Contractor Report

Permanent Markers Monument Survey

Waste Isolation Pilot Plant
Carlsbad, New Mexico

August 31, 2000

Contractor Report

Permanent Markers Monument Survey

Waste Isolation Pilot Plant
Carlsbad, New Mexico

August 31, 2000

Prepared for:

Westinghouse Government Environmental Services Company
Waste Isolation Division
P.O. Box 2078
Carlsbad, New Mexico 88221

Prepared by:

John Hart and Associates, P.A.
2815 Candelaria Road, N.W.
Albuquerque, New Mexico 87107
(505) 344-7868

Table of Contents

List of Tables

List of Figures

1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) has been constructed by the U.S. Department of Energy (DOE) in southeastern New Mexico as a disposal facility for transuranic (TRU) wastes. The WIPP is subject to the provisions of U.S. Environmental Protection Agency (EPA) environmental protection standards defined in 40 CFR Part 191 (EPA, 1993) and compliance certification criteria set forth in 40 CFR Part 194 (EPA, 1998).

These standards and compliance criteria include requirements pertaining to the implementation of a system of passive institutional controls (PICs) for the WIPP. PICs are required by 40 CFR 191.14(c) and 40 CFR 194.43. The primary purpose of the PICs program is to provide a permanent record that identifies the location of the repository and its dangers, thus reducing the likelihood of inadvertent human intrusion into the repository. The EPA regulations specify that radioactive waste disposal systems must be designated by multiple PICs including permanent markers and long-term records.

The DOE Carlsbad Area Office (CAO) is currently implementing programs to ensure full compliance with the provisions of these standards and compliance criteria. As part of this implementation activity, alternative materials for the construction of permanent markers are being investigated. One of the considerations important to the selection of markers materials is the ability of the marker material to be inscribed with warning messages and the durability of these messages over very long time frames.

In its Compliance Certification Application (CCA) for the WIPP (DOE, 1996), the DOE provides details regarding the implementation of the permanent markers program. An important objective of the program is to develop information useful in optimizing the design of the marker systems by evaluating alternative configurations, alternative materials and aid in the development of final designs. One related activity identified in the CCA is the survey of monuments within 150 miles of the WIPP site, to obtain any information useful in the selection of markers materials and the development of markers designs.[1]

This report documents the results of a survey performed by John Hart and Associates, P.A. of Albuquerque, New Mexico, working under contract to the Westinghouse Government Environmental Services Company, LLC in the summer of 2000. The objective of this survey was to collect and compile information relevant to the assessment of the durability of ancient inscriptions made on various rock types.

---

[1]Several of the sites surveyed for this report are outside the 150-mile zone surrounding the WIPP. These sites were included in the survey as the number of available sites within the 150-mile zone is limited. These sites provide relevant information within similar climatological zones.

1.1 Related DOE Commitments

The WIPP Compliance Certification Application (CCA) includes a DOE commitment to perform a survey of monuments within a given area surrounding the WIPP site. The DOE commitment is in regard to testing to take place during the disposal phase; it is quoted below.

> *The major subjects which may be evaluated during this testing program are:*
>
> - *Survey representative monuments within a 150 mile radius of the WIPP to more extensively evaluate the climatic environmental affects on granite.*

In regard to the timing of this activity, the DOE states:

> *The following activities described in Appendix PIC will be addressed in the first five years of WIPP operation:*
>
> > *Survey stone monuments within a 150 mile radius of WIPP to evaluate the environmental affects on various types of granite (blue, gray, black etc.).*

1.2 Study Objectives

The objective of the survey was to determine how well various rock types, within similar climatological zones, have performed as media for inscriptions in terms of both legibility and durability. The assumption inherent in this objective is that old inscriptions in rock are analogs for the WIPP permanent markers; therefore, the older the inscription, the greater the relevance. The study objective includes increasing the understanding of the effects of several independent factors that affect rock inscriptions – rock texture and hardness, intrinsic rock durability, location and orientation (aspect) of inscriptions, and climate and weathering processes. Specific objectives that derive from these general objectives include documenting:

- rock properties
- inscription characteristics
- apparent age of inscriptions
- exposures to and processes of weathering and erosion

2.0 Survey Rationale and Methods

The rationale for the performance of the survey and the methods employed are described in this section. The rationale discussion addresses the selection of monument types, site selection criteria, and background studies. The methods discussion addresses site access factors and a description of measurements taken and observations made in the field.

2.1 Selection of Monument Types

The CCA commitment, discussed in Section 1.1 above, to perform a monument survey contains little guidance regarding the definition of "monument" and what types of monument should be surveyed. The term "monument" is commonly used to mean a grave marker or historical marker. Restricting the term to those meanings would limit the types of monuments to those erected during the historic period, say the last four hundred years. To determine whether any inscriptions are analogous in durability to that sought for the WIPP permanent markers, the definition of "monument" for this study was interpreted to include any material bearing an inscription, regardless of message or intent, that has remained in place and exposed to the elements for longer than the historic period. Using this definition, the monuments that were left were those most analogous to the WIPP permanent markers – petroglyphs of prehistoric age and fully exposed to environmental stresses.

2.2 Survey Site Selection Criteria

Sites included in the survey were selected on the basis of their individual relevance to the WIPP permanent marker performance requirements (set forth in the Draft *Permanent Markers Implementation Plan* (DOE, 1999)), similarities in material types to rock materials considered for use at the WIPP site, similar climatological setting, maximum age, and the least amount of preservation or restoration. Specifically:

1. Sites were limited to those that contain rock types that might be used in the permanent markers. Included were sites with durable sandstone, fine-grain igneous rocks (basalt, rhyolite, andesite) and coarse-grain igneous rock (e.g.; granite, diorite).

2. Sites were limited to those that are located in arid to semi-arid climates at elevations up to those that sustain pinon-juniper woodlands, but not higher elevations that receive more rainfall and support larger trees.

3. Sites were selected from those known or suspected to contain inscriptions that are at least 600 years old, with preference given to the oldest sites.

4. Sites were eliminated from consideration if they had received major restoration or

artificial preservation (measures other than protection from vandalism or collection).

5. Sites were limited to those that contain rock inscriptions (petroglyphs); rock paintings (pictographs) were considered to be irrelevant to the WIPP permanent marker design because all messages on WIPP markers are planned to be inscribed.

2.3 Background Studies

Given the survey site selection criteria, background studies were focused on publicly available information sources, principally archeological reports and publications that deal with pre-Columbian cultures and rock art. Contacts were made with state and federal parks, the U.S. Bureau of Land Management, the U.S. Forest Service, the Western Archeological and Conservation Center in Tucson, Arizona, and the Rock Art Museum in Tempe, Arizona. The Museum of New Mexico Laboratory of Anthropology provided the majority of background information used in this survey; direct personal assistance was received from Curtis Schaafsma, Curator of Anthropology, and Polly Schaafsma, both of whom shared their own extensive experience with southwest rock art as well as the Laboratory's field records of their own surveys of many of these sites.

2.4 Site Access

The initial list of sites that met the selection criteria included 17 sites (including two sites at Rowe Mesa) in New Mexico and two in Texas (Figure 1). Of the 16 sites surveyed, five are on private or leased land, five are on public land, and six are on state or federal parks or monuments. Owners or lessees of lands with petroglyphs were contacted for permission to enter and conduct survey activities. Public agencies including the New Mexico State Land Office, the U.S. Bureau of Land Management, and the U.S. Forest Service were contacted for public land access and required fees were paid. Entry fees were paid where required for entry to parks and monuments.

Three sites were eliminated from the survey. One of these (Diablo Canyon) is on public land in Texas but could not be accessed because all roads to the site cross private land and all had gates that were locked due to recent vandalism. One New Mexico private landowner refused permission to the Olive Buttes site for access for reasons not given. The third site, Luna #5, could not be found in the field.

2.5 Measurements and Documentation

Measurements and observations were made at each site to satisfy the specific objectives of the study as outlined above. A more detailed description of those objectives is provided below:

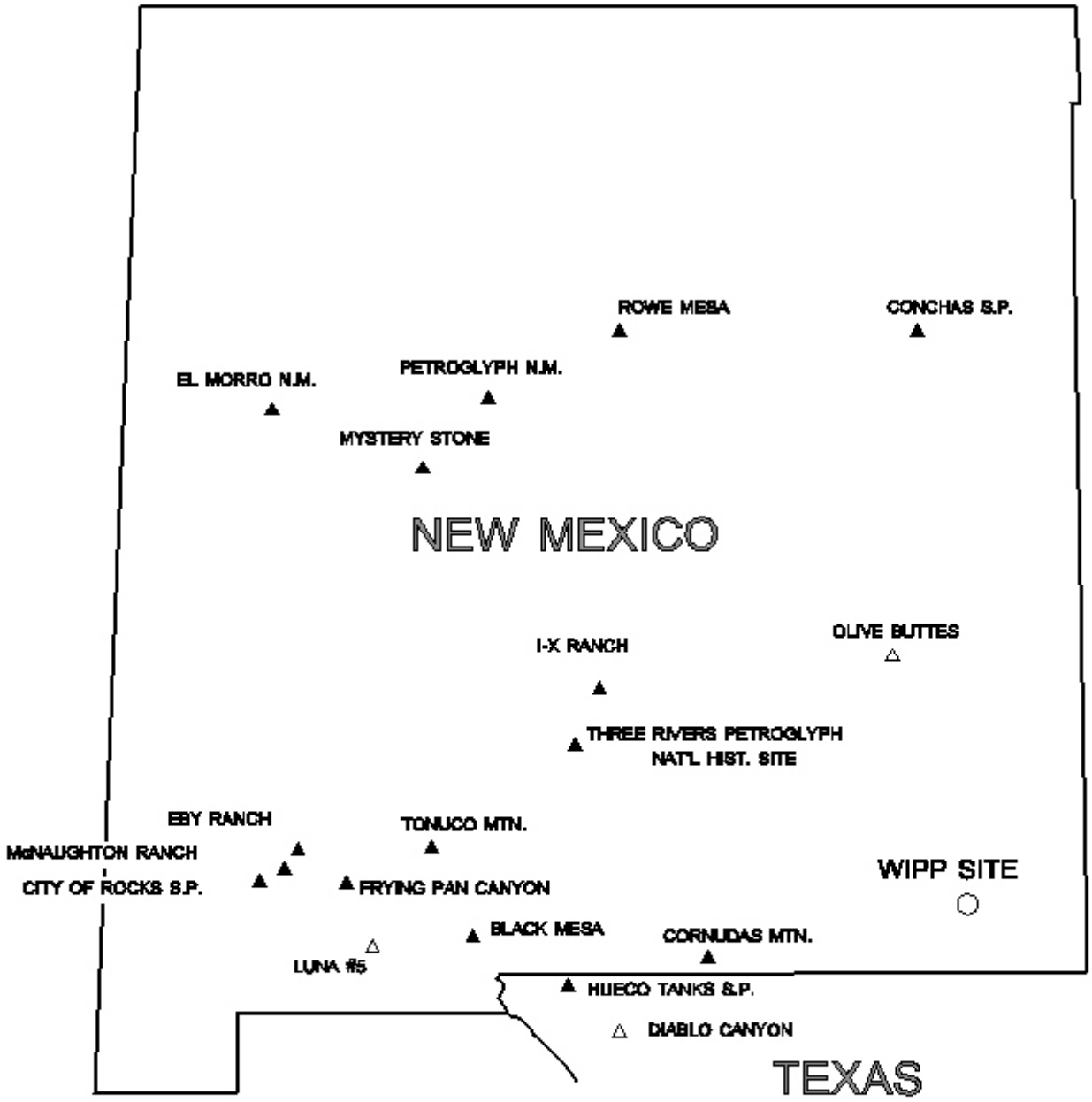

Figure 1. Monument survey sites

Rock properties important to the durability and inscribability of the rock included petrologic classification, texture, surface form and roughness, type and extent of weathering, and overall extent of patination (see Section 3.5 for a discussion of patination).

Inscription characteristics included apparent inscription type (i.e.; chiseled, scraped, pecked), form, range of widths and depths, and aspect (direction and inclination of inscribed surface).

Apparent ages of inscriptions were estimated based on the types of images, relative position of multiple layers of images, evidence of weathering within the inscription, amount of repatination and lichen growth on the inscriptions.

Exposures to and processes of weathering and erosion were evaluated from the position of the petroglyphs with respect to slopes, watercourses, surrounding terrain features and the climatic zone.

Observations and measurements were recorded on site data worksheets. Digital photographs were made to illustrate representative characteristics of rocks and their petroglyphs.

3.0 Survey Findings

Data collected during the survey are described in this section. The descriptions include rock types encountered, types of inscriptions, exposure of inscriptions, inscription condition, and inscription ages. Photographs of inscriptions (petroglyphs) referred to throughout this report are included as Attachment 1.

3.1 Site Reports

Site reports were prepared for each site visited during the survey and are included as Attachment 2 of this report. Some salient features of the sites are summarized in Table 1.

3.2 Rock Types

Petroglyphs surveyed in this study were inscribed into sandstones (six sites), fine-grained igneous and pyroclastic rocks (eight sites), and coarse-grained igneous rocks (two sites). The sandstones were all well indurated and resistant to erosion as evidenced by their positions as cliff formers or caprock on mountains. Petroglyphs were inscribed more deeply in sandstone than in the other rock types, but all rock types found in the survey preserved the inscriptions well. The only difference in durability was related to exfoliation, as discussed below.

3.3 Methods and Forms of Inscription

At all surveyed sites, pre-Columbian inscriptions had been made by pecking or scraping. Although both forms of inscription have survived for hundreds to thousands of years, the pecked images are deeper and, therefore, appear to be more durable.

Pecked inscriptions are characterized by contiguous crater-shaped pits in the rock surface, each about 1-3mm wide and deep, apparently made by a pointed stone or antler struck by another stone to break out small pieces from the rock surface (Photo #1). Pecked images usually have sharply defined lateral boundaries and are 2mm or more in depth.

Scraped inscriptions were apparently made by simply scratching the rock surface with a stone (Photo #2). Lateral boundaries of the scraped images were less well defined, especially on rough coarse-grained surfaces. Scraped inscriptions were less than 2mm deep, often too shallow to measure.

Widths of both pecked and scraped inscriptions vary widely, depending on the image. However, none of the surveyed images were less than 3mm wide, and most were at least 5mm wide.

Table 1. Features of Petroglyphs at Surveyed Sites

Site Name And Location	Rock Type	Inscription Age(s)	Method of Inscription	Level of Exposure	Condition of Inscriptions
Mystery Stone Valencia Co., NM	Andesite	Anasazi to recent	Pecked, Chiseled	High	Fair
I-X Ranch Lincoln Co., NM	Andesite Porphyritic	Archaic, Mogollon	Pecked, Scraped	High to Extreme	Fair to Good
Three Rivers National Rec. Site	Andesite Porphyritic	Mogollon	Pecked, Scraped	Extreme	Fair to Good
Black Mesa, Doña Ana Co., NM	Basalt	Archaic, Mogollon	Scraped, Pecked	Moderate	Fair
Petroglyph N.M., Albuquerque, NM	Basalt	Archaic, Anasazi	Scraped, Pecked	Moderate	Fair
Hueco Tanks S.P. Hudspeth Co., TX	Diorite	Mogollon	Pecked	Sheltered to Slight	Fair to Good
Cornudas Mtn., Otero Co., NM	Diorite Porphyritic	Archaic, Mogollon	Scraped	Moderate	Good
Eby Ranch, Faywood, NM	Rhyolitic Welded Tuff	Archaic, Mogollon, Apache, recent	Pecked	High	Good to Poor
McNaughton Ranch, Luna Co., NM	Rhyolitic Welded Tuff	Archaic, Mogollon	Scraped	High	Good to Poor
City of Rocks S.P. Faywood, NM	Rhyolitic Welded Tuff	Mogollon (Mimbres)	Scraped	Sheltered	Good
Frying Pan Canyon Luna Co., NM	Sandstone	Archaic, Mogollon	Pecked, some Scraped	High to Extreme	Good
Tonuco Mtn., Doña Ana Co., NM	Sandstone	Archaic, Mogollon	Pecked	Moderate to High	Fair to Good
El Morro N.M. Cibola Co., NM	Sandstone	Anasazi to recent	Pecked, Chiseled	Moderate	Fair to Poor
Conchas Lake S.P., San Miguel Co., NM	Sandstone	Archaic, Anasazi	Pecked	Moderate	Good
Rowe Mesa Site #1, San Miguel Co.,NM	Sandstone	Archaic	Pecked	Extreme	Fair
Rowe Mesa Site #2, San Miguel Co., NM	Sandstone	Archaic	Pecked	Extreme	Fair

At one site, the “Mystery Stone” in Valencia County, New Mexico, the rock is inscribed with V-shaped grooves about 2mm deep and 3-5 mm wide (Photo #3). The grooves are very uniform, straight, and consistent throughout the very large inscription. Fresh rock powder is still stuck to the bottoms of some of the grooves. It is evident that this inscription was made with a hard metallic tool.

3.4 Aspect and Level of Exposure

As used in this survey, aspect means the direction and inclination of the petroglyph surface. Directions and inclinations were measured by field compass and recorded according to approximate direction (e.g.; NE, W, SW) and to the nearest 10 degrees inclination from horizontal. Petroglyph aspects covered the whole range of possible direction as well as inclinations from horizontal to 20 degrees past vertical. No discernible difference in petroglyph condition was observed, based on aspect.

Level of exposure is a qualitative description of the location of the petroglyphs with respect to sun, rain, wind and runoff. Extreme exposure is a condition without shelter, totally exposed to sun during all seasons and daylight hours, to wind and rain from all directions, and to local runoff. High exposure indicates shelter from wind and runoff from one half of the compass rose, but otherwise fully exposed. Moderate exposure means exposure to half the compass rose and some shelter from adjacent terrain. Slight exposures have limited direct sun and protection from all but one quadrant of wind and rain. Sheltered locations are surrounded by obstacles to wind and sun or located on the underside of inclined rocks. The differences in exposure of petroglyphs at any site did not result in measurable differences in the condition of those petroglyphs, nor were discernible differences observed between sites based on exposure.

3.5 Inscription Condition and Visibility

Several factors that affect inscription condition and visibility were observed and evaluated: inscription size, contrasts in texture and color, boundary sharpness, and mechanical weathering.

The importance of *inscription size* is obvious; larger petroglyphs were easier to see. Inscription depths and widths affect visibility and, as stated above, were measured. Deeper inscriptions were more visible than shallow inscriptions on repatinated surfaces at close range, but wider inscriptions, regardless of depth or repatination, were more visible at a distance.

Visibility of petroglyphs was strongly affected by *contrasts in texture and color* between the host rock and the inscription grooves, and this contrast was more important than size, width, or depth in being able to locate petroglyphs. The color and texture of rock surfaces in the Southwest that have been exposed for long periods of time are commonly darkened and muted by a patina that results from a combination of chemical and microbial processes not yet well understood. In nearly all the sites surveyed, the petroglyphs were created by breaking the patinated layer, usually the outermost 1-2 mm of darkest color, leaving a groove that is a lighter color or different texture than the undisturbed surface (Photos #4 and 5). Over time, from several hundreds to thousands of years, the inscription is repatinated; i.e., the patina reforms on the disturbed rock surface. Even if a petroglyph is relatively large, it might be easily missed if it is totally repatinated, while a very small petroglyph with sharply contrasting color or texture (no repatination) would be very visible (Photo # 6).

Boundary sharpness is the visible distinction between the inscription groove and the adjacent rock surface. Observations of the oldest petroglyphs, those of Archaic age, reveal that boundary sharpness deteriorates over time. Edges of grooves gradually round to a flattening transition to the uninscribed rock; in effect, the inscription broadens and its slopes flatten (Photo #7). If this loss of groove boundary sharpness is accompanied by repatination, the visibility of the inscription is greatly reduced (Photo #8).

Mechanical weathering contributes gradually and on a small scale to loss of boundary sharpness, but it also acts on a larger scale in the form of scaling or exfoliation. The exfoliation process was most obvious in the intrusive igneous rocks of the Cornudas Mountain site (porphyritic diorite) and Hueco Tanks site (diorite), as shown in photos #9, 10, and 11. In exfoliation, the rock surface gradually peels away like an onionskin in thin (5-20mm) layers. Similar scaling of rock surface, although less regular, was observed in sandstone (Photo #12) and andesite (Photo #13).

Inscription condition was assessed primarily on the basis of visibility but also included consideration of the groove depth and boundary sharpness. Excellent condition was reserved for petroglyphs that looked fresh and sharp, a description applicable only to historic inscriptions at El Morro, that are discounted for this study. Good condition indicates clear visibility, measurable depth, and no apparent erosion of the inscribed surface (Photo #14). Fair condition means some degradation in visibility or depth, in some cases with erosion (exfoliation or spalling) in some locations (Photo # 15, 16). Poor condition describes inscriptions that are difficult to see due to erosion, weathering, or perhaps less than typical original craftsmanship. Two sites with exposed petroglyphs on rhyolitic welded tuff had a number that were in poor condition (Photos # 17 and 18). At all other sites, petroglyphs were mostly in fair to good condition.

3.6 Petroglyph Ages

In general, absolute ages of petroglyphs are impossible to determine directly. For this survey, previous studies by Polly Schaafsma and others were used to identify the cultural periods and approximate ages of petroglyphs in the area of interest and to select the sites with the oldest (Archaic) petroglyphs (Schaafsma, 1972; Schaafsma, 1979). Curtis Schaafsma and Polly Schaafsma indicated that petroglyph ages are estimated based on correlation of images depicted in petroglyphs with identical or similar images in pottery and other artifacts on which dating techniques, such as carbon-14 isotope concentrations, have produced absolute ages (personal communication, May 18, 2000).

The age of petroglyphs examined in this survey range from less than 100 years to as much as 6000 years. Emphasis was placed on Archaic age petroglyphs, ranging in age from about 1800 years to 6000 years, which were examined at 10 of the 16 sites surveyed. Petroglyphs of Mogollon and Anasazi age, about 600 to 1800 years old, were examined at 13 sites, including seven that also contain Archaic petroglyphs. The Archaic petroglyphs are called Desert

Abstractions and are characterized by geometric patterns that do not represent any life form or cultural object (Schaffsma, 1979). These patterns include parallel straight or wavy lines, circles in concentric or chain patterns, cross-hatched or intersecting diagonal lines, circles with radial lines, and irregular lines (Photos #19 and 20). Mogollon and Anasazi petroglyphs also include circles but are more representational, depicting human forms (anthropomorphs), animals, spirits, and weapons (Photos #21 and 22). Apache and other more recent cultures have left inscriptions at some of the sites, but they can usually be distinguished by the absence of repatination or lichens. At several sites, a type of lichen with bright chartreuse color has formed in the inscription grooves (Photos #23, 24, and 25), fixing the minimum age of the petroglyph at about 600 years, the time this lichen takes to get established on a rock surface (C. Schaafsma, personal communication, May 18, 2000).

The actual ages of petroglyphs at two sites, Rowe Mesa Site #1 and #2, have been established by two independent scientific methods, carbon-14 dating and soil morphology. At these sites, the petroglyphs are on a flat sandstone surface. Over at least part of those surfaces a soil profile was developed, then partially eroded. A charcoal layer at the rock-soil contact and the soil profile morphology have independently provided ages for the underlying petroglyphs of about 5900 years (Brent Abel, USFS, personal communication, June 16, 2000)(Photos # 26 and 27).

4.0 Conclusions

Reasonable conclusions based on the results of the monument survey are identified in this section. Issues such as the durability of various rock types, the effects of aspect, the rates of erosion of inscriptions, the effects of inscription form, and the importance of contrast in color and texture are addressed.

4.1 Durability of Rock Types

The petroglyphs examined in this survey involved the most common types of hard rock occurring in the Southwest with the exception of granite, on which no petroglyphs of prehistoric age have been identified within a few hundred miles of the WIPP site. All the petroglyph rocks are very durable and resistant to erosion, but not all are apparently capable of preserving inscriptions for thousands of years. The intrusive igneous rocks most like granite, the porphyritic diorite of Cornudas Mountain and the diorite of Hueco Tanks, exhibited exfoliation that caused gradual loss of petroglyph inscriptions. Because exfoliation is a common weathering mechanism of intrusive igneous rocks, this class of rocks would probably not be able to keep an inscribed surface intact for more than a few thousand years. If not jointed or otherwise fractured, the other rock types (sandstone, basalt, andesite, and rhyolite/welded rhyolitic tuff) appears to weather more evenly and to be able to retain inscriptions for thousands of years. Chemical weathering rates are relatively slow in the arid Southwest climate, so all of these rock types should be able to remain chemically intact for at least 10,000 years and possibly much longer. Therefore, any of these rocks could be considered for use in the WIPP permanent markers.

4.2 Effects of Aspect

The direction and inclination of the petroglyph surface has no observed effect on the longevity of the petroglyph. This conclusion seems to be contrary to logic; surfaces exposed to the prevailing wind direction should show more erosion. Nevertheless, survey observations revealed no aspect that was better for petroglyph survival than any other.

4.3 Rates of Erosion of Inscriptions

None of the survey observations were able to support a determination, or even a reasonable estimation, of erosion rates of inscriptions. Although measurements of inscription depth might have revealed differences in erosion rates according to aspect or rock type, in fact differences in inscription depth could not be attributed directly to erosion because 1) the inscription depths at each site do not vary measurably from one petroglyph to the other, and 2) the original depths of inscriptions cannot be ascertained. It is worth noting, however, that where the soil covered only

about half of a petroglyph at the Rowe Mesa #1 site, the inscription depths of the covered side are not measurably different from the uncovered side.

Lacking any data to indicate to the contrary, it is reasonable to conclude that petroglyphs will erode at the same rate as the rest of the rock surface. Considering the fact that the petroglyph rock surfaces are generally patinated and the older petroglyph grooves are repatinated, it is apparent that the rate of inscription erosion must be less than the rate of patination, which takes hundreds to thousands of years to develop to a depth of 1-2mm. This conclusion is consistent with the fact that even scraped Archaic inscriptions less than 1mm deep have survived at least 1800 years.

The apparent substantial durability of the several rock types bearing petroglyphs indicates that erosion rates of rock surfaces are slow enough to lend confidence that rock inscriptions can last at least 10,000 years. It also supports the conclusion that chemical weathering and mechanical weathering rates are very slow in the Southwest.

4.4 Effects of Inscription Form

The form of the inscriptions (shape, depth, and width) is remarkably consistent between generations of petroglyphs at each site and between sites for each archeological period. Petroglyphs that have familiar shapes, like circles and human bodies, are more readily recognized than irregular shapes, regardless of age. Circles exist at all the petroglyph sites, and during the field surveys a circle was frequently the first image noticed and the visual trigger to look more closely for other petroglyphs. Shapes that are similar to natural rock contours, like curves and wavy lines, are more difficult to see, especially in mid-day light.

Depth of inscription, while possibly having an impact on inscription durability, has little effect on image visibility, but groove width is very important, especially on rock surfaces with more coarse textures due to either mineral particle size or surface roughness. On coarse-texture surfaces, grooves narrower than the amplitude of roughness or the largest mineral size are difficult to see, especially under low sun angles.

4.5 Importance of Contrast in Color and Texture

The contrast between color and texture of the inscription groove and the color and texture of the host rock surface is the most important factor in the visibility and legibility of petroglyphs that are inscribed into patinated rock surfaces. As important as this color contrast is in recognizing petroglyphs, its importance will be much less for any WIPP permanent marker inscriptions, which would be placed on fresh, unpatinated rock surfaces. Patination of the marker surfaces would probably develop as the same rate across the whole marker surface, including the inscription

grooves, so it is unlikely that color contrast would ever contribute to the visibility of the WIPP inscriptions.

The primitive tools of the Archaic and Mogollon/Anasazi people were not capable of producing smooth grooves. The grooves of the recent "Mystery Stone" inscriptions are not deeper or wider than the older petroglyphs, but both the Mystery Stone grooves and historic age grooves of El Morro's Inscription Rock are more visible because the metal tools used to create them were capable of making sharp boundaries and smooth surfaces in the grooves. The sharp edges and smooth surfaces of the grooves provide a distinct textural contrast that makes the inscription stand out visually.

5.0 Recommendations

Recommendations based on the monument survey are provided in this section. Recommendations are provided on rock type, form of inscriptions, and additional studies.

5.1 Rock Type

Rocks of hardness and durability suitable for use as WIPP permanent markers are available within a few hundred miles of the WIPP site. Basalt and sandstone are the most abundant, so one or both of these should be selected for further evaluation, including durability and inscribability testing. Granite and other intrusive igneous rocks that are susceptible to exfoliation should not be used.

5.2 Form of Inscriptions

To the extent consistent with the necessary written and symbolic warnings and messages, inscriptions should be as large as possible, with groove widths several times the largest mineral particle size. Unless the rock is very fine grained like basalt, it probably will not be practical to inscribe letters smaller than about 25mm minimum plan dimension or less than 5mm deep.

5.3 Additional Studies

Given the consistent findings over the 16 sites included in this survey, it is anticipated that additional monument (petroglyph) surveys would not be useful. However, studies on material properties of rock and man-made materials would be useful, with emphasis on surface hardness, methods to create and preserve color contrast, and the effects of rock texture on inscribability and inscription durability.

References

Personal Communication between Alan K. Kuhn and Polly Schaafsma and Kurt Schaafsma, May 18, 2000.

Personal Communication between Alan K. Kuhn and Brent Able, United States Forest Service, June 16, 2000.

Schaafsma, Polly, 1972, *Rock Art in New Mexico*, New Mexico State Planning Office, Santa Fe, New Mexico, 1972.

Schaafsma, Polly, 1979, *Indian Rock Art of the Southwest*, School of American Research, Santa Fe, New Mexico 1979.

U.S. Department of Energy (DOE), 1996, *Compliance Certification Application* (CCA), U.S. DOE, Washington, D.C.

U.S. Department of Energy (DOE), Draft Report: *Permanent Markers Implementation Plan*, Aug. 31, 1999

U.S. Environmental Protection Agency (EPA),1993, *40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule*, Federal Register, Vol. 5, No. 242, pp. 66398-66416, December 20, 1993, Washington, D.C.

U.S. Environmental Protection Agency (EPA),1996, *40 CFR Part 194 Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations: Final Rule*, Federal Register, Vol. 61, No. 28, pp. 5224-5245, February 9, 1996, Washington, D.C.

U.S. Environmental Protection Agency (EPA),1998, *40 CFR Part 194 Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the Disposal Regulations: Certification Decision; Final Rule*, Federal Register, Vol. 63, No. 95, pp. 27354-27406, May 18, 1998, Washington, D.C.