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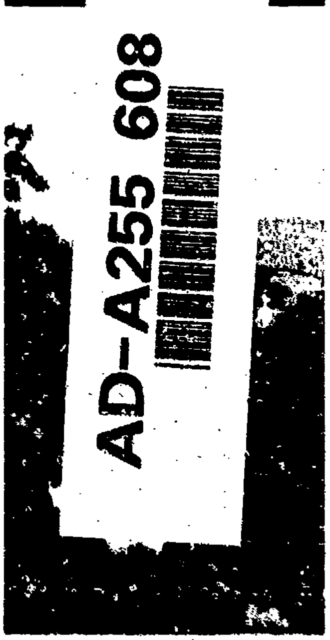

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STABILIZATION OF DAKOTA SANDSTONE SURFACE OF THE FARIS CAVE PETROGLYPHS KANOPOLIS LAKE PROJECT, KANSAS

by

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Native american rock art sites are affected by numerous types of impacts originating from both cultural and natural sources. Some of the most difficult losses to control are those resulting from weathering or deterioration of the stone itself. This report discusses the results of field and laboratory experiments that examined the use of a stone strengthener and water repellent to solidify porous and poorly bonded Dakota Formation Sandstone in central Kansas. The results indicate that these chemicals, which are based on organosilicon compounds dissolved in a ketone carrier, provide substantial cementation of the sand grains with no detrimental change in the color, porosity, or permeability of the stone. This technology will significantly prolong the existence of important petroglyphs on sandstones.

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Preface

This study was conducted as part of Work Unit 32357, entitled "Field Preservation of Cultural Sites," of the Environmental Impact Research Program (EIRP). The EIRP is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), and is managed by the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES). Technical Monitors were Dr. John Bushman, Mr. David P. Buelow, and Mr. Dave Mathis of HQUSACE. Mr. Paul Rubenstein of HQUSACE also provided technical guidance and review. Drs. Frederick Briuer, WES, and Roger Grosser, US Army Engineer District, Kansas City, provided technical reviews of the report. Dr. Roger T. Saucier, EL, WES, was the EIRP Program Manager.

The work was conducted under provisions of Contract No. DACW39-90-M-0445 between WES and the Kansas Geological Survey, University of Kansas. Dr. David A. Grisafe of the Survey was the Principal Investigator and prepared the report.

The study was conducted under the direct supervision of Dr. Paul R. Nickens, Resource Analysis Group (RAG), Environmental Resources Division (ERD), EL. General supervision was provided by Mr. H. Roger Hamilton, Chief, RAG; Dr. Conrad J. Kirby, Chief, ERD; and Dr. John Harrison, Director, EL.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
gallons (US liquid)	3.785412	liters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
pounds (force) per square inch	6.894757	kilopascals
square feet	0.09290304	square meters
yards	0.9144	meters

STABILIZATION OF DAKOTA SANDSTONE SURFACE OF THE FARIS CAVE PETROGLYPHS: KANOPOLIS LAKE PROJECT, KANSAS

Introduction

1. Rock art originating from prehistoric and historic American Indians, as well as early settlers, provides a link to our past. Although such rock art has received some degree of notoriety, notably in the western United States, rock art sites are scattered throughout the country. Yet, outside of the realm of archeologists and hobbyists, many sites are unknown except for a few local residents. Kansas contains many examples.

2. Some sites have been subjected to varying forms of vandalism, but as a whole, the most destructive force acting on all rock art is natural weathering. Rock art sites are gradually attacked by a variety of phenomena, including freeze-thaw, wet-dry and heat-cool cycling, wind and water erosion, biological growth, salts, atmospheric pollution, and mineral weathering. Naturally, the geographical location of a site (with regard to its climatic characteristics) and the degree of protection provided to the site play major roles in determining which agent or agents are most detrimental.

3. Despite the attempts to protect sites from vandalism, little work has been done in finding a suitable treatment to increase the durability of the stone itself. However, before treating any stone, it is necessary to understand the nature of the stone. For example, there is little point in treating a stone with a chemical solution if the stone has no absorption. Thus, it is important to understand certain basic mineralogical and physical characteristics of the stone and be able to evaluate the changes of such properties as a result of any type of treatment.

4. There are natural reservations to treating petroglyph sites since such art is irreplaceable. A treatment could produce more problems than cures. However, while debating the merits and durability of a treatment, nature continues to erode such art, and many sites cannot afford to wait much longer before destruction is complete.

5. Greater emphasis has been placed on the chemical treatment of historical stone structures, particularly in Europe, than on treating petroglyphs. While not identical, there are similar problems and constraints in treating a building or a rock art site. Past experience with buildings provides useful guidelines for selecting a successful method for treating

petroglyph sites. Some proposed methods of treatment border on the exotic. About 20 years ago, when epoxy cement became popular, it was proposed that holes be drilled behind petroglyphs and epoxy cement pressure-injected into the holes. Such a method has great potential to destroy rock art.

6. The primary objectives of this project were to (a) outline a testing program that can be used to understand the nature of the stone both before and after treatment with a chemical solution and (b) show the effectiveness of silicic ethyl ester or ethyl silicate dissolved in the low-viscosity carrier methyl ethyl ketone and applied to a soft, porous sandstone bearing petroglyphs at the Faris Cave Site to prolong the life of the petroglyphs.

Discussion of Requirements To Meet the Objective

7. Simple nondestructive testing can be used to determine the basic properties of the stone. To examine the mineralogy, x-ray analysis or optical microscopy can be used, and to determine the porosity/permeability characteristics, capillary or immersion absorption and vapor or liquid transmission. The latter physical characteristics can also be measured on treated stone. In addition, compressive strength measurements are often used to evaluate the effectiveness of a stone-strengthener treatment. Other methods to evaluate a treatment include freeze-thaw cycling and wet-dry cycling. The latter is particularly important for stones that contain significant amounts of expandable clay minerals. The important point to remember is that most of the physical property measurements do not require expensive instruments and can be done in almost any laboratory.

8. One may be misled into thinking that a waterproof agent coating the surface of the rock art will be sufficient to stop deterioration caused by moisture. While this may help, it must be remembered that moisture is present throughout the stone. Fractures, joints, bedding planes, and the natural permeability of the stone all provide avenues for moisture to reach the rock art, including moisture from the ground moving upward and outward.

9. Many sites, particularly those on uncemented sandstones that are held together primarily by interlocking grains or sandstones that have undergone extensive weathering with little remaining cement, need to be treated with a cementing agent to bind the grains of the stone together before any waterproofing agent is applied. Such a cementing agent gives the stone

additional strength that will enable it to better withstand the stresses caused by natural weathering phenomena.

10. Certain requirements must be met by any strengthening agent being considered for preserving a rock art site, as summarized below.

- a. Strengthening agent should penetrate stone to a sufficient depth to treat all of the zone of weathering.
- b. Agent should cause an increase in strength.
- c. Stone should be able to breathe after treatment so that the stone can rid itself of moisture.
- d. Treatment should not cause any color change.

11. Many attempts, using a variety of treatments, have been made to preserve stone on historical structures. Many of these probably have done more harm than good because of their failure to meet one or more of the above requirements, even when an increase in strength seems to have been attained.

12. To achieve the desired depth of penetration, the stone must have a certain amount of accessible porosity or permeability. However, one must also consider the properties of the penetrating agent. Depth of penetration will be enhanced by having the penetrating agent be of a low molecular weight and completely dissolved in a low-molecular weight, low-viscosity hydrocarbon carrier. Such a system would be expected to achieve greater penetration than an aqueous colloidal suspension such as an alkali silicate. In addition, the latter type of agent would be more prone to cause surface enrichment of the colloidal material, producing a lightening of the stone color due to the formation of a thin crust. Also, aqueous solutions often do not have neutral pH values, and in some cases, reaction with minerals in the stone and possible discoloration may occur. In contrast, organic systems, such as the one used in this study, possess neutral pH values.

13. Perhaps the most overlooked requirement in a strengthening agent is its effect on the permeability or vapor transmission of the stone. The agent must not completely seal the pore system of the stone, or problems will likely develop over time because of the excess moisture trapped behind the exterior of the stone. Such moisture can become rich in soluble salts that may crystallize during dry seasons just beneath the sealed pore zone. Then, a period of wet weather may cause rehydration of an anhydrous salt, and consequent volume expansion will occur. In colder climates, trapped moisture may lead to sanding and spalling. Remember that water begins to expand once the temperature drops below 4 °C, and additional expansion occurs if the moisture

freezes. One needs only to recall the cracking, spalling, and potholes that appear in roads during the winter to realize how detrimental freezing can be. In summary, any treatment of rock art must allow the stone to breathe in order to minimize the destructive effects of excess moisture trapped in the rock.

14. Considering the stringent requirements for a safe and effective strengthening agent for use on rock art sites, the agent chosen for this study is based on ethyl silicate completely dissolved in the low-viscosity carrier/solvent methyl ethyl ketone. The low viscosity and low molecular weight of this solution ensure good depth of penetration for any stone, providing it has some degree of permeability. It is a colorless solution with a neutral pH value and would not be expected to cause any discoloration of the stone. In the United States, the sole supplier of this strengthening agent, known as Conservare OH, is the Process Solvent Company, located in Kansas City, KS.

15. The past experience of the author with this system in testing dimension stones from historically important buildings showed no discoloration of the stone, an increase in strength, and good depth of penetration; in addition, the system did not completely seal the pores. The mechanism involves a slow hydrolysis or reaction between the ethyl silicate and moisture in the stone to produce a silica-based cement. Strength measurements indicate the system is especially effective when applied to soft, porous sandstones and has led some researchers to believe a chemical bond is formed (-Si-O-Si-) between the hydrolysis-produced silica and the silica sand grain. Considering the above, the system seemed an ideal candidate to increase the durability of a rock art site where petroglyphs had been carved into a soft sandstone.

Site Selection and Description

16. The State of Kansas contains a significant number of rock art sites. A few have seen extensive visitation and consequently include large amounts of graffiti. Few remain in pristine condition with respect to graffiti. The highest density of known rock art sites occurs in central Kansas, an area abundant in its outcrops of soft, porous sandstones belonging to the Dakota Formation. As expected, most of these sites occur near rivers, streams, or springs.

17. Such outcrops are very common in Ellsworth County, near the center of the state. The stone is often soft and porous, and varies in color from nearly white to buff to red to brown. The variation in color is due primarily

to the amount and type of iron-bearing minerals, commonly limonite, goethite, and hematite. At some locations the sandstone contains clay minerals, while other locations may be completely void of clays and contain only quartz and a small amount of iron mineralization. The stone often supports biological growth (algae, mosses, and lichens) and contains abundant vertical joints. Such joints have led to blocks of petroglyphs parting and falling from the cliff face at one of the state's most famous petroglyph sites, the Indian Hill Petroglyphs on the northern shore of Kanopolis Lake.

18. It was decided that an easily accessible site on Corps of Engineers' property near Kanopolis Lake (Figure 1) would be ideal for this initial investigation. The site chosen is commonly called the Faris Cave Site or Three Cave Site, located at the east side of the Smoky Hill River just upstream from Kanopolis Lake. The name is attributed to the Faris family, who used the three small rooms carved into the base of the cliff by the previous owner, Charles Griffee, during the 1880s (Figure 2). The family may have temporarily lived in the caves while building their home, taking advantage of the still-active spring in the northernmost cave for storing food. Later, the middle cave was used as a one-room schoolhouse while the southernmost cave housed a generator. At the cave area and for approximately 150 ft* to the north and south, the graffiti density is so great that any previous American Indian carving has been obliterated or obscured except for a few isolated glyphs. As for early settlers, the earliest found to date is attributed to Henry Burke, 1865. Sand slopes at the base of the cliff have buried much graffiti and, possibly, additional Indian petroglyphs.

19. The question naturally arises as to why some of the graffiti and petroglyphs seem relatively "fresh" while others are badly weathered. The answer is based on several factors, such as the age, degree of protection, density of the stone, depth of the carving, and degree of case hardening. Some areas of stone are quite soft and carvable with a fingernail, while other areas are relatively hard on the surface. Not surprisingly, the Indian petroglyphs at this site are generally on stone that contains a hard exterior surface.

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* A table of factors for converting non-SI units of measurement to SI units is presented on page 3.

20. A detailed description of the glyphs and distances between them is not the main focus of this study; however, to the north of the caves are a buffalo, cross, animal heads (deer or wolf, bison?), the front of what may be a lizard, a sunburst or head with headdress (nearly obliterated by firearms), and a few other glyphs of uncertain nature. To the south of the caves are two quadripeds (horses?), a fish, and bow-and-arrow and other arrow glyphs. During the project, an isolated glyph was found on a boulder in a small draw approximately 150 yd north of the caves. Examples are shown in Figures 3 and 4.

21. Throughout the area there are zones of appreciable biological growth that may be hiding other glyphs, but since the sandstone is so porous, such growth penetrates the stone. To remove the growth might cause damage to the exterior surface. In addition, some locations show a thin, often peeling white crust of salt and sand on the lower 1 to 3 ft of the cliff. Plant growth in the form of shrubs and vines at the base of the cliff may slowly abrade the surface when blown by the wind. A similar effect occurs higher on the cliff surface from tree branches. In addition, tree roots growing into joints and fractures on the cliff may slowly enlarge these openings and assist in removing blocks of stone from the face of the cliff.

Experimental Procedures

22. After examining the area and photographing the site, two small test panel areas were selected to observe the effects, if any, caused by the use of the Conservare OH stone strengthener sprayed on the panels and subsequent spraying of a mixture of strengthener and water repellent (Conservare H), prior to actual treatment of the petroglyphs. A stainless steel sprayer, equipped with Viton plastic fittings and gaskets, was used for all applications of the Conservare products (Figures 5 and 6). The Viton is necessary because normal gasket materials such as neoprene rubber would be dissolved by the methyl ethyl ketone common to these products.

23. In situ capillary absorption measurements were taken at several locations near the petroglyphs and on test panels, to obtain an initial idea of the permeability of the stone. The simple capillary tube device is designed for measurements on vertical surfaces (Figure 7). After sealing the 1-in.-diam bottom of the device to the sandstone surface with mastic, the tube was filled with water and the time was recorded for 5.0 ml of water to be

absorbed. Some difficulty was experienced in obtaining a good seal because of the very friable nature of the stone and biological growth at some locations (Figures 8 and 9).

24. Small blocks of sandstone that had fallen were collected and taken to the laboratory where they were fabricated into 1.5-in.-diam cores and then trimmed to obtain relatively parallel ends. All cores were between 1.5 and 1.75 in. in height. A trim saw was also used to fabricate 1.5-in.-diam wafers 0.25 to 0.375 in. thick for eventual vapor transmission measurements. Irregular pieces from the blocks were examined under a reflected light microscope and then ground into -200 mesh powder with an alumina mortar and pestle for subsequent chemical (by atomic absorption) and x-ray diffraction studies.

25. Randomly selected sets of nine cores were used for various treatment cycles; one set was used as a control (untreated). The treatment cycles used on the cores and wafers are shown in Table 1. All treatments were by capillary absorption using a thin layer of chemical solution in a stainless steel pan and placing the cores in a vertical position for the selected amount of time. This method of treatment was chosen since it more closely resembles field treatment conditions than complete immersion. The wet weight of each core was recorded immediately after treatment. Cores and wafers were allowed to cure in air for at least 3 weeks before any additional treatment since the reaction is nearly complete after this period of time. After 3 weeks, the cured weight was recorded.

26. Sets of cores were evaluated for their absorption characteristics using the weight of water absorbed after 24 hr immersion and also by capillary absorption on a water-saturated sponge. For the latter method, the weight gain was recorded as a function of time.

27. The compressive strength for six cores from each set was obtained using a Riehl Precision Hydraulic Universal Testing Instrument (model KA-60). The remaining three cores from each set were evaluated for their freeze-thaw resistance using a cycle of 16 hr in a freezer at -20 °C followed by immersion in room temperature water for 8 hr.

Results and Discussion

28. In situ capillary absorption measurements showed that the sandstone at the Faris Cave Site acted like a sponge. The time required for 5.0 ml of water to be absorbed, using a 1.0-in.-diam opening, varied from 22 sec to a

maximum of 155 sec. These values indicate high permeability and, therefore, a good depth of penetration by the proposed chemical treatment.

29. A summary of the chemical analyses for seven samples is shown in Table 2. In general, the stone consists of over 96 percent silica and about 1.5 percent iron oxide. The remainder is divided between the loss on ignition at 1,000 °C and several oxides. The low alumina content indicates the absence of any significant amounts of clay or feldspar minerals. This is in agreement with optical microscopy. Optically, one observes quartz grains, many with a thin, fine-grained buff coating, and occasional grains of opaque mineral(s) and muscovite mica. Based on these observations, this sandstone would be classified as an arenite or arenaceous sandstone. The x-ray diffraction patterns showed only the presence of quartz (Figure 10). Since the iron oxide content is low and iron minerals and iron-bearing clay minerals are often poorly crystallized, the absence of any iron minerals in the diffraction patterns is not surprising. The color under the microscope suggested that some of the iron may be present in traces of clay or as limonite. A piece of sandstone higher on the cliff face that possessed a higher iron content did show traces of goethite in the x-ray diffraction pattern.

30. The average weight percent capillary water absorption as a function of time for each set of cores is shown in Table 3. The data show that the uptake of liquid is very rapid for the control; increasing the number of treatment cycles tends to slow this rate of uptake. Table 4 summarizes the 24-hr absorption obtained by both capillary and immersion methods. As expected, with increasing treatment cycles, the amount of water absorbed after 24 hr decreases for both capillary and immersion measurements. Since the stone continues to absorb liquid after several treatments, the treatment has not completely sealed the pore system. For this particular stone, the results indicate that vapor transmission studies are not necessary.

31. Table 5 shows the weight gain for cured cores after their final treatment, along with their compressive strength. The weight gain can be considered a measure of the amount of solids deposited into the pore structure and increases with additional treatments. Particularly notable are the compressive strength values which show that strength more than doubled after only one treatment. The data show an unusually large improvement in strength and clearly show the successful cementation of individual sand grains to one another.

32. As mentioned earlier, three cores from each treated set and three untreated cores were evaluated for their freeze-thaw resistance by submitting them to 16 hr at -20 °C followed by 8 hr immersion in water. Except for complete failures, cores were submitted to a total of 100 cycles, and the weight loss was measured after every 25 cycles.

33. Table 6 shows the percent weight loss for each set of cores after 25, 50, 75, and 100 cycles. The data show an increased resistance to freeze-thaw cycling (lower weight loss) with increasing numbers of treatments. Two of the untreated cores failed completely (disintegrated completely to sand grains) during the first 25 cycles, while the third core in the set failed completely on the 33rd cycle. By contrast, none of the treated cores failed completely during the 100 cycles, including those given only a single 2-min capillary absorption treatment (Figure 11). However, the latter cores were friable, suggesting that more than one consolidation treatment is necessary for this type of stone.

34. As expected, small weight losses occurred by sanding (the removal of grains from the exterior surface). With increasing numbers of treatments, the increased bonding minimized the amount of grains removed in this manner. A few of the treated cores showed areas of swelling and cracking during the first 25 cycles, but no complete failure occurred after 100 cycles. The cause of this swelling is unknown but was never observed at the site.

35. Finally, the previously mentioned test panels were treated with two coats of Conservare OH stone strengthener and two coats of Conservare H. Each application, followed by at least a 3-week cure, used a coverage rate of 10 sq ft/gal. The resulting surface is quite hard, and no apparent discoloration has occurred, as shown in Figure 12. The resulting in situ capillary absorption measurements showed that the combined treatments reduced the absorption to about one-fifth to one-tenth the original absorption, but the remaining permeability would be sufficient to allow the stone to breathe and rid itself of excess moisture.

36. The results obtained from the test panels coupled with results obtained from the completed laboratory testing led to the treatment of the petroglyphs using the same sequence of treatments and application rates described for the test panels. A low-pressure, fine spray was used to eliminate the removal of the sand grains from the surface of the sandstone during treatment. In an attempt to minimize runoff and apply equal amounts of chemicals to all surfaces, a fan tip was used on the sprayer and the surface was

treated by slow horizontal passes across the bottom of the area, gradually working to the top of the panel being treated.

Summary

37. When the project was begun, it was felt that a strength improvement of at least 30 to 40 percent should be obtained to justify the expense of treating the petroglyphs. Clearly, as shown in Table 5, this goal was exceeded with a single treatment. However, the very weak nature of the stone suggests that the stone at this site is held together by interlocking grains and has little or no chemical bonding. This fact, coupled with high permeability and breathability of the stone after several treatments, has justified the use of two treatments of strengthener on the petroglyphs, followed by two applications of the strengthener-water repellent mixture. This, of course, increases the expense associated with increased chemical consumption; however, the additional cost is more than justified to preserve these petroglyphs.

38. Finally, the testing methods and chemical treatment outlined in this report indicate this methodology would be suitable for the preservation of rock art on soft porous sandstone and also has the potential for use on other types of stone possessing a moderate degree of permeability. Only by further research will this potential be realized. At present, the US Army Engineer District, Kansas City, is supporting an examination and treatment of two other small petroglyph sites in Red Rock Canyon and along Alum Creek. Both sites are located on Corps property near the northern shore of Kanopolis Lake.

Table 1

Chemical Treatments of Sandstone Cores Using

Conservare OH and H Products

	Treatment Time Using Capillary Absorption, min				
Treatment	OH*	OH	OH	H**	H
Control	0	0	0	0	0
1 OH	2	0	0	0	0
2 OH	2	2	0	0	0
3 OH	2	2	10	0	0
2 OH + 1 H	2	2	0	10	0
3 OH + 2 H	2	2	10	10	10

* Stone strengthener.
** Strengthener-water repellent mixture in a 2:1 ratio.

Table 2

Summary of Chemical Analyses of Sandstones by Atomic Absorption

(Weight Percent Composition)

	Sample							
Oxide	1B	2C	3T	4B	5C	6T	7B	Average
SiO_2	96.21	94.27	96.57	96.95	96.66	96.64	96.29	96.23
Al_2O_3	0.23	0.24	0.21	0.22	0.28	0.22	0.22	0.23
Fe_2O_3	2.15	2.62	1.09	1.02	0.85	1.01	1.61	1.48
TiO_2	0.52	0.53	0.57	0.51	0.53	0.52	0.72	0.56
MnO	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
CaO	0.06	0.15	0.04	0.04	0.04	0.03	0.04	0.06
MgO	0.03	0.04	0.02	0.02	0.02	0.02	0.02	0.02
K_2O	0.36	0.34	0.38	0.37	0.38	0.37	0.34	0.36
Na_2O	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Loss on ignition	0.79	1.55	0.68	0.38	0.68	0.78	0.45	0.76
Total	100.39	99.78	99.59	99.54	99.47	99.62	99.72	99.73

Table 3

Average Capillary Absorption Values as a Function of Time and Treatment for Sandstone Samples

Treatment	Percent Weight Gain (per Unit of Time in Minutes) 0.5	1.0	2.0	5.0	60	120
Untreated	15.3	15.8	15.8	15.8	--	--
1 OH	6.0	8.7	11.8	12.8	12.9	12.9
2 OH	1.6	2.7	4.3	7.8	10.1	10.1
3 OH	0.8	1.2	1.6	2.3	6.4	7.1
2 OH + 1 H	0.9	1.2	1.6	2.3	6.6	7.2
3 OH + 2 H	<0.1	0.1	0.2	0.3	1.0	1.3

Table 4

Comparison of 24-hr Absorption Values by Capillary Absorption and Immersion for Sandstone Samples as a Function of Treatment

Treatment	Absorption Value in Weight Percent: Capillary	Immersion
Untreated	15.8	16.1
1 OH	12.9	13.8
2 OH	10.2	11.0
3 OH	7.3	8.7
2 OH + 1 H	7.4	8.6
3 OH + 2 H	1.5	4.3

Table 5

Percent of Solids Deposited and Compressive Strength as a Function of Treatment for Sandstone Samples

Treatment	Percent Solids	Compessive Strength psi	Percent Improvement
Untreated	0.0	1,080*	--
1 OH	5.3	2,550	136
2 OH	9.8	3,050	182
3 OH	13.4	4,750	340
2 OH + 1 H	12.9	4,640	330
3 OH + 2 H	17.5	7,650	608

* Denotes maximum value for untreated cores. Because of the somewhat irregular surfaces of the tops and bottoms of the cores, all were capped with a high-density plaster material to ensure uniform distribution of the load. Three of the six cores were so weak that the caps became loose and yielded much lower values that were considered inaccurate. Had all six cores of the control set been used to obtain an average value, the treated cores would have shown an even greater percent improvement.

Table 6

Percent Weight Loss from Freeze-Thaw Cycling of Sandstone Cores

	Number of Cycles			
Treatment	25	50	75	100
Untreated	76.0	100.0	100.0	100.0
1 OH	0.0	0.8	2.8	4.6
2 OH	0.0	0.1	0.8	1.3
3 OH	0.0	0.0	0.3	0.6
2 OH + 1 H	0.0	0.1	0.3	0.4
3 OH + 2 H	0.0	0.0	0.0	0.0

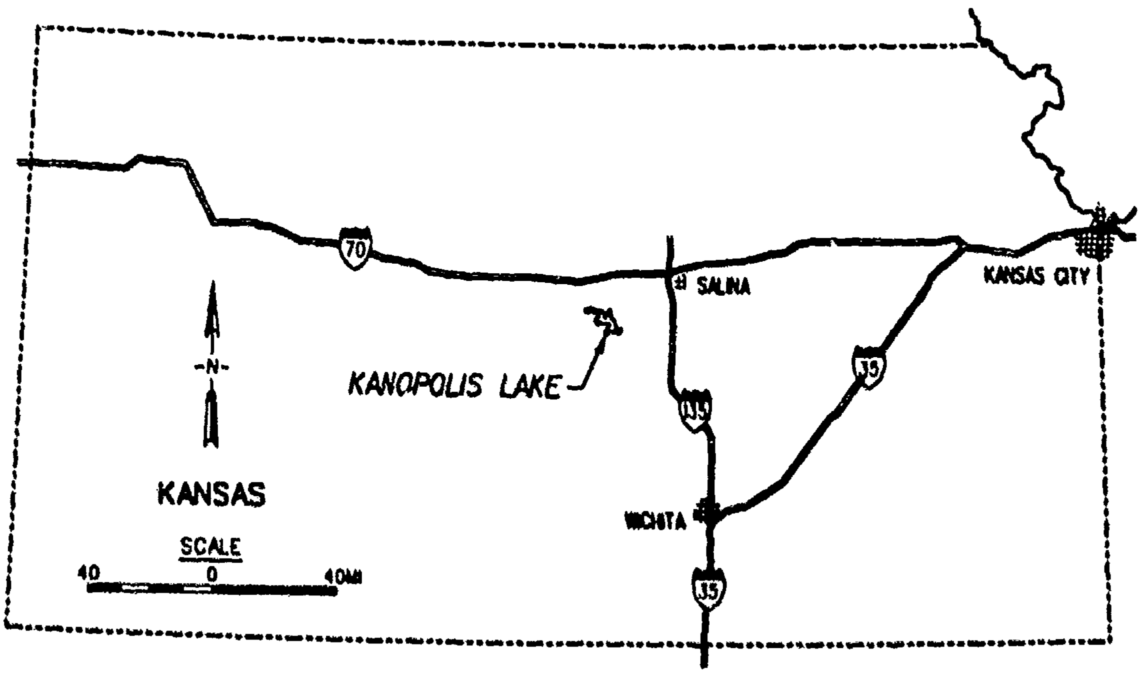

Figure 1. Location map showing the Kanopolis Lake Project, Ellsworth County, Kansas

Figure 2. Approach to Faris Cave Site, showing the three doorways to the late-19th century man-made caves or rooms at the base of the cliff. The northernmost room (extreme left) still contains an active spring

Figure 3. Example of aboriginal petroglyphs and historic period graffiti

Figure 4. This bow-and-arrow glyph at the Faris Cave Site is thought to be Pawnee in origin and symbolizes a hunting campsite

Figure 5. Small areas along the cliff were selected as test areas and sprayed with stone strengthener

Figure 6. This test panel has just been sprayed and appears darker relative to untreated areas. This darkening disappears in a matter of days as the result of evaporation of the keytone/solvent carrier and by-product ethyl alcohol

Figure 7. In situ capillary absorption measurement. The time required for the stone to absorb 5 ml of water was used as a relative measurement of the ability of the stone to absorb water

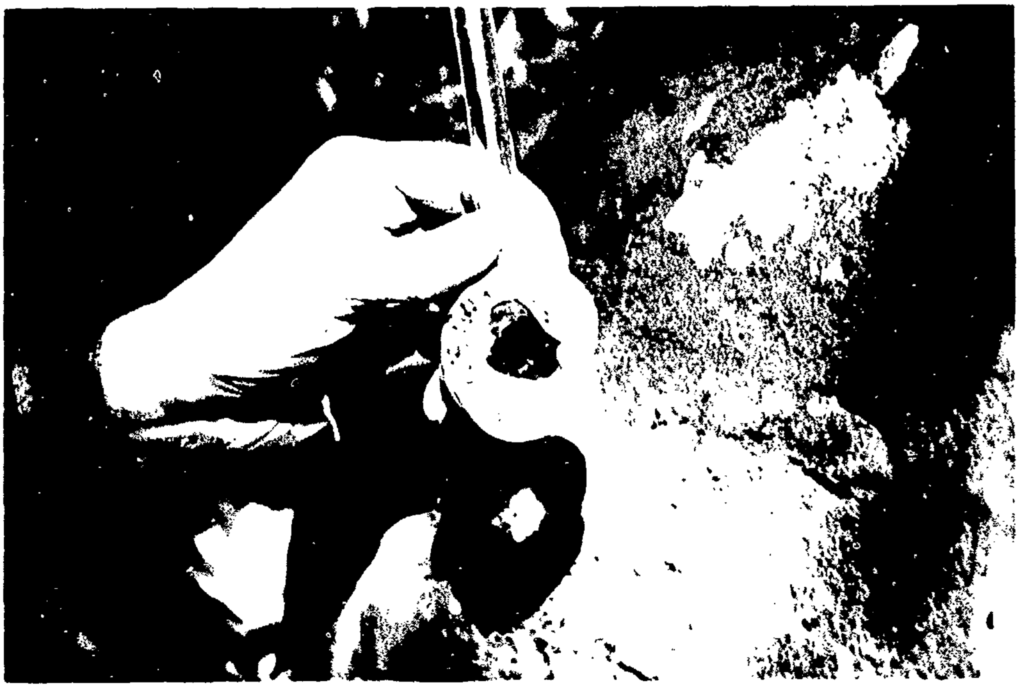

Figure 8. Biological growth often made it impossible to form a watertight seal (note residue on ring of mastic) between the base of the capillary tube and the sandstone

Figure 9. The flat edge of rock hammer was used to gently scrape off most of the biological growth in order to form a watertight seal for the capillary tube

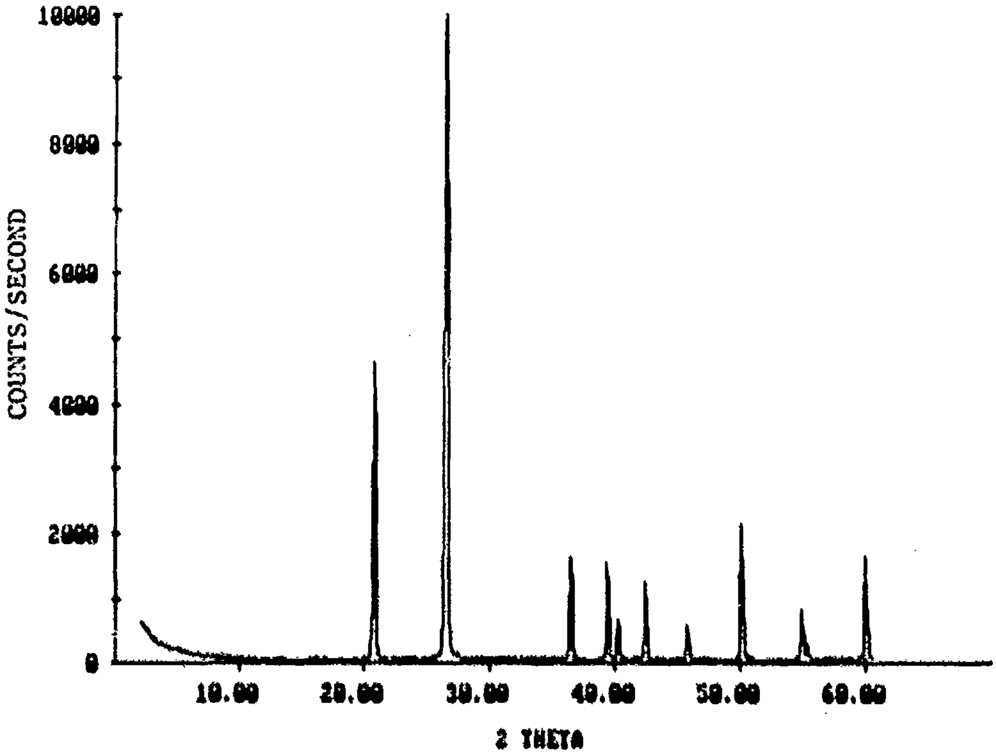

Figure 10. X-ray diffraction pattern (2 theta versus counts per second) for a sample of the Dakota Formation sandstone at the Faris Cave Site. All seven samples collected at the site yielded the same pattern with all diffraction peaks due to quartz

Figure 11. Results after 25 freeze-thaw cycles. The three cores on the left had received one 2-min capillary absorption treatment with Conservare OH stone strengthener. These cores show no damage. By contrast, the core on the right is all that remains from a set of three untreated cores. The other two cores completely disintegrated

Figure 12. Left side has been treated twice with OH and once with H; right side has not been treated. No discoloration has resulted from the treatments