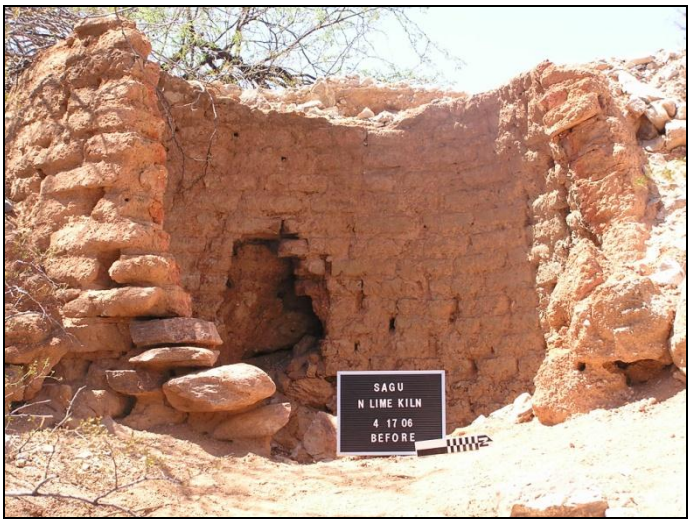
The Preservation Treatment and Documentation of Historic Lime Kilns in Saguaro National Park, Tucson, Arizona.

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with contributions by Nicole Arendt







SCOPE OF WORK

In FY 06, Saguaro National Park received funding through the Vanishing Treasures program (NPS) to document and preserve historic lime kilns in the Rincon and Tucson Mountain Districts. Before treatment and stabilization began, condition assessments were completed by Kevin Harper (SOAR) in 2003, and Jeremy Moss and David Yubeta in 2006. The 2003 condition assessments included written descriptions of each kiln, metric measurements, photographs, and Auto-Cad line drawings (which could not be used due to distortion). SAGU requested assistance from the preservation crew at Tumacacori National Historical Park for the treatment work. The crew from Tumacacori NHP included Jeremy Moss (VT Archaeologist, project leader), David Yubeta (VT Exhibit Specialist, preservation crew foreman), Ray Madril (VT masonry specialist), Bobby Jimenez, Pedro Tanori, and Connie Charles.

In the Rincon Mountains District, work was completed in FY 06' on the North Lime Kiln (LCS 07544, SAGU 83A-30, AZ BB:14:74), South Lime Kiln (LCS 07545, SAGU 83A-30, AZ BB:14:74), Lime Kiln #3 (LCS 58643, SAGU 83A-7, AZ BB:14:165) and the Camino Loma Alta Kiln (AZ BB:14:451), which is not on the List of Classified Structures (LCS) because it was not owned my the park during the last LCS update. The kilns in the Tucson Mountains District include the Sus Lime Kiln Ruin (North Sus Kiln, LCS 58642) and the Sus Lime Kiln Ruin #2 (South Sus Kiln, LCS 58644).

Preservation treatment of the Rincon Mountains District kilns began April 17th, 2006 and was complete by May 4th, 2006. The Tucson Mountains District kilns were treated between June 19th and June 21st, 2006. The goal of treatment is to improve the condition of the kilns, preferably without significantly modifying the historic integrity of the structures. Therefore, rebuilding was avoided, but minor rebuilding was necessary at four of the six kilns. Minor rebuilding of wall ends was essential for improving the structural integrity of wall sections in danger of collapse. Treatment work focused on repointing, filling voids and cracks, capping, and grading for proper drainage.

Throughout the project natural local materials were used. No amended mortars or cements were used, and local soil was mixed to make mud mortar. At most of the kilns the soil used for stabilization mortar matches the unburned mortar used in original construction. However, as the kiln was used, the mortar became redder from oxidization of iron-minerals in the clays, thus altering the original color of the mortar. Mortar samples from exterior unburned portions of kiln walls were used for mortar color matching. Any rocks added to the wall were found on the inside of the kilns or near exterior walls, in keeping with the philosophy of in-kind replacement.

Where adobe bricks were used in kiln construction, repairs utilized fallen or partially eroded bricks near the kiln. Therefore, no new non-historic adobe bricks were added. The top of the walls were capped with either a course of rocks set in new mud mortar or a sacrificial coat of mud. Water was diverted away from the structures by re-grading surrounding slopes, stabilizing slopes with rock, and filling gullies and soil pipes/rodent holes. Holes in the surrounding ground and slope near structures were filled with rock and mud. The interior of two kilns was filled with sand to aid drainage, and in one kiln cloth was placed and covered with sand to slow runoff and decrease lateral erosion.

The kilns will require yearly monitoring to detect changes in structural condition. Changes in drainage patterns, cap erosion, and the development of wall voids will be the most immediate issues. Now that the lime kilns are stabilized they require cyclic maintenance. This means that the clock is ticking. It is estimated that the lime kilns will require at least minor work in 2 to 5 years. This is only an estimate; therefore it is crucial that the kilns are monitored yearly and intermittently following large rainfall events. Monitoring following a rainfall event in late July 2006 found the structures in good condition with some minor cracking of the mud cap of the North Kiln. Inspection in August 2007 revealed the treatments are holding up well, with minor mortar joint and cap cracking/erosion evident.

This report summarizes the history, archaeology and documentation of the kilns and the preservation methods employed at the six lime kilns. Photographs and drawings are used to highlight repairs and structural issues. Maintenance recommendations are offered and research issues identified.

Documentation Procedures

Documentation of preservation treatment is essential to meet the Secretary of the Interiors Standards in Historic Preservation. It is vital to have a record of the structures' architectural details before and after treatment. All work at the lime kilns was documented using treatment forms, digital photography, and black and white film with a photo board and north arrow in the picture. Digital photographs are used throughout the report, while black and white photos are cataloged and stored at WACC. One copy of the b/w photos is stored at the park. In addition, three vitrified adobe/lime samples from the interior of the kilns were collected, analyzed at the Material Sciences Department of the University of Arizona, and cataloged and stored at WACC for future analyses.

Photographs of each wall section were taken before and after treatment. Since the lime kilns are round, it is difficult to define wall sections according to exact cardinal directions (i.e. north, south, etc). As a solution to this problem walls are divided into sections that overlap to ensure that the photographs documented the whole structure. For instance, photos of the north wall also include sections of the east wall and vice-versa. Wall sections were divided according to the direction the photographer was facing with some overlap on the edge of the photos (north, east, west, south). Photos were taken to highlight original structural details and to show general wall conditions before and after treatment. After treatment photos were taken from similar locations as before treatment photos to show changes or improvements to wall condition.

Western Mapping Inc. of Tucson were contracted to create topographic and planimetric maps of the kilns and associated features/artifacts and to conduct laser scanning (LIDAR) documentation of the structures. LIDAR scanning utilizes technology that allows for millimeter

to centimeter accuracy in architectural mapping. The level of detail possible far out weighs that of other architectural recording techniques. Coupled with the use of digital photography, LIDAR scanning allows for the production of an image that shows individual rocks and mortar joints accurately, and in three dimensions. The digital photography is used to create architectural sheets that can be taken into the field during condition assessments and annotated to show subsequent preservation events or erosion problems. The park is given hard copies of the maps and electronic versions of the structural 3-D models that can be viewed with a provided freeware program. Because contracting took too long, the products document the kilns after treatment.

The Autodesk program, AutoCad (2007), was used to annotate digital photos taken after treatment. Each wall section has an annotated digital photo. The photos were not rectified using photo targets because photos of the round kiln walls have too much distortion to use accurate measuring coordinates. Therefore, annotation of digital photos is done merely to provide a visual record of treated wall areas, and to show different treatments for each wall section. In the future, annotated photos can be used to show and differentiate treatments, providing a visual preservation treatment history. The AutoCad files can serve as a record of treatments with annotations labeled by year. This is vital information for stabilization histories and for tracking the condition and effectiveness of preservation treatment materials (e.g. mortars, plasters, mud, caps, etc.). Appendix B is the annotated photos of every wall section after treatment.

The topographic plan-view maps where created using laser scanners at 10cm contour intervals. All artifacts, artifact scatters and features that could fit on a map are included in the plan views. Slope grading and preservation rip-rap are also shown in the plan view maps. Each map has a slightly different scale.

During treatment of the kilns the following information was recorded using a treatment form: 1) hours spent and number of people on each task (repointing, wall capping, rebuilding, etc.), 2) amount and type of treatment materials used (e.g. 2 5 gallon buckets of unamended mortar), 3) mix used to make treatment materials (e.g. 2 buckets sand, 1 water), 4) metric area of

wall treatment by treatment type (e.g. 2.1 m^2 of west wall repointed). This information is useful for tracking expenditures and for producing scopes of work and budget estimates for future treatments of the kilns. Any architectural details noticed during work were also recorded on the form.

THE HISTORY, CONSTRUCTION, AND USE OF LIME KILNS

The term "lime" is used to refer to a variety of products made from limestone and chalk, which are both forms of calcium carbonate ($CaCO^3$). The earliest lime kilns in the Old World date to the Neolithic Period in Europe and the Nile Valley. In Rome, lime was used to plaster the exterior and interior of buildings and special types of lime were manufactured for different purposes. In the New World, lime was used in Central Mexico and South America prehistorically. As early as 4800 B.C. Peruvians used lime as a mineral supplement in foods and as an extractive agent with coca (Wingate 1985). The Maya, Aztec, and other Mexican societies used lime for plaster and other building materials and for enriching agricultural soils. Until the invention of cement in the early 1800's lime was the primary binding agent in mortars used to hold bricks together and to protect exterior walls. In many areas of the U. S. cement was slow to catch on and lime was used into the early 1900's. Lime dust was and is still used in agricultural practices. Agricultural lime promotes decomposition of organic debris into humus and increases soil porosity. Lime is also used as a chemical component in the manufacturing processes of glass, ceramics, bleaching powder, paper, paints, glues and many other modern products.

In the New World, prehistoric peoples burned lime in the open and there is scant evidence of constructed prehistoric lime kilns. However, pottery kilns are found, suggesting that lime kiln technology could have existed prehistorically. No kilns used for the firing or calcination of limestone are known prior to the Spanish *entradas* (Jones 2005:187). Spanish kiln technology evolved from Iberian, Moorish, and Roman sources and was introduced shortly after the arrival of the Spanish into the New World (Costello 1977; Lister and Lister 1987:51-53).

The steps for manufacturing quicklime from limestone include loading, burning, cooling, unloading, and kiln repairing or cleaning. Throughout time the formal production of lime has followed these same five steps. With one kiln the steps must be done in sequence over the course of multiple days. **Quicklime** is the unmixed lime powder resulting from the firing of limestone at high temperatures. The purer the limestone, the higher the temperature needed to burn it. The lowest temperature that pure calcium carbonate will calcine, or lose carbon dioxide, is 1648 degrees F (900 degrees C). Kilns can be fired up to 2200 degrees F (1204 degrees C), but impurities are sufficiently burned off between 900 and 1100 degrees C. The process that results in quicklime is a chemical process where carbon dioxide molecules are released turning limestone into calcium oxide. This quicklime is very volatile and wants to regain an oxygen atom to become stable calcium carbonate. The addition of water creates a more stable form of calcium carbonate that can be mixed according to use. Quicklime mixed with a high water ratio is more useful for white-washing; less water creates a more putty-like lime useful as mortars or hard plasters. The process of mixing water with lime is called **slaking**. Slaking quicklime creates calcium hydroxide. The lime putty that results from slaking is mixed with two to three parts sand to make plaster. The plaster hardens or cures over time as it absorbs carbon dioxide in the air, replacing the carbon dioxide driven off during firing, and reverting to calcium carbonate (limestone). Slaked or hydrated lime that is not used right away can be stored under water to prevent it from curing prematurely. It is the completion of the chemical process- from calcium carbonate to calcium oxide to calcium hydroxide and back to calcium carbonate- that makes lime harder.

Chemical Process of Lime Production

1. CALCINATION

calcium carbonate *CaCO3* + heat ➞ calcium oxide *CaO* + carbon dioxide *CO2* ***(quicklime)***

2. HYDRATION

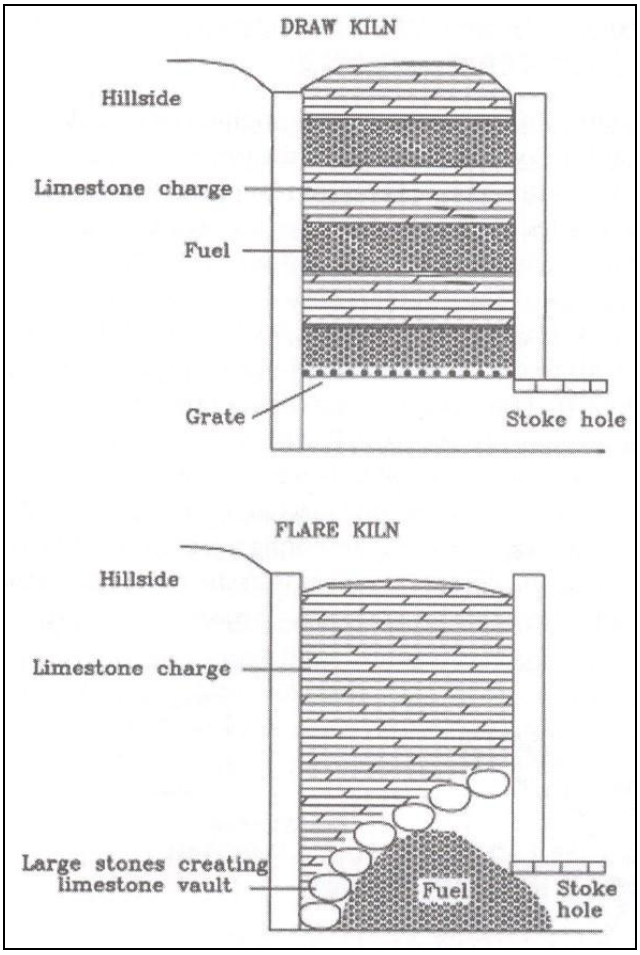
calcium oxide (*CaO)* + water (*H2O)* ➞ calcium hydroxide *Ca(OH)2* ***(slaked or hydrated lime)***

3. CARBONATION

calcium hydroxide *Ca(OH)2* + carbon dioxide *CO2* ➞ calcium carbonate + hydrogen /heat (***CaCO3 H)***

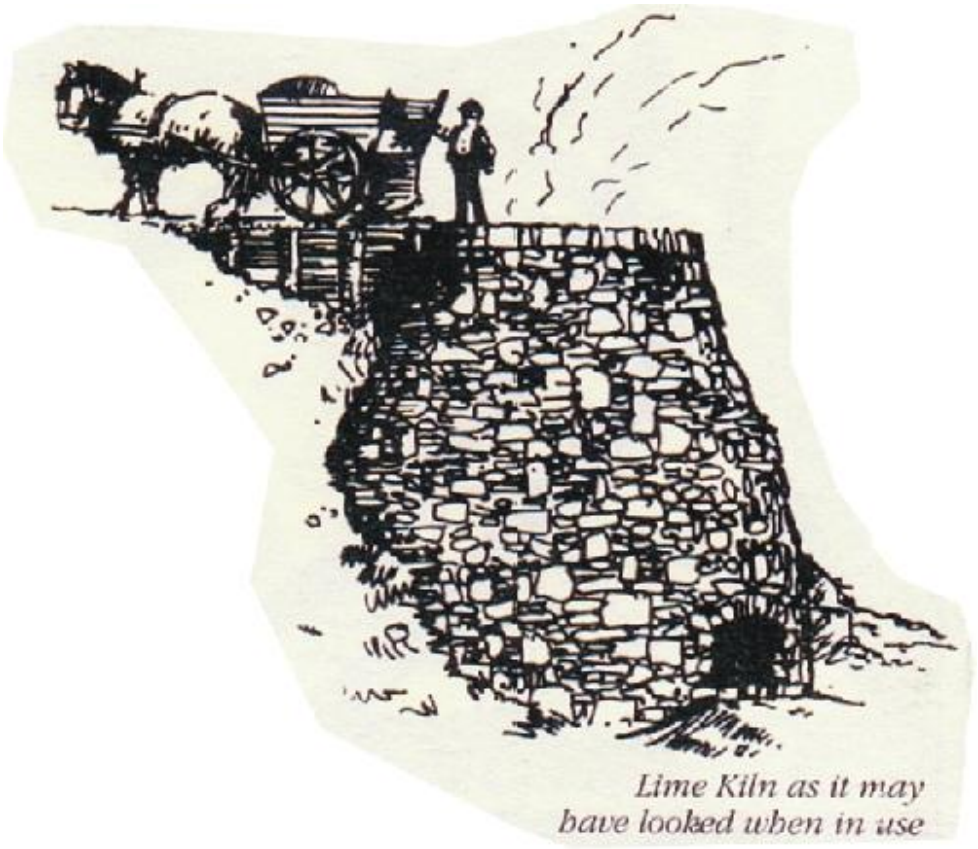
There are three basic types of lime kilns, each constructed differently to address problems with loading, burning, cooling, unloading limestone and supply/demand. The simplest type of kiln is the 'clamp kiln', where firing takes place in a mound of mixed fuel and stone, sometimes in an excavated pit. Some of the earliest lime kilns were clamp kilns. The most common kiln is the flare or intermittent kiln which use permanent masonry structures and are fired intermittently. Within a rectangular or domed kiln super-structure, the top loaded charge of stone is separated from a stoke pit or furnace below with a grate or thick layer of stone. Flare or intermittent kilns use a lot of fuel as they have to be filled, fired, and allowed to cool completely before the lime can be removed. The burning of each charge of limestone constitutes a separate operation. The process of loading, burning, cooling and unloading is repeated as needed. Intermittent kilns are usually built into the side of hills or river banks to facilitate loading limestone from the top and removal of burned limestone through the base. Fuel was placed on the bottom before limestone was loaded. All of the kilns in the Rincon and Tucson Mountain Districts can be classified as intermittent flare kilns operating on an as needed basis. The majority of the kilns in the Tucson Basin are flare kilns built into the side of washes for easy top loading and thermal insulation (Betancourt 1978; Wells and Reutter 1997; Zahniser 1966).

The third type of kiln is the 'draw' or continuous kiln which is designed for constant production of lime. Like intermittent kilns, draw kilns are permanent structures, often constructed against an artificial bank to enable top loading. This type of kiln can contain one or more 'pots' or charge holes (tapering chambers within which the burning of the fuel and limestone took place). At the base of the pot, draw holes or 'eyes' allow a controllable airflow through the kiln and provide access to draw out the lime. When firing a continuous kiln the fuel and lime had to be built up in particular layers. The first layer was of small pieces of wood, then there was sometimes a layer of coal and then a layer of limestone. The coal and limestone layers would be repeated to the top, where a final layer of coal was added. It could take up to two days to fire the kiln.



Draw (continuous) and flare (intermittent) kilns. (From Jones 2005)

Wood abundance is a major concern in designing or choosing the type of kiln to build. In the Rincon and Tucson Mountains Districts, mesquite and palo verde are good fuels. All of the SAGU lime kilns are located in areas that once had abundant stands of mesquite and palo verde. Fuel was probably a major issue, however, with the radius of clearing extending outward from the kiln, altering the landscape near the kilns, and possibly reducing growth of new saguaros. Overtime fire wood would have to be collected far from the kilns and transported by wagon to kiln sites. This increased fuel cost reduced the profitability of lime operations.



Example of a flare or intermittent lime kiln similar to the SAGU kilns.

History of the Rincon Mountain District Lime Kilns

The majority of available historical information on SAGU lime kilns refers to those in the Rincon Mountain Unit. The history of the Rincon District lime kilns is gleamed from interviews with local ranchers who worked the kilns and ran cattle in the Rincon Mountains area. The information is mostly from local newspapers, and from early historical documents pertaining to the industrial growth of Tucson. The kilns' history of ownership is complex, but details are known concerning how they were used and constructed. Most of these details were documented during interviews, newspaper articles and research compiled by Berle Clemenson (1987) in his historic resource study of Saguaro National Park.

The first documentation of lime kilns in the Tucson area is from an Arizona Weekly Star article from 1878 that lists two operating lime kilns in Tucson. An advertisement in the Arizona Daily Star from Nov. 6th, 1879 stated that "Mr. A Caballero has for some time been supplying this market with the finest quality of lime." In 1880, the Weekly Arizona Citizen comments that before the railroad, "There is little lime to be had for building and that is of bad quality. It seems to be burnt to death. With a mountain of fine stone within stone's throw of Tucson this need not be." Lime kilns continue to be mentioned in local newspapers until the early 1900's. In 1901, a paragraph in the Arizona Daily Star suggests that locally produced lime was becoming scarce: "Lime was sold yesterday in Tucson for $15 a ton, and yet there are hills of lime rock in sight of us. Who will start a lime kiln in Tucson?"

In September 1897, surveyor Philip Contzen found an "old lime kiln" at the location of the two remaining Cactus Forest Trail kilns, while recording subdivisions of Township 14 South Range 16 East (Clemensen 1987:113; Contzen 1897:10). The kiln was not in operation at the time of his visit. NPS archaeologist Paul Beaubien also mentions these kilns in 1936. He states that they are about a quarter mile southeast of the ranger station and were operated by soldiers when Camp Lowell was moved to a new location in 1873. He also observes that they "present the same appearance as the lime kiln at Tumacacori National Monument" (Beaubien 1936:260). Beaubien may be referring to the North Lime Kiln near the Cactus Forest Trail, however there is no evidence that the Cactus Forest Kilns were operated by soldiers from Camp [Fort] Lowell, although they may have supplied lime to Fort Lowell.

Eight to twelve lime kilns are said to have existed in the Rincon District alone. Today the park knows of four lime kilns in the Rincon District. Three of the kilns cluster along a wash near the Cactus Forest Trail, while the fourth is located near Camino Loma Alta Road along the southern boundary. The three kilns near the Cactus Forest Trail have been nominated for the National Register of Historic Places. The kilns represent a once active local industry that helped build early Tucson.

The beginning date for the use of the kilns is not known with certainty, although Clemenson (1987:111) notes that "tradition [with unknown citations] states that the first kilns were operated within the Rincon unit boundary to supply lime in the construction of Ft. Lowell in 1873." The date of 1873 comes from a newspaper article in the Citizen from July 24th, 1969. In this article Charles B. Maguire said "the kilns were operated by Manuel Escalante and Angel Benites during the construction of Ft. Lowell in 1873." Clemenson (1987) suggests that this date is too early, as David Faust, ex-Superintendent of Fort Lowell State Park, said that a search of Fort Lowell records shows that lime was not used at the fort until 1882. However, it is possible that lime was used as early as 1872-1873, but its purchase was not recorded until 1882.

Demand for lime does not appear to have been high until the 1880s, and the industry in Tucson appears to have developed during the second half of that decade and into the 1890s. All lime kilns appear to have been closed by 1920 (Clemensen 1987:112-114). Clemenson deduces that dating the start of lime kiln use can be done by studying the development of house construction and building spurts in early Tucson. His analysis shows that lime for use as mortar or exterior plaster probably did not begin before 1880, when the Southern Pacific Railroad reached Tucson. The railroad brought people and goods, increased local wealth, produced greater demand for housing, and made lime easier to transport, thus reducing costs. A local depression in the 1880's probably curtailed building and lime production so that local lime was only produced in small quantities. It suffices to say that local lime was being produced for Ft. Lowell and Tucson by 1882, but only in small quantities and on an as needed basis.

Newspaper interviews provide information on local lime operations. Tucson newspapers began to carry advertisements for lime in the early 1880's, but the lime for sale was from California. Written statements about local lime kilns first appear in the 1890's. The Citizen reported that in 1896 a Juan Romero Sr. died when the wall of the kiln he was working in collapsed. The kiln was three miles from Tucson. There are several oral history notes taken from 1969 discussing the operation of the kilns in the Rincon Mountain Unit by several individuals

directly involved in kiln operation, Frank Escalante and Joe Moreno, who worked with family members operating the kilns (Escalante, et al. 1969; Moreno 1969a, 1969b). Additional information was provided by a younger Frank Escalante, whose father worked at one of the lime kilns (Bowden 1982; Escalante 1983). The 1969 oral histories from Escalante and Moreno are from the same year as, and related to, an article in the Tucson Daily Citizen (Kuehlthau 1969). The oral histories contain information on the operation of the kilns, including the firing, labor and wood costs, dates of operation, ownership, who the lime was supplied to and obtaining the lime rocks for the kilns (Escalante, et al. 1969; Moreno 1969a, 1969b). This industry was discontinued by 1920 (Clemensen 1987:112-114; Moreno 1969a, 1969b).

On July 24th,1969 the Citizen ran the article on the Rincon lime kilns. This article featured interviews with locals that worked on ranches using the Rincon lime kilns. Although Clemenson claims that there were eight kilns in the Rincon area, the article quotes Joe Moreno (then 65 years old) who said there were "11 kilns altogether in the Rincon area because every ranch family also had its own kiln." Moreno worked the Rincon lime kilns with his father Carmen between 1914-1917. He was ten years old and the pay was .50 cents for a 12 hour day and $1 for a 24 hour day. Moreno (1969b) describes his jobs: "my jobs were to load limestone rocks on wagons, cut green mesquite and palo verde wood for fire, and rake out lime. Limestone was found only in certain hills in the area and had to be hauled to the kilns."

Before the Morenos used the kilns the Escalante family operated them. The history of the Escalantes is told in a Citizen article from January 9, 1982. Some of the information is also from Tom Carroll's taped interviews with Frank Escalante and Charles Maguire on December 11th, 1969. The interviews concerned the history and land use of the Rincon area, and seem to have been spurred by the earlier Citizen article of July 24th, 1969. Frank Escalante, then 58 years old, discusses his family's history in the Rincon Mountains area. "The kilns were worked all year long, and many roads led into and out of the area." Many of the Escalantes operated lime kilns. Frank Escalantes' grandfather Manuel made a living making lime, and also died making lime. In

1909 “the old man [Manuel Escalante] was bringing a wagon load [of lime] with Frank’s uncle who was then a boy. The Pantano [wash] was running and the wagon got stuck. He started carrying bags off to lighten the wagon. He had a heart attack. The old man sat under a tree by the wash and died.” In the 1969 article in the Citizen, Joe Moreno, Manuel’s brother-in-law, tells a slightly different story concerning the cause of Manuel Escalante’s death. Moreno says that after the wagon got stuck Manuel “started to shovel the lime to lighten the load. He breathed in and swallowed lime dust, and died right there in the river bed”.

Escalante helped his brother, Manuel, make lime twice from 1906 to 1908. There was permanent water in a tinaja above the kilns that could be counted on to provide water for the stock that pulled the wagons that brought the rocks. His brother used blue rocks that were blasted from the hill and then rolled to the bottom of the hill, as well as loose rocks picked up along the stream. The lime took four days and four nights to make. The ashes could then be raked out and more wood, preferably green palo verde or, if not available, green mesquite (dry wood was considered to be poor), could be added. This would occur every two to three hours, using 10 to 15 cords of wood in the entire process. Wood was cut in the area of the lime kilns and out in the direction of Freeman Road, as there was green palo verde in that area. Not much wood was cut in the direction of Broadway, as this area was mostly mesquite. A cord of wood cost $2.00 and cutting it up cost $1.00. The lime was done when the top turned yellow (Escalante 1969).

Rocks were of three colors; pink, red and blue. “The blue rocks were selected for making lime. The rocks were blasted off the hill and then rolled to the bottom of the hill where they were picked up and put in the wagon to be brought to the kiln. Loose rocks along the stream were also picked up. It took four days to make the lime. The lime could be made with or without the iron bars that are in one of the kilns [Lime Kiln #3]. If the iron bars are not used then you placed the big rocks down first forming a hollow structure and then place the smaller rocks on the outside. The ashes can be raked out and more wood added. When the top turns

yellow then the lime is done. Wood is added every two to three hours and during the four day period 10-15 cords of wood will be used (Escalante 1969)."

Tom Carroll's interviews with Joe Moreno confirmed some of Escalante's comments about the lime kilns, but also contradicted a few details. For instance, Moreno says that the limestone was sufficiently heated when the flame at the top of the kiln turned blue, whereas Frank Escalante said the rock was ready when the flame turned yellow. So is the kiln ready to be emptied when the flame is yellow or when it is blue? The answer is that it depends. The color of a flame is determined by temperature, but related to the type of fuel used and the type of material being heated. The blue part of a flame is at least 1400 degrees celcius, whereas the yellow part is 800 degrees celcius. Limestone must be heated to at least 900 degrees celcius to reduce the rock to powder. So the correct color is probably somewhere between the yellow and blue phase, at temperatures between 800 and 1200 degrees celcius.

Moreno mentioned that kilns [located east of Tucson and possibly Saguaro kilns] supplied Cypriano Ortiz with lime to construct the malpais [lava rock] wall surrounding the University of Arizona and that the lime was hauled by Dionico Telles and Andrus Herrerras (Maguire 1969; Jones 2005:192).

The kilns were last operated by Ramon Maldonado and Ygnacio Ramirez in 1920. Two of the kilns [in the area] were constructed by Ygnacio Ramirez in 1914 and 1915, who was one of the last to use the kilns, along with Ramon Maldanado. In 1920 the industry was stopped by judicial order due to complaints from ranchers that the cutting of mesquite and palo verde was depleting the bean crop they depended on for cattle feed (Kuehlthau 1969; Moreno 1969b). It is uncertain if Moreno is talking about the SAGU lime kilns throughout the interview, but evidence suggests that the SAGU lime kilns were not operated after 1920, but their exact date of construction is unknown.

History of the Tucson Mountains District Lime Kilns

Very little information is available specifically on lime kilns in the Tucson Mountains. The one mention comes from a 1920 bulletin, which states that limestone from the west side of the Tucson Mountains had been mined for many years to manufacture lime, but that none had been burned for some time, perhaps suggesting that the lime kilns in this area had been abandoned prior to this date (Jenkins, Wilson, and Allen 1920:16). Clemensen cites a phone conversation with Ed Herreras, stating that "the lime kilns at Snyder Hill southwest of Tucson began operating in the 1890s" (Clemensen 1987:113). At least one of the Tucson Mountain District kilns (North Sus Kiln) was probably built in the mid 1890's and operated until sometime before the 1920 article. Clemensen (1987:114) suggests that the kilns "ceased to operate by 1910." Their greatest use was probably between the mid-1890's to 1920 when Tucson experienced rapid growth and increased need for lime.

Archaeologist Kenneth Rozen described the Tucson Mountain Unit lime kilns in a U of A term paper from 1977. Much of the paper discusses the historical background and chemical process of manufacturing lime, but he also describes two lime kilns in the Tucson Mountain unit (including drawings), near the Sus Picnic Area, between two peaks. These are "kiln A, located a quarter mile west of the intersection of the Bajada Loop Road and the picnic area road, at the southern tip of the western peak, situated on the south bank of an arroyo that flows past the limestone peak, and kiln B, located at the northern base of the western peak, on the southern bank of an arroyo that flows through the outwash plain north of the picnic area (Rozen 1977:8). He also mentions limestone outcrops and a quarry on the northern slope of the peak, at an elevation of about 2600 feet (Rozen 1977:8)."

Kiln A is a circular shaft of unshaped stone, available locally, laid without mortar, with an inside diameter of approximately seven feet and an outside diameter of approximately twelve feet (Rozen 1977:8). The top of the shaft is level with the top of the top of the arroyo bank, about 20 feet above the bottom of the arroyo (Rozen 1977:8). The northern portion of the shaft

has apparently fallen into the arroyo and the remaining shaft is filled to within four feet of the surface with soil, unburned limestone, and stones that have fallen from the wall of the shaft . There is a pile of limestone behind the kiln on the top of the bank and, at the base of the bank, deposits of "what appears to be a lime of reasonably good quality" are partially obscured by soil that may have slumped from the bank above (Rozen 1977:9). Trash was not abundant near the kiln, with only a large nail and a metal can observed. While the top opening of the shaft was well situated for supplying limestone, no opening was visible at the base of the kiln, but probably would have been present (but may be presently obscured with soil) to facilitate the removal of lime (Rozen 1977:11). Rozen suggests that the fuel used in this kiln was wood from the local area. This was likely a temporary, intermittently used kiln for the small-scale production of lime (Rozen 1977:11).

Kiln B, the north Sus kiln, is situated in a small hill about 67 feet from the main course of the wash (Rozen 1977:9). These kiln remains are also a circular shaft of unshaped stone with an inside diameter of seven feet, but with a lining of a double layer of fire brick. Above the fill, the maximum height of wall of the shaft is approximately four feet. The brickwork and stone portions of the kiln appear to have been laid with a brick colored mortar (Rozen 1977:9). A metal pipe with a single seam and a diameter of 1 ¼ inches extends from the center of the shaft to a height of about 53 inches above the fill (Rozen 1977:9). A partially buried rectangular structure eight feet in length is in front of the shaft (the side facing the wash). A way from the kiln to the wash is lined on either side with two small ridges of soil, in one of which is embedded regularly spaced pieces of limestone a few feet from the kiln. Behind the kiln, the hill is covered with limestone and solidified lime, extending from the center of the kiln to a radius of approximately fifteen feet (Rozen 1977:10). The shaft of the kiln has either been removed or deteriorated below the surface near the summit of the hill, revealing the stratigraphy, which consists of several discrete alternating layers of limestone pieces and solidified lime. Near the edge of the wash, further away from the kiln, are several deposits of poorly burned lime and a

thick deposit of ash is found further north along the wash. A large amount of metal trash, a small amount of glass and possible stoneware can be found in the area around the kiln (Rozen 1977:10). Again, an opening is not visible at the base of this kiln, but was probably present and is obscured by soil (Rozen 1977:12). It is possible that the top of the kiln may not have extended much beyond the top of the hill, which would have facilitated the loading of the limestone into the kiln, with is also supported by the presence of limestone in this area (Rozen 1977:12-13). It is suggested that the kiln was operated intermittently, with wood used as a fuel most of the time (Rozen 1977:13).

Geologic Occurrence and Quality of Limestone at Saguaro NP

Limestone of varying quality is available in the vicinity of both the Rincon and Tucson Mountains kilns. Both districts have Paleozoic Era limestones including the Escabrosa, Horquilla, Colina and Concha limestones. The Escabrosa and Horquilla limestones make excellent choices for producing quicklime. Both types are available near the Rincon and Tucson Mountains lime kilns. Limestone is mostly calcium carbonate and magnesium carbonate. The best quality quicklime is made from limestone with 90-95% calcium carbonate (CaO_3) and 1-2% magnesium carbonate. The crystalline structure of limestone affects its ability to calcine or be made into quicklime. Some limestones will shrink when heated, while others will break apart or not allow CO_2 to escape during firing, due to the tight packing of crystals and the rock's density. There can be significant variability within limestone formations, requiring testing and selection of suitable rock for making quicklime. Kiln operation varies depending on the type of limestone used and the size of the rock heated in the kiln. In general, it is best to use the lowest temperature with the shortest cooling time to allow full calcination. For some limestones, higher temperatures will cause increased shrinkage, reduction in volume, or increased porosity. Selecting the right limestone and understanding the temperatures needed is an art form requiring experimentation and observation. Even with modern technology it is an experimental process.

PRESERVATION TREATMENT AND DOCUMENTATION OF THE RINCON MOUNTAINS DISTRICT LIME KILNS

Three of the four lime kilns of the Rincon Mountains District are located near the Cactus Forest Trail; North Kiln (Lime Kiln #2, SAGU 30, Locus A, AZ:BB:14:74), Lime South Kiln (Lime Kiln #1, SAGU 30, Locus A, AZ:BB:14:74), Lime Kiln #3 (SAGU 7, Locus 1, AZ:BB:14:165). The fourth lime kiln is the Camino Loma Alta Kiln (AZ BB:14:451), located near the southern boundary of the Rincon District. The North and South Kilns are located 30m from each other along a spur trail of the Cactus Forest Trail. The South Kiln has an interpretive sign and both kilns are visited by hikers, bicyclists and horseback riders. Lime Kiln #3 is across a large drainage, ~200m to the northeast. The North and South Kilns are more similar to each other than to Kiln #3, but all of the kilns were constructed differently. Kiln #3 is almost 11 feet deep at it's maximum height, while the North and South Kilns are currently more shallow. Work was also completed at the Camino Loma Alta Kiln which is located near the southern boundary of the Rincon District near Camino Loma Alta road. The Camino Loma Alta Kiln is the largest kiln in the park.

Existing Documentation of Cactus Forest Trail Lime Kilns

Lyle Stone conducted the only formal documentation and condition assessment of two of the Cactus Forest Trail, Rincon District lime kilns, the North and South kilns. "These were both constructed in a cut-out section of an alluvial terrace edge, with the top at ground level (for supplying fuel) and the face exposed towards the dry wash (for lime removal), and the terrace deposits surrounding the remaining sides reducing heat loss during firing" (Stone 1976:2,4). The North Kiln (L. Stone's Kiln 1) was constructed of coursed adobe and according to Stone was in "fairly stable condition", while the South Kiln (L. Stone's Kiln 2) was constructed of angular granite masonry set in mud mortar and was in poor condition and "appears to be rapidly deteriorating", and "both appear to have been heavily used" (Stone 1976:3-4). Stone (1976) suggests that based on their physical condition, Kiln 2 is at least 10 to 15 years older than the

other, but both are suggested to have been in use until their abandonment around 1920 (Stone 1976:5).

Stone named the kilns Lime Kiln # 1 (North Kiln) and Lime Kiln # 2 (South Kiln), respectively. However, on the 1976 archaeological site sketch map Simpson labels the North Kiln as "Lime Kiln #2" and the South Kiln as "Lime Kiln #1". In this manuscript they will be referred to as the North (#1) and South Lime Kiln (#2).

In 1976, Stone measured the kilns' dimensions, completed cross-section drawings, photography, and maps of the kilns. Detailed mapping of Lime Kiln #3 was not completed at this time. A more detailed map of other associated historic sites surrounding the three kilns was made in 1983 during the archaeological survey (see Figures below).

All three of the Cactus Forest lime kilns are built into the edge of alluvial terraces near an active drainage that eventually feeds the Tanque Verde Wash. Building kilns into alluvium serves two purposes vital to lime kilns. First, and foremost, the kilns retain heat better when built into soil; and the soil the kilns are built into is highly cemented, retaining heat better than loose soil. Second, the kilns can be loaded by wagon from above, requiring less physical labor. All three Cactus Forest Kilns have, or had, evidence of a side entrance or stoking opening for starting and feeding the fire and removing fired limestone. However, there are no physical remnants of a stoking opening at the Camino Loma Alta Kiln, and historic photos have not been found. It is probable that all of the kilns were a bee-hive shape, but today only Kiln #1 retains its' beehive shape.



The North and South Lime Kiln environment. Kilns are built into the terrace edge. Photo by Stone (1976).

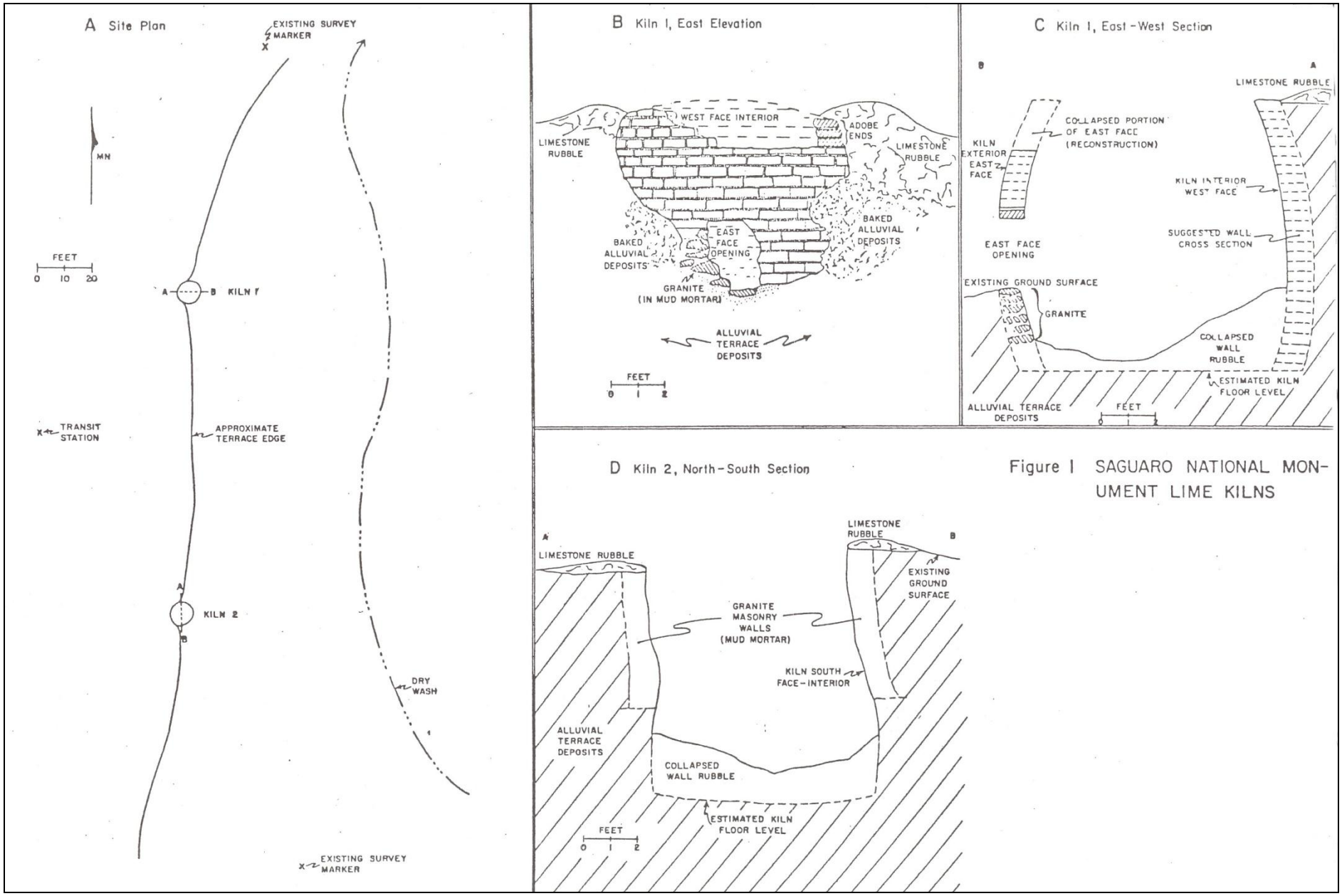
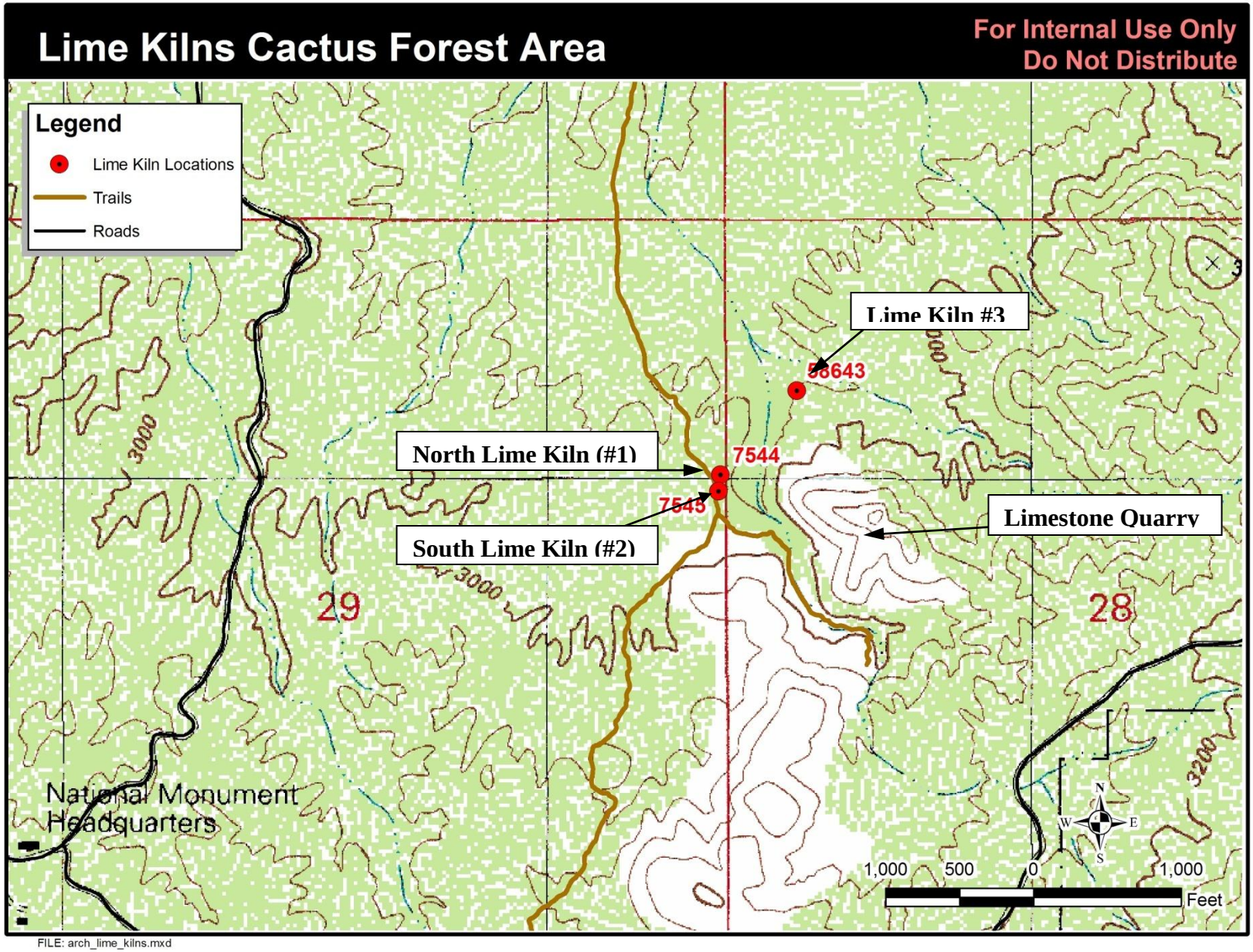
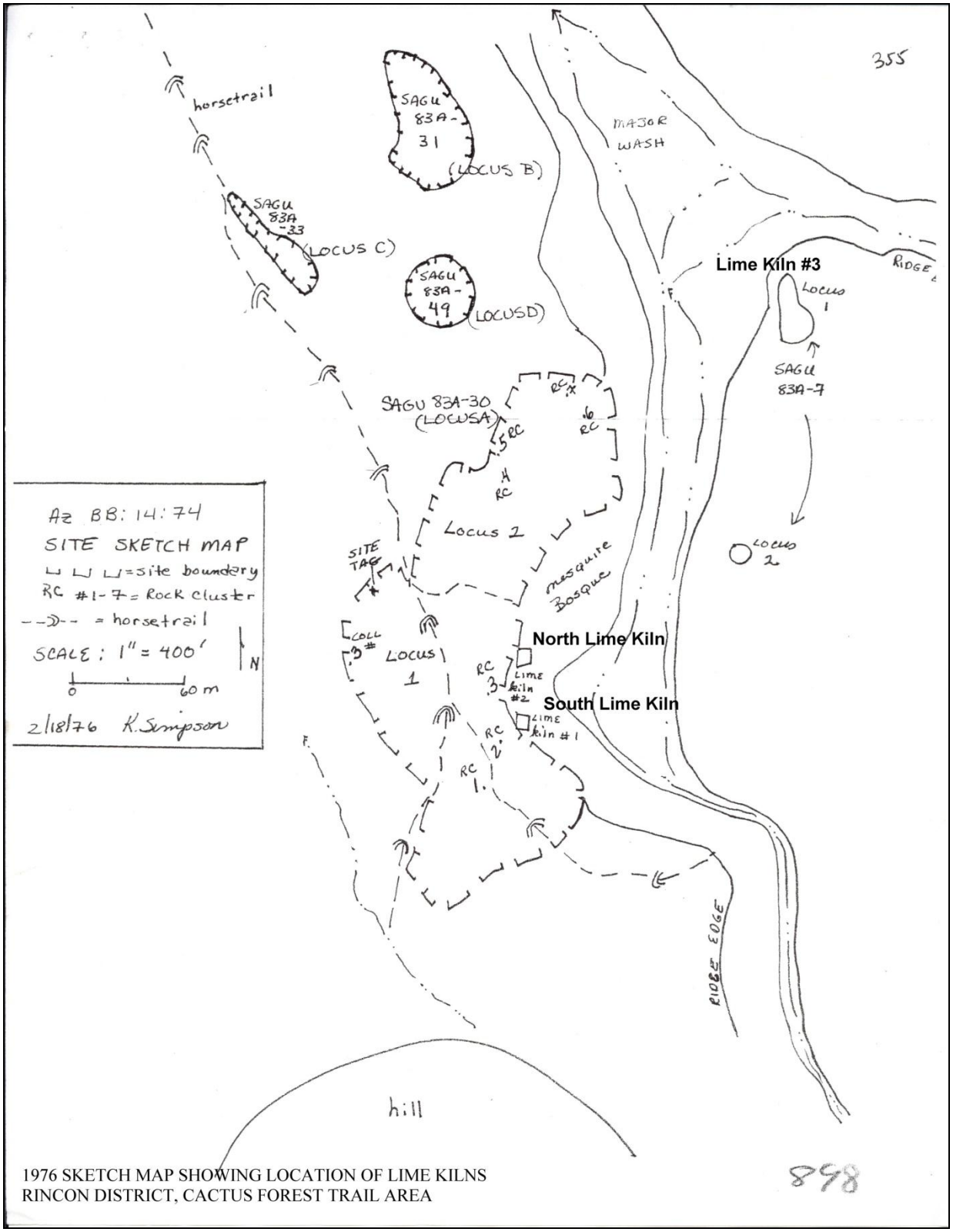


Figure 1 SAGUARO NATIONAL MONUMENT LIME KILNS

Lyle Stone (1976) maps of Kiln #1 (N. Kiln) and #2 (S. Kiln). Kiln #3 was not mapped in 1976, but was included in the 1994 National Register nomination.

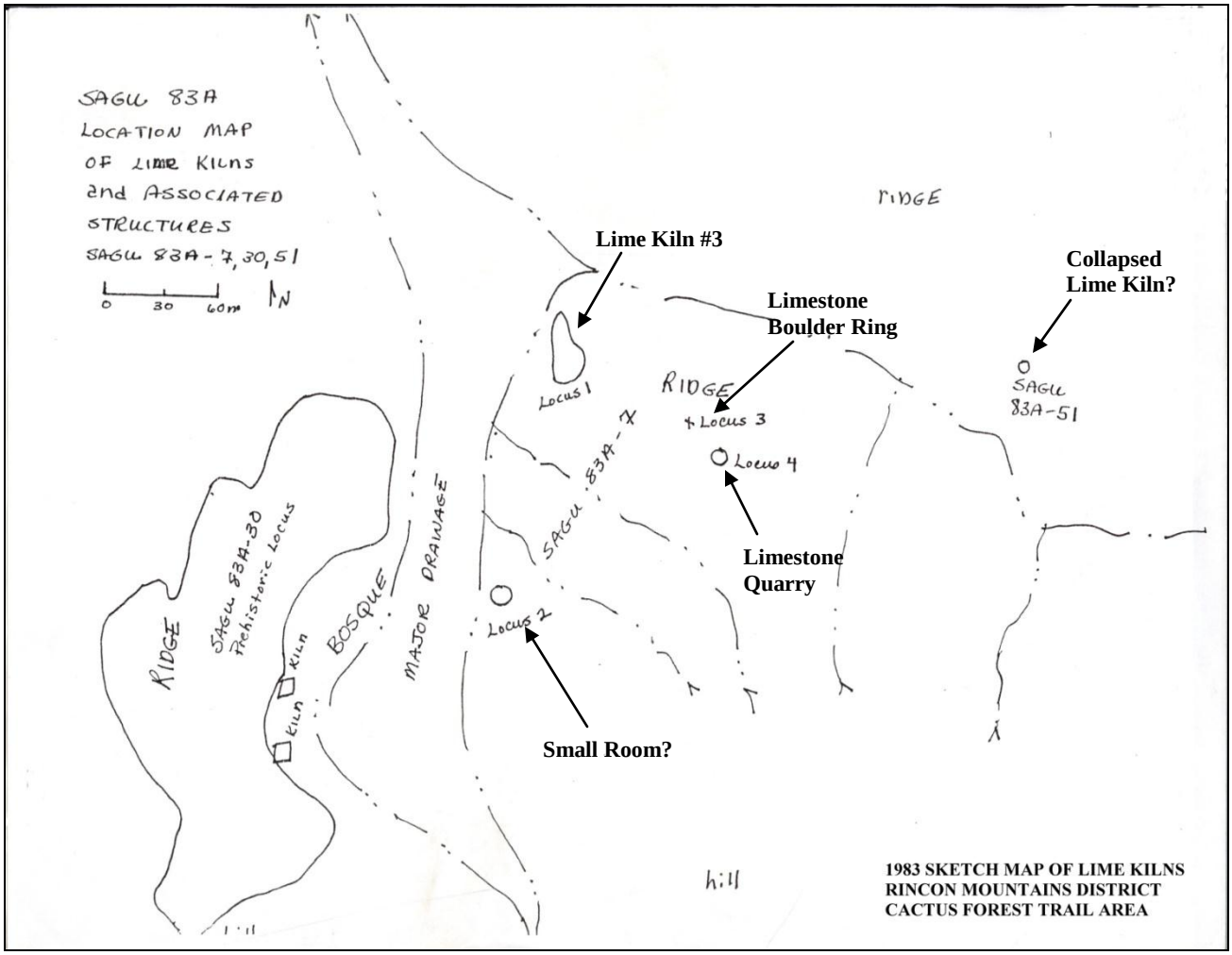


Cactus Forest Trail Lime Kilns. Cactus Forest Trail (in brown) follows a portion of the wagon road that leads to the quarry and lime kilns.



1976 SKETCH MAP SHOWING LOCATION OF LIME KILNS
RINCON DISTRICT, CACTUS FOREST TRAIL AREA

Simpson's 1976 archaeological sketch map of the North and South Kilns and associated sites. (NOTE: The kilns are labeled differently than used by Stone in his cross-section drawings.) Lime Kiln #3 was given a different site number than Kilns #1 and #2.



The 1983 archaeological survey sketch map showing lime kilns and associated archaeological sites. Locus 1-4 are part of SAGU 83A-7 (AZ BB:14:165).

Green Glaze and Kiln Age

All three of the Cactus Forest kilns have wall areas covered in a green glaze of vitrified lime, rock, and/or adobe. Adobe bricks are fused in areas, and rocks are covered with a glassy lime shell. This shell actually helps preserve the original construction materials and keeps the kiln walls sturdy. Interestingly, the visual characteristics of the interior glazes in each kiln differ.



North Lime Kiln, southeast wall, highly burnt/vitrified interior with green glaze.

The section on material analyses discusses the chemical make-up of some of the glazed or vitrified portions of the kilns. It is tempting to say that kilns with large vitrified wall areas were used more than kilns that lack vitrified walls. However, there are several factors that may contribute to differences in glaze characteristics:

1) intensity of individual heating events
2) type of fuel used
3) height of fuel stacking
4) height of limestone when heated (how full?)
5) location of hottest part of fire in kiln bottom/draft.

Since we do not have detailed information about all of the variables contributing to the visual characteristics of vitrified or glazed wall portions, we cannot know whether it is directly correlated with age or intensity of use. However, if vitrification, or area of burnt brick, is used as a proxy measure of age and/or intensity of use then the South Lime Kiln was used the most and is the oldest kiln. Lime Kiln #3 has the least amount of glaze, however there is also evidence that the kiln walls were rebuilt at least once. Below Lime Kiln #3 are brick/lime piles representing clean outs or repairs to the interior brick/rock walls of the kiln. There is also evidence of removing and replacing the interior kiln facing at the North Sus Lime Kiln in the Tucson Mountains District. The material analyses show that the green glaze found on the interior of the kilns is formed by the heating of lime that adheres and bonds with the rough surface of the adobe bricks, thus forming a substance consisting of different compounds; mostly made of calcium, silica, and magnesium. The thickness of the glaze and the percentage of Calcium and magnesium may be a proxy measure of the amount or frequency of lime burning in the kilns. If Ygnacio Ramirez built two kilns in 1914 and 1915, and was one of the last to use the kilns in the Rincon District, it is possible that he built Kiln #1 (North Kiln) and Kiln #3. Both of these kilns are in better shape and have less lime glaze on their interiors than Kiln #2. Perhaps Kiln #2 (South Kiln) is the oldest kiln and the other two were added later. Yet, it is uncertain whether these are the kilns constructed in 1914 and 1915 by Ygnacio Ramirez.

The North Lime Kiln (Kiln #1)

LCS#: 07544
SAGU SITE #: 83A-30, Locus A.
STATE #: AZ BB 14:74.

The North Lime Kiln (#1), located along a social trail of the Cactus Forest Trail, is the best preserved of the three kilns. It was built into the edge of an alluvial terrace overlooking a large drainage east of the Cactus Forest Trail. The walls are constructed of adobe with mud mortar. Adobe bricks measure 30 x 25-28 x 9 cm. The adobes are sun-dried bricks that became harder through successive firings of the kiln. Interior adobes are burnt to a max depth of 10cm. The mortar is a reddish-brown mud mortar with a small fraction of gravel/pebbles. The mortar was probably made using the red soil just above the kiln along the Cactus Forest Trail and surrounding the kiln area; but the mortar is also scorched giving it a deeper red color than the soil.

The maximum height of the kiln is 222cm with 18 courses of brick. Wall thickness ranges from 25cm to 28cm. Smaller bricks, used for the upper courses, are curved inward to make the distinctive beehive shape of most intermittent flare kilns. Surrounding the kiln are piles of fired limestone, unfired limestone, quicklime, ash/lime deposits, and evidence of kiln cleaning. Periodic cleanings and/or repairs are required to remove fire-damaged adobes/stones, fix cracks in attempts to increase efficiency. Ash was cleaned out after every firing to ensure quicklime purity. Burned rejected limestone was piled up to 20m away from kilns, and often used as insulation near the top and sides of kilns. Piles of burned limestone, and recalcified quicklime surround and encase five out of the six Saguaro kilns. All of the kilns have scatters or smaller concentrations of historic artifacts. The artifacts surrounding the kilns reflect activities associated with lime production, metal tool use, subsistence, and on-site camping.

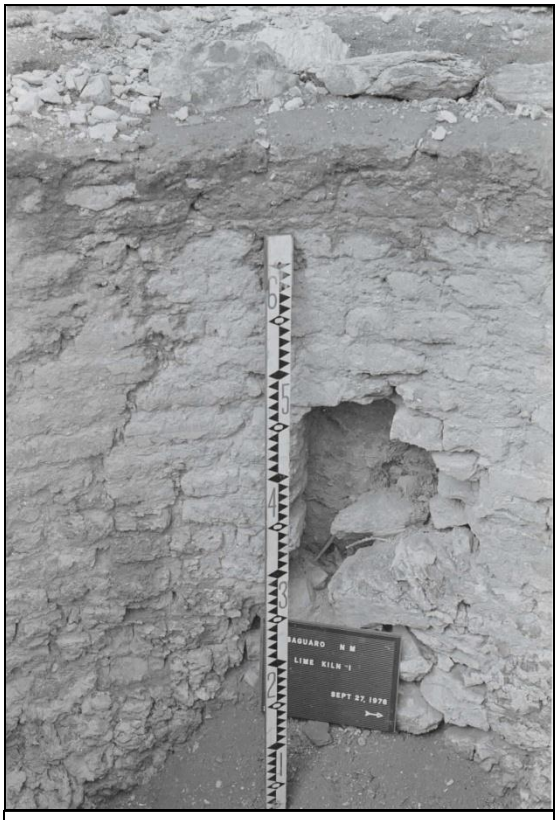


North Lime Kiln, north wall, 2006. Note the burned/vitrified interior adobe surface and limestone debris surrounding kiln.



Recalcified processed lime (quicklime), with burned and unburned limestone deposit west of kiln. The deposit is waste from the unloading of limestone into the kiln, and the loading of quicklime from the kiln.

In 1976, Lyle Stone hypothesized that the large hole in the west wall interior was a flue. He describes the hole as "a small aperture through the kilns' west face…This opening joins a vertical tunnel or shaft (now limestone filled) which extends upward to ground surface. This opening may have been a flue for the passage of air through the burning wood fuel."



North Lime Kiln hole that Stone believed was a flue, 1976.



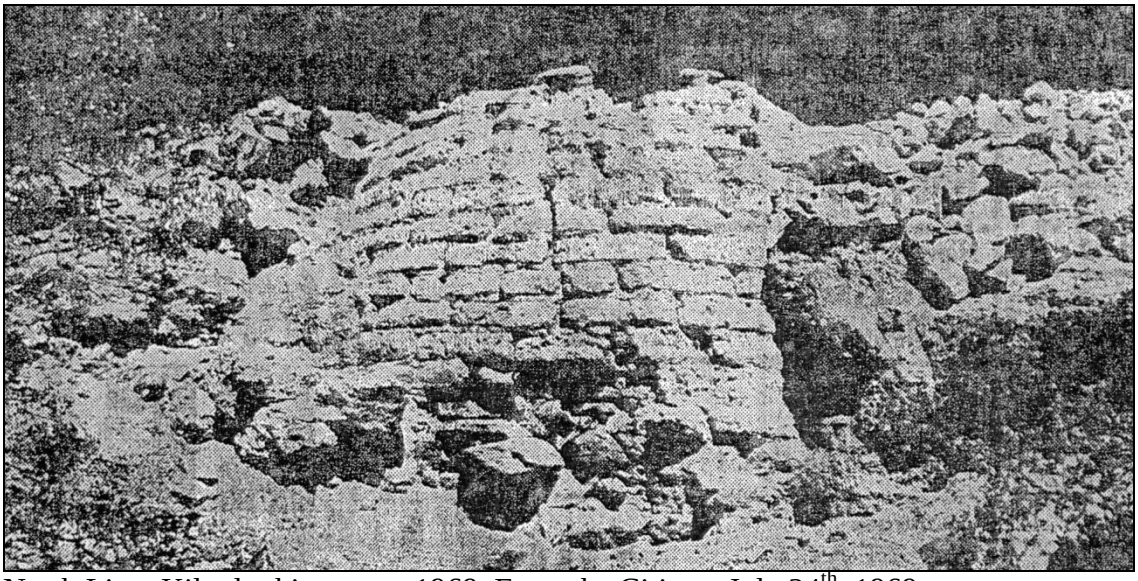
North Lime Kiln, hole in west wall before treatment, 2006.

It seems unlikely that the hole in the west wall section is a flue. Kilns need to retain heat. Oxygen is available through a small opening at the top and the stoking hole at the bottom (east side) of the kiln. Stone took black and white photographs of the kilns in 1976. Appraisal of these photos shows that the hole looked much like it did before treatment in 2006. Lime kilns are not usually constructed with a flue due to heat loss and the need to keep the kiln at consistently high temperatures. The hole that Stone thinks is a flue looks more like a hole formed by a combination of rodent activity and erosion behind the wall. The hole in the west wall probably

formed when adobe bricks bulged and fell into the interior of the kiln. Then rodents and erosion created hollow tunnels behind the wall. As erosion continued the soil holes became filled with limestone debris from the surface and surrounding fill.

Condition Assessments

The first formal condition assessment of the Cactus Forest Trail kilns was done by Kevin Harper (SOAR) in 2003. TUMA staff conducted another assessment in 2006. Both assessments had similar results. The North Kiln is better preserved than the South Kiln, but was in need of preservation treatment to prevent further loss of historic fabric. Photos of the North Lime Kiln taken in 1969, 1976, and 1993 show an intact kiln. In 1996, the east wall collapsed, perhaps due to vandalism, although the photographs show a crack formed throughout the middle of east wall above the opening. By 2003, the whole east side of the kiln had blown out and is currently strewn over a 4m x 4m area down the east slope. Once this section of wall collapsed other wall portions were weakened, increasing the likelihood of further wall collapse. In addition, drainage issues surrounding the kiln were causing water to pool in the center and eroding the river bank that the kilns are built into.



North Lime Kiln, looking west, 1969. From the Citizen, July 24th, 1969.



North Lime Kiln, looking west, 1976. Note the eastern opening and how the burned and consolidated soil enclosed the kiln. Photo by Lyle Stone.



North Lime Kiln after collapse of the east wall in 1996. Note the remnant of the kilns' opening at the base of the east wall.

Preservation Treatment of the North Lime Kiln (#1)

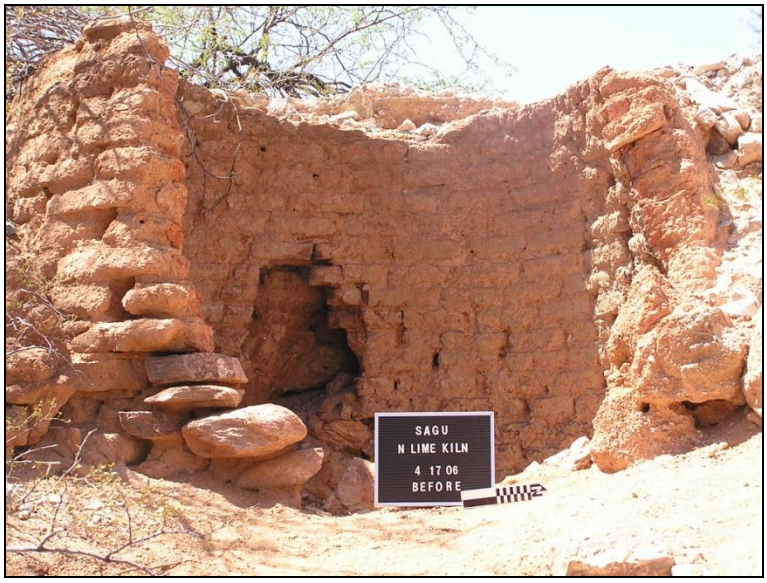
Preservation work at the North Lime Kiln focused on stabilizing exposed wall ends, filling vertical wall cracks, filling the west wall hole, repointing mortar joints, protecting the top of the wall, and redirecting drainage away from the interior of the structure. The table below shows the amount of preservation materials added, measured areas of repair, the mortar mix used to repoint mortar joints and cap the walls, and the number of person hours worked. The data is organized by each wall section (N, S, E, W). At the North Kiln work was completed in two days. Most of that time was spent repointing eroded mortar joints and filling cracks. The mortar used for repointing/repairs was mixed using nearby soil that approximated the color and consistency of the original mortar. An original mortar sample was collected and is stored at WACC. The original mortar has a high percentage of silt and clays with mica (muscovite), abundant plagioclase feldspar, and quartz sand grains. It is reddish-yellow (Munsell 7.5 YR 6.5/6) in its' unheated state and varies towards red in its' heated state near the interior of the kiln. The replacement mortar is a little more grey in color than the original mortar. It can be visually differentiated from original mortar, but is unobtrusive. No cement or synthetic materials were added to the mortar mix. The south and east wall section received the most repointing.

Although we tried to avoid rebuilding wall sections, a small portion of the north and east wall ends needed to be strengthened by adding a few courses of adobes and stones. Original adobes from the kiln interior were used, rocks were added when we ran out of suitable adobes. The north wall end was rebuilt and stepped to strengthen the wall. Two courses of the east wall were rebuilt and tied into the northern rebuilt section to provide structural stability. Overall only 1.875m^2 of wall was rebuilt.

The large hole in the west wall was filled using salvaged original adobes and a few rocks and set in unamended mud mortar. Before the adobes and rocks were placed the hole was filled with rubble and mud mortar. A few smaller holes were also filled in the north and southeast wall

sections. The wall tops were capped with flat stones and covered with a thin mud cap that is considered sacrificial and in need to replacement every 3 years. The cap was inspected in July 2007, when minor cracking was noted.

The slope surrounding the kiln was graded using soil/gravel and surrounding rocks to create positive drainage away from the structure. Holes near the exterior kiln walls were filled with rock, gravel and mud to slow water from entering. Cloth mesh was placed on the bottom of the kiln, which was filled with sand from the wash and graded for positive drainage to the east out of the entryway/stoking hole remnant.



North Lime Kiln, before treatment.



North Lime Kiln, after treatment.

NORTH LIME KILN(#1)

Location of Work

Wall	*Repointing (m2)*	*Total Cap (m3)*	*Wall Repair (m3)*	*Mortar Added*	*Comments*
		$2.648m^3$ Cap mix= clay stain		12 WB	
North	$1.86m^2$		$.675m^3$	75	10-15 rocks in NE section of wall where wall end was rebuilt. Old adobes from the bottom also used.
West	$1.1m^2$		$.70m^3$	65	old adobes from bottom of kiln
South	$2.07m^2$			60	
East	$2.06m^2$		$.50m^3$	70	entrance/fuel hole repaired using rock, small portion of upper wall rebuilt, cap is large flat rock (7rocks)
TOTAL	$7.02m^2$	$2.648m^3$	$1.875m^3$	270 gal	

Mortar Mix
1 dirt, no sand

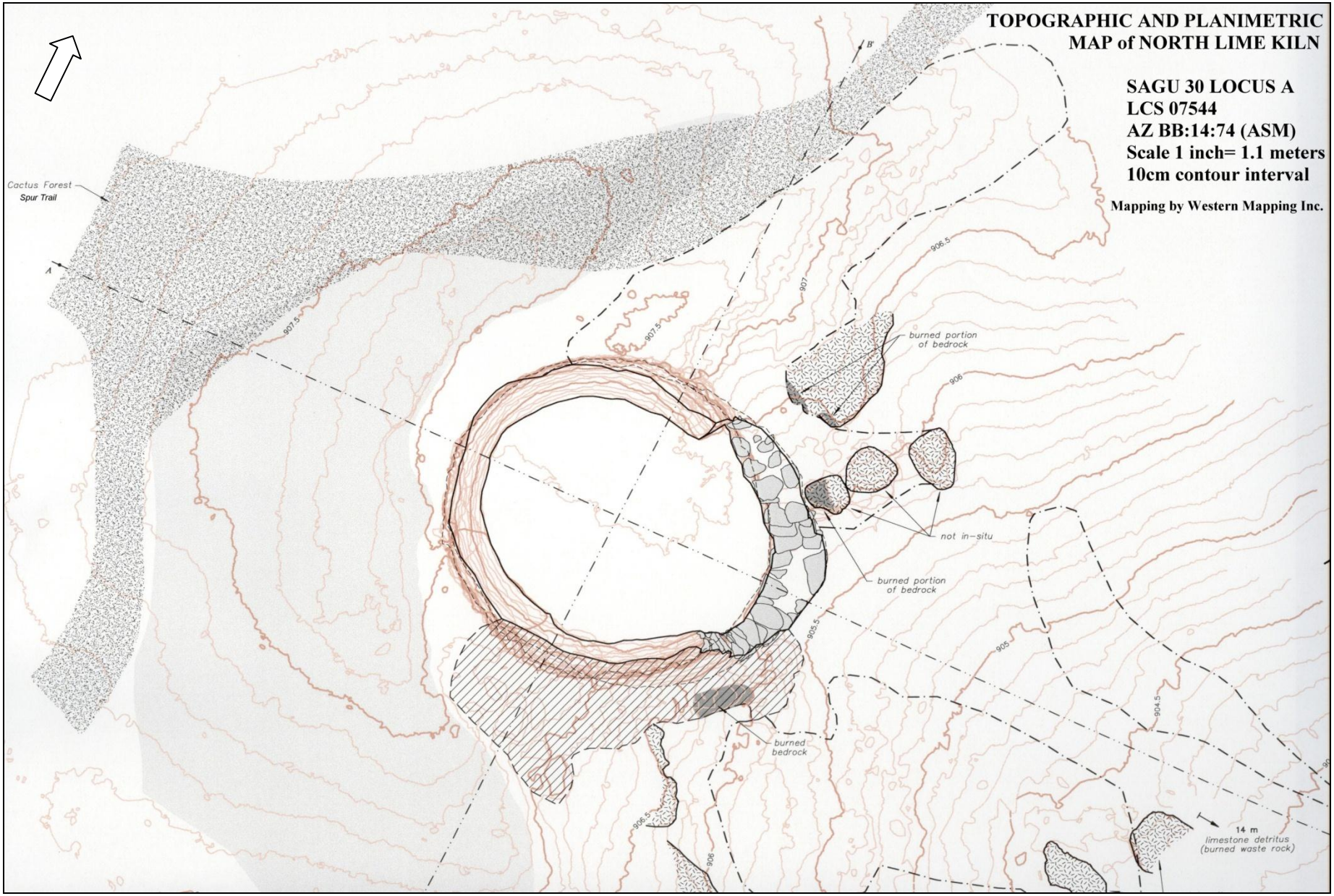
Special Features

North Wall	thick, wavy, flow like glaze, burnt area	area= $1.33m^2$			sample submitted to U of A for material testing
South Wall	same as above	area= $1.69m^2$			
Borrow Pit (mortar) (2 holes)	30m NW of kiln	area= $0.546m^3$			red dirt with high clay content. dirt from under trees and bushes

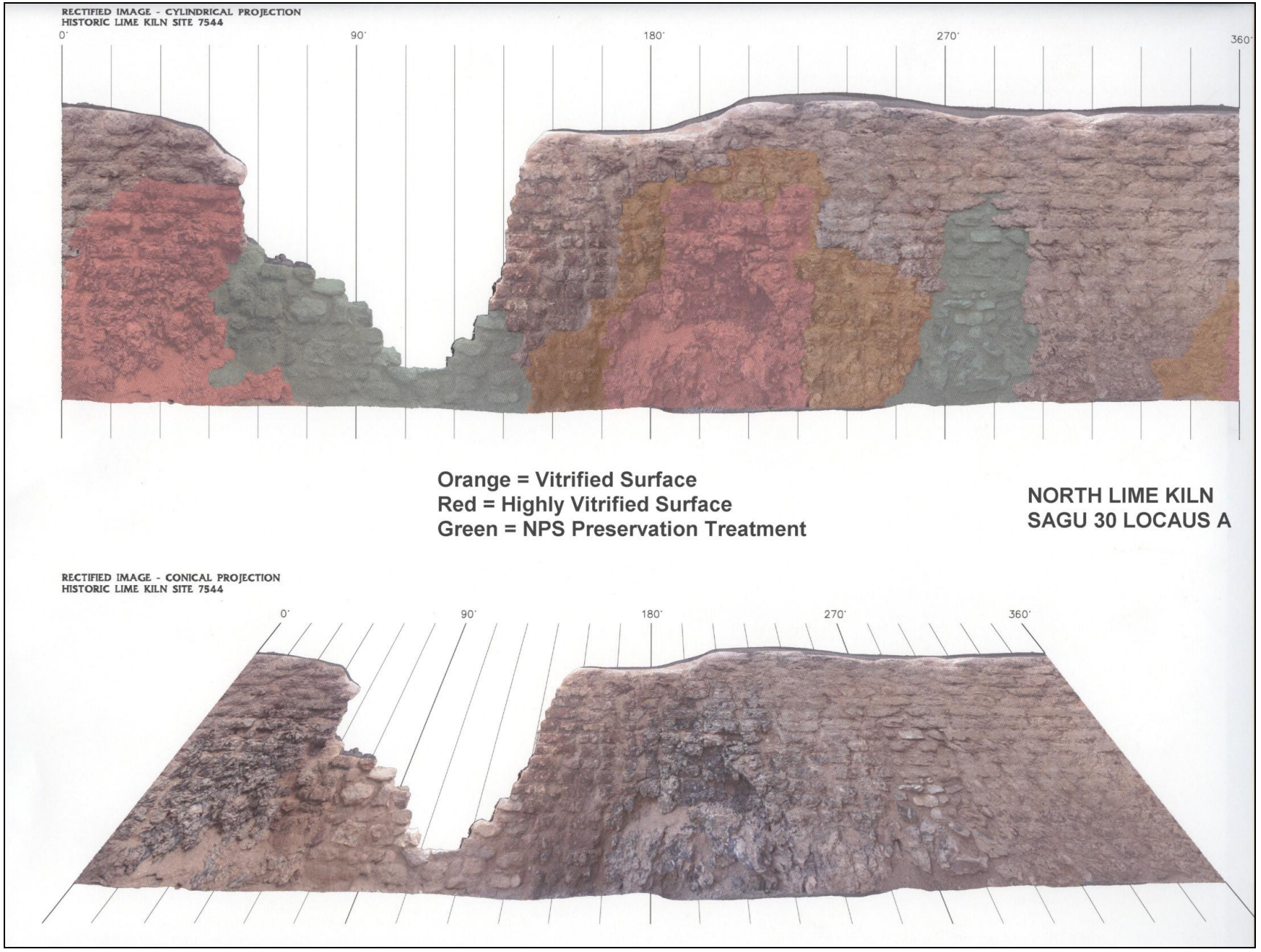
NORTH LIME KILN (#1) cont.

Time/Labor

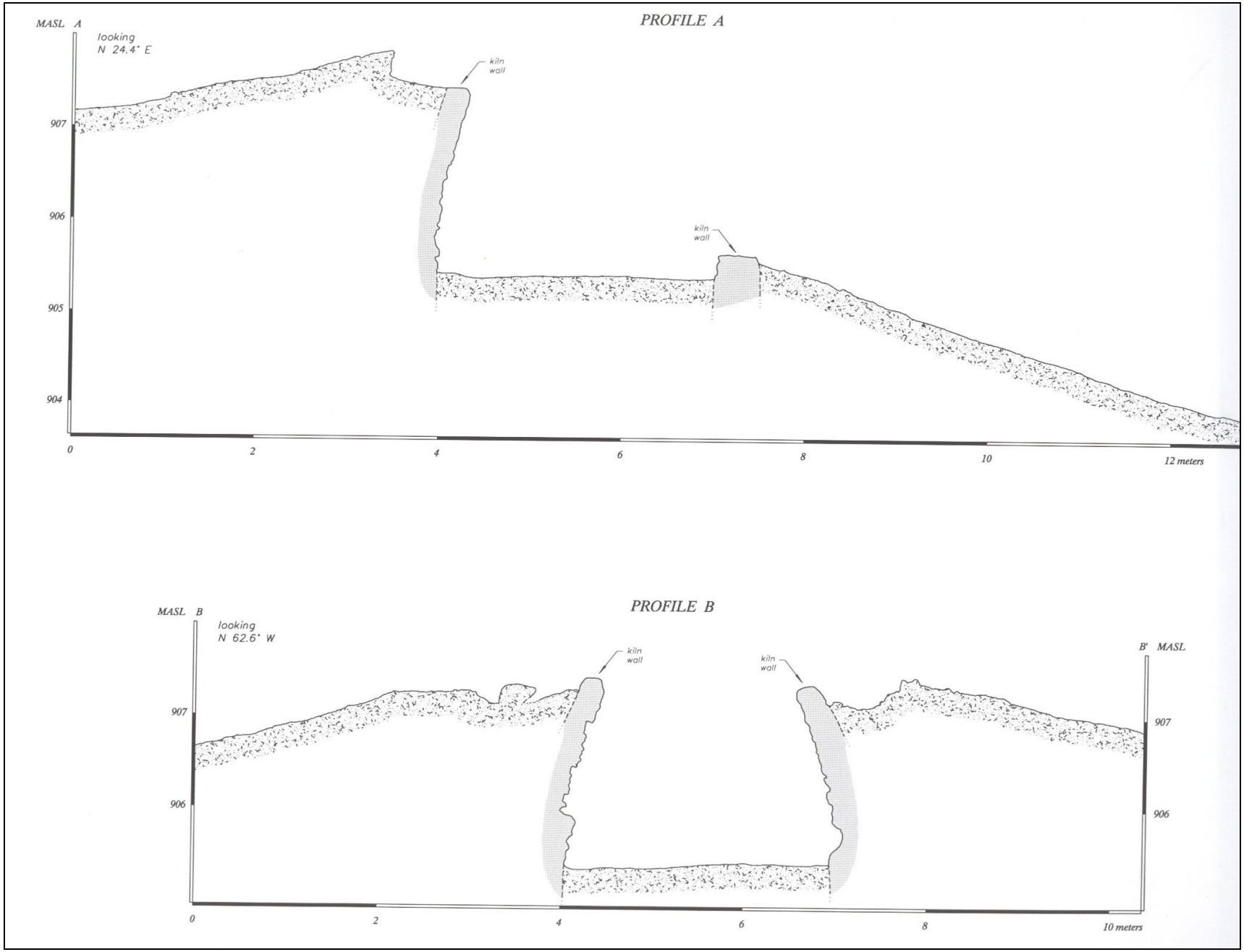
Task	Time Spent (Total hours)	# of people	hours per person	
Repointing	3.5	2	1.75	mortar mix- 1 bucket of dirt no sand
Capping	2.5	1	2.5	mix- thin clay stain
Wall Repair	5	1	5	used salvaged adobes and rock
Documentation	4	1	4	digital and black and white photos
Veg Removal	0.5	2	0.25	bushes trimmed back
Hauling Equipment	0.5	3	0.16	
Ruins Assessment	1.5	1	1.5	
Erosion Control	2	1	1	rock armored slopes, filled kiln with sand and slope graded away



Map of North Lime Kiln (#1). Light grey shaded area is hardened lime, hatched areas are preservation rip-rap, dimpled areas are exposed burned sediments/bedrock, and dashed line areas mark the extent of burned rock waste.



North Lime Kiln Architectural Sheet, showing vitrified/glazed interior surfaces (burned areas) and NPS treatments.



North Lime Kiln, cross-section profiles A and B.

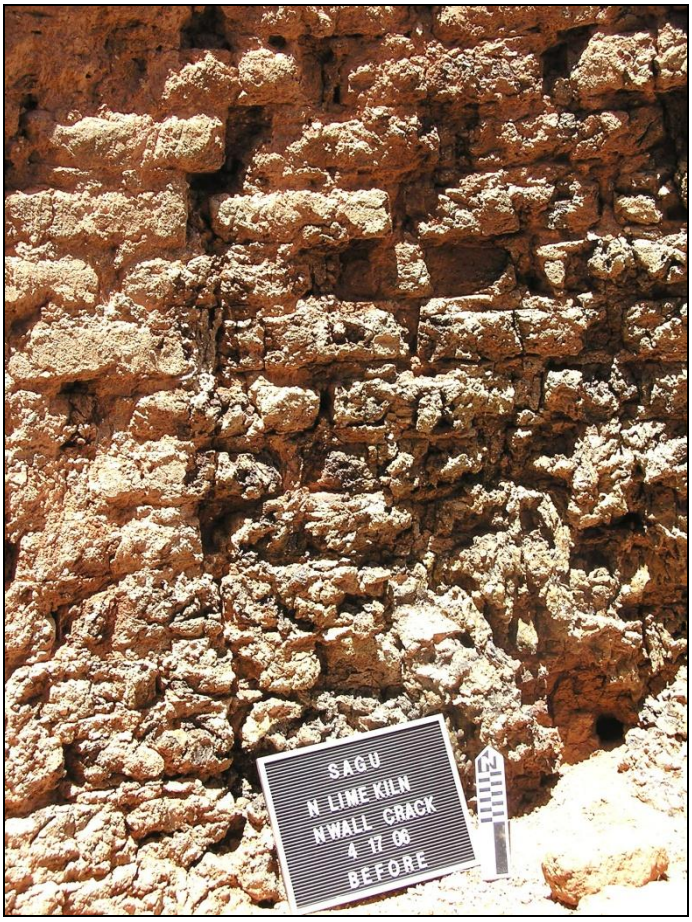
SAGU, CACTUS FOREST TRAIL LIME KILNS, NORTH LIME KILN (#1)
Before and After Photos, Color Digital



Cactus Forest Trail, North Lime Kiln (#1), North Wall Section, Before Treatment.



Cactus Forest Trail, North Lime Kiln (#1), North Wall Section, After Treatment.



Cactus Forest Trail North Lime Kiln (#1), North Wall Section Crack, Before.


Cactus Forest Trail, North Lime Kiln (#1), Close-up of North Wall Crack, After Treatment.



Cactus Forest Trail, North Lime Kiln (#1), Southeast Wall Section, Before Treatment.



Cactus Forest Trail, North Lime Kiln (#1), East-SE Wall Section, After Treatment.



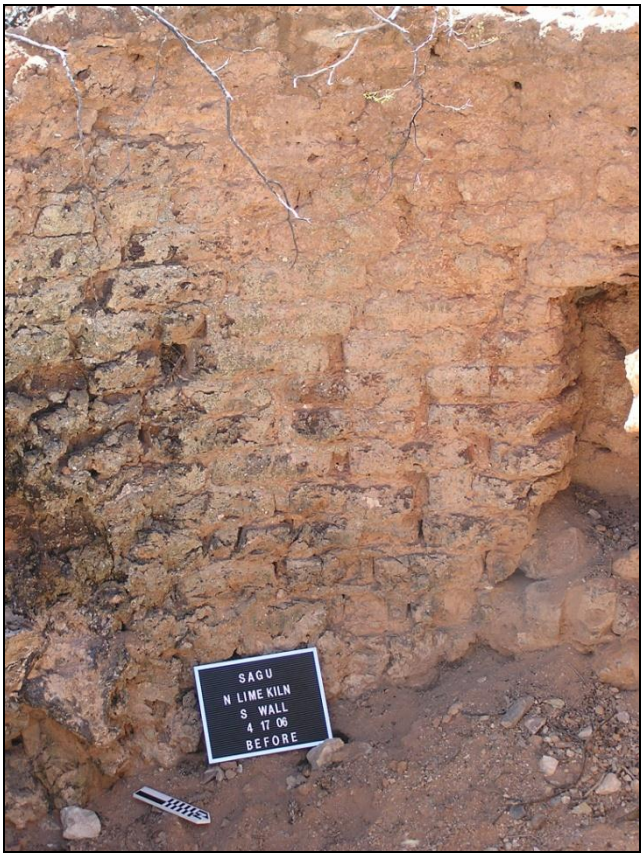
Cactus Forest Trail, North Lime Kiln (#1), West Wall Section Hole, Before.



Cactus Forest Trail, North Lime Kiln (#1), West Wall Section Hole, After Treatment



Cactus Forest Trail, North Lime Kiln (#1), West Wall Section, After Treatment



Cactus Forest Trail, North Lime Kiln (#1), South Wall Section, Before Treatment



Cactus Forest Trail, North Lime Kiln (#1), South Wall Section, After Treatment.



Cactus Forest Trail, North Lime Kiln (#1), looking south at mud cap.



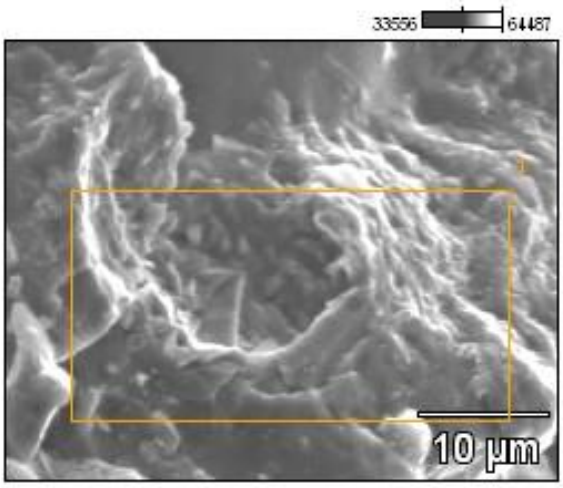
Cactus Forest Trail, North Lime Kiln (#1), looking south at close-up of mud cap.

Material Analysis

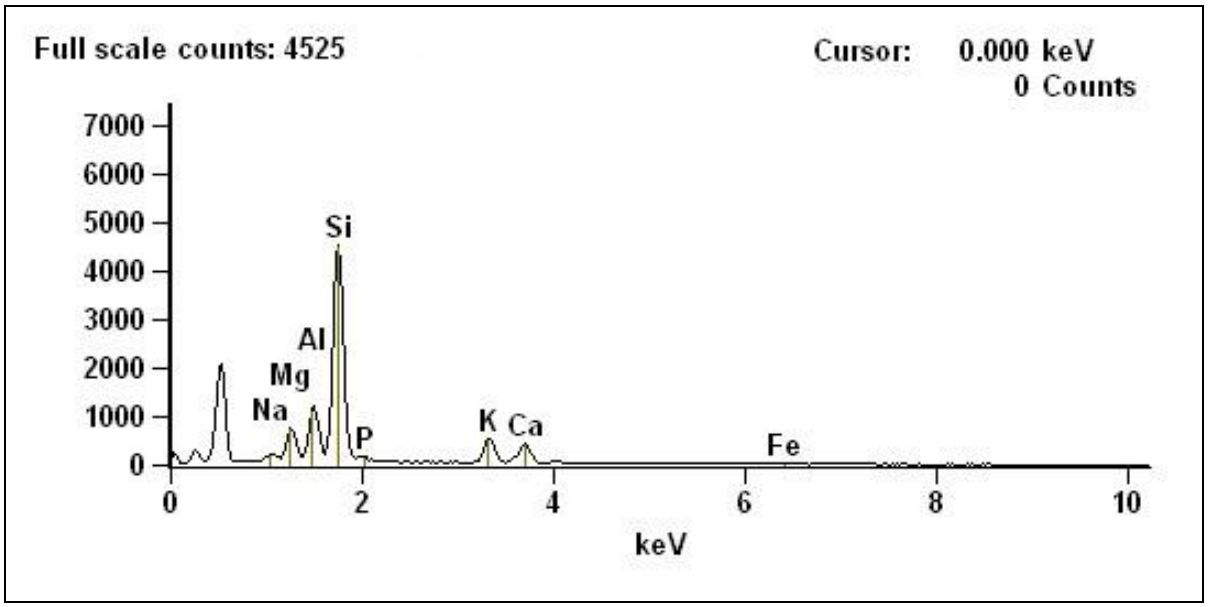
The North Lime Kiln appears to have been used extensively and heated to high temperatures, creating a distinctive green vitrified glaze with a wavy, almost dripping appearance on areas of the kilns' interior. The north/northwest and south/southeast wall sections are the most vitrified. The vitrified north wall section measures 1.33m^2 and the south measures 1.69m^2. A sample of the vitrified glaze from the north wall section was submitted to the University of Arizona and Dr. Pamela Vandiver for chemical analysis. Minerals in vitrified portions of the kiln interior have re-crystallized. The chemical composition of the vitrified north kiln interior sample was analyzed using a Scanning Electron Microscope (SEM) and Energy Dispersive Analysis. Two sides of the sample were analyzed: the exterior flat side without the heavy glaze deposit, and the interior side with the wavy glaze.



Adobe brick sample from North Lime Kiln, northwest wall. Exterior of brick fragment in left, interior in right. Note the wavy, melting appearance of the greenish glaze on the interior.



North Lime Kiln, NW Wall sample. SEM photo at 2,500X.
The exterior of the adobe brick sample is melted clay, giving the surface a rough appearance compared to un-melted clay which is smooth.



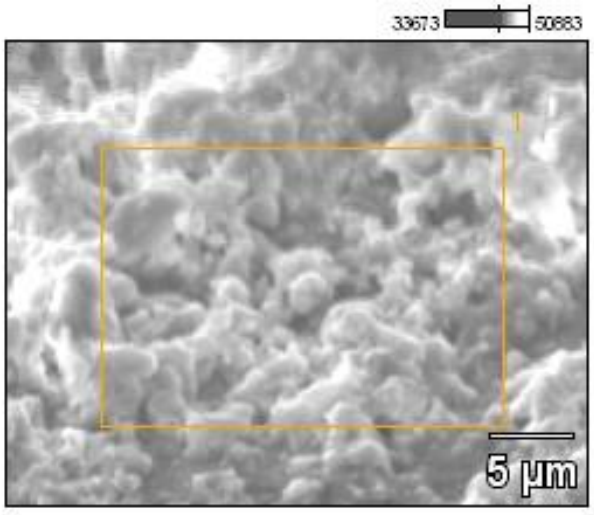
Elemental graph of North Lime Kiln adobe brick, exterior side sample.

Elements identified in SEM analysis of adobe brick (exterior), North Lime Kiln, NW Wall.

Filter Fit Chi-squared value: 1.373
Correction Method: Proza (Phi-Rho-Z)
Acc.Voltage: 15.0 kV Take Off Angle: 51.8 deg

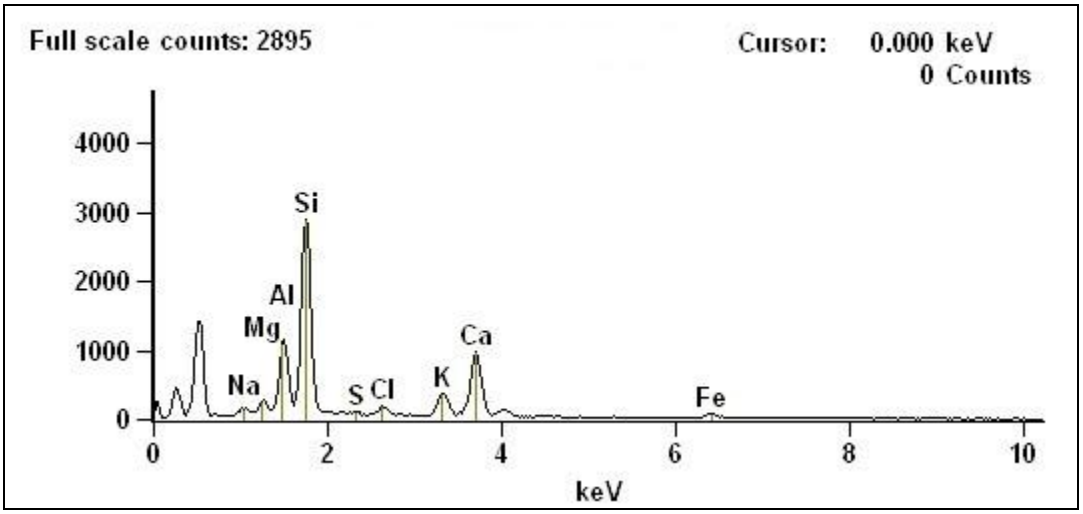
Element	***Wt.%***	***Compound Formula***	***Wt.%***
O	45.68S		---
Na	1.44	Na^2O	1.94
Mg	3.82	MgO	6.34
Al	6.14	Al^2O^3	11.61
Si	27.90	**SiO2**	**59.69**
P	0.74	P2O5	1.71
K	6.68	K^2O	8.05
Ca	**5.82**	**CaO**	**8.14**
Fe	1.76	Fe^2O^3	2.52
---		---	

The next image shows the glassy or glazed, interior part of the sample that was tested on the SEM at 3,000x magnification:



North Lime Kiln (#1), Vitrified Brick Surface, SEM at 3000x mag.

The charts that were returned from the scan follow:



Elemental graph of North Lime Kiln adobe brick, interior side sample.

Elements identified in SEM analysis of adobe brick (interior), North Lime Kiln, NW Wall.

Element	Norm. Wt.%	Norm. Formula	Norm. Compound	
O	41.71S			---
Na	1.23		Na^2O	1.66
Mg	1.01		MgO	1.68
Al	7.10		Al^2O^3	13.42
Si	21.47		**SiO2**	**45.94**
S	0.35		SO^3	0.88
Cl	1.60		Cl	1.60
K	5.09		K^2O	6.13
Ca	**16.73**		**CaO**	**23.41**
Fe	3.70		Fe^2O^3	5.29
Te	0.00		TeO^2	0.00
Total	100.00			100.00

As can be seen from the above charts, the CaO and Ca (calcium) content in the compound from the bricks' interior surface is much higher than the sample from the bricks' exterior, suggesting that the glaze formed from the adhesion of lime powder (heated limestone dust) and subsequent heating of lime remaining on the surface of the kiln interior. The interior glaze also has less Magnesium (Mg) and Magnesium Oxide (MgO) due to off-gassing during firing at extremely high temperatures.

The glaze on the interior of the North Kiln is a compound formed from the bonding of heated lime (CaO, calcium oxide) with minerals in the adobe brick. The high amount of silica is from the sand particles and sand mixed in the adobe brick. Magnesium, aluminum, potassium and iron are minerals in the soils used to make the adobe bricks and are related to local soil parent material (i.e. bedrock or alluvium). The oxides of these minerals are formed from heating, indicating that significant alteration of the adobe brick occurs during firing of the kiln.

The South Lime Kiln (Kiln #2)
LCS#: 07544
SAGU SITE #: 83A-30, Locus A.
STATE #: AZ BB 14:74.

The South Lime Kiln (#2) is located near the Cactus Forest trail 30m south of the North Lime Kiln (#1). A small wayside is located in front of the kiln. The kiln is built into the side of the alluvial terrace in the same manner as the North Lime Kiln, but with local rock and some adobe bricks. It measures 204 cm at its maximum height; 54 cm at its minimum height; and 46 cm at its greatest thickness. The maximum opening at the top of the kiln is 228 cm. The adobe bricks measure 9cm x 25-28cm x 30cm, the same as the North Lime Kiln. However, the South Lime Kiln's construction is different than that of the North Lime Kiln. The South Lime Kiln has a double wall made of sun dried adobe brick encased by rock. There are no intact structural remains of the east side of the kiln except for a small amount of brick along the base. The original mortar is unamended soil mixed with water and used like a "mud" mortar for the brick. Some rock has been placed in the brick matrix of the wall as well. It was not possible to get an accurate count of the number of courses due to lime plaster adhering to the interior wall. The interior is encased by a hard lime shell that appears as a green glaze in spots. The largest vitrified or burnt wall section occurs on the south wall. The rock used in kiln construction probably came from the bedrock outcrop across the drainage to the east. There is a rock pile between the North and South Kilns that appears to be from construction and cleaning-out of the kilns. A mortar sample could not be taken since the whole interior wall is incased in lime and exposed mortar is crumbling and too burnt/vitrified to adequately describe.

There is lime debris in and around the kiln. In the region of the kiln known as the "cleanout" lime debris extends west 1.95 m from the kilns western edge. The area around the top of the kiln is compromised from the amount of fill that has washed out from around the

exterior of the kiln. The site receives visitation and foot traffic along its western edge. The entire east region of the kiln is blown out and no longer exists except for a small number of what appear to be basal bricks. A small washed out area also extends from this region and continues down the slope to the minor wash below. Acacia, creosote and mesquite surrounds the kiln and encroaches on walls.

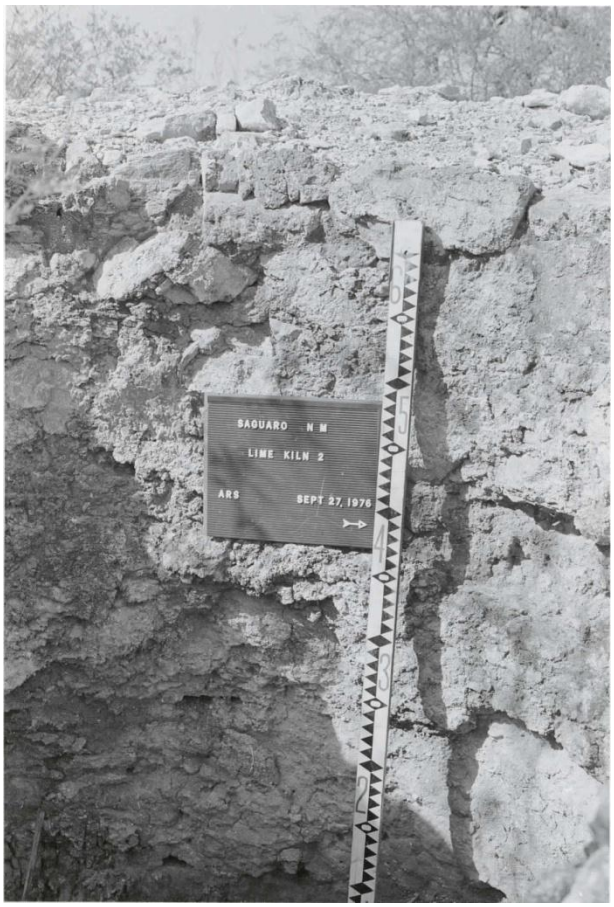
Condition Assessments

Condition assessments were done by Stone (1976), Harper (2003), and in 2006. The assessments indicate that the environmental factors affecting the condition of the kiln include water from rainfall and the wash, vegetation, animals, and insects. Vegetation is growing on or near the kiln and both animals and insects use the kiln for habitation. The mortar is weakened from insects burrowing/nesting in the mortar matrix. Animals are actively burrowing in and around the kiln. Visitors were placing garbage in the kiln which was cleaned out during Harper's documentation in 2003, and foot traffic may be damaging the upper wall portions. The kiln's condition is precarious given the "blown out" areas and the fill being washed out from the exterior surface. All condition assessments suggest that visitors should be refrained from walking up to the kiln for their safety and to ensure that further impacts to the kiln do not occur.

Comparison of Stone's 1976 photo and photos from 2003 and 2006 show that the eastern side has changed the most in the last 30 years. In 1976 the eastern opening is intact (see picture below). The opening goes through the dense alluvium of the terrace edge and is the fire stoking hole. Sometime after 1976 the opening collapsed downward. In addition, the southwest slope detached and slid on top of the collapsed opening. This movement lowered the height of the ground surface on the east side of the kiln. From this time on, the exposed wall ends weathered and were impacted by visitors and rodentia. The southwest slope is unstable and rodents have taken advantage of the disturbed slope, weakening the south wall section.



Cactus Forest Trail, South Lime Kiln in 1976. Note the intact opening (east side) and intact wall ends.



Cactus Forest Trail, South Lime Kiln (#2). Photo by Stone (1976)



Cactus Forest Trail, South Lime Kiln in 2003. Photo by K. Harper (SOAR)

Preservation Treatment of the South Lime Kiln (#2)

The preservation treatment of the South Lime Kiln (#2) took one and a half days to complete and consisted of repointing, filling holes and cracks, rebuilding of wall ends, and re-grading to improve drainage. Vegetation was removed where it encroached on the structure. A rock and mud cap was placed on the top course of the wall to protect the top of the wall where people stand and to improve drainage away from the structure. The north slope along the north wall was armored with local rock and unamended mud and re-graded for drainage away from the structure. The southeast slope near the eroded east wall section, and surrounding the southern wall section, had huge rodent holes and was in danger of collapsing. The holes were filled with unamended mud and rock and the bank was stabilized. A concavity at the base of the south wall section was filled with mud and rock. The end of the north wall section where the wall had partially collapsed was rebuilt with local rock and mud to strengthen the wall. A small portion of the remaining east wall outline was covered with mud to protect it from further erosion.



Cactus Forest Trail, South Lime Kiln (#2), Site Overview Looking West, Before Treatment.



Cactus Forest Trail, South Lime Kiln (#2), Site Overview Looking West, After Treatment.

South Lime Kiln (#2)

Location of Work

Wall	***Repointing (m2)***	***Total Cap (m3)*** $2.412m^3$	***Wall Repair (m3)***	***Mortar Added (gallons)***	***Comments***
North	$0.84m^2$		$.79m^3$	45	~20 rocks added
West	$0.84m^2$			15	6 small to med. sized rocks added
South	$0.27m^2$		$1.65m^3$	45	~35 rocks added to voids and to close up exposed wall end and fill holes in the slope near wall
East	0		$.06m^3$	1.5	small portion of exposed wall covered with thick cap of mud mortar
TOTAL	$1.95m^2$	$2.412m^3$	$2.5m^3$	106.5 gal	

Mortar Mix
2 dirt, 1 sand
(5 gallon buckets)

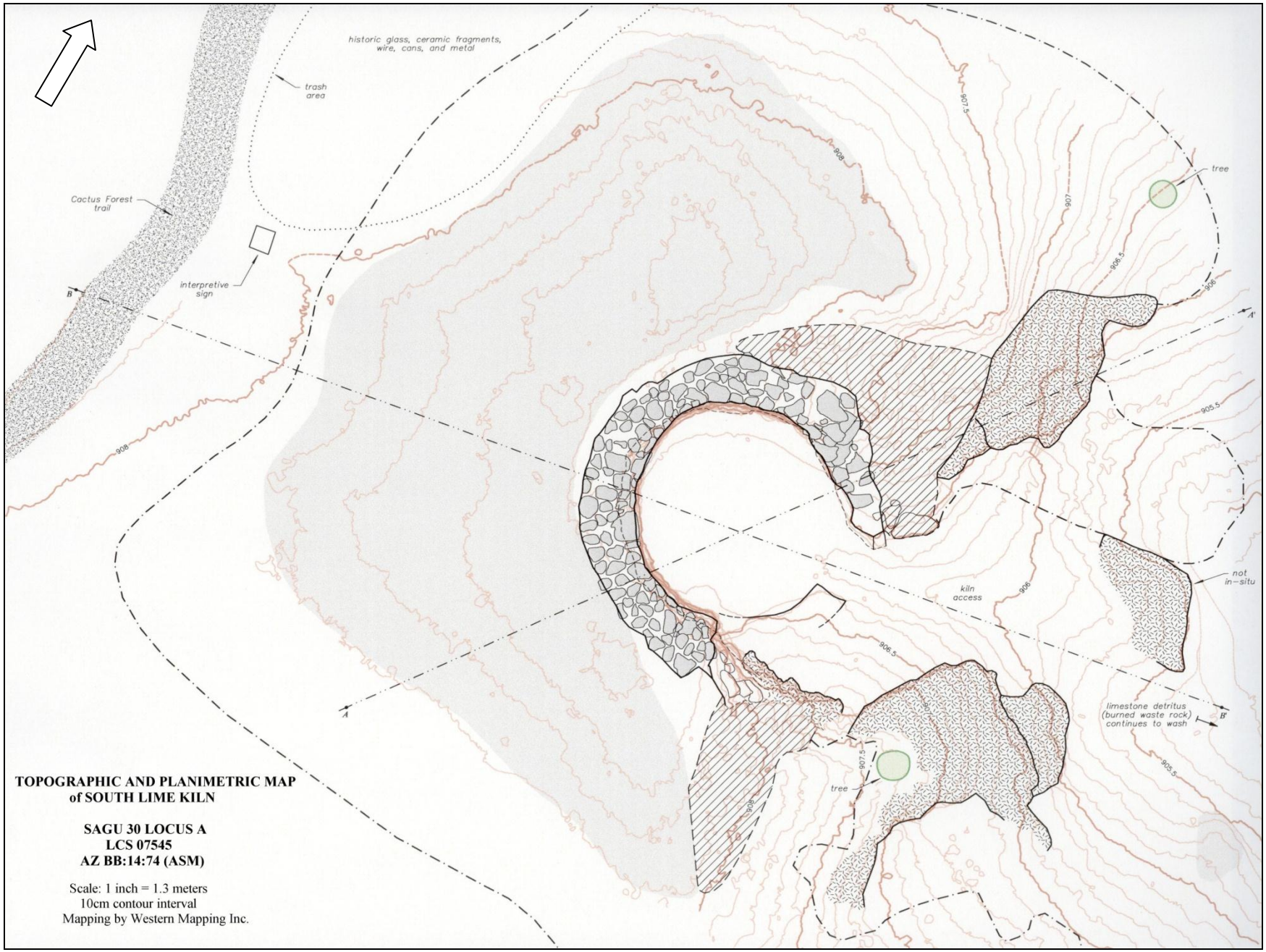
Special Features

South	whole interior is burnt, but thickest burnt area has glaze	area= $1.12m^2$			sample submitted to U of A for material testing
Borrow Pit (mortar) (1 hole)	30m S. of kiln near creosote bush, brown dirt	area= $1.44m^3$			

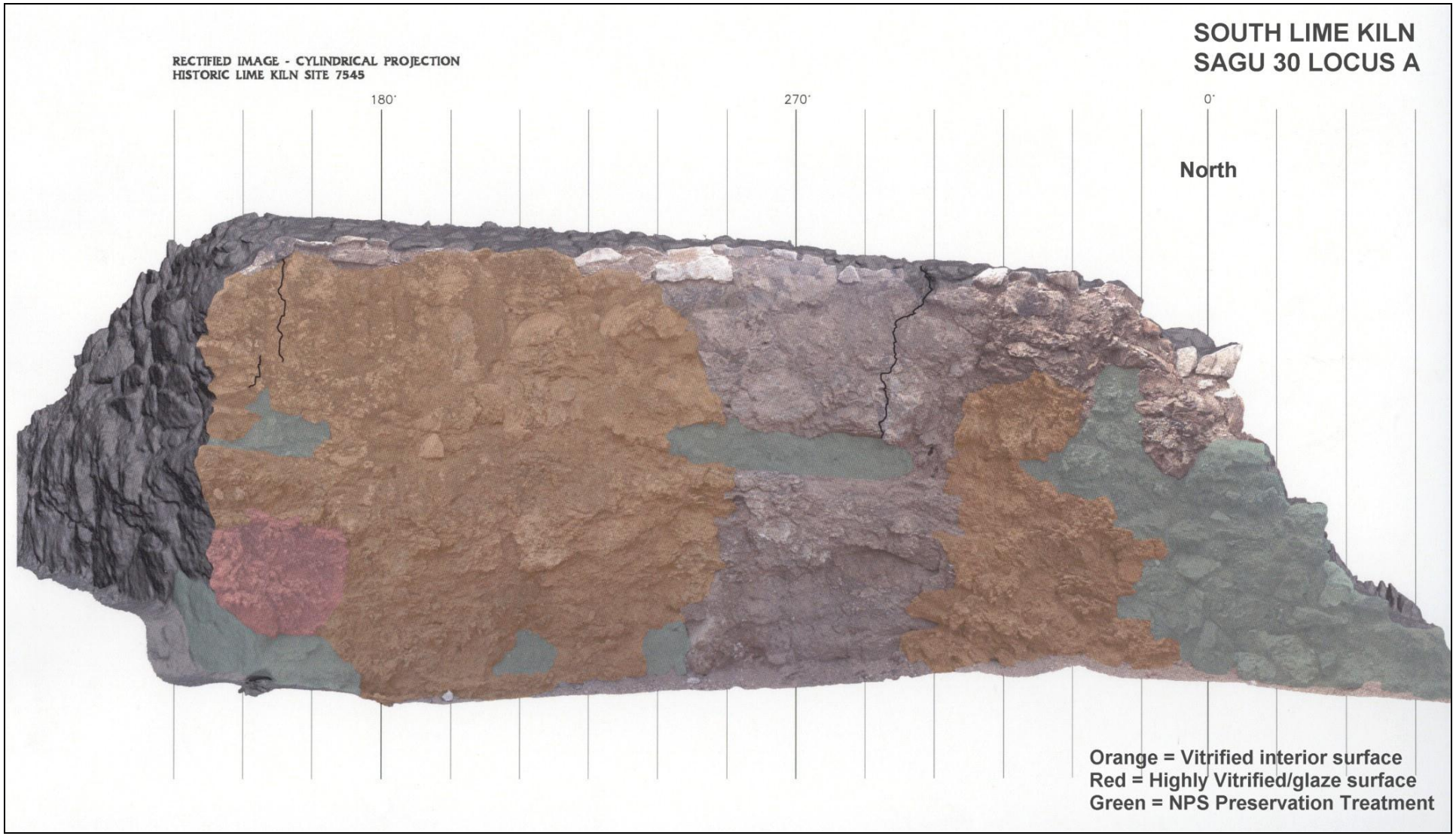
LIME KILN 2 (South Lime Kiln)

Time/Labor

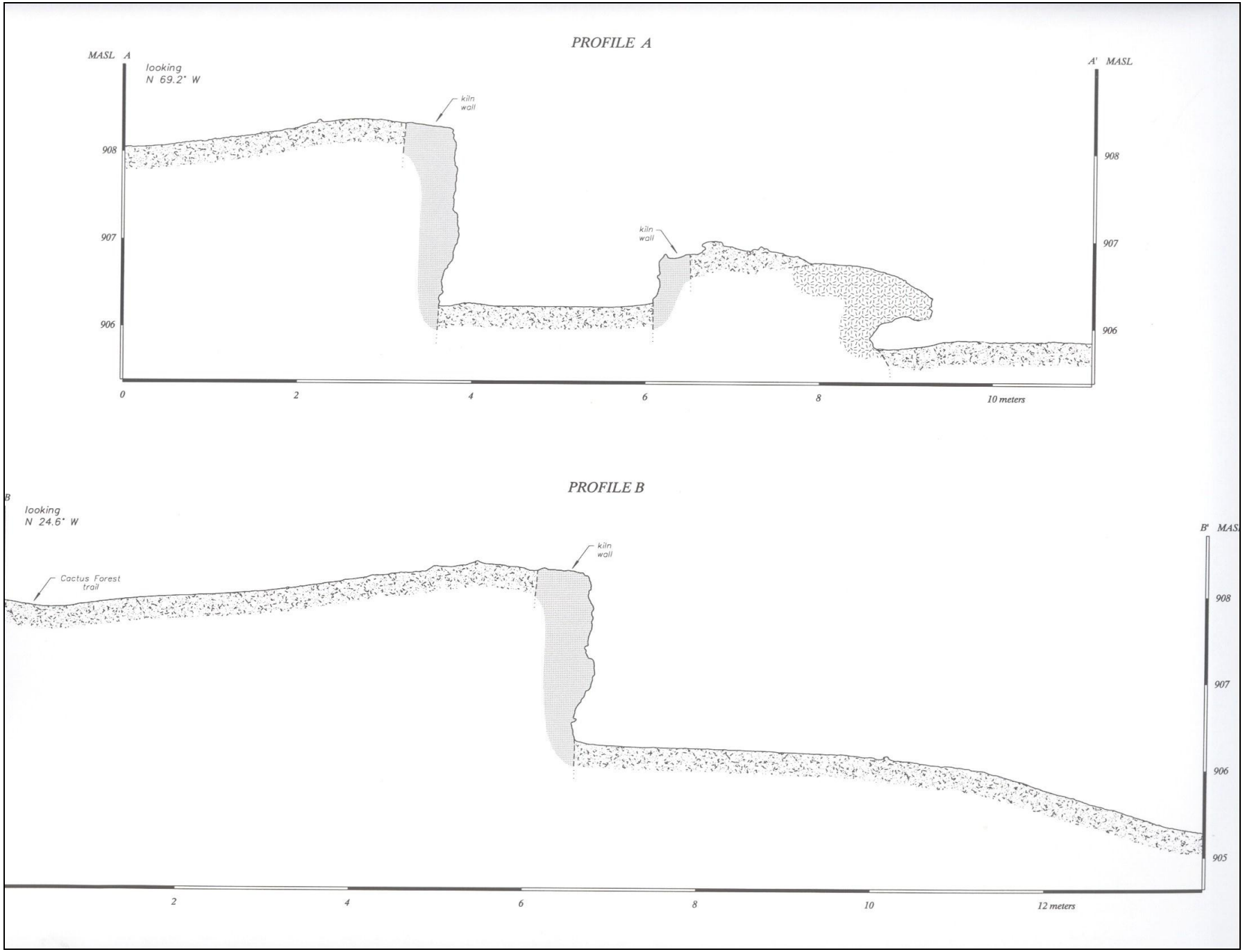
Task	***Time Spent (Total hours)***	***# of people***	***hours per person***	
Repointing	4.5	2	2.75	mortar mix- 2 buckets of dirt, 1 sand
Capping	2.5	2	1.25	rocks and mortar (88 rocks med-large)
Wall Repair	4	1	4	used salvaged rock from kiln slopes
Documentation	4	1	4	digital and black and white photos
Veg Removal	0.5	2	0.25	bushes trimmed back
Hauling				
Equipment	0.5	3	0.16	
Ruins Assessment	1.5	1	1.5	
Erosion Control	2	2	1	rock armored slopes, filled holes with mud
TOTAL	**19.5**			



Topographic and planview map of South Lime Kiln (#2) and associated features. Light grey is processed lime, recalcified lime and limestone debris from loading and unloading kiln. Hatching is preservation rip-rap and spotted/shaded areas are soil/bedrock exposures.



South Lime Kiln Architectural Sheet, showing vitrified/glazed surfaces, NPS preservation treatment, and cracks.



Profiles of South Lime Kiln, Cactus Forest Trail.

SAGU, CACTUS FOREST TRAIL, SOUTH LIME KILN (#2), Color Digital Photos



Cactus Forest Trail, South Lime Kiln (#2), North Wall Section, Before Treatment.



Cactus Forest Trail, South Lime Kiln (#2), North Wall Section, After Treatment.



Cactus Forest Trail, South Lime Kiln (#2), North Wall Section End, After Treatment.



Cactus Forest Trail, South Lime Kiln (#2), West Wall Section, Before Treatment.



Cactus Forest Trail, South Lime Kiln (#2), North Wall Section, After Treatment.



Cactus Forest Trail, South Lime Kiln (#2), South Wall Section (photo board is incorrect), Before Treatment.



Cactus Forest Trail, South Lime Kiln (#2), South Wall Section, After Treatment.



Cactus Forest Trail, South Lime Kiln (#2), S-SE Wall Section, After Treatment.



Cactus Forest Trail, South Lime Kiln (#2), East Wall Section, Before Treatment.



Cactus Forest Trail, South Lime Kiln (#2), East Wall Section, After Treatment.



Cactus Forest Trail, South Lime Kiln (#2), North Slope/Exterior, After Treatment.



Cactus Forest Trail, South Lime Kiln (#2), Close-up of stone and mud cap.


Cactus Forest Trail, South Lime Kiln (#2), Close-up of stone and mud cap.

The Archaeology of the North(#1) and South(#2) Lime Kilns

The North and South Lime Kilns have several associated archaeological features and artifact concentrations. Archaeological features located near the kilns include: **1)** piles of limestone from the collecting of limestone, **2)** piles of limestone from the cleaning of the kiln, **3)** limestone debris from the reduction of large pieces of limestone prior to firing, **4)** a depression or dug out area created for the processing of lime, **5)** a wagon road (now a horse trail), **6)** 2-3 hearths and **7)** 4-7 rock cairns that may be survey markers. Historic artifacts are concentrated from the base of the kiln down-slope to the wash. Artifacts include metal scraps, cans, glass and cookery. The table below lists the type of artifacts identified during the 1983 survey.

North and South Kiln Historic Artifacts

KILN 1 & 2 ARTIFACTS	
Ceramic Types	
Porcelain	(1)
Whiteware	(1)
Glass	
Bottle, Liquor	(9)
Culinary	(1)
Household	(1)
White glass	(10)
Metal	
Food Containers, utensils	(14)
Industrial	(3)
Domestic	(2)
Military	(1)
Ammunition	(1)
Personal	(1)
Cans	
Crimped seams	(12)
Total	(57)

Note: The artifacts listed above were found between the North and South kilns.

The 1983 survey form also mentions significant artifacts including: a gas/oil can stamped "Property of Air Force USA", shotgun shell case "1901 No. 12 New Rival", a metal fastener "Alfred Benjamin & Co." (collected 40m North of Kiln #2). Other artifacts include a "Prince Albert" tobacco can, and fragments of white earthenware with printers mark "K.T. & K. Granite" which was collected near Kiln #1. The firm of Knowles, Taylor, and Knowles used this mark on tableware, sanitary ware and toilet ware ca. 1890-1907. Five pieces of amethyst glass were also recorded. It is noted on the original site form that the shotgun case was collected, however it was identified just northwest of Kiln #2 on September 13th, 2007.

Three other historic sites are located near Kilns 1 and 2 and given the same state number as the kilns (BB:14:74), but different SAGU numbers. SAGU 83A-33 (also called Locus C of AZ:BB:14:74) was previously recorded by King (1976). It is 300m north-northwest of the kilns near the horse trail that was once the access road to the kilns. It is described as "a 10m long line of strewn limestone blocks arranged into three rough jumbles. These blocks were 3m west of and parallel to the horse trail, which was once a dirt access road to the lime kilns…Several pieces of barbed wire were noted. The limestone blocks are of the form used in the lime kilns." This site is definitely associated with the lime kilns and may be a staging station for the transport of limestone from the quarries to the north to the kiln via the access road mentioned above (see picture below).

The other historic site near the kilns is SAGU 83A-49 or Locus D of AZ:BB:14:74. The site is located ~250m north of the kilns and has few artifacts. Three archaeological features were noted in 1983; Feature 1: 5 boulders standing on end (3m long), and 15 other cobbles and boulders in alignment or lying flat. "The piece of over-fired, brick red adobe and red-fired stone are also in the alignment." Feature 2: 6m SW of F 1 is a scatter of 16 cobbles in a roughly defined line. "It appears to be displaced." Feature 3: 19m south of F 2 is a rock ring of 10 boulders and cobbles. 8m south is a Prince Albert can. 7m NE are pieces of a wooden stake.

"This may be an old surveyor's stake similar to those at SAGU 30 (the kilns). Pieces of fired adobe are located between F 2 and F 3."

The third historic site near Lime Kilns 1 and 2 is AZ:BB:14:165 (SAGU 83 A-7). The site has four loci, including Lime Kiln #3 located northeast of kilns 1 and 2. Locus 2 is located on the same terrace as Lime Kiln #3 on a lower slope 150 m northeast of Kiln #1. The site is the remains of a one to two-room structure with a semi-circular enclosure. No artifacts were found. "Possibly, this was a provision shed or other small room(s) associated with the nearby kilns". Locus 3 is located ~75m east of Lime Kiln #3 (Locus 1) and is described as "a rock ring of ca. 20 limestone boulders. It measures 4.3' x 3.3'. No charcoal or artifacts were noted." Locus 4 is ~20m southeast of Locus 3 and is limestone quarry with a large pit into a limestone knoll. The pit measures 21.9' NW/SE x 12.2' NE/SW and 1.5'-2.3' deep.



SAGU 83A-49. Feature 1. Rock alignment north of North Lime Kiln believed to be associated with kilns.



SAGU 83A-49. Feature 1. Rock alignment north of
North Lime Kiln believed to be associated with kilns.





Pile of limestone boulders north of the lime kilns.



Broken mano (groundstone) near limestone boulders.

Lime Kiln #3
LCS 58643
SAGU#: SAGU 83A-7.
STATE #: AZ BB:14:165.

Lime Kiln #3 is located northeast of the North (1#) and South (#2) Lime Kilns along a minor drainage that connects with the main wash near Kilns 1 and 2. Like the other kilns it is built into a slope along the drainage. It is constructed of large granite boulders, smaller rock and lime/mud mortar with some possible fired brick in the basal portion of the wall. The walls are not uniform in thickness and are one to two rocks in cross-section. The kiln measures 277 cm across the top; and the kiln's maximum measurable height was 60 cm where intact. It was not possible to count the number of courses due to the lime debris that had fused to the kiln's interior wall. The north and east region of the kiln is intact while the south and west region are severely impacted. A large hole exists at the bottom of the kiln in the west region facing out toward the drainage. Limestone debris extends 2.7 m from the top edge of the kiln. Large granite boulders ring the kiln and make up at least the top 1/3 of the kiln. Acacia and creosote surround the exterior of the kiln. Where rock has collapsed or been removed from the interior of the kiln, there is exposed alluvial deposits. Fired limestone has also fused to the interior kiln walls. This has occurred along the bottom 1/3 of the south region and the lower 2/3 of the east wall running back to the south. Most of the south wall, ~70% is gone, exposing alluvial deposits. Some of the exposed alluvial deposits appear to be heated suggesting that either heat penetrated beyond the rock wall or the kiln was fired after the collapse or removal of the rock wall interior. Just outside the west region of the kiln is a flat area that is strewn with large granite boulders measuring as much as 60cm by 38 cm. The boulders continue down to the drainage from this area. Surrounding the kiln, to the west is evidence of kiln cleaning and piles of burned granite and debris from the kiln. It is possible that these deposits are refuse from rebuilding kiln walls and cleaning the interior.

Condition Assessment

Stone (1976) and Harper (2003) conducted condition assessments before the TUMA crew in 2006. All assessments note that construction of kiln three is difficult to discern due to its poor condition. It appears that the kiln was sunk deep into consolidated dense alluvium and was lined with rock and uncertain quantities of small brick. The biggest impact to the kiln has been water and rodents. Environmental factors that affect the condition of the kiln include water from rainfall and the wash, vegetation, animals, and insects. Vegetation is growing on or near the kiln as mentioned above. Both animals and insects use the kiln for habitation. The mortar is weakened from insects burrowing/nesting in the mortar matrix. Animals are actively burrowing in and around the kiln. The walls of the kiln have been severely impacted from extreme firing temperatures associated with producing lime, natural erosion processes, and animals burrowing. The NW and SE wall sections have a heavy vitrified glaze (burnt) near the bottom. The north and west wall regions are precarious and the slope is littered with evidence of wall fall.



Lime Kiln #3, looking south. Photo taken in 1976.



Lime Kiln #3, looking south. Photo taken in 1976.



Lime Kiln #3, looking east/southeast. Photo taken in 1996.



Lime Kiln #3, looking east/southeast. Photo taken in 2006.

Preservation Treatment of Lime Kiln #3

At Lime Kiln #3 the goal was to stabilize the top three courses of rock wall and fill holes in the kiln interior. The treatment took one and half days. Large holes in the east and west walls were filled with rock and mud. The upper half of the kiln is a rock wall. The mortar joints of the rock wall were repointed and a few new rocks added on the top to form a rock cap. Cracks in the lower inset bench (?) were filled with mud and larger holes near the bottom filled with mud and rock. Rock was added around the outer edge of the rock wall cap (at top) to form a small slope away from the wall cap.



Lime Kiln #3, looking south/southeast, before treatment.



Lime Kiln #3, looking south, after treatment.

LIME KILN 3

Location of Work

Wall	***Repointing (m2)***	***Total Cap (m3)***	***Wall Repair (m3)***	***Mortar Added (gallons)***	***Comments***
		$3.55m^3$			
North	$3.1m^2$			75	
West	$2.9m^2$		$0.30m^3$	65	
South	$4.1m^2$		$0.88m^3$ (SW Wall)	85	~32 rocks added to fill hole (20 gallons of mortar)
East	$3.14m^2$		$0.43m^3$	75	11 rocks added to fill hole (10 gallons of mortar)
TOTAL	$13.24m^2$	$3.55m^3$	$1.61m^3$	300 gal	

Mortar Mix

2 dirt, 1 sand, 3/4 gravel

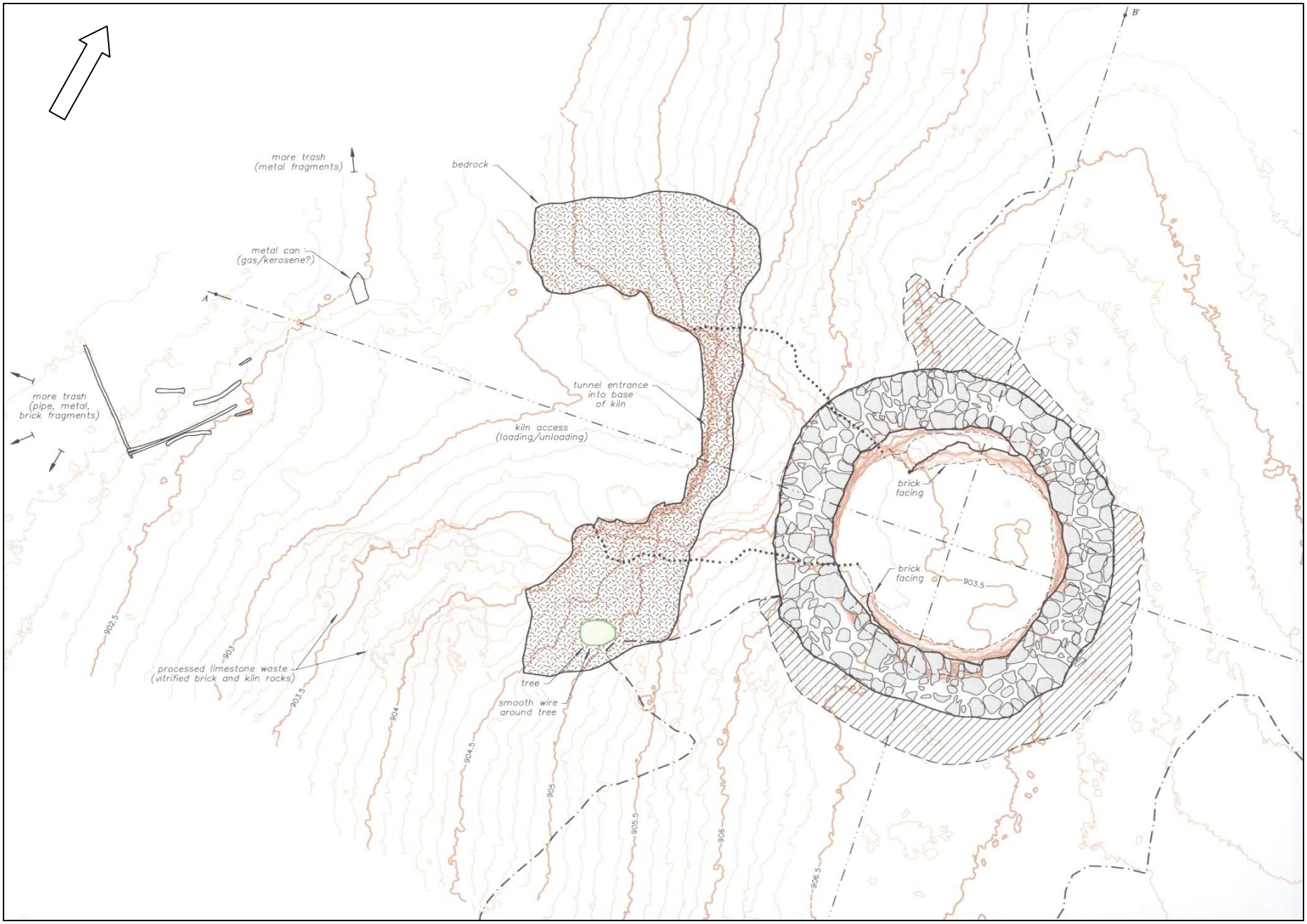
Special Features

North	heavily glazed	area= $2.88m^2$			sample submitted to U of A
South	whole interior is burnt, but thickest burnt area has glaze	area= $.30m^2$			for material testing
Borrow Pit	20m E. of kiln on ridge top	area= $1.95m^3$			dirt light brown, near trees

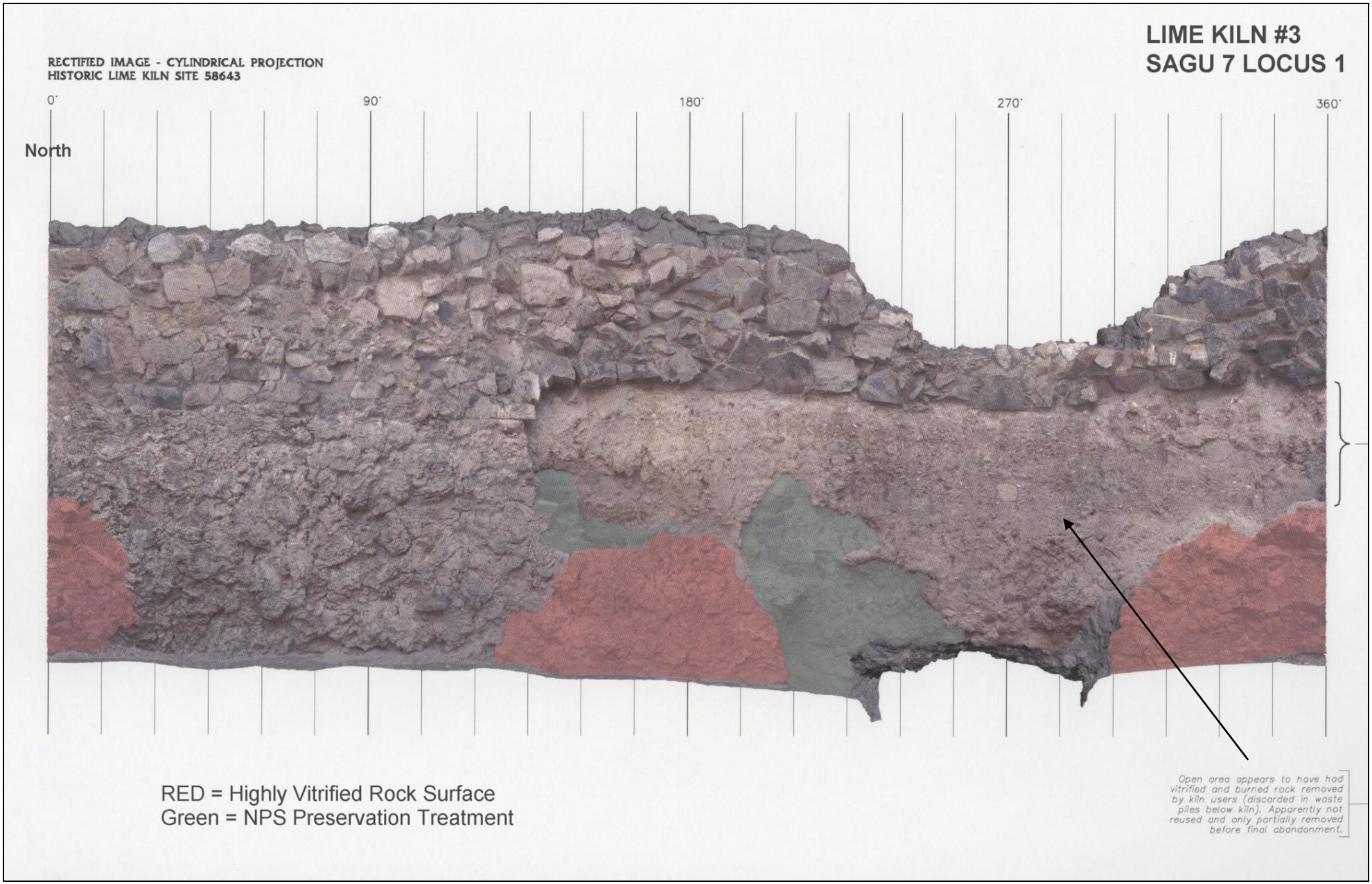
LIME KILN 3

Time/Labor

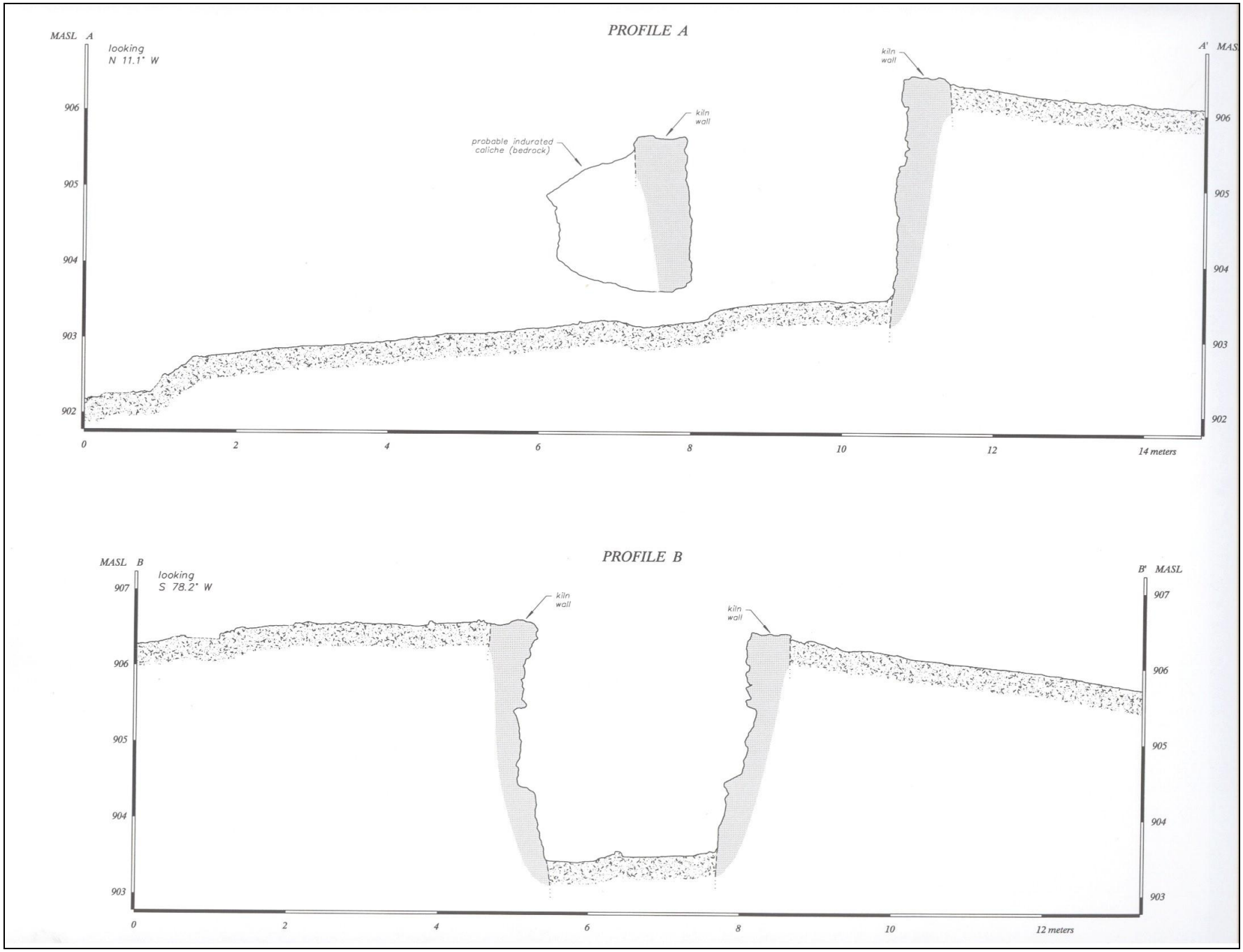
Task	***Time Spent (Total hours)***	***# of people***	***hours per person***	
Repointing	6	2	3	mortar mix- 2 dirt, 1 sand, 3/4 gravel
Capping	2.5	2	1.25	few new stones added to cap mostly repointing of top stones (~25 rocks added) cap extended at a slope using small rocks along the ext. ext rocks extend cap 25cm (60 gallons of mortar used in cap)
Wall Repair	3	1	3	used salvaged rock from kiln slopes
Documentation	4	1	4	digital and black and white photos
Veg Removal	0.5	2	0.25	bushes trimmed back
Hauling Equipment	0.5	3	0.16	
Ruins Assessment	1.5	1	1.5	
Erosion Control	2	2	1	rock armored slopes, filled holes with mud and rock floor filled with sand slightly
TOTAL	**19**			



Topographic and Planimetric Map of Kiln #3. Stippled areas are exposed alluvium/bedrock and hatched areas are preservation rip-rap. Artifacts and limestone piles are indicated. The "vitrified brick and kiln rocks" is evidence of kiln cleaning and reconstruction of the interior.



Lime Kiln #3. Architectural sheet showing areas of high vitrification and NPS preservation treatments. Arrow pointing area with evidence of kiln wall repair/reconstruction. This section of the kiln interior wall appears to have been removed and piled below the kiln.



Profile of Lime Kiln #3, Cactus Forest Trail. Note the concave bench-like area of the north and south wall; used to help support the limestone superstructure during firin

CACTUS FOREST TRAIL, LIME KILN # 3
Before and After Treatment Photos, Color Digital



SAGU, Cactus Forest Trail, Kiln #3, Before Treatment. Looking southwest.



SAGU, Cactus Forest Trail, Lime Kiln #3, After Treatment. Looking S-SW at cap.



SAGU, Cactus Forest Trail, Lime Kiln #3, Before Treatment. Looking southwest.



SAGU, Cactus Forest Trail, Lime Kiln #3, After Treatment, Wall Cap. Looking S-SW.



SAGU, Cactus Forest Trail, Lime Kiln #3, North Wall Section, Before Treatment.



SAGU, Cactus Forest Trail, Lime Kiln #3, North Wall Section, After Treatment.



SAGU, Cactus Forest Trail, Lime Kiln #3, East Wall Section, Before Treatment.



SAGU, Cactus Forest Trail, Lime Kiln #3, East Wall Section, After Treatment.



SAGU, Cactus Forest Trail, Lime Kiln #3, South Wall Section, Before Treatment.



SAGU, Cactus Forest Trail, Lime Kiln #3, South Wall Section, After Treatment.



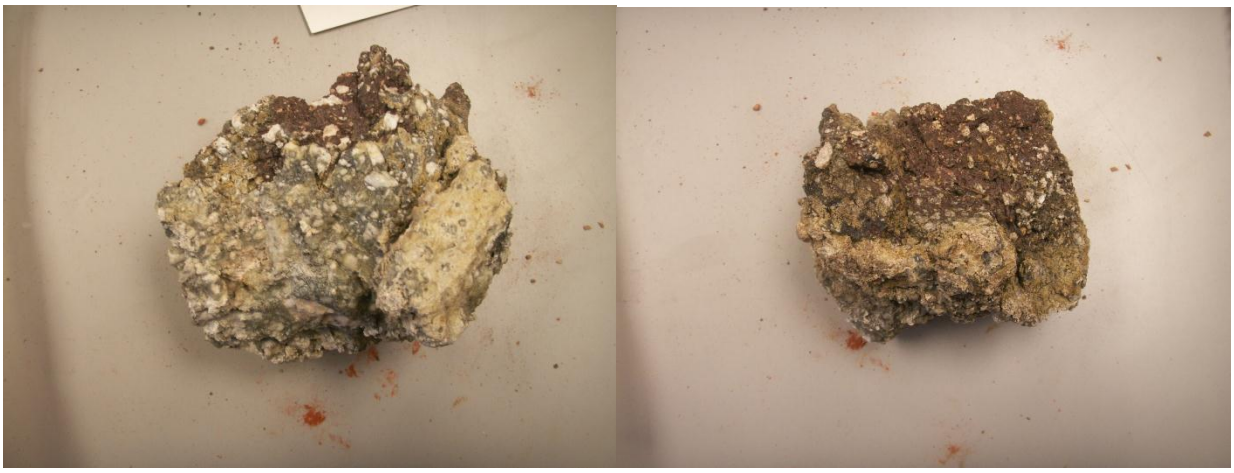
SAGU, Cactus Forest Trail, Lime Kiln #3, West Wall Section, Before Treatment.



SAGU, Cactus Forest Trail, Lime Kiln #3, West Wall, After Treatment.

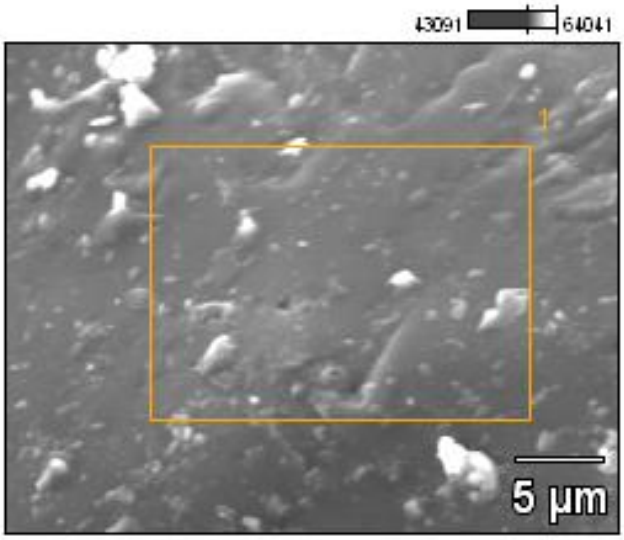
Material Analysis:

A sample of highly burnt adobe brick found below the kiln was submitted to U of A for chemical analyses. The sample differed from the other sample as there was less vitrification and it was questionable where the brick originally came from since it was found on the slope below the kiln. The chemical composition of one of the brick surfaces was analyzed using a Scanning Electron Microscope (SEM) and Energy Dispersive Analysis (check).



Opposing surfaces of a highly fired brick found below kiln #3.

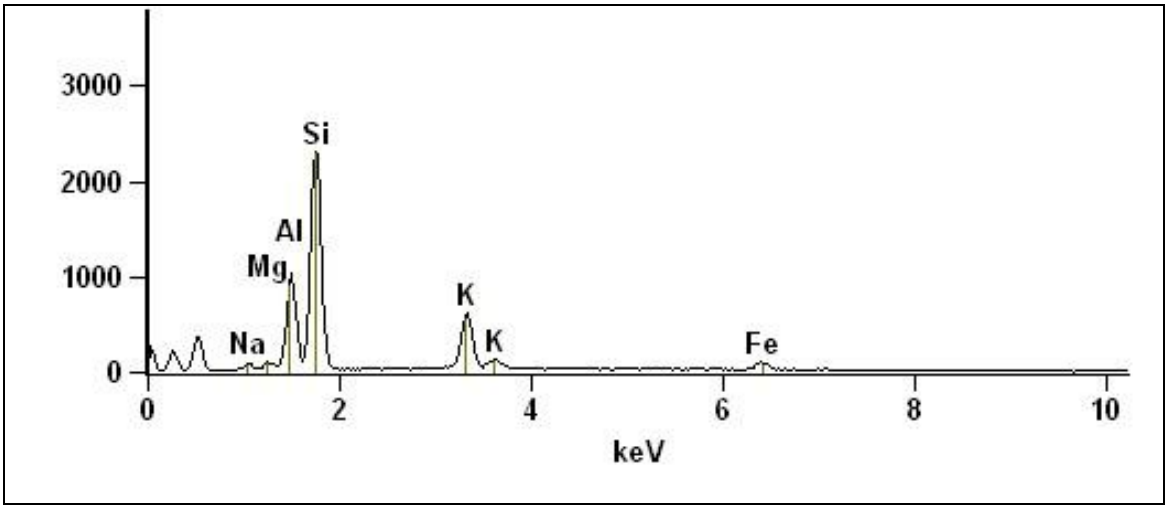
SEM photo at 3000x magnification. Note how surface is smooth compared to other samples. White spots are foreign particles- not real texture.



Chemical composition of sample from Lime Kiln #3.

Filter Fit Chi-squared value: 1.527
Correction Method: Proza (Phi-Rho-Z)
Acc.Voltage: 15.0 kV Take Off Angle: 51.8 deg

Element	Wt.%	Norm. Compound	
O	43.72	S	---
Na	1.21	Na2O	1.63
Mg	0.51	MgO	0.85
Al	9.07	Al2O	17.13
Si	25.62	SiO2	54.80
K	12.58	K2O	15.15
Fe	7.30	Fe2O3	10.43



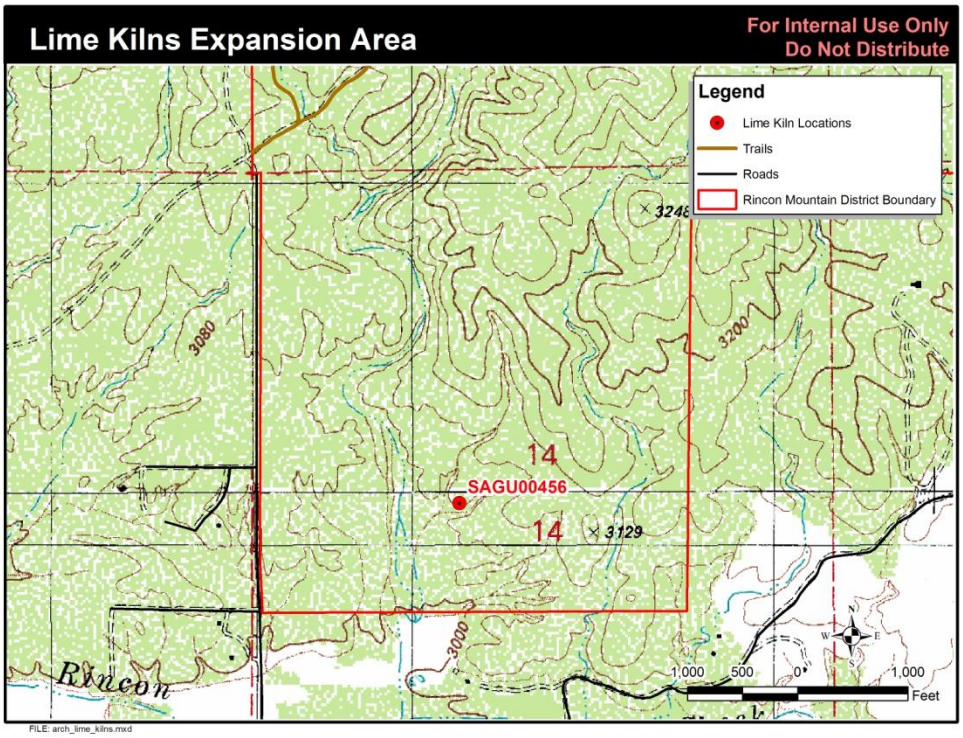
Graph of elemental composition of Lime Kiln #3 brick sample.

There was no lime (Ca or CaO2) detected in the sample. These results suggest that the brick sample from Lime Kiln #3 came from an area of the kiln wall that was heated but did not touch or receive lime powder on its surface to form the green lime glaze. However, the U of A lab did not test all surfaces of the brick and appear to have tested a surface that was freshly broken- thus removing the original interior surface that usually have the lime glaze; therefore the results of the chemical analysis of the Lime Kiln #3 sample is inconclusive.

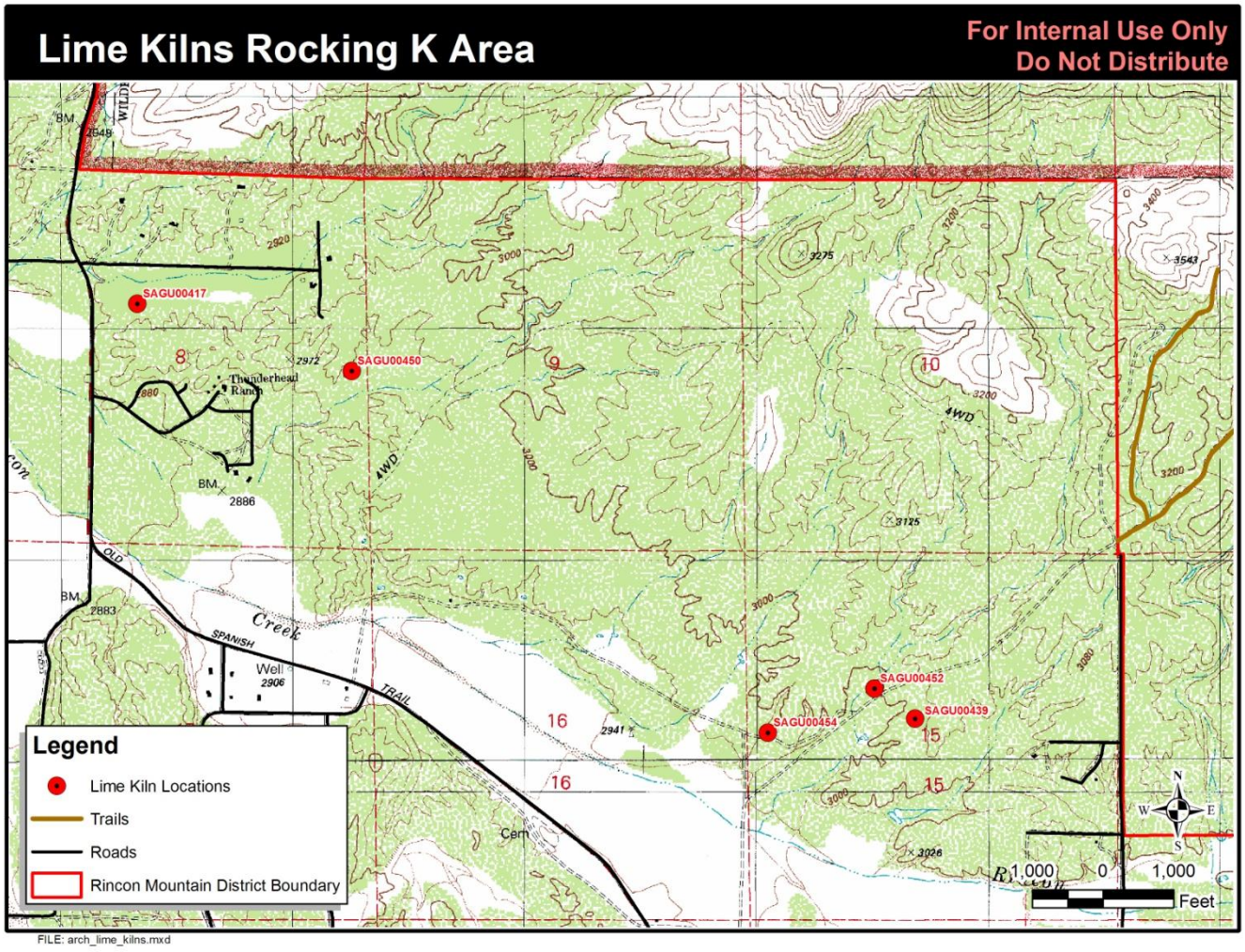
The Camino Loma Alta Lime Kiln

SAGU#: SAGU 456.
STATE#: AZ:BB:14:451.

The Camino Loma Alta Kiln is located on SAGU expansion lands near the southern boundary of the Rincon Mountains District off the Camino Loma Alta road near the Rocking K Ranch. It is situated on a hill above the junction of two washes, north of the southern boundary fence. It is constructed of granite rock and unamended mud mortar and is the largest of the six kilns. The kilns' maximum wall height is 1.74m; minimum height is 63cm; and maximum wall thickness is 32cm. The interior diameter of the kiln measured east-west is 2.94m. The kiln wall is a single stone wide. There are ~10-11 courses of rock remaining. There is a considerable amount of wall fall and rubble along the interior of the wall and surrounding slopes. Debris piles to the east appear to be from construction or cleaning of the kiln. The kiln does not appear to have been used that often since there is little evidence of burning and no vitrification or interior glaze. It is surrounded by creosote, saguaro cactus, and acacia. Deposits associated with kiln loading and cleaning are located along the west edge of the kiln and on the slope east of the kiln.



Topographic map showing Camino Loma Alta Lime Kiln (SAGU 456).



Topographic map showing location of other lime kilns located in the area of the Rocking K Ranch.

There is no existing documentation on the history of the Camino Loma Alta Lime Kiln. Its age is uncertain and it lacks some of the same wall features as the other SAGU kilns. There is no evidence left of a bottom opening and there does not appear to be a ledge or bench for supporting the superstructure of limestone during firing. There is almost little evidence of firing. This evidence usually appears as vitrified or burnt wall sections, ash deposits and extreme fire reddening. However, the kiln is filled with wall fall, suggesting that these features may be buried. The kilns' diameter and the huge amount of rock in and around the kiln indicate that it was of significant height and large enough to support a major lime operation. The kilns'

proximity to the railroad suggests that lime could have been processed and transported via the railroad. The trail to the kiln is an old road that is cut through a large hill neat Camino Loma Alta. The present road appears to have been made by a bulldozer. The road runs past the kiln to the north up a drainage and towards the mountains. It is possible that the newer bulldozed road follows an older wagon road that lead to the top of the hill above the lime kiln. The Camino Loma Alta Lime Kiln may have been associated or operated around the same time as other kilns in the Rocking K Ranch area. There is little known about the kilns in the Rocking K Ranch area. A few metal artifacts are located above the kiln to the west, but none of them are diagnostic.

The Camino Loma Alta kiln has a lime powder deposit surrounding the top of the kiln on the west side near where the kiln was loaded from. The lime powder is the result of removing fired/processed lime form the kiln and loading it into wagons for transport. Other evidence that the kiln was loaded and unloaded from the west side is the pattern of fired and unfired limestone debris that spreads out to the west.

Condition Assessments

Since Saguaro had only recently acquired the expansion lands, condition assessment or documentation had never been done before Kevin Harper visited in 2003. The 2006 condition assessment confirmed Harper's assessment. Factors affecting condition include inherent construction flaws like unstable soils associated with building the kiln on a slope and environmental factors like water from rainfall and the wash, vegetation, animals, and insects. Vegetation is growing on or near the kiln as mentioned above. Both animals and insects use the kiln for habitation. The mortar is weakened from insects burrowing/nesting in the mortar matrix. Animals are actively burrowing in and around the kiln, however less than at the other kilns. The Camino Loma Alta Kiln is in better shape that the other SAGU kilns, perhaps because it was used for a short period of time.



Camino Loma Alta Lime Kiln, East Wall Exterior Section, Before Treatment, 2006.



Camino Loma Alta Lime Kiln, East Wall Exterior Section, After Treatment, 2006.

CAMINO LOMA ALTA LIME KILN

Location of Work

Wall	***Repointing (m2)***	***Total Cap (m3)*** 2.412m^3	***Wall Repair (m3)***	***Mortar Added (gallons)***	***Comments***
North	0.84m^2		.79m^3	45	~20 rocks added
West	0.84m^2			15	6 small to med. sized rocks added
South	0.27m^2		1.65m^3	45	~35 rocks added to voids and to close up exposed wall end and fill holes in the slope near wall
East	0		.06m^3	1.5	small portion of exposed wall covered with thick cap of mud mortar
TOTAL	1.95m^2	2.412m^3	2.5m^3	106.5 gal	

Mortar Mix
2 dirt, 1 sand
(5 gallon buckets)

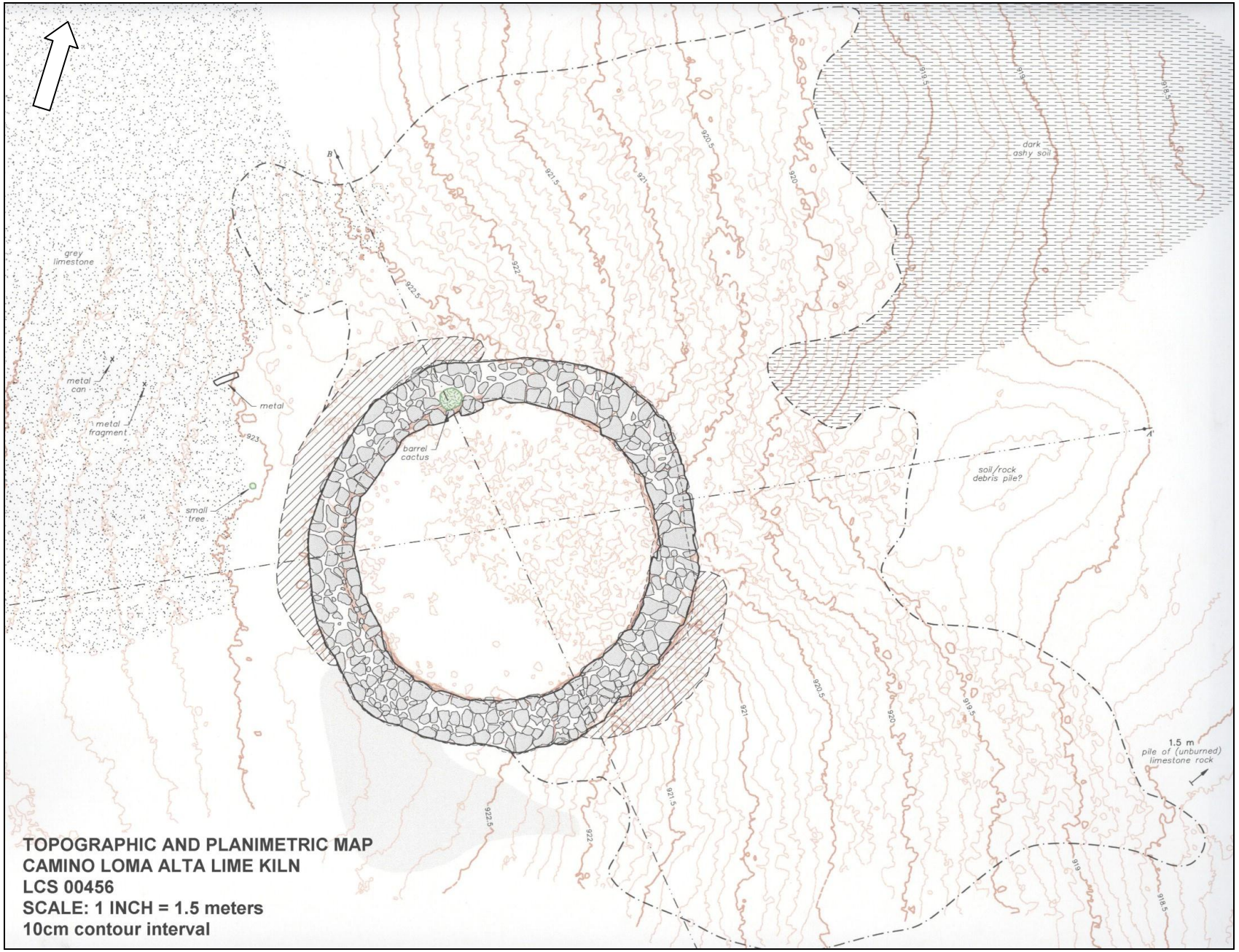
Special Features

South	whole interior is burnt, but thickest burnt area has glaze	area= 1.12m^2			sample submitted to U of A for material testing
Borrow Pit (mortar) (1 hole)	30m S. of kiln near creosote bush, brown dirt	area= 1.44m^3			

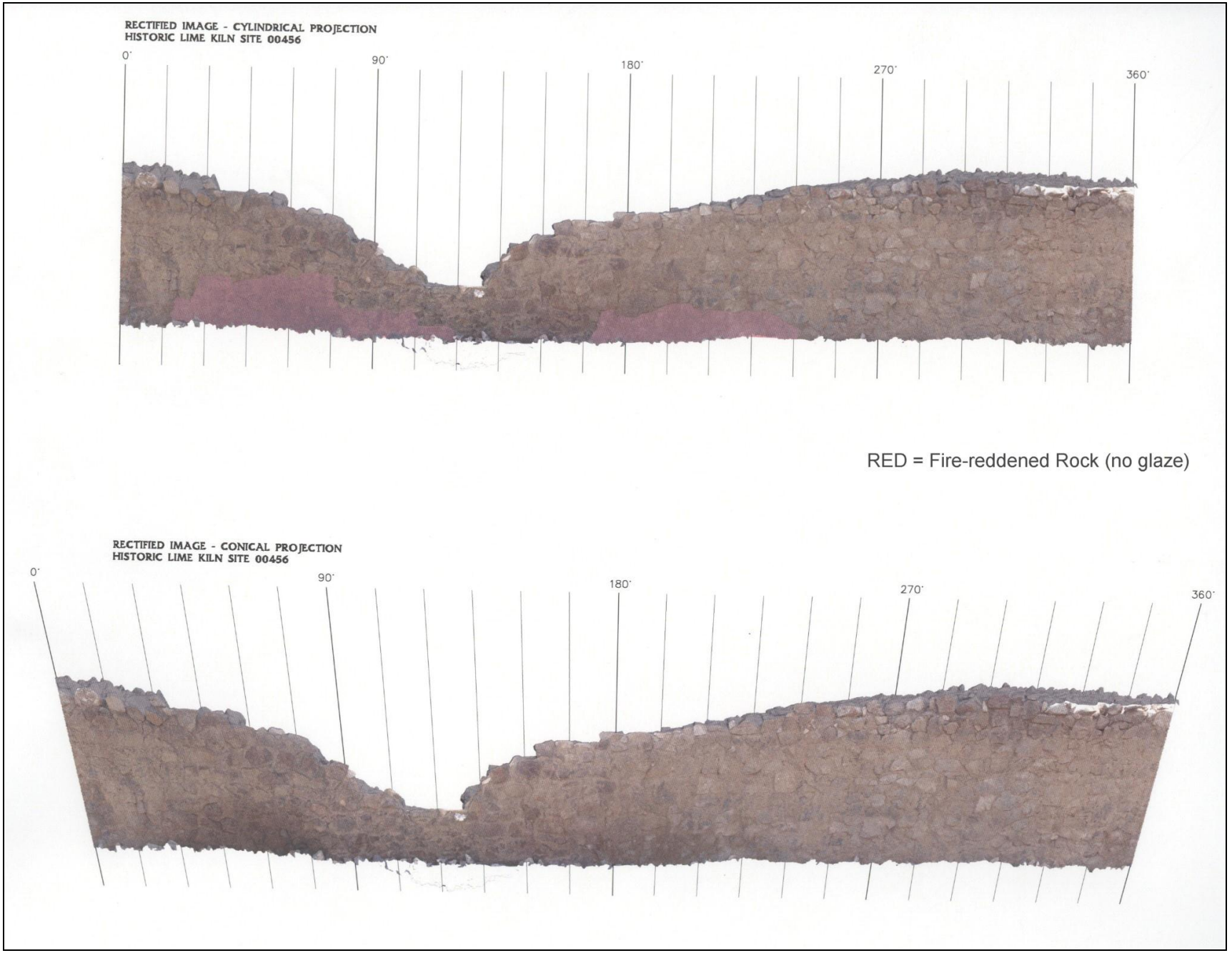
CAMINO
LOMA ALTA
LIME KILN

Time/Labor

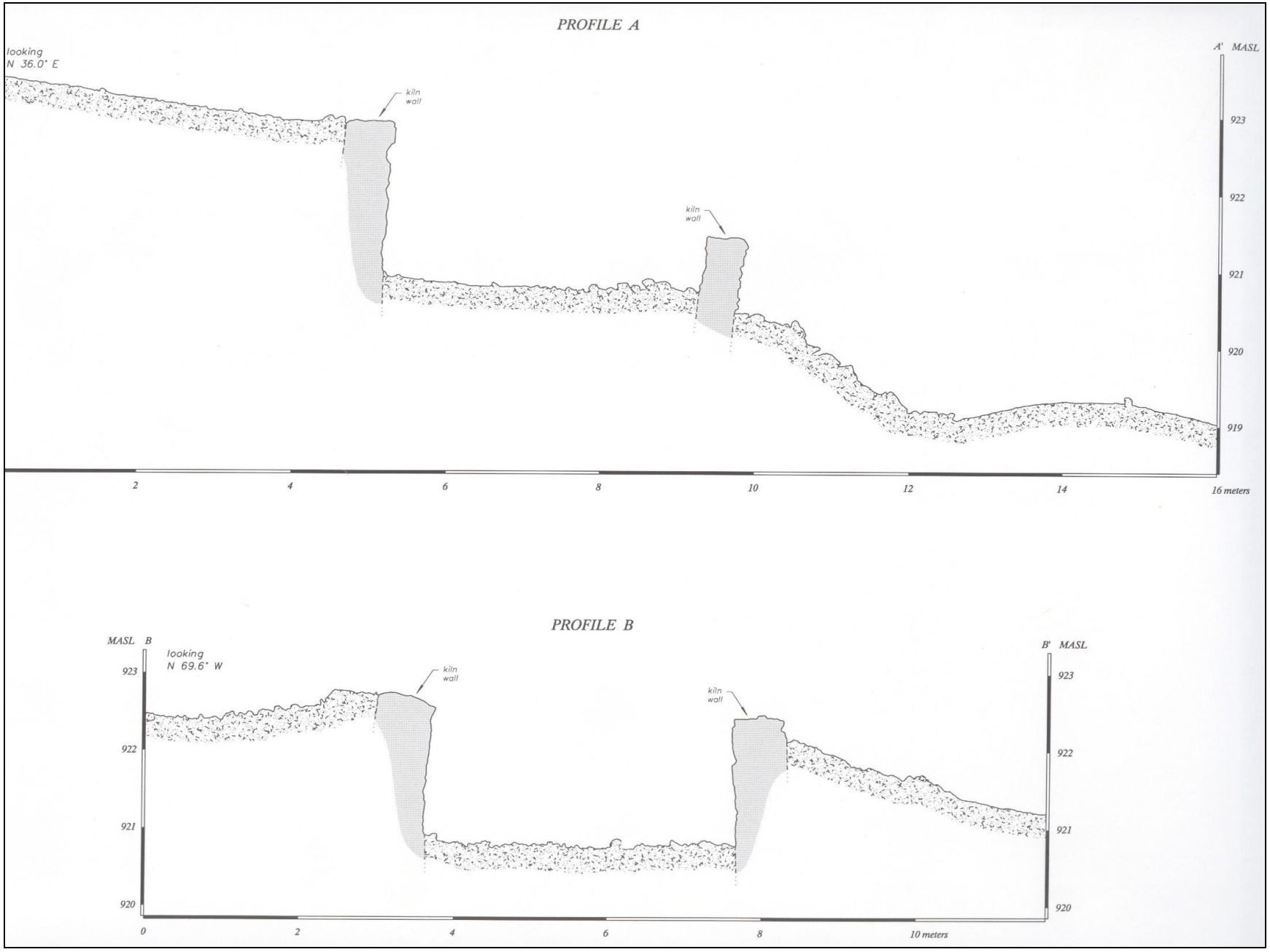
Task	***Time Spent (Total hours)***	***# of people***	***hours per person***	
Repointing	4.5	2	2.75	mortar mix- 2 buckets of dirt, 1 sand
Capping	2.5	2	1.25	rocks and mortar (88 rocks med-large)
Wall Repair	4	1	4	used salvaged rock from kiln slopes
Documentation	4	1	4	digital and black and white photos
Veg Removal	0.5	2	0.25	bushes trimmed back
Hauling Equipment	0.5	3	0.16	
Ruins Assessment	1.5	1	1.5	
Erosion Control	2	2	1	rock armored slopes, filled holes with mud and rock.
TOTAL	**19.5**			



Map of the Camino Loma Alta Lime Kiln, SAGU. Dashed line marks extent of limestone debris. Hatching is preservation rip-rap. Shaded areas are cemented processed lime waste. Dimpled area to the west of kiln (w/metal artifacts) is fired/unfired limestone debris.



Camino Loma Alta Lime Kiln Architectural Sheet. Conical and Flat projection (due to roundness). All wall areas repointed with mud mortar.



Profile of Camino Loma Alta Lime Kiln, Rincon Mountains District.

CAMINO LOMA ALTA LIME KILN
Before and After, Color Digital Photos



Camino Loma Alta Lime Kiln, North Wall Interior Section, Before Treatment.



Camino Loma Alta Lime Kiln, North Wall Interior Section, After Treatment.



Camino Loma Alta Lime Kiln, East Wall Interior Section, Before Treatment.



Camino Loma Alta Lime Kiln, East Wall Interior Section, After Treatment.



Camino Loma Alta Lime Kiln, East Wall Interior Section, After Treatment.



Camino Loma Alta Lime Kiln, South Wall Interior Section, Before Treatment.



Camino Loma Alta Lime Kiln, South Wall Interior Section, Before Treatment.



Camino Loma Alta Lime Kiln, South Wall Interior Section, Before Treatment.



Camino Loma Alta Lime Kiln, South Wall Interior Section, After Treatment.



Camino Loma Alta Lime Kiln, West Wall Interior Section, Before Treatment.



Camino Loma Alta Lime Kiln, West Wall Interior Section, After Treatment.



Camino Loma Alta Lime Kiln, East Wall Exterior Section, Before.



Camino Loma Alta Lime Kiln, East Wall Exterior Section, After Treatment.



Camino Loma Alta Lime Kiln, NE Wall Exterior Section, Before Treatment.



Camino Loma Alta Lime Kiln, NE Wall Exterior Section, After Treatment.



Camino Loma Alta Lime Kiln, SE Wall Exterior Section, Before Treatment.



Camino Loma Alta Lime Kiln, SE Wall Exterior Section, After Treatment.



Camino Loma Alta Lime Kiln, SE Wall Exterior Section, After Treatment.



Camino Loma Alta Lime Kiln, SE Wall Exterior Section, After Treatment.



Camino Loma Alta Lime Kiln, E Wall Exterior Section, After Treatment.



Camino Loma Alta Lime Kiln, E Wall Exterior Section, After Treatment.



Camino Loma Alta Lime Kiln, E Wall Exterior Section, After Treatment.



Camino Loma Alta Lime Kiln, Looking East, Cap (Top of Wall), Before Treatment.

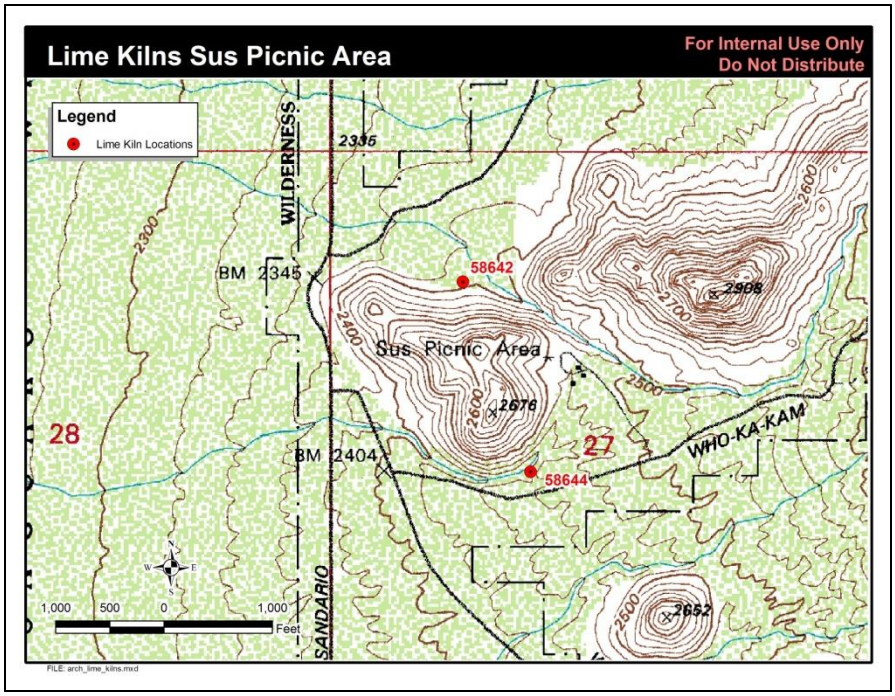


Camino Loma Alta Lime Kiln, Looking East, Cap (Top of Wall), After Treatment.

North Sus Lime Kiln (B)

AZ AA:12:101 (ASM)
SAGU 20, LCS 58642

The North Sus Lime Kiln is located near a wash just west of the Sus Picnic Area. It is accessed by a trail that leads from the picnic area and is visited by the public. It is also called Sus Lime Kiln B. The kiln is constructed of rock, adobe brick and unamended soil mortar. It measures 206 cm across; with a maximum height of 59cm, minimum height of 10cm, and wall thickness of 25 cm. The limestone debris and lime deposits surrounding the kiln are 64cm above the top of the remaining kiln wall and extend out from the kiln edge ~3.2 m. There is also a limestone debris and ash pile located 15 m northwest of the kiln (see picture below). Small granite stones are used in some regions of the predominantly small adobe brick interior wall. Small burrows exist in and around the kiln. There is only a small amount of vegetation in or around the kiln, mostly grasses. A foothill palo verde and acacia are growing along the west and northeast side of the debris area. A minor wash is located 20m north of the kiln.



Location of the North (58642) and South (58644) Sus Lime Kilns.

There is very little information on the history of the North Sus Lime Kiln. It's location, construction, and encasement by a large amount of fired/unfired limestone, processed lime, and fencing debris suggests that it was used intensely and/or for a long time. The kiln is located at the base of a large hill with a limestone outcrop. There is faint evidence of an old wagon road to the southwest along the slope heading up to the limestone outcrop. The kilns' construction is unique compared to the other kilns. It is constructed of granite cobbles/boulders and small adobe bricks. The kiln has a double wall with granite rocks forming the outer wall (two stones wide) and small adobe bricks (measuring 14cm x 10cm x 7cm.) forming the interior facing. This interior brick facing has areas of high vitrification and glazing. There appears to be two sizes of brick- the larger brick measures 21cm x 10cm x 7cm. In some places the smaller brick was made by chipping off portions of the large brick to fit into irregular spaces between the bricks. The interior is highly burnt and has an area of glazed surface on the northwest and south wall sections. To the west of the kiln, near the wash, are the remains of lime processing and kiln loading. In this area two other types of brick were found. The picture below shows the different bricks found around the kiln.



Brick types found at the North Sus Lime Kiln.

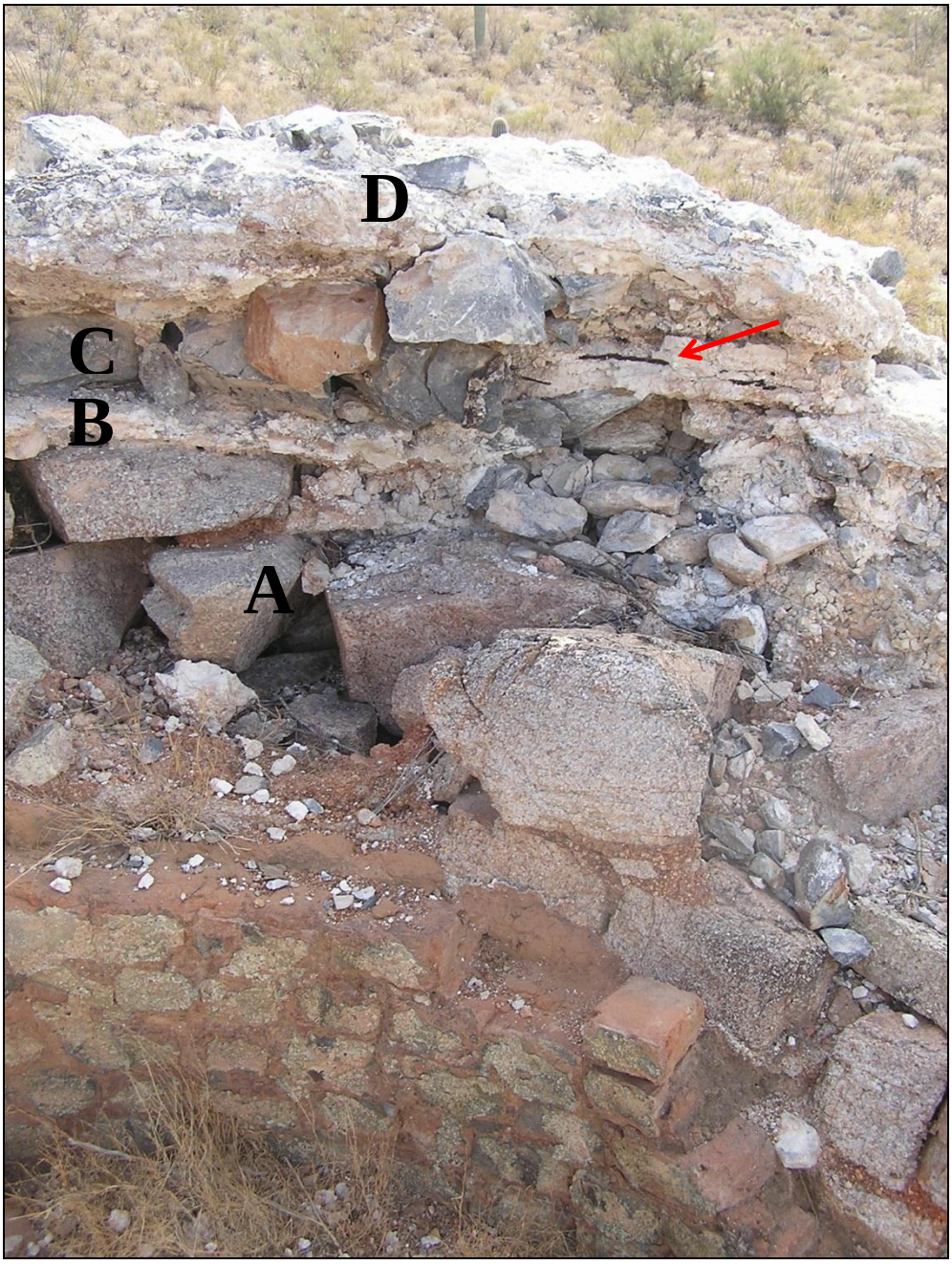


Limestone, processed lime, and ash deposits northwest of North Sus Lime Kiln.

The frequency and different types of brick found near the kiln suggest that the interior brick facing of the kilns' double wall was replaced or repaired using different brick types. It is possible that a study of the brick produced at local brick shops could help date kiln construction if kiln bricks cannot be positively connected to local brick shops.

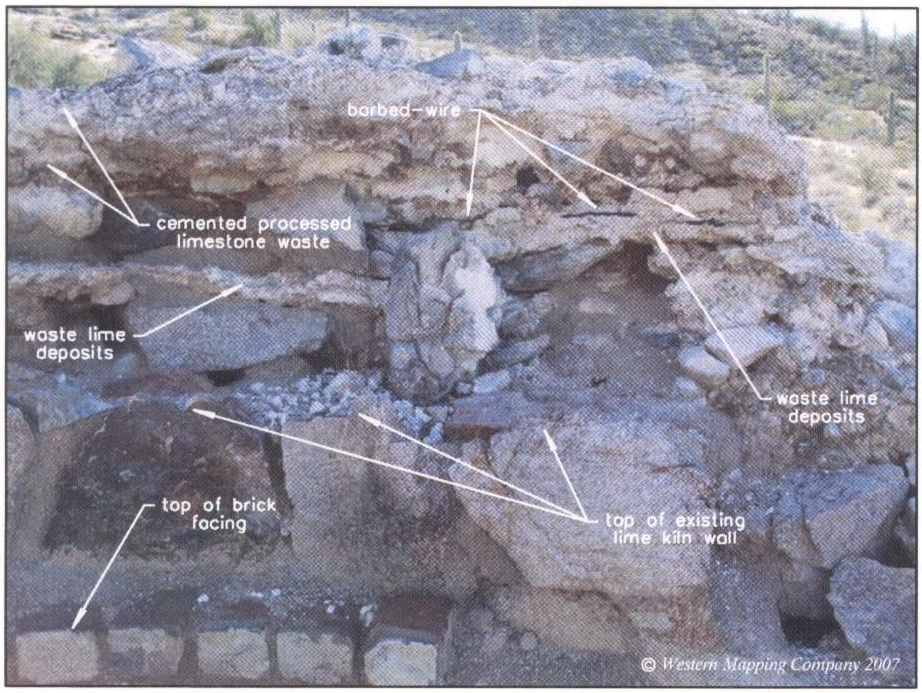
The limestone debris encasement that surrounds the North Sus Lime Kiln is an interesting feature. The layers of the encasement are exposed in areas where the wall has collapsed. There are two exposures of the deposit that have visible layering or stratigraphy. The east and south sections have a large exposure showing the different interweaving layers of unburned limestone, processed lime (powder), burnt limestone, and granite. The layers represent the loading and

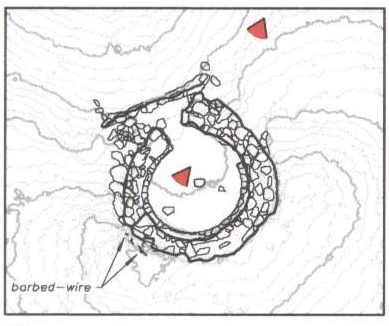
unloading of limestone and processed lime and periodic cleaning of the kiln interior. Within the layers is the remains of a barbed-wire fence that may have once enclosed the kiln.



North Sus Lime Kiln, south profile. Layers of lime processing debris encase the kiln. The stratigraphy consists of; construction debris on the bottom (**A**), capped by a layer of processed/burned lime (**B**), a layer of unburned limestone (**C**), and on the top a layer of processed lime w/unburned limestone (**D**). Note the barb-wire fence embedded in lime deposits (arrow). This is probably the remains of a fence placed to stop cows from falling into the kiln. Barbed-wire was patented in 1873.







camera view

PIMA COUNTY, ARIZONA
SAGUARO NATIONAL PARK

BARBED-WIRE EMBEDDED IN LIME SLAG

SUS LIME KILN B
NORTH KILN

SAGU 20 - LCS 58642
AZ AA:12:101 (ASM)

Mapping, 3D Lidar scanning, and digital cartography
by Western Mapping Company 2007

Other notable features of the North Sus Lime Kiln are two small slope retaining walls. The one closest to the kiln runs roughly east-west and stabilizes the northern slope of the kiln base. It is 2.5 meters long and 45cm in height. There is space between the retaining wall and the outer edge of the kiln wall. The lime debris encasement does not extend to the north side near the retaining wall- suggesting that loading/unloading occurred from the south sides of the kiln.



Retaining wall on north side of North Sus Lime Kiln.

Farther, and to the northeast of the kiln, is another retaining wall that looks more like rip-rap, but effectively holds the slope on which a wagon may have approached the kiln. This retaining wall shored-up the wagon road used to load and unload the kiln, also suggesting that the kiln was loaded/unloaded from the south/southwest and/or west sides.



North Sus Lime Kiln, looking south east. Small retaining wall northeast of kiln along possible kiln access road.



North Sus Lime Kiln, looking south east. Close-up of small retaining wall northeast of kiln along possible kiln access road.

Condition Assessment

Condition assessments were completed by Harper in 2003 and by TUMA staff in 2006. The results were similar- indicating the need for mortar joint repointing, fill adjustments and re-grading for drainage. Environmental factors that affect the condition of the kiln include water from rainfall and the wash, vegetation, animals, and insects. Vegetation is growing on or near the kiln as mentioned above. Both animals and insects use the kiln for habitation. The mortar is weakened from insects burrowing/nesting in the mortar matrix. Animals are actively burrowing in and around the kiln. Visitors have impacted the kiln by removing rubble and walking in and around the kiln since the trail from the picnic area runs through the site down the wash.

Assessments indicate that treatment should include; filling voids, adding mortar to joints, adding material to the base of the lime kiln that is exposed, and minimizing erosion from runoff. Due to visitors standing on the edge of the kiln and erosion the top of the kiln will needed to be filled with mortar to better fasten the existing top course, and in some places the top course had to be re-laid. Also, assessments indicated that material should be added to the base of the exposed areas of the kiln to prevent further erosion of original material. There was minor erosion from runoff that needed to be reduced. Assessment indicated that rodents are impacting the site. Exclusion of rodentia is impossible, but effects can be slowed by filling holes.



North Sus Lime Kiln overview looking south, 2003.


View of North Sus Lime Kiln construction and debris, 2003.

Preservation Treatment of the North Sus Lime Kiln, Tucson Mountains District

Preservation treatment focused on stabilizing the interior brick wall and the outer granite rock wall, capping the top of the wall, repointing mortar joints, filling rodent holes, and redirecting drainage. The interior brick wall was repointed using unamended mud mortar made from nearby soils. The top 1-2 courses of bricks were re-laid using bricks found near the interior wall and within the kiln. Loose bricks were re-set in correct position with the glazed/vitrified side facing outward. Near the wall ends the brick wall was repaired by re-laying fallen bricks to make the end of the wall stepped rather than abrupt. The top of the interior brick wall was capped with unamended mortar to serve as a protective layer. The outer rock portion of the kiln wall was repaired by replacing granite rocks and mudding them in to form a rock cap that was two rocks thick in most areas; this matches the width and construction of the original rock portion of the kiln wall. Rebuilding of the wall, at the wall ends, was done in two places to stabilize the wall and improve drainage; the northwest and northeast wall sections. This resulted in an almost complete kiln wall with the two wall ends coming close to each other but not connecting. This opening allows water to drain away and out of the structure. The retaining wall just north of the kiln was repointed and capped with mud. The slope surrounding the kiln was regraded for drainage to the N/NE and SW. The table below summarizes treatment by wall section and provides measurements and labor estimates.



North Sus Lime Kiln, North Retaining Wall (exterior), Before Treatment.



North Sus Lime Kiln, North Retaining Wall Section, After Treatment.

SUS LIME KILN, NORTH KILN (B)

Location of Work

Wall	***Repointing (m2)***	***Total Cap (m3)***	***Wall Repair (m3)***	***Mortar Added (gallons)***	***Comments***
North	0	0	.133m^3	6	1.6m rebuilt- off of end of east wall wall rebuilt/capped with local granite and mud
West	.40m^2	.075m^3	.085m^3	4	rebuilt for 2.5m in length wall rebuilt with local granite and mud. Rocks from the vicinity were used.
South	.45m^2	.039m^3	.166m^3	3	replaced one full course of bricks bricks salvaged from inside kiln
East	0	.459m^3	0.24m^3	5	4.1m long cap consisting of a core-veneer like wall made of granite and mud
N. Retaining Wall	1.081m^2	.113m^3	.0528m^3	1	3 rocks replaced (granite)
TOTAL	1.981m^2	0.686m^3	0.677m^3	19	

Mortar Mix

2 dirt, 1 sand
(5 gallon buckets)

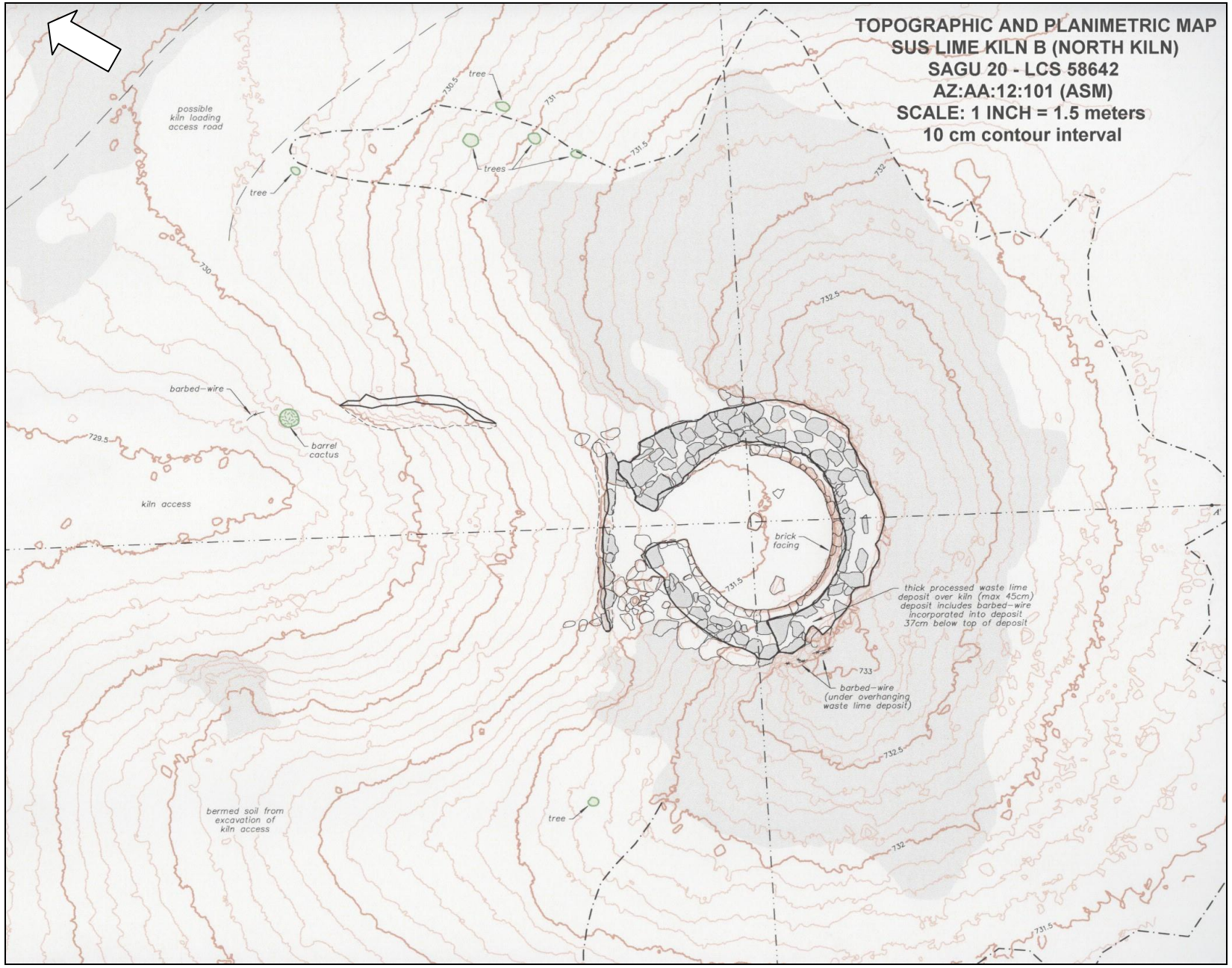
SUS LIME KILN, NORTH KILN

Special Features

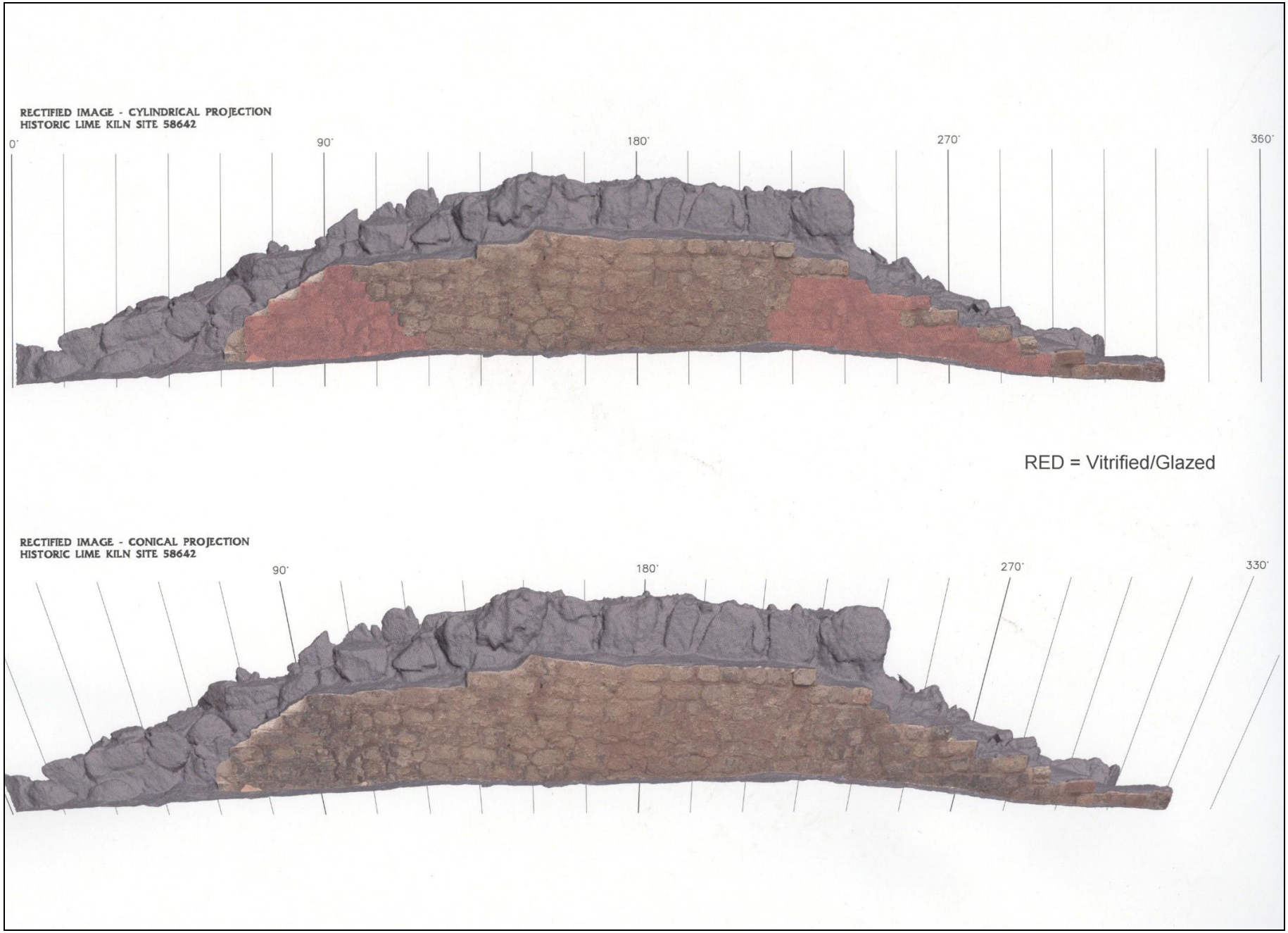
East Wall Interior	The bricks are more vitrified in a.60 x .20m patch
South Wall Interior	Bricks are more vitrified
Wall Rebuilt	total of 75 rocks used to rebuild outside wall made of granite
Brick Wall Reset	33 bricks replaced, bricks from the base of the wall were reset

Time/Labor

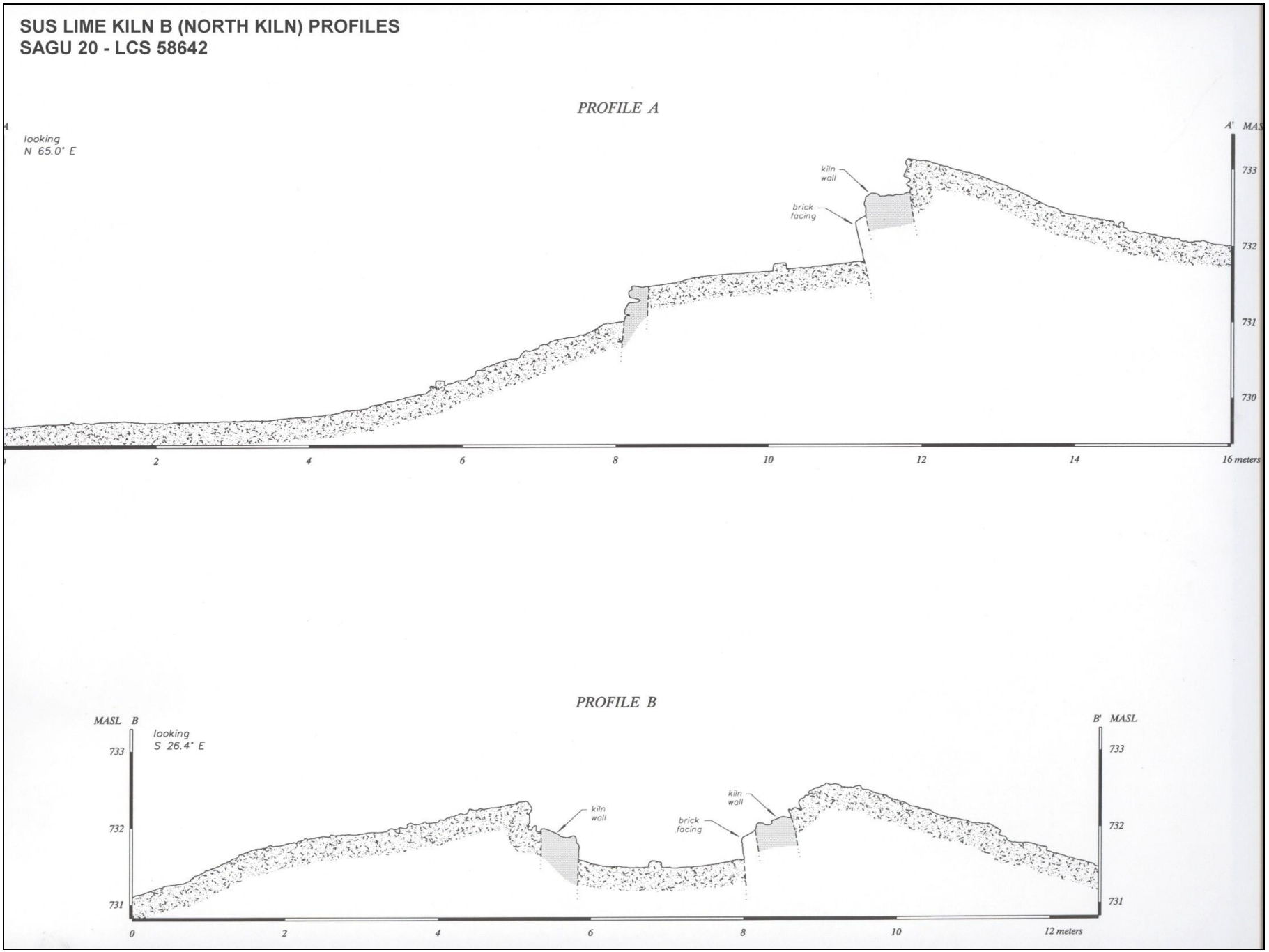
Task	***Time Spent (Total hours)***	***# of people***	***hours per person***
Repointing	2	2	1
Capping	5	2	2.5
Wall Repair	5	2	2.5
Documentation	2	1	2
Veg Removal	0	0	0
Hauling Equipment	2	4	0.5
Ruins Assessment	1	1	1
Erosion Control	0.5	1	0.5
TOTAL	**17.5**		



Topographic and planimetric map of North Sus Lime Kiln (B), Tucson Mountain District. Shaded areas are processed lime and/or piles. Dash line is extent of all lime debris surrounding kiln. Small linear dashed line west of kiln (near barrel cactus) represents a stone wall that supports a steep slope. Dashed lines crossing the map are profile lines (see profile below). Map by Western Mapping Inc.



Architectural Sheet for the North Sus Lime Kiln. NPS repairs are not labeled. The top course of adobe bricks/rocks were replaced by NPS and the whole wall repointed where needed. The north and west ends of the wall were rebuilt by NPS staff.



Profiles of North Sus Lime Kiln (B), Tucson Mountains District.

SUS LIME KILN NORTH PHOTOS, Color Digital Before and After Treatment



North Sus Lime Kiln, West Wall Section, Before Treatment.



North Sus Lime Kiln, West Wall Section, After Treatment.



North Sus Lime Kiln, South Wall Section, Before Treatment.



North Sus Lime Kiln, South Wall Section, After Treatment.



North Sus Lime Kiln, East Wall Section, Before Treatment.



North Sus Lime Kiln, East Wall Section, After Treatment.



North Sus Lime Kiln, NE Wall Section, Before Treatment.



North Sus Lime Kiln, NE Wall Section, After Treatment.



North Sus Lime Kiln, NE Wall Section, After Treatment.


North Sus Lime Kiln, Overview of West Cap, After Treatment.



North Sus Lime Kiln, Site Overview, Before Treatment.



North Sus Lime Kiln, Site Overview, After Treatment.



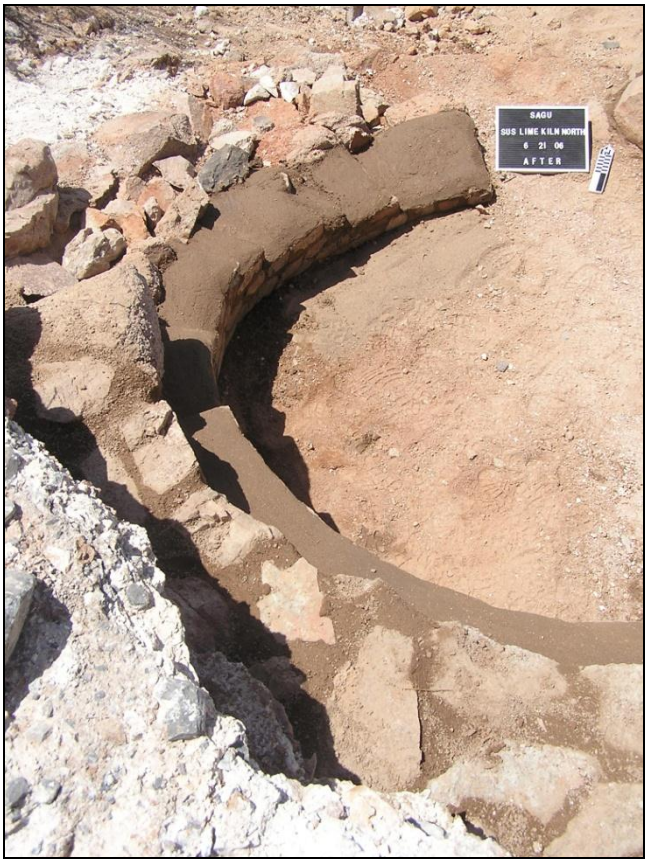
North Sus Lime Kiln, North Retaining Wall (exterior), Before Treatment.



North Sus Lime Kiln, North Retaining Wall Section, After Treatment.



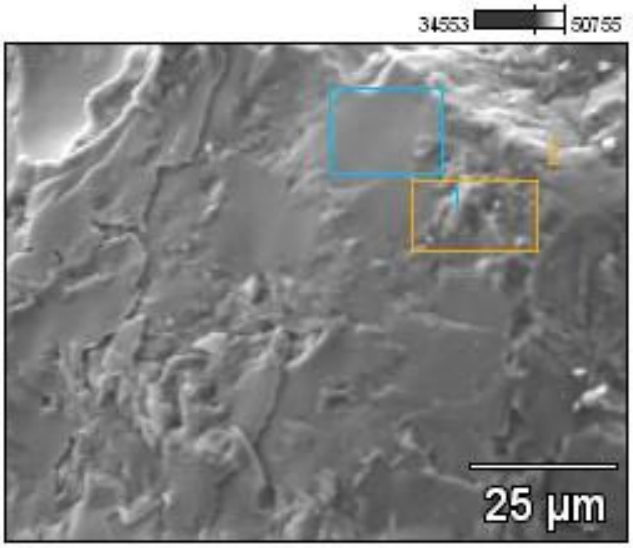
North Sus Lime Kiln, looking southeast, after treatment.



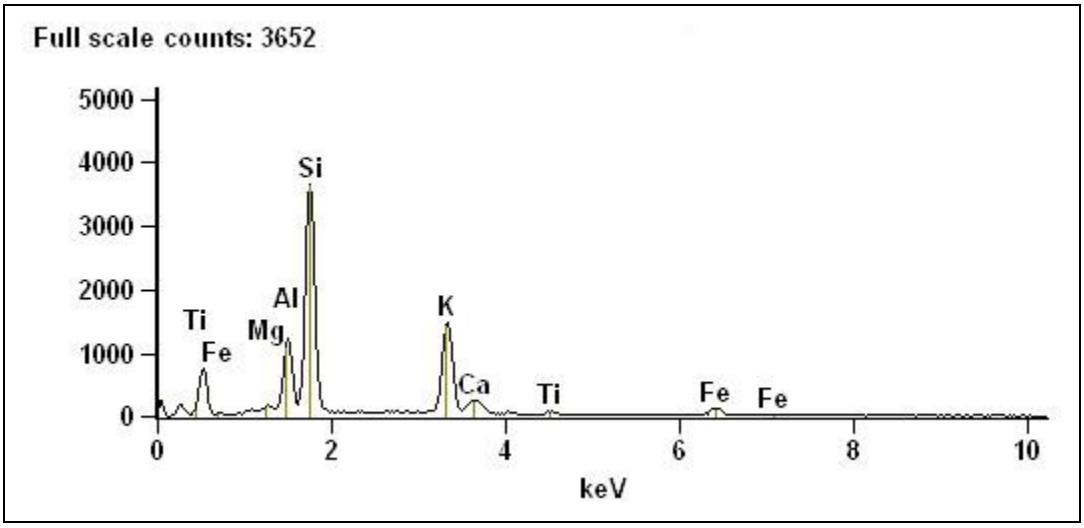
North Sus Lime Kiln, looking northwest, after treatment.

Material Analysis: Sus Lime Kiln North

A brick sample found in the kiln interior (perhaps from the south wall) was examined using the SEM scan. Both the exterior and interior were analyzed. The exterior appears as a smooth surface, and is pictured below at 1000X magnification:



The elemental breakdown of the sample is shown in the graph and chart below:



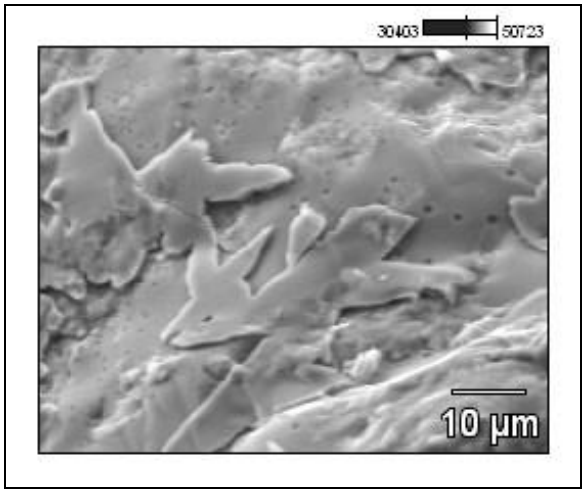
The above graph shows the elemental breakdown of the sample being examined and take note that this is at 3,652 full scale counts; this means it is more accurate as this count is high for this examination. The computer also breaks this graph down into percentages of the total and separates the chart into normal and compound formula sections:

Filter Fit Chi-squared value: 1.790
Correction Method: Proza (Phi-Rho-Z)
Acc.Voltage: 15.0 kV Take Off Angle: 51.8 deg

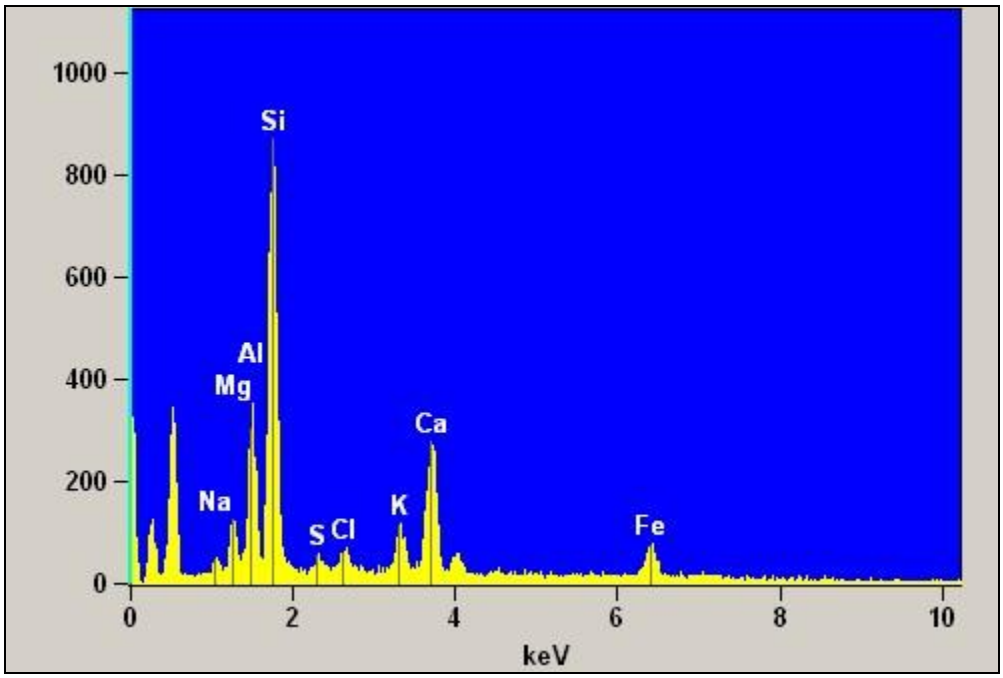
Element	Normal	Compnd Formula	Normal	Compound
O	41.13		S	---
Mg	0.41		MgO	0.68
Al	6.87		Al2O3	12.97
Si	**23.78**		**SiO2**	**50.88**
K	19.48		K2O	23.47
Ca	**2.03**		**CaO**	**2.84**
Ti	0.66		TiO2	1.10
Fe	5.63		Fe2O3	8.06
Total	100.00			100.00

Being that lime is Calcium Oxide, we look to the CaO display and see that only 2.84% of the sample is CaO. This makes sense because in this SEM sample we are examining the side of the brick without the green glaze (exterior of the brick) that signifies lime, but we still see that there is enough CaO to confirm that lime was present in this brick.

Moving on to the next sample, we will be examining the same brick, but this time we are looking for jagged markings on the interior surface. The jagged markings show us a glassy surface, which in turn, indicates lime crystals. The following picture, taken on the SEM for this sample, shows lime crystal and was the best example found of lime being present in the sample:



The picture above showing the lime crystals was taken on the SEM at a magnification of 1,500X. To find the crystalline surfaces like this, I scanned over the surface of the object until I found bubbles in the rock and then zoomed in to find the crystalline structures. The following images are the chemical breakdown for the glassy surface in graph and chart form:



Filter Fit Chi-squared value: 0.796
Correction Method: Proza (Phi-Rho-Z)
Acc.Voltage: 15.0 kV Take Off Angle: 51.8 deg

Element	Normal	Normal	
Wt.%	Formula	Compound	
O	41.05	S	---
Na	1.13	Na2O	1.52
Mg	2.25	MgO	3.74
Al	6.79	Al2O3	12.83
Si	**18.19**	**SiO2**	**38.92**
S	1.02	SO3	2.54
Cl	1.40	Cl	1.40
K	3.45	K2O	4.15
Ca	**14.36**	**CaO**	**20.09**
Fe	10.36	Fe2O3	14.82
---		---	
Total	100.00		100.00

As can be seen in the two charts above, the Calcium column is much higher than in the exterior sample, with a Calcium Carbonate percentage of 20.09%. This confirms the original assumption that the lime green coating is in fact where the most lime is found on this particular rock sample; and the green glaze forms from the heating of lime on the adobe brick surface. The results also show the surface of the exterior sides of bricks have less magnesium and magnesium compounds than interior brick surfaces. This probably relates to magnesium within limestone. The variation in magnesium counts between the brick samples from the different kilns may be a result of the percent of magnesium within different limestone sources or variation within a single source. However, understanding all of the factors explaining the chemical distribution of the samples is beyond the scope of this report.

South Sus Lime Kiln (A)

LCS 58644
SAGU#: SAGU 20
STATE#: AZ:AA:12:101 (ASM)

The South Sus Lime Kiln is located south of the north lime kiln, just south of Sus Hill on the south side of the drainage. In 2003, Kevin Harper and staff from SAGU could not locate the kiln. Harper concluded that the kiln had eroded into the wash. In 2006, TUMA staff located the kiln along the edge of the deeply incised drainage south of Sus Hill. The kiln is the smallest kiln investigated and has little evidence of use. It also appears dry-laid, although this is probably due to the fact that it was either never finished or used or only used once or twice and the mortar has eroded. There is less evidence of limestone burning and fewer piles of processed lime than at the other kilns. Small piles of unheated limestone are located east of the kiln, but there are no white, cemented lime deposits like at the other kilns. This kiln may have operated for a short period of time, but there is little to suggest that it produced much lime. During treatment a small lime powder deposit was found in the approximate location of the fallen north wall inside the kiln and along the steep bank. Rozen (1977) mentioned this deposit as well. The lime deposit suggests that the kiln was fired at least once.

Condition Assessment

TUMA staff were the first to conduct a condition assessment. The kiln could not be located in 2003 (Harper 2003). The assessment in 2006 identified few problems with the kiln. Most immediate issues were erosion of the northern slope overlooking the steep drainage, and failure of wall portions due to differential fill and a lack of mortar.

Preservation Treatment of the South Sus Lime Kiln

Treatment of the South Sus Lime Kiln consisted of a large amount of repointing, minimal wall end rebuilding, and capping of the wall tops with stone/unamended mud. The slope along the east and west wall sections was regarded and a small incised drainage filled in. The treatment information is shown in the table below along with labor estimates. To ensure the stability of the remaining wall portions a small area of wall on the north side was rebuilt, resulting in a nearly complete wall outline of the kiln.

SUS LIME KILN, SOUTH KILN (A)

Location of Work

Wall	***Repointing (m2)***	***Total Cap (m3)***	***Wall Repair (m3)***	***Mortar Added (gallons)***	***Comments***
North	0	0	1.10m^3	4	granite rocks from slope below kiln were used to rebuilt the wall to just above grade
West	1.7m^2	0.113m^3	.235m^3	4	rebuilt wall end stepped
South	1.5m^2	0.113m^3		3	
East	1.3m^2	0.125m^3	.328m^3	4	rebuilt wall end stepped using local rock
TOTAL	4.5m2	.351m3	1.663m3	15	

Mortar Mix
2 dirt
(5 gallon buckets)

local dirt was coarse with a good amount of sand already, but clay content made the dirt usable. Dirt source was 25m east of kil

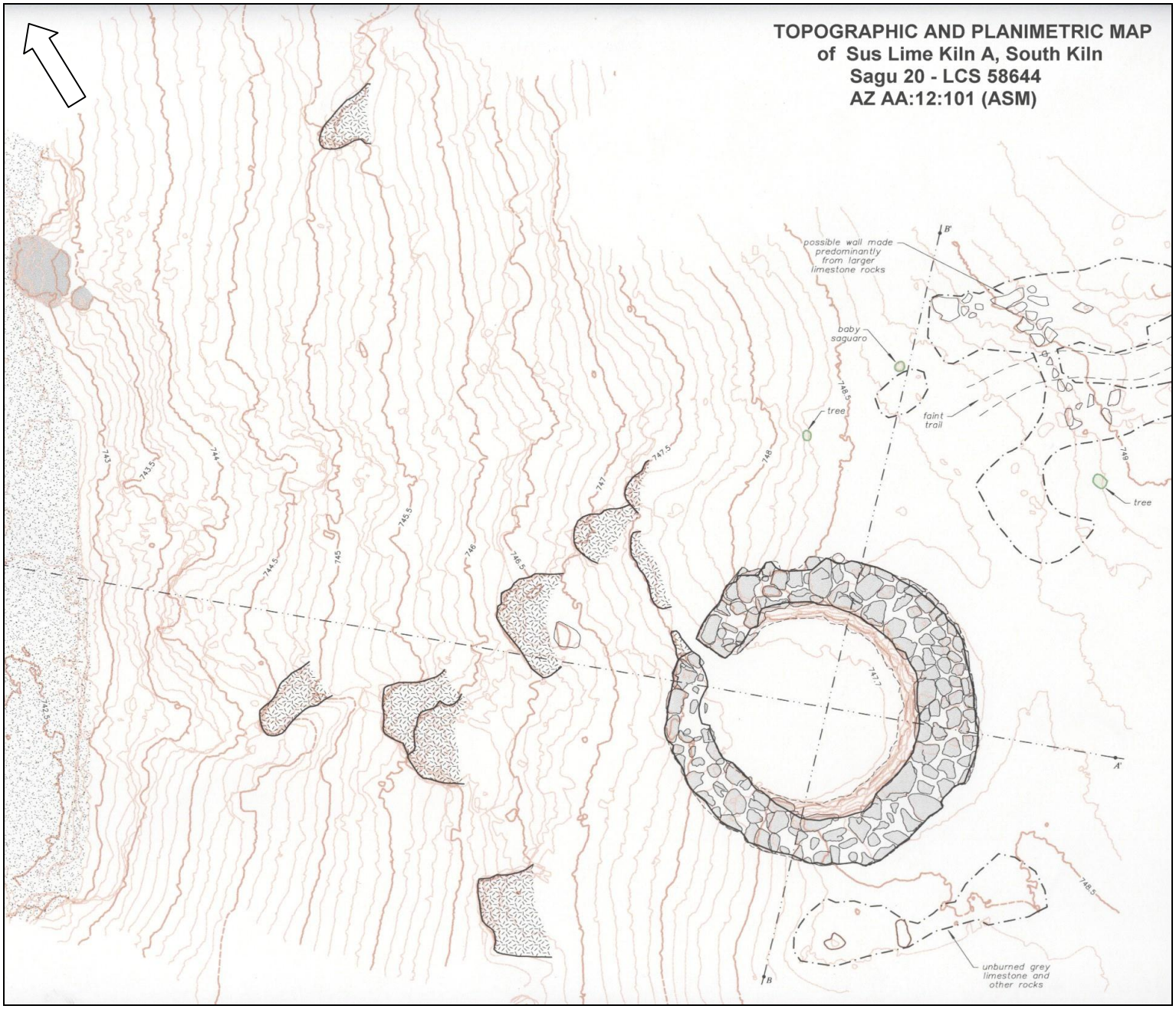
Special Features

North Wall Interior	70cm x 70cm patch of powder lime (burned lime- area maybe where entry was)
Cap	Cap of 46 rocks added and set in mud
Drainage	slopes graded to north along east wall and to southwest along SW wall exterior

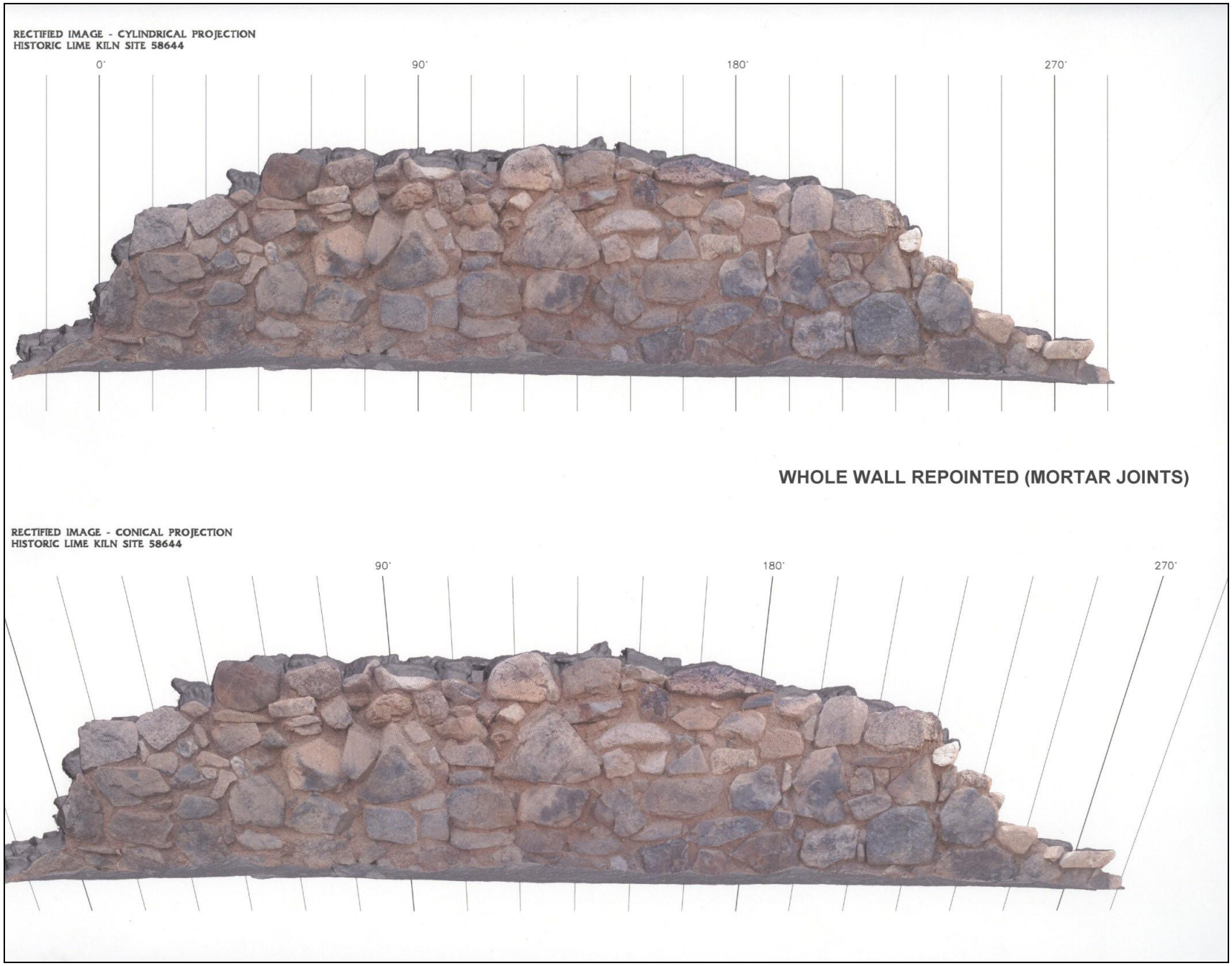
SUS LIME KILN,
SOUTH KILN (A)

Time/Labor

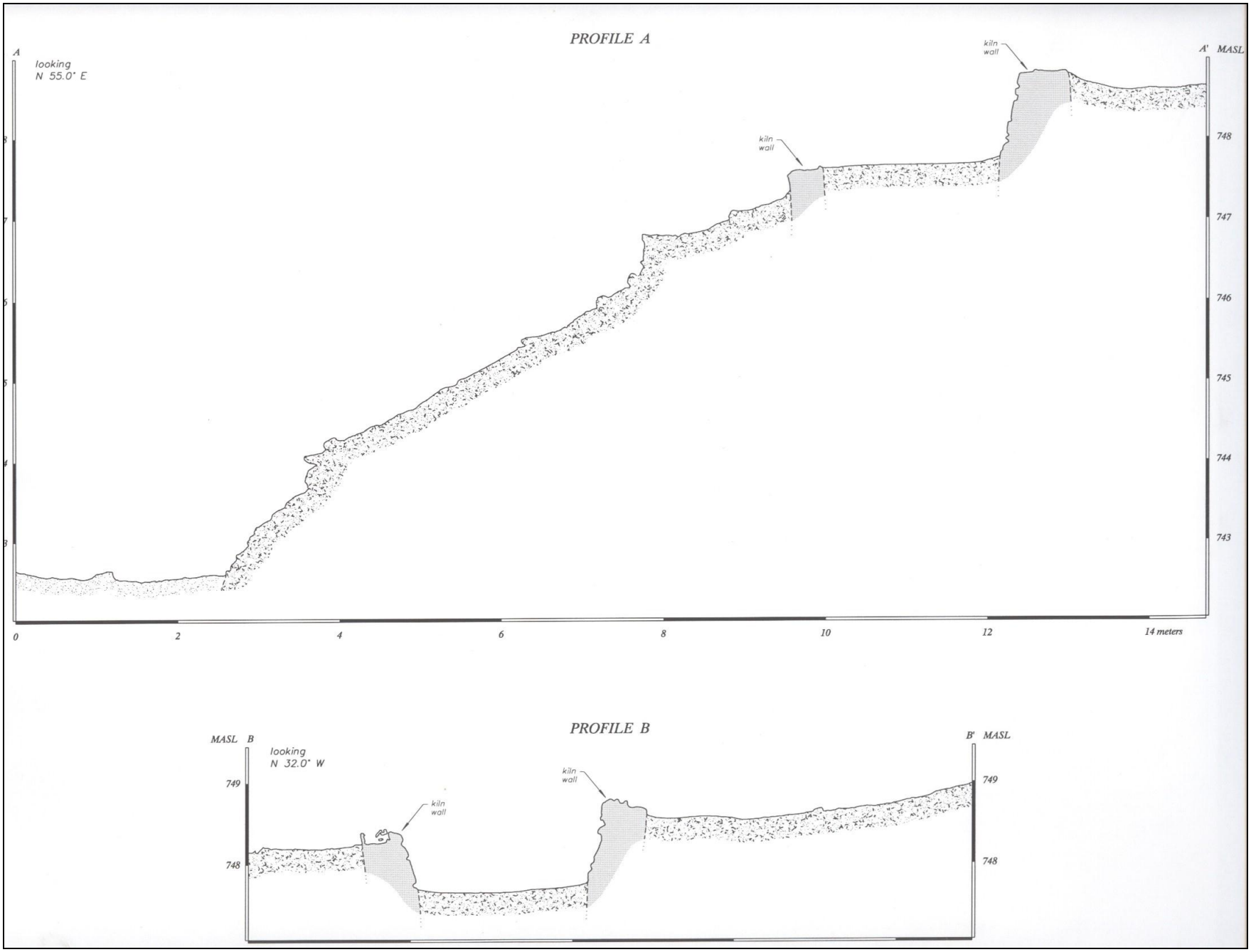
Task	***Time Spent (Total hours)***	***# of people***	***hours per person***
Repointing	6	3	2
Capping	2	1	2
Wall Repair	2	2	1
Documentation	2	1	2
Veg Removal	0.5	1	0.5
Hauling Equipment	1	3	0.3
Ruins Assessment	1	1	1
Erosion Control	1	2	0.5
TOTAL	**15.5**		



Topographic and Planimetric Map of South Sus Lime Kiln, Tucson Mountains District. 10cm contour interval. 1 inch=1.4m.



South Sus Lime Kiln (A) Architectural Sheet.



South Sus Lime Kiln Profile A and B.

South Sus Lime Kiln
Before and After Treatment Photos, Color Digital



South Sus Lime Kiln, Looking northeast, East Wall End, Before Treatment



South Sus Lime Kiln, Looking east, East Wall End, Before Treatment



South Sus Lime Kiln, Looking southeast, After Treatment



South Sus Lime Kiln, Looking south, East Wall End, Before Treatment



South Sus Lime Kiln, Looking south, South Wall Section, Before Treatment



South Sus Lime Kiln, Looking south, South Wall Section, Before Treatment



South Sus Lime Kiln, Looking south, West Wall End, Before Treatment



South Sus Lime Kiln, Looking southwest, West Wall End, After Treatment



South Sus Lime Kiln, West Wall, After Treatment



South Sus Lime Kiln, Wall Top, Before Capping



South Sus Lime Kiln, Looking north/northeast, After Treatment (Capping)



South Sus Lime Kiln, Looking north/northeast, After Treatment (Capping)



South Sus Lime Kiln, Looking north/northeast, After Treatment (Capping)

MANAGEMENT RECOMMENDATIONS

All six of the lime kilns treated in 2006 will require preservation maintenance in 3-5 years. Yearly condition assessments should be completed every year following monsoon season. A condition assessment form (w/manual on use) that can be used during yearly inspections is included as Appendix B. Appendix A is the annotated photographs showing the 2006 treatments. Appendix C is the itemized budget for the 2006 project.

Informal condition assessments were done at all of the kilns in 2008. Results show that the 2006 treatment is holding up well, but beginning to erode. Most of the observed problems are with capping, which may need repairs more frequently than mortar joints on vertical wall faces. Overall, all of the kilns are still in good condition as of 2008.

Cyclic maintenance consisting of replacing or repairing the cap, repointing eroded mortar joints, regrading for proper drainage and replacement or re-setting of any loose rocks, should occur every 3-5 years depending on resource condition. All work should be documented using photography, condition assessment forms, and notes. The annotated drawings shown in Appendix A can be changed in AutoCad to reflect changes in condition and/or new preservation treatments. It is recommended that only unamended mortar be used rather than cement or other hardening substances. Although unamended mortars have a shorter maintenance cycle, they are historically accurate and allow walls to breathe, which decreases erosion due to the trapping of moisture.

The 2006 treatment and documentation project was a success. We were able to accurately document the kilns and their associated features and archaeology and treat the structures in a manner that will ensure their structural and historic integrity. It is now up to SAGU to make a commitment to preserve the structures beyond the 2006 project by conducting yearly condition assessments and preservation work as needed. This proactive approach will ensure that the structures remain in good condition for future generations.

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1969b *Notes from an interview by Charles B. Maguire*, 4 July 1969. Folder 13: Historical File; Transcripts of Early Settlers/Early Saguaro Personnel; Photo [H18 History and Archeology] 1960-1985, Box 11, SAGU Records Collection, SAGU Accession #257, SAGU Catalog #2636, Western Archeological and Conservation Center, National Park Service, Tucson, Arizona.

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APPENDIX A: CONDITION ASSESSMENT FORM AND MANUAL

Condition Assessment Wall Form

Saguaro Lime Kilns

DATE:	
SAGU Site #:	
ASM #:	
LCS ID #:	
Structure Name:	
Structure#:	
Wall ID #:	
Wall Name/Description:	
Examined by:	

Part I. Impacts

Code	Value	Definition
0	No Impact	No Impact is present
1	Low	The continuing effect of the impact(s) is (are) known, and will not result in significant or irreparable damage; and/or there is no direct threat to visitor or staff safety.
2	Moderate	A wall will be significantly damaged or irretrievably lost if action is not taken within 5 years; and/or there is a potential threat to visitor and/or staff safety.
3	Severe	A wall will be significantly damaged or irretrievably lost if action is not taken within 2 years; and/or there is an immediate and severe threat to visitor and/or staff safety.

Summarize Wall Condition:

	Impact Code	Location of Impact		
		Cap	Mid	Base
Wall collapse				
Leaning segments				
Bulging segments				
Differential fill				
Drainage impacts				
Animal activity				
Insect activity				
Cracking				
Detachment				
Surface erosion				
Water dampness				
Friability				
Efflorescence				
Biological growth				
Visitor impact				
Vandalism				
Other (describe) _____				
TOTAL SCORE				

Condition Assessment Wall Form

Saguaro Lime Kilns

Part II. Treatment Recommendations

Treatment Type	Place a Check √ in all boxes that apply						
	Location of Impact			Treatment Urgency			
	Cap	Mid	Base	Immediate (ASAP)	High (1-2 Years)	Medium (3-5 Years)	Low (6> years)
Re-point							
Re-cap							
Replace Stones							
Fill Cracks							

Insect Control							
Animal Control							
Vegetation Control							
Modify Fill/Drainage							
Remove Graffiti							
Other: (Describe) _____							

Summarize Treatment Needs:

Condition Assessment Wall Form Guide

Saguaro Lime Kilns

Date: Indicate the date in the following format (i.e. Month/Day/Year).

SAGU#: Add the SAGU site number.

State # (ASM#): Arizona State Museum number.

LCS ID #: Indicate the LCS # (i.e. IDLCS 012345).

Structure Name: Indicate the known structure name

Kiln #: Indicate the designated kiln number (i.e. Kiln 1). Refer to map for kiln numbers.

Wall ID #: Indicate the designated Wall ID, e.g. N, W, South, etc.

Wall Face: Indicate whether wall face is interior (int.) or exterior (ext.).

Wall Name/Description: Indicate the descriptive name of the wall, i.e. north wall, east wall, etc.

Examined by: Indicate all personnel collecting and recording data on this particular wall/form.

Impacts

Quantify the overall wall condition and the individual condition of architectural elements that make up the wall (stone, mortar joints, adobe). Assign a numerical score for each condition based on the % of the wall affected by the impact, % of exposed stones affected by the impact, the % of total mortar joints affected by the impact, the % of total adobe fabric affected by the impact, and the % of total wood affected by the impact: 0= No Impact, 1= Insignificant (<10%), 2= Low (10-25%), 3= Moderate

(26-50%), and 4= High (51%>). Add the respective scores for the Wall, Stones, Mortar Joints, Adobe and enter the cumulative scores in the TOTALS boxes. Add all cumulative scores for each category together for a TOTAL SCORE.

Type of Impact Definitions

Wall collapse: Sections of the existing wall have collapsed since the last assessment.

Leaning segments: Segments of the wall are leaning.

Bulging segments: Segments of the wall are bulging causing a swell or bend in the wall.

Differential fill: Unequal fill loads are escalating erosion or other categories of impact.

Drainage impacts: Overall wall deterioration is directly related to rills, gullies, arroyos or pooling.

Animal activity: Burrowing, nesting, digging, disturbing, or other evidence of the presence of animals.

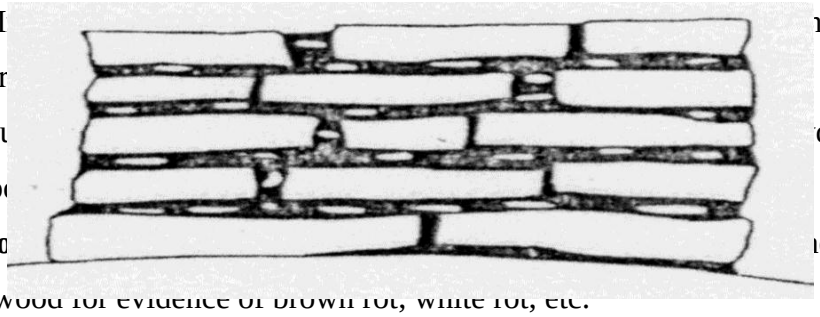
Insect activity: Burrowing, nesting, digging, disturbing, or other evidence of the presence of insects.

Cracking: Fractures occurring in the wall as a whole, stones, mortar or adobe fabric.

Detachment: Separation of wall from adjacent walls/cliff face; separation of mortar from joints; separation of stone from the wall, separation of adobe fabric from the wall; wood material detached from architecture.

Surface erosion: Ongoing disintegration attributable to a physical erosion such as wind or water abrasion.

Water dampness: I



noff or humidity.

Friability: Granular

Efflorescence: Accu

der. Most typically affects mortar and p

Biological growth o

ien) or higher plant forms with roots. Inspect wood for evidence of brown rot, white rot, etc.

Visitor impact: Normal visitation has created erosion, collapse, or alteration in historic fabric.

Vandalism: Intentionally created erosion, collapse, alteration or graffiti upon historic fabric.

Other: Other impacts not identified above. Describe the impact.

Treatment Recommendations

Location of Impact

The Location of impact provides information regarding where or in which part of the wall an impact is occurring. For example, if wall collapse has occurred only in the top two courses throughout the entire wall, √ the "Cap" box. However, if the entire wall has collapsed, √ boxes Cap, Mid and Base.

Cap: The top two courses of Wall Stone
Mid: The Middle section of the wall between the basal courses and cap.
Base: The basal courses of the wall

Cap *(top two courses)*

Mid *(middle courses)*

Base *(bottom two basal courses)*

Treatment Urgency:
Refer to the chart and √ the appropriate box to indicate the location of the treatment type and the urgency. If no treatment action is needed, then state this as "No treatment needed" in the summary section.

Summarize Condition

Use this section to elaborate on specific details such as the location or severity of deterioration. Some examples of how to describe condition and the location of impacts are presented below:

1. dampness and surface erosion are confined to the base of the wall
2. efflorescence occurs only at the top of the wall and within the mortar joints
3. Surface erosion is due to the wall's setting beyond the dripline.

Make sure your statements describe the overall condition of the wall in relation to the impact matrix. Also, be aware that the matrix score may not accurately represents the wall's true condition and threats. For example, a small section of wall may actually be affected by erosion, resulting in a low rating within the matrix. However, the small area affected could threaten the entire stability of the entire wall (i.e. Basal erosion).

APPENDIX B: ANNOTATED PHOTOGRAPHS SHOWING PRESERVATION TREATMENTS

NORTH LIME KILN (#1)

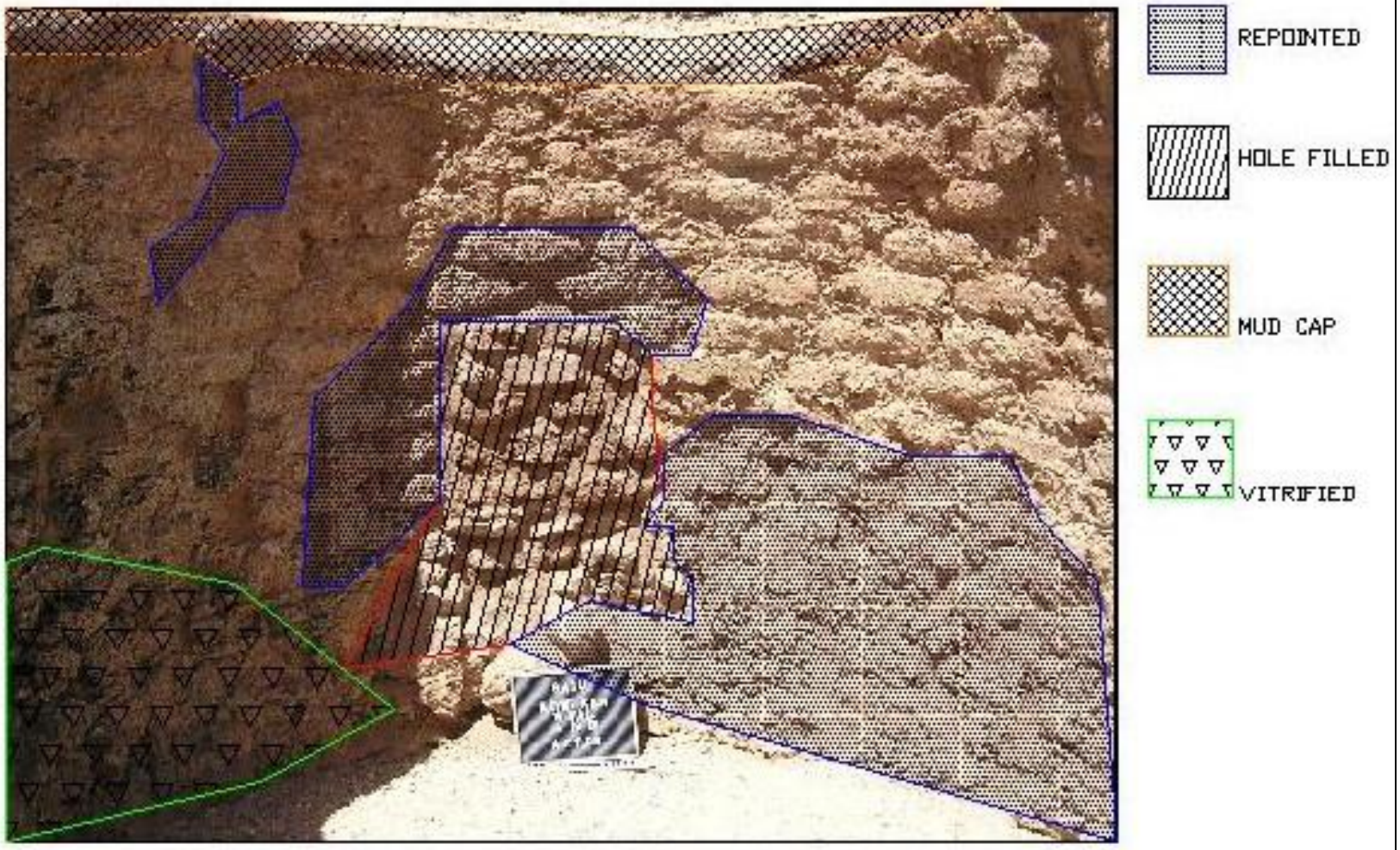
SAGU, North Lime Kiln (#1), Stabilization



North Lime Kiln, Lime Kiln #1, East Wall (and NE Section), After Treatment

NORTH LIME KILN, EAST/NE WALL SECTION

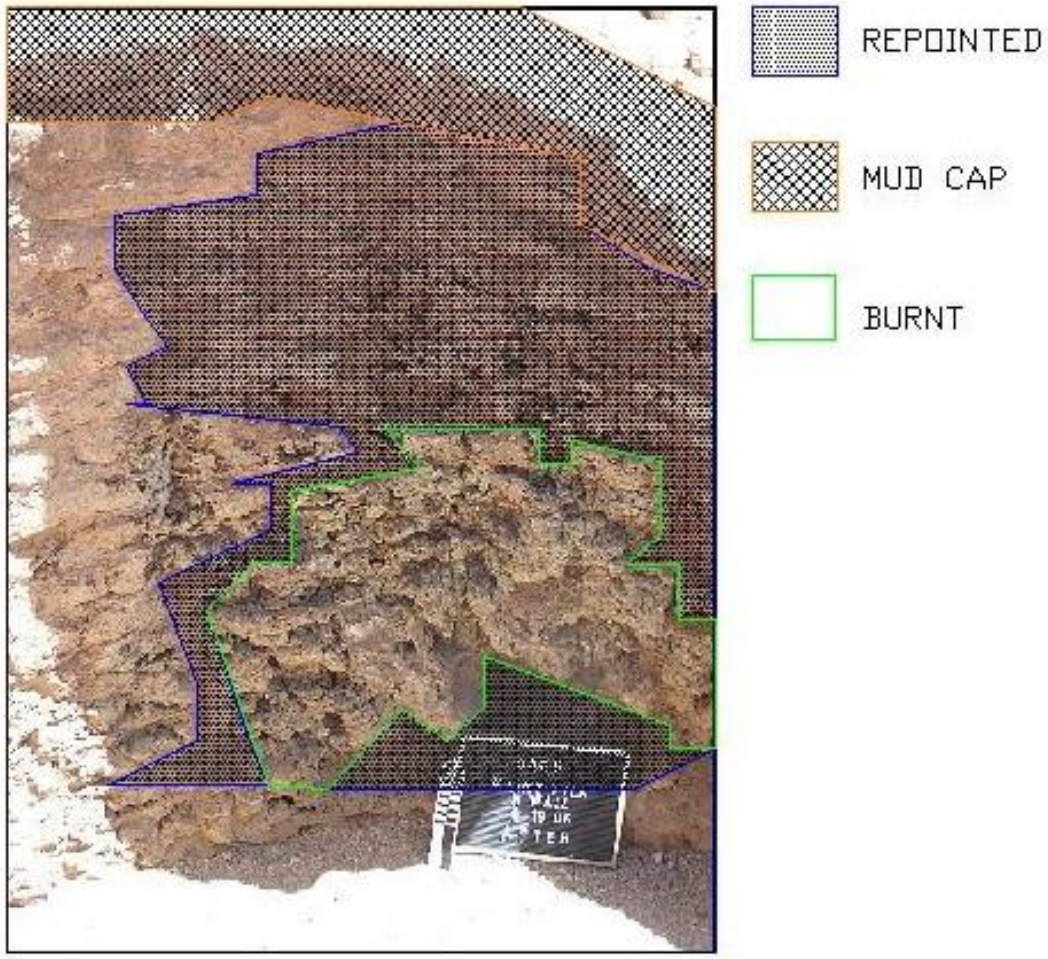
SAGU, NORTH LIME KILN (#1)



North Lime Kiln (Kiln #1), West Wall Interior, After Treatment

NORTH LIME KILN, NORTH WALL SECTION

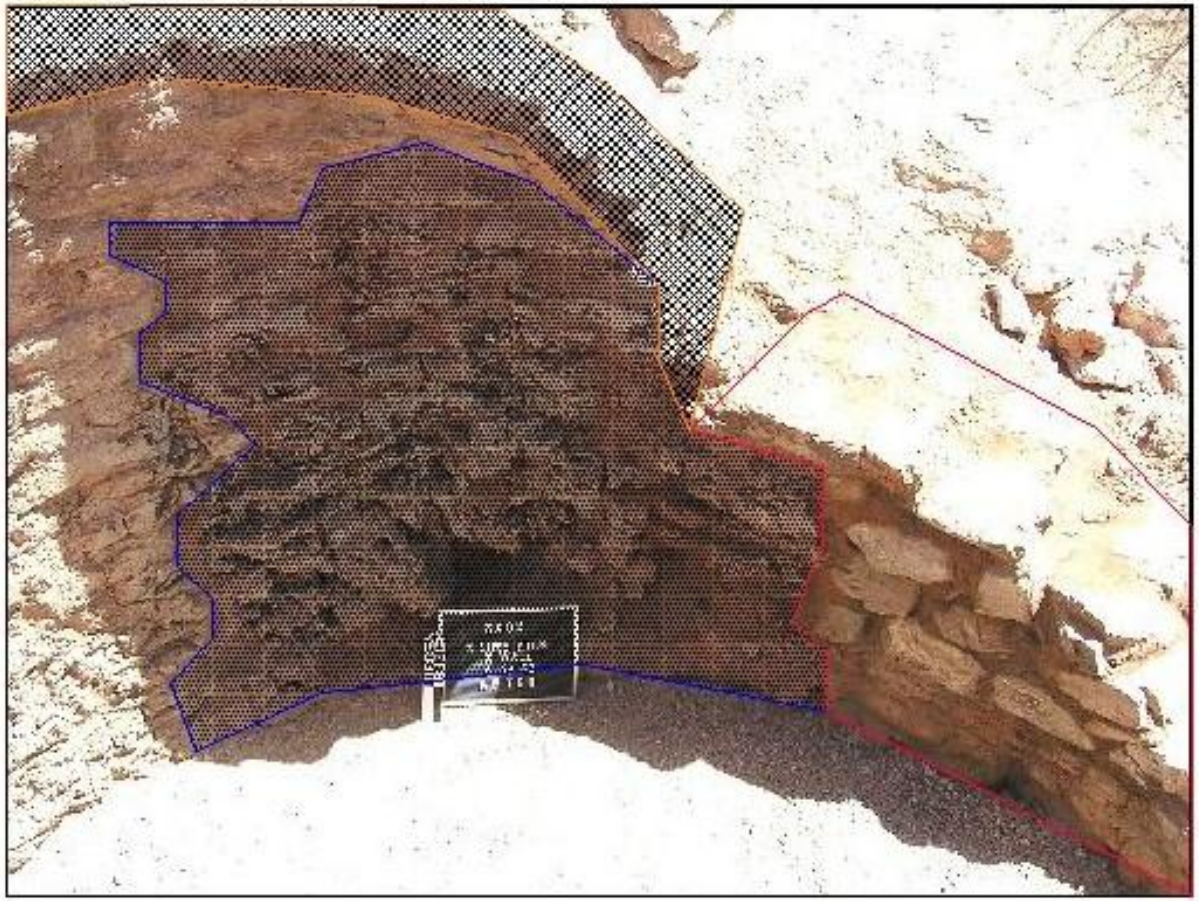
SAGU, NORTH LIME KILN (#1)



North Lime Kiln, Lime Kiln #1, North Wall Interior, After Treatment

NORTH KILN, NW WALL SECTION

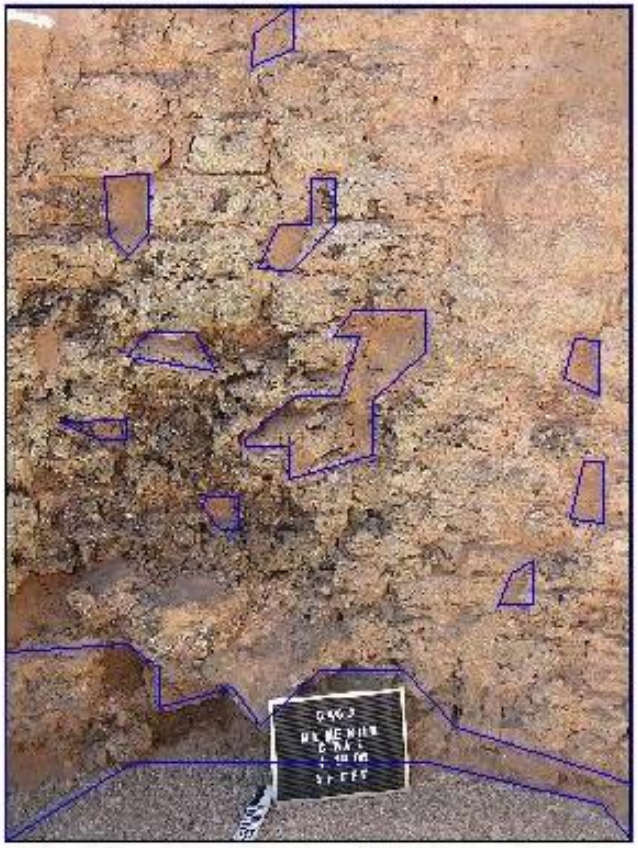
SAGU, NORTH LIME KILN (#1)



North Lime Kiln, Lime Kiln #1, North-NW Wall Interior, After Treatment

NORTH LIME KILN, SOUTH WALL SECTION

SAGU, LIME KILN #1

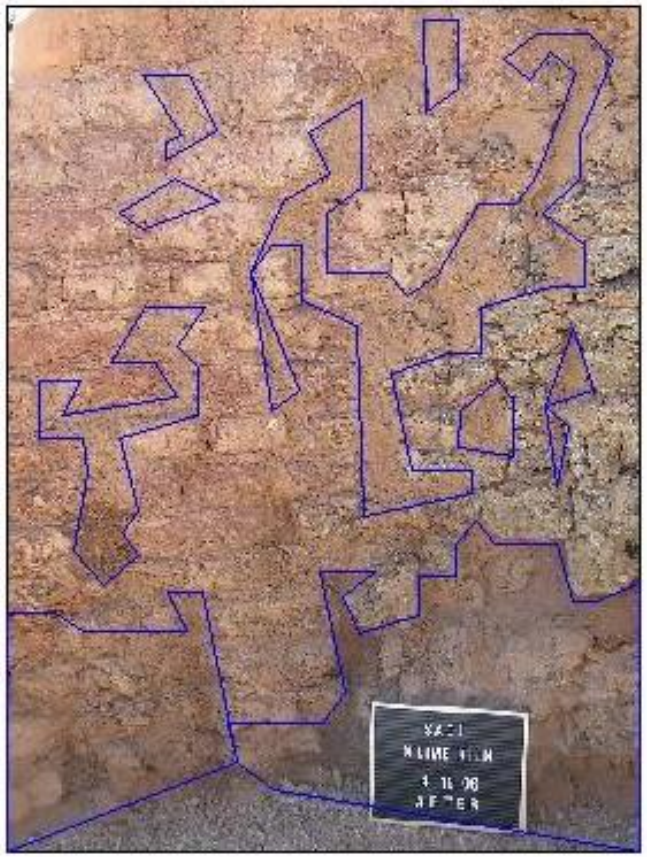


REPOINTED

North Lime Kiln, Lime Kiln #1, South Wall Interior, After Treatment

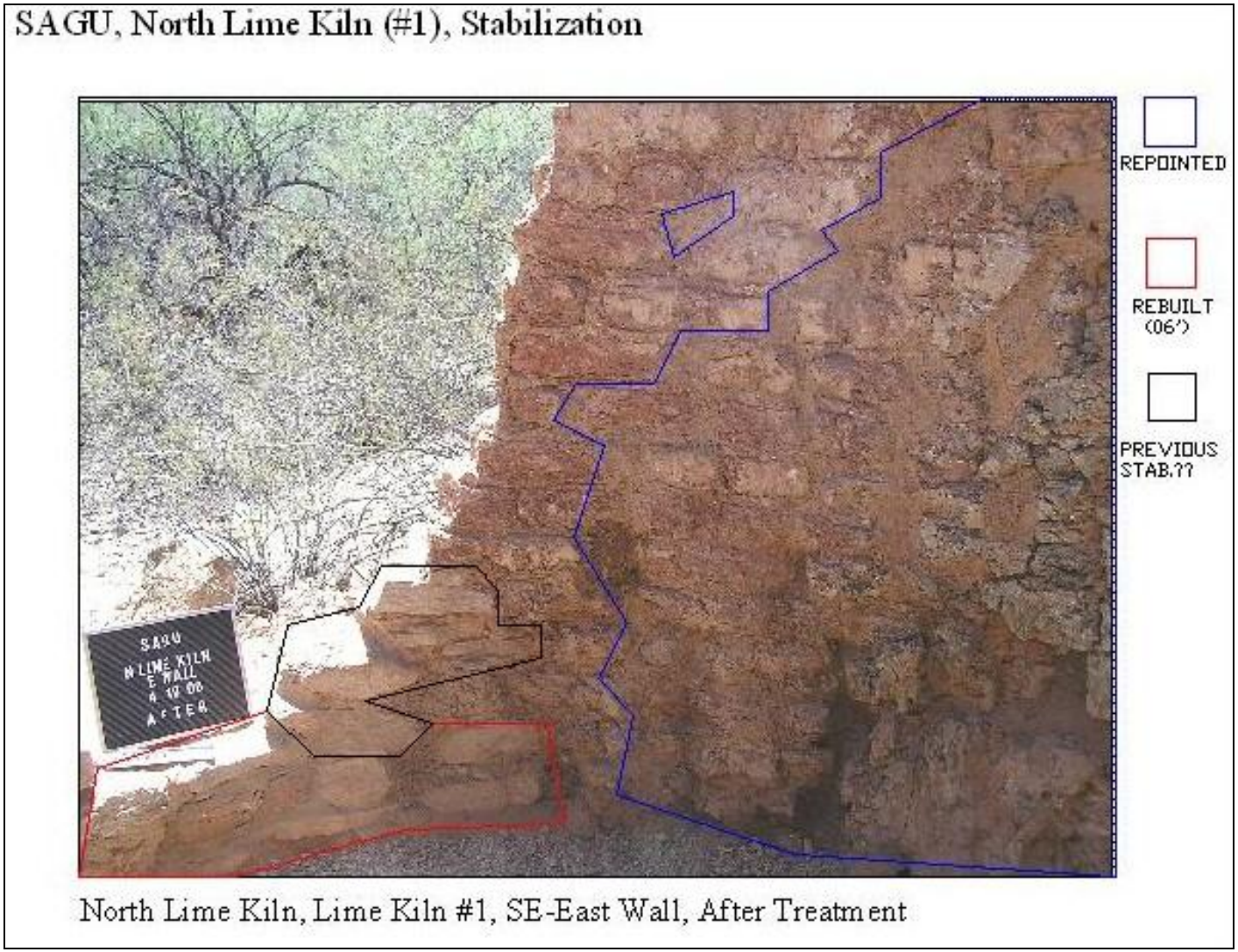
NORTH LIME KILN, S/SE WALL SECTION

SAGU, North Lime Kiln (#1)

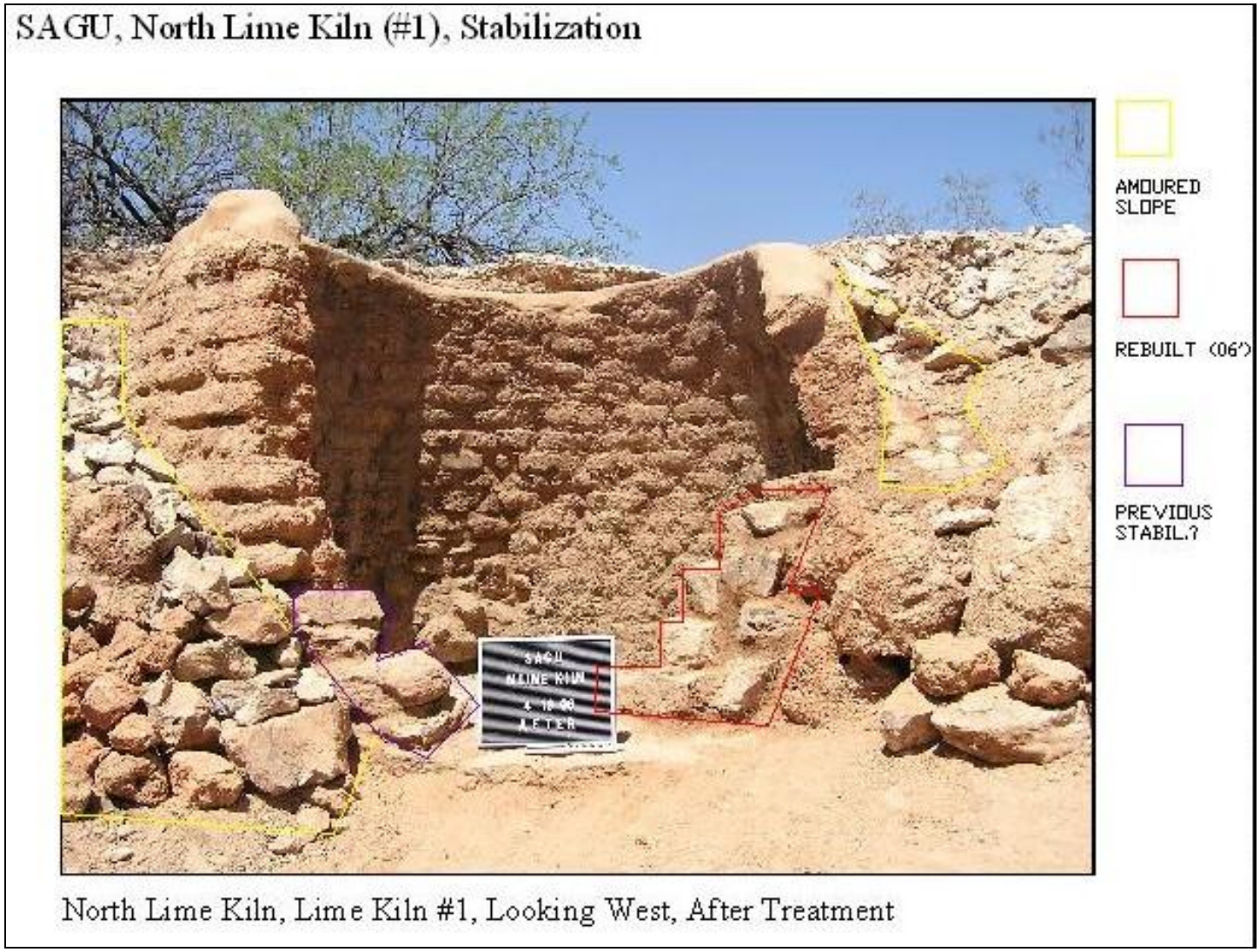


North Lime Kiln, Lime Kiln #1, S/SE Wall Interior, After Treatment

NORTH LIME KILN, SE/E WALL SECTION



NORTH LIME KILN, EXTERIOR, LOOKING WEST



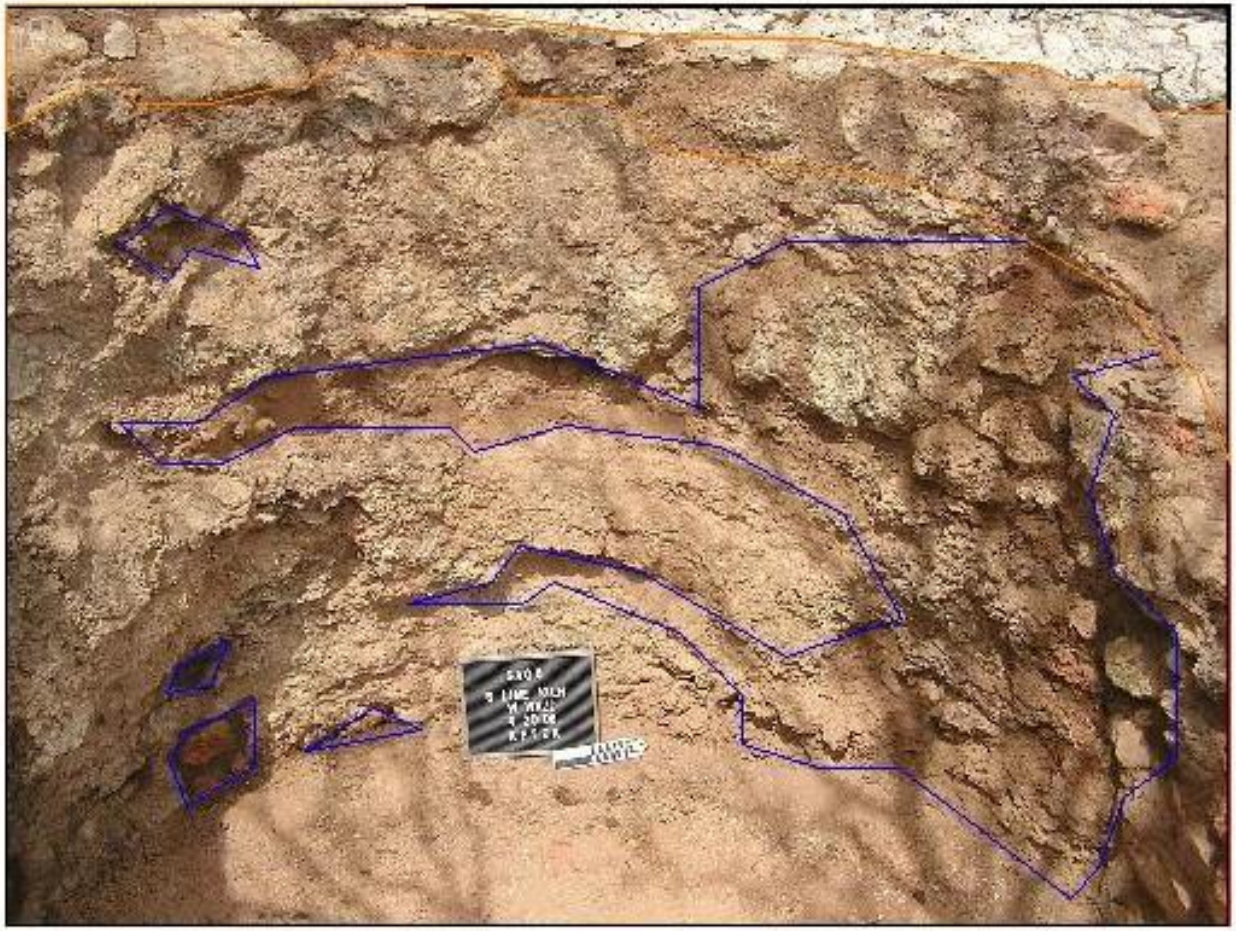
SOUTH LIME KILN (#2)

SAGU, South Lime Kiln (#2), Stabilization



South Lime Kiln, Lime Kiln #2, North Wall, After Treatment

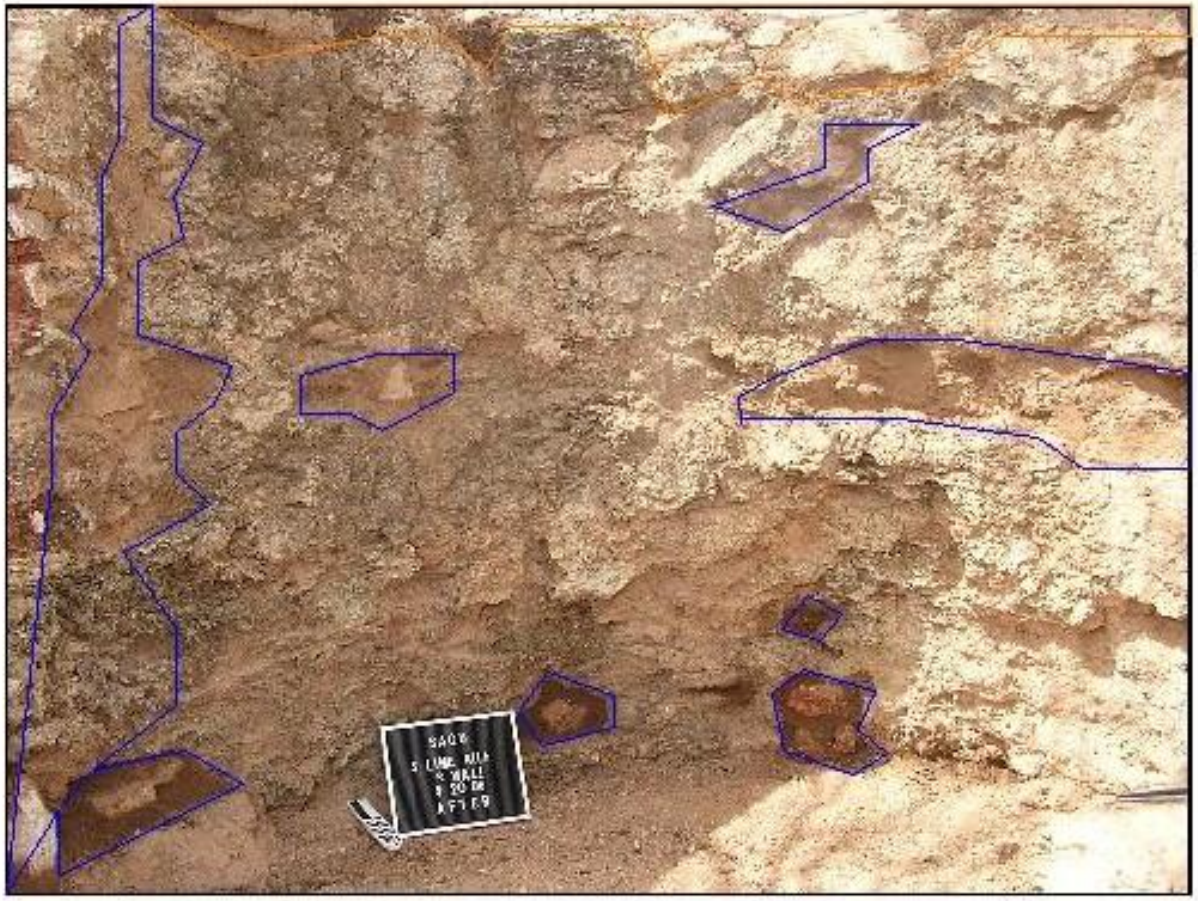
SAGU, South Lime Kiln (#2), Stabilization



South Lime Kiln, Lime Kiln #2, West Wall, After Treatment

SAGU, South Lime Kiln (#2), Stabilization

AZ:BB:14:74
SAGU 30, LOCUS A,
LCS# 07545



REPOINTED

STONE/
MUD CAP

South Lime Kiln, Lime Kiln #2, South Wall, After Treatment

SAGU, South Lime Kiln (#2), Stabilization



South Lime Kiln, Lime Kiln 2, South Wall and Slope, After Treatment

CAMINO LOMA ALTA LIME KILN

SAGU, Camino Loma Alta Kiln, Stabilization



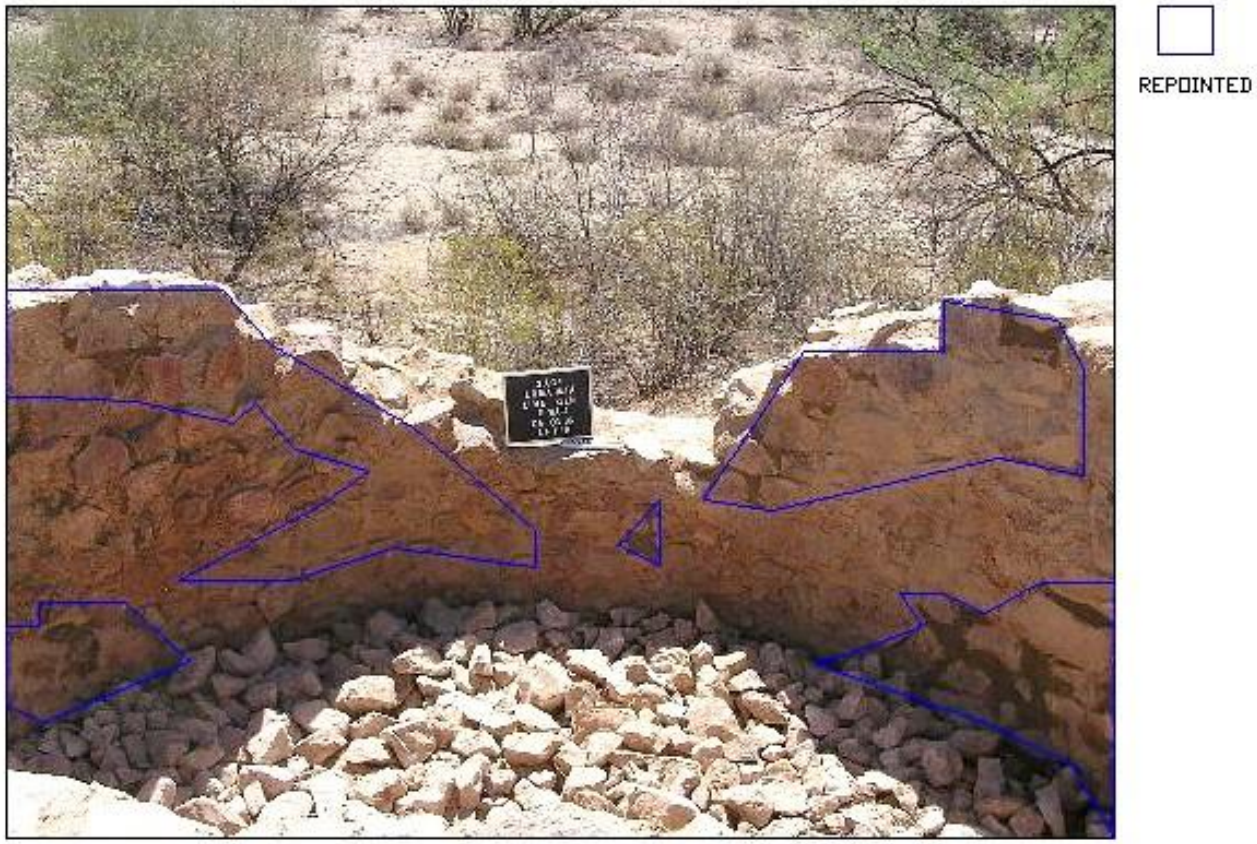
Camino Loma Alta Lime Kiln, S-SE Wall Exterior, After Treatment

SAGU, Camino Loma Alta Kiln, Stabilization



Camino Loma Alta Lime Kiln, East Wall Exterior, After Treatment

SAGU, CAMINO LOMA ALTA KILN, STABILIZATION



Camino Loma Alta Lime Kiln, East Wall Interior, After Treatment

SAGU, Camino Loma Alta Kiln, Stabilization



Camino Loma Alta Lime Kiln, N-NE Wall Exterior, After Treatment

SAGU, CAMINO LOMA ALTA KILN, STABILIZATION



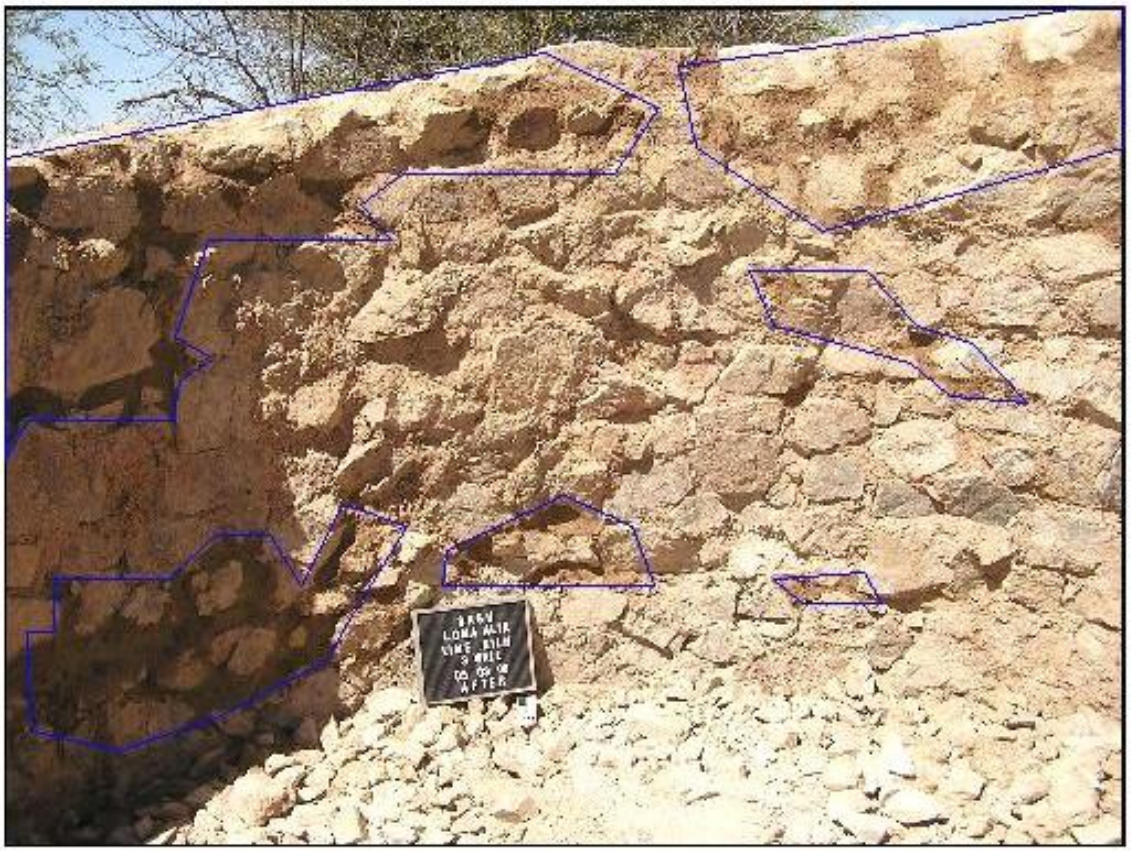
Camino Loma Alta Lime Kiln, North Wall Interior, After Treatment

SAGU, CAMINO LOMA ALTA KILN, STABILIZATION



Camino Loma Alta Lime Kiln, West Wall Interior, After Treatment

SAGU, CAMINO LOMA ALTA KILN, STABILIZATION



Camino Loma Alta Lime Kiln, South Wall Interior, After Treatment

SUS LIME KILN, NORTH KILN, EAST WALL

SUS LIME KILN, NORTH KILN, STABILIZATION



Sus Lime Kiln, North Kiln, East Wall Interior, After Treatment

SUS LIME KILN, NORTH KILN, STABILIZATION



Sus Lime Kiln, North Kiln, West Wall Interior, After Treatment

SUS LIME KILN, NORTH KILN, NORTH (NE) SECTION

SUS LIME KILN, NORTH KILN, STABILIZATION



Sus Lime Kiln, North Kiln, East- NE Wall Interior, After Treatment

SUS LIME KILN, NORTH KILN, SOUTH WALL

SUS LIME KILN, NORTH KILN, STABILIZATION



Sus Lime Kiln, North Kiln, South Wall Interior, After Treatment

SUS LIME KILN, NORTH KILN, RETAINING WALL

SAGU, SUS LIME KILN, NORTH KILN, STABILIZATION



Sus Lime Kiln, North Kiln, Looking South, Retaining Wall, After Treatment

SUS LIME KILN, SOUTH KILN, E/SE WALL SECTION

SUS LIME KILN, SOUTH KILN, STABILIZATION



Sus Lime Kiln, South Kiln, S-SE Wall Interior, After Treatment

SUS LIME KILN, SOUTH KILN, WEST WALL SECTION

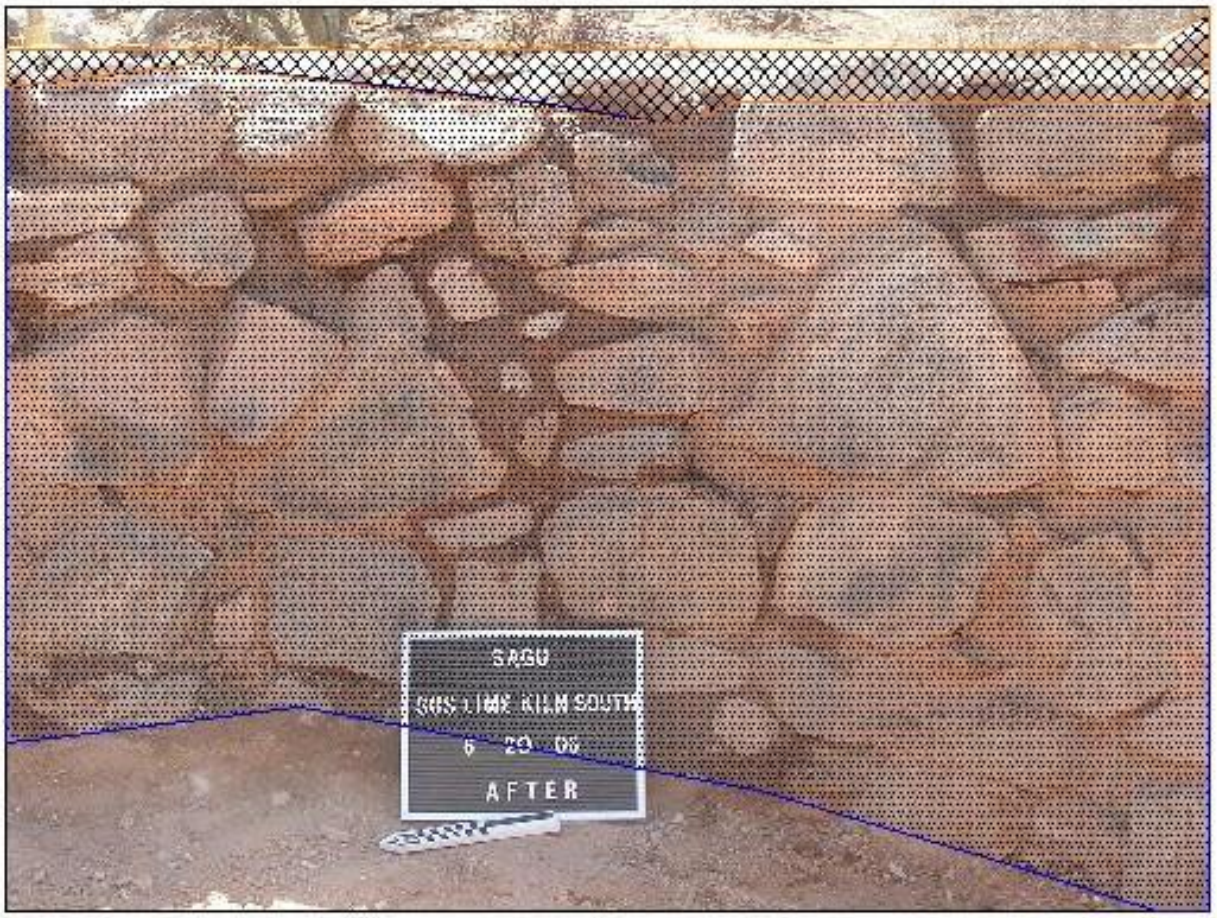
SUS LIME KILN, SOUTH KILN, STABILIZATION



Sus Lime Kiln, South Kiln, West Wall Interior, After Treatment

SUS LIME KILN, SOUTH KILN, SOUTH WALL SECTION

SUS LIME KILN, SOUTH KILN, STABILIZATION



Sus Lime Kiln, South Kiln, South Wall Interior, After Treatment

SUS LIME KILN, SOUTH KILN, LOOKING SOUTH AT REBUILT WALL SECTION

SUS LIME KILN, SOUTH KILN, STABILIZATION



Sus Lime Kiln, South Kiln, Looking South at Rebuilt Section, After Treatment

APPENDIX C: WESTERN MAPPING SCOPE OF WORK AND PROJECT BUDGET

July 17, 2006

SCOPE OF SERVICES

3D Laser Scanning, Mapping and Architectural Documentation
at
Saguaro National Park (Historic Lime Kilns)
(PI: Jeremy Moss, Archaeologist, TUMA)
(SAGU Contact: Meg Wessner)

Task 1- Establish permanent datums with UTM coordinates for the four lime kilns (Lime Kiln #1, #2, #3 and Camino Loma Alta Kiln) in the Rincon Mts. District and two lime kilns (Sus Lime Kilns 1 and 2) in the Tucson Mts. District.

Project Description:
The survey project will include establishing accurate UTM coordinates and sea level elevation for six site datums and two additional caps near the historic lime kilns. All surveying will be conducted using high-accuracy RTK-GPS, geodetic quality total stations and leveling systems. The datums will be established to ensure horizontal accuracy of 2.5cm or better (95% CI) and vertical accuracy of 4.0cm or better relative to the UTM coordinates as determined though the use or regional NGS CORS stations. These type of surveys generally attain accuracies of about half the stated 95% CI suggested above.

** NPS (TUMA and SAGU) staff will 1) assist in vegetation mitigation meeting conservation standards in and around features and sites to be mapped, 2) identify site boundaries around the Lime Kilns with pin flags, 3) locate any artifacts within the area of the lime kiln to be mapped, 4) provide logistical support to Western Mapping Company survey scanning teams using pack-mules to pack in and out equipment in remote project locations.

Deliverables (Task 1):
1) Six permanent datums tied to UTM 12 NAD83 NAV88.
2) Two additional datums will be established to aid in survey and future park mapping needs.
3) UTM coordinates for the datums will also be recorded.

Task 2- 3D Laser Scanning, Model Data and Production of Planimetric (w/topography) Maps of the Six Historic Lime Kilns in the Rincon and Tucson Mts. Districts

Project Description:
This project involves high resolution 3D scanning of the six historic lime kilns at SAGU. All scanning will be geo-referenced so that data produced from the project can be integrated with the park GIS. Scan resolution will vary and will be determined in the field. The scanned data will be used to produce 3D TIN models for use in the development of planimetric maps and architectural profiles. All maps will have digital and hard copy versions. Planimetric maps of the six kiln sites will include limits of rock debris piles, ash areas, other site features, point-provenienced artifacts (<50) and artifact concentrations.

** NPS, (TUMA and SAGU) staff agree 1) assist in vegetation mitigation meeting conservation standards in and around features and sites to be mapped, 2) identify site boundaries around the Lime Kilns with pin flags, 3) locate any artifacts within the area of the lime kiln to be mapped, 4) provide logistical support to Western Mapping Company survey scanning teams using pack-mules to pack in and out equipment in remote project locations.

Deliverables (Task 2):
1) Six point geo-referenced clouds,
2) Six TIN models
3) Six 3D Autocad drawings defining wall edges, wall tops, wall bases, and structural features. A copy of 3D model viewer will be provided and park staff trained in its use.
4) Six planimetric site maps with 5-10cm topography and architectural CAD data from scanning of the kilns. Hardcopies of the maps will be produced at a scale suitable for proper viewing of site features, which will include (2) 11" x 17" maps (2) 24" x 26" and 8" x 11" maps.
5) 12 profile maps (2 of each kiln).

Task 3- Historical Research/Digital Cartography of Old GLO and USGS Sheets, etc.

Project Description:
Project is to aid historical research of the lime kilns and help identify historic features not seen today like historic roads, trails or limestone quarries associated with the lime kilns.

Deliverables (Task 3):
Geo-referenced digital historical map data pertaining to roads, trails, structures and limestone quarries associated with the lime kilns will be created for the final report on the historic lime kilns of Saguaro. It is uncertain how much data, including maps, will be produced since some the information may not exist.

Task 4- Digital Photography for the Creation of Architectural Documentation Sheets

Project Description:
Project is to aid in the creation of color architectural sheets and to add color to the laser scanned image of the kilns through rectified digital photography. This will add significant detail to the scanned image and will result in the creation of architectural sheets which are essential for detailed monitoring and documentation of structural condition through bi-annual or tri-annual monitoring.

Deliverables (Task 4):
1) Original digital photographs with electronic photo log. (undetermined number of photos)
2) Digital and hardcopy versions of each architectural sheet.

DATE OF COMPLETION:

All work shall be complete within one year from issuance of the task order

GOVERNMENT COST ESTIMATE

Task 1- Establish permanent datums with UTM coordinates for the four lime kilns (Lime Kiln #1, #2, #3 and Camino Loma Alta Kiln) in the Rincon Mts. District and two lime kilns (Sus Lime Kilns 1 and 2) in the Tucson Mts. District.

Task 2- 3D Laser Scanning, Model Data and Production of Planimetric (w/topography) Maps of the Six Historic Lime Kilns in the Rincon and Tucson Mts. Districts

Task 3- Historical Research/Digital Cartography of Old GLO and USGS Sheets, etc.

Task 4- Digital Photography for the Creation of Architectural Documentation Sheets

Staff	**Hourly Cost**	**Hours**	**Total**
Holmlund	94.60	80	7,568.00
Haas	52.03	180	9,365.40
Nicoli	52.03	140	7,284.20
Kraybill	42.57	240	10,216.80
Scott	44.94	160	7,189.60
Total		800	41,624.00

Direct Costs

Equipment (3D Laser scanner, Kinematic GPS, Total Station) ……..	5,080.00
Vehicle (5 days @ $55/day) ……	275.00
Mileage (500 miles @ $0.20/mi.) ……	100.00
Supplies (datums) …….	100.00
Plots ……..	48.00
Total …….	5,603.00
Grand Total …….	***47,227.00***