The Analysis of Sandstone Deterioration at the Northeast Point of Inscription Rock at El Morro National Monument

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Chapter 1: Introduction

1. Project Justification

El Morro National Monument was designated in 1906 as a national monument; one of a small group of natural and archaeological sites in the American southwest identified for their natural and cultural significance. Its nomination was based on the inscriptions left by 16th and 17th century Spanish explorers and over the following centuries, by travelers and locals alike. Many years after its designation, pictographs and petroglyphs created before and after the arrival of the Spaniards would come to be recognized as an expression of Native American indigenous culture and a long-lived presence at the site. People were drawn to this location near modern day Ramah, New Mexico because of a permanent water source at the base of the rock. Snowfall and rain collects at the top of the rock and run down the face, forming a pool at its base and then into an arroyo. The soft sandstone allowed for messages and signatures to be left behind; hundreds of inscriptions have been carved into the rock, giving the formation the name of Inscription Rock. Unfortunately, the same quality of the rock that allowed for easy carving is leading to erosion and delamination.

The northeast point of El Morro extends out towards the nearby road producing a form like the prow of a ship. Prior to the 1940s, the pool at the base was much smaller and the arroyo much larger. The arroyo wrapped around the point allowing water to flow at its base. In the 1940s the pool was dammed in order to create a larger water source and the arroyo was filled in, but when the pool overflows today the underground drainage still

closely follows the arroyo's path. The stone at the point is extremely friable and weathering in a manner different from any other location at the site.

This research will focus on the deterioration of the northeast point of Inscription Rock. It will explore the decay mechanisms through a comparative analysis of discreet conditions over time using past and present documentation. Potential causes will be considered as a function of the geo-chemical nature of the rock, hydrology, vegetation, topography and macro-geology of the point, moisture, salts, thermal response, and frost. The study will also examine how the treatment of sections of the point with ethyl silicate consolidants from 1996 through 2004 have influenced or changed the weathering patterns at the point, and if so whether the change has been beneficial or detrimental to the overall condition of the point and the inscriptions that are located there.

The National Park Service hopes to further investigate possible treatments for the northeast point, but a responsible treatment cannot be found without first answering the questions of how and why the sandstone is deteriorating, and how previous treatments have affected decay. Without further treatment the last of the inscriptions at the northeast point will most likely be lost in the near future. For this purpose, all available bibliography, surveys, photographs, treatment reports and studies conducted at this site will be reviewed to gain more information about the changes that have occurred over the years.

A detailed conditions assessment was conducted in the field on the entire lower AA section of the northeast point. Previous surveys focused on the inscriptions and the

stone that immediately surrounds them. The sections of the point that have been previously documented can be used to assess and evaluate the type and pattern of stone decay and for selected locations, suggest trends in the deterioration. Selected analyses have been conducted to better understand physico-chemical properties of the stone and associated decay processes and to corroborate previous findings.

It is hoped that the present study will give sufficient insight into the deterioration problems affecting this specific area of the site in preparation for management decisions regarding the preservation of the northeast point of Inscription Rock.

2. Literature Pertaining to El Morro

Concern for the monument has led the Park Service to commission many reports that tell the history of the site, assess the condition of the inscriptions, and characterize the monument, its constituents, and surroundings. To date there are several reports on the geology of the site, the hydrology of the site, a vibration study, a report of the microflora at El Morro, and a copious amount of work has gone into documenting the inscriptions, rating their conditions, and treatment of the sandstone.

2.1. Geology

El Morro is located in a rural, isolated section of central northwest New Mexico, at the southern part of the Zuni Mountains. The land formation that comprises the El Morro National Monument may best be described as a cuesta, "a type of inclined mesa formed by the erosion of tilted strata."[1] The El Morro cuesta is comprised of Zuni and Dakota Sandstones. The Zuni Sandstone stretches upward for more than 200ft, including a bleached zone in the rock at the upper levels. The Zuni stone is then topped with a 30ft layer of Dakota Sandstone.[2] George Austin, the Senior Geologist at the New Mexico Bureau of Mines and Mineral Resources did an extensive geological investigation at the site in 1991. His report indicates that the Zuni Sandstone was created by eolian dunes in the Middle Jurassic. The deposition of the sand by wind explains the fine to medium-fine, well-sorted nature of the grain. A change in climate in the Late Jurassic allowed for fluvial reworking of the stone, commencing the diagenetic processes that created the

[1] Cross, Aaron. "Stratigraphy, Sedimentology, and Surface Water Quality at El Morro National Monument," (Master's thesis, 1996).1
[2] Ibid 1.

greater part of the natural consolidant; authigenic clays. Leaching in an acidic environment during the Early Cretaceous period accelerated this development. The last stratum capping the monument is Dakota Sandstone.[3]

El Morro is located in the southern part of the Zuni Mountains. Zuni Sandstone is the rock that comprises the northeast point of Inscription Rock, and is therefore the sandstone that concerns this analysis the most. Zuni Sandstone is an argillaceous sandstone, primarily composed of quartz and some feldspar of uniform grain size, shape, sorting, and mineralogy, and bound together with clay. Both Austin and Cross allude to the uniformity of the material. Recently performed XRD has confirmed the primary composition of quartz, feldspar, and kaolinite clay. SEM has shown the uniformity of shape and grain size in the sample. Cross made the following observation as to the compaction of the stone.

> Neither bending, fracturing, nor deforming were observed in Zuni Sandstone grains, and rearranging appears to have been minimal. Grain contacts are mostly of the tangential or long variety with no observed sutured contacts, and intergranular space is largely preserved. Although the Zuni Sandstone was sufficiently buried to impart a well-developed joint system, the stress was insufficient to suture grains or effectively reduce intergranular space.[4]

The quartz grains in the Zuni Sandstone show no signs of dissolution, but petrographic analysis by Cross found that a sample from the northeast point showed a

3 Austin, George S. "Geological and Hydrological Assessment of El Morro National Monument." (New Mexico Bureau of Mines and Mineral Resources, 1992).

4 Cross, Aaron. "Stratigraphy, Sedimentology, and Surface Water Quality at El Morro National Monument," 43.

dissolution of the clay rims, clay being the primary natural consolidant.[5] Further characterization of the sample found a high level of porosity, no oversized pores, small globs of carbonate, and kaolinite in vermicular stacks.[6] The dissolution of the rims and this particular mix of conditions were not found in any of the other sixteen samples taken from the Zuni Sandstone for petrographic analysis.

The clay predominantly found is kaolinite, but chlorite, illite, vermiculite, and a mixed-layer illite-smectite can be found in lesser quantities. "The X-ray diffraction reflections are sharp and illustrate the well-crystallized nature of authigenic kaolinite. Chlorite in the Zuni, in particular chlorite cement, is also well crystallized. Kaolinite and chlorite appear to be formed post-depositionally and authigenically."[7] This is true of the majority of the clays as well as for detrital grains. Detrital grains of both chlorite and calcite were found in a sample taken by Austin from the northeast point.[8]

2.2. Hydrology

Schackel points out that the human need to change the surrounding environment to fit our desires and needs, specifically the introduction of grazing animals, the creation of footpaths, and other situations that called for the removal of vegetation, led to an increase in runoff and surface erosion of the ground near the monument.[9] She cites a *Southwestern Monuments Monthly Report* and the Historic Structures Report on the pool

5 Cross, Aaron. "Stratigraphy, Sedimentology, and Surface Water Quality at El Morro National Monument," 52.

6 Ibid Appendix D-1.

7 Austin, George S. "Geological and Hydrological Assessment of El Morro National Monument," 7.

8 Ibid 4; 8.

9 Schackel, Sandra. " A Century of Change: A Photographic History and Analysis of Vegetation Conditions, El Morro National Monument, 1891-1983." Southwest Region, National Park Service, united States Department of the Interior, February 25, 1984.

at the base of the cuesta in pointing out the rate at which the arroyo was growing before measures were taken to erase the feature from the grounds.[10] It was stated that in 1889 the gully could easily be crossed in one step at its widest place, but by 1916 Evon Vogt observed that the arroyo was both fifteen feet wide and deep.[11]

The pool was dammed with concrete in 1926 by custodian Evon Vogt. Prior to the damming of the runoff from the face of the rock fed an arroyo that wrapped around the point and ran northward towards the road. This arroyo was filled-in as part of a Civil Works Association project that was completed in 1934. Dynamite and pack animals were used to collapse the arroyo, and create a gentler curve in the landscape. The dam was destroyed by a rock fall in the summer of 1942, and was subsequently replaced with a second concrete barrier that is still in place today.[12] Vegetation covering the area where the arroyo once stood would indicate that the soil holds at least enough moisture to sustain the abundance of plant life.[13]

Although previous reports have assumed, or cited other sources stating the existence of a water table under the rock, the Remke van Dam and Jan Hendrickx hydrology report drafted in August of 2006 concluded that there was no such water table under the northeast point of inscription rock or under the pool. This was based on the use

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10 Ibid.

11 Schackel, Sandra. " A Century of Change: A Photographic History and Analysis of Vegetation Conditions, El Morro National Monument, 1891-1983."

12 Oliver, Anne and Antoinette Padgette. "A History of Inscription Preservation at El Morro National Monument 1849-2005,"(draft. Historic Architecture Group, National Park Service, United States Department of the Interior, Intermountain Support Office, Santa Fe, New Mexico, October, 2005) 6.2.

13 Van Dam, Remke L. and Jan M.H. Hendrickx. "Hydrological Investigation at El Morro National Monument,"(Draft. New Mexico Tech, Socorro, New Mexico, August 2006)2.

of ground penetrating radar (GPR) and piezometers. The piezometers were placed near the northeast point, in areas where the arroyo once stood, and near the pool. Those near the point, or in the arroyo near the point were found to be dry during the test season of July and August 2004.[14]

Seasonal variations in moisture conditions were measured using electromagnetic induction measurements. This data was collected in March, July, and August of 2004. High readings in March were attributed to snowmelt, and those in August were due to the rainy season. July was a dry month. The researchers found that the presence of the cliff does significantly influence the moisture content of the nearby ground.[15] The authors of the report do not specify if this is due to the shade given by the cuesta or if there are other reasons, but in studying the water at the pool it was found that rainwater and snow melt enter through the top of the cuesta and percolate down through the stone matrix to the pool.[16] It is unknown what percentage of the pool water is made up from the moisture that had infiltrated the stone, but the pool water certainly contains direct rainfall and runoff in addition to the percolated moisture. Tests to study the hydraulic properties of rock were conducted, but proved to be inconclusive. The samples being used disintegrated before the test was completed.[17]

14 Van Dam, Remke L. and Jan M.H. Hendrickx. "Hydrological Investigation at El Morro National Monument,"2.

15 Ibid. 3-4.

16 Ibid. 13.

17 Ibid.12.

Chapter 2: Literature Pertaining to El Morro

2.3. Microflora

St. Clair submitted a final report to the park service in 2001 on the impact of lichens on the inscriptions at the monument. Among other things, St. Clair studied the variety of microflora on the monument, reported on their possible detrimental effects on sandstone, and used indicator species to illustrate whether air pollution was a problem at El Morro. Although the lower AA section, the focus of this study, was not sampled directly the following 43 lichens and mosses were found at the monument:

> *Acarospora fuscata, Acarospora sp.1, Acarospora sp.2, Acarospora sp.3, Acarospora sp.4, Aspicilia desertorum, Aspicilia sp.1, Caloplaca decipiens, Caloplaca fraudans, Caloplaca siderites, Caloplaca sp.1, Caloplaca sp.2, Candelariella sp., Collema sp., Dermatocaropon sp., Lecanora cenisia, Lecanora cenisia, Lecanora novomexicana, Lecanora valesiaca, Lecanora sp.1, Lecanora sp.2, Lecidea sp.1, Lecidea sp.2, Lecidea sp.3, Lecidea sp.4, Lecidella sp., Lepraria sp., Melanelia sp., Peltula sp., Physcia caesia, Physcia sp., Physcia/ Phaeophyscia sp., Rhizocarpon, Rinodina sp. Staurothwlw sp., Toninia sp., Xanthoparmelia sp.*[18]

Some of the lichens found do produce weak organic acids and chelating agents that may contribute to the dissolution of magnesium silicates and ultimately the deterioration of the sandstone. Testing of the indicator species *Usnea hirta* found that air pollution levels were not at a harmful level for the site, and were not cause for concern as of the reports submission in 2001.[19]

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18 St. Clair, Larry. "Impact of Microflora (Lichens) on the Condition of the Sandstone and Inscriptions at El Morro National Monument, Ramah, New Mexico." np.

19 Ibid.

2.4. Vibration Study

A vibration study was conducted by King in 2003. The report aimed to assess the risk of vibrations from the nearby road and visitor foot traffic. It was found that "the natural vibration periods of the rock columns are far below the vibrations induced by the heavy trucks."[20] One of the five sites tested in the vibration study at El Morro was the northeast point. It is interesting to note that "the natural period of this point of rock is from 2-3 seconds 0.5 – 0.3 Hz however; the shorter slab has a natural period of 0.06 to 0.08 seconds (13-17 Hz). The horizontal particle motion diagram indicates the tall column is moving in line with the mesa whereas the shorter slab is moving offline."[21] Although interesting, the difference in frequency was not noted to pose a danger. The final analysis concluded that "the inscriptions would be at a vibration risk from the highway IF [sic] they were located within 200 feet of the roadway or 300 feet if the roadway was rough or pot-holed."[22] The nearest inscription currently resides 400 feet from the road. "Expansion of the roadway or if the condition of the road deteriorated, the vibration risks will increase to moderate."[23] The researcher noted that the tests were not conducted during blasting at the gravel pit up the road. It was not believed that the mining was a danger to El Morro in its then current state in 2003, but if mining were to

20 King, Ken and Elaine King. "El Morro National Monument Preliminary Vibration Study," (K. King independent consultant, El Morro National Monument, National Park Service, United States Department of the Interior, September 2003,) summary.

21 King, Ken and Elaine King. "El Morro National Monument Preliminary Vibration Study," 6.

22 Ibid, 14.

23 Ibid, 14.

move closer, or the size of the charge used in the blasting were to change risk would need to be reassessed.[24]

2.5. Human Occupation and Use

The ruins of a pueblo are perched on the top of the Dakota sandstone stratum of the cuesta, marking the past site of human habitation. It is not known with any certainty what tribe inhabited the land, but it is known that the pueblo was constructed at the same time as other Zuni towns in the late 1200s. The site was deserted only seventy-five years after its formation. The people that occupied the pueblo at El Morro left pictographs,[25] and carved handholds into the face of the sandstone.[26] The land was farmed by the local Native American population during the thirteenth, fourteenth, and fifteenth centuries. The area was logged during the same time period and into the 19th century. The first grazing animals were introduced by the Spaniards in the sixteenth century.[27]

The first known inscription was left in 1605 by the first Governor of New Mexico, Don Juan de Oñate. Spaniards heading northward and eastward followed in his path, stopping at El Morro to benefit from the pool, and leaving sign of their passing. The tradition of leaving an inscription continued as the new Americans moved westward after the Mexican-American war. Inscriptions were left by soldiers, cavalry men, railroad workers, and settlers moving west. In the 1920s, the Caretaker of the monument, Evon

24 Ibid.

25 El Morro, National Park Service, [n.d.]

26 Mooseman, Fred. Verbal communication.

27 Schakel, Sandra. " A Century of Change: A Photographic History and Analysis of Vegetation Conditions, El morro National Monument, 1891-1983."

Vogt either removed himself or ordered the removal of any inscription left after 1906, the year that the monument came under federal protection.[28] Inscriptions were hacked off with axes or scrubbed off with wire brushes. Even today, people from around the world still would want to carve the stone, and must be dissuaded by park service employees. When newly left inscriptions are found rangers remove the graffiti with a graffiti removal kit that includes a metal wire brush.[29]

2.6. History of Preservation

In the early days of inscription preservation at El Morro, graphite pencils were used to darken inscriptions in order to create a better viewing experience for the visitor. The pencil was pressed firmly into the markings in order to inscribe the carvings more deeply into the stone, and insure against erosion. Unfortunately, this process would have dislodged grains of sand silt and clay, gradually deepening the inscriptions. When this was deemed to be too destructive Rising Sun brand stove polish[30] was applied with a sable brush to darken the writings, and make them more visible. The last known record of

28 Sievers, Douglas W."El Morro: A unit History", National Park Service, United States Department of the Interior, August 14, 1970.; "Interview with Bob Budlong….September 29, 1971."

29 Oliver, Anne. "El Morro National Monument Pilot Inscription Treatment Program July 1996," National Park Service, United States Department of the Interior, Intermountain Cultural Resources Center, November 1996.

30 No patent could be found for Rising Sun brand stove polish. Patent number 598948, filed June 2, 1896, issued February 15, 1898, for electric battery for medical purposes indicates that rising sun stove polish, which can be used in the production of this patented item, is at least in large part graphite, although a review of patents for stove polishes developed during the second half of the nineteenth century could contain a number of ingredients beyond graphite including soaps, oils, alkali earth materials, lamp-black, borax, alum, benzene, rosin, and organic products.

the darkening of the inscriptions is from 1957. It is unknown how long after that year the process was continued.[31]

The friability and high erosion rate of the stone sent the monument's caregivers searching for consolidants and means of preservation early on. In 1925, El Morro's first custodian, Evon Vogt experimented with the use of paraffin wax in preservation. He started by testing the wax on an inscription of his own making, "Colorless coatings save old inscriptions," and then moved on to the more well known of the historic inscriptions. Oliver and Padgett report that those that were treated are still in good condition, whether from the use of paraffin or their well protected locations on Inscription Rock.[32]

Budlong followed in Vogt's footsteps as caretaker of the monument, serving in the position from 1936 through 1942. In 1941 Budlong undertook the massive task of cleaning and waterproofing inscriptions. According to the July 1941 issue of *Southwestern Monuments Monthly Report* he first removed the clay wash from the surface of the stone, and then sprayed an aluminum stearate, diluted in a petroleum distillate vehicle to the surface of the stone. In this manner he waterproofed the north face of Inscription Rock. This method of moisture protection was used at least through 1943.[33]

The thinking behind the use of paraffin wax evolved to the use of chemically derived consolidants by the 1960s. Several consolidants were tested in Nine Pine Cove during this decade. The cove is not near the northeast point of inscription rock, and there

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31 Oliver, Anne and Antoinette Padgette. "A History of Inscription Preservation at El Morro National Monument," 5.1.

32 Ibid, 5.3.1.

33 Ibid, 5.3.2.

is no mention of any use of these consolidants moving past the test phase. Many of the records are missing, but what little is known has been collected by Anne Oliver and Antoinette Padgett in *A History of Inscription Preservation At El Morro National Monument: 1849-2005*. The list of test products included Daraweld[34], Daracone[35], and a synthetic resin called Pencapsula.[36]

The northeast point experienced a huge loss in 1979. Park Ranger, Steve Miller reported in a memorandum in June of that year that a large segment of panel AA13 had crumbled away due to natural causes. Upon closer study Park Service employees noted that seven inscriptions had been lost from this one panel.[37] In 1980 a list of names at the northeast point that had been lost to erosion was created. Two panels (AA3 and AA4) were listed as buried. Two inscriptions were noted as obscured by a white discoloration in panel AA6, eight inscriptions (panels AA8, AA9, AA13, and AA14) were partially missing. Twelve were listed as certainly missing (panels AA10, AA13, and AA14). Three inscriptions from AA12 were presumed missing, but the panel was so altered the documenter was not sure that they were looking in the correct spot. A fracture in AA14a

34 No patent can be found for this particular product, but a patent issued in December of 1968 for the fabrication of masonry walls and partitions (Patent number 3416276) lists an adhesive named Daraweld produced by Dewey-Almy Chemical Company. The only other product produced and used during this time period with a similar name is Daraweld-C (patent number 4172063). Daraweld-C is a vinyl acetate copolymer latex used primarily as an additive in cement to increase bonding. It was used in mid-century preservation treatments at Casa Grande. The product was used at Casa Grande in the creation of a render.
http://www.nps.gov/archive/cagr/adhi/adhi5a.htm. accessed 4 March 2007

35 A silicone water repellent, patent number 3007812.

36 No patent found.

37 Miller, Steve. Supervisory Park Ranger for the record, June 30, 1979. unpublished memorandum, record, H-1415.

was noted as a new threat that had not been noted in past documentation.[38] In 1990 Superintendent Reed Detring decided that something must be done about the continued degradation of the inscriptions at El Morro and convened a meeting that included members of the Getty Conservation Institute, and started the El Morro Inscription Preservation Program (EMIPP)[39]

In 1992 rock art conservator, Antoinette Padgett, began an assessment of the conditions of the panels. The then-current state of the panels was compared to photographs of the panels that were taken in 1955 by Howell and McNeil. Padgett took photographs of the panels that were being monitored that year. Based on visual observation Padgett found that salt, insect activity, clay/water wash, the presence of biogrowth, graffiti, and graffiti removal, moisture, unknown accretions, and loss were deterioration factors that were mapped on overlays of the photographs. Written documentation for each panel was completed, and recommendations were made as to future documentation, condition assessments, and the long-term monitoring and care of the panels.[40] The assessment project that was begun in 1992 was carried on in 1993 and 1994 with the addition of Barthuli to the team. In 1992, fifty panels were assessed; in the following years, 610 panels were completed. A numerical value system that ranged from

38 This record is titled only Names Etc. Lost to Erosion on the Point of Inscription Rock As Surveyed in July of 1980. No name is associated with the document. It was found as a single sheet of paper in file H22, "List of Inscriptions," Archival box H and K, located in the fire proof case in the archive room at El Morro.

39 Oliver, Anne and Antoinette Padgette. "A History of Inscription Preservation at El Morro National Monument,"

40 Oliver, Anne and Antoinette Padgette. "A History of Inscription Preservation at El Morro National Monument," 4.3

0 to 6 was created to gauge the threat to each panel. A monitoring program was started based on the priority rating of the inscriptions.[41]

The EMIPP and the work done by Padgett and Barthuli laid the ground work for treatment options to be considered. A cooperative agreement was struck between El Morro and the Architectural Conservation Laboratory at the University of Pennsylvania in 1993. Dawn Melborn wrote her 1997 thesis on spot weld epoxy treatments and cement based grout treatments for delamination at El Morro. Scott Kreilick began looking into the use of mechanical pinning in 1996. He eventually settled on a dry system pinning method that used a stainless steel pin with a nylon sheath to reattach fragments of inscriptions that had broken away from the rock face. Both of these methods proved to be helpful in areas of the rock that suffered from delamination and spalling, but do not address the problem of granular disintegration at the northeast point.

In 1996, under the supervision of Frank Matero, Veronica Aplenc tested an aliphatic epoxy resin, sold under the brand name Eponex 1510, and an ethyl silicate, sold under the brand name of Conservare OH for use at El Morro. The epoxy resin had a slightly higher resistance to abrasion, and altered the water absorption rate less than the ethyl silicate, but both consolidants proved to be acceptable.[42] The ethyl silicate was chosen for its ease of use at the site. The ethyl silicate was applied in the commercial form of Conservare OH by Anne Oliver, first in 1996, and then in 1997, 2000, and 2004. Of the forty-four inscriptions treated, eight have needed re-treatment since 1996. Six of

41 Ibid. 4.4

42 Aplenc, Veronica and Frank Matero. "Consolidation of Zuni Sandstone from El Morro National Monument"

the forty-four treated inscriptions fell into the AA section of the northeast point; three of those have needed re-treatment since 1996.[43]

A small pinyon tree and a chamisa bush were removed from a crack that had formed between the upper and lower AA section of the rock in 1996. The crack that was left behind was filled with hydraulic lime-based mortar. The stone has eroded considerably since the mortar was placed. In the summer of 2006 the stone had eroded as much as 14 cm at the center of the ledge. The top of the ledge dips in the center where a joint in the face of the northeast point allows water to funnel from the top of the stone down the center face of the AA section.[44] For a visual comparison of the condition of the northeast point in 1955 and 2007, and the eroded joint, see chapter 6, figures 6.1 through 6.3.

43 Oliver, Anne and Antoinette Padgette. "A History of Inscription Preservation at El Morro National Monument,"

44 Ibid.

3. Laboratory Analysis

3.1. Sampling and Testing Methodology

A sample of Zuni Sandstone was taken from El Morro National Monument in the summer of 2006 to confirm and advance Austin and Cross' findings. The cultural resource was deemed too valuable to core samples from the surface of the stone, so a piece that had fallen from the area just over the southern corner of the ledge above the northeast point the previous October was taken. The sample was a pale yellowish green, friable and roughly 9 inches x 7 inches x 7 inches. X-ray diffraction, thermo gravimetric analysis, differential thermal analysis, and scanning electron microscopy were used to better understand the composition and matrix of the stone.

Figure 3.1 Sample taken from El Morro National Monument 18 August 2006

3.2. X-Ray Diffraction

3.2.1. Objective:

X-ray diffractometry (XRD) measures the Bragg angle at which the x-rays are reflected from a crystalline sample. When compared against a database of known samples crystalline compounds within the sample can be identified. This test was run against the El Morro sandstone to confirm past findings on the composition of the stone.

3.2.2. Procedure:

The sample was first ground in a mortar and pestle to a fine powder. A small portion was placed on a piece of glass with a drop of acetone. A razor blade was used to drag the sample across the surface to form an even coating. The sample was scanned at 2 stops at a 60 scan speed, meaning that 2 angles were scanned a minute. The pattern that results from the scan was then compared against a database of known compounds.

3.2.3. Results:

Comparison of the sample with the ICID database suggests the presence of kaolinite and quartz and possibly orthoclase. The sample spectra and matches are presented below.

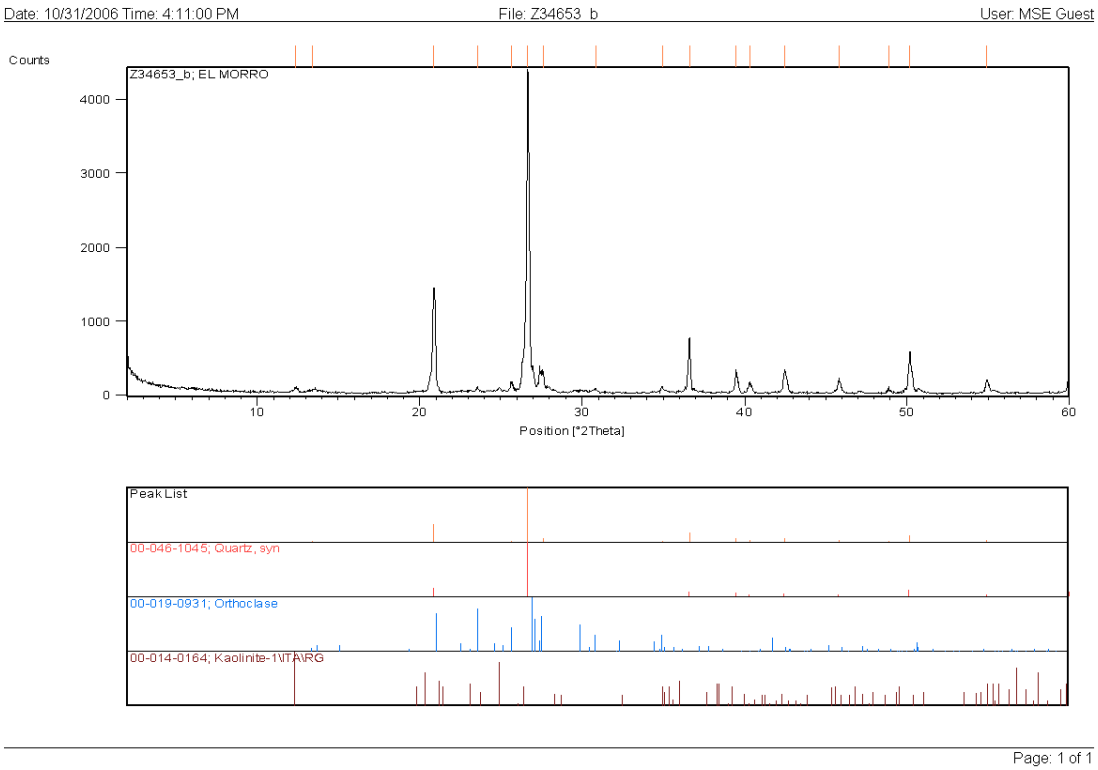


Figure 3.2 XRD results for El Morro Sandstone

3.3. Thermo Gravimetric Analysis and Differential Thermal Analysis

3.3.1. Objective:

Thermo gravimetric analysis (TGA) measures the mass of a given sample as it is heated, and analyzes the composition of the material based on the loss of weight as a function of heat and time. Differential thermal analysis (DTA) is able to measure endothermic and exothermic reactions to determine phase transitions, melting points, and temperatures at which compounds within the material crystallize.

3.3.2. Procedure:

A 27.5906 mg sample was prepared for analysis by mildly abrading the surface of the larger sample with a metal spatula. The powder was then placed in a glass vial. This was taken to the Laboratory for Research on the Structure of Matter (LRSM) at the University of Pennsylvania. A graphite cell was used to tare the scale inside the TGA-DTA machine. The powdered sample was then packed into the cell, and placed in the apparatus. Air was pumped out as a less combustible gas, argon, was pumped in and the temperature was set to 1000 . The temperature rose at twenty degrees per minute.

3.3.3. Results:

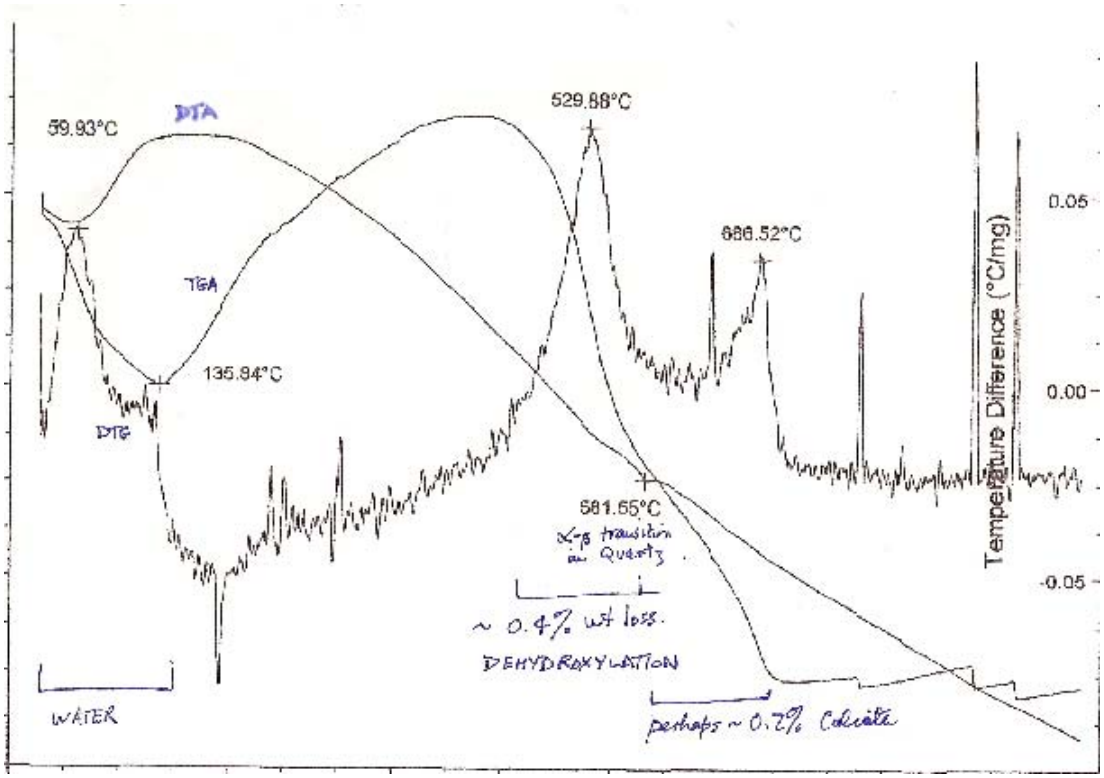


Figure 3.3 TGA-DTA results. Written notes are by Dr. Andrew McGhie.

The top line of the chart is the DTA, the middle line is the TGA, and the last line is the derivative weight. The DTA line compares the weight of the sample with that of the reference compound. The TGA line combines thermal analysis and thermogravimetry. It measures endothermic and exothermic reactions. The DTG line represents the loss of weight.

The first spikes in the DTG line that stretch to about 150 degrees represent the surface water being driven off. This is a minor loss to the overall weight of the sample. The incline of the TGA line between about 225 degrees and 350 as an instrumental error; the instrument was drifting at this point. The slight divot in the DTA line at 581.55 degrees Celsius is the alpha beta transition in the quartz. The 0.4% weight loss around 530 degrees may indicate dehydroxylation of clays.

The spikes in the DTG line around 686 degrees are indicative of calcite. The calcite was only present in trace amounts in the sample. The overall weight loss reflected in this spike is about 0.2%.

3.4. Scanning Electron Microscopy

3.4.1. Objective:

A sample of the sandstone was studied using a scanning electron microscope to better understand the fabric and texture of the rock.

3.4.2. Procedure:

A previously cut and mounted sample was coated in silver paint and placed in a vacuum, covered in vaporized gold, and positioned inside the scanning electron

microscope. Ten volts were used in the scanning of the sample. Photographs were taken between 20X and 5000X.

3.4.3. Results:

Upon close examination the sandstone sample was found to be composed of a fine, homogenously sorted grain. At 2000X it is evident that the cementing matrix of the sandstone is clay. Figure 5 shows platelets of clay surrounding the grains.

The photographs taken of the sample are attached in the following pages.

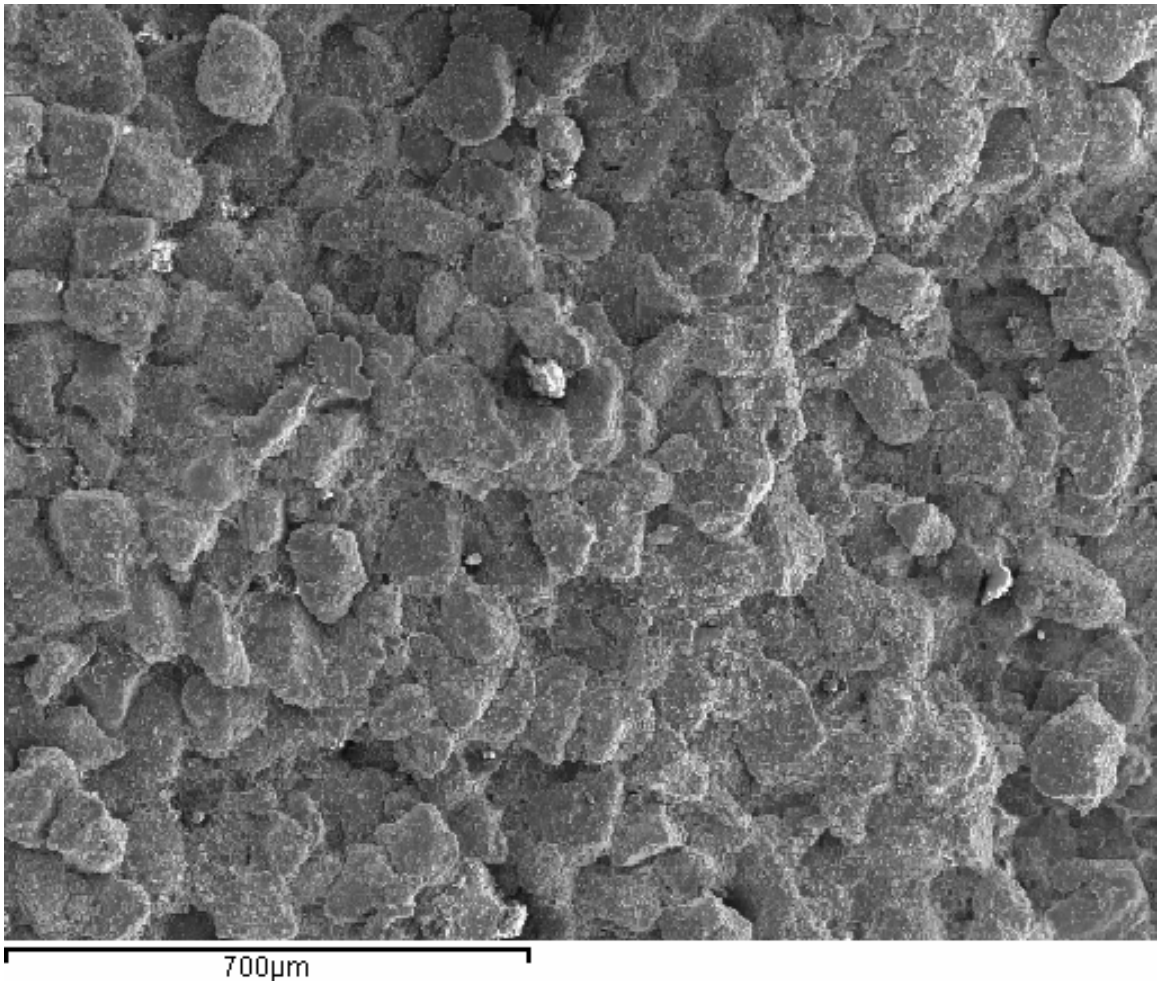


Figure 3.4, 75X: The sandstone is comprised of homogenous grains coated and held together by a clay cementing matrix.

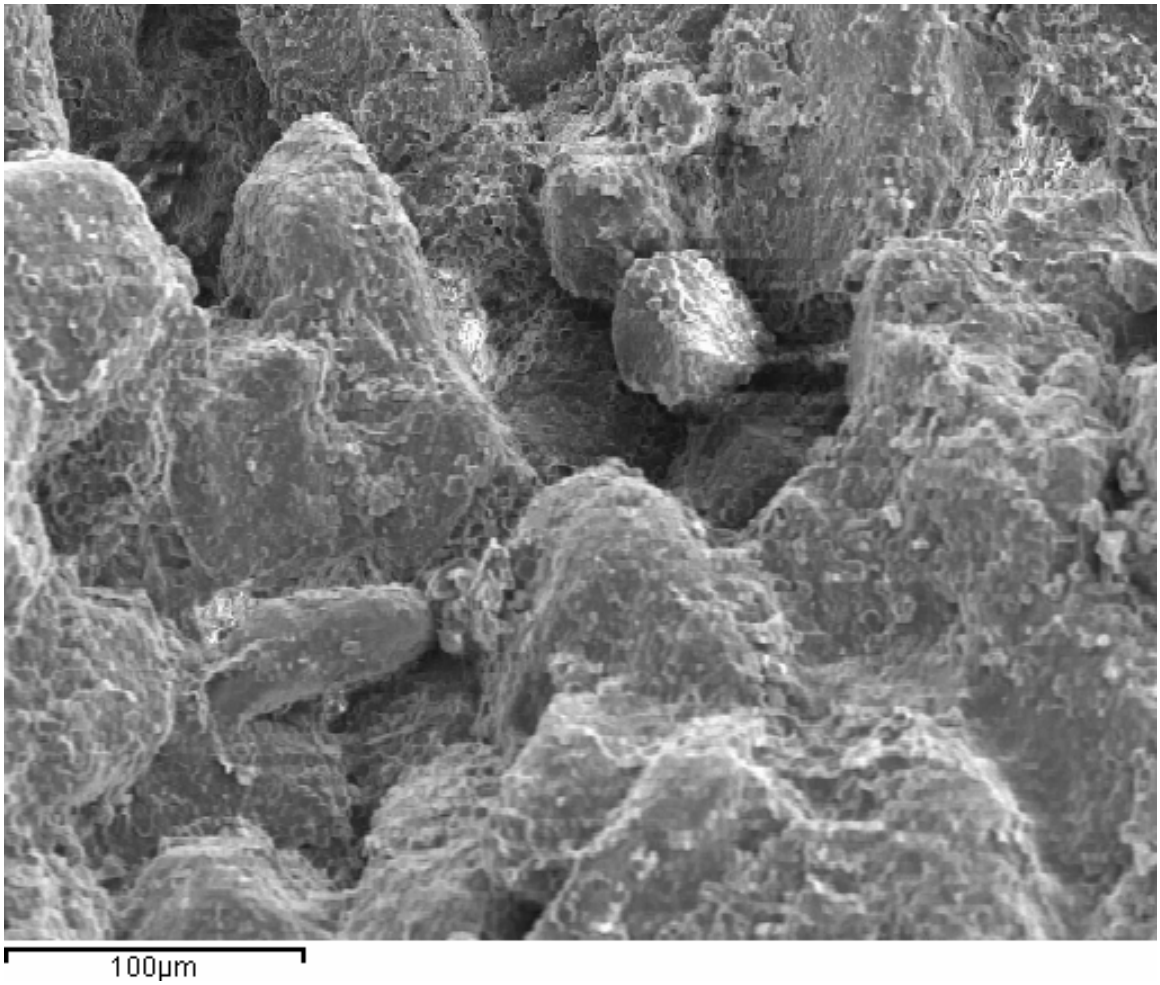


Figure 3.5, 300X: Note the mineral grains coated with a clay matrix.

3.5. Summary of Results

The results of the analysis reinforce the findings of both Austin and Cross. The Zuni Sandstone at the northeast point is largely composed of well sorted grains of quartz, poorly bound by kaolinite clay. Orthoclase, a member of the feldspar family is a predominate constituent of the stone, and of a similar grain size as the quartz. Calcite is also present, making up only about 0.2% of the sample stone. The thin sections examined by Austin showed the calcite found in this section of the monument to be in the form of detrital grains.[45] Out of the eleven samples that were taken in Austin's geological survey, the sample from the northeast point was the only one to have calcite in a granular form.

45 Austin, George S. "Geological and Hydrological Assessment of El Morro National Monument." (New Mexico Bureau of Mines and Mineral Resources, 1992).

4. Literature of Sandstone Decay

Weathering is a natural phenomenon wherebv the climatic effects of precipitation, sun, wind, and other atmospheric conditions greatly influence the durability of the rock.[46] All sandstones share certain intrinsic characteristics based on their lithogenesis. As sedimentary rocks, they all display bedding discontinuity and a wide range of porosities based on grain size, shape and sorting. Cementing minerals generally determine the overall durability of sandstones, all other aspects being equal. Argillaceous and calcareous sandstones tend to be less durable than ferruginous or siliceous types. Although all sandstones are altered by the extrinsic agents of weathering, many conditions can be traced back to moisture and indeed problems pertaining to salt and frost damage would not occur without the presence of moisture and the mechanics of moisture cycles.

4.1. Necessary Conditions for Decay and Contributing Factors

4.1.1. Moisture

The movement of moisture into, within, and out of stone depends largely on the porosity and permeability of the material in question. Weathering tends to increase the percentage of large pores and decreases the number of capillary pores,[47] thereby altering

46 Mitchell, D. J., David P. Halsey, Karl Macnaughton, David E. Searle. "The Influence of Building Orientation on Climate Weathering Cycles In Staffordshire, UK.," In Proceedings of the 9th International Congress on Deterioration and Conservation of Stone, Venice, June 19-24, 2000, ed. Vasco Fassina (Amsterdam: Elsevier, 2000), 134-144.

47 Amoroso, G.G and V. Fassina. *Stone Decay and Conservation: Atmospheric Pollution, cleaning, Consolidation and Protection*., Materials Science Monograph II, (Amsterdam: Elsiver, 1983);

the way in which the rock absorbs, transports, and loses water. Moisture can enter rock through the capillary rise of ground water, through the absorption of penetrating rain, fog, and melting snow, and by the adsorption of water in the vapor phase as humidity. The wetting-drying cycles involved in the absorption and eventual evaporation of moisture eventually lead to the swelling and contracting of the stone, otherwise known as hydric or hygric dilation. Through the mechanism of hydric dilation, many sandstones have been shown to expand in the range of 500 μm/m, but clay-rich sandstones, like those found at El Morro National Monument, can swell and contract up to 5000 μm/m.[48] Under laboratory conditions the material is able to return to its normal dimensions after the pore liquid evaporates; however Snethlage and Wendler surmise that under field conditions

Wendler, Eberhard, Ludwig Sattler, Peter Zimmermann, Dietrich D. Klemm, and Rolf Snethlage. "Protective Treatment of Natural Stone Requirements and Limitations with Respect to the State of Damage.," In *Proceedings of the 7th International Congress on Deterioration and Conservation of Stone, Lisbon, Portuga,l 15-18 June 1992*. ed. J. Delgado Rodrigues, Fernando Henriques, and F. Telmo Jeremias (Portugal: Laboratório Nacional de Engenharia Civil, 1992), 687- 695;

Ihalainen, Pekka. "Changes in Porosity of Some Plutonic Building Stones Depending on the Type of Artificial Weathering Treatment.," In *III International Symposium on the Conservation of Monuments in the Mediterranean Basin*, *Venice, Italy, 22-25 June 1994*. ed. V. Fassina, H. Oh, F. Zezza (Venice: Soprintendenza ai beni artistici e storici di Venezia, 1994), 109-113.

Pèrez-Bernal, J.L., and M.A. Bello. "Weathering Effects on Stone Pore Size Distributions." In *Protection and Conservation of the Cultural Heritage of the Mediterranean Cities, Sevilla, Spain, 5-8 April, 2000*. ed. Galán and Zezza (Lisse: A.A. Balkema Pub., 2002) 203-207.

Ihalainen, Pekka. 1994. changes in Porosity of Some Plutonic Building Stones Depending on the Type of Artificial Weathering Treatment.,

Pèrez-Bernal, J.L., and M.A. Bello. 2002. Weathering Effects on Stone Pore Size Distributions.

48 Vincente, M.A., J. García-Talegón, A.C. Iñigo, E. Molina, V. Rives. "Weathering Mechanisims of Silicated Rocks in Conteniental Environments," In Conservation of Stone and Other Materials: Proceedings of the International RILEM/UNESCO Congress "Conservation of Stone and Other Materials: Research Industry Media" held at UNESCO headquarters, Paris, June 29 – July 1, 1993.ed. M.J. Thiel (London: E&FN Spon LTD., 1993) 320-327.

the sandstone could suffer from material fatigue after repeated wet-dry cycling. This would result in permanent deformation and possible collapse after dilation.[49]

Wendler has shown, using a sample of Sander Schiff sandstone, that a given sample can be divided into three zones according to moisture absorption. The outer surface zone has the highest rate of moisture absorption, and therefore the highest propensity for hydric and hygric dilation. In the sandstone tested, this zone was the outer 8 mm of stone. The middle zone, between 12 and 20 mm deep, expanded and contracted with moisture absorption less than the surface zone. The difference in expansion rates between the surface and middle zones suggests a possible cause for mechanical failure and damage to the middle zone. The inner zone is the un-weathered portion of the stone. Testing of the Sander Schiff showed this zone to be roughly 20 to 30 mm deep and relatively unaffected by moisture absorption.[50]

The moisture distribution within any rock will depend upon the geo-chemical properties of that rock and the surrounding environment. If the material is permeable and transports moisture well, the moisture distribution may go deeper within the rock than if the stone was dense and less permeable. If the surrounding wind speed and thermal conditions allow for quick drying. then the moisture distribution may be closer to the surface. When salts are present they will be found in the pores of those areas that

49 R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation. In Saving Our Architectural Heritage: The Conservation of Historic Stone Structures, Dhalem Workshop, Berlin, March 3-8 ,1996. ed. N.S. Baer and R. Snethlage (chichester: Wiley, 1997), 7-24.

50 Wendler, Eberhard. "Contour Scaling On Building Facades – Dependence On Stone Type and Environmental Conditions." In Materiasl Issues in Art and Archaeology II: Materials Research Society Symposium Proceedings, San Francisco, April 17-21, 1990. ed. Pamela B. Vandiver, James Druzik, George Segan Wheeler (Pittsburgh: Materials Research Society, 1991), 265-271.

transport the most moisture. The areas of the stone that receive the most moisture will therefore be the areas that also reveal the most damage.[51]

4.1.2. Freeze-thaw cycling

The freezing of moisture within masonry pores is purportedly one of the more commonplace means of deterioration in colder climates. If the material was to be fully saturated and then frozen the matrix of the sandstone would need to expand to accommodate the growth of ice crystals within the pores. When this occurs the sandstone matrix can deform and yield to the internal disruptive pressures of ice crystallization. If partially saturated the material contracts as the pore liquid freezes, drawing moisture from surrounding pores, and creating capillary under pressure that can cause contraction of the rock. The contraction and expansion of the stone is similar to hygric and hydric dilation in that it can cause material fatigue after the countless cycles that can occur in the field. [52]

4.1.3. Thermal Expansion

Dilation and contraction can also be caused by thermal radiation. This can be particularly damaging if, as is generally the case with large rock outcrops and stone buildings, exposure to sunlight is partial. The difference in surface temperature can cause differential expansion and contraction which in turn can lead to internal stresses resulting in rock failure. This was illustrated in an experiment conducted by Thomas Paradise, whereby two exposed rock surfaces in a quarry were monitored. The primary difference

51 R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation."

52 R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation."

between the two test panels was the orientation of each panel relative to the sun, and the amount of thermal energy received. The panels deteriorated differently, suggesting that thermal radiation from sunlight can accelerate the deterioration of stone. Paradise also noted that the micromorphology and specifically the spacing of the grains in sandstone affect the stone's susceptible to this type of damage.[53] Another study found that sandstone was better able to accommodate internal stresses than a material like granite,[54] but as Snethlage and Wendler point out the constant expansion and contraction that will occur in a natural environment will eventually lead to deformation and mechanical failure. As Snethlage and Wendler also note, if salts are involved in the system then this can greatly effect and exaggerate dilation and subsequent retraction.[55]

53 Paradise, Thomas R. "Sandstone Architectural Deterioration in Petra, Jordan." In Proceedings of the 9th International Congress on Deterioration and Conservation of Stone, Venice, June 19-24, 2000, ed. Vasco Fassina (Amsterdam: Elsevier, 2000), 135-144.

54 Vincente, M.A., J. Garcia-Talegón, A.C. Iňigo, E. Molina, and V. Rives. "Weathering Mechanisms of Silicated Rocks in Continental Environments." In Conservation of Stone and Other Materials, Proceedings of the International RILEM/UNESCO headquarters, Paris, June 29- July 1, 1993. ed. M.J Thiel (London: E&FN Spon, 1993), 320-327.

55 R. Snethlage and E. Wendler. " Moisture Cycles and Sandstone Degradation."

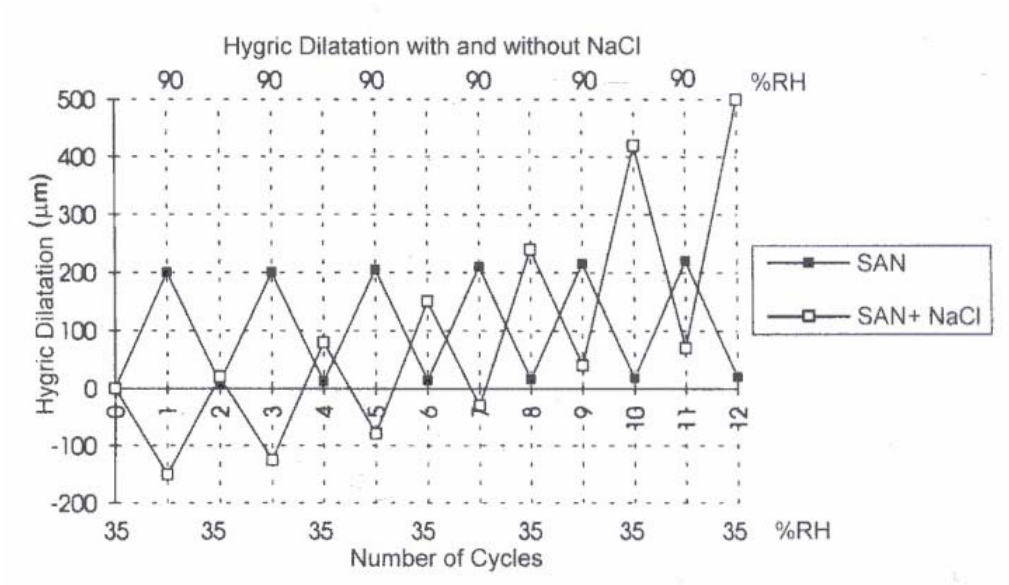


Figure 4.1 The effects of NaCl on the hygric dilation of Sander Schilf sandstone as illustrated by Snethlage and Wendler in "Moisture Cycles and Sandstone Degradation."

4.1.4. Air Pollution

Air of poor quality, in many cases due to industrialization, may contain detrimental compounds such as SO_2, N_2O, NO_2, NH_3, and CH_4. These gases contain harmful molecules that settle out of the atmosphere as dry deposition. The molecules are then free to react with atmospheric moisture to form acidic compounds that affect the surface as well as sub-surface pore structures of rock and stone.[56] It is a generally held truth that rural areas are less susceptible to the damages caused by air pollution, and pollutants are not currently a large concern, but if there were to be a change in air pollutant causing industry in the region then air quality should be monitored.

56 Honeyborne, David. "Weathering and decay of masonry." In Conservation of Building and Decorative Stone, Butterworth-Heinemann Series in Conservation and Museology, ed. John Ashurst and Francis G. Dimes (London: Butterworth, 1990), 153-178.

4.1.5. Salts

Soluble salts can be attributed to a variety of sources. Ions can be leached from the soil, the stone itself, associated building components such as mortars and grouts, atmospheric deposition, past treatments, and from associated biological agents, both plant and animal. Chloride salts can originate from ground water particularly if humans are in nearby habitation and maritime environments, from deicing salts, or from biological sources. Sulfates and nitrates may be derived from dry deposition caused by air pollution. Nitrates specifically may come from nearby agricultural fertilizers or animal waste, and groundwater can be a source of all of these salts and others such as carbonates[57].

Hydrate forming salts are driven to self-equalize, and will bond with water to form a solution.[58] In nature salts are often present in solution not as a sole compound, but as a complex mixture. In such cases the prerequisites needed for an individual salt to precipitate are altered by the other compounds present. Salts that are less soluble will precipitate out sooner, and will be closer to the solution's point of entry within a material. A more soluble salt will be carried farther via moisture transport, and will therefore crystallize at a higher level on a vertical surface than the less-soluble salt. Assuming that there is no blockade to moisture transport within the stone, the distance traveled by a salt before it precipitates will depend upon several factors, including not only the type of salt,

57 Arnold, Andreas and Konrad Zehnder. " Salt Weathering on Monuments." In The Conservation of Monuments in the Mediterranean Basin, Proceedings of the 1st International Symposium, Bari 7-10 June 1989. ed. Fulvio Zezza (Brescia: Grafo, 1990), 31-58.

58 Charola, A. Elena. "Salt in the Deterioration of Porous Materials: An Overview." *Journal of the American Institute for Conservation* 39(3)2000 :327-343.

R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation."

but the other varieties of salts present in the solution, the relative humidity, porosity of the stone, and the conditions forcing evaporation. [59]

Salts can significantly alter the hygric dilation of the rock. In laboratory tests the salt-free system returns to its normal size after drying, but a stone contaminated by salt will dilate upon drying instead of wetting, and with each drying cycle the stone dilates exponentially more without returning to the baseline state.[60] Snethlage and Wendler have noted that salts can be a self perpetuating cycle if the source is not blocked. With each drying cycle, the grains within the matrix of the sandstone are pushed farther and farther apart, leaving spaces for salt solution to enter. Upon the next drying cycle the precipitate will push the grains farther apart.[61]

4.1.6. Wind

In addition to the obvious drying effects of wind, airborne particles can abrade the surface of the stone. Sand particles generally travel close to the ground, reaching only about 1 m high. Fine silt and clay particles may travel farther and higher. In addition, the force of wind driven rain laden with these particles can exacerbate the deteriorative effects of wind abrasion. A current of air can also serve to create a negative force while

[59] Charola, A. Elena. " Salt in the Deterioration of Porous Materials: An Overview."; Arnold, Andreas and Konrad Zehnder. "Salt Weathering on Monuments."
[60] R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation."
[61] Ibid.

moving away from, and whipping around the side of a monument. This creates suction that can mechanically pull particles from the stone matrix.[62]

4.2. The Effects – The Major Weathering Forms Effecting El Morro

Snethlage and Wendler have attempted to connect many of the most common stone deterioration mechanisms to cyclical moisture fluctuations and their relationship to salts and the mechanical failure of the stone.[63] Fitzner acknowledges that all of the above mentioned factors and mechanisms can cause or contribute to a weathering pattern on the surface of stone, but a direct association between a weathering form and a singular cause can be limiting. While he allows for the consideration of possible environmental and petrological sources, Fitzner and others advocate for the analysis of weathering forms through clear, precise, descriptive language and a classification and mapping system that will be discussed in more detail farther below.[64] The weathering forms found at El Morro National Monument are complex and will be discussed more fully below. These forms were selected for a more in-depth analysis due to their occurrence at the northeast point of Inscription Rock. Fitzner lists 70 some odd forms, sub-forms, and transitional forms.[65]

62 Delgado-Rodriguez, J. and Gil Saraiva, J.A. "Experimental and Theoretical approach to the Study of the Mechanism of Wind Erosion of Stone in Monuments." In Proceedings of the 5th International Congress on Deterioration and Conservation of Stone, Lausanne, 25-27 September, 1985. Ed. G. Felix (Presses Polytechniques Romandes, 1985), 167-175.

63 Ibid.

64 Fitzner, B. , Heinrichs, K.Kownatzki, R. " Weathering Forms – Classification and Mapping." In Natursteinkonservierung in Der Denkmalpflege. Ed. Rolf Snethlege (Berlin: Ernst & Sohn, 1995), 41-88.

65 Ibid.

4.2.1. Subtractive Conditions

4.2.1.1. Granular disintegration

Granular disintegration or "sanding" or "sanding off" (Snethlage, Wendler and others) is loss of grain cohesion and is visible as the detachment of individual grains from the rock surface, identified as friability. Fitzner lists granular disintegration as a sub-form of detachment, and as a transitional form leading to flaking.[66] Granular disintegration tends to form when moisture is maintained close to the surface of the stone, within the first 1 to 2 mm of the surface zone. Snethlage and Wendler believe that this type of damage is due to salt crystallization within this outer zone,[67] but there may be many other factors or mechanisms that can contribute to the disaggregation of sandstone. Dilation and contraction caused by thermal energy input[68], freeze-thaw cycles, and the suction and abrasion caused by wind[69] may all contribute to this weathering form. Areas of the stone that stay moist longer due to environmental conditions (micro-climate) or the shape of the stone will be more prone to granular disintegration. Sections that dry more quickly are more likely to have contour-scaling as the primary mean of deterioration.[70]

66 Fitzner, B. , Heinrichs, K.Kownatzki, R. " Weathering Forms – Classification and Mapping."

67 R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation."

68 Vincente, M.A., J. Garcia-Talegón, A.C. Iňigo, E. Molina, and V. Rives. "Weatheirng Mechanisms of Silicated Rocks in Continental Environments."

69 Delgado-Rodriguez, J. and Gil Saraiva, J.A. "Experimental and Theoretical approach to the Study of the Mechanism of Wind Erosion of Stone in Monuments."

70 R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation..";

Matovic, Vesna B., Dragan J. Milovanovic, Slobodan M Joksimovio. "Durability of Sandstones in Serbian Ancient Monasteries and Modern Buildings." In *Proceedings of the 9th International Congress on Deterioration and Conservation of Stone, Venice, June 19-24, 2000*, ed. Vasco Fassina (Amsterdam: Elsevier, 2000), 135-144.

4.2.1.2. Flaking

Flaking can appear as a single flake or as a sequence of flakes. In the case of the latter, flaking can be thought of as a transitional form leading to contour scaling, or given the arrangement of the flakes the form may in actuality be considered contour scaling.[71] Flaking usually occurs when moisture is maintained in the surface zone, and the drying rate is high enough to maintain a constant draw of moisture into the afflicted section of the rock.[72] Flaking can also be induced by treatments such as consolidation or hydrophobic coatings where the treatment alters the response of the stone surface to moisture, temperature, and other contributing factors thereby causing failure.

4.2.1.3. Contour Scaling

Contour scaling appears as multiple flakes parallel not necessarily to the plane of the rock, but rather to the surface of the stone. The flakes can appear one on top of another forming a stepped recession into the rock. Wendler points out that clay rich sandstones in particular tend to produce contour scaling. Contour scales tend to appear in exposed areas that wet and dry very quickly,[73] and have the moisture transport zone slightly deeper than areas afflicted by granular disintegration and flaking.[74] As with

71 Fitzner, B. , Heinrichs, K.Kownatzki, R. "Weathering Forms – Classification and Mapping.";
R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation".

72 R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation."

73 Wendler, Eberhard. "Contour Scaling On Building Facades – Dependence On Stone Type and Environmental Conditions."

74 R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation."

granular disintegration, contour scaling tends to occur in areas that collect snow and rain.[75]

4.2.1.4. Alveolar Erosion

Alveolar erosion tends to occur in areas with intense weathering, and where capillary rise from ground water accounts for the moisture in the stone.[76] Snethlage and Wendler regard alveolar erosion as a special case of sanding.[77] They believe this weathering form to be the result of a high salt concentration in the pore fluid, inhomogeneities in the rock structure that result in an irregular behavior in the moisture transport system, and shelter from the rain so that the salts are not washed out of the stone. The irregular moisture transport brings the pore solution riddled with salts closer to the surface of the stone in specific locations. The places where the salt is left to crystallize closer to the surface suffer from granular disintegration; while the surrounding stone does not deteriorate in the same way. This creates holes or pits in the stone that are self perpetuating. The holes will maintain a higher level of dampness since they are sheltered from the sun and because of this, the sandstone within the holes will continue to slough off grains of sand, and grow deeper with time and repeated cycles.[78]

75 Vincente, M.A., J. Garcia-Talegón, A.C. Iňigo, E. Molina, and V. Rives. "Weatheirng Mechanisms of Silicated Rocks in Continental Environments."

76 Matovic, Vesna B., Dragan J. Milovanovic, Slobodan M Joksimovio. "Durability of Sandstones in Serbian Ancient Monasteries and Modern Buildings."

77 R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation."

78 Ibid.

4.2.2. Additive Conditions

4.2.2.1. Clay Wash

Fitzner would classify this weathering form as soiling, a sub-form of Discoloration and Deposit.[79] As rain and snow melt wash down the surface of the stone the liquid releases and transports particles of dust, clay, and sand. This debris is washed down over the façade of the stone, creating a deposit. Several washes can create a thin layer that may eventually flake, taking with it aggregate from the surface of the stone.[80]

Clay washes can be as significant for the moisture patterns they reveal as they are for the erosion they can cause.

4.2.2.2. Efflorescence

Salt may manifest itself visually as efflorescence on the surface or subflorescence below the surface. Salt deposits can range from isolated grains scattered in or on the surface of the stone, to a thick continuous crust.[81] A full discussion of the mechanisms behind efflorescence can be found under the necessary conditions for decay in the moisture and salt sections.

4.2.2.3. Biological Colonization

Biological colonization can take the form of higher plant life or microbiological colonization such as biofilms or lichens. Higher plant forms often occur in cracks and fissures where the roots of the plant can take hold and mechanically invade and

79 Fitzner, B. , Heinrichs, K.Kownatzki, R. "Weathering Forms – Classification and Mapping."

80 Padgett, Antoinette and Kaisa Barthuli. " El Morro Inscription Assessment Project, 1994." Division of Conservation, Southwest Regional Office, National Park Service, United States Department of the Interior, March 1995.

81 Fitzner, B. , Heinrichs, K.Kownatzki, R. "Weathering Forms – Classification and Mapping."

deteriorate the stone, creating a new ingress for rain and snow. Both higher and lower forms can be found at El Morro, but lichens are the variety of plant life causing the most concern at the northeast point. Lichens are known to release organic acids and chelating agents, which can react with the stone that they colonize to extract specific ions from the minerals.[82] Wendler and Prasartset point out those areas of the Khmer – style sandstone monuments in Thailand that are covered in lichens suffer from less severe loss. Admittedly the centuries old monuments were not monitored over the very long term, but the authors noted that scaling and granular disintegration do not occur in areas covered by lichen. Those areas suffering from an overgrowth of lichen have a lower incidence of loss in comparison to those that are not. These areas primarily experience disaggregation, only to the depth that the hyphi can penetrate. Admittedly some varieties of lichen will consume elements of the stone by the acids released. For this reason the protective versus destructive properties of lichen are not definitive have a need for further study.[83]

4.3. Recording Conditions for Assessment

Documentation and recording are a necessary start to any conservation project. By conducting a condition assessment a conservator may record weathering forms, and compare the current condition of a monument with what is known of its past state of

82 St. Clair, Larry L. and Katy B. Knight. 2001."Impact of Microflora (Lichens) on the Condition of the Sandstone and Inscriptions at El Morro National Monument, Ramah, New Mexico." (Provo, Utah: Brigham Young University, August 15, 2001).

83 Wendler, Eberhard, and Chompunut Prasartset. "Lichen Growth On Old Khmer-Style Sandstone Monuments in Thailand: Damage Factor or Shelter." In 12th Triennial Meeting, Lyon, 29 August -3 September 1999: Preprints (ICOM Committee for Conservation). Ed Janet Bridgland (London: James & James, 1999), 750-754.

repair.[84] The end goal of classifying weathering forms may be to qualify, quantify, and interpret the deterioration of the stone, to develop a diagnosis, create weathering models, and assist in the development of the appropriate preservation measures.[85] It is important to begin an assessment with a clear understanding of what needs to be learned from and about the site. This will determine the methodology needed.[86]

The forms and classifications given by Fitzner are an example of well laid out language, but it is only intended as a starting point.[87] The forms must be defined anew, with an illustrated glossary for each site. A standardized use of vocabulary allows for a higher degree of repeatability, and easier communication within the community of architectural conservation.[88] This should be done with clear, precise, well defined terminology, and classifications. Levels of intensities can be written into definitions, and indices of deterioration created for later quantification.[89] The symbology and colors that will be used in the field to map the forms should be assigned to each weathering form in the glossary. Once a methodology is in place a pilot survey can be conducted to examine

84 Frank Matero, "Managing Change: the Role of Documentation and Condition Survey at Mesa Verde National Park." Journal of the American Institute of Conservation 2003, 42(1):39-58.

85 Fitzner, Bernd, Kurt Heinrichs, and Dennis La Bouchardiere. "Weathering Damage in Pharonic Sandstone Monuments in Luxor-Egypt." Building Stone Decay: Observations, Experiments and Modeling September- October 2003, 38(9-10): 1089-1103

86 Frank Matero, "Managing Change: the Role of Documentation and Condition Survey at Mesa Verde National Park."

87 Fitzner, B. , Heinrichs, K.Kownatzki, R. "Weathering Forms – Classification and Mapping."

88Frank Matero, "Managing Change: the Role of Documentation and Condition Survey at Mesa Verde National Park."; H.A. Viles, rapporteur, D. Camuffo, S. Fitz, B. Fitzner, O. Lindqvist, R.A. Livingston, P.-N.V. Maravelaki, C. Sabbioni, T. Warscheid, "Group Report: What Is the State of Our Knowledge of the Mechanisms of Deterioration and How Good Are Our Estimates of Rates of Deterioration?," In *Saving Our Architectural Heritage: The Conservation of Historic Stone Structures, Dhalem Workshop, Berlin, March 3-8, 1996.* ed. N.S. Baer and R. Snethlage (Chichester: Wiley, 1997) 7-24.

89 Fitzner, B., Heinrichs, K., La Bouchardiere. "Damage Index for Stone Monuments," In Protection and Conservation of the Cultural Heritage of the Mediterranean Cities, Proceedings of the 5th International Symposium on the Conservation of Monuments in the Mediterranean Basin, Sevilla, Spain, 5-8 April 2000. ed. Emilio Galán and Fulvio Zezza (Lisse: A. A Balkema Pub., 2002), 315-326.

which forms are present, and what should be mapped. This venture into the field may alter the view of what is needed, and the formed methodology must be open to modification at this point in the project.

Photographic or laser documentation of the site will be needed to conduct the final condition assessment. Before entering the field to take the photographs it should be decided what detail is needed for the final assessment. The area that each photograph covers, and the distance from the surface of the stone that the photograph should be taken, is based on the need for detail. The photographs should contain reference points for later rectification. These points may be natural configurations on the surface of the stone, architectural details, or phototargets placed on the façade. Once the area of the stone to be photographed is known, and reference points decided, images should be taken methodically. The camera/scanner must be stabilized to minimize shaking, and the lens should be square with the surface of the stone so that rectification and the possibility for distortion can be kept to a minimum.[90]

The act of visually assessing a structure can be surprisingly subjective. This must be acknowledged in every assessment, and insured against with the use of precise terminology and pictorial glossaries that describe the criteria for each form. This practice insures that despite possible differences in surveyor opinion the assessment can be repeated by future conservators.[91] Surveyors re-enter the field with copies of the photographs that were taken in the photodocumentation phase. Using permanent ink, and

[90] Frank Matero, "Managing Change: the Role of Documentation and Condition Survey at Mesa Verde National Park."

[91] Ibid.

the symbology and colors chosen for each form in the glossary, the forms are mapped onto these photographs by hand.[92] A condition assessment should be conducted methodically, systematically, and within arms reach of the stone when ever possible. By looking closely at the rock, touching the stone when possible, and taking the time to write the glossary a conservator begins to notice the relationships between the weathering forms, the stone, and the surrounding environment, and these notions can serve the architectural conservator well when it comes time for the analysis of the data collected during the condition assessment.[93]

The analysis of a conditions assessment has been altered with advances in digital technology in the past decade. Today, the data recorded by hand in the field is digitally enhanced by being entered into such programs as AutoCAD or Geographical Information System (GIS). The newer technology allows for information to be better and more easily manipulated to show relationships between weathering forms, the structure, and the surrounding environment.[94]

Documenting and analyzing weathering forms is helpful in understanding the current state of the monument, however a comparison of the weathering forms over time gives a more complete picture of the evolution and possible pattern of deterioration.[95] Therefore in the final analysis a comparison of the current condition with the past

92 Frank Matero, "Managing Change: the Role of Documentation and Condition Survey at Mesa Verde National Park." Fitzner, B. , Heinrichs, K.Kownatzki, R. "Weathering Forms – Classification and Mapping."

93 Frank Matero, "Managing Change: the Role of Documentation and Condition Survey at Mesa Verde National Park."

94 Ibid.

95 Ibid.

condition captured by past assessment programs, photographs, sketches, and writings are important.[96] Each source should be considered and weight given accordingly.

96 Löfuendahl, Runo, Helmer Gustavson, Bengt A. Lundberg. "Weathering of Runestones in a Millennian Perspective." Proceedings of the 9th International Congress on Deterioration and Conservation of Stone, Venice, June 19-24, 2000, ed. Vasco Fassina (Amsterdam: Elsevier, 2000), 134-144.

5. Methodology

Prior condition assessments commissioned by the National Park Service have focused on panels that were created based on the density and position of inscriptions, but the panels do not encompass the entire face of the rock. Figure 5.1 shows those that have been already assessed in past studies.

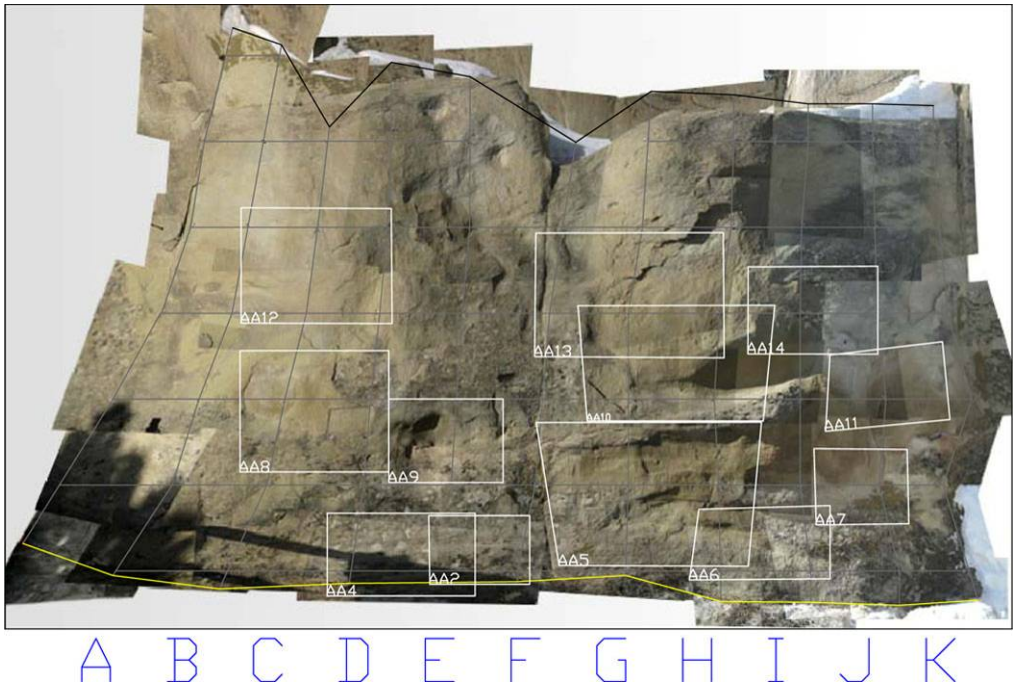


Figure 5.1 The flattened image of the northeast point. The white boxes indicate the panels that have been evaluated in past surveys.

Deterioration, which threatens the integrity of the inscriptions, stretches across several panels and into areas not assessed because they do not have inscriptions. Therefore, it will be difficult to see how the panels fit into the grander context and deterioration at the northeast point. The isolated treatment of a panel can affect the porosity and permeability of the stone, and can affect not only how the treated area decays, but how the surrounding stone deteriorates as well. In turn, this can negatively

affect treated panels. For example, the undercutting of some panels has been noted since they have been treated with ethyl silicate.[97]

Such observations suggest that an incomplete understanding of the weathering of the entire point can have a deleterious effect on the object in question if the formulated preservation plan does not address all the deterioration factors appropriately. It is the premise of this surveyor that before a proper preservation plan for the northeast point can be conceived, an analysis of the state of deterioration must be conducted for the northeast point as a whole. In doing this, patterns of deterioration for the entire lower AA section may become more evident, and a treatment plan may be devised which would hopefully preserve not just the panels, but the panels in-situ, as close to their original context as is possible in the twenty-first century.

This work will assess the entire northeast point and continue the study of panels AA2, AA4, AA5, AA6, AA7, AA8, AA10, AA11, AA12, AA13, and AA14 in chapter seven.

5.1. Formation of a conditions glossary

For this purpose, a graphic conditions glossary was created based on photographs taken during a field visit in July and August of 2006. These images were studied to determine which weathering forms were present at the northeast point. A representative image of each form was selected to represent the condition, and a description of the symbology to be used in the mapping was done. The terminology was decided upon

97 Oliver, Anne. "The Variable Performance of Ethyl Silicate: Consolidated Stone at Three National Parks." Apt Bulletin 33 no 2/3 (2002): 39-44.

based on Fitzner, the work done at El Morro National Monument by Padgett, Barthuli, and St. Clair, and past projects completed by the Architectural Conservation Lab at the University of Pennsylvania.

5.2. Photodocumentation

5.2.1. The grid

Before the northeast point was documented, a 2' grid was super-imposed on the surface of the stone for ease in later monitoring and conditions mapping. A laser level was used to create datum lines from which to work. A horizontal datum was laid at mid-level and phototargets were placed at two-foot intervals. To minimize the use and movement of a ladder close to the face of the monument, the laser level was then turned 90 degrees so that vertical lines intersected a phototarget from the horizontal line that was all ready laid out. This insured that the ladder only needed to be moved and placed against the rock surface once for each vertical line placed. Phototargets were then placed along this line at a spacing of every two feet from the horizontal datum line. In some places the granular disintegration was so severe that push pins were needed to hold the targets in place. If less than two feet were left at the top of the monument or at the base, then the distance from the last target to the top of the stone or the ground was noted. The problem with this system of measurement was related to the geometry of the monument, which fans out at the bottom, and undulates in other areas. The result was that although the vertical lines were 24 inches long, the top and bottom of the newly formed squares were not. For this reason the top and bottom of each new panel was measured and recorded for the creation of the grid. Ten columns of panels were created, each column

containing between five and six panels. Overall fifty-eight squares were formed as shown in Figure 5.2 in red.

5.2.2. Photography

Once the targets were laid the photodocumentation could begin. Color photographs were taken with a seven mega-pixel Canon Power Shot SD550. An A-frame ladder was placed a set distance from the cliff face, squarely in front of each newly formed column of panels. Due to the uneven nature of the stone's surface, the surrounding terrain, and a wooden fence that stood between the footpath and the monument it was not always possible to take a photograph at an exact distance from the surface of the rock. The camera lens was parallel with the surface of the stone from distances of just under 1 – 1½ meters. Each vertical line was labeled alphabetically from left to right, and each row numerically from the base of the stone to the top. Each photograph was labeled by the letter of vertical line that formed its left border and by the number of the row, ranging from A1 to J6.

5.2.3. Montage

The photographs were uploaded to an IBM ThinkPad T43 computer. The measurements taken between phototargets were used to create a grid in AutoCAD LT 2007. This grid was imported into Photoshop CS2 to use for photo-rectification. Each photograph was brought into Photoshop and the targets were aligned with the grid in its alphanumerical slot. The rectified pictures were then pieced together in Photoshop to create a montage (fig. 5.2). Time and resource constraints precluded mapping fourteen

conditions on fifty-eight panels in the time allotted. In addition, the National Park Service requested that the phototargets be taken down as soon as possible: for these reasons the photographs were montaged together before returning to the field. The montage was then quartered into four parts for greater detail. These quarters were printed in color on 8.5x11 inch paper and placed between acetate sheet covers. These quarters of the montage were used for conducting the conditions assessment.

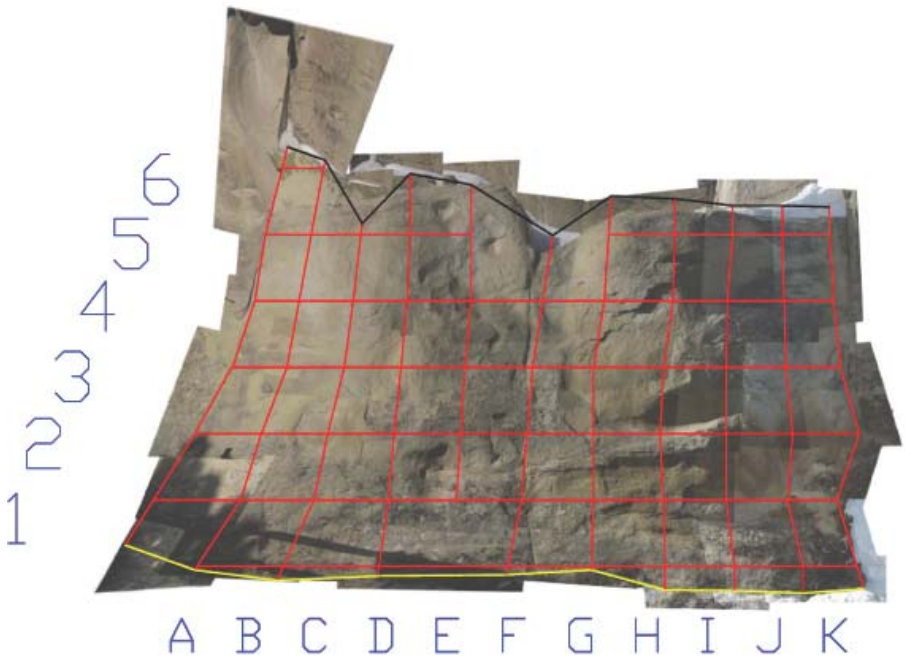


Figure 5.2 The montage of all fifty-eight photographs with the grid superimposed.

5.3. Condition Assessment

The Conditions Assessment took place between February 3rd and the 6th of 2007. A heavy snowstorm left parts of the monument covered in six to seven inches of snow (fig. 5.3). Snow was removed from the base of the cliff by hand and lightly brushed off of the stone surface, leaving roughly one half inch on the stone where removal had been

necessary. The rest of the snow was removed by time, sunlight, and a rise in ambient temperatures. This approach to snow removal was taken due to the destabilizing effect the moisture had on the granular disintegration. If snow was brushed away with a heavy hand, or closer to the surface of the point, deterioration was evident.

Once the rest of the snow had melted, the acetate covered photographs were taken into the field to begin the condition assessment. In order to sound the upper portions of the rock, a ladder resting on the lower AA section would have been needed. Out of concern for the surface of the stone, this was not employed: therefore all of the upper regions assessed visually from the ground. Over the three days in question the relative humidity was low, the weather was generally sunny with occasional brief snow flurries. Temperatures varied between 45°F and 0°F (7 ºC and -17 ºC) in the evening. Temperatures during observation times were generally between 30 and 20 Fº (-1 ºC and -6ºC), and snow depth was between 4 and 5 inches. Despite less than optimal weather conditions, the surface of the stone was studied and recorded in detail and the areas within reach were carefully sounded. Possible relationships between weathering forms were noted on the acetate sheets.

Figure 5.3 Snow covering the northeast point. Picture taken by Burris 31January 2007.

5.4. Digital Formatting

The twelve acetate sheets with the weathering forms drawn into place were scanned and brought into AutoCAD. The phototargets were aligned with the grid that had been previously drawn in order to confirm proper scale and placement in reference to other sheets. Each condition was then traced, based on the images that had been scanned; cross-referenced with the hard copies of the assessment; and against the photographs themselves to ascertain that the conditions were indeed being drawn in the correct locations. These conditions were then turned into polygons for later analysis. Each type of weathering form was drawn into its own layer so that in the analysis stage, layers could be turned on and off to better show the relationship betweens different weathering forms and their position on the surface of the stone.

5.5. Analysis

The analysis of the northeast point is qualitative as a quantitative analysis of the surface area would have required a topographic survey such as that created with a laser scanner. The scale used in creating the grid is highly functional for a conditions assessment, but the natural surface of the sandstone undulates and curves, and this scale does not entirely correct for depth changes.

The topography of the rock surface, its mineralogy, the micro climate, and the relationships between different weathering forms were all taken into consideration in the analysis of the deterioration of the northeast point. The current condition of the northeast point was evaluated through the first-hand experience of field assessment, followed by the digitization of the information. Once the condition assessment was made in AutoCAD it was possible to turn layers on and off to better understand the relationship between weathering forms. These images were plotted on a large scale and studied.

Most of the historical documentary photographs focused on the panels, which made a more in-depth study of the panels possible. Howell and McNeill's 1955 survey, Padgett and Barthuli's 1993 survey, and the author's own photographs from 2007 were all compared. In addition those panels that had been previously treated had a more in-depth assessment record, in some cases spanning from 1996 to 2004. Karen Fix completed the most recent assessment of all of the panels in the lower AA section in 2006. This information was used to examine the deterioration of the panels over the last fifty-two years, and to analyze the condition of the consolidated panels compared to those that were left untreated.

6. Conditions

As discussed in chapter five, past condition assessments at El Morro National Monument have focused on individual panels. This report acknowledges the panels to be only part of a greater whole that must be scrutinized as well. By focusing on only one section it was possible to assess the condition of the whole of the northeast point. In so doing, it can be observed as to how the panels are representative of the greater condition, and future preservation plans may be made for the rock as a whole.

The following is an analysis of the major weathering forms present at the northeast point and as much as possible their relationship between one another and the micro-climate and topography of the Point.

6.1. The Micro-climate at the Northeast Point

The northeast point of Inscription Rock displays a unique microenvironment created by the interaction of the prevailing weather conditions with the unique geometry of the rock at this location. Freeze-thaw temperatures at El Morro can occur from October through April. In January daytime temperatures can reach into the 40s and 50s F (12º to 4º C) on an almost daily basis, and the evening lows can easily reach the single or negative digits F (-12º to -25º C). Rainfall occurs throughout the year, and snow can fall between October and June.[98]

The stone is perfectly configured to allow for the infiltration of moisture. As a natural land formation, all of El Morro is subject to rising damp and moisture infiltration

98 El Morro National Monument. Record of River and Climatological Observations. 1938-1955, 1962-1974, 1986-2006

from above, but the northeast point is unusual in its size and separation from the rest of the formation. As the vibration study suggests, the northeast point has a natural vibration different than that of the surrounding monument[99] and the open fissure behind the point and the faults surrounding it nearly cleave the section from the rock around it. Even if the fissure and faults are only millimeters wide, it will affect moisture transport from the AA section to the neighboring rock.

It is unknown how deep the fissure behind the northeast point reaches into the rock, but it does allow moisture to infiltrate the backside of the section. Moisture can also penetrate the section from the sandstone ledge over the point and from capillary rise at grade. The natural vertical fissures in the stone channel water and snow melt from the top of the section, bringing more moisture to the areas surrounding the faults. The undulating surface of the rock allows plenty of areas for snow to collect, water to pool, and alcoves to hide damp stone from the drying effects of the sun.

Similar sources of moisture exist throughout the monument, but the smaller size of the point means that moisture infiltrating the stone matrix from the top of the rock has less area to travel before it meets moisture entering the stone through capillary rise, possibly keeping the stone damper than its taller counterparts. This, combined with the drying effects of the wind, can pull more moisture into the stone through capillary action so that water may be moved through the rock at a faster rate than at other areas in the formation

99 King, Ken and Elaine King. "El Morro National Monument Preliminary Vibration Study," 2003.

The prevailing winds at El Morro are south to southwest.[100] When standing at the point on a breezy day one can begin to understand the severity of the winds around the point; not only in abrading the surface with air-borne particles, but also creating suction that pulls loose grains free of the matrix.[101]

There are many times throughout a given day when sunlight warms one facet of the rock and not the other. This, as Thomas Paradise has shown,[102] and as discussed in chapter four of this thesis, can be detrimental to the stone. The difference in thermal energy absorbed by the stone causes a difference in the dilation of the stone matrix that can accelerate the deterioration of the sandstone. As previously discussed the sandstone that makes up El Morro National Monument is a very poor quality rock. The high clay content will cause the stone to dilate and contract more intensely. As Snethlage and Wendler point out, the cycle of dilation and contraction will determine mechanical failure.[103] If the stone fails to contract to its original state then the matrix will be more permeable.

6.2. Description of the Current Conditions

When reduced to its most basic geometric shape the lower AA section of the northeast point of Inscription Rock could be compared to the bottom half of a cone cut in half along the Y axis. In reality the base flares out along the eastern edge of the point

100 Fred Mooseman, personal communication.

101 Delgado-Rodriguez, J. and Gil Saraiva, J.A. "Experimental and Theoretical approach to the Study of the Mechanism of Wind Erosion of Stone in Monuments."

102 Paradise, Thomas R. "Sandstone Architectural Deterioration in Petra, Jordan."

103 Snethleage and Wendler. "Moisture Cycles and Sandstone Degradation."

more than at the northern border of the AA section, and the surface of the stone pitches and inclines, curving outward, and forming both small and large depressions and outcrops. There is a central natural fault that runs from the ledge above the lower AA section to the sandy soil at the base. The southern edge of the northeast point is delimitated by a faint natural line. A second natural fault along the northern edge separates the bulbous AA section from the comparatively flat and lichen-ridden BB section. The conditions mapped closely follow and are influenced by this topography.

The shape of the northeast point has changed significantly in the past forty years. A photograph taken in 1955 by Howell and McNeill shows a pinyon tree growing on the southern side of the comparatively flat ledge (fig 6.1). The pinyon was removed in 1996, and the open fissure where the roots had taken hold was grouted with a hydraulic lime-based mortar to insure against water infiltration.[104] The ledge has since eroded to form a V shape with the central fault acting as a drain to funnel water run off and debris (fig 6.2). A line of mortar marks the height of the ledge when it was grouted in 1996. It ranges from 1-14cm above the current V-shaped ledge (fig 6.3).[105]

104 Oliver, Anne and Antoinette Padgette. "A History of Inscription Preservation at El Morro National Monument," 5.4.2

105 As measured by author in August of 2006

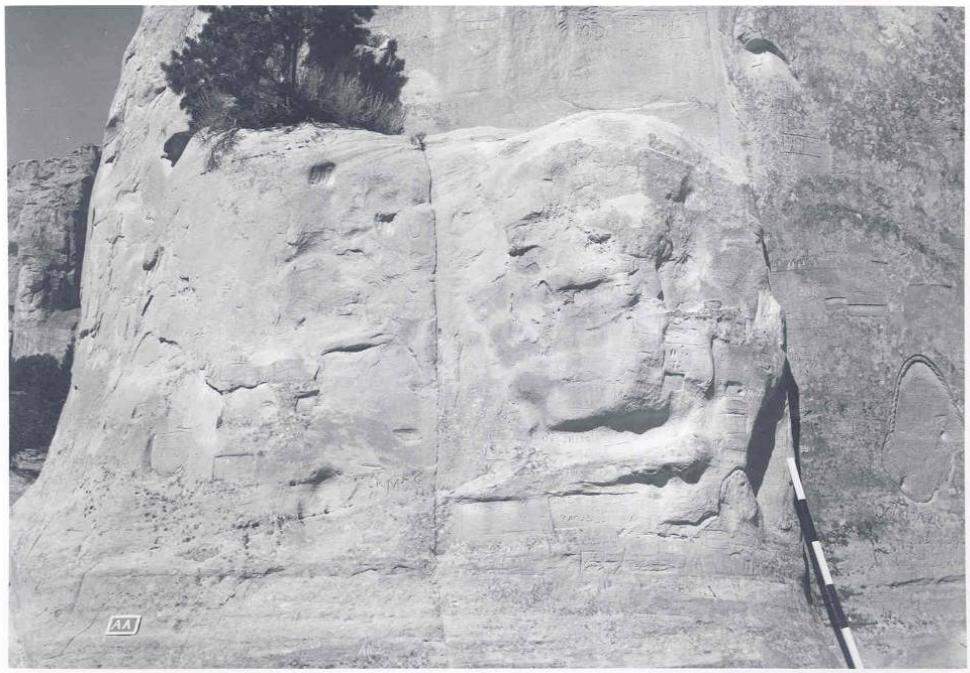


Figure 6.1 Northeast point 1955. Photograph by McNeil and Howell.

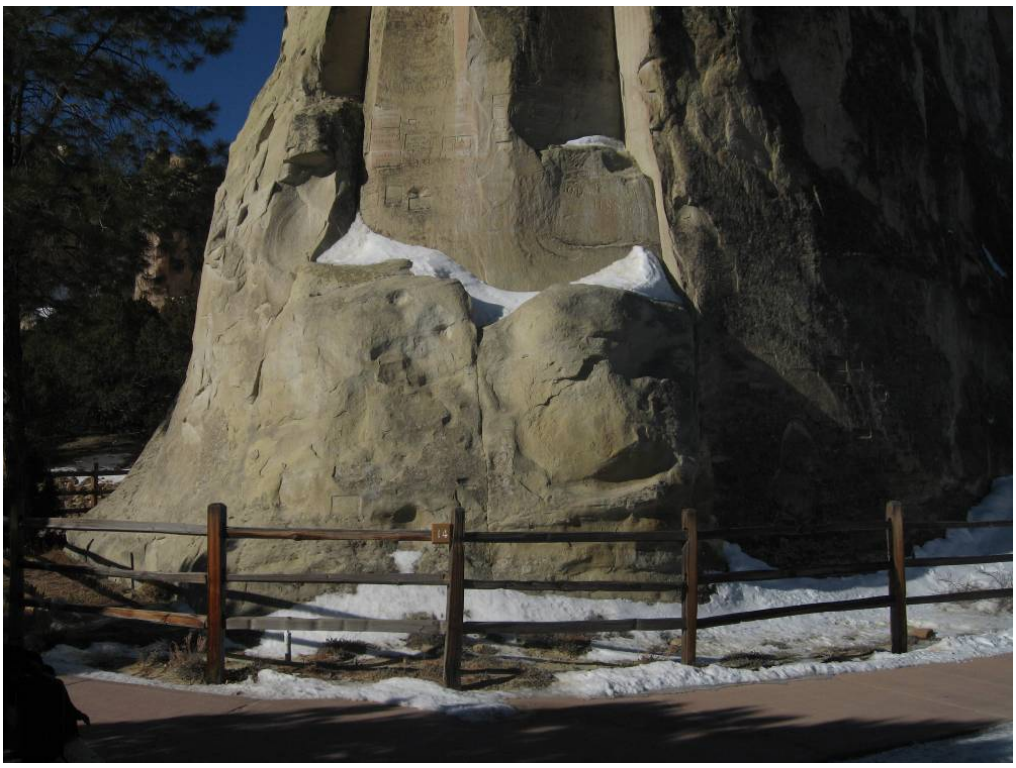
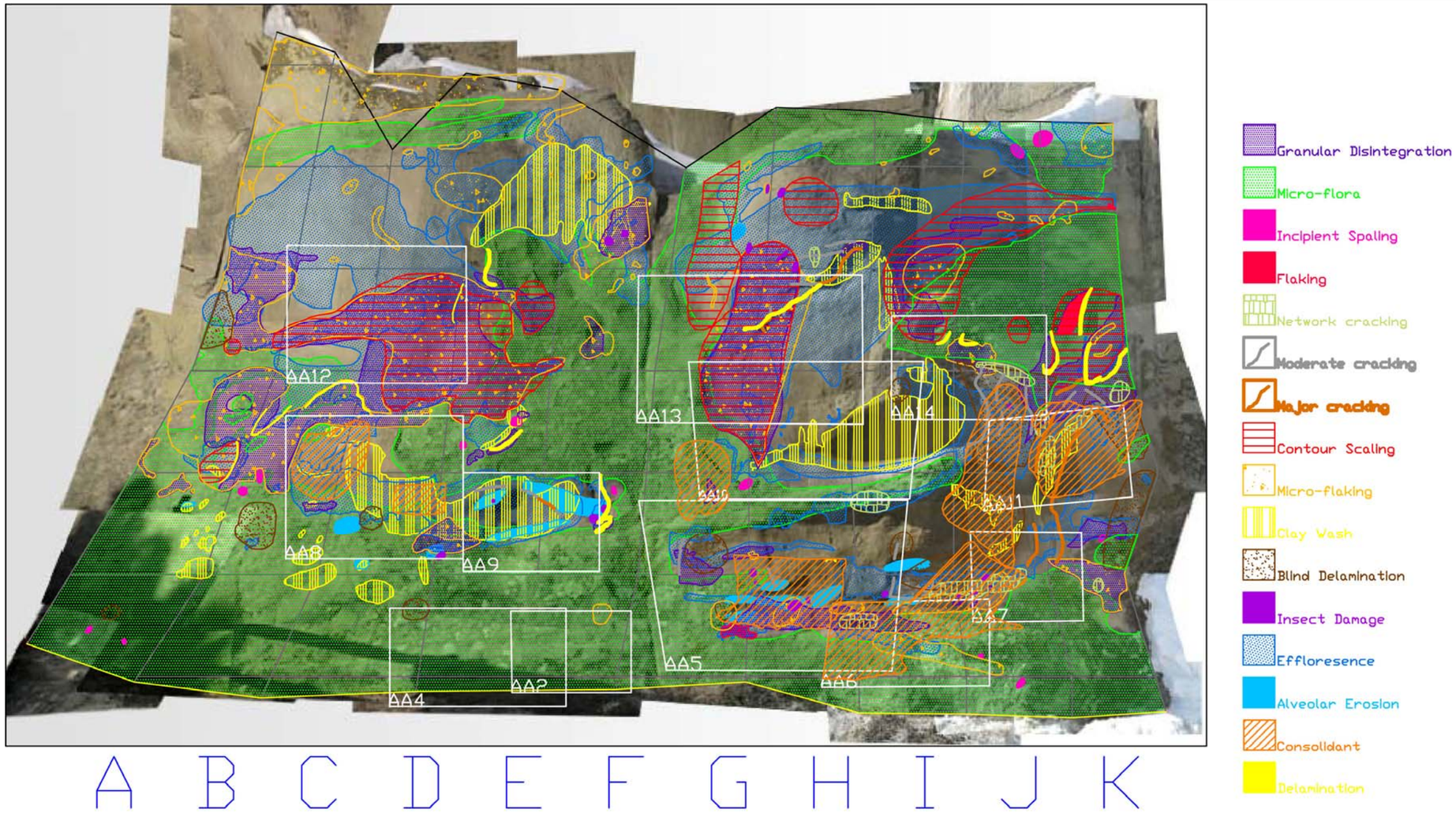


Figure 6.2 Northeast point 2007. Photograph by Burris

Figure 6.3 A) Hydraulic lime-based mortar that was used to seal the open fissure in 1996. B) The new level of the eroded northeast point at the low point just above the central fault. Picture taken in August 2006 by author.

The following subsections address the weathering forms found at the northeast point. Figure 6.4 shows all of the conditions mapped at the point. Each subsection that follows will address 1 to 3 of these conditions, show photodocumentation of how the weathering forms may appear, and provide a map of where those individual weathering forms were found during this survey.



Blind delamination was only evaluated to the height that the surveyor could reach without a ladder, slightly higher than half the height of the lower AA section.

Figure 6.4 Conditions map for all of the conditions noted at the northeast point.

6.2.1. Microflora and Incipient spalling

Larry St.Clair has identified and categorized the microflora at El Morro, including 43 varieties of lichens and mosses.[106] The microflora at El Morro can appear as gray, black, brown, white, and greenish hued blotches on the surface of the stone (fig. 6.5).[107] The 2007 survey also considered a pale gray discoloration that appeared between lichen colonies as a biofilm. For this reason the area of the northeast point covered in microflora may be over estimated in this conditions survey. This should be taken into consideration when using the conditions map that was produced (fig 6.6).

Figure 6.5 An example of found at the northeast point.

106 For a complete list of the species found consult chapter two or the conditions glossary in appendix A.

107 St. Clair, Larry. "Impact of Microflora (Lichens) on the Condition of the Sandstone and Inscriptions at El Morro National Monument, Ramah, New Mexico." np.

The microflora does appear to have a protective quality at the northeast point. Areas covered in biogrowth do not suffer from granular disintegration. Micro-flaking and contour scaling only appear in cases where the biogrowth is light, or cases in which the weathering form was present before the microflora consumed that section of the stone. This may also be due to the inability of the microflora to form on unstable surfaces, or the period of time required to develop an advanced lichen colony. Insects also appear to prefer stone unsullied by the lichen colonies.

Microflora may also suggest detrimental effects as well. Those panels that have been covered by microflora for decades show a gradual erosion of the outer layer of stone, possibly due to the weak organic acids produced by some of the lichens at the northeast point.[108] However it is important to note that the rate of loss can be quicker in an unconsolidated section of stone that is suffering from granular disintegration than in an area covered in microflora.

Incipient spalling is directly related to microflora at the northeast point. Incipient spalls are planar discontinuities that have become partially separated from the parent rock. The spall may be separated from the surface of the stone by 0º to 60º.[109] Incipient spalls only appear in areas with heavy lichen growth at the northeast point. They occur when a circular shaped lichen colony dries out and begins to lift away from the surface of the stone, taking the outer grains of the stone with it.

108 Ibid.

109 This definition is based on that given by the University of Pennsylvania ACL in the conditions glossary for the Pennsylvania Blue Project: The Second Bank of the United States

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Given the observed beneficial as well as detrimental effects of microflora at the northeast point, biogrowth should not be removed from the point without careful contemplation and a well studied plan for the safeguarding of the sandstone that is currently being protected by the microflora.

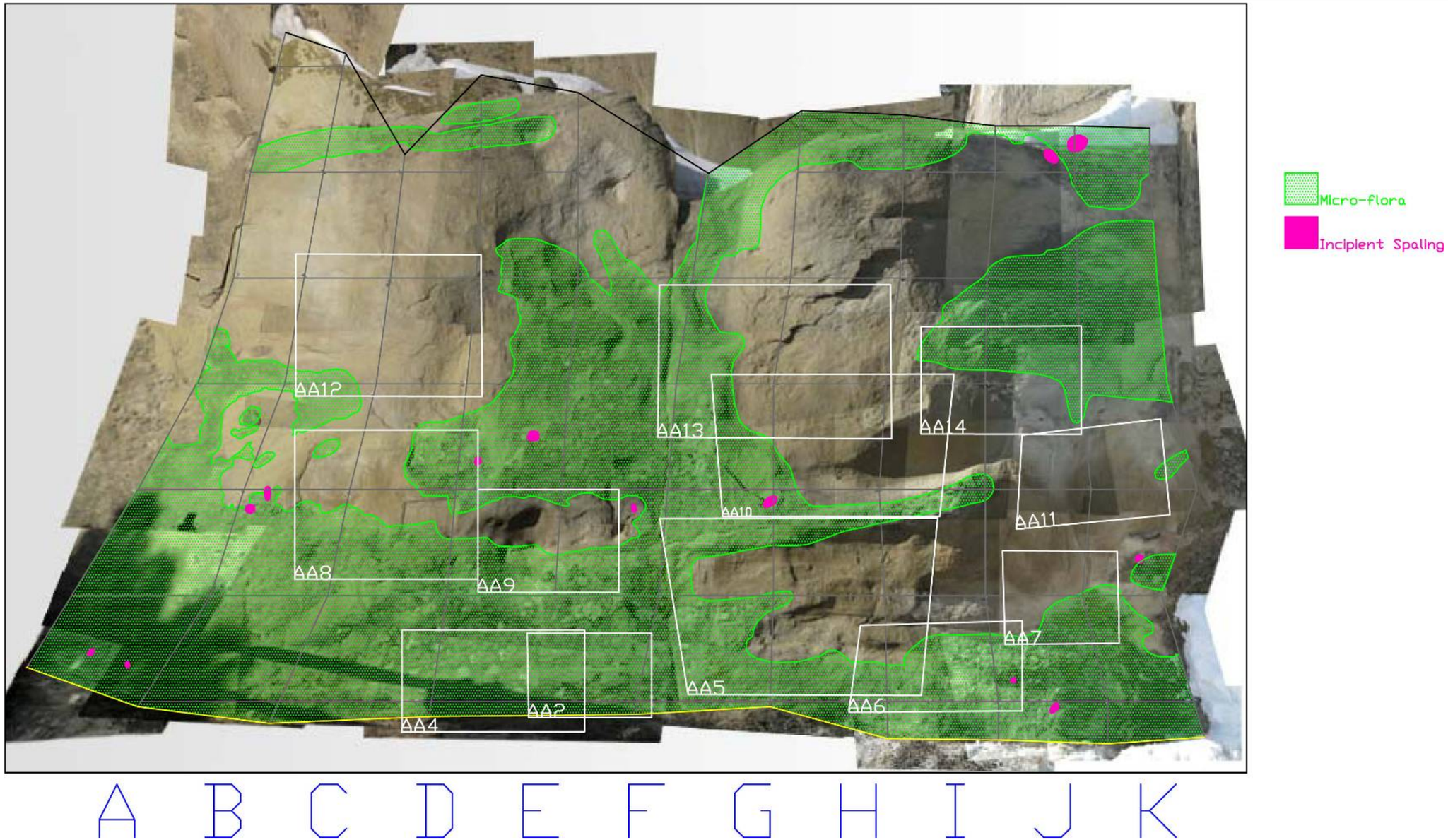


Figure 6.6 Conditions map of microflora and incipient spalling

6.2.2. Granular disintegration

Granular disintegration is the detachment of individual grains of sand from the rock evidenced by a friable stone surface. Grains of sand can be dislodged from the surface with the light brush of a hand (fig.6.7). This particular condition has been treated in the past in some locations at the northeast point with ethyl silicate and will be discussed in greater detail in chapter seven.

Figure 6.7 Granular disintegration can be seen in the sandy texture in portions of the above rock.

Chapter 6: Conditions

The 2007 survey found that granular disintegration mainly appears in areas that are not protected by microflora, and have suffered dimensional loss, leaving a fresh, un-weathered rock surface exposed (fig 6.8).

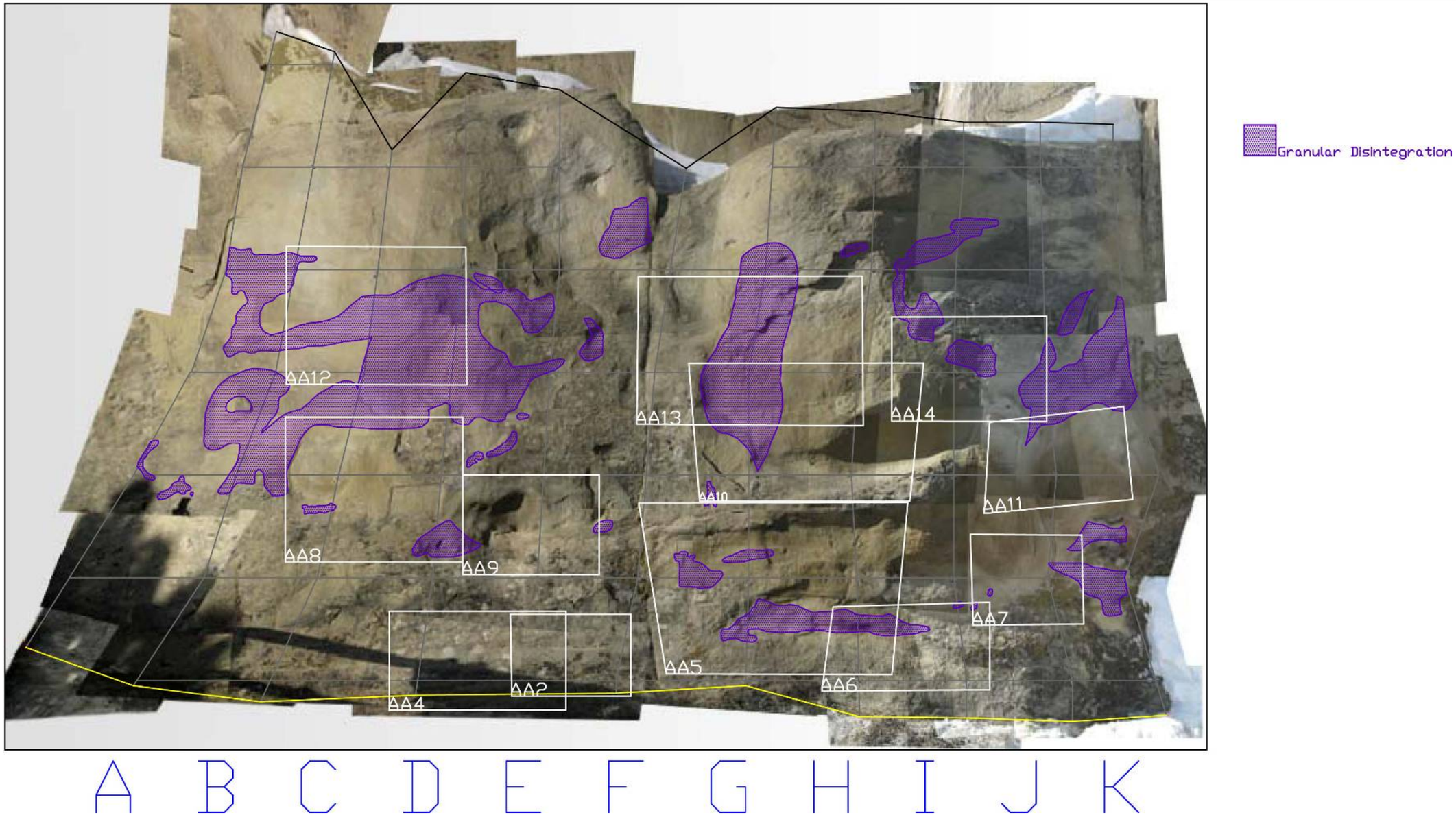


Figure 6.8 Conditions map of granular disintegration

6.2.3. Micro-flaking

Micro-flakes are thin detachments from the surface of the stone that are roughly even in thickness and on the centimeter scale. Micro-flaking appears all over the point and follows no pattern that can be seen at the resolution in which this survey was conducted. A detailed topographic map of the Point created with a laser scanner may find a relationship between micro-flaking and the surface contour of the rock, but none can be seen at this time (fig. 6.9, 6.10).

Figure 6.9 An example of micro-flaking.

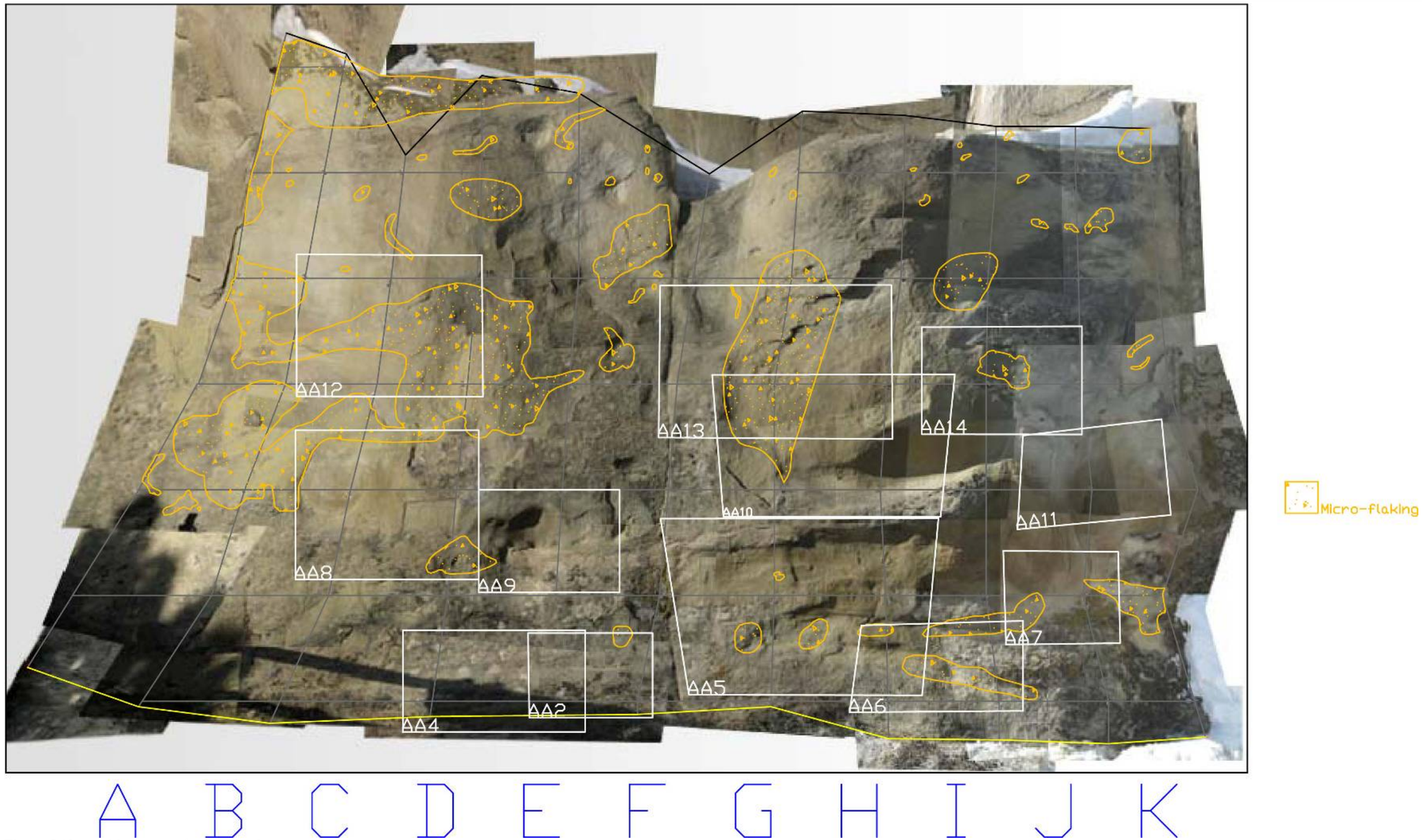


Figure 6.10 conditions map of micro-flaking.

6.2.4. Contour scaling

Contour scaling is the detachment of larger, platy stone elements parallel to the stone surface, but not following the bedding planes of the stone (fig 6.11).

Figure 6.11 An example of contour scaling.

At the northeast point this weathering form only appears in the mid-range and top of the AA section (fig 6.12). It is commonly found in conjunction with micro-flaking and granular disintegration. In the comparison of historical photographs in the next chapter it was found that after a large scale dimensional loss the exposed un-weathered stone will

be afflicted with granular disintegration, micro-flaking, and contour scaling for decades afterwards until the new surface reaches a relative equilibrium. Presumably case hardening may be occurring as well, and at some point in the future it is further presumed that another large scale loss in the same area will occur, starting the decay cycle anew.

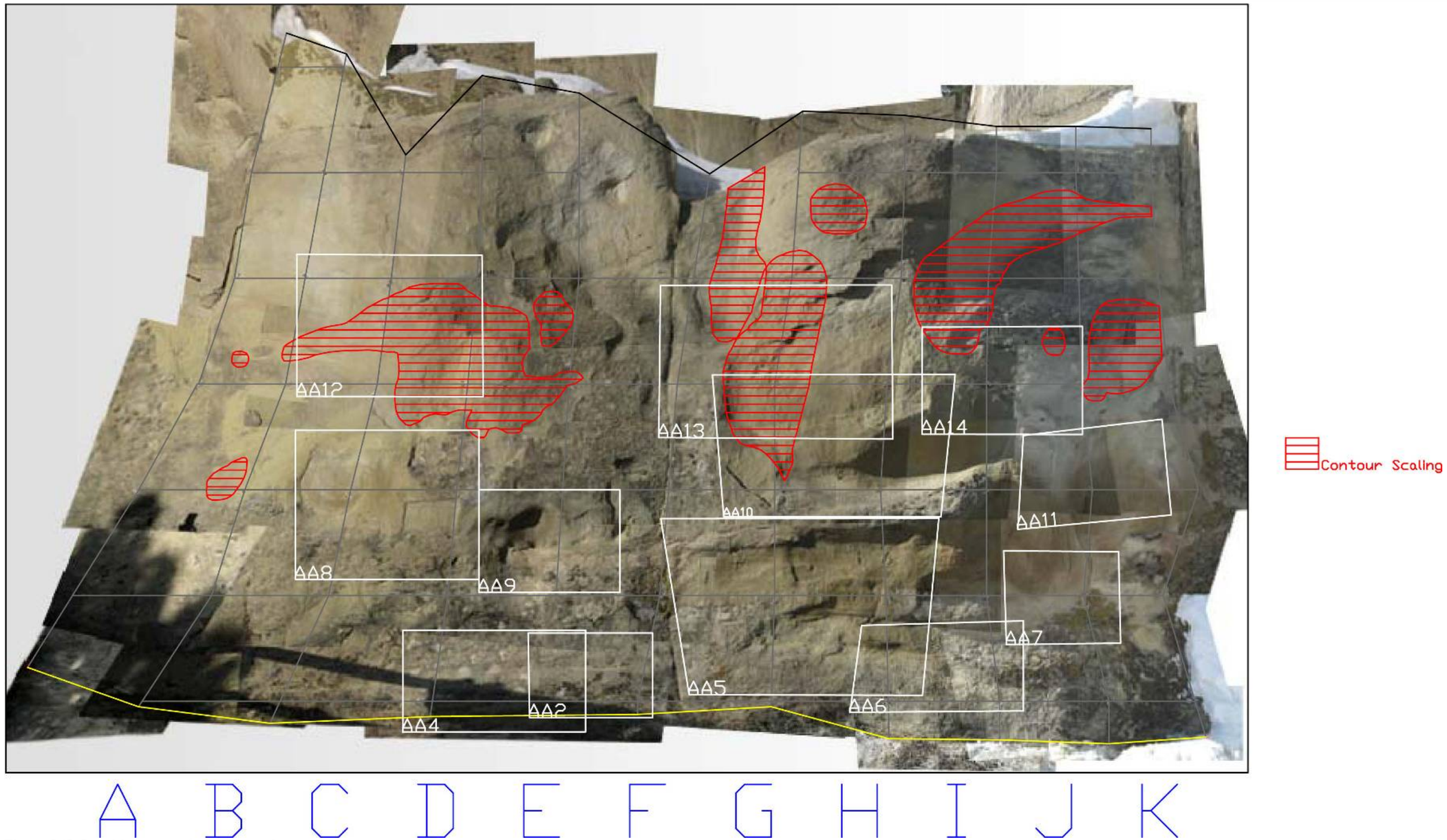
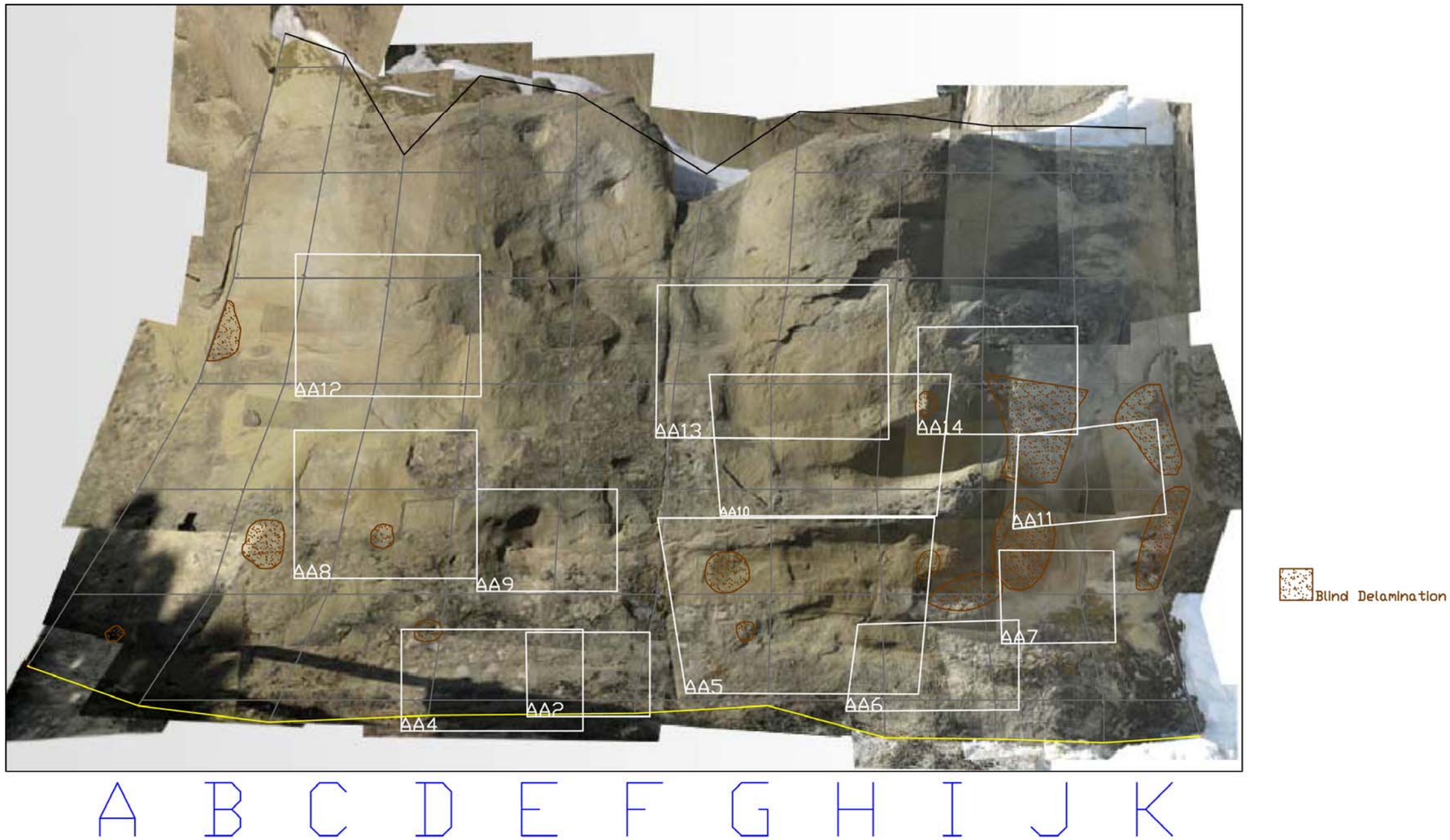


Figure 6.12 Conditions map of contour scaling.

6.2.5. Blind delamination

There are no visual cues for blind delamination but when sounded by tapping, the stone sounds hollow. Because sounding is necessary to find blind delamination any section being evaluated must be within reach of the surveyor. The lack of a ladder in the survey meant that blind delamination was only noted in the bottom 2/3 of the point. The lack of blind delamination in the upper portion of the conditions map should not be taken for the lack of the condition, only the surveyor's inability to reach the top of the point (fig 6.13).



Blind delamination was only evaluated to the height that the surveyor could reach without a ladder, slightly higher than half the height of the lower AA section.

Figure 6.13 Conditions map of blind delamination.

6.2.6. Delamination

Delamination is the detachment of the stone parallel to the surface of the northeast point(fig 6.14, 6.15). This occurs prior to loss, but as can be seen from historical photographs, delamination at El Morro can remain stable for decades.

Figure 6.14 An example of delamination.

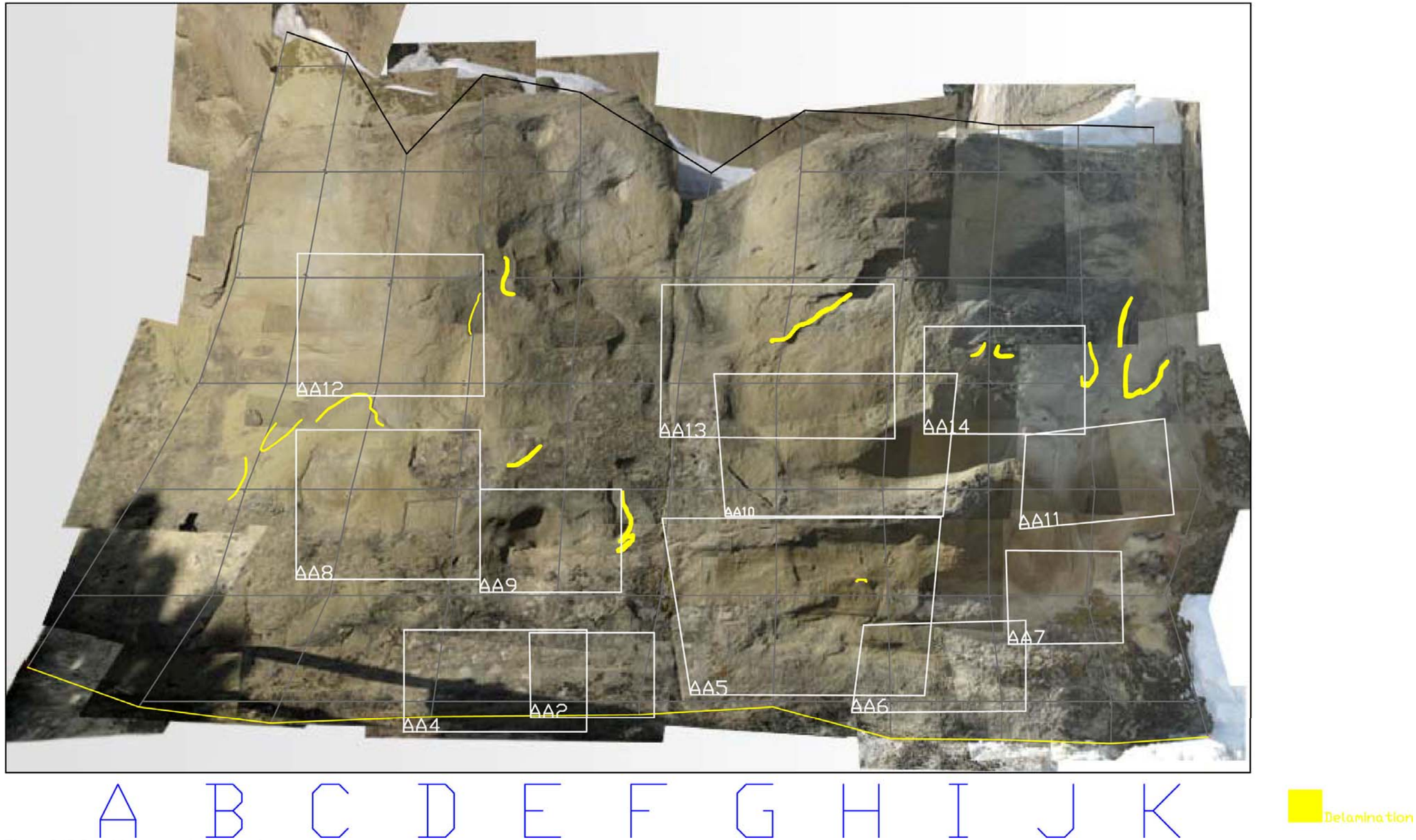


Figure 6.15 Conditions map of delamination.

6.2.7. Efflorescence

Surveys at El Morro have had the unusual problem of having difficulty visually differentiating between clay wash and efflorescence. The substance demarcated as efflorescence in the 2007 survey was a powder on the surface of the stone that was pale silver to white in color (fig. 6.16). By this definition salts were visible as low as nine inches above the ground and covered large areas of the stone up to the top of the point. Efflorescence did not seem to relate to any other weathering form. The most influential factor in the patterns formed by the salts was the topography of the stone (fig 6.17).

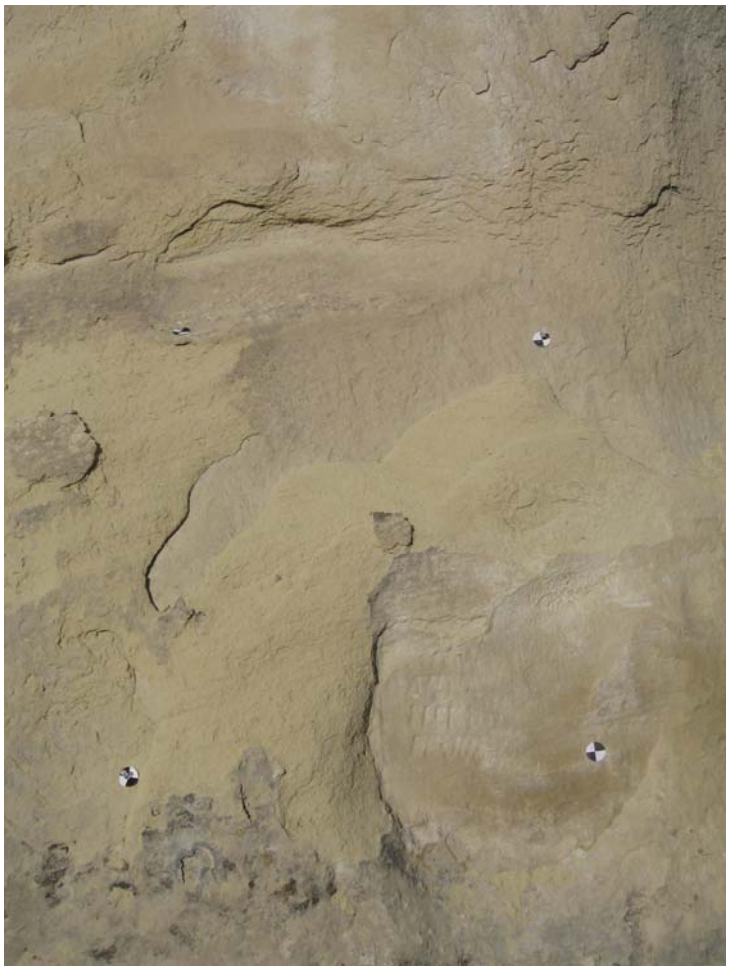


Figure 6.16 The white streaks in the upper portion of the photograph and in the lower right are examples of the form recorded as efflorescence in the 2007 survey.

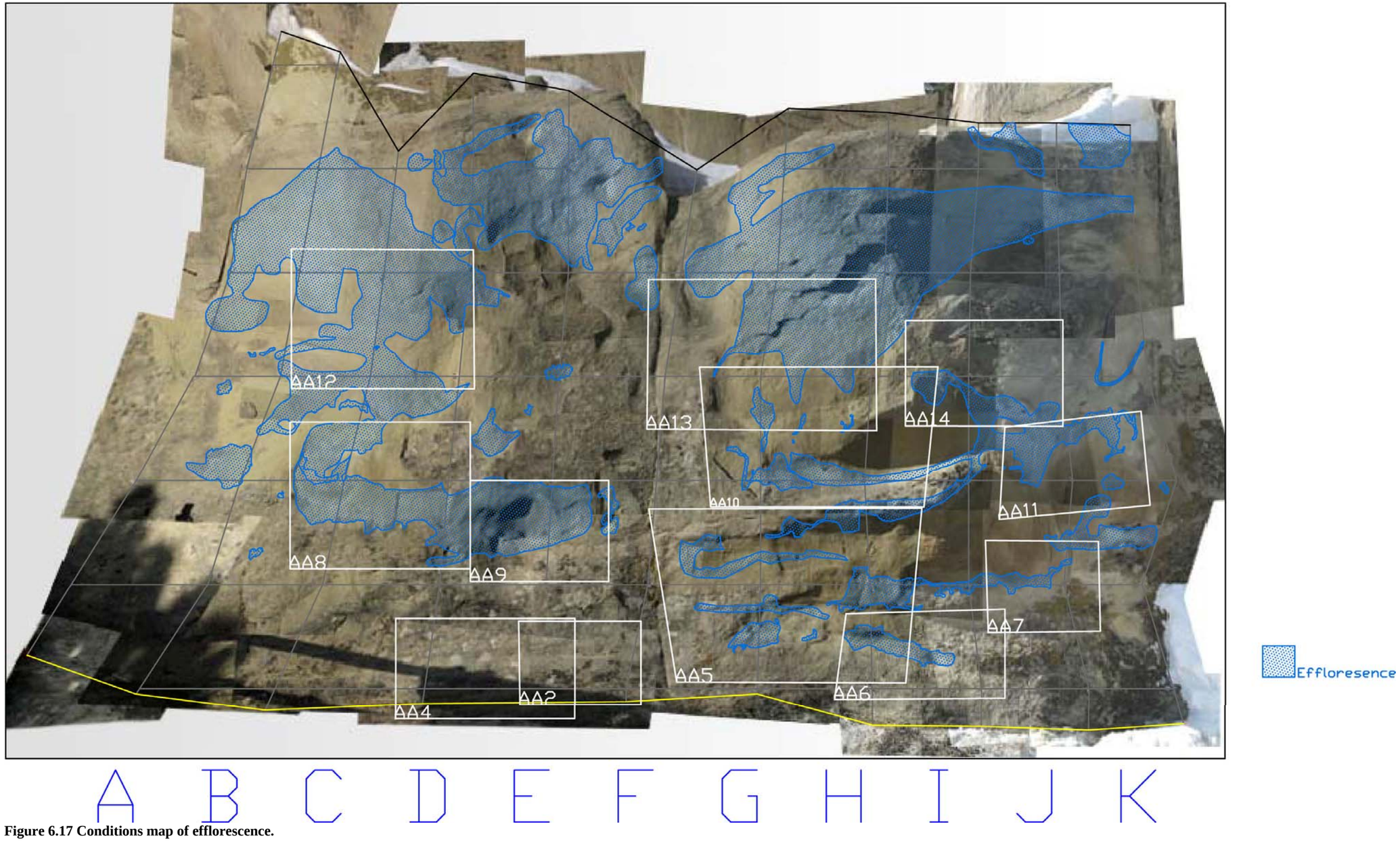


Figure 6.17 Conditions map of efflorescence.

6.2.8. Clay wash

Clay wash is a sign of an area of active water runoff, and is defined as a thin layer of clay that has been left behind on the stone surface by rainwater or snowmelt (fig 6.18). Clay wash can usually be easily brushed away. Padgett and Barthuli define clay wash as a deposit that

> occurs as thick, long drips or as a complete wash over whole panels. Some areas contain several layers of clay wash which have built up, hardened and beginning to spall. In other areas, the wash appears to be recent, forming a loose deposit which can be gently brushed away. The source of the clay wash appears to be from the top of the outcrop in some areas, while elsewhere the wash emanates from horizontal cracks or joints in the rock.[110]

Clay wash is directly related to the shape of the stone. It may be that large parts of the surface of the stone are covered in clay wash, but those areas that are recessed and protected from the cleansing effect of rain, or those parts of the rock that allow rain and snow melt to pool are where clay wash is found at the northeast point, and where it is allowed to build up as Padgett and Barthuli describe without washing away. For this reason clay wash can generally be found in protected areas that do not receive direct rain wash (fig. 6.19).

[110] Antoinette Padgett and Kaisa Barthuli. "El Morro Inscription Assessment Project, 1994." p8

Figure 6.18 An example of the build up of clay wash.

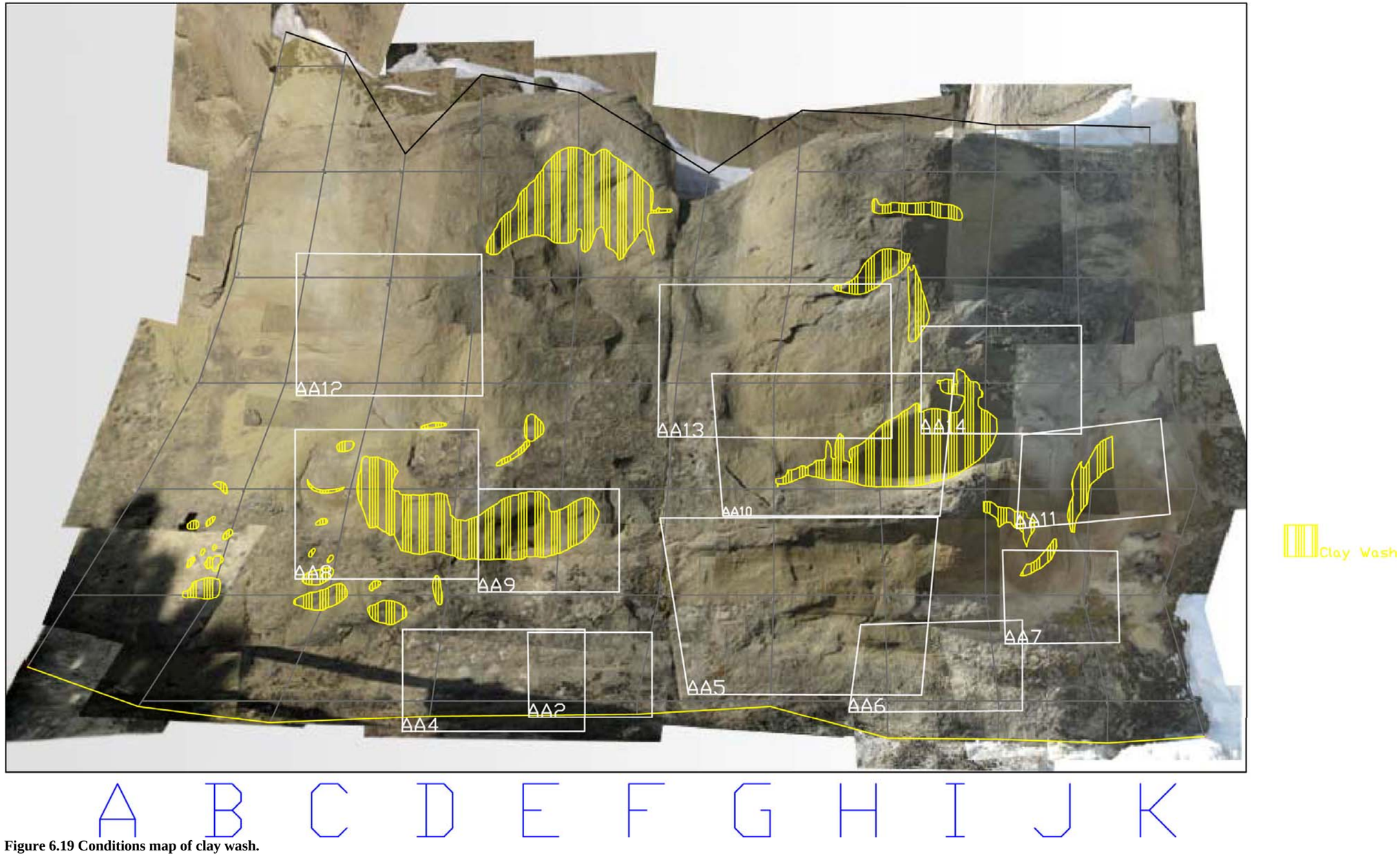


Figure 6.19 Conditions map of clay wash.

6.2.9. Insect damage

Insects may move into pre-existing holes created by weathering or anthropomorphic activity. Insect holes will be perfectly round and will ordinarily be accompanied by webs and or frass, but the northeast point of Inscription Rock is not protected from the environment, and traces of insect boring can be easily swept away by the elements (fig. 6.20, 6.22).

Figure 6.20 An example of insect damage.

6.2.10. Alveolar Erosion

As pointed out in chapter four, Snethlage and Wendler believe alveolar erosion to be a special case of granular disintegration.[111] A combination of the irregular structure in the natural stone and soluble salts transported in solution through capillary absorption cause irregular behavior in the moisture transport system. This causes the salt to precipitate out of solution at different depths relative to the surface of the stone, and this in turn leads to the differential erosion of the surface in a formation that appears like holes or pitting.[112] Alveolar erosion can be differentiated from insect damage in several ways. Alveolar erosion will tend to follow bedding planes within the stone, and the holes created by this condition can be irregularly shaped, whereas insect burrow holes are nearly circular (fig. 6.21).

111 R. Snethlage and E. Wendler. "Moisture Cycles and Sandstone Degradation."

112 Ibid.

Figure 6.21 The red arrows in this photograph point to a line of alveolar erosion following the bedding plane of the stone.

Damage due to alveolar erosion at the northeast point is not terribly advanced. The holes created by alveolar erosion are small at this location. It primarily appears where there is no microflora. The highest concentration of alveolar erosion appears between 1-4 feet in height and within 6 feet in either direction of the central fault (fig. 6.22).

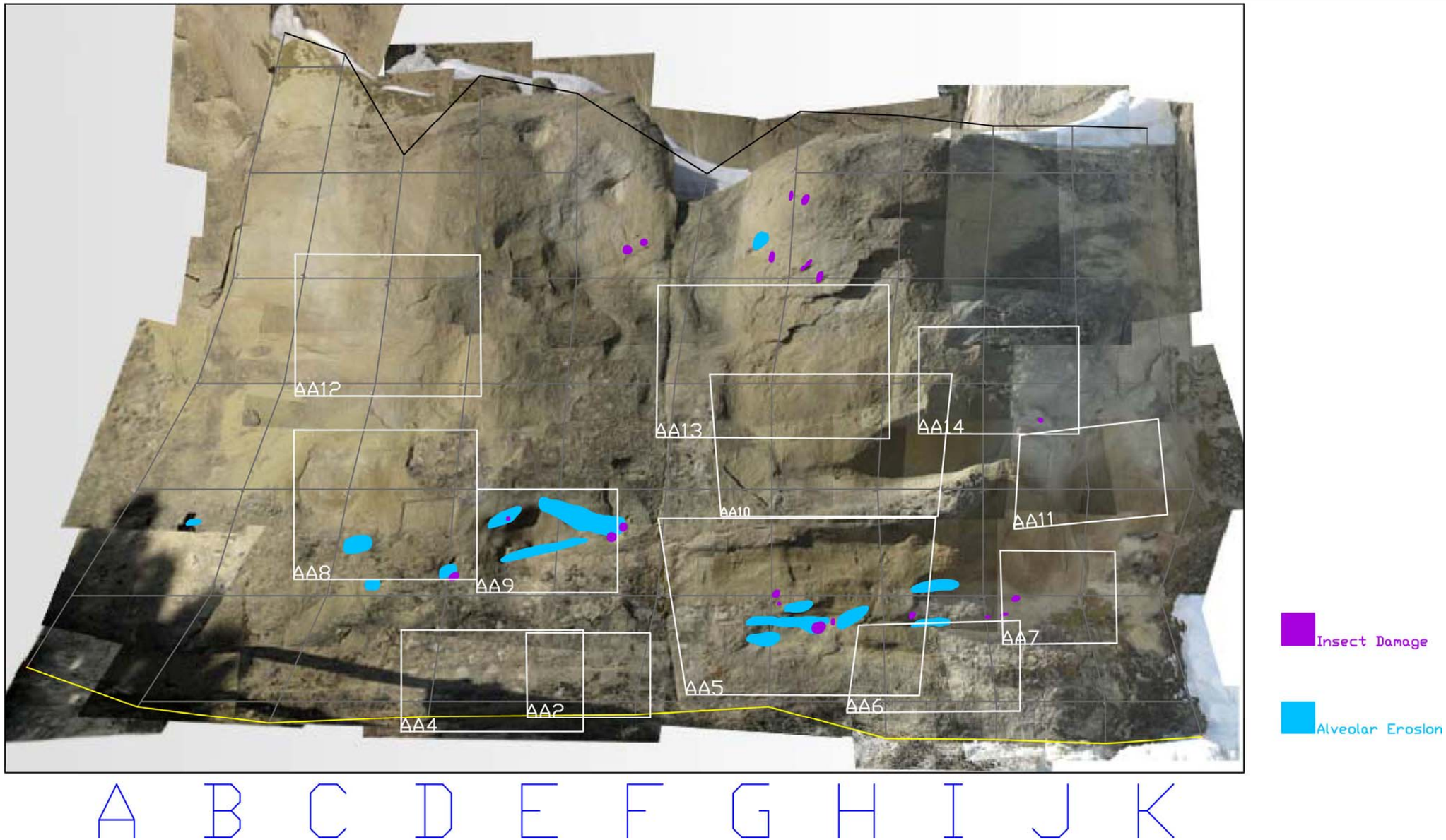


Figure 6.22 Conditions map of insect damage and alveolar erosion.

6.2.11. Cracking

Cracking is listed in three categories: major cracking, moderate cracking, and network cracking. Major cracks are those wider than 1/8 inch, moderate cracks are those between 1/16 inch and 1/8 inch, and network cracking is a patterned web of fine intersecting cracks occurring on the surface of the stone (fig 6.23, 6.24, 6.25). Cracking can remain stable at El Morro for extended periods of time, but new moderate and network cracks have formed in response to dimensional loss, and in some cases consolidation. This will be addressed further in chapter seven in the section on treated panels (fig.6.26).

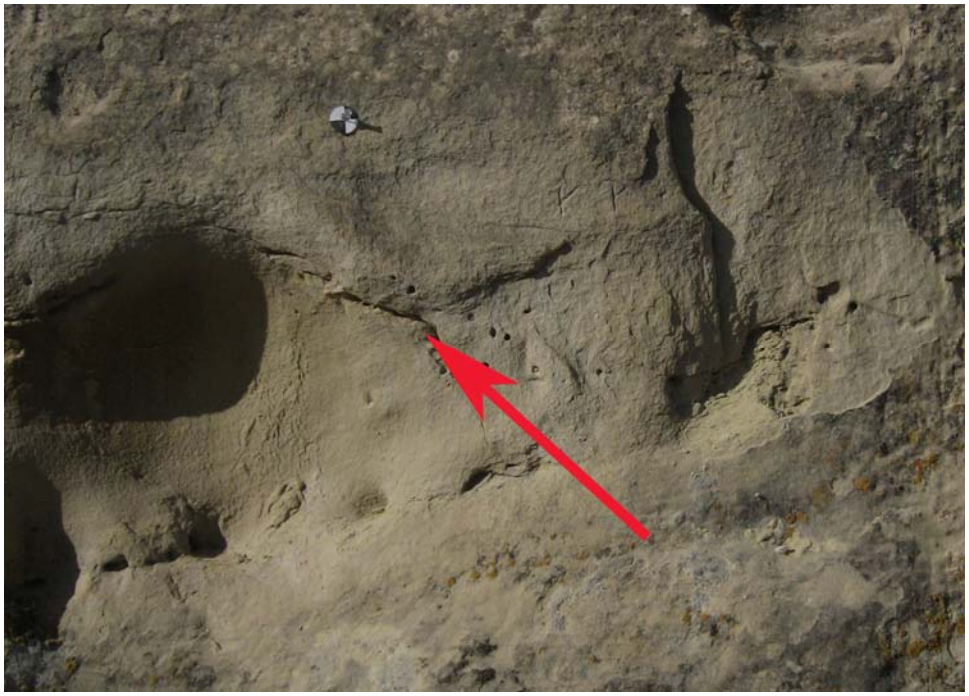


Figure 6.23 An example of a major crack.

Figure 6.24 An example of a moderate crack.

Figure 6.25 An example of network cracking.

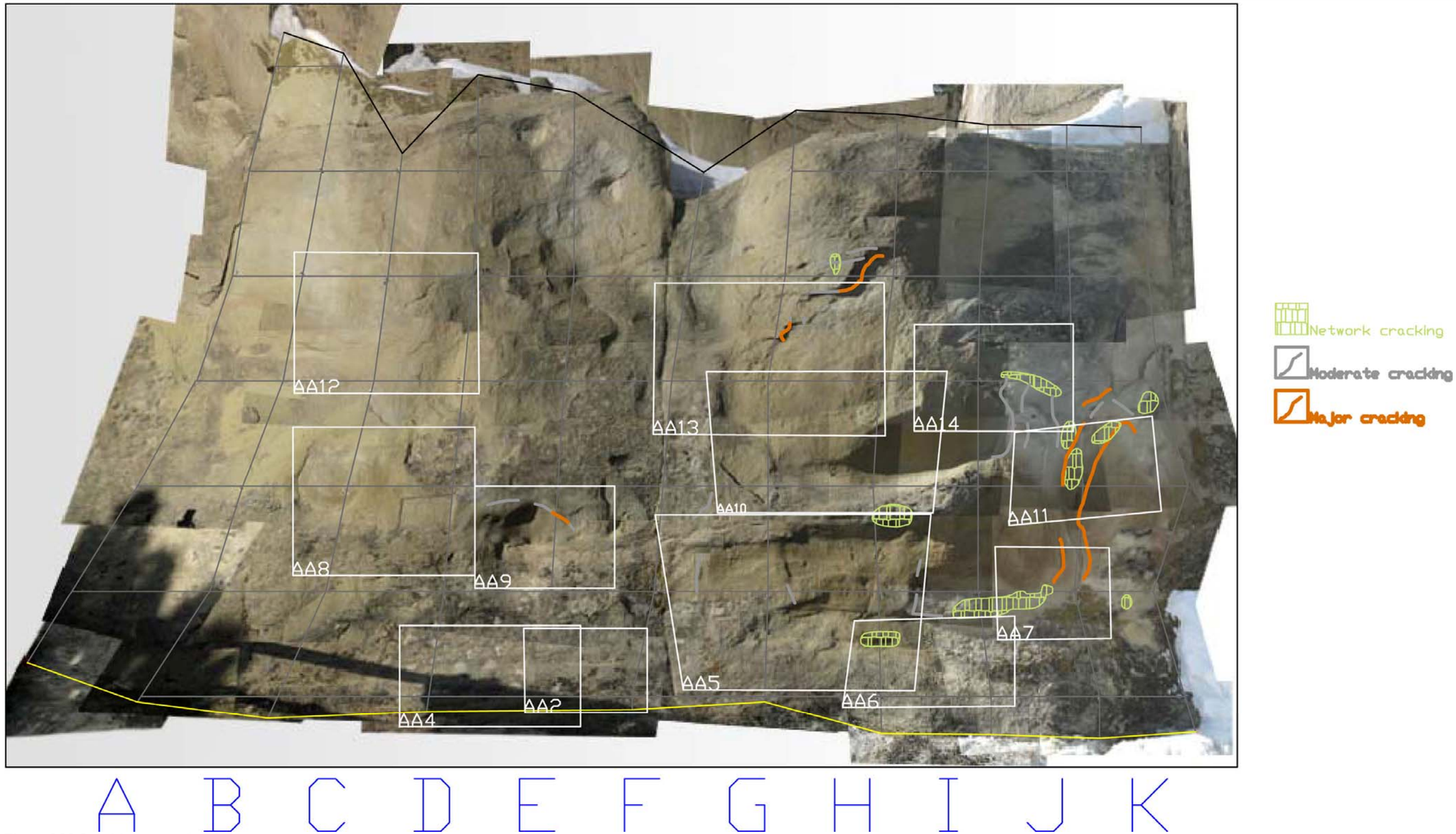


Figure 6.26 Conditions map of major, moderate, and network cracking.

6.2.12. Dimensional Loss

Dimensional loss was detected by comparing 1955 and 1993 photographs to the current conditions at the northeast point. Loss has occurred on the meso and micro scale between 1955 and 1993, and again from 1993 to present.

Loss can only be measured by historical comparison. The only available photographs for such a comparison are those taken of the panels. For this reason dimensional loss will be discussed with in the historical analysis of the panels.

7. Comparative Analysis of Individual Panels

7.1. Panel Conditions

The panels that have been used historically to document conditions at the northeast point do not fit perfectly into the grid system used in the 2007 survey. Projecting a three-dimensional object onto a two-dimensional image creates distortion. When the panels were included in the AutoCAD drawing of the condition assessment they were distorted to fit the area that they covered. In the new grid system this does not always create a perfect rectangle. Some panels, particularly AA12, AA13, and AA14 were so changed from photograph to photograph that it was impossible to place them in the grid with any accuracy. They have been drawn into the map as rectangles at or near the area that Padgett and Barthuli indicated in their 1995 summary of their survey work. Any differences from Padgett and Barthuli's model are due to the distortion inherent in the flattening of the point, and are based on defining features of the rock.

The section devoted to each panel included the location of the panel, the proximity of the panel to the ground, the ledge at the top of the lower AA section, and/or the natural fault that runs down the center of the point. All of these have potential to be sources of moisture, whether through capillary action, infiltration, or by creating a channel that rain and snow melt may run down. The shape of the stone is also addressed, as well as the weathering forms that are present. The progression of the weathering forms, loss, and the panel's overall condition is followed from 1955 to 1993 to the present using available photodocumentation. In addition overlays have been created in

AutoCAD to show loss in the time between photographs. The below key will assist in reading these overlays.

Figure 7.1 Key to be used in reading of the AutoCAD overlays.

In the overlays small scale loss has been defined as granular disintegration, flaking, and any loss less than 1 square inch, whereas dimensional loss is a gross loss larger than 1 square inch.

7.1.1. Panel AA2

Panel AA2 is located at grade level above sandy ground, and is traversed on the right side by the natural fault that runs down the center of the lower AA section. AA2 is a relatively flat, vertical panel. The top inclines away from the viewer. The panel was covered in microflora in 1955 yet despite this, a number of inscriptions were visible at that time. The inscriptions documented in the 1955 photograph (fig 7.2) were no longer visible by 1993 (fig 7.3, 7.4). The panel was obscured by minor plants and did not show any large scale dimensional loss. The surface of the stone appears eroded away, and several spalls occurred in the forty year period between the two photographs. The panel was still covered by in 2007 (fig 7.5), and there were several small additional losses due to spalling since 1993. The 2007 survey found a small amount of micro-flaking in the upper right hand portion of the panel. The surface of the rock is relatively hard compared to areas of the northeast point that do not have a biofilm.

Figure 7.2 Panel AA2. Photo taken in 1955 by McNeil and Howell.

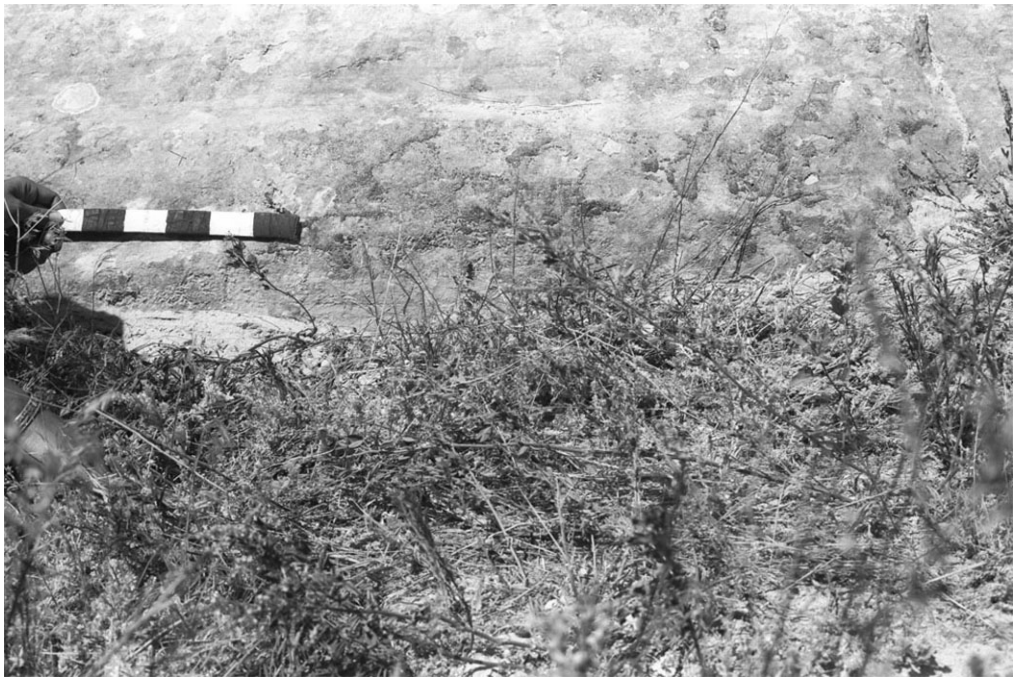


Figure 7.3 Panel AA2. Photo taken in 1993 by Padgett and Barthuli.

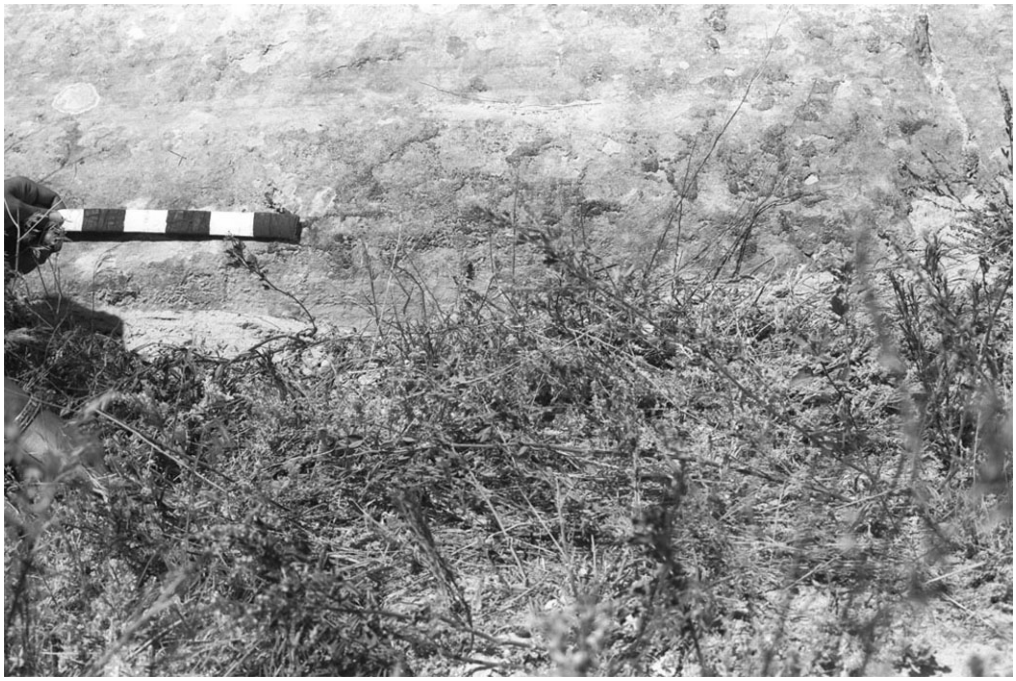


Figure 7.4 Panel AA2. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.5 Panel AA2. Photo taken in 2007 by Burris.

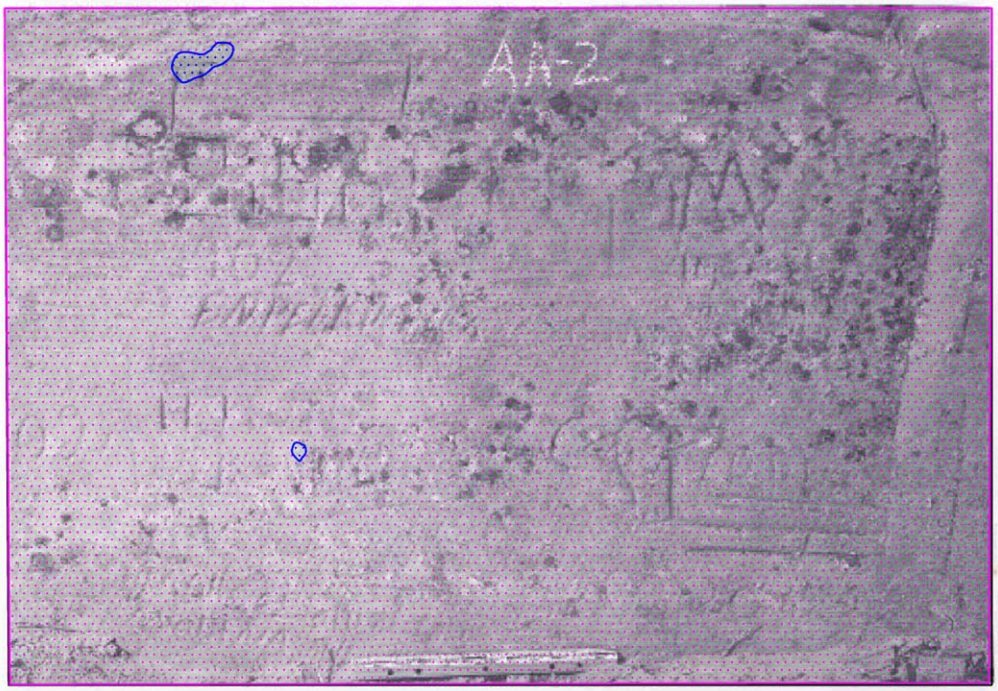


Figure 7.6 Panel AA2. Photo taken in 1955 with an overlay of the loss that occurred between 1955 and 1993.

Figure 7.7 Panel AA2 Photo taken in 1993 with an overlay of the loss that occurred between 1993 and 2007.

7.1.2. Panel AA3

AA3 was listed as buried in 1980.[113] It was not recorded in the 1993 survey by Padgett and Barthuli, and has not been found for documentation in subsequent surveys.

7.1.3. Panel AA4

Panel AA4 is a relatively flat panel inclined slightly towards the top of the monument. It is located just to the left of panel AA2 at ground level, contiguous with the sandy soil, and the right edge of the panel is roughly 11 to 15 inches from the natural fault at the center of the point. The 1955 photograph shows a centrally located inscription (fig 7.8). Several other inscriptions are in the lower right hand corner and at the top of the photo. Like AA2, the entire panel is covered in microflora. There is a flake several inches long in the upper left hand of the panel. As the 1993 photograph indicates, this flake has only slightly changed in nearly forty years (fig 7.9, 7.10). A portion of the edge of the flake has fallen away, but the same general shape and size of the flake remains. Only faint impressions of the inscriptions can be seen in the documentation from 1993. The entire panel is still covered in , and there are five small areas of loss due to spalling that have occurred since 1955.

In 2007 parts of the box that once surrounded the central inscription were still visible in raking light but no other inscriptions can be seen (fig 7.11). Microflora still covers the entire panel. Spalling has continued, and three new small areas of loss have

113 This record is titled only Names Etc. Lost to Erosion on the Point of Inscription Rock As Surveyed in July of 1980. No name is associated with the document. It was found as a single sheet of paper in file H22, "List of Inscriptions," Archival box H and K, located in the fire proof case in the archive room at El Morro.

occurred since 1993. The 2007 survey found an area of blind delamination in the upper right hand corner.

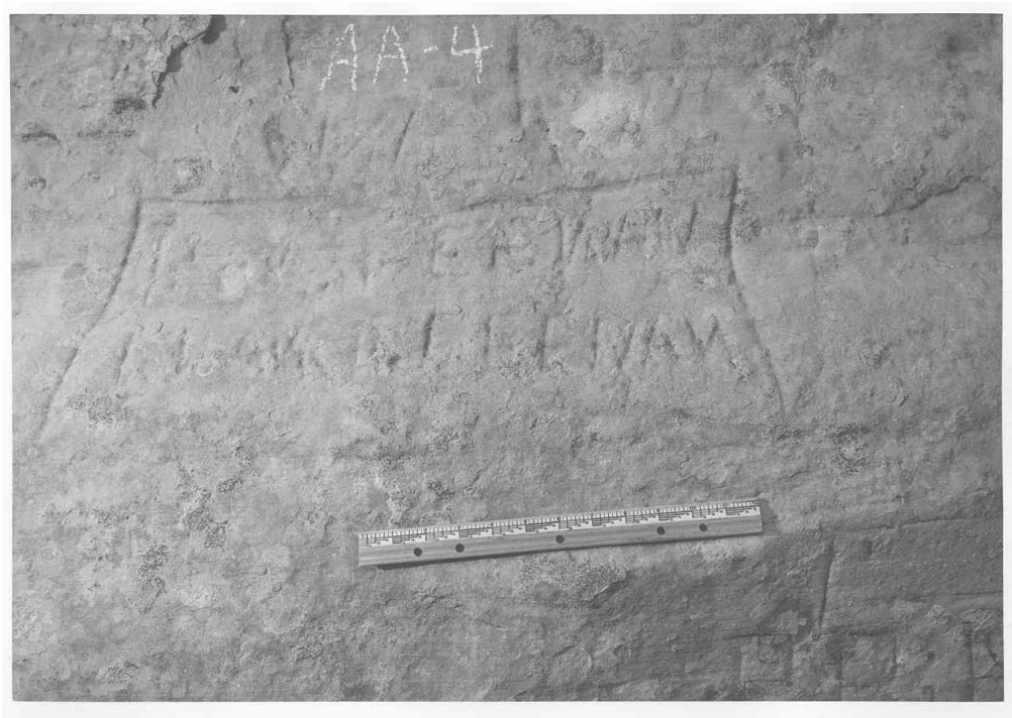


Figure 7.8 Panel AA4. Photo taken in 1955 by McNeil and Howell.

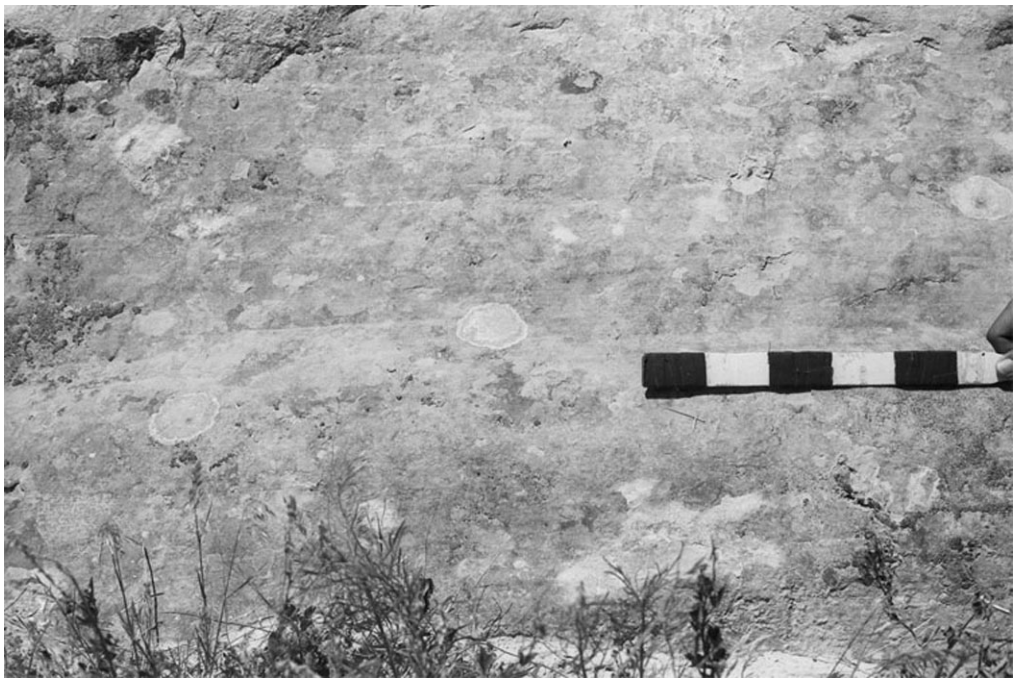


Figure 7.9 Panel AA4. Photo taken in 1993 by Padgett and Barthuli.

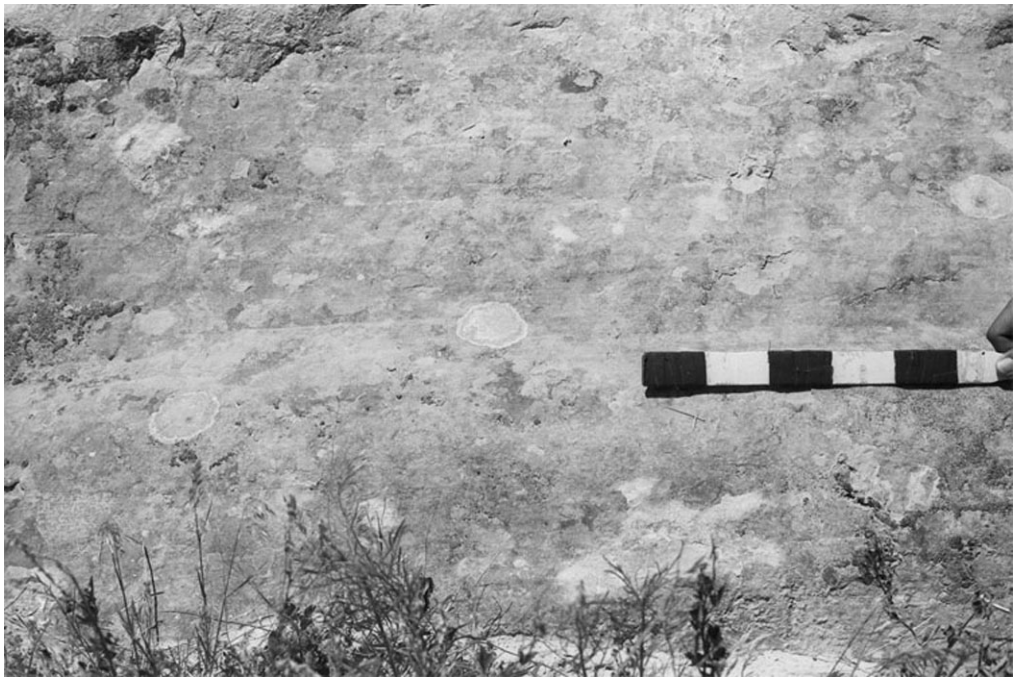


Figure 7.10 Panel AA4. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.11 Panel AA4. Photo taken in 2007 by Burris.

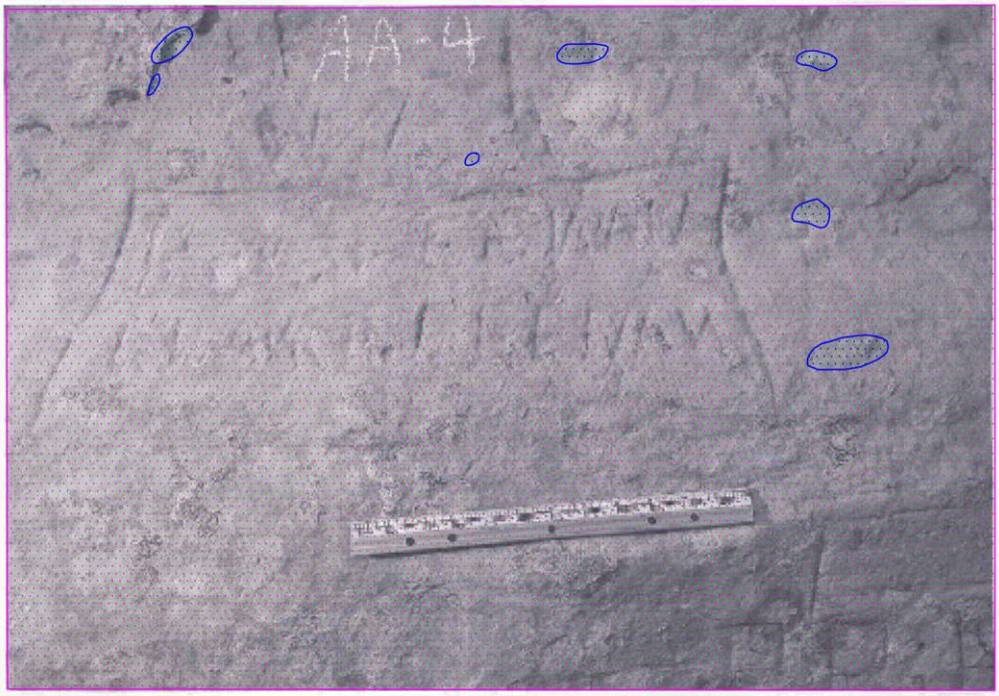


Figure 7.12 Panel AA4. Photo taken in 1955 with an overlay of the loss that occurred between 1955 and 1993.

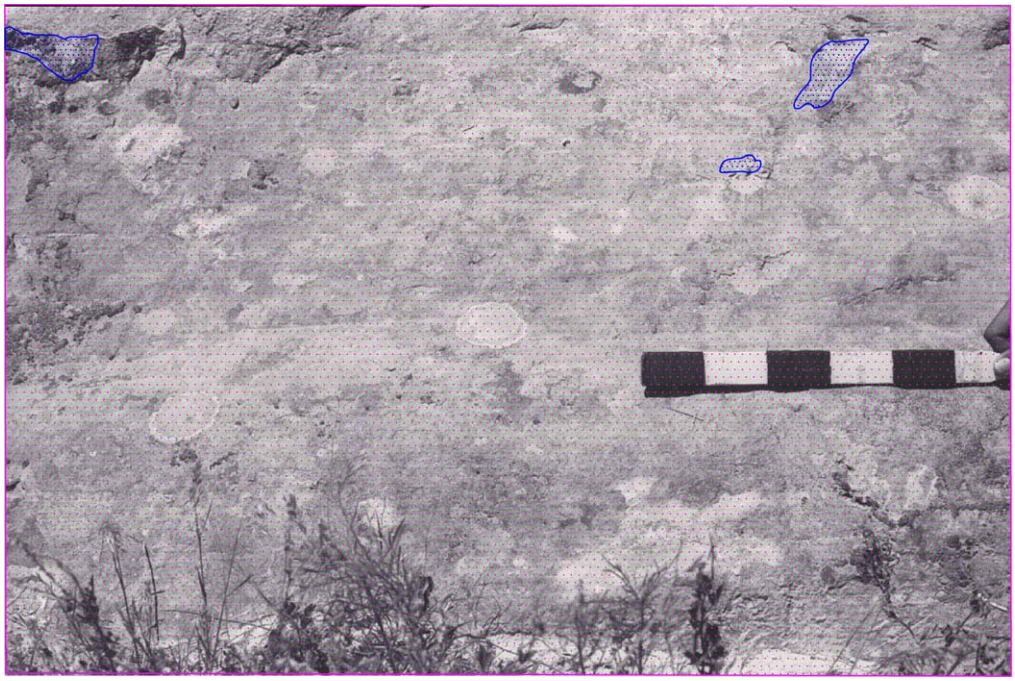


Figure 7.13 Panel AA4. Photo taken in 1993 with an overlay of the loss that occurred between 1993 and 2007.

7.1.4. Panel AA5

The panel is located less than 3 inches above the sandy soil at its closest point to the ground. It overlaps the natural fault in the rock in the upper left hand corner of the panel. The lower corner is slightly under a foot away from this fault. AA5 sits under the ledge found below an alcove in AA10. There are several horizontal depressions that run across its surface. These once held inscriptions. The panel itself is relatively planar in the vertical.

The 1955 photograph for panel AA5 is no longer with the collection and is not available for analysis. The first documentary photograph available is from 1993(fig 7.14). This image depicts two large rectangles that overlap near the top of the panel. These areas once held inscriptions. They are now relatively smooth compared to the surrounding stone. The remains of an H and several other indiscernible letters are located in the upper left hand corner of the left rectangle. An overhang is above the rectangle on the right, and just below both the rectangles, a band of lichen stretches half way through the image covering part of an inscription. The line of microflora stops two-thirds of the way through the writing to reveal the end of the inscription. The edges of the revealed letters are flaking away. The bottom half of the panel is rough and riddled with micro-flaking and contour scaling.

AA5 was deemed a prime candidate for consolidation, and was first treated with ethyl silicate in a methyl ethyl ketone solvent sold under the commercial name of Conservare OH in 1996. A 1998 assessment of the panel noted that “the inscription remains well consolidated, but hairline cracks have developed in the consolidated

area."[114] The following year the panel was listed as having granular disintegration and spalling. It was also noted that the panel was "already treated, but still unstable."[115] Panel AA5 was retreated with Conservare OH in 2004. No photodocumentation could be found for the second treatment, but it is known that the second treatment covered the area that was consolidated in 1996, and some of the area that surrounded it.[116]

In 2007 the remains of the inscription in the upper left hand corner appear unchanged, but the inscription in the middle of the panel is less legible than it had been in 1993 (fig 7.15). Loss has occurred and although there is still some micro-flaking and contour scaling, the lower half of the panel has a more rounded appearance than it did in 1993. There has been a great increase in alveolar erosion and/or insect damage in the central area of the panel that was consolidated, and network cracking has appeared in a small section of the overhang above the rectangles.

114 Oliver, Anne. "El Morro National Monument Pilot Inscription Treatment Program July 1996," appendix C.

115 Ibid, appendix D.

116 Oliver, Anne, personal communication. 25 October 2006.

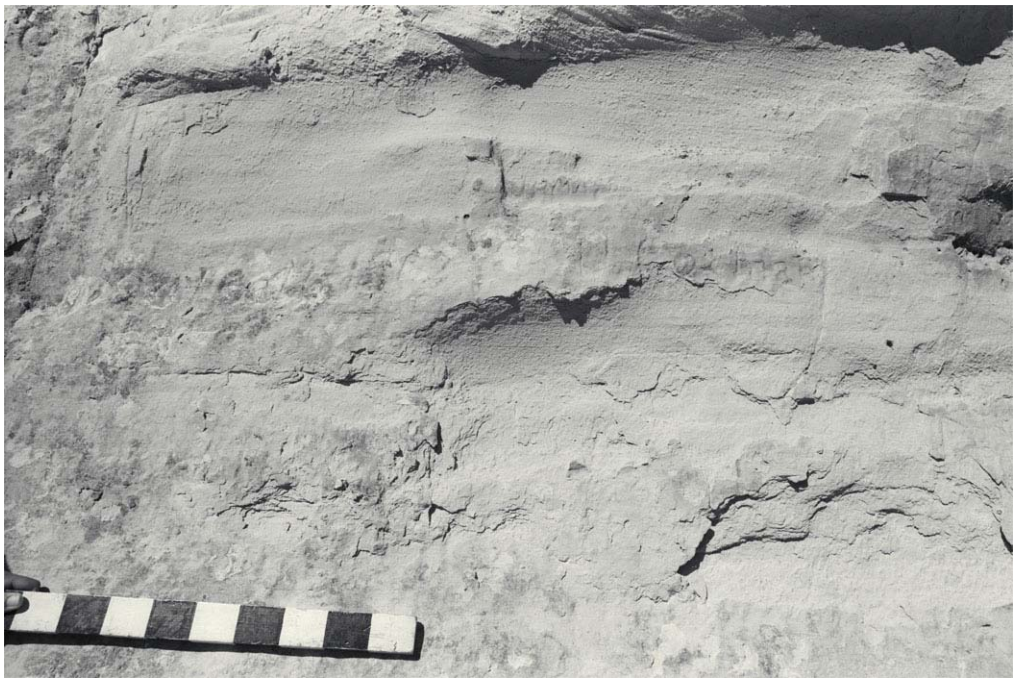


Figure 7.14 Panel AA5. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.15 Panel AA5. Photo taken and montage in 2007 by Burris.

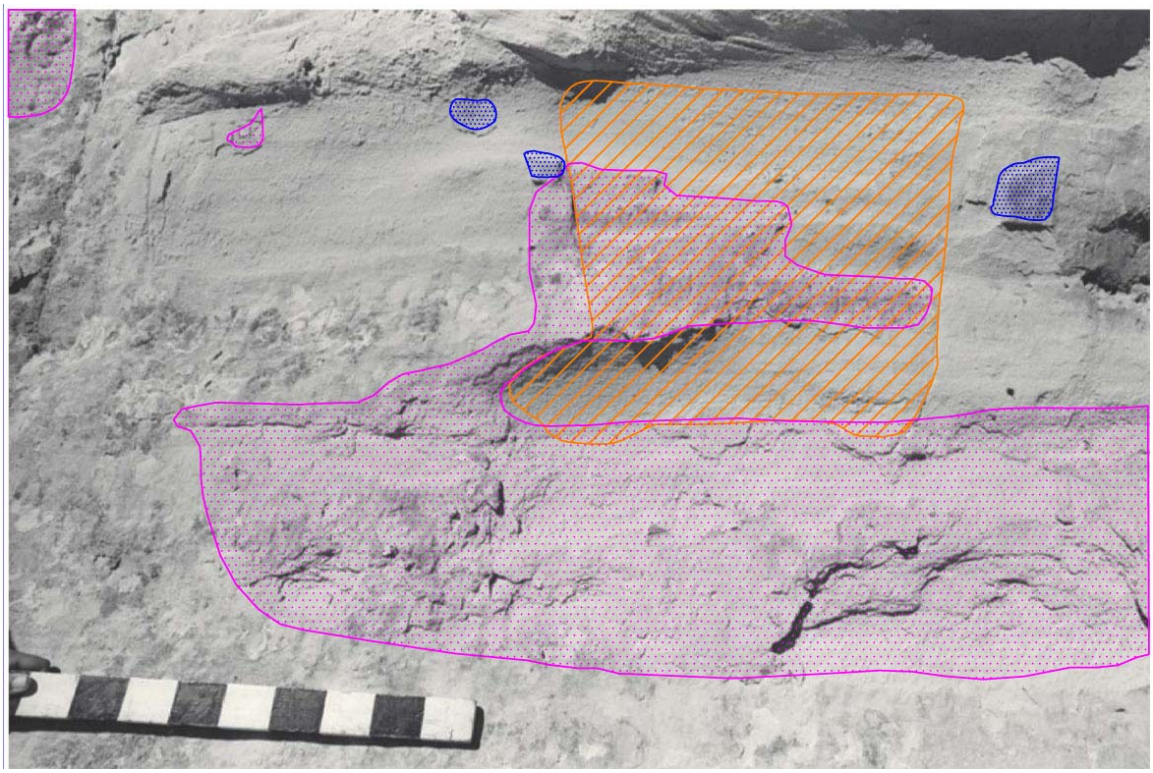


Figure 7.16 Panel AA5. Photo taken in 1993 with an overlay of the change that occurred between 1993 and 2007

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7.1.5. Panel AA6

Panel AA6 is about 6 inches above the sandy ground, and roughly mid-way between the center fault and the northern edge, between the AA and BB sections. When the panel was first photographed in 1955 it was relatively flat and vertical, but as will be seen in the description, by 2007 the upper quarter of the AA6 protrudes over the rest of the panel.

In 1955 a fair number of inscriptions were visible (fig 7.17). At that time the lower three quarters of the panel were covered in microflora, and insect damage appeared in the upper central portion of the panel.

By 1993 large portions of the panel are missing (fig 7.18, 7.19), except for a flaking inscription in the uppermost left hand corner, the inscriptions in the top right and center of the photograph are gone due to relief and dimensional loss. Areas of micro-flaking and contour scaling affect the areas where the inscriptions had once been. Most of the surface of the panel is listed as unstable in the 1993 survey. Microflora still covers the stable portion of the bottom three quarters of the panel, but areas that have suffered such loss as described above do not contain advanced lichen colonies. By 1993 the insect damage had increased, and was moving outward from the central top location documented in 1955.

Panel AA6 was consolidated with Conservare OH in 1997. Excess consolidant was removed first with methyl ethyl ketone, but the solvent proved to cause a white

bloom to form on the surface of the stone. Its use was discontinued and a 10% aqueous ammonium hydroxide solution was used instead to remove the consolidant.[117] In 1998 an assessment listed the inscription and treatment in good condition,[118] but in the following year it was noted that "almost no traces of the inscription remain."[119] A 2003 assessment recorded the loss of small flakes and the loss of the entire inscription in 2000. The conservator questioned whether the remainder of the inscription should be consolidated, but ethyl silicate was never reapplied to the site.

Despite treatment additional areas of loss adjacent to those seen in 1993 had occurred by 2007 (fig 7.20). Large sections of loss have undercut the top third of the left side of the panel, and leveled sections that were between areas of loss in the 1993 photograph. In addition to this, small areas of loss associated with spalling have roughened the appearance of the surface of the stone on the right side of the panel. Flaking and granular disintegration have led to a more rounded appearance on the surface of panel AA6 since then.

117 Oliver, Anne. "El Morro National Monument Pilot Inscription Treatment Program July 1996," appendix A

118 Ibid, appendix C

119 Ibid, appendix D

Figure 7.17 Panel AA6. Photo taken in 1955 by McNeil and Howell.

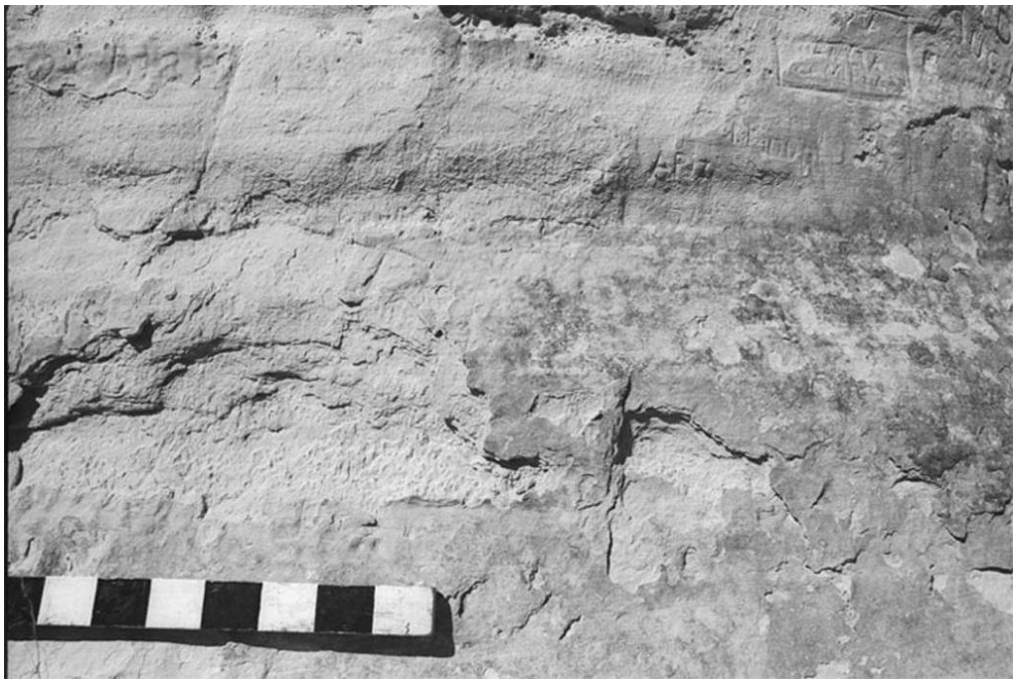

Figure 7.18 Panel AA6. Photo taken in 1993 by Padgett and Barthuli.

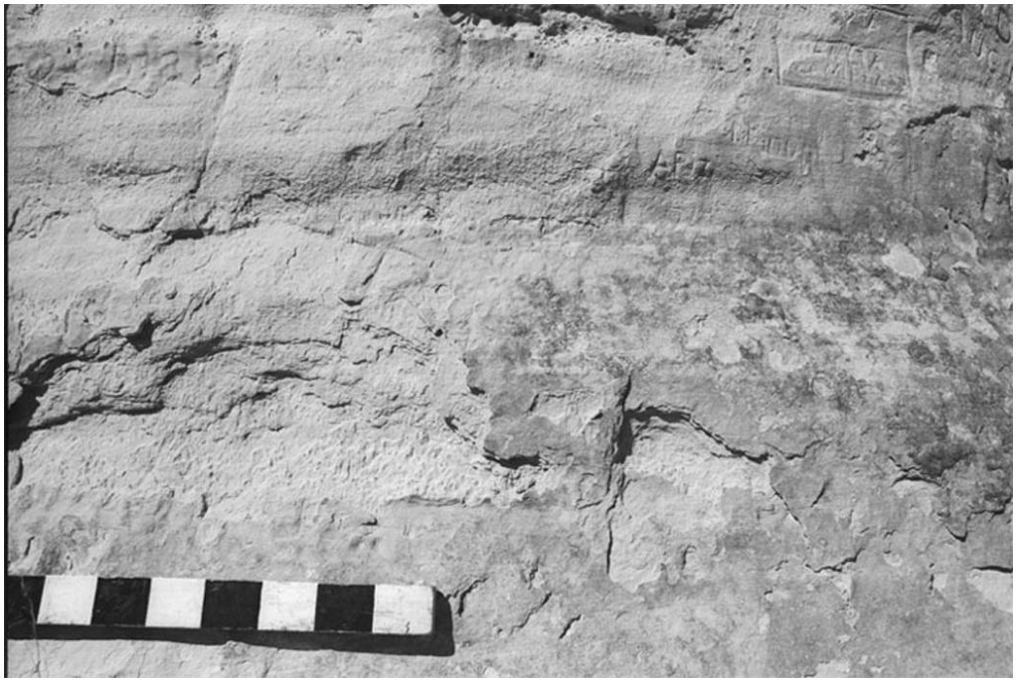

Figure 7.19 Panel AA6. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.20 Panel AA6. Photo taken in 2007 by Burris.

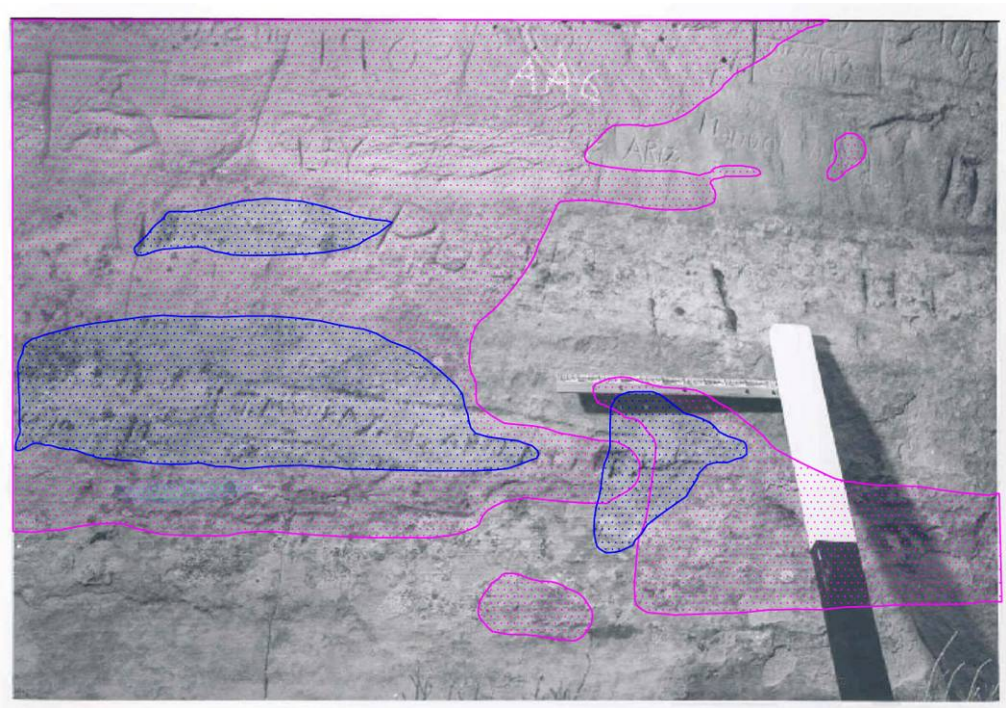

Figure 7.21 Panel AA6. Photo taken in 1955 with an overlay of the loss that occurred between 1955 and 1993.

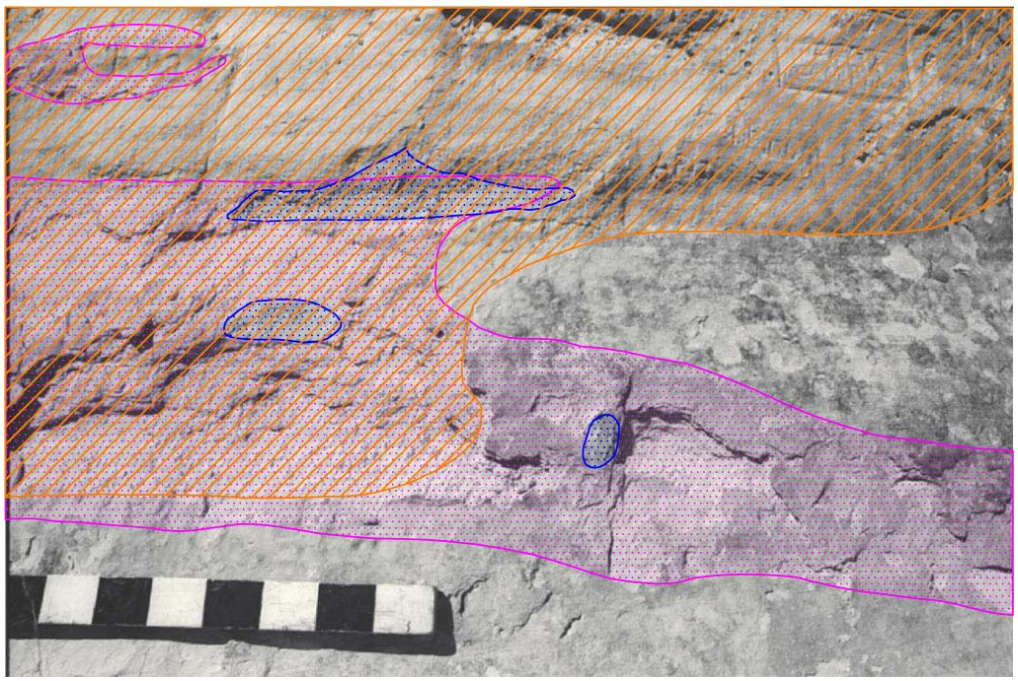

Figure 7.22 Panel AA6 Photo taken in 1993 with an overlay of the changes that occurred between 1993 and 2007.

7.1.6. Panel AA7

Panel AA7 (fig 7.23) is approximately 19 inches above ground level, and 9 inches from the northern edge of the AA section. It is just below AA11, and is subject to similar weather conditions. A stable major crack runs through AA11. The base of this crack becomes a delamination and continues into the center of Panel AA7. An egg shaped inscription with a border fashioned to look like a rope is on the left side of AA11, with the bottom portion of the inscription extending into the top left hand side of AA7. The bedding of the stone angles down and to the right in this panel. An inscription dated 1714 follows the bedding in the center of the panel, and a second inscription, "Von Dom," is above and to the left of the first carving. Several other small inscriptions dot the surface of the stone. Microflora covers three quarters of the panel. The areas not covered in biogrowth are the upper left hand corner and several patches in the upper right.

Many of the predominant features on the surface of panel AA7 have proven to be stable in the 1993 photograph (fig 7.24, 7.25). Many of the inscriptions are still present, and there has been no change in the large delamination that runs into the center of the panel. Areas covered in microflora have suffered from spalling. One particularly noteworthy spall removed a large portion of the "4" in "1714." One area in the upper right hand corner that was not covered in microflora in either year suffers from micro-flaking in 1993.

The 1993 survey listed the main agent of deterioration as micro-spalling. The survey noted that the area was damp, and that there were possible efflorescences below

the "Van Dom" inscription. The panel was consolidated in 1997 with Conservare OH; no lichen removal was noted at the time.[120] An assessment in 1998 listed the panel in good condition. The following year it was noted that although the panel had been treated, deterioration continued. In 2003 two small flakes were noted missing below the panel, and the following year in 2004 the panel was reconsolidated.

By 2007 (fig 7.26) the microflora has completely consumed the 1714 inscription and a portion of the "Van Dom" inscription. The area that the microflora covers has not expanded, but the biogrowth makes the inscriptions difficult to impossible to see. Spalling related to the microflora has continued, and a second area afflicted with micro-flaking has appeared to the left of the microflora.

120 Oliver, Anne. "El Morro National Monument Pilot Inscription Treatment Program July 1996," appendix A

Figure 7.23 Panel AA7. Photo taken in 1955 by McNeil and Howell.

Figure 7.24 Panel AA7. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.25 Panel AA7. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.26 Panel AA7. Photo taken in 2007 by Burris.

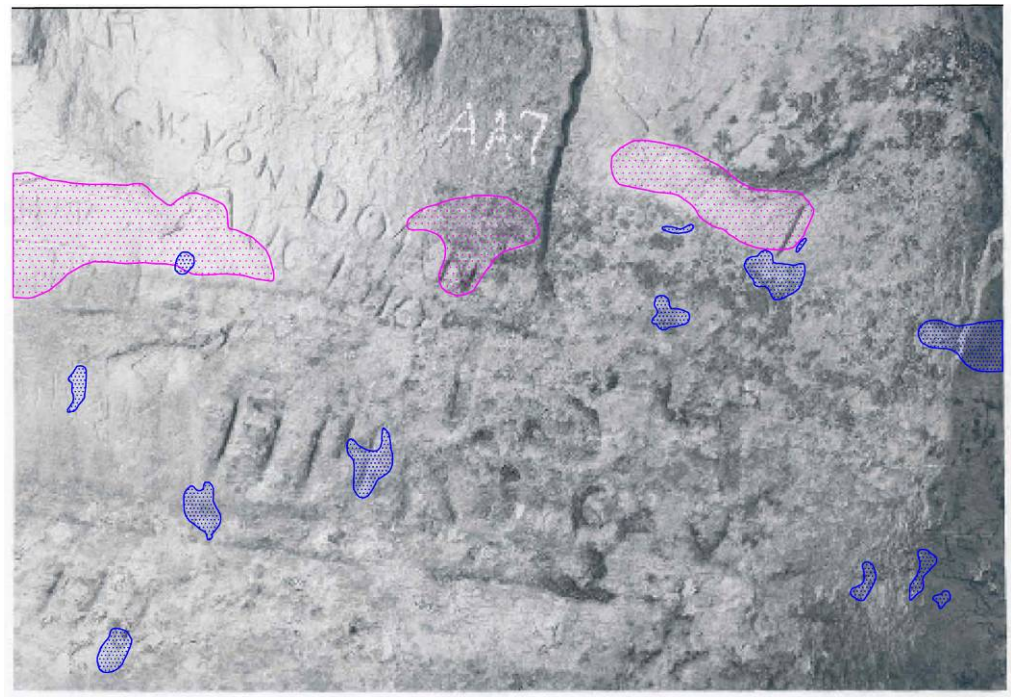

Figure 7.27 Panel AA7 Photo taken in 1955 with an overlay of the loss that occurred between 1955 and 1993.

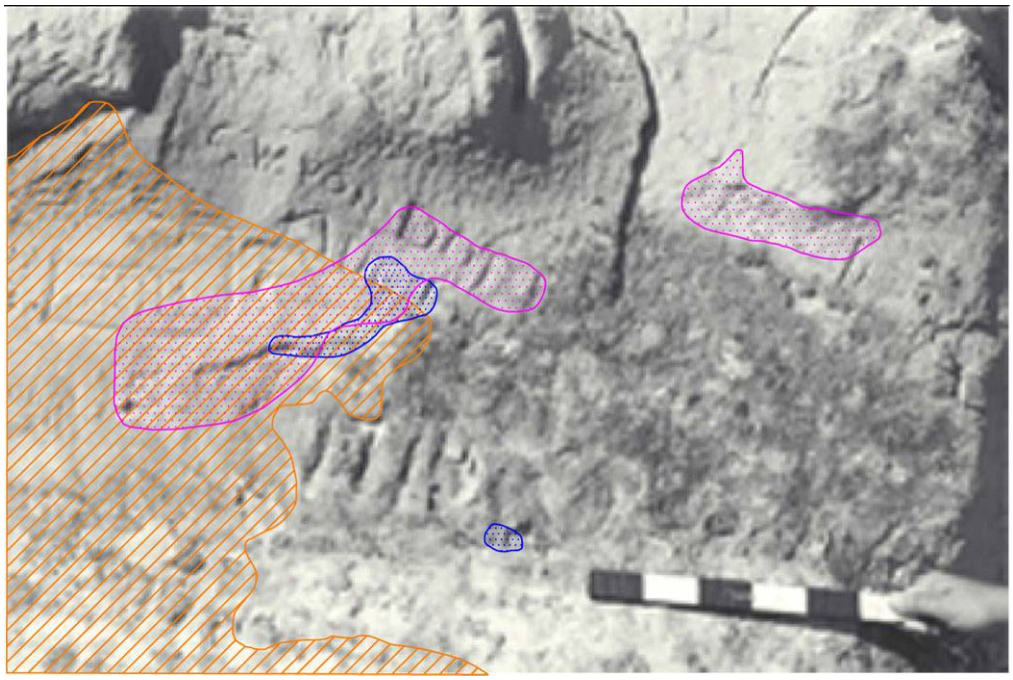

Figure 7.28 Panel AA7. Photo taken in 1993 with an overlay of the changes that occurred between 1993 and 2007.

7.1.7. Panel AA8

Panel AA8 is roughly two feet seven inches above the ground, slightly more than five feet below the top of the sandstone ledge, and three and one half feet to the left of the central fault in the stone. The two main inscriptions within the panel reside on the lightly curved surface of the stone, with a relatively flat area of stone above angled towards the top of the section. The surface of the stone below the inscriptions pitches outward so that the sandstone angles more steeply towards the ground. There are two inscriptions in this panel. The inscription on the left has been carved into an area of sandstone characterized by a rounded bottom that curves up to straight, parallel sides, and a relatively flat top. A four lined inscription is within the geometric shape, and is dated 1812. To the right of the panel is a rectangular inscription about half the size of the first carving. In the 1955 photograph the panel had obviously suffered a loss above the inscriptions (fig 7.29). The sandstone here has a rough texture compared to the surrounding rock. Microflora covers the top right hand corner and the bottom half of the panel, just intruding into the lower regions of the inscriptions.

The 1993 photograph shows roughly the same configuration for the microflora (fig 7.30, 7.31). The lichen had not expanded significantly from the areas that they inhabited in 1955, but the panel has suffered losses in the intervening forty years. The inscription on the left lost approximately two thirds of the written inscription, and the stone to the left and above the writing. The inscription to the right suffered loss in the lower right hand corner of the inscription and several inches below the carving due to

flaking and spalling. The 1993 survey listed two active clay wash areas. The panel was also damp at that time with possible efflorescence.

AA8 was consolidated in 1997 with ethyl silicate in the form of Conservare OH. Excess consolidant was removed using a 10% aqueous ammonium hydroxide solution. The follow up assessment conducted the following year found the panel and the treatment to be in good condition, but in 1999 discolorations and a substance on the surface of stone that was noted as new salts were noted.[121]

Consolidation appears to have prevented dimensional loss from the inscriptions, but the carvings are slowly eroding so that the writing becomes fainter. The 2007 survey shows that the area above and to the left of the left hand inscription suffers from intense granular disintegration and micro-flaking (fig7.32). Contour scaling has formed in the upper right hand corner of the panel, and clay wash is still a concern.

121 Salt analysis has not been conducted to prove or disprove the existence or variety of salt.

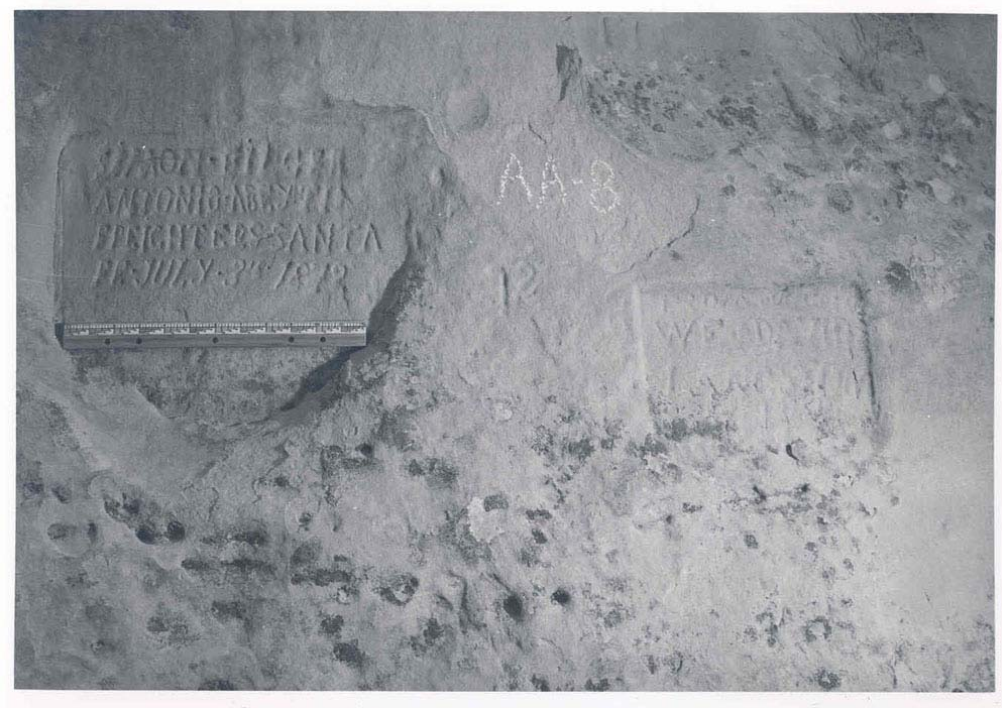

Figure 7.29 Panel AA8. Photo taken in 1955 by McNeil and Howell.

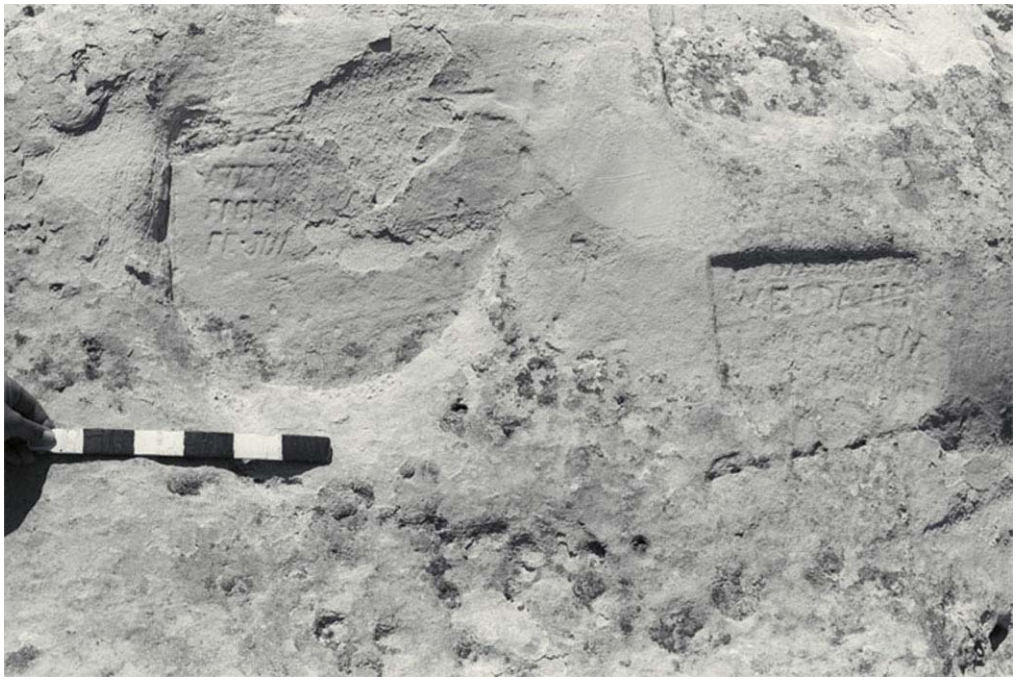

Figure 7.30 Panel AA8. Photo taken in 1993 by Padgett and Barthuli.

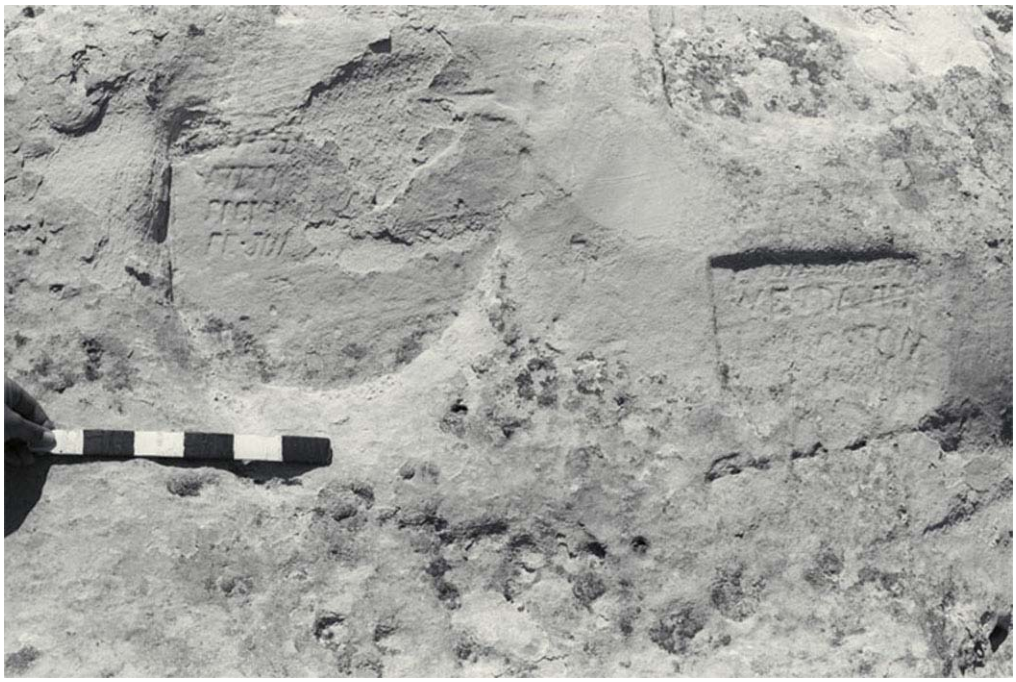

Figure 7.31 Panel AA8. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.32 Panel AA8. Photo taken in 2007 by Burris.

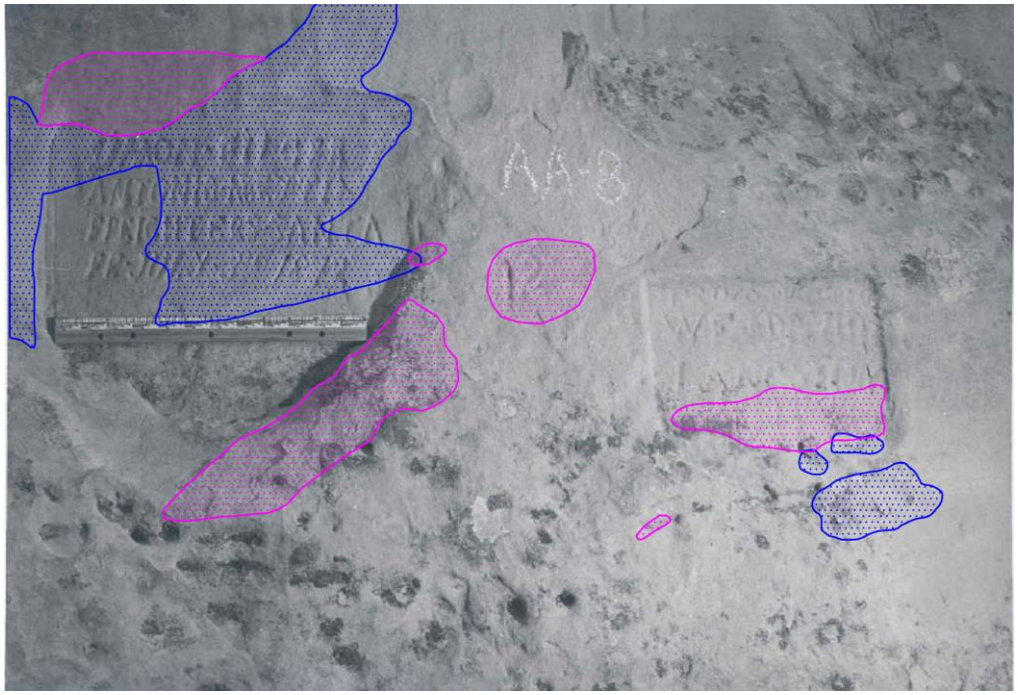

Figure 7.33 Panel AA8. Photo taken in 1955 with an overlay of the loss that occurred between 1955 and 1993.

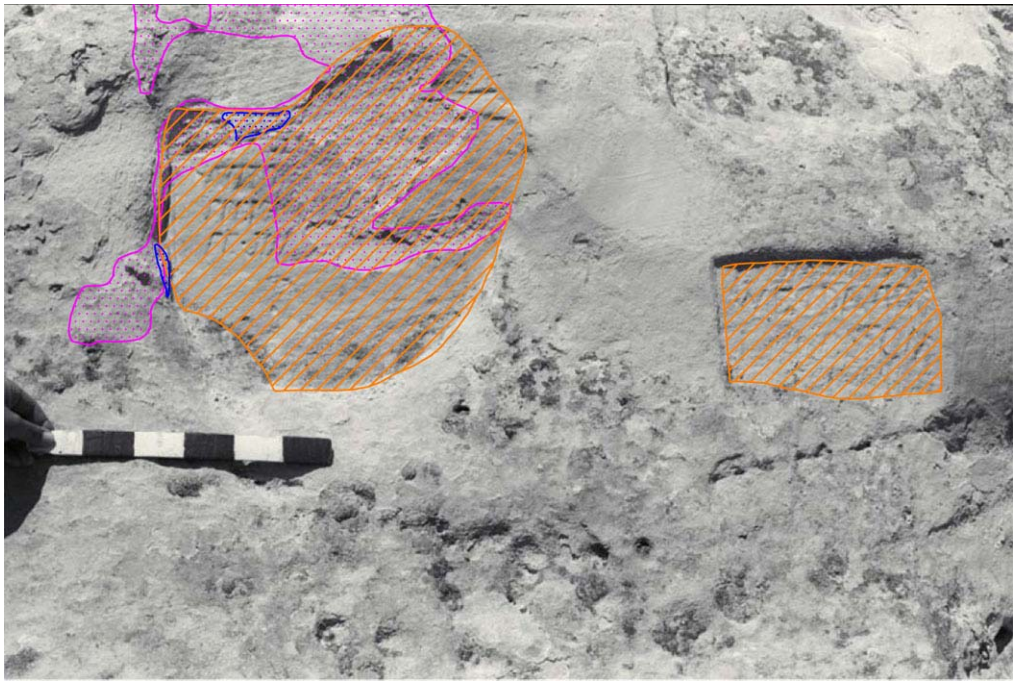

Figure 7.34 Panel AA8. Photo taken in 1955 with an overlay of the changes that occurred between 1993 and 2007.

7.1.8. Panel AA10

Panel AA10 is roughly 3 feet 9 inches above the ground, slightly farther from the ledge above, and between 7 and 13 inches to the right of the central fault. AA10 encompasses part of the second major depression in the northeast point. This is located in the right hand half of the panel. A ledge sweeps up underneath the hollow, angling downward to the right. The ledge is the same outcrop described in the top right hand corner of AA5. The left hand half of the panel is relatively vertical.

The 1955 photo of this panel is missing, and cannot be used for comparison. The oldest photograph that can be used dates to the 1993 survey (fig. 7.35). The only remaining inscription in the 1993 photograph, located in the lower left hand corner is illegible and flaking. To the left and below the inscription microflora can be found, and above the inscription the surface of the stone is roughened. There appears to be contour scaling and micro-flaking.

The inscription and the area immediately surrounding it were consolidated with Conservare OH in 1996, and were described as in good condition in 1998.[122] However the following year the records inferred that the treated area was not fairing well, and an effective treatment may not be available.[123] The inscription was recorded as entirely lost in 2000,[124] but in 2003 further stone loss was noted. The conservator questioned at that time whether the cracks that were left after the loss should be filled. No record of such treatment could be found.

122 Oliver, Anne. "El Morro National Monument Pilot Inscription Treatment Program July 1996," appendix C

123 Ibid, appendix D

124 Ibid, appendix E

The 2007 photograph shows a large loss from where the treated inscription had been (fig 7.36). A thick edge below the site indicates that it may have been lost in one or several large flakes. There are additional areas of loss above the hollow in the right hand corner. Contour scaling and micro-flaking cover the same areas as in 1993 and the only changes in microflora have been due to the loss of surface.

Figure 7.35 Panel AA10. Photo taken in 1955 by McNeil and Howell.

Figure 7.36 Panel AA10. Photo taken and montage in 2007 by Burris.

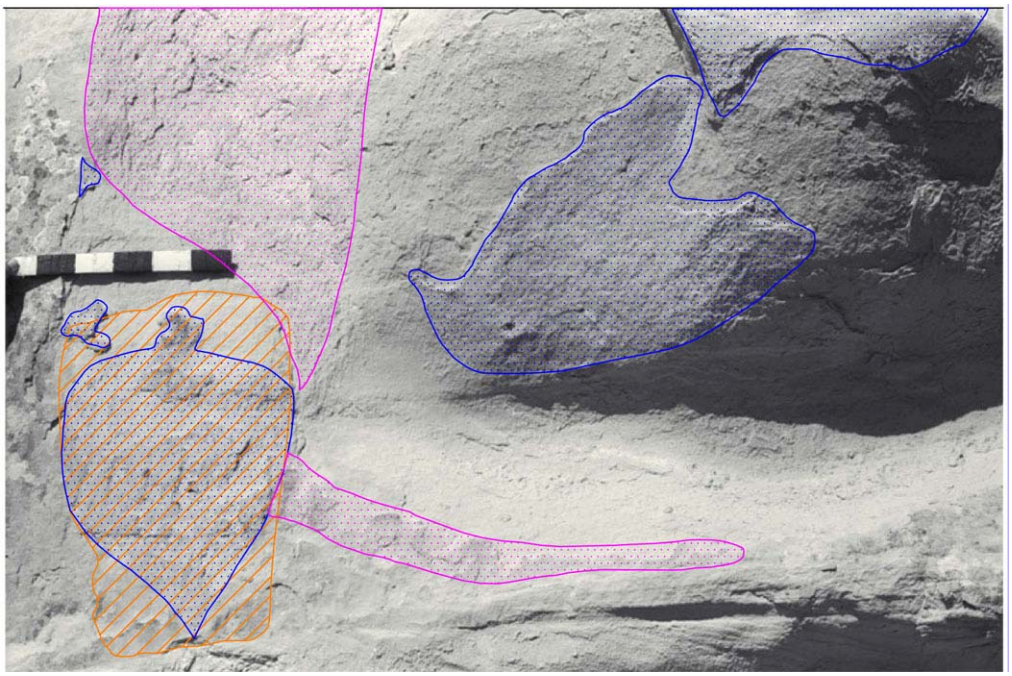

Figure 7.37 Panel AA10. Photo taken in 1993 with an overlay of the changes that occurred between 1993 and 2007.

7.1.9. Panel AA11

Panel AA11 is nearly 4 feet above ground level, slightly fewer than 5.5 feet from the ledge at the top, and is 3-4 inches from the northern edge of the AA section. The area directly above the chalk writing in the 1955 photograph sweeps up and over a flat egg-shaped area on the right (fig 7.38). This creates a hood over the right side of the panel with a surface that is perpendicular to the relatively open field to the north. Below and two the left of this formation is a smaller oval surrounded by a protruding carved rope. A number of inscriptions are within both described features. On the left hand side of the panel, above the carved rope are three rectangular carvings, and an “M” above an incised “3.”

The 1993 photograph shows that there has been some loss next to and on the top of two rectangles in the left hand corner (fig 7.39, 7.40). The upper portion of the oval to the right, and the flat hood that reaches above it has lost a thin surface layer as well, and the "M" has suffered some deterioration.

The larger oval, a large portion of the hood, the rectangles, and the left side of the inscription surrounded in the carved rope were consolidated with Conservare OH in 1996 and again in 1997. It was noted in 1998 that "the inscription remains well-consolidated, but adjacent unconsolidated areas continue to erode at a rapid rate and threaten to undercut the consolidated slab above the inscription. 'FS Riggs' has been undercut and lost in this manner."[125] The panel was re-consolidated with Conservare OH in 2000, and no change was noted when it was assessed in 2003.

The 2007 photograph shows that major cracking has formed along the outer edge of the hood (fig 7.41). As noted in the 1998 assessment the lowest rectangle containing the inscription "FS Riggs" is almost entirely gone, as well as the "M," the "3," and the upper left hand corner of the inscription surrounded in the carved rope. Erosion has worn what is left of the rope pattern away until it is barely recognizable as such, and is nearly level with the surface of the stone. The 2007 survey found large areas of blind delamination over the upper two rectangles, and the upper right hand corner of the larger oval shape. Granular disintegration encroaches into the upper areas of this same oval, and

125 Oliver, Anne. "El Morro National Monument Pilot Inscription Treatment Program July 1996," appendix C

network cracking that may or may not have existed before consolidation is just below that. The survey also found network cracking and clay wash on the surface of the hood.

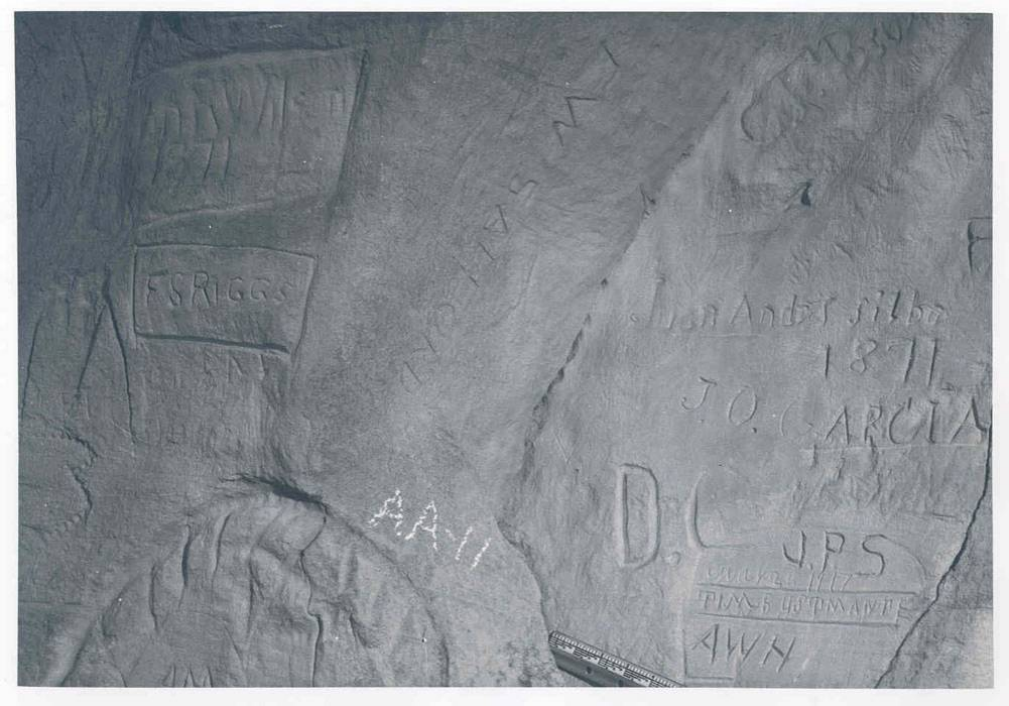

Figure 7.38 Panel AA11. Photo taken in 1955 by McNeil and Howell.

Figure 7.39 Panel AA11. Photo taken in 1993 by Padgett and Barthuli.

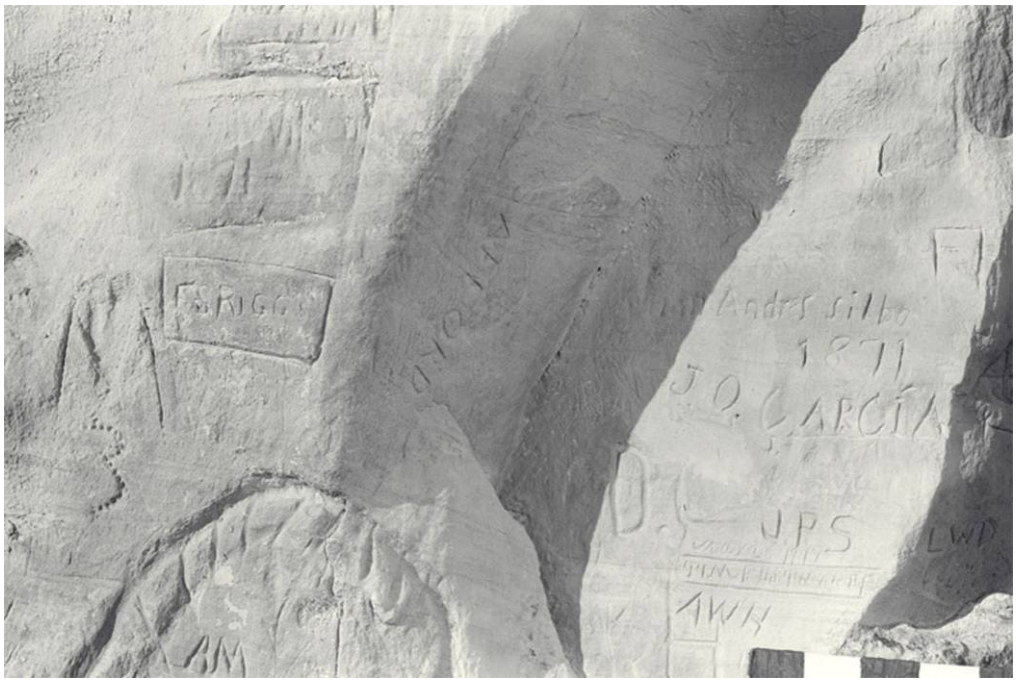

Figure 7.40 Panel AA11. Photo taken in 1993 by Padgett and Barthuli.

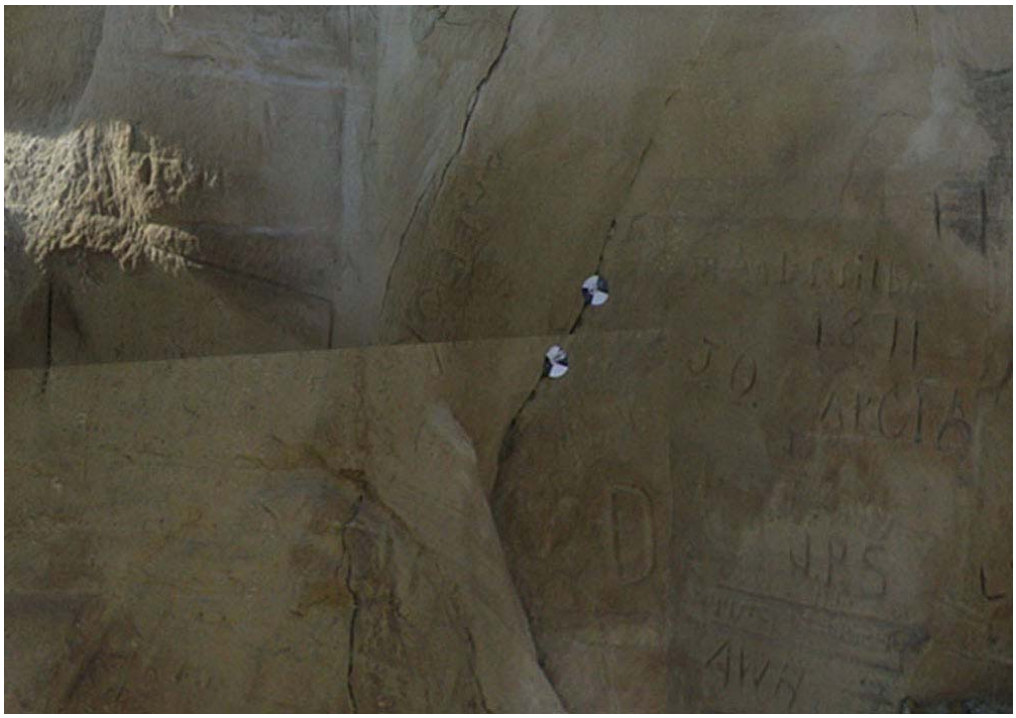

Figure 7.41 Panel AA11. Photo taken and montage in 2007 by Burris.

Figure 7.42 Panel AA11. Photo taken in 1955 with an overlay of the loss that occurred between 1955 and 1993.

Figure 7.43 Panel AA11. Photo taken in 1993 with an overlay of the changes that occurred between 1993 and 2007.

7.1.10. Panel AA12

Panel AA12 is 6 feet 7 inches above the ground, and just 1 foot 10 inches below the lowest point in the ledge. The panel is directly above AA8. The face of the rock angles softly towards the ledge above the panel. Presently, the main features of the stone are the weathering forms that mark the surface; contour scaling, flaking, and granular disintegration, but the 2007 image is vastly different from the photographs taken in 1955 and 1993.

The 1955 photograph shows some inscriptions on an irregular band of stone that stretches from the upper left hand corner of the picture to the lower right hand corner (fig 7.44). The upper right hand and lower left hand corners show signs of loss both on the micro and meso scale. These areas are subject to micro-flaking, contour scaling, and there is evidence of large scale flakes, and possible delamination. The central area below the band of stone has suffered some loss, but part of an inscription remains. The band of stone that runs through the middle of the picture has areas of microflora.

The panel was so changed by 1980 that a park service employee documenting large scale loss at the northeast point was not sure that he was looking at the correct panel. Presuming that he was indeed evaluating the correct Panel 3, inscriptions were found to be missing due to the loss. [126] The 1993 picture shows that the band of stone and all inscriptions are gone, presumably subject to loss on the meso scale (fig 7.45, 7.46). There are large areas of micro-flaking and contour scaling where the loss has occurred.

126 This record is titled only Names Etc. Lost to Erosion on the Point of Inscription Rock As Surveyed in July of 1980. No name is associated with the document. It was found as a single sheet of paper in file H22, "List of Inscriptions," Archival box H and K, located in the fire proof case in the archive room at El Morro.

There are several large flakes, and possibly delamination on the surface of the stone. Small areas of microflora intrude on the panel at the bottom of the picture.

In 2007 the surface of the stone is again so changed as to be unrecognizable when compared with the 1993 photograph (fig 7.47). Again large areas of micro-flaking and contour scaling can be seen, but the areas affected by these conditions have changed. Sections of the stone that were afflicted with these weathering forms in 1993 are comparatively smooth now. Large flakes or delamination have formed, but these conditions have their edges facing the ground, whereas the most predominate flakes seen in 1993 had an edge facing to the north.

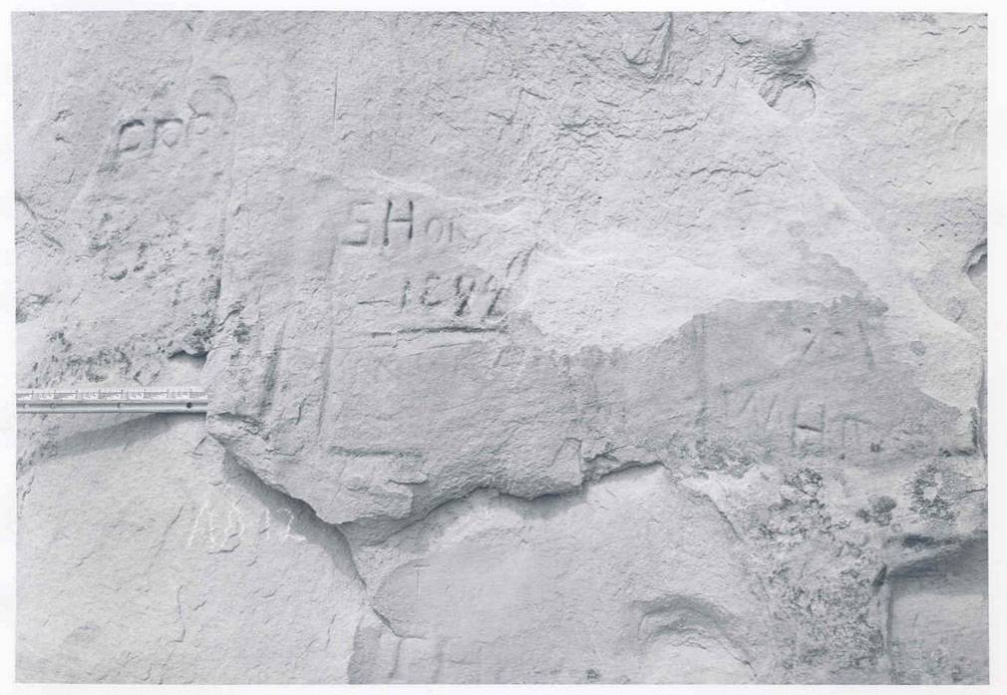

Figure 7.44 Panel AA12. Photo taken in 1955 by McNeil and Howell.

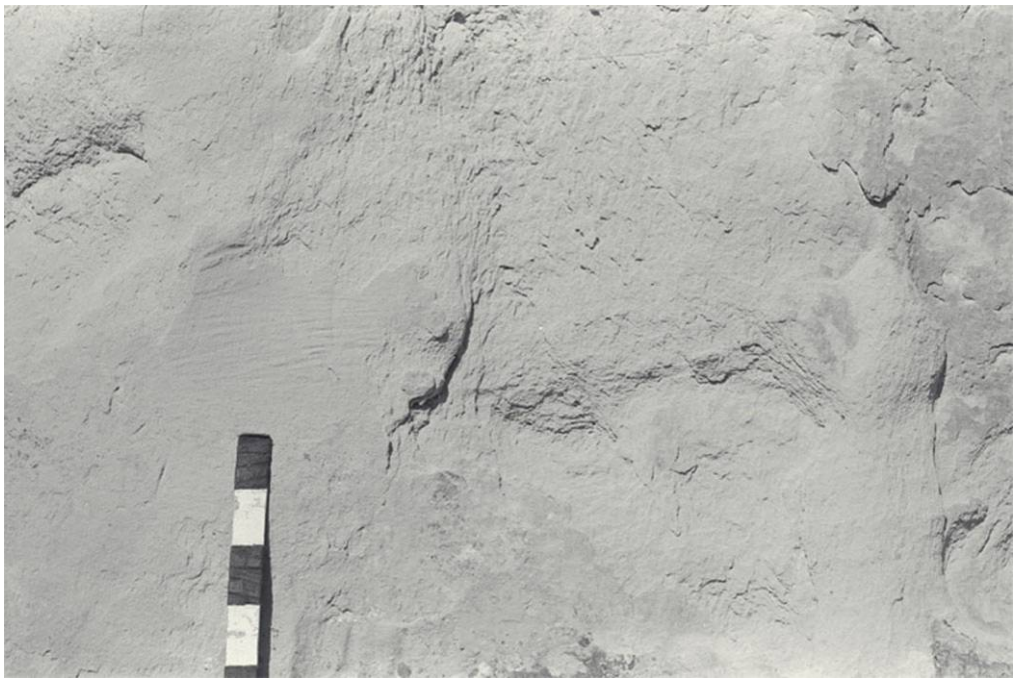

Figure 7.45 Panel AA12 Photo taken in 1993 by Padgett and Barthuli.

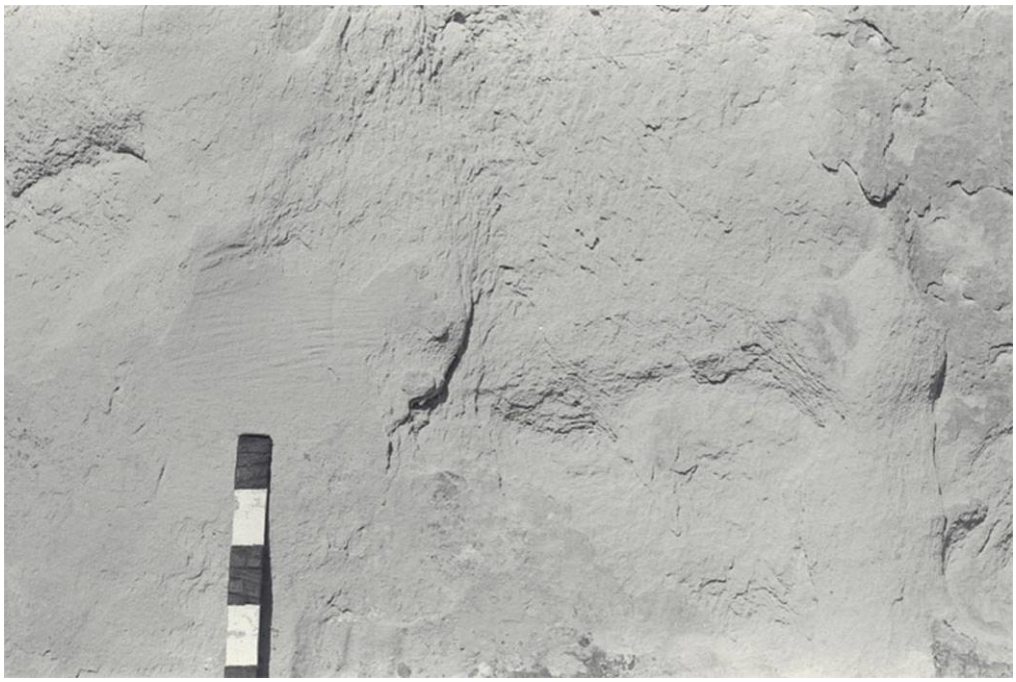

Figure 7.46 Panel AA12. Photo taken in 1993 by Padgett and Barthuli.

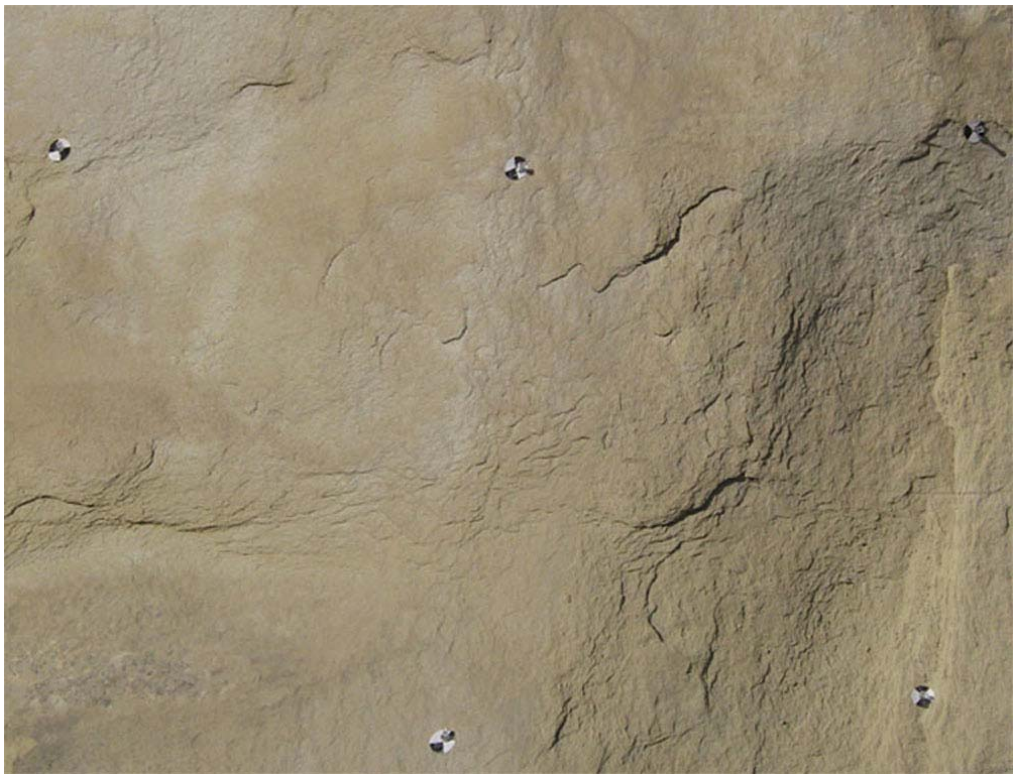

Figure 7.47 Panel AA12. Photo taken in 1993 by Burris.

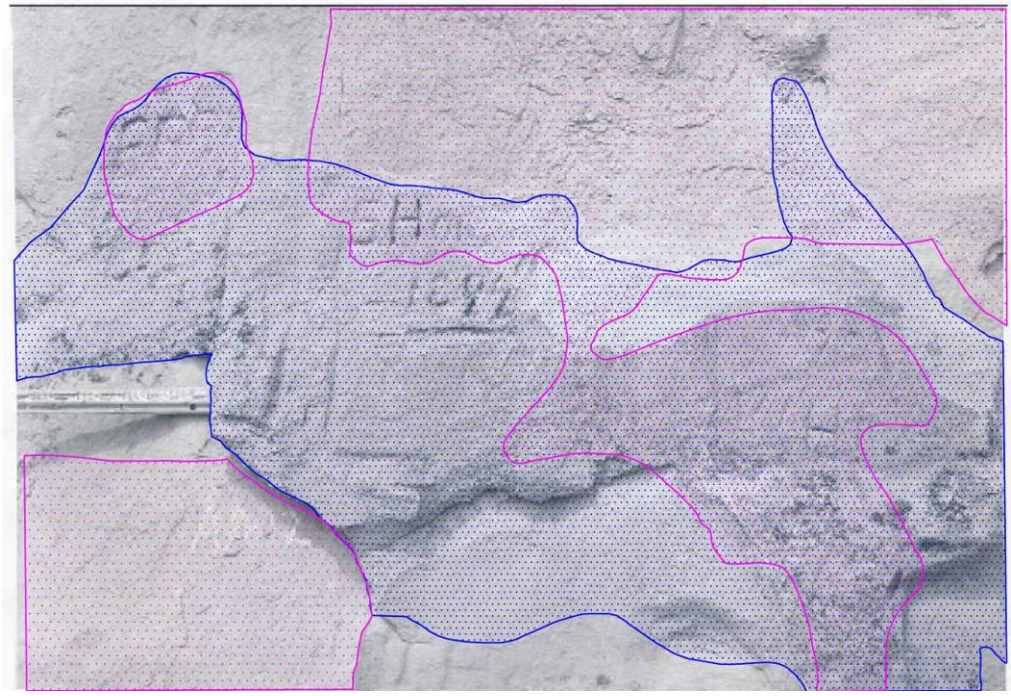

Figure 7.48 Panel AA12. Photo taken in 1955 with an overlay of the loss that occurred between 1955 and 1993.

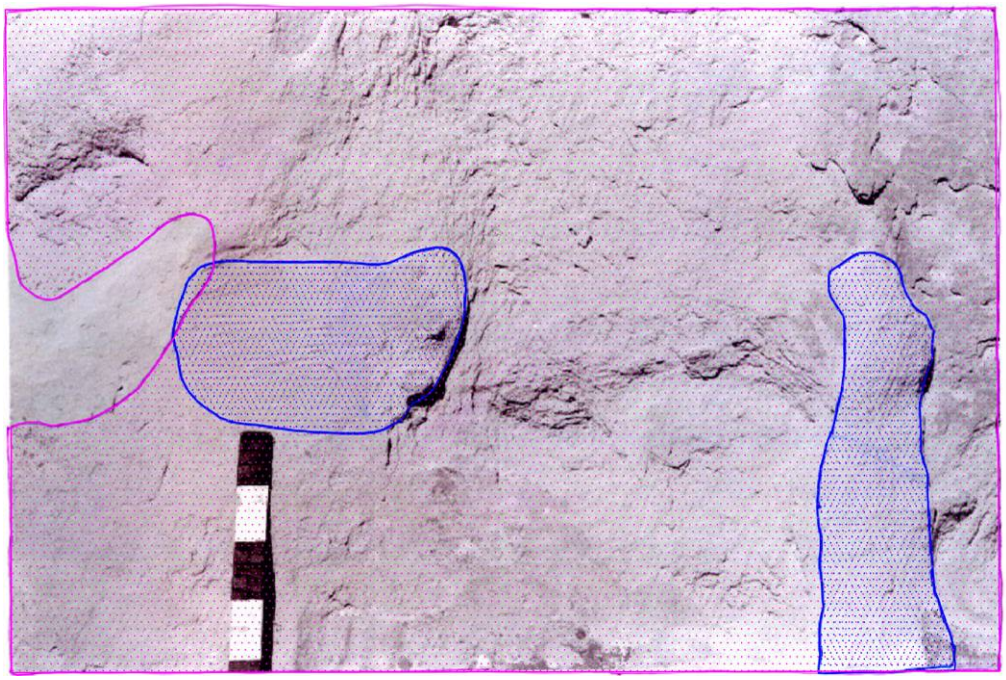

Figure 7.49 Panel AA12. Photo taken in 1993 with an overlay of the loss that occurred between 1993 and 2007.

7.1.11. Panel AA13

Panel AA13 is located slightly less than 2 feet below the ledge of the lower AA section, and overlaps the fault that runs through the center of the stone. Like panel AA12, AA13 is nearly unrecognizable when compared to a picture of the panel taken in 1993, and neither the 2007 or the 1993 images bear a slight resemblance to the photo taken in 1955.

The 1955 image shows the central fault in the upper left hand corner of the panel, and the upper edge of the hollow from panel AA10 in the lower right corner (fig 7.50). The topography of the area in between appears almost as rolling hills. The image shows that the surface of the stone is riddled with insect damage.

Inscriptions were listed as missing or partially missing in 1980,[127] but the next available photodocumentation of AA13 was not taken until 1993 (fig 7.51, 7.52). Large sections of the surface have been lost in the interim, and no inscriptions remained in 1993. Judging by the thickness of the remaining stone fragments some of that loss may have been on a meso scale. Where surface area was lost, contour scaling, flaking, and micro-flaking have emerged as problems. Other than the fault and the hollow in the lower right, the only remaining feature is a small ridge that angles up and to the right in the mid-right of the picture.

127 This record is titled only Names Etc. Lost to Erosion on the Point of Inscription Rock As Surveyed in July of 1980. No name is associated with the document. It was found as a single sheet of paper in file H22, "List of Inscriptions," Archival box H and K, located in the fire proof case in the archive room at El Morro.

Chapter 7: Panel Assessment

The ridge and the large section of sandstone that it resided on were missing by 2007 (fig 7.53). The only identifiable features found when comparing the 1993 photograph with those taken in 2007 were the fault and the hollow in the lower right hand corner. A lichen colony in the lower left hand corner also remains. The surface of the rock is still prone to micro-flaking and contour scaling in 2007, but large scale flakes have begun to emerge where there was once only micro-flaking.

Figure 7.50 Panel AA13. Photo taken in 1955 by McNeil and Howell.

Figure 7.51 Panel AA13.Photo taken in 1993 by Padgett and Barthuli.

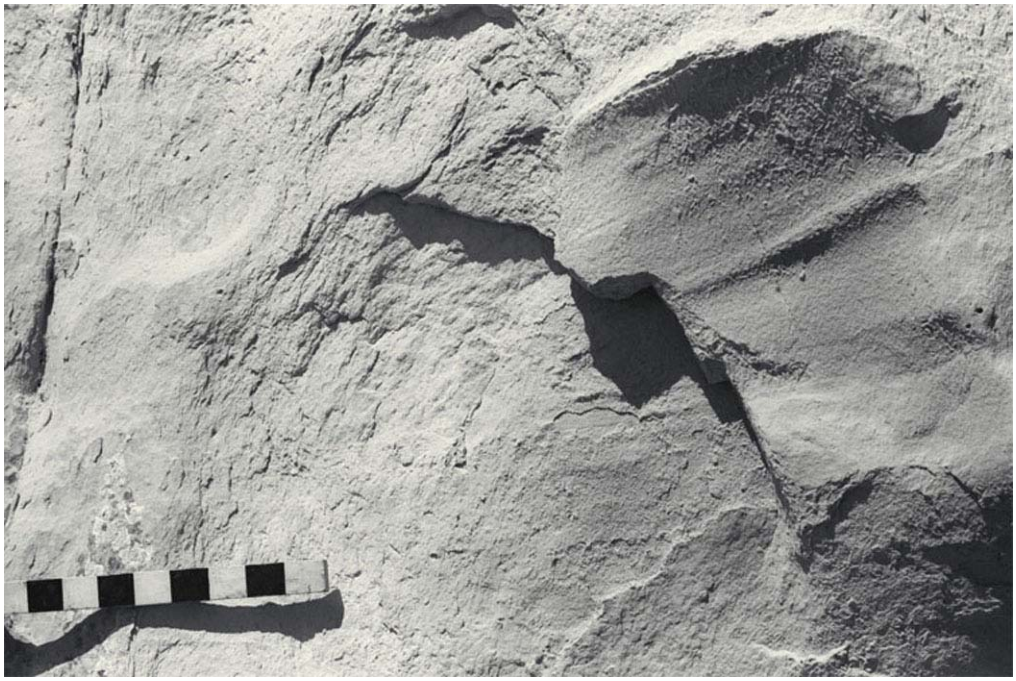

Figure 7.52 Panel AA13. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.53 Panel AA13.Photo taken and montage in 2007 by Burris.

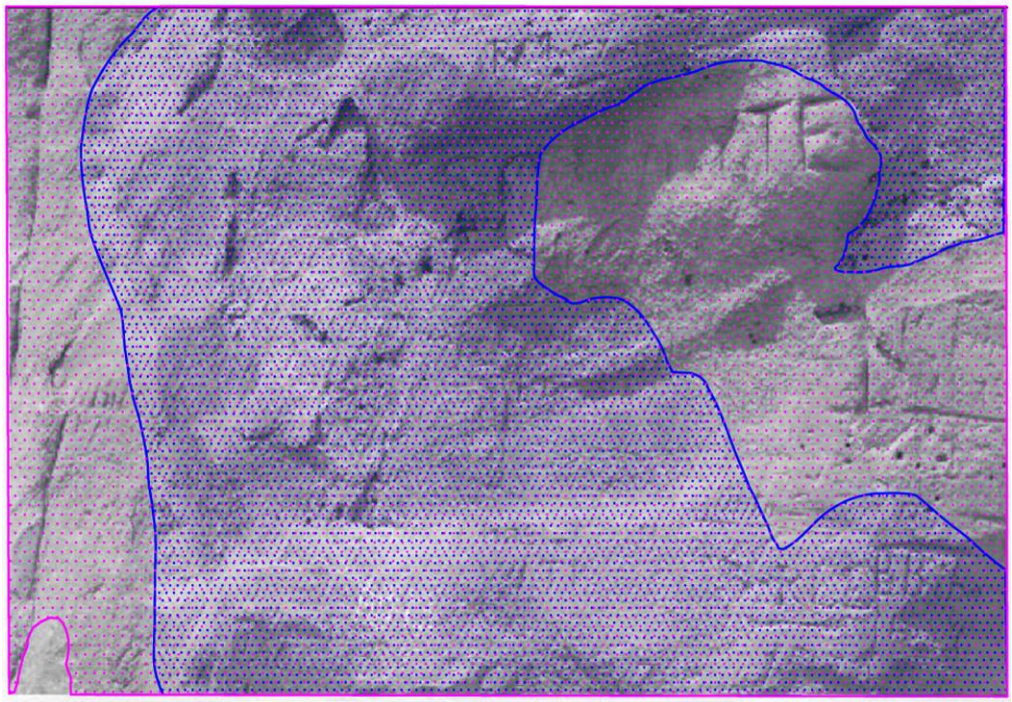

Figure 7.54 Panel AA13. Photo taken in 1955 with an overlay of the loss that occurred between 1955 and 1993.

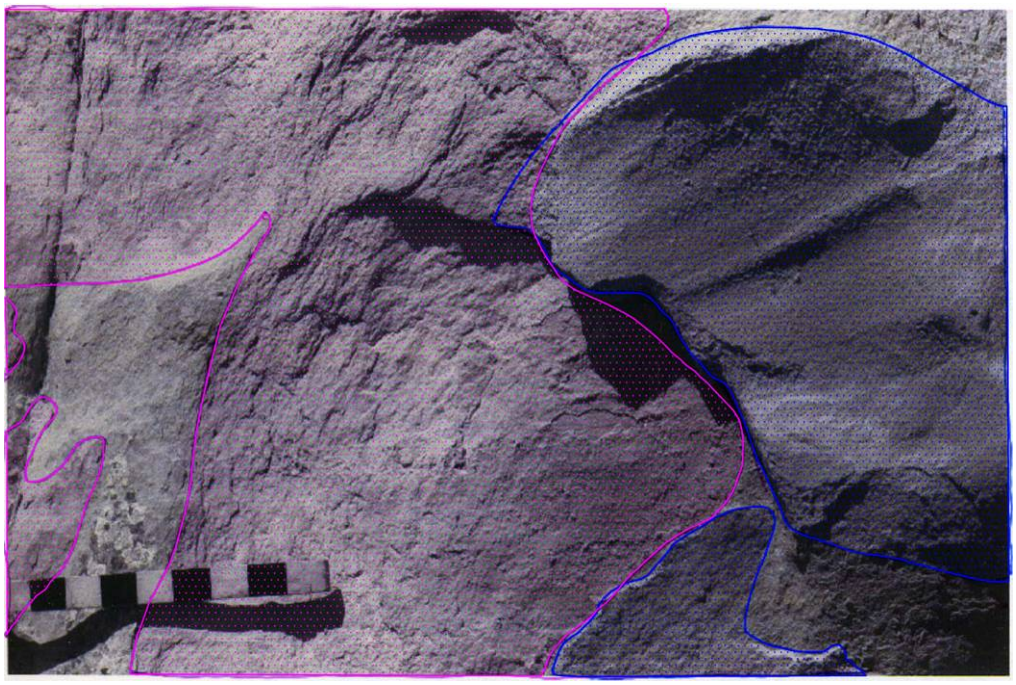

Figure 7.55 Panel AA13. Photo taken in 1993 with an overlay of the loss that occurred between 1993 and 2007.

7.1.12. Panel AA14

Panel AA14 is 5 feet 9 inches above the ground, 3 feet 9 inches from the top of the ledge, and 1foot 10 inches from the right hand edge of the lower AA section. Similar to panels AA12 and AA13, AA14 has experienced loss on a meso scale.

The 1955 photograph shows a slightly curved surface with a large amount of loss in the upper quarter of the picture (fig 7.56). The loss has left an angular depression on the upper left, and seems to have created a small ledge over the inscriptions that cover the surface of the stone. The top left hand corner of the large oval from panel AA11 intrudes into the lower right hand corner of the picture. Above the three rectangles listed in panel AA11 is a perfectly circular hole that will remain unchanged throughout the photodocumentation. This hole is in the lower right hand of the photograph, just to the left of the top of the large oval.

The 1993 photograph shows a completely changed surface (fig 7.57, 7.58). No inscriptions remain. The ledge that was at the top of the 1955 picture is now gone, replaced with a roughened incline. The area where the inscriptions once stood appears roughened. The upper left hand corner of the panel is suffering from micro-flaking and small areas of contour scaling.

Panel AA14 is listed as untreated, but photodocumentation of the 1996 treatments shows that the consolidation of the rectangular inscriptions in AA11 stretched into the bottom right hand corner of panel AA14. The photographs taken in 2007 are difficult to read in comparison to previous pictures (fig 7.59). The surface of the stone appears to be

more textured, but it is not possible to tell if this is due to lighting or actual changes to the surface of the stone. Two rounded areas of loss in the upper left corner of the photo border two round delamination. Another circular section of loss in the upper left hand corner is now an area of contour scaling. Micro-flaking can be found in the center of the panel. A large amount of moderate cracking has appeared on the surface of the stone above and around the treated area.

Figure 7.56 Panel AA14. Photo taken in 1955 by McNeil and Howell.

Figure 7.57 Panel AA14. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.58 Panel AA14. Photo taken in 1993 by Padgett and Barthuli.

Figure 7.59 Panel AA14. Photo taken and montage in 2007 by Burris.

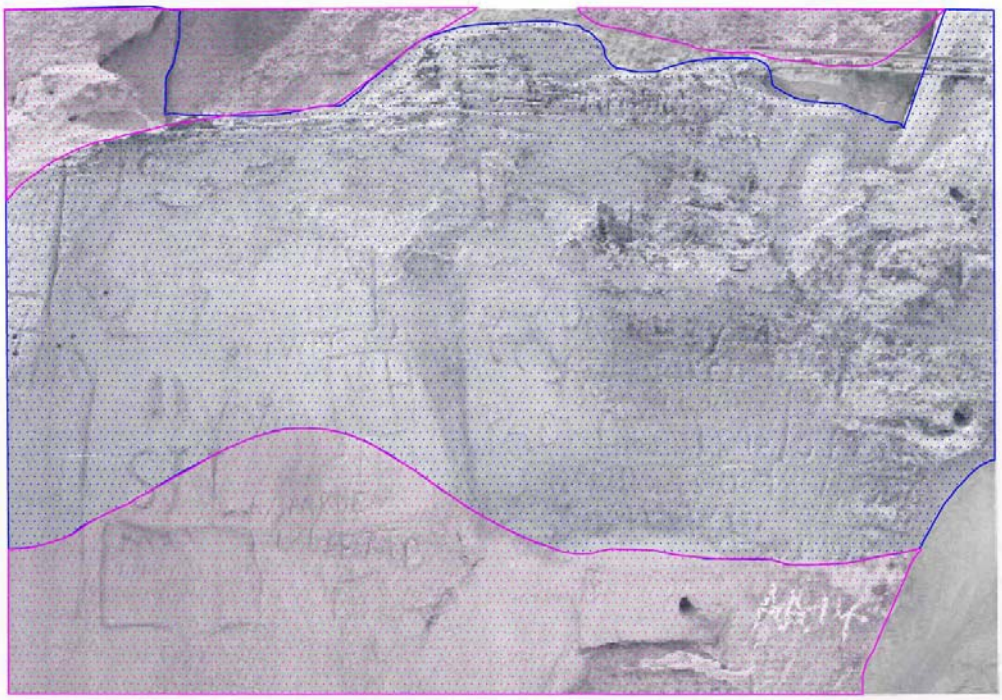

Figure 7.60 Panel AA14. Photo taken in 1955 with an overlay of the loss that occurred between 1955 and 1993.

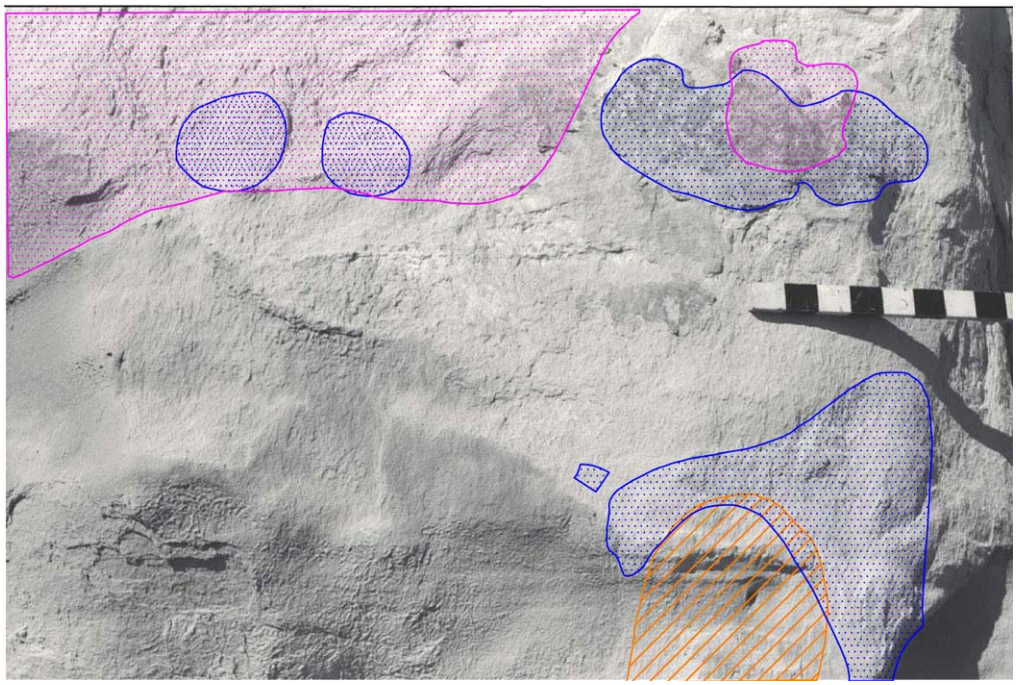

Figure 7.61 Panel AA14. Photo taken in 1993 with an overlay of the changess that occurred between 1993 and 2007.

7.2. Summary Observations on Treatment

Ethyl Silicate as manufactured by Wacker Chemie and sold in the United States by ProSoCo under the commercial name of Conservare OH 100 has been used to consolidate the sandstone at the northeast point since 1996. In that time AA5, AA6, AA7, AA8, AA10, AA11, and AA14 have been treated. The varying shape of the stone and the combination of weathering elements make each of these panels unique. They cannot be compared to one another, but simple conclusions on the effects of the treatment can be drawn from the condition of the consolidated and unconsolidated stone within each of these panels.

Figure 7.62 The position of all of the panels at the Point with the location of the consolidated Error! Bookmark not defined. **rock noted in orange.**

7.2.1. Panel AA5

By 1998, two years after panel AA5 was first consolidated, hairline cracks were reported on the surface of the treated stone.[128] Granular disintegration was noted within three years of treatment.[129] The panel was last consolidated in 2004. Granular disintegration was again noted in January of 2007, but covering a smaller surface area than the panel treated. Deterioration around the consolidated area has not accelerated.

7.2.2. Panel AA6

Panel AA6 was treated in 1997, although it was listed in good condition the following year,[130] almost no trace of the inscriptions remained two years after treatment,[131] and it was deemed lost by 2000.[132] Granular disintegration and micro-flaking currently occur within the consolidated area. Such small scale loss has continued both inside and outside the treated zone. The loss that occurred outside of the consolidated stone is not a reflection of the treatment, but rather a continuation of the loss that was already in place before consolidation.

7.2.3. Panel AA7

Panel AA7 was consolidated in 1997 and again in 2004. Granular disintegration was re-occurring within two years of the first treatment, but has not yet re-occurred after

128 Oliver, Anne. "El Morro National Monument Pilot Inscription Treatment Program July 1996," appendix C.

129 Ibid, appendix D.

130 Ibid, appendix D.

131 Ibid, appendix E.

132 Ibid, appendix F.

the last consolidation. In comparison granular disintegration does appear on the opposite side of the panel along with micro-flaking. This weathering form pre-dates the treatment on the other side of the panel and is not related. It only shows that the weathering pattern has not changed outside of the consolidated stone.

Upon a visual inspection it would appear that the treatment of AA7 has been relatively successful, but sounding the stone reveals that parts of the treated area send back a hollow sound. Large portions of the treated area in AA7 are suffering from blind delamination. It is unknown whether or not this pre-dates treatment, but there is a possible relationship.

7.2.4. Panel AA8

Panel AA8 was consolidated in 1997. A small amount of flaking has occurred at the edges of the left hand treatment in the panel. There has also been a general erosion of the surface of the consolidated area to the left, but granular disintegration is not active. The area to the right that has been treated appears unchanged since the treatment.

The difference in how the two treated portions of the panel have weathered is most likely due to their exposure to the elements. Moisture, thermal radiation, and temperature should be fairly similar for the two halves of the panel, but the stone gently curves so that differential wind velocity may aid in abrading or drying the left side of the panel more than the right side.

7.2.5. Panel AA10

Panel AA10 was treated in 1996, and was lost in 2000.[133] The stone that is now missing was one large piece nearly covering the entire consolidated area. The line of consolidant and the breakage point in the stone are so similar that the relationship between the consolidant and the loss on a meso scale is extremely likely. This is not to say that the loss would not have occurred on a smaller scale over a longer period of time if it had not been treated.

7.2.6. Panels AA11 & AA14

Panel AA11 was consolidated in 1996, 1997, and again in 2000. With each treatment the area consolidated was widened to protect against the undercutting of the inscriptions by the fast paced erosion of surrounding stone.[134] Although it is listed as untreated elsewhere, the consolidation of AA11 reaches into the lower right hand corner of AA14. Granular disintegration is no longer found within the treated area, but as with panel AA7, large portions of the consolidated stone are suffering from blind delamination. Several moderate cracks have appeared in recent years between the two heavily consolidated portions of the panel.

Panel AA14 has suffered a large scale dimensional loss above and to the north of the treated area. The loss encroaches on the consolidated stone, but clearly follows a line similar to the line of consolidant. In addition new moderate sized cracks have formed radiating outwards from the treatment.

133 Oliver, Anne. "El Morro National Monument Pilot Inscription Treatment Program July 1996," appendix E.

134 Oliver, Anne, personal communication. 25 October 2006.

It is interesting to note that panel AA11 has the largest percentage of surface area consolidated among any of the treated panels. It is possible that the repeated treatments have changed the permeability of the panel more than would be desired, so that a higher amount of moisture is being transported through the stone above the consolidated area.

7.2.7. Conclusion

Out of the seven panels treated, three panels were noted for the return of granular disintegration covering a smaller area within three years of treatment. Micro-flaking occurred at the edge of one treatment area; one panel noted network cracking within two years; and two other panels developed moderate sized cracks related to the treatment. In the worst cases, loss on the meso scale possibly related to the consolidation, has occurred in two panels. The good news is that, in many cases, the treatment appears to have slowed deterioration, and has not poorly affected the surrounding stone in most cases.

The natural inclination to increase the area and frequency of consolidation may have proven to be detrimental to the fabric in some panels. Although a second round of consolidation has improved the granular cohesion in all four panels, it is also potentially related to the blind delamination that is occurring in the same areas that were treated in AA7, AA11, and AA14. The granular disintegration is no longer active in the treated areas of these panels, but a possible relationship to blind delamination, large scale dimensional loss, and dramatic moderate cracking is worrisome.

At least in part, panels AA7, AA11, and AA14 may have reacted differently to multiple consolidations due to their proximity to one another. There are three treated

areas of stone within these panels, all consolidated at least two times, and without much distance between treatment areas. It is possible that the permeability of a large section of the stone has been altered at this location.

Although ethyl silicate has proven to be helpful in slowing erosion in parts of the northeast point, its continued use in the same areas or near another consolidated section of stone is not recommended without first questioning what the goals of further consolidation are.

8. Conclusion and Recommendations

This study has reviewed the extensive conservation research that has been conducted at El Morro National Monument. In particular it has focused on the composition of the sandstone and its decay phenomena, as revealed at the northeast point. It also presents a time-based analysis of the deterioration of the panels at the northeast point, and has assessed the ethyl silicate consolidation treatments that were applied to these panels.

Since deterioration of stone is inevitable, particularly for this monument since it cannot be feasibly taken out of its environment, the objective is to find solutions that will slow down the deterioration rate. For this purpose, the following recommendations are suggested.

8.1. Recommendations

8.1.1. Conservation Recommendations

Three dimensional scan and conditions analysis - If the point is to be maintained at or near its current condition, a better understanding of how the point weathers and how moisture moves through the stone is needed. The condition survey presented in this work is a step in this direction, but the recording methods were limiting. The topography of the stone can only be accurately captured with micron-level laser scanner. Such a scan could serve as a record document for the northeast point, could be used in modeling the point, and would allow for the conditions to be mapped in three dimensions. Such a survey would permit a quantitative analysis of the deterioration.

Chapter 8: Conclusion and Recommendations

Environmental Monitoring – Environmental monitoring is needed to better understand the micro climate affecting the northeast point. This should be taken on by a qualified firm, institution, or individual experienced in environmental monitoring. Necessary data may include ambient temperatures, the temperature within the stone over an extended period, the surface temperature of the stone at several points both in the sunlight and the shade, and a mapping of wind velocity and direction around the northeast point. If a model of wind patterns at the northeast point can be created it will help plan further conservation efforts, and could inform the design of a barrier system to reduce the weathering effects upon the stone.

Design a Barrier System – A barrier system could detract from the historic landscape and visitor experience, and if incorrectly designed could create a new unexpected micro-environment with unforeseen effects. In contrast, a properly designed temporary barrier system could protect the northeast point from some of the most intense weathering during critical times of the year, and slow its deterioration considerably. In addition, a creative design solution may potentially add to the visitor experience. A team experienced in environmental monitoring and mitigation through natural or artificial means should undertake the design of any such solution to insure that possible negative effects are averted in the design and implementation phases.

Consolidation Treatments - A more conservative use of the ethyl silicate consolidant is recommended. In particular, since this product is still being improved as a better understanding of its action is attained. Treatment has proven effective in some of

the panels, but repeated use over a large area will change the permeability of the sandstone, and may lead to dimensional loss and moderate sized cracking. Further work could be done to test this theory. Samples of treated and untreated sandstone from the point should be tested in their response to water absorption and desorption, freeze-thaw and salt cycling, and thermal response. Further testing with newer generation ethyl silicates are suggested as well as the application of surfactants to reduce hygric responses of the clay-rich sandstones to moisture.

8.1.2. Interpretation Recommendations

Despite the above mentioned work many of the inscriptions at the northeast point of Inscription Rock will eventually weather away in time. The National Park Service acknowledges this fact and should interpret all past, present, and future attempts to conserve the tangible and intangible aspects of the resource.

This is an excellent and reasonable approach to the task at hand, but this may also be the time to look forward to, and strategize for the interpretation plan that will follow as the northeast point further deteriorates, and loses its inscribed messages.

The upper AA section, the stone above the ledge, contains dozens of inscriptions, many left by railroad workers and cavalry men in the mid-nineteenth century. These travelers would not have been able to reach this area to leave their mark if it wasn't for standing on the lower AA section. This paper has largely focused on the northeast point, but it is only one small section of El Morro National Monument. It gives context to the historical and natural landscape that surrounds it. As the stone deteriorates further, how

should the park service communicate the stories of the inscriptions and the historical landscapes that have been lost and changed?

There are several possible answers to this question. The first is a continuation of how the National Park Service already interprets the site. The ongoing losses at the northeast point and its continued conservation could be incorporated into the educational material at the visitor center. Why and how the stone deteriorates and what is being done to preserve the site are questions that can be answered for audiences of multiple ages.

Second, large scale loss could occur in the future. There is good evidence to suggest that sections of the rock that are suffering from blind delamination, particularly if they have been consolidated in the past, will be lost in large part relatively soon. In this regard, management could act to extend the life of these areas with mechanical repair methods, most notably micro-pinning and micro-injection grouting. If in situ treatment is not possible, areas of inscription could be detached and displayed indoors, however this is a permanent and irreversible decision. Laser scanning could easily be translated through laser cutting into solid 3 dimensional facsimiles of the inscriptions for visitors to see in the Visitor Center. In the event of catastrophic deterioration this record could be used to create a “new” northeast point. Although not authentic, such a mock-up would maintain the context of the historical landscape, and allow the visitor to see the inscriptions as they remain today. An experienced professional, firm, or institution would be needed to scan and process the data from the northeast point.

Chapter 8: Conclusion and Recommendations

8.2. Conclusion

El Morro National Monument is difficult to preserve. It is a natural rock formation that has been created by nature and altered by thousands of individuals including the current stewards. Before the preservation of the northeast point continues it is important to identify what is desired and what is possible in the conservation of the point. The natural inclination of the stone is to continue the cycle of decay until equilibrium is reached. How and if the National Park Service decides to alter that process should be well thought out with the best scientific and cultural studies to support a decision.

Bibliography

Amoroso, G.G and V. Fassina. *Stone Decay and Conservation: Atmospheric Pollution, cleaning, Consolidation and Protection. Materials Science Monographs II.* Amsterdam: Elsevier, 1983.

Arnold, Andreas and Konrad Zehnder. "Salt Weathering on Monuments." In *The Conservation of Monuments in the Mediterranean Basin, Proceedings of the 1zt International Symposium, Bari, 7-10 June 1989*, ed. Fulvio Zezza, 31-58. Brescia: Grafo, 1990.

Austin, George S. "Geological and Hydrological Assessment of El Morro National Monument." New Mexico Bureau of Mines and Mineral Resources, 1992.

Charola, A. Elena. Salt in the Deterioration of Porous Materials: An Overview. *Journal of the American Institute for Conservation* 39, no.3 (2000): 327-343.

Conservation Program and Historic Architecture Program. "Inscription Treatment Project El Morro National Monument 1997-2004." Southwest System Support Office, Intermountain Region, National Park Service, United States Department of the Interior, October 1997 (updated November 1997, December 1998, June 1999, August 2000, September 2003, September 2004).

Cross, Aaron. "Stratigraphy, Sedimentology, and Surface Water Quality at El Morro National Monument." Master's thesis, 1996.

---. Weathering of the El Morro Inscriptions. *Cultural Resource Management* 20, no.10 (1997): 30-32.

Delgado-Rodriguez, J. and Gil Saraiva, J.A. "Experimental and Theoretical approach to the Study of the Mechanism of Wind Erosion of Stone in Monuments." In *Proceedings of the 5th International Congress on Deterioration and Conservation of Stone, Lausanne, 25-27 September, 1985*. Ed. G. Felix, 167-175. Romandes: Presses Polytechniques,1985.

El Malpais and El Morro National Monuments. "Collection Management Plan: El Malpais and El Morro National Monuments." National Park Service, United States Department of the Interior. September 2004.

El Morro National Monument. Record of River and Climatological Observations. 1938-1955, 1962-1974, 1986-2006.

Ennis, Marie. Non-destructive Testing at El Morro. *Cultural Resource Management* 20, no.10 (1997): 35.

Bibliography

Fitzner, B. , Heinrichs, K.Kownatzki, R. "Weathering Forms – Classification and Mapping." In *Natursteinkonservierung in Der Denkmalpflege*, ed. Rolf Snethlage, 41-88. Berlin: Ernst & Sohn, 1995.

Fitzner, B., Heinrichs, K., La Bouchardiere. D. "Damage Index for Stone Monuments." In *Protection and Conservation of the Cultural Heritage of the Mediterranean Cities, Proceedings of the 5th International Symposium on the Conservation of Monuments in the Mediterranean Basin, Sevilla, Spain, 5-8 April 2000,* ed. Emilio Galán and Fulvio Zezza, 315-326. Lisse: A.A. Balkema Publishers, 2002.

Goldman, Don. Protecting the Messages on El Morro. *Cultural Resource Management* 18, no.2 (1995): 8-9.

Greene, Jerome A. "Historic Structure Report The Historic Pool, El Morro National Monument, New Mexico." Denver Service Center, Historic Preservation Division, National Park Service, United States Department of the Interior, Denver, Colorado, April 10, 1977.

Honeyborne, David. "Weathering and decay of masonry." In *Conservation of Building and Decorative Stone*. Butterworth-Heinemann series in conservation and museology, ed. John Ashurst and Francis G. Dimes, 153-178. London: Butterworth, 1990.

Howell and McNeill. Survey Photos. National Park Service, United States Department of the Interior, El Morro, New Mexico, 1955.

Ihalainen, Pekka. "Changes in Porosity of Some Plutonic Building Stones Depending on the Type of Artificial Weathering Treatment.," In *III International Symposium on the Conservation of Monuments in the Mediterranean Basin*, *Venice, Italy, 22-25 June 1994*. ed. V. Fassina, H. Oh, F. Zezza, 109-113. Venice: Soprintendenza ai beni artistici e storici di Venezia, 1994.

King, Ken and Elaine King. "El Morro National Monument Preliminary Vibration Study." K. King independent consultant, El Morro National Monument, National Park Service, United States Department of the Interior, September 2003.

Löfuendahl, Runo, Helmer Gustavson, Bengt A. Lundberg. "Weathering of Runestones in a Millennian Perspective." In *Proceedings of the 9th International Congress on Deterioration and Conservation of Stone, Venice June 19-24, 2000*, ed. Vasco Fassina, 135-144. Amsterdam: Elsevier, 2000.

Matero, Frank and Veronica Aplenc. "Consolidation of Zuni Sandstone from El Morro National Monument." In *El Morro National Monument Inscription Preservation Program*, 1- 14. El Morro National Monument, National Park Service, United States Department of the Interior, 1996.

Matero, Frank. "Managing Change: the Role of Documentation and Condition Survey at Mesa Verde National Park." *Journal of the American Institute for Conservation* 42, no.1 (2003):39-58.

Matovic, Vesna B., Dragan J. Milovanovic, Solbodan M. Joksimovio. "Durability of Sandstones in Serbian Ancient Monasteries and Modern Buildings." In *Proceedings of the 9th International Congress on Deterioration and Conservation of Stone, Venice June 19-24, 2000*, ed. Vasco Fassina, 135-144. Amsterdam: Elsevier, 2000.

Melbourne, Dawn. Epoxies, Grouts, and Inscriptions. *Cultural Resource Management* 20, no.10 (1997): 33-34.

Miller, Steve. Steve Miller, Supervisory Park Ranger for the record, June 30, 1979. unpublished memorandum.

Mitchell, D.J., David P. Halsey, Karl Macnaughton, David E. Searle. "The Influence of Building Orientation on Climate Weathering Cycles In Staffordshire, UK." In *Proceedings of the 9th International Congress on Deterioration and Conservation of Stone, Venice June 19-24, 2000*, ed. Vasco Fassina, 135-144. Amsterdam: Elsevier, 2000.

National Park Service. United States Department of the Interior. *El Morro*, n.d.

National Park Service. "Casa Grande Ruins: Administrative History." http://www.nps.gov/archive/cagr/adhi/adhi5a.htm.

Oliver, Anne. "El Morro National Monument Pilot Inscription Treatment Program July 1996." National Park Service, United States Department of the Interior, Intermountain Cultural Resources Center, November 1996.

---. Pilot Conservation at El Morro. *Cultural Resource Management* 20, no.10 (1997): 36-37.

Oliver, Anne, T. Scott Kreilick, Karen Fix. "Inscription Treatment Project El Morro National Monument." Edited by Anne Oliver. Conservation Program, Southwest System Support Office, Intermountain Region, National Park Service, United

States Department of the Interior, October 1997 (revised November 1997 and December 1998).

Oliver, Anne. "Inscription Treatment Project El Morro National Monument, Appendix C. Inscription Assessment Project, 1998." Conservation Program, Southwest System Support Office, Intermountain Region, National Park Service, United States Department of the Interior, December 1998.

---. "Inscription Treatment Project El Morro National Monument, Appendix D. Inscription Assessment Project, 1999." Conservation Program, Southwest System Support Office, Intermountain Region, National Park Service, United States Department of the Interior, 1999.

---. "Inscription Treatment Project El Morro National Monument, Appendix E. Inscription Assessment and Treatment Records, 2000." Conservation Program, Southwest System Support Office, Intermountain Region, National Park Service, United States Department of the Interior, 2000.

---. "The Variable Performance of Ethyl Silicate: Consolidated Stone at Three National Parks." *APT Bulletin* 33 no.2/3 (2002):39-44.

---. "Inscription Treatment Project El Morro National Monument, Appendix F. Inscription Assessment Project, Monitoring and Treatment Program, and Outcrop Area Documentation, 2003" Conservation Program, Southwest System Support Office, Intermountain Region, National Park Service, United States Department of the Interior, 2003.

---. "Inscription Treatment Project El Morro National Monument, Appendix G. Inscription Treatment Project, Monitoring and Treatment Program, and Outcrop Area Documentation, 2004" Conservation Program, Southwest System Support Office, Intermountain Region, National Park Service, United States Department of the Interior, 2004.

Oliver, Anne and Antoinette Padgette. "A History of Inscription Preservation at El Morro National Monument 1849-2005." draft. Historic Architecture Group, National Park Service, United States Department of the Interior, Intermountain Support Office, Santa Fe, New Mexico, October, 2005.

Padgett, Antoinette and Kaisa Barthuli. Rock Art Documentation and Assessment. *Cultural Resource Management* 20, no.10 (1997): 28-30.

Bibliography

---. "El Morro Inscription Assessment Project, 1993." Division of Conservation, Southwest regional office, National Park Service, United States Department of the Interior, April 1994.

---. " El Morro Inscription Assessment Project, 1994." Division of Conservation, Southwest regional office, National Park Service, United States Department of the Interior, March 1995.

Paradise, Thomas R. "Sandstone Architectural Deterioration in Petra, Jordan." In *Proceedings of the 9th International Congress on Deterioration and Conservation of Stone, Venice June 19-24, 2000*, ed. Vasco Fassina, 135-144. Amsterdam: Elsevier, 2000.

Pèrez-Bernal, J.L., and M.A. Bello. "Weathering Effects on Stone Pore Size Distributions." In *Protection and Conservation of the Cultural Heritage of the Mediterranean Cities, Sevilla, Spain, 5-8 April, 2000*. ed. Galán and Zezza, 203-207. Lisse: A.A. Balkema Pub., 2002.

Pühringer, Josef, Frantsek Make, Johannes Weber. "Deterioration of Gotland Sandstone at the Royal Palace, Stockholm." In *Proceedings of the 7th International Congress on Deterioration and Conservation of Stone, Lisbon, Portugal, 15-18 June 1992*. ed. J. Delgado Rodrigues, Fernando Henriques, and F. Telmo Jeremias, 687-695. Portugal: Laboratório Nacional de Engenharia Civil, 1992.

Sayre, William O. "Geochemical Survey of the Historic Pool at El Morro National Monument." College of Santa Fe, National Park Service, United States Department of the Interior, September 30, 1997

---. Progress Report for Biological Characterization of El Morro National Monument Pool. College of Santa Fe, National Park Service, United States Department of the Interior, February 1, 1995.

Schackel, Sandra. "A Century of Change: A Photographic History and Analysis of Vegetation Conditions El Morro National Monument, 1891-1983." Southwest Region, National Park Service, United States Department of the Interior, February 25, 1984.

Sievers, Douglas W. "El Morro: A Unit History." El Morro National Monument, National Park Service, United States Department of the Interior, August 14, 1970.

Snethledge, R. and E. Wendler. "Moisture Cycles and Sandstone Degradation." In *Saving Our Architectural Heritage: The Conservation of Historic Stone Structures,*

Dahlem Workshop, Berlin, March 3-8, 1996. ed. N.S. Baer and R. Snethlage, 7-24. Chichester: Wiley, 1997.

St. Clair, Larry L. and Katy B. Knight. "Impact of (Lichens) on the Condition of the Sandstone and Inscriptions at El Morro National Monument, Ramah, New Mexico." Brigham Young University, Provo, Utah, August 15, 2001.

University of Pennsylvania Architectural Conservation Laboratory. "Pennsylvania Blue Project, Independence National Historical Park." Historic Preservation Department, University of Pennsylvania. 2003.

Van Dam, Remke L. and Jan M.H. Hendrickx. "Hydrological Investigation at El Morro National Monument." Draft. New Mexico Tech, Socorro, New Mexico, August 2006.

Viles, H.A. rapporteur, D Camuffo, S. Fitz, B. Fitzner, O. Lindqvist, R.A. Livingston, P.-N.V. Maravelaki, C. Sabbioni, T. Warscheid. "Group Report: What Is the State of Our Knowledge of the Mechanisms of Deterioration and How Good Are Our Estimates of Rates of Deterioration?" In *Saving Our Architectural Heritage: The Conservation of Historic Stone Structures, Dahlem Workshop, Berlin, March 3-8, 1996.* ed. N.S. Baer and R. Snethlage, 7-24. Chichester: Wiley, 1997.

Vincente, M.A., J. Garcia-Talegón, A.C. Iňigo, E. Molina, and V. Rives. "Weatheirng Mechanisms of Silicated Rocks in Continental Environments." In *Conservation of Stone and Other Materials, Proceedings of the International RILEM/UNESCO headquarters, Paris, June 29-July 1, 1993*. ed. M.J. Thiel, 320-327. London: E&FN Spon, 1993.

Wendler, Eberhard. "Contour Scaling On Building Facades – Dependence On Stone Type and Environmental Conditions." In *Materials Issues In Art and Archaeology II: Materials Research Society Symposium Proceedings, San Francisco, April 17-21 1990.* ed. Pamela B. Vandiver, James Druzik, George Segan Wheeler. 265-271. Pittsburgh: Materials Research Society, 1991.

Wendler, Eberhard, Ludwig Sattler, Peter Zimmermann, Dietrich D. Klemm, and Rolf Snethlage. "Protective Treatment of Natural Stone Requirements and Limitations with Respect to the State of Damage." In *Proceedings of the 7th International Congress on Deterioration and Conservation of Stone, Lisbon, Portugal, 15-18 June 1992*. ed. J. Delgado Rodrigues, Fernando Henriques, and F. Telmo Jeremias, 687-695. Portugal: Laboratório Nacional de Engenharia Civil, 1992.

Wendler, Eberhard, and Chompunut Prasartset. "Lichen Growth On Old Khmer-Style Sandstone Monuments in Thailand: Damage Factor or Shelter." In *12th Triennial*

Meeting, Lyon, 29 August- 3 September 1999: preprints (ICOM Committee for Conservation). Ed. Janet Bridgland 750-754. London: James & James, 1999.

Zampropoulos V., Sotiropoulou ch., Patriklou F., Karampotsos A. "Ancient Theatre of Sikyoni: Corrosion Patterns and Propositions for Conservation – Restoration." In *Proceedings of the 10th International Congress on Deterioration and Conservation of Stone, Stockholm June 27-July 2, 2004.* ed. Daniel Kwiatkowski and Runo Lüfuendahl, 915-922. Sweden: Elanders Gotab, 2004.

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