the Tahai and Vinapu areas around the year 700 A.D. One of the *ahu* at this latter site, identified as Ahu Vinapu I, has a back retaining wall of such careful crafting that its construction technique has been compared with the stone walls at Cuzco and Machu Pichu in Peru. However, the South American walls are of solid stone blocks and not slab walls holding back rubble fill as is the case at Vinapu. The reason for this exceptional jointing is that the slabs used for this *ahu* were taken from the flaggy mugearite and benmoreite lava flows of the Rano Kau volcano which develop well-defined orthogonal joints (fig. 18).

Figure 18. Benmorite lava from Rano Kau was used to construct this wall at Vinapu (Photo: G. Lee)

Which *ahu* received the first statue has, as yet, not been elucidated, since some *ahu* had new shrines built over them before statues were installed. However, it is believed that the first statues date to the 8th century and, by the 12th century, statue carving was in full swing and the "classical" *moai*, as exemplified by the statue on Ahu Ko te Riku at Tahai (fig. 17), was being sculpted. It is estimated that statue carving continued until the economic crisis broke out around the 17th century. Considering that approximately 1000 statues were carved (including some 400 still unfinished in the quarry) over these ten centuries, the average production rate was about one hundred statues per century. But since it is known that intense statue carving was carried out between the 11th and the 17th century, the average production rate increases to about 1.5 statues per year. Taking the estimated twenty workers per statue per year, the implication is that an average of thirty carvers worked daily at the Rano Raraku quarry.

Although most statues were carved from volcanic tuff at Rano Raraku, a few were carved out of other types of stone, such as basalt, red scoria and trachyte. From this last material, originating at Poike volcano, seven complete statues, ranging in size from over one meter to slightly greater than 2 meters, have been documented. Most of the statues have remained in the vicinity of Poike except two which were taken from Poike and were installed in front of the Governor's office (fig. 19). In February 1993, the Council of Rapanui Elders decided to return these to their place of origin on Poike (fig. 20). They now lie amidst the rubble of an *ahu* on the far eastern end of the peninsula, rarely seen by anyone.

Figure 19. Left: trachyte statues from Poike before their removal from Hangaroa village (Photo: G. Lee)

Figure 20. Right: moving the statues back to Poike in 1993 (Photo: G. Lee)

Only about a dozen complete statues remain of those that were carved out of the Puna Pau red scoria. One of the best known is the headless torso at Ahu Vinapu II, said to be a female figure. At one time it had two heads, forming a Y shape that was supposed to have served as a support for the staves holding a wrapped up corpse during the mourning period. After the body decomposed, the bones were buried. Records of the early expeditions to the island indicate that pairs of such statues were found for every *ahu*. Given the incomplete surveys carried out, the statement can only be taken as an indication that more than one such statue was found (fig. 21).

None of the red scoria statues appear to have been erected on *ahu*, but were found near them or sometimes incorporated into *ahu* architecture or even into *ahu* walls, as found in the west and east wing walls of Ahu Heki'i and the back sea wall of Ahu Hanga Tavari.

East of Vinapu is a red scoria statue called Moai a Umu, lying in isolation on the edge of a cliff. Apparently it is not related to any *ahu* and may have been in transit. A similar statue is found at the base of Maunga Pui on the west-southwest slopes of Terevaka.

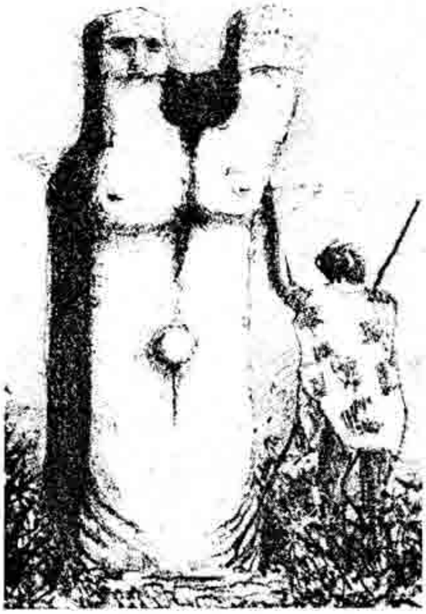

Figure 21. Early drawing by Palmer showing two headed statue carved from red scoria

A red scoria statue with an unusual triangular head was found at an unnamed *ahu* and re-erected by Thor Heyerdahl in 1956; he gave it the name "Mata Mea." It is standing amongst the rubble of an ancient *ahu*, now private property, close to the island's R. P. Sebastion Englert Museum. The statue can be seen peeping from underneath some trees over the wire fence just south of the Museum (fig. 22). Most of the other red scoria statues on the island consist of broken torsos or isolated heads.

The majority of the ten documented basalt statues are found in museums; only two are still found outdoors on the island. One is included in the corner of the back wall of Ahu Maitaki Te Moa and only the back and part of the right side of the statue can be seen. The other one is lying on its back, the head pillowed in some boulders, close to that same *ahu*. Of the remaining eight statues, two are in the British Museum of Mankind, London, and were taken from the island in 1868. One, is called the Moai Hava, the dirty statue, and is believed to have been taken from the area around Mataveri.

The second and most important basalt statue was found half-buried in one of the 'Orongo houses (fig. 23). The statue, with its back decorated with carved petroglyphs representing bird-men, *tangata manu*, dance paddles, *ao*, and *komari* (vulva forms), has been considered a transitional element between the ancestor cult involving the *ahu moai* and the birdman cult, developed after the ecological crisis in the 17th century. However, its position when found—facing a wall and partially buried—suggests that it had not been actively used in ceremonies at least at the time of its excavation. The name of the statue has been reported as Hoa Haka Nana Ia, "the wave-breaker," but can also be interpreted as Hoa Hakananai'a, meaning "the friend that was stolen."

Figure 22. The red scoria statue called "Mata Mea" before it was obscured by foliage (Photo: G. Lee)

A smaller *moai*, called Titahanga 'o te Henua, the "Boundary of the Land," was found in a cave on Motu Nui, and it apparently marked the lower end of the bisecting line which divided Easter Island into the territories, Ko te Mata Nui and Ko te Mata 'Iti, the two major groups of clans, the Tu'uaro and the Hotu'iti, respectively. The statue was acquired in exchange for a yacht blanket by Mrs. Routledge in 1914. It is only about one-half meter in height, and is presently in the Pitt Rivers Museum, Oxford.

Figure 23. The back of Hoa Hakananai'a, the basalt *moai* now in the British Museum (After Drake 1992)

The Musées Royaux d'Art et d'Histoire, Brussels, has a fourth, rather plump statue called Pou Hakanononga, meaning "God of the Tuna Fishermen." It was taken by the French-Belgian mission in 1935 from the rubble of Ahu Arongo, in Hanga Roa, where it was lying face down.

A fifth basalt statue is in the Smithsonian Institution and is one of the eight statues from Ahu O 'Pepe, located near to La Pérouse bay. It was taken aboard the USS *Mohican* during the American archaeological expedition in December 1886.

Two other basalt statues, one a rather stocky figure, are on mainland Chile in the Museo Nacional de Historia Natural in Santiago. And the eighth *moai*, in two pieces, is in the R. P. Sebastion Englert Museum on the island. The torso of this apparently female figure was found during Anakena excavations by Heyerdahl and taken to the Kon Tiki Museum in Oslo. In subsequent (1987) excavations at the site, he found a very long and narrow head, with unusually close-set eyes and what appears to be a headdress on top. It measures 95 cm while the torso is only 78 cm long. Upon this finding, he had the torso returned to the island. The statue, not yet rejoined as of this writing, is locally called Ava Rei Pua after the wife of the mythological king, Hotu Matu'a.

It is ironic that precisely the statues carved in basalt, a resistant material, are found indoors in museums, whereas those carved from the far more susceptible red scoria or Rano Raraku tuff are left to weather and erode out-of-doors.

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The Moai Ages

The *moai* is standing on its *ahu*, listening to the waves breaking on the shore behind his back and looking on to the plaza in front of him and . . . thinking? wondering? at the spectacle his creators present as they perform the various ceremonies that mark each year and are repeated year in, year out. But as time goes by, different persons will enact these ceremonies and, some centuries later, the *moai* will perceive a change in ambiance. Finally violence will be rampant and he will witness many deaths until one day, he himself is attacked and thrown over, thus sparing him the misery that comes over the people.

Figure 24. Ahu Tahai at the restored archaeological site of the same name (Photo G. Lee)

But the *moai* himself has aged. Stone may be more enduring than other materials but, it too, eventually turns to dust. In mineralogical terms, it turns into clay. Because our time-frame, i.e., life-span, is so much shorter than that of a stone *moai*, it is hard for us to comprehend this aging process. To illustrate, imagine a virtual figure, similar to the statue at Ahu Tahai (fig. 24), or one of those at Ahu Anakena, as an example. We will assume that the statue was carved in the 12th century.

The sculpting that takes place in Rano Raraku's quarry stresses the tuff being carved: the birth of the statue is also stressful from the materials point of view. It is hammered and chiseled, chipped, and pecked. After a year of this mistreatment, when the statue is completed, it is tied with ropes and lowered from the quarry into a pit. And the stone is seared by the ropes and scraped, scratched and bumped on the mountain slope as it slowly makes its way downhill. Then, as the statue stands in the pit, more chiseling and chipping and pecking and burnishing stresses the surface of the stone.

During all this time, rain and wind buffet the newly-exposed stone, and the sun heats and dries it again and again.

Then the trip to the *ahu* begins. Whether by rolling on a sled-like contraption, or by swiveling and tilting, or by swinging belly down from a biped, or by just being dragged along on its back, the stone is again scratched, bumped and scraped on the ground or the rollers, as the long journey proceeds. Many a day goes by until the statue is ready to be erected on the *ahu*. And more knocking, bumping, and scratching occurs (fig. 25) until the *moai* is finally standing up on its *ahu*. And then the *moai* may be "crowned" with a *pukao*, top-knot (fig. 26). This is believed to represent a hair style worn on occasions, with hair bunched on the top of the head and colored with red earth, *ki'ea*—a sacred color. So now the *moai* is weighed down by the load of a *pukao* whose average weight may be estimated at 5 tons.

For five centuries, the statue, with its bruised outer stone skin and under constant pressure, suffers the cold of winter rains and the heat of the summer winds, while sea spray reaches it periodically, leaving some salt behind in the stone. Micro-organisms find adequate footholds in the

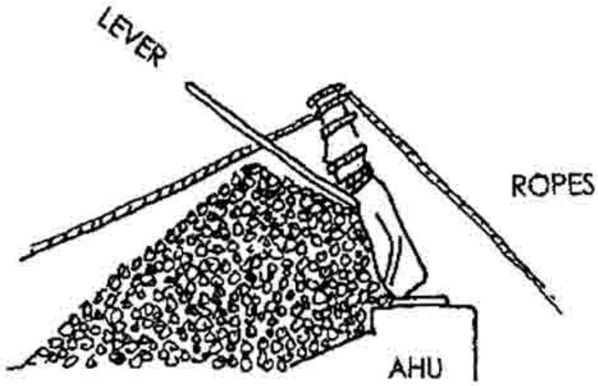

Figure 25. Probable method of raising statues onto the *ahu* using a ramp of small stones and wood levers (Drawing by G. Lee)

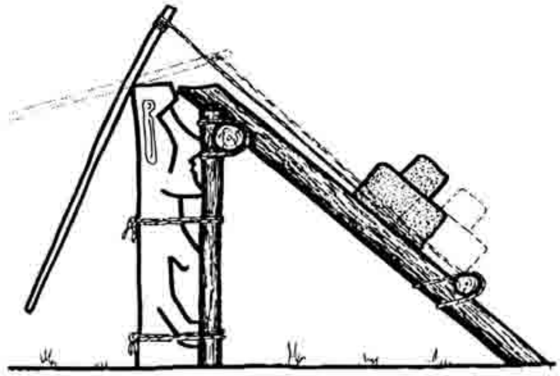

Figure 26. Suggested method of moving the *pukao* by means of a lever and a ramp of two beams (Drawing by P. Pavel)

surface roughness. First bacteria settle, then algae and fungi, and, if the environmental conditions are appropriate, lichens can develop. This biological "attack" will contribute to the acceleration of the weathering of the outer "skin" of the statue, which is some 5 to 10 cm in depth.

And then the *moai* is toppled over! Or it may have fallen during an earthquake. It now lies flat on its belly or back at the angle of the ramp leading to the *ahu*. During that toppling, its neck was broken from the impact against the ground and its back was trampled on during the ensuing fights. Fires may even have been started and the stone subjected to flames. The sudden heating of the stone and subsequent cooling will induce microfissures in its "skin" opening yet more pathways for water and micro-organisms to penetrate into its body (fig. 27).

Figure 27. The *moai* known as "Paro" at Ahu Te Pito te Kura lies broken at its site on La Pérouse bay. Legend states that it was the last statue left standing (Photo: G. Lee)

For three centuries it lies abandoned, subjected to more rain and wind and heat. Its back exposed to the elements, it starts to erode at a increased rate. With the change in position, there is a change in the biological colonization. Areas previously exposed to the air and sun are now protected (such as the ground side of the statue) and consequently the type of organism that can flourish will change. As with humans, resistance to the environment decreases with age. So too, the young *moai*, while recently on the *ahu*, was stronger and stood up better to wind, weather and biological attacks. But after so many years, fallen and broken, it no longer has its original resistance, and the weathering process accelerates.

But some *moai*, like those at Ahu Tongariki, have suffered even more. Because the *ahu* is located in a low-lying area, Hanga Hotu Iti, it was totally disturbed when a tsunami, originated by

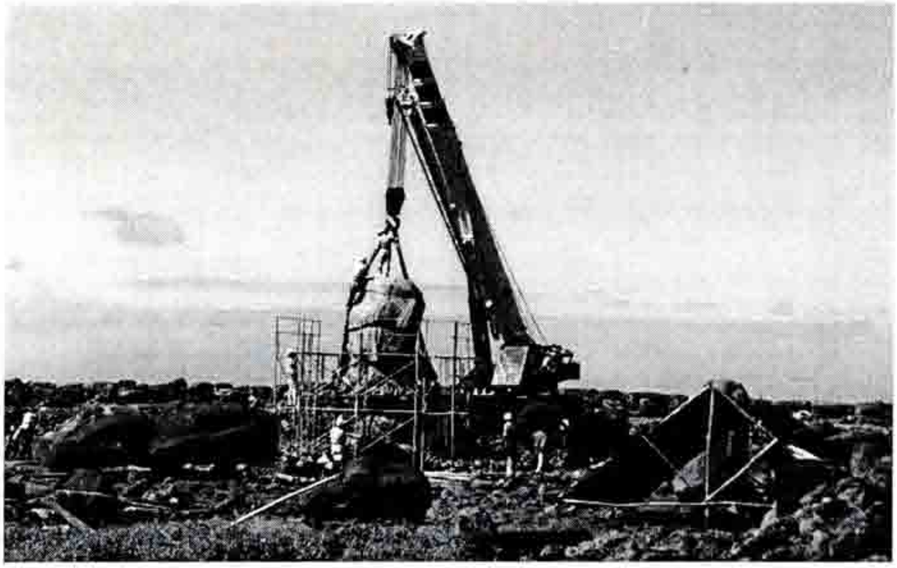

Figure 28. *Moai* going up at Ahu Tongariki. The large crane was brought from Japan to erect the statues (Photo: E. Morales)

a strong earthquake in Chile, struck the island in May 22, 1960. The tsunami hit early in the evening but high waves continued throughout the night. Along the coast of the bay, water rose 13 m above normal and covered a large area reaching, in some instances, 700 m inland. As a result Ahu Tongariki with its fifteen toppled *moai* was totally disrupted and the *moai, puako* and large slabs from the *ahu's* back wall were rolled around and strewn over an area of about 3.5 acres (1.4 hectares). Although this has not been the only tsunami to hit the island, it can still be considered the largest and most destructive of those recorded in the Pacific.

But men come again and decide to stand the *moai* on the *ahu* (fig. 28). And the poor statue is stressed again while he is cemented back into place, because the base had also suffered and thus he no longer could stand as he once stood. He has his head cemented back in place, so that he can proudly look down again on the men around him. And again the *pukao* is set on him, putting the stone back under pressure (fig. 29).

And once more he is buffeted by winds and weather, now reaching him from all sides. And another change in the biological colonization will occur.

How much longer can he stand up to this?

Figure 29. Ahu Tongariki reconstructed. (Photo: G. Lee)

Appendix on Stone Deterioration

The weakly stratified and moderately lithified tuff in the Rano Raraku quarry has a horizontal to slightly tilted bedding (30°). Most of the *moai* were carved along the bedding, but some were cut at an angle and even perpendicularly to it. The rock in this quarry is a yellowish tuff . It has a glassy, vesicular matrix containing many xenoliths (from the Greek *xenos*, foreign, *lithos*, stone) which range in size from lapilli (2-64 mm), mostly olivine, augite and rare plagioclase, to basalt inclusions up to 45 cm in diameter. Secondary minerals, i.e. minerals that form at the expense of others while the rock was still subjected to steam or hot water from the volcano, such as zeolites are also found. The vitreous matrix also contains vacuoules (trapped air bubbles) (figs. 30 and 31).

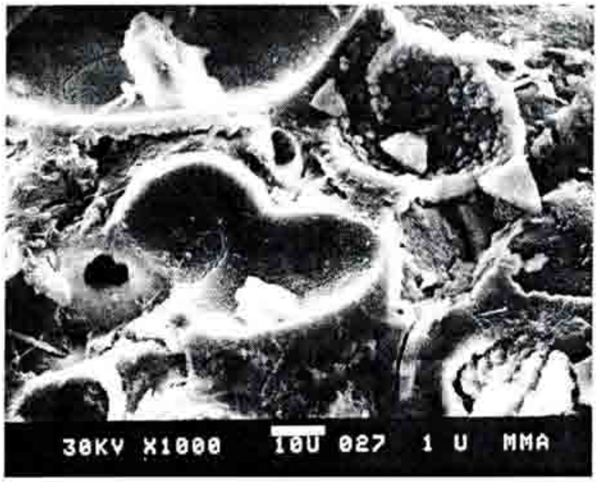

Figure 30. Scanning electron micrograph showing the round depressions which are trapped air bubbles in a glassy matrix (Photo: A. E. Charola and R. J. Koestler)

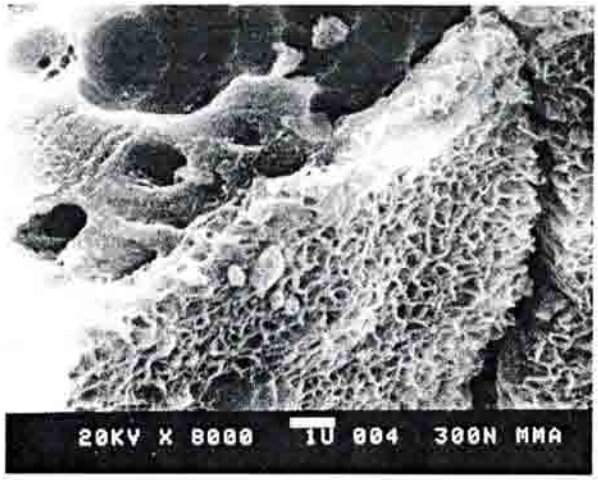

Figure 31. Scanning electron micrograph at higher magnification showing the spongy looking surface of the zeolite minerals found in the tuff (Photo: A.E. Charola and R. J. Koestler)

The tuff is not a homogeneous material and there are differences between the strata in the quarry. The most obvious differences are in the coherence and size of the contained inclusions. Some tuff is fine-grained with a dense structure and others contain coarse clasts. The color also varies from light brown to yellowish with a greenish tinge. The differences in color are particularly striking when *moai* from different strata are side by side (fig. 32). Some individual *moai* are even carved out of two juxtaposed strata.

The lowering of the statues from the quarry, their transport, erection on *ahu*, toppling over and re-erection, induce mechanical damage that can range from minor fissures to fracturing of the statue in two or more pieces. Several examples of statues that have suffered this last type of damage can be seen in the Rano Raraku quarry and at various *ahu*. The smaller fissures will accelerate weathering by increasing water penetration and by providing footholds for the growth of micro-organisms.

The crowning of the *moai* with a *pukao* has a two-fold effect. On one hand it protects the statue from rain hitting the flat top of the head directly and, on the other, it puts the tuff of the statue under compression. It can be estimated that this last stress is fairly low. The pressure to which the *moai* is subjected is approximately 1.25 kg/cm^2, i.e., 18 psi—calculated for the virtual *moai*

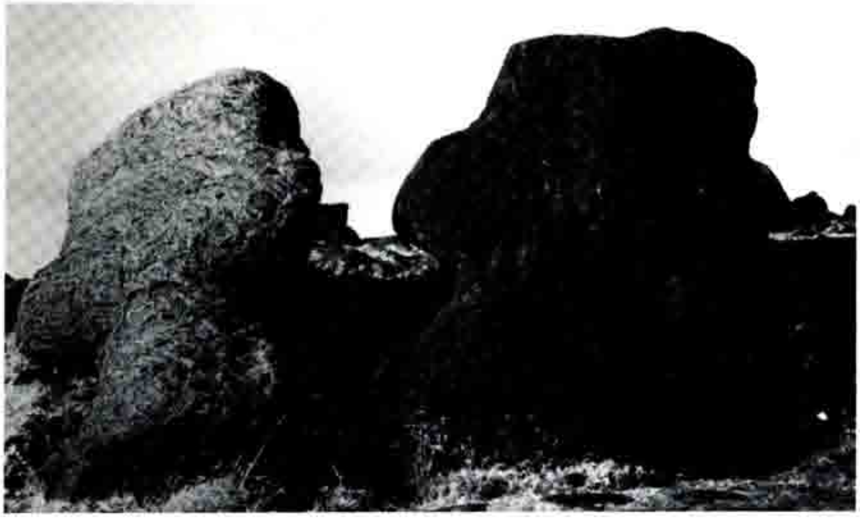

Figure 32. Two of the *moai* at Ahu Vaihu display the natural variation in color of the tuff (left is yellowish, right brownish) and the difference in quarrying orientation. (Photo: A. E. Charola)

under discussion, and considering that the area on which the *pukao* rests is about 4000 cm^2 (corresponding to an elliptical flat top surface of the head with axes measuring 1 m x 0.50 m), and estimating an average weight of 5 tons for the *pukao*. Even if the *pukao* does not sit flat on the head, as the undersides are usually hollowed, the increase in pressure that can result is far from the measured compressive strength of the sound Rano Raraku tuff which is approximately 65 ± 15 kg/cm^2. But the deteriorated skin of the statue undoubtedly has a lower compressive strength and if concentrated stresses, such as those resulting from a slanted-sitting *pukao*, are applied long-term, localized creep phenomena may occur, leading ultimately to the failure of this stressed material. Furthermore, even small loads can increase the rate of other deterioration factors when time is measured in centuries.

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What Ails The Moai?

The *moai* has aged. The stone, a volcanic tuff which consists of a glassy matrix in which other minerals are embedded, has weathered over the centuries and deteriorated by the action of many factors. These can be natural, such as rain and wind, or anthropogenic, such as the stresses induced during its moving and installation on the *ahu*, the effect of the weight of the *pukao*, the vandalism resulting from the internal wars during the ecological crisis of the 17th century and the re-erection in this century.

Among the natural factors that affect the tuff of the *moai*, rain may be the most important one. The gusting rains during the frequent showers on the island can erode the soft stone mechanically. Thus the surface of the statue will slowly abrade away. Since the stone is heterogeneous, some parts—like the vitreous matrix—are softer than others, such as basalt inclusions. Wind erosion compounds this deterioration, particularly for toppled or half-buried *moai*, because sand is carried by the wind and it does not usually rise above 3 feet (1 m) off the ground.

Figure 33 Closeup of the back of a statue at Ahu Vaihu, showing harder inclusions left behind after weathering (Photo: A.E. Charola)

Rainwater will also penetrate into the volcanic tuff through its pore system. How much water will go into the stone and how fast it will enter depends on the size of the pores. Large pores allow more water to enter rapidly but, unless the rain continues, the water will remain close to the surface where it will evaporate faster. Small pores will permit little water to enter but what does get in will go deeply into the stone. Water in the smaller capillaries will take longer to evaporate and the stone may remain damp inside while the surface is dry. Water in contact with the tuff for longer periods will have an opportunity to dissolve out some of its constituent materials, in particular from the glassy matrix. Even if the amount dissolved is very, very small, over many centuries the damage induced can be significant. The dissolved material will be transported through the stone in solution and, when the water evaporates, it will be deposited in that area. The result of this chemical dissolution process can be seen clearly in the toppled statues at Ahu Vaihu. The water from the rain will wet the stone and percolate through it, in the process dissolving some of the glassy matrix. The exposed top surface will slowly erode and dissolve leaving the more resistant inclusions in evidence (fig. 33). The solution, enriched in silicates, will trickle downward through the *moai*, and as it reaches the protected front of the statue, the water will evaporate and leave a white deposit of silica behind.

Figure 34 Honeycomb weathering on the back sea wall of Ahu Akahanga (Photo: A. E. Charola)

This damage is magnified significantly if soluble salts are present in the water. Because the *moai* is standing close to the shore, sea spray and fog, both containing salt from the sea, will reach it or envelop it and the salty moisture will penetrate into it. The water evaporates when the statue dries, but the salt is left behind. Again, the amount may be very small, but it tends to accumulate over time. Even though the rain will wash off any salts deposited on the surface, those left inside the pores will remain. These salts will dissolve when the stone next gets wet and will precipitate out as it dries. So there is a permanent movement of salts being carried in and out of the stone by water and moisture. As the salts crystallize again and again, they exert mechanical pressure in the pores and eventually the surface breaks down. This deterioration can take various forms: it can powder or flake, or even form deep holes in a fairly regular pattern, which in France received the picturesque name of "*maladie alvéolaire*" but is usually referred to as alveolar deterioration or honeycomb weathering. Some examples of this type of deterioration can be found in the blocks of the back-wall of Ahu Akahanga (fig. 34).

Sudden changes in temperature, such as occur when a shower falls upon the previously sun-heated *moai*, will also contribute to the deterioration of the stone. While the sun shines on the *moai*, the outer stone layer is heated, the interior remaining cold. This difference in temperature already induces a stress which is increased when cold rains cools the immediately exposed "skin" contracting it suddenly while the sub-surface is still warm. As the outer stone layer weathers, its coherence decreases with respect to that of the interior stone resulting in differential movements upon changes in temperature. This same mechanism is also operative at a mineralogical level. As the tuff has diverse inclusions in the glassy matrix, each will expand to a different degree and stresses will occur. These can induce separation of the inclusions from the matrix or even fissures and cracks in the matrix itself. Thus the overall porosity of the stone increases which in turn allows more water to penetrate its interior.

Finally, the growth of algae and lichens on the *moai* will also contribute to the deterioration of the tuff. Algae growing on the surface of the stone gives rise to the formation of a dark patina which makes the yellowish tuff of the *moai* appear grayish. This patina or bio-film will tend to retain moisture thus increasing the water-induced damage discussed above. It will also serve to trap dust, spores and other material suspended in the air thus providing a substrate for the growth of other microflora, such as lichens. These organisms may penetrate into the stone to a depth of about 0.5 inches (1 cm) or more with their hyphae as shown in figs. 35 and 36. Lichens growing on stone, called *saxicolous*, can inflict mechanical stress to the substrate through the expansion-contraction cycle that occurs upon wetting and drying. This results in spalling of the stone. Lichens also can selectively dissolve some elements from the tuff through the complexing agents they secrete, weakening its structure by this leaching effect.

Figure 35. Scanning electron micrograph showing a mass of hyphae (from lichens and algae) within the "skin" of a *moai* (Photo: A. E. Charola and R. J. Koestler)

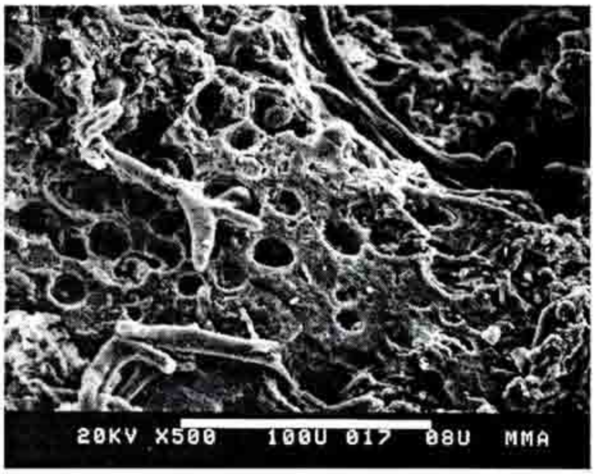

Figure 36. Scanning electron micrograph at higher magnification showing how hyphae penetrate (through cracks and vacuoles) the "skin"of a *moai* (Photo: A. E. Charola and R. J. Koestler)

Some lichens are capable of colonizing a stone for centuries and, in some instances, millennia. Since they grow at a fairly regular rate their size can be used to determine their growth time and indirectly, the age of the object on which they are growing. For dating some of the *moai* and *ahu*, the relative concentric-growing lichens *Lecidea paschalis*, *Diploschistes anacticus* and *Physia picta* have been used. The maximum age that could be determined from the growth of these lichens on uncarved boulders and rocks, is approximately 800 years. The growth rate of *Diploschistes anacticus* and *Physia picta* was calculated from photographs of the back wall of Ahu Vaihu, taken in 1914 and in 1961, to be of 12 and 17mm per year, respectively. The resulting date obtained from all these measurements is of approximately 430 ± 30 years, indicating that the lichens started growing around the 16th-17th century. This corresponds to the period of decline of the civilization, with internal wars and the change in the cult of the ancestors to that of the bird-man. At this point, the quarrying of the *moai* was abandoned and the *moai* on the *ahu* were toppled. The consequent neglect of these sites may have allowed the undisturbed growth of the lichens.

As weathering continues, increased through biological activity, clays develop as the final stage of tuff alteration. Clays are very small, platy minerals with the capability of adapting their water content to the ambient relative humidity. When they take up water, they expand; when they lose water, they contract. Repeated cycling through expansions and contractions induces "fatigue" in the matrix of the tuff resulting in its mechanical weakening. This mechanism also contributes to the overall deterioration of the stone.

But natural causes, as discussed above, are seldom as damaging as man himself can be, both through indirect and direct actions. An example of his indirect actions is the introduction of animals to the island. In the last century, practically the whole island was turned into a sheep farm, which at one point had some 20,000 animals. Today the great herds of sheep are gone but cattle and horses roame freely through most archaeological sites. And when a *moai* is conveniently left standing on the bare ground, as is the case of the so-called "traveling *moai*" at Tongariki, the animals use it as a rubbing post. The introduction of the falcon locally called "*tiuque*" (*Milvago chimango*) resulted over the years in a significant increase in bird population

Figure 37. *Tiuque* perched on a statue near Tongariki. The statue is known as the traveling *moai* because it was on display in Japan. It was returned to the island in 1982 (Photo: G. Lee)

which uses the restored *moai* as perches, leaving droppings on them which not only deface them but contribute to deterioration by the introduction of soluble salts into the system. (fig. 37)

Without considering willful actions such as warfare and vandalism, man can inflict damage through ignorance of the susceptibility of the stone, through carelessness and/or disregard. Only two examples will be mentioned to illustrate this point. The first concerns molds that were taken to prepare replicas for an exhibition at the Senckenberg Museum in Frankfurt. The silicone molds were applied to two complete *moai* heads and the front of the *moai* with a boat carved on it at the Rano Raraku quarry, and to part of the sea-wall of Ahu Vinapu (fig. 38). The mold-taking process is generally safe when applied to relatively smooth and hard surfaces. In the cases mentioned, upon removal of the mold, lichens were pulled off and with them grains and flakes of the surface—the amount removed depending on the friability of the surface: more for Rano Raraku tuff, less for Vinapu basalt. The loss of the lichens from the Ahu Vinapu wall curtails any possible dating efforts.

The *moai* with a carving of a boat on its front (figs. 39 and 40) suffered the greatest loss because the tearing of the lichen hyphae removed proportionally more of the details in the carved surface.

Another example is described vividly by Katherine Routledge in an article derived from her book *The Mystery of Easter Island*:

> The most striking sight witnessed on the island was a fire on the hillside. In order to see our work more clearly, we set alight the long, dry grass, always a virtuous act on Easter Island, that the live stock may have the benefit of the fresh shoots. In a moment the whole landscape was ablaze. The mountain, wreathed in masses of driving smoke, grew to portentous size. In the quarries, below the whirl of flame, the great statues stood out calmly, with quiet smiles, like stoical souls in Hades.

Unfortunately, this practice still continues. Even though it is not as frequent in the quarry, fires still occur there occasionally, as happened in 1996 in the interior of the crater affecting some 47 *moai*. But fires occur more frequently on other archaeological sites. Burned *hare paenga* stones are a common sight. That the life of these stones, and of any statues that come within the range of the fire, is significantly shortened, is not immediately obvious to those lighting the fires. Only the *moai* know that their future has been abbreviated.

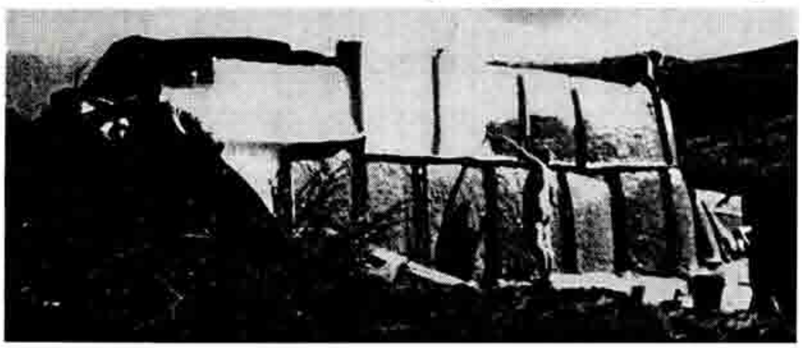

Figure 38. Making a mold of the wall at Vinapu for Senckenberg Museum display, 1989. The removal of the mold also removed lichen from the stones (Photo: Helen Williams)

Figure 39. This statue, which stands on the exterior slopes of Rano Raraku, has a petroglyph of an historic ship incised on its torso. This photograph was made prior to the mold-taking (Photo: A. E. Charola)

Figure 40. The same statue after removal of the mold. The lighter rectangular area, which is most visible at the bottom , shows where the mold removed lichen as well as the surface of the stone (Photo: G. Lee)

Appendix on Stone Deterioration

The glassy matrix is more susceptible to weathering than the mineral inclusions, because glass is really a "frozen liquid" and not crystalline. The structure of glass (fig. 41) is a disordered silicate matrix with cations, such as sodium (Na^+), potassium (K^+) and calcium (Ca^{++}) ions balancing the charges.

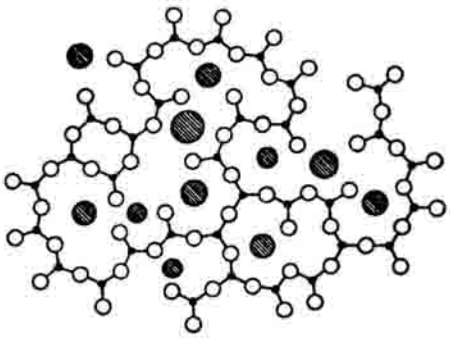

Figure 41 The structure of glass. In the order of decending size the shaded circles represent K^+, Na^+ and Ca^{++}

When water (HO-H) gets in contact with a glass, the very small and mobile hydrogen ion (H^+) is capable of entering the silicate matrix and, to balance the electrical charges, sodium ions (Na^+) will leave the matrix.

Since these ions are larger, there are voids left in the matrix which induce shrinking in the silicate structure with the consequent formation of cracks in the glass. This mechanism, called selective leaching and ion exchange, is responsible for the "crizzling" of ancient glasses.

As a result of the ion exchange, the water in contact with the surface of the glass is enriched in sodium ions (extracted from the glass matrix) and hydroxyl ions (OH^-) left behind by the removal of the hydrogen ions that migrated into the matrix. This will increase the pH of the water, i.e., turn it alkaline, which eventually will dissolve the silicate matrix and etch the surface of the glass. Summarizing, the decay mechanism of the glassy matrix proceeds through an ion-exchange mechanism leading to the subsequent dissolution of the matrix. The dissolved silicates redeposit at the point where the solution evaporates (fig. 42).

Figure 42. White silica deposit on the face of a *moai* at Tongariki. The deposit formed in protected areas (eye sockets and base of the nose) while the *moai* lay toppled on its face. The tsunami that hit the area rolled statues over and this head was turned face up (Photo: G. Lee)

The clays that result from the weathering of the tuff can also contribute to the deterioration of the stone. These minerals are mostly platy because of their crystallographic sheet-like structure. This layered structure facilitates the uptake of water which is accommodated between the layers resulting in an expansion of the mineral structure (fig.43). Since the water is only adsorbed it is lost easily with the resulting contraction of the structure. Although clays are a minor component in the tuff, the stone is capable of expanding approximately 0.7 mm/m when subjected to a 60% RH environment and even more when immersed liquid water.

Repeated wetting and drying, results in expansion-contraction cycling and weakens the structure of the stone mechanically, leading to loss of cohesion.

The action of fire on stone is that of imposing thermal stress on the material. The differential expansion between the heated outer layer and the inner cooler stone can lead to fracturing and even to shattering of the statue in the worst cases. The different expansion coefficients of the various minerals constituting the stone induce fissuring which will accelerate the overall deterioration of the stone.

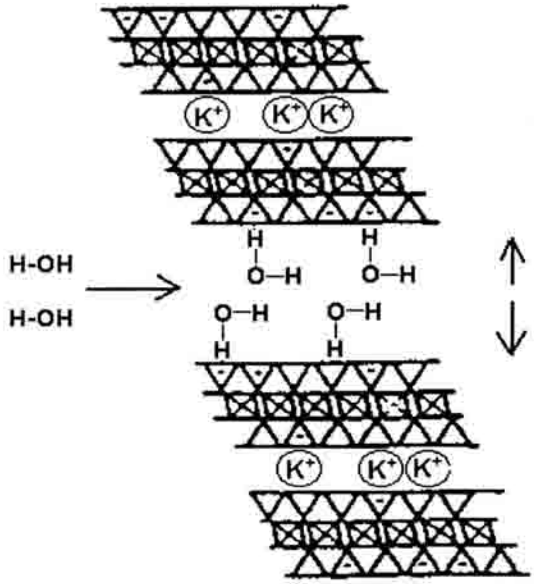

Figure 43. Diagramatic sketch of the expansion of clays due to water entering the layered structure of these minerals (from Wendler)

The deterioration of the tuff cannot be ascribed to one single factor. In general all factors contribute to the deterioration and act synergistically. However, water is probably the single most important factor because it is capable of several mechanisms: mechanical erosion through striking rain; chemical dissolution upon penetration into the stone; transporting soluble salts and re-crystallizing them upon evaporation; providing the necessary conditions for biological colonization; and, contributing to the structural weakness of the stone through the hygric swelling of the clays.

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Can the Moai be Saved?

After centuries of lying abandoned, a *moai* has been re-erected on his *ahu*. When this occurred, some 30 years ago, the statue was cemented down (fig. 44) on the *ahu* because the base of the *moai* had been damaged. In ancient times the base was flat and the moai was held steady by wedging stones under it. Thus a different material was incorporated into the statue and will affect its overall behavior.

Cement mortar is dense, with a lower porosity than the tuff of the *moai* and hence does not allow water to permeate through it at the same rate. The mortar effectively acts as a moisture barrier and results in the collection of moisture at the base of the statue. Thus the base of the *moai* remains damp for much longer periods of time than it would have when erected originally. Such dampness can be recognized by the darker shade of the stone. The stone appears darker because the film of moisture on it makes it more reflectant and hence less light is scattered. The same effect is obtained upon polishing a surface: a smooth surface reflects more light and appears darker, a rough surface scatters more light in all directions and appears lighter in colour.

Figure 44. *Moai* at Ahu Hanga Kio'e showing the cement base and the silica deposit just above it (Photo: A. E. Charola)

The prolonged dampness of the lower part of the statue evidently increases the time available for the chemical dissolution of the glassy matrix of the tuff, of the swelling and shrinking of any clays present, of movement and re-crystallization of salts and increasing the softness of the stone thus making it more susceptible to mechanical erosion.

The problem introduced by using cement mortars had not been known at the time of the re-erection. Only later studies have demonstrated that when two materials, un-matched in characteristics such as strength and porosity are joined together, deterioration problems are increased.

Independently of the problem introduced by the use of cement mortars, the overall deterioration of the *moai* requires some solution to prevent the *moai* from disintegrating completely. As in the case of medicine, no cures can be found unless the cause of the problem has been identified. Hence the importance of understanding the ailments affecting the *moai* to be able to give an accurate diagnosis and then find an appropriate remedy.

The diagnosis of the ailment of the *moai* can be summarized as follows:

a) loss of the strength of the tuff due to the various processes discussed in the previous chapter, and,
b) identification of the main cause of the problem: water.

Figure 45. The *moai* at Ahu Hanga Kio'e covered with a protective tent during treatment (Photo: A. E. Charola)

The remedy for the *moai* must therefore address these two points:
a) strengthening the stone
b) preventing water from getting into it.

A possible solution that addresses these two points has been found and was actually applied to the *moai* at Ahu Hanga Kio'e over the summer of 1986-87. This *moai* was chosen because it was one of the most deteriorated of the re-erected *moai*. This particular *moai* had its head re-attached with a steel bar and cement mortar.

The procedure involved several steps. These were:

a) a tent was installed over the *moai* to protected from rain and sea spray (fig. 45);
b) its surface was cleaned of biological growth and dirt deposits;
c) after the *moai* had dried out for several months under the tent, it was completely wrapped up with cellulose wadding, except for the flat top where the treatment was to be applied. The wadding was covered with a polyethylene film to avoid evaporation of the solution to be applied;
d) a consolidating solution was dripped slowly on the exposed top of the head until the statue was saturated. Then the top of the head was also covered with the plastic film and the *moai* left to "digest" the solution;
e) after one day, the cellulose wrapping was quite dry; the *moai* had absorbed all the solution from it and the statue then was unwrapped;
f) after another day the tent over the *moai* was removed;
g) after two months to allow the consolidating treatment to become effective, any soluble salts remaining in the *moai* were removed through poulticing. Insoluble silica deposits, as found at the base of the *moai* (fig.44), were left in place since they are not harmful in this case;
h) a water-repellent solution was applied by spraying the surface of the *moai*.

The treatment was carried out by the National Conservation Center of Santiago, Chile (Centro Nacional de Conservación y Restauración) within the framework of the CHI/79/013 project with support from the United Nations Development Program (UNDP) and UNESCO, and the assistance and collaboration of Wacker Chemie, GmbH.

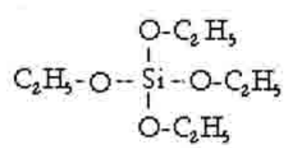
The treatment has proven effective so far. To keep its effectivity, it is important that the water repellency of the *moai* be maintained. Since this is a surface treatment, it tends to lose efficacy over time. Water-repellent systems have to be re-applied periodically, when the effectiveness of the previous application is diminished. The time frame for re-application can range from 5 to 15 years. The *moai* at Hanga Kio'e is still protected from the applied treatment but a re-treatment should be seriously considered in the near future. Although re-treatment is not as expensive as the original complete intervention, it is particularly complex for a statue on Easter Island because of the distances involved and the fact that there is no resident conservator on the island.

The remedy found for the *moai* can be considered equivalent to the medications humans take when sick. They cure but do not ensure eternal youth or immortality. The treatment is expected to slow down the deterioration process, but it cannot stop it. As in the case of medicine, however, new remedies are being searched for and it is likely that better products, with longer actions and fewer side-effects will be developed in the future.

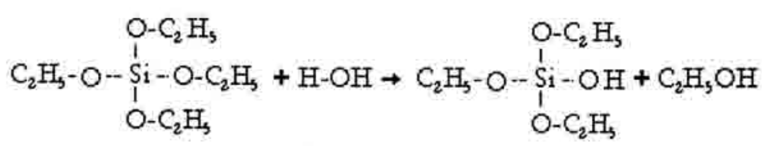
Presently, there is only one sure way to stop deterioration: installing the *moai* permanently under cover in an adequate environment. *Moai* in museums will outlast all of those outdoors for centuries. But a *moai* in a museum no longer "lives": it is not on the *ahu*, it can not hear the sea or feel the sun, it can no longer watch the spectacle presented by the descendants of his creators. Is this solution worth it?

Appendix: Brief Introduction to the Chemistry of Stone Treatments

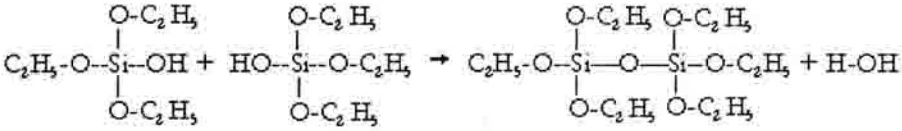
The consolidation of the Hanga Kio'e *moai* was carried out with a product based on an oligomeric silicate ester (Wacker OH modified from the commercially available product by the addition of a fungicide and less volatile solvents). An oligomer (from the Greek *olig-* few) means a small polymer, i.e., few repeating units. (It is called an ester because this is the generic name for the reaction products between an acid and an alcohol. In this case, the acid would correspond to the theoretical silicic acid [$Si(OH)_4$] reacting with ethyl alcohol [C_2H_5OH]). The resulting monomeric silicate ester, properly designated ethyl silicate, has the formula:



This compound can react with water, in what is called a hydrolysis reaction, to produce an alcohol (ethyl alcohol) and leaving a hydroxyl [OH^-] group attached to the Si. The reaction can be written as follows:



The hydrolized molecule, called a silanol, can react with another such molecule, producing a dimer, i.e., the first step in a polymerization. The reaction occurs through loss of water, and is called a condensation:



The commercial oligomeric product has about 3 to 6 units. These can continue to hydrolyze and condensate until all ethoxy groups [-O-C_2H_5] have reacted and the result is a three-dimensional network based on the [-Si-O-Si-] sequence, a hydrated silica [SiO_2.aq] with an amorphous structure (fig 46).

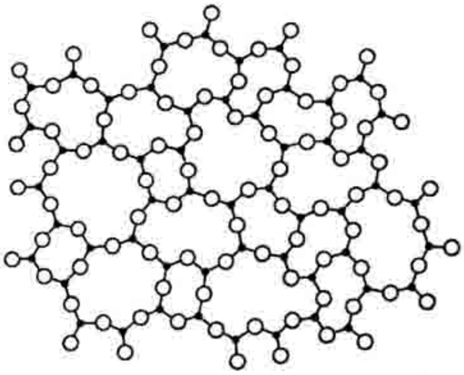


Figure 46. Drawing of the amorphous structure of silica

However, in practice the reactions take time to occur and not all the ethoxy groups hydrolyze nor do all the silanols [-Si-OH] produced condense. Therefore the network produced is not perfect and may continue to polymerize over years. At that point, stresses can be induced in the three-dimensional network which can, in some instances, break it down. This problem is prevented in part by the addition of catalyzers but studies are still underway to understand the mechanism of long-term polymerization.

The product leaves a coating of a gel-like substance that effectively covers the surface of the vitreous matrix and its inclusions. This can be explained by the chemical affinity between like materials, that is, all are silica or silicate based compounds. The introduction of this amorphous, gel-like silica-polymer increases the density of the stone and the coherence between its different minerals thus improving the overall mechanical resistance of the tuff. While the overall porosity of the stone decreases, the initial cracks that form upon the elimination of water from the gel-like substance provide sufficient micropores (pores in the nanometer range, i.e. 10^{-9}m) to allow the stone to “breathe”, by permitting the passage of water vapor through it.

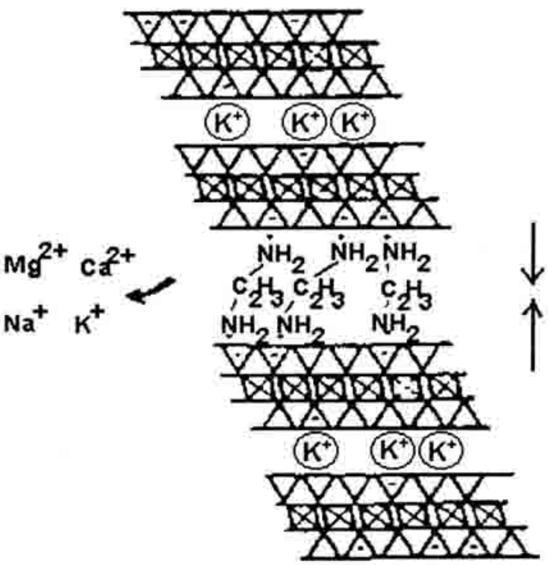


Figure 47. The treatment with surfactants decreases hygric dilation because it holds the layered structure together (from Wendler)

Further research carried out in the ten years since the consolidation treatment was applied has shown that the silicate-ester treatment can present problems. One of them is that the moisture absorption of the tuff is increased for the silicate-ester treated material as a result of partially filling the larger pores with the gel and from the cracks formed during the hardening of the gel-like film thus increasing the overall number of micro-pores. The micro-pores will allow water moisture to condense within the stone and remain deep inside. The introduction of segments of linear polymers (di-methyl siloxane, for example -see below for explanation of the term) into the three-dimensional network introduces some flexibility into the structure and prevents the formation of cracks.

As mentioned, the consolidation treatment only strengthens the stone. However, deterioration mechanisms still continue. Among these is the hygric dilation due to the expansion-contration cycling of the clays in the tuff. A treatment that has proven successful in the treatment of other clay-bearing stone and has been tested in the laboratory for the Rano Raraku tuff, is based on a bi-functional surfactant (butyl di-ammonium chloride). The surfactant, applied in an aqueous solution, penetrates and remains between the crystallographic layers of the clays, holding them together and preventing the movement of water and the consequent swelling and contracting of the mineral structure (fig. 47).

Another problem is the formation of white silica deposits on the surface of the stone resulting from the dissolution of the glassy matrix. The deposition of amorphous silica in the tuff from the treatment might possibly enhance this problem. No solution has as yet been found for this problem but studies and research continue.

The water-repellent treatment applied to the Hanga Kio'e *moai* was a siloxane based product (Wacker 090 S modified from the commercial product by the use of less volatile solvents). The siloxane is the equivalent of the oligomeric silicate ester discussed above but in which one ethoxy group [$-O-C_2H_5$] has been replaced by an alkyl group, such as ethyl [$-C_2H_5$], propyl [$-C_3H_7$], butyl [$-C_4H_9$] or octyl [$-C_8H_{17}$]. In the case of the di-methyl siloxane, two ethoxy groups have been replace by two methyl [$-CH_3$] groups. The alkyl groups do not hydrolyze and are the ones that confer hydrophobicity to the treated substrate. These groups effectively coat the stone with a non-polar "film" (fig. 48).

The treatment only prevents the penetration of liquid water (like a rain-coat, which is in fact made from a textile treated with a similar product) but does not hinder the movement of moisture, either its ingress or, more important yet, its evaporation. This "rain-coat" will lose its effectiveness with time mainly because the surface gets dirty or it is mechanically eroded, and hence re-application of this protective treatment is required periodically.

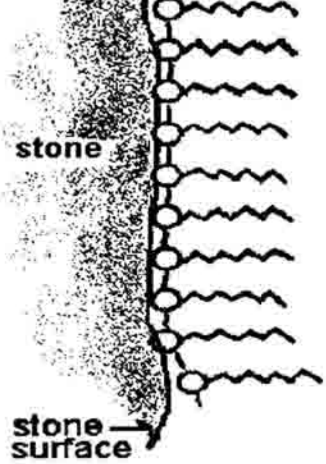


Figure 48. The siloxane chain, represented by the linked circles, attaches itself to the stone surface by its chemical affinity. The alkyl groups, represented by the "tails," face outward and confer water-repellency to the surface

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Moai as Petroglyphs

Apart from the statues for which the island is justly famous, *moai* have also been depicted in petroglyphs. These generally appear in clusters of "mini-*moai*", ranging in size from 15 to 80 cm long, and can be found all around the island. Some have been carved into the Rano Raraku tuff, directly on the giant *moai* in the quarry. However, most are carved on basalt *papa* or boulders such as those found inland from Ahu Te Tenga, at Hanga Oteo, Terevaka Vai Atare, or the Rano Kau volcano (fig. 49).

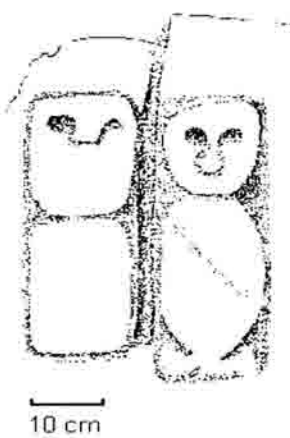

Figure 49. Small carvings representing tiny *moai* are found at many sites around the island
(Drawing, G. Lee)

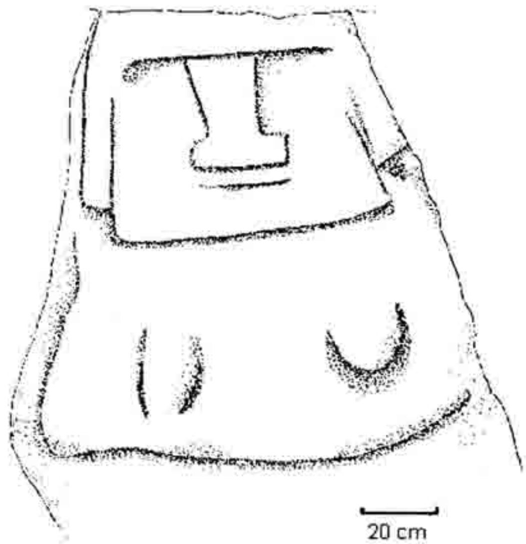

Figure 50. This large (140 x114 cm) petroglyph of a female *moai* at Ava O Kiri is unusual for its size as well as its sex
(Drawing: G. Lee)

Two larger petroglyphs, about 1.5 m in length, were documented by Georgia Lee. They represent truncated female figures, carved in shallow bas-relief. One is at Ava O Kiri (a water-cut ravine inland from Anakena) while the other lies near the road to 'Orongo. Both have cartoon-like features, but while the first one (fig. 50) has an enigmatic smile reminiscent of the Mona Lisa, the second has a broad nose and mouth reminiscent of the cluster of small mini-*moai* at Papa Te Kena on the north coast.

Petroglyphs have been carved into all types of stone and objects. A few examples will help to give an idea of the variety of designs and techniques. On *moai,* carvings range from bas-relief birdmen and *komari* on the back of the basalt *moai* in the British museum (see fig. 23, page 15) or fine bas-relief of dorsal details, presumably representing the knot tying the *hami,* the sacred loincloth worn by kings, as is found on the tuff *moai* at Ahu Naunau. Incised designs are also found on *moai,* such as the ship carved on the front of the tuff *moai* at the Rano Raraku quarry. Undoubtedly this is a late carving as it represents a European vessel (see fig. 39, page 27).

On many red scoria *pukao*, incised canoe shapes and cupules can be seen. Some are still lying in the quarry area at Puna Pau, while others lie fallen at Ahu Vaihu and Ahu Vinapu. Many of the fallen *pukao* at Ahu Akahanga were decorated with stylized frigate bird motifs carved on their sides. Unfortunately, these details are fast eroding as this material is even more susceptible to weathering than the Rano Raraku tuff.

Even simple beach cobbles, *poro*, were incised with *komari* or other designs. They are called *maea mo moa*, stone for fowls, and it is said they promoted fertility of eggs.

The basalt *papa*, surface lava which come mostly from Maunga Terevaka, have been used extensively to carve petroglyphs. One of the most important sites is located at Tongariki, close to where the island's largest *ahu* was recently reconstructed. The carved *papa* were usually associated with dwellings of which only a few scattered *hare paenga* (house foundation stones) remain today. According to local lore, the birdman lived in one of these during his year of confinement. This appears to be confirmed by birdman petroglyphs carved on the rocks. One such panel contains a *taheta*, a basin to collect water, along with other figures including Makemake faces (fig. 51). Other motifs on the *papa* at Tongariki are turtle figures and tuna fish. Both of these sea creatures played important roles in the culture since only nobility was allowed to eat them.

Figure 51. Some of the petroglyphs at Tongariki. Visible in this picture are a birdman and makemake motifs and a large *taheta* surrounded by small cupules (Photo: A. Padgett)

Another interesting petroglyph site, of the major sites defined on the island, is the panel at Pu Hakanini Mako'i, located north of Hanga Roa, on the west coast. The panel is on basalt lava flow from Maunga Terevaka and is just south of the *aa* lava flow that covers part of the Rohio area. The panel depicts roosters and what appears to be a canoe (fig. 52). In that area, the fracturing of the *papa* is a miniature example of the typical columnar jointing caused during the cooling of the lava (fig. 53). It is a mini version of the Giant's Causeway, Antrim, in Northern Ireland, or the Picture Gorge in Oregon.

Figure 52. Petroglyphs at Pu Hakanini Mako'i. Motifs include roosters and sweeping canoe-shaped forms (Photo: A. Padgett)

Petroglyphs carved on *papa*, since they are only slightly raised above ground level and have a coarse surface, are often difficult to see. Hence, not only free-roaming livestock walk over them but also tourists who are unaware of the existance of these carvings. This results in both significant surface erosion and applied pressure inducing stresses large enough to crack the *papa*. Any fissures that appear are immediately invaded by grass and other plant growth, which in turn induce more stresses, causing the *papa* to break apart. Unfortunately, this often occurs in the middle of a petroglyph motif, disrupting the image.

Figure 53. Columnar jointing is shown at the petroglyph site of Pu Hakanini Mako'i (Photo: A.E. Charola)

Of all the petroglyph sites, the most impressive is the sacred precinct of Mata Ngarau at 'Orongo, on the southwest corner of the island on the outer slope of the Rano Kau crater. The basalt boulders at this site have been carved with nearly two thousand petroglyphs, over a third of the total number for the entire island. The carving techniques evolve from simple outline to bas-relief and can best be appreciated in the birdman motif (fig. 54). This is one of the most important motifs, the site having been mainly used for the Birdman ceremony. The other significant motif, while not as striking as the birdman carvings yet far more frequent, is the *komari*, vulvae representations related to fertility as well as to sex. Both these motifs are characteristic of Easter Island since they are very rare in the rock art of other parts of Polynesia. Other important motifs at this site, although not as recurrent, are those of eye masks, related to the Makemake deity; and *manupiri*, two birdman joined at the hands and feet. Many of the *komari* and the eye mask motifs are superimposed on the birdman carvings.

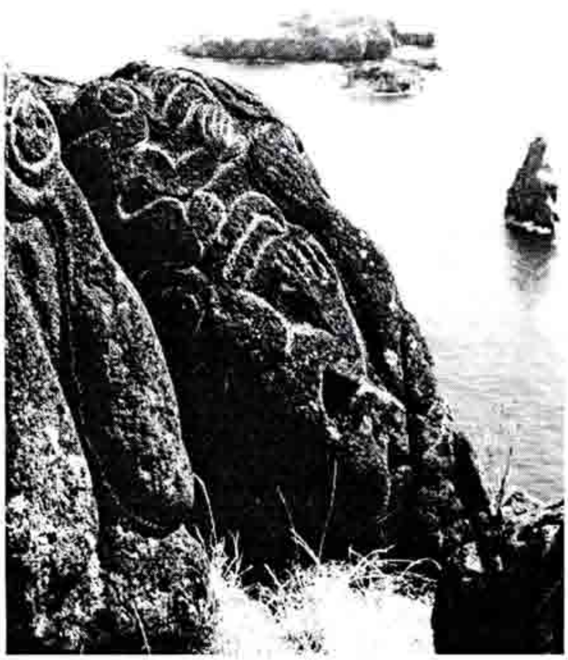

Figure 54 Birdman petroglyphs at 'Orongo; the islets of Motu Nui, Motu'iti and Motu Kaokao are in the background (Photo: K. Wellmann)

The basalt boulders on which the petroglyphs are carved tend to deteriorate in successive layers, usually referred to as "onion skin peeling". This is the result of cooling—from the outside toward the interior—suffered by these blocks in their genesis. This cooling process generates slightly differentiated layers which may sometimes trap air-spaces as the lava condenses.

The prominent location of these boulders at the edge of the sea, receiving full sun practically the entire day and the strong winds and rain, contribute to weathering of this stone in a process similar to that of the volcanic tuff. As basalt is more dense and uniform, the process is slower. On the other hand, because the carvings are only so deep, any surface loss is far more significant for this art form. Consequently, the growth of algae and lichens threaten them more than the

Figure 55. Birdman petroglyphs on horizontal surfaces in the "court" of Mata Ngarau receive maximum erosion from natural causes as well as foot traffic from visitors (Photo: G. Lee)

plain slabs of *ahu* sea walls. And erosion, such as resulting from tourists walking over the horizontal boulders in the "court" at Mata Ngarau (fig. 55) is so severe that some of the petroglyphs are to the vanishing point.

The losses that some of these figures have undergone have already been pointed out, and could be established because of the careful documentation program carried out some fifteen years ago on the island (fig.56).

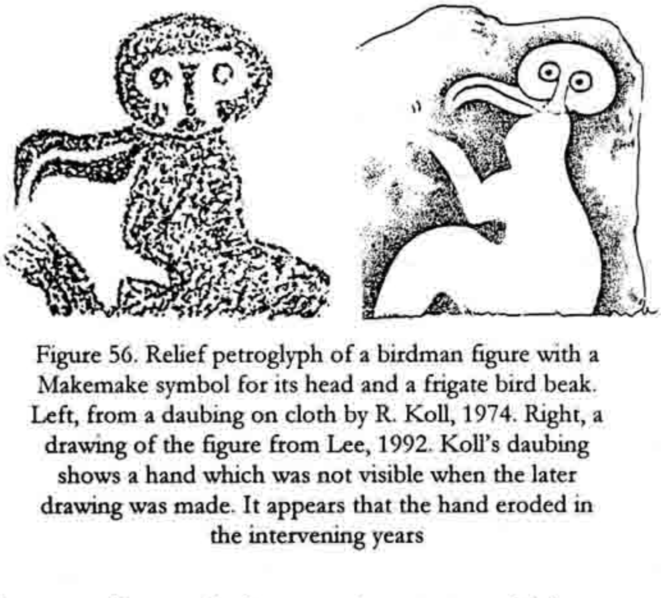

Figure 56. Relief petroglyph of a birdman figure with a Makemake symbol for its head and a frigate bird beak. Left, from a daubing on cloth by R. Koll, 1974. Right, a drawing of the figure from Lee, 1992. Koll's daubing shows a hand which was not visible when the later drawing was made. It appears that the hand eroded in the intervening years

The Mata Ngarau site is on the edge of the cliff, some 300 m above sea level. A terrace existed around this edge which over time has eroded through wind and rain, leaving boulders hanging perilously over the steep seaside slope. It is said that some boulders already have rolled into the sea, and it has been documented that some outward lying boulders have moved more than a meter down and out over the past twenty years. The site is currently under study to determine the most appropriate method of preservation.

If there is a "medicine" available for statues, its application is far more difficult in the case of petroglyphs carved on *papa* and lying, sometimes partly burried, on the ground. In this case, protection is the main solution. An excellent example is found at the petroglyph site at Ahu Ra'ai, near La Pérouse bay. The petroglyph area is now surrounded by a stone wall that not only defines the petroglyph location but keeps livestock out of the site. Simple deterrents such as this help toward the preservation of the petroglyphs, for hoof marks and manure disfigure the surfaces wherever animals can access them. The setting-off of a site by means of a wall also has a psychological value it implies that the area is special, is cared for, and thus garners greater respect from tourists as well as the local population (fig.57).

The issue of vegetation growth around petroglyph sites can be addressed by regular maintenance. But the "safe" removal of lichens from affected petroglyph panels is not an easy task. Even with the application of a biocide to kill the growth first, the removal may entail some loss

Figure 57. Aerial view of the petroglyph site at Ahu Ra'ai showing a stone wall around the petroglyph area. The oval area is a *manavai* (Photo: D. and E. Dvorak)

of surface. Probably the safest approach is to manage the microclimate, since lichens are particularly susceptible to it. Changing it can result in a natural "dying off". In the same way, normal changes in microclimate, because trees grow and shade petroglyphs, may result in rapid lichen colonization: a panel near Anakena beach shows dramatic changes in only thirteen years (figs. 58 and 59).

Yet natural weathering is relatively slow compared to some of the actions inflicted by man himself. Leaving aside vandalism, the damage that can result from even careful mold taking was already mentioned. However, when latex or similar resin castings have been attempted, the result has been the defacing of the panels. One such example is found at Vai Tara Kai Ua, where unsightly streams of resin were left running down the rock face. Another is found in a turtle motif at Tongariki where white latex was left in the rock pores, giving it a "salt and pepper" appearance. And probably the most destructive practice—because of its ubiquity—involves the marking or painting of the petroglyph grooves so tourists can see them more easily. The worst case is when this marking is done with small stones, and the grooves get scored and scraped in the process, defacing or even changing the original design. This long-standing practice is difficult to eradicate, since the damage is gradual and not immediately evident to the average eye. However, the documentation programs will serve as a basis for education programs.

Figure 58. Petroglyph panel above Anakena as it appeared in 1982. Lichen is beginning to form on the surface (Photo: W.D. Hyder)

Figure 59. The same panel as shown at left, in 1995 (Photo: R. James)

The above discussion shows the importance of periodic documentation of the rock art which serves to determine when and how changes occur. This documentation can also aid in devising protective measures and in evaluating their effectiveness. As mentioned, the original documentation was accomplished fifteen years ago. Two years ago, a second project—a conservation assessment—was done. The data are being analyzed to determine losses that have occurred. Hopefully this process will be repeated in another twelve years to check for changes resulting from increased visitation and weathering.

The preservation of this rock art poses a real problem. So far, only preventive measures can be applied: keeping animals and tourists from walking over the sites, preventing the growth of lichens, algae and grasses, preventing fires and, finally, educating local inhabitants and tourists so that they will not outline the petroglyphs to enhance their visibility—a popular practice hard to eradicate.

The list is misleadingly simple: the difficulty lies in its application.

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Epilogue

The preceding pages may leave many with a feeling of dismay and hopelessness. Yet against this backdrop of death and decay is the continuing quest for eternal youth. Although it may never be achieved, significant advances have been made.

While continuing our search for "the cure," we must not forget to provide the protection that will prevent major deterioration. It is this last attitude, which may be called the conservation attitude, that makes a difference in the end. It will extend the life of our heritage thus increasing the probability of having a heritage by the time the cure is found.

The conservation attitude has to be acquired. Particularly with respect to these stone monuments which outlive us for so many generations that perceiving the deterioration they suffer within our lifetime is very difficult to the untrained eye. The loss to the monuments can be observed clearly when they are compared with previous records. The importance of careful and appropriate documentation, carried out by professionals, cannot be emphasized too much. Only thus can we obtain the data to visualize the damage that occurred and to determine the causes that induced it. And, since man's actions are among the most damaging, it will allow us to mend our ways so we may better perform our custodial role towards our inherited heritage.

Hopefully these pages will lead many to pause and ponder on the consequences of thoughtlessly performed actions and will help to develop the conservation attitude required for the preservation of the magnificent heritage of Easter Island.

Lexicon of Geological and Mineralogical Terms

aa lava: Hawaiian term used to describe rough blocky lava flows which, for the more viscous lavas, have jagged, spiny and clinker-like (scorariaceous) surfaces.

aphyric: a texture with no visible large grains.

augite: a mineral of the pyroxene group $(Ca,Mg,Fe,Al)_2(Al,Si)_2O_6$.

basalt: a fine-grained, sometimes glassy, basic igneous rock.

benmoreite: fine-grained intermediate trachybasaltic igneous rock, similar to rhyolite, but containing some olivine.

caldera: a large, mostly circular shaped hollow, formed mainly by the collapse of the summit into the magma chamber.

clay minerals: hydrous alumino silicates with a sheet structure (phyllosilicates) resulting from alteration of igneous or metamorphic rocks. Clay particles are very small ($< 4\mu m$) and when mixed with an appropriate amount of water produce a plastic mass. There are four main groups of clay minerals: kaolinite, illite, montmorillonite and palygorskite. These minerals have the ability to lose or take up water depending on temperature and relative humidity present. Particularly the montmorillonite group is noted for its capability of accommodating water between its crystal layers, resulting in a significant expansion.

crater: a bowl-like hollow in the summit of a volcano directly above the vent.

cupule: small man-made circular depression in stone

feldspar: an important group of rock-forming silicate minerals. There are two main groups, the alkali feldspar group which ranges from potassium to sodium feldspars, and plagioclases which range from sodium to calcium feldspars.

felsic: containing light-colored minerals such as feldspar, feldspathoid and quartz (silica) from which the acronym was taken.

hawaiite: an fine-grained intermediate volcanic rock similar to andesite, but containing some olivine.

hotspot: stationary plume of rising magma from the mantle which generates chains of volcanoes as the plates move over it.

mafic: containing dark ferro-magnesian minerals.

mugearite: a fine-grained intermediate volcanic rock similar to basalt, containing oligoclase instead of calcic plagioclase.

obsidian: volcanic glass.

olivine: a group of silicates ranging from iron silicate (fayalite) to magnesium silicate (forsterite). It is the intermediate mineral within the olivine group of (single silicate structures or nesosilicates) rock-forming minerals, with the composition $(Mg,Fe)_2SiO_4$

pahoehoe: Hawaian term used to describe 'ropy' or undulating lava flows with billowy, sometimes shiny surfaces, resulting from more fluid lava.

peridotite: a class of rocks consisting mainly of olivine minerals.

phenocrysts: crystals embedded in the matrix of a rock that can be seen by the naked eye.

plagioclase: a series of sodium to calcium feldspars. It is a group of minerals within the feldspar mineral group whose composition ranges from albite ($NaAlSi_3O_8$) to anorthite ($CaAl_2Si_2O_8$). They are framework silicates or tectosilicates.

porphyritic: a texture with relatively large crystals set in a finer-grained groundmass. The original name derives from the Imperial Porphyry (from the Greek porphyreos, purple), a stone with reddish-purple groundmass and white phenocrysts.

pyroclastic: broken rock fragments erupted by a volcano, or layers of these fragmented rocks.

pyroxene: a group of (chain structure or inosilicates) rock-forming minerals, with composition raging from $MgSiO_3$ to $FeSiO_3$ or to $(Ca,Mg)(SiO_3)_2$ and $NaAl(SiO_3)_2$

rhyolite: a fine-grained to glassy acid volcanic rock.

shield-volcano: a volcano that emits, from clustered vents, very fluid lava, with few fragmented layers, building up gentle slopes that resemble shields.

somma: a circular or crescent ridge that is steep on its inner side having been the rim of an ancient crater.

tholeiite: the most silicic type of basalt containing about 50% silica, basic plagioclase and pigeonite (a pyroxene), with interstitial glass or quartz-alkali feldspar intergrowths.

trachyte: fine-grained alkali-intermediate igneous rock.

zeolite: a group of hydrous silicates (frame-work or tecto-silicates) with a structure that leaves open channels through the lattice and is capable of exchanging ions. They were used for softening hard water, where the Ca^{++} ions of the water were exchanged for Na^{+} ions originally present in the mineral.

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Photo: R. Z. Gianzone

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The red scoria statue called "Mata Mea" (Photo: G. Lee)

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