APPENDIX G

DUST STUDY

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DEVELOPMENT, DUST AND ROCK ART IN NINE MILE CANYON, UTAH

A PRELIMINARY REPORT ON THE IMPACT OF DUST GENERATED BY INDUSTRIAL TRAFFIC ON DIRT ROADS IN NINE MILE CANYON

Prepared for the Bureau of Land Management
By
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1 BACKGROUND AND SUMMARY INTRODUCTION TO THE REPORT

1.1 INTRODUCTION

Nine Mile Canyon is located within the rugged heartland of central Utah. It offers many outstanding scenic, recreational, historic and prehistoric resources. Among all of these resources, the prehistoric and early historic rock art of Nine Mile Canyon arguably takes pride of place.

The West Tavaputs Plateau is rich in energy resources, specifically large fields of natural gas. Nine Mile Canyon provides the primary access road to the West Tavaputs Plateau. The need for energy has increased exponentially in the United States. The technologies employed to extract and transport gas from any site, including the West Tavaputs Plateau, have improved greatly. A need for energy, in tandem with advanced technology, now makes exploitation of the gas fields economically feasible.

The West Tavaputs Plateau does not have a single "owner." There are privately held lands (6 percent) and State of Utah lands (8 percent), but much of the West Tavaputs Plateau is in the public domain as federal lands (86 percent), under the jurisdiction of the Bureau of Land Management. The BLM has existing leases with the Bill Barrett Corporation (BBC) and other oil and gas operators. These leases allow BBC and other operators to exercise valid lease rights, which permit utilization and upgrades of existing infrastructure, including installation of gas well pads, pipes, roads, and other support systems for the purpose of extracting and transporting natural gas.

Although utilization of Nine Mile Canyon remains subject to strict federal regulations, environmental and other citizen groups have raised many concerns. The outstanding rock art has become a major issue and source of contention. Specifically, there is fear that the drilling of gas wells, road construction, road traffic, and installation of other infrastructure, will create extraordinary amounts of dust that will settle on, and permanently disfigure, the many important rock-art panels in Nine Mile Canyon and in adjacent canyons.

Another major concern is the use of magnesium chloride, employed for dust abatement on the roads in some areas of the canyon. Magnesium chloride can be an effective control for dust. However, it is also a documented agent of deterioration of concrete and works of art, as will be explained in this report.

The BLM is the principal steward of the resources of Nine Mile Canyon, both the natural gas and the rock art. The BLM anticipated that dust could pose a threat to the rock art of Nine Mile Canyon and thus took action in 2005 to initiate a scientific study of potential dust problems, including possible mitigation measures. Under the supervision of Julie Howard, BLM archaeologist, a grant was written to the Department of Energy requesting funds for a study of impacts from dust. Unfortunately, the grant was declined.

Subsequently in 2006, at the request of the BLM, BBC agreed to fund a study of dust in Nine Mile Canyon. Preservar, Inc. (principal and author of this report, Constance S. Silver) initiated this study in 2006. The first phase of the project was completed in December, 2006. The primary objectives were to research precedents, if any, for scientific studies of the effects of dust on rock art, and to establish a research design that would conform to prevailing scientific standards for the study of particulates, especially the impacts of particulates on works of art.

A significant finding is that this study of the effects of dust on rock art in Nine Mile Canyon is pioneering research. One earlier, highly focused study of dust and auto emissions near rock art was undertaken in Australia at the Split Rock Site (Watchman 1998). Currently, only one study with relevance for Nine Mile Canyon was located, underway at the highly important petroglyph site in Burrup, Australia. As will be discussed in this report, the differences between the two projects---Burrup and Nine Mile Canyon---are substantial. Thus, while the Burrup project cannot serve as a model for the current research in Nine Mile Canyon it may be possible to utilize some of the project's data collection systems.

The second phase was initiated in July, 2007. The second phase entailed field work in Nine Mile Canyon to record scientifically the genesis and impacts of dust on five selected rock art sites, and to collect samples for laboratory analysis.

The third and final phase of this research will be completed in late 2007. The final report will include all data and provide concrete recommendations for a course of action to protect the rock art of Nine Mile Canyon from impacts from dust.

Although this is an interim report, it does provide conclusive findings and is able to make recommendations for the protection of the rock art of Nine Mile Canyon.

The following sections of this report will:

1. Summarize the development of the dust study in Nine Mile Canyon.

2. Explain the data resulting from field work undertaken in July, 2007.

3. Describe the results of the laboratory analysis of sample collected in the field in July, 2007.

4. Make conclusions about the effects of dust on the rock art of Nine Mile Canyon.

5. Provide timely recommendations for methods to mitigate the dust and address the conservation problems now posed by the affected rock art.

1.2
RESEARCH DESIGN

The research design for the study of dust in Nine Mile Canyon was developed to address two principal objectives. The first objective is to determine whether dust released into the air, primarily by various types of vehicles in Nine Mile Canyon, can settle on, and permanently alter, adjacent rock art. A second concern is the use of magnesium chloride as a dust-abatement system in Nine Mile Canyon.

1.3
LITERATURE REVIEW

A review of literature was undertaken on the scientific analysis of dust and particulates in general, and as dust relates to cultural property, specifically rock art. This research confirmed that the overall scientific literature on dust is remarkably vast because dust is a powerful vector that affects the entire planet, from climate change to human health.

However, scientific literature on the impacts of dust on cultural property is quite sparse, although there is a large body of literature on the effects of hydrocarbon pollutants on cultural property. Indeed, there is almost no scientific literature on the effects of dust on rock art specifically.

1.4
DEVELOPMENT OF THE RESEARCH DESIGN: THE SCIENTIFIC STUDY OF DUST IN NINE MILE CANYON

Theoretical and instrumental methodologies appropriate for analysis of dust on rock art in Nine Mile Canyon were developed following extensive literature searches. As described, there is a vast amount of scientific literature on dust and other particulates, and on many possible methodologies for its study. Consequently, the major challenge for this study was to cull information in order to develop highly practical and cost-effective systems for the scientific study of dust specifically in Nine Mile Canyon.

The selected analytical methods eventually were adapted from industrial hygiene models. A major analytical laboratory in the United States, EMLS, was selected to provide analytical services, for several reasons. EMLS has a dedicated department for the study of particulates and has had extensive experience in this area of analysis and research. EMLS also is able to provide unified services: assist in development of field collections systems; provide the required instrumentation; undertake laboratory analysis of samples collected in the field; provide scientific reports on the findings; and assist in the interpretation of results.

Two field collection systems were devised in collaboration with EMLS. One system utilizes a particle counter (the Lighthouse 3016/5016). This instrument records the size and concentration of particulates by size in the air in real time. By using the particle counter, it is thus possible to record the relative concentrations of particulates in the air, by particulate size, at any site before, during and after the approach of a vehicle.

Five quite different rock-art sites in Nine Mile Canyon were selected for study. In addition to on-site analysis with the particle counter, samples were collected in the field. Bulk samples were taken from roads adjacent to the five rock-art sites, to determine the size and mineralogical profile of particulates subject to disturbance by vehicles. Petri dishes were left at the selected rock art sites for a period of 24 hours. The purpose was to determine the amount of dust that settles from the air and to analyze the settled dust to ascertain the nature and probable source of the particulates.

Additionally, at some sites small samples of rock were removed from the extremities of panels, in order to determine if they have become contaminated overtly with dust and with magnesium chloride. Secondarily, a study will be made of the porosity of the samples, to determine the extent to which particulates can become entrapped on and in the surface of a rock-art panel. Entrapment of particulates, for the most part, is an inverse ratio of the sizes of the pores of the stone in relationship to the size of the depositional particulates: the larger the pores and the smaller the particulates, the more particulates will settle and become fixed in the surface of a rock art panel.

1.5
OBSERVATION

In July, 2007, the author and Julie Howard, Archaeologist, BLM, spent four days in Nine Mile Canyon, to observe traffic and dust at five selected rock-art sites. On-site observation of the roads and rock-art sites was a highly important component of the research. It was possible to study the industrial traffic, its effects on the road, the generation and duration of clouds of dust, and the deposition of the dust on rock art sites

1.6
FIELD WORK

In July, 2007, particulates in the air were studied with the particle counter before and after the passage of traffic on the road at the five selected rock art sites. Depositional particulates were collected in petri dishes exposed at sites for a period of 24 hours. Samples of some rock also were collected, to determine the deposition of magnesium chloride and stone porosity relative to the particle size deposition of air-borne particulates.

1.7
LABORATORY ANALYSES

Sixteen samples were collected during the field work in July, 2007. They were sent to EMLS for analysis. The results will be discussed in a following section of this report.

1.8
SUMMARY CONCLUSIONS

Data collected during the field work in July, 2007, confirmed that heavy vehicular traffic has pulverized the dirt roads of Nine Mile Canyon and releases clouds of fine particulates into the air. If a rock art panel is nearby---as is the case with the site 42Cb239, the Hunt Scene---dust will settle on the panel and does create a very serious conservation problem for the rock art of that specific panel.

However, the extent to which dust produced by vehicular traffic is able to migrate throughout Nine Mile Canyon and settle in a deleterious manner on all rock-art panels is less clear. The analytical methods used during this study cannot provide definitive answers at this stage of the research, for several reasons. First, there is now a constant "background noise" of industrial and particulate pollution everywhere in North America and Europe. Second, there is always particulate "background noise" produced naturally, by normal soil erosion conditions, wind and vegetation in the form of pollen and resinous exudates. Third, human activity in Nine Mile Canyon had altered the natural environment at least 80 years before the current energy-related work began. Fourth, the extraordinary drought conditions and massive fires near Nine Mile Canyon in July, 2007, certainly added to that "background noise" of fine particulates, in the form of smoke and extensive fine dust produced by the desiccation of the natural and altered landscapes of the area.

Consequently, there is no way to determine what a normal particulate "baseline" would have been for Nine Mile Canyon. Therefore, it seems unlikely that it will be possible to ascertain definitively how current development alters the natural particulate baseline in a deleterious manner that negatively impacts the rock art.

Nevertheless, even when these caveats are factored into the overall analysis, the collected data does support the visual observation that heavy vehicular traffic on untreated roads will produce fine particulates that will settle on and damage nearby rock art. The outstanding rock art of Dry Canyon alone provided a simple and highly instructive lesson. The Dry Canyon site was used as a control because it is not subject to development activities. There is almost no vehicular traffic in Dry Canyon, and its road has remained hard-packed and in good condition. In Dry Canyon, the particle counter's readings of air-borne particulates were relatively low and were very similar to readings taken at sites that are adjacent to roads that have been treated with a dust abatement material. These readings contrasted greatly with the very elevated particulate readings taken at the Hunt Scene, located on a pulverized area of the road, after the passage of heavy traffic. Hence, it can be concluded that where the roads remain compacted, blocking the genesis of dust, damaging clouds of particulates are not created.

Consequently, it is imperative that roads adjacent to rock-art sites be solidified in some manner. Some areas of the Nine Mile Canyon road have been treated with a hardening substance generically referred to as "magnesium chloride." Magnesium chloride has the documented capacity to damage concrete buildings and works of art. For this reason, its use in proximity to the rock-art sites of Nine Mile Canyon must be carefully considered.

Analyses undertaken in the course of this study raise a critical and unexpected question about the composition of the road hardener used in Nine Mile Canyon. It is referred to as magnesium chloride, but thus far it has been impossible to isolate and identify magnesium chloride in the laboratory. One possible explanation is that the magnesium chloride was per-mixed with hydrated magnesium oxide and water to produce the hardening agent that is referred to as Sorel cement. Perhaps the magnesium chloride is chemically transformed during the creation of Sorel cement. If this is the case, the perceived risks associated with magnesium chloride may not be present in Nine Mile Canyon because there is no magnesium chloride present. However, this mystery will need to be resolved as soon as possible during continuing research.

The final section of this report examines these and other findings in detail and provides a list of recommendations that focus on development of a safe and effective dust abatement system for the canyon's road and identification and conservation treatment of impacted rock art sites. It is also recommended that systems for monitoring of air quality and laboratory analyses of collected samples be further explored, developed and implemented.

2
UNDERSTANDING PARTICULATES.

2.1
SUMMARY OF THE LITERATURE REVIEW: FOCUS AND CAVEATS

As described, the first unit of the study was a review of literature. In its many forms, dust has become a critical subject of research in all scientific disciplines. The result is scientific literature on dust that is truly vast. A major challenge for this study, therefore, was to narrow the focus to areas of research that are specifically germane to the understanding of dust deposition on rock art.

Consequently, the literature review focused on the following areas:

The scientific definition of dust.

Scientific standards for the measurement and analysis of dust.

The general effects of dust, in general, on cultural property.

Analysis of dust specifically on rock art.

Section 2 of this report provides a general summary of the scientific definition of dust.

2.2
THE SCIENTIFIC DEFINITION OF DUST AND THE EFFECTS OF DUST GENERALLY ON CULTURAL PROPERTY

There is no doubt that deposition of dust on cultural property is a major concern in conservation. At the very least, dust soils a surface, and the soiling can become a permanent aesthetic flaw if the particulate is so fine that it becomes entrapped within the surface or fabric of an object.

However, dust also can be chemically active and even corrosive. Some dusts are hygroscopic and will attract and hold molecular water on stone. That liquid water in turn can be acidic and act as a corrosive or, conversely, create a welcoming microclimate for microbes. In this regard, it should be noted that microbes can act as a significant vector for the deterioration of stone. If freezing occurs, very damaging mechanical action will take place through freeze-thaw cycles.

A case in point is the dust that is generated by modern building construction. Harmful dust can come from many sources, including new concrete and cement buildings. These buildings give off a dust of ultra-fine particulates at the low end of the range (0.01 microns) which can easily pass through most normal air filtering systems. The alkalinity of these particulates is strong enough to damage hardened oil paint, silk, and various dyes and pigments (Toishi 1965). This case provides some idea of the complexity of air-borne particulates and their potential to harm cultural property.

Fortunately, however, a standard publication on conservation *The Museum Environment* (Thomson 1994), helps to answer questions essential to this study: how is dust defined scientifically and why is it a source of real concern for the conservation of all types of cultural property? Relevant passages from *The Museum Environment* (131-135 and 244-253) are provided:

> THE PROBLEM
>
> . . .The problem of solid dirt in the air of cities is not new, and complaints date back much further than Faraday and Eastlake's investigation of air pollution in the National Gallery, London.[1] The acid vaopours which belched out of furnaces with the smoke were also known to Faraday. However, the automobile has produced a distinctly modern form of pollution known as the oxidant type.
>
> Air pollution is associated with towns and industry and is almost entirely caused by the burning of fuels.
>
> To deal with air pollution we must be able to measure it, and it is simplest to adopt a universal system applicable to both solids and gases, for gasses can be weighed just like solids. We therefore measure the concentration of a pollutant by finding the weight of it in a given volume of air. The unit commonly used is *micrograms* of pollutant per cubic metre of air, abbreviated $\mu g/m^3$ or μgm^{-3}. A microgram is a millionth of a gram. If we write the word 'Air Pollution' firmly with a soft pencil on a piece of paper we might add about 100 µg to its weight.
>
> Concentrations of gases are often quoted in parts per million (ppm) or parts per billion (ppb). Note one billion equals one thousand million. One part per million of sulphur dioxide in air simply means that if we could separate the sulphur dioxide from the air its volume would be one millionth of the volume of the air it came from. . .

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[1] This refers to a report of 24 May, 1850, written by the interdisciplinary team of scientist Michael Faraday, designer Charles Eastlake, and art historian William Russell, to the House of Commons regarding the effects of air pollution on works of art in the National Gallery, London.

. . . In town museums the suspended dirt in the air gives rise to an obvious problem. Some of the particulates are heavy enough to settle in still air, but our major concern is with those that are too small ever to settle under their own weight, and therefore to enter into the furthest corners of buildings. Dirt on museum objects, especially textiles, not only becomes unsightly as it accumulates, but sooner or later necessitates the risky operation of cleaning.

Within the last half-century various gaseous pollutants have become a world-wide hazard to the health of both people and antiquities.

PARTICULATES

Two terms are currently in common use for the solid particles suspended in the air: particulates and aerosol. The former will be used here. Other terms, particularly 'smoke' which is sometimes limited to the products of incomplete combustion, are too imprecise. Particles that settle in still air can be referred to as dust, or sometimes grit, which seems most appropriate.

The sizes of particulates are conveniently scaled by quoting diameters in microns (1 micron ((abbreviated as µm) = 1 thousandth of a millimetre). In what follows, a size of one micron means a diameter (not radius) of one micron.

The particulates, though they might all seem too small to measure, vary hugely in size. Particles larger than 15 or 20 microns settle near their source of origin or at worst on window sills. Particles smaller than this remain suspended until trapped on some surface. The bottom end of the scale can be taken as 0.01 micron, a hundredth of a micron. . . and a good deal smaller than the wavelength of visible light (1/2 micron). This gives us a range of three orders of magnitude in diameter, or 1000 to 1. . .

Since the particulates produced outside the building arise largely from the burning of fuels in power stations, and from vehicles and heaters there is a lot of sooty and tarry material in them. They are also usually acid from adsorbed sulphur dioxide and often contain traces of metals such as iron which can catalyse deterioration.

Particulate distributions are today most commonly represented in this fashion, following the work of Junge. The only differences are that we usually divide particulates into groups by diameter rather than area, and it is more useful to consider the mass of particulates in a given size range rather than their number. . .

. . . The particulates in the air – the actual suspended dirt particles – fall into three distinct size ranges. Starting at the large end, the upper size limit is governed by the maximum size of particle still in the air at some distance from its source. This is obviously a variable quantity: in a sandstorm grains well over 1mm (1000 microns) in diameter can be carried large distances. In still air everything over about 15 microns settles, but smaller particles remain indefinitely suspended until they hit and stick to something. . .

The size range of the largest particulates, from above 1 to 20+ microns, is called the Coarse Particulate range, because it has been formed either by direct mechanical action (e.g dust formation, grinding processes, fine sand) or shot directly into the air as particles (e.g. ash, pollen, sodium chloride from the sea). Rain rapidly scavenges coarse particulates but has little effect on particulates below 2 microns.

But not all particulates are thrown into the air directly. Some are formed in the air itself. So we now turn our attention to the smallest particulates, in the Nuclei range, comprising all particles below 0.1 microns diameter. A more or less complete coverage is obtained with a scale that begins at 0.01 microns. One typical man-made source of these ultra-fine particles is the automobile (there is a wider range from the combustion of coal), but nature produces them too from aromatic plant evaporates which polymerise in the air on dry sunny days to form a haze of Nuclei.

Whatever the source, the Nuclei are unstable and therefore transient, with a half-life of no more than 12 hours. Indeed to bag a fair sample of man-made transient Nuclei from a heavy traffic route the sampler should be less than a couple of kilometers away.

By coagulation the Nuclei transfer themselves to the Accumulation range. This, our third and middle range, comprises diameters roughly between 0.1 and 2 microns. We shall now be able to see that this Accumulation range is the most important for museums to deal with and therefore dictates the type of air filter to use.

First, the black tarry matter in smog started life as gases formed in the higher-temperature combustion processes (cars and oil-fired power plants). Photochemical reactions yielded particulates in the Nuclei range, which presently coagulated into the Accumulation range.

Secondly, this range includes sulphates and nitrates, the end oxidation products of SO_2 and NO_2, together with ammonia.

Thirdly, it can be calculated that most of the surface in an average collection of particulates is on those in the Accumulation range. All particles adsorb gases and vapours. Therefore, most of the adsorbed pollutant gases will be on particles in the Accumulation range. . .

. . .To make sure of a sample where the distribution of particles had aged, falling into the Accumulation range of about 0.1 to 2 microns, the sampler was taken out to the desert 200 km NE of Los Angeles where local emission of large particles was very low and cars were not present. Nevertheless, when the wind was in the right direction a fairly large sample of aged Fine particulates carried from Los Angeles was collected. The small hump between 1 and 10 microns shows that some Coarse particulates were also present.

In general particulate counts have this bi-modal distribution, meaning that there are two peaks. The peak with mass maximum around 10 microns shows the Coarse particulates. The second peak, near 0.1 microns represents the Nuclei and accumulation particulates. . .

PARTICULATE CONCENTRATIONS TODAY

In the U.K. and probably in most of Western Europe the situation was - literally – at its blackest before the passing of the Clean Air Act in 1956. Smoke levels at Kew, a suburb of London, were falling when records were started in 1922. Average winter levels were near 1000 μg/m^3 in London in the early 1950s, whereas the average winter level near the National Gallery (one of the smokiest areas of London) had fallen to 160μg/m^3 by 1967. The yearly average level for London now is only 40μg/m^3. This can be taken as an average sort of figure for towns in Western Europe. . .

There are not now any pockets of pure country air left in Europe and North America, industrial pollution having spread over the whole area to give background levels of around 20 μg/m^3.

Apart from urban pollution, natural particulates produced by forest and plant cover, including volatile material given off by them and polymerisd by sunlight, may contribute up to 15 μg/m^3, but usually much less. . .

3.
DUST ON ROCK ART

3.1
BACKGROUND

A literature search was undertaken utilizing the key words "rock art" and "dust." Not surprisingly, several titles were located that incorporate these key words. However, the articles are general and predictable in their concerns and advice, for example, urging care not to stir up dust that could settle on rock art when visiting sites.

Over the last 40 years, undoubtedly the best scientific studies of rock art environments and conservation have taken place in the great Paleolithic caves of France and Spain. However, the caves differ so greatly from the canyons and cliff faces of Nine Mile Canyon that they do not present useful analogs for this study.

Consequently, when the articles on the Paleolithic caves and the generalized literature on rock art preservation are filtered out, there is scant scientific literature on dust on rock art.

However, before examining the few relevant studies on dust and rock art, it is useful to review environmental studies undertaken in Venice, Italy, almost 40 years ago because in many was they set the foundation for subsequent studies of particulates on cultural property. This pioneering research was on the effects of air pollution on the exterior architecture and sculpture of Venice. It identified the complexities of pollution and its effects on cultural property Operating out of Palazzo Papadopoli, monitoring stations were set up all over the ancient city of Venice, recording the types and rates of air pollution and other meteorological data. These data were fed into a computer center in the palace. The resulting data were impressive and ultimately quite critical for the preservation of the city.

Briefly summarized, it had been assumed that most of the harmful pollution came from two nearby industrial centers on the mainland, Mestre-Marghera. However, the long-term monitoring proved that much of the harmful pollution, in reality, was being generated in Venice itself. This research led to the development of concrete steps to control air pollution in Venice and in Mestre-Marghera. This pioneering research demonstrated that pollution can be monitored and quantified, and the remedial interventions can be effective.

3.2
RELEVANT LITERATURE ON DUST IMPACTS ON ROCK ART

The few relevant studies of the impacts of dust on rock art come from past and on-going rock-art studies in Australia.

The role played by dust in the deterioration of rock art located on panels and in shelters probably first was articulated by Moorwood in 1994 (Moorwood 1994). However, the first true scientific study of this problem appears only recently, in 1998 (Watchman. (1999). Watchman's research confirmed that dust kicked up from vehicular traffic on nearby unpaved roads can settle on and impact rock art. His research took place at the Split Rock site in North Queensland. Analyses indicated that dust particles can include carbon-rich compounds that probably are created in diesel exhausts which become attached to the dust while still hot. Transported as aerosols in the wind, this material settles on rock art and can significantly distort the carbon system of the surface deposits

In 1998, Kakadu National Park in Australia became a focus of concern due to the ascertained and potential dangers posed to this World Heritage Site by proposed uranium mining at the Jabiluka mining and milling centers. Prof. F. Francioni was sent on a mission to Kakadu by ICOMOS, and he produced a report *ICOMOS World Heritage Committee Mission to Kakadu 1998.* Unfortunately, it would appear that few of the report's sixteen recommendations were enacted. Mining clearly has gone ahead, including several lawsuits over safety lapses, as reported by BBC news in February, 2006. Unfortunately, there seem to be no follow-up studies in Kakadu that would confirm or refute the assumption that particulates from mining and milling have affected the rock art.

However, a line literally has been drawn in the sand at the spectacular rock art site at Dampier, in northwest Australia. This site and the current and on-going studies for its conservation undoubtedly provide the most relevant analog for Nine Mile Canyon, although with important caveats. Specifically, the environments of Nine Mile Canyon and Dampier are almost diametric opposites. Nine Mile Canyon is located at a relatively high altitude in the semi-arid Southwest, while Dampier is a humid marine environment. In Nine Mile Canyon, the rock art is both pictographs and petroglyphs in shelters and on rock faces. At Dampier the rock art is petroglyphs primarily on bolders.

The primary threats are from industrial development at Dampier, so air pollution is the focus of the research. In Nine Mile Canyon dust is the principal threat, although magnesium chloride may eventually be shown to be a threat.

There is an excellent summary of the Burrup Peninsula/Dampier Island site, controversy and conservation program, in *GeoNews* (Nov 2004). The research organization referred to as CSIRO is a scientific research arm of the Australian government:

The Burrup Peninsula formerly Dampier Island is one of the 47 islands that make up the Dampier Archipelago. The Burrup (Peninsula) and the islands house what is considered to be the largest and possibly the oldest gallery of petroglyphs anywhere in the world. The Dampier Archipelago is located off the northwest coast of Western Australia in the Pilbara.

The Burrup, an artificial peninsula, previously called Dampier Island, is the largest of the islands. It was connected to the mainland in the mid-1960s and is a 117 sq km assemblage of huge granophyre (granite) rock boulder hills interspaced with meandering valleys. The petroglyphs date back from 6000 – 40,000 years. There may be as many 500,000 and the mix of styles and engravings in one location makes this site globally unique.

In northwestern Australia, more than one million aboriginal petroglyphs are concentrated in the landscape. On a scattering of remote islands called the Dampier Archipelago, located off the northwest coast of Australia, people have been carving images on rocks for thousands of years. In some areas the rock carvings are so dense that they cover every available surface of the deep red weathered rocks. Over the past 30 years, this remote region, once home only to Aboriginal tribes, has become increasingly industrialized. With further development planned, the government of Western Australia has commissioned a study of this rock art to determine what role industry might play in the deterioration

This is the largest and most important petroglyph series in the world, but no one knows for sure how many petroglyphs there are in the 2.7-billion year old plutonic stones in Dampier, but almost certainly there are more than one million.

Currently the 22 kilometer long Burrup Penninsula, which is located in the middle of the Dampier region, is one of Australia busiest ports and hosts three large industrial facilities, a salt processing plant, a liquid natural gas processing plant and an iron processing plant. The government of Western Australia had proposed adding six new industries to Burrup, thus bringing the debate over development versus cultural heritage preservation to a head

The government appreciates the cultural and heritage value of the rock art while recognizing (that) the Burrup industrial precinct is of vital economic importance to the local state and national economies. So before deciding on a location, the government commissioned researchers from CSIRO (Australia's national scientific research organization) and Murdoch University to monitor sites both near the industrial building and far across the Burrup Peninsula.

Work began in the summer of 2004 and will continue for 4 years. Scientists will monitor atmospheric emissions and their effects on the rocks. At the end of the study period, they will report their findings to the government and recommend any future actions says Murray who is chair of the Burrup Rock Art Monitoring

Management Committee, which oversees the studies. "These studies are to be the most thorough scientific research of impacts on rock art ever undertaken in Australia." Murray says.

The CSIRO project is interdisciplinary and large in scope. Atmospheric scientists will measure ambient concentrations and deposition of pollutants from seven different sites. Microbiologist will examine the role of microbes in deteriorating the rock, and test whether increased level of nitrogen or sulfur from emissions promote further microbial activity. And geochemists and archaeologists will assess the amount of weathering on the rock by analyzing physical, mineralogical and chemical changes of the rocks using optical and scanning electron microscopes. They will also use a mineral mapping tool to record subtle color and mineral spectral changes in the surface minerals over time between the engravings and the adjacent undisturbed rock surfaces.

The *GeoNews* article was in response to the CSIRO Newsletter of September, 2004, and to a large body of adverse publicity brought against the government of Australia by many rock art organizations and the World Monuments Fund. A delegation was sent to the Burrup and the entire site was put on its "Most Threatened List," to the consternation of the government of Western Australia.

The CSIRO Newsletter, of CSIRO Atmospheric Research, Issue 14, September 2004, summarizes the research project:

CSIRO has been commissioned by the Western Australian Government to complete the first ever study into possible effects of industrial emission on Aboriginal rock art on the Burrup Peninsula, in the Pilbara region of Australia's remote northwest.

In addition to housing internationally significant collections of rock art, the area is home to a busy port and industries, including natural gas exploration and iron ore loading, which employ tens of thousands of people. Allegations have been made that increased rainwater acidity, dust deposition and enhanced gas concentrations have deteriorated the art over several decades, but no systematic study of the problem has been completed.

The four-year monitoring program supported by the local Aboriginal communities, involves monitoring air pollutants by CSIRO Atmospheric Research, studies of colour changes by CSIRO Manufacturing and Infrastructure Technology, and investigation of the mineral composition of the rock surfaces by CSIRO Exploration and Mining. The project is in collaboration with Murdoch University, who are carrying out microbiological studies of the rock art.

The CSIRO Atmospheric Research component of the project, led by Mr. Rob Gillett and involving Dr. Greg Ayers, has established sampling systems in consultation with the local Aboriginal community at seven sites, from north Burrup, Gidley Island and Dolphin Island to close to the industrial areas. Ambient concentrations of a range of pollutants and dust in the air and on the rock surfaces are being measured along with the microclimate.

"At each site we will measure nitrogen dioxide, sulfur dioxide, ammonia, BTEX gases (benzene, toluene, ethylbenzene and xylenes), aerosols such as air pollutant particles and dust, as well as rain, temperature, humidity, wind speed and wind direction," says Mr. Gillett.

The collected gas, particle and weather data will be used to establish the origin of air pollutants and dust, to address concerns about possible effects of current and future industry emissions on the rock art of the Burrup Peninsula.

The study aims to investigate natural processes and emissions that might degrade the rock art, to monitor changes over time and propose management measures if required for on-going preservation and conservation.

This research project has now reached its mid-point. Apparently, no provisional reports on the results to date have been published.

3.3
CONCLUSIONS

The literature search confirmed that there is no project that sets a precedent or provides an exact model for a dust study in Nine Mile Canyon. However, research that took place more almost 40 years ago in Venice confirms that atmospheric monitoring over a wide area can provide critical information about pollution and its effects on cultural property. Currently only one project, at Burrup, Australia, appears to have research goals similar to those outlined for Nine Mile Canyon. However, Burrup and Nine Mile Canyon are dissimilar in many ways. Nevertheless, it is possible that Burrup can provide very useful analogs for Nine Mile Canyon once the Burrup research concludes in about 2 years and if it is decided that investigations should continue at Nine Mile Canyon.

However, the problem of dust in Nine Mile Canyon is current and active and must be addressed immediately. Consequently, it was concluded that site specific avenues of research would have to be developed and implemented specifically for Nine Mile Canyon.

4.
NINE MILE CANYON AND DRY CANYON: FIELD SAMPLING, JULY 2007

4.1
NINE MILE CANYON

Nine Mile Canyon is about 70 miles long. It was formed about 55 million years ago from lake sediments. As the land was up-lifted, Nine Mile Creek began cutting the canyon. The sediments of the lake formed the massive sandstone and shale formations visible today.

Native Americans utilized the area for at least 8,000 years, leaving behind the outstanding rock art that is the focus of this study. Nine Mile Canyon was first mapped around 1869 by John Wesley Powell. In 1886, a trail in the canyon became a Federal Highway. The US 9th Cavalry built the road in the canyon and a telegraph line to service the military post at Fort Duchesne soon after. Homesteading in the canyon began in earnest around 1905, with the introduction of cattle throughout the network of primary and secondary canyons. By the 1950s, networks of roads were installed to facilitate mining and energy-related extractive work. This industrial activity has continued on and off since the 1950s, but resumed on a major scale beginning around 2000.

4.2
SUMMARY OF SAMPLING METHODOLOGY

From July 9-12, 2007, the author and Julie Howard, Archaeologist, BLM, utilized five sites in Nine Mile Canyon to study whether dust is generated by vehicular traffic and, if so, to what extent those impacts can be documented, identified and quantified.

The five sites were selected based on their locations and configurations, allowing the development of a simple hypothesis for sampling. It was hypothesized that a rock-art site located close to an untreated area of road would be subjected to the heaviest contamination by dust generated by vehicles. Contamination by dust should be markedly minimized if a site is located on a section of road that was treated with magnesium chloride for dust abatement or is located in some sort of protected environment, such as the shelter of Rasmussen Cave. Finally, a control site, in Dry Canyon, was selected for study. It was hypothesized that a site located away from industrial activity, on a road that has no heavy vehicles, should show the least amount of dust contamination.

4.2.1
PARTICLE COUNTER

Two field collection systems were devised in consultation with scientists from the analytical laboratory, EMLS. One collection system utilizes the Lighthouse Airborne Particle Counter 3016/5016. This instrument uses a laser-diode light source and collection optics for particle detection. Particles scatter light from the laser diode. The collection optics collect and focus the light onto a photo diode that converts the bursts of light into electrical pulses. The pulse height is a measure of the particle size. Pulses are counted and their amplitude is measured for particle sizing. Results are displayed as particle counts in the specified channel.

The data format is either Raw or Normalized. Raw data displays the actual number of particles counted. The format from the Differential, rather than the Cumulative count, was selected for the field work because the measurements were being taken in the open air, rather than in a discrete volume of air, such as would be found in a room. Readings of one minute were taken at the five sites. A count was taken when no traffic was on the road. A second count was taken just after the transit of vehicular traffic.

4.2.2
LABORATORY ANALYSES OF SAMPLES

Physical samples also were taken from each of the five sites, for analysis by EMLS. Bulk samples of adjacent road material were collected. Petri dishes were left at all the sites for a period of 24 hours. The purpose was to collect the particulates that settle from the air and to analyze their component chemistry, with the objective of determining their loci of origin. At some sites, small samples of rock were removed from the extremities of panels, in order to determine if they have become contaminated with dust and magnesium chloride. Secondarily, a study will be made of the porosity of the rock samples, to determine the extent to which particulates can become entrapped on and in the surface of a rock-art panel.

The collected samples were sent to EMLS for analysis. The results of the analyses are included as Appendix 1 of this report. The elemental spectra created by Scanning electron microscopy/X-Ray diffraction are provided. These spectra are like *de facto* signatures that identify each sample. Very similar spectra almost certainly indicate dust samples that have the same point of origin and conversely, different spectra almost certainly indicate different points of origin. Hence, nearly identical spectra from a road sample and from depositional dust on an adjacent rock art panel would signal that the panel likely is being contaminated from the road.

EMLS was requested to investigate the possible presence of magnesium chloride in each sample. It has been assumed that sections of the road were treated with magnesium chloride for dust abatement. Thus, identification of magnesium chloride in samples from the road and in depositional dust at rock art sites almost certainly would confirm that sites are being contaminated from the road.

However, contamination of rock art by magnesium chloride also would be a cause for concern. Magnesium chloride is the name for the chemical compounds that are salts having the formulas $MgCl_2$ and its various hydrates $MgCl_2(H_2))_x$. They are highly soluble in water because they are typical ionic halides. Liquid magnesium chloride or in powder form is applied to control dust and erosion on unimproved dirt and gravel roads and at dusty job sites. Because it is so hygroscopic, it will absorb moisture from the air, which controls the number of small particulates that can get into the air. Magnesium chloride can also be mixed with hydrated magnesium oxide to form a hard material called Sorel cement. As will be explained further in this report, magnesium chloride increasingly is being condemned as a highly corrosive and reactive compound that is implicated in the deterioration of cement buildings, vehicles and vegetation. The stewards of the resources of Nine Mile Canyon thus should proceed with prudence when using this compound in proximity to natural and cultural resources.

4.2.3
VISUAL OBSERVATION

Lastly, simple visual examination proved invaluable. As the photographs included with this report show, it is possible to identify road areas that produce exceptional amounts of dust as a result of vehicular traffic and road degradation, and to observe their deposition on rock-art panels.

4.3
THE FIVE TEST SITES:
RESULTS OF FIELD SAMPLING
AND LABORATORY ANALYSES

Each test site is described. The descriptions of the five sites are derived from site forms provided by the BLM. Data from readings with the particle counter are provided. Laboratory analyses are explained. Insofar as possible to date, conclusions are made regarding the particulates at each site and the threats they pose

4.3.1
SITE 1
HARMON CANYON SITE
42Dc162

Description:

The site is located along a low cliff face, about 46 feet from the road. The site consists of groups of petroglyphs located on the second tier of cliffs above the road, facing southeastward. The panels include: an interesting sheep hunting scene with two hunters with bows and arrows; two sheep tracks, two fields of dots; two crude anthropomorphic figures; and a complex abstract, web-like configuration

The road has been heavily treated for dust abatement with (assumed) magnesium chloride, and it gets constant watering. Dust is visibly abated by this road treatment. However, substantial dust is present on areas of the panel, but it is not clear when this dust was deposited.

Date of Examination: July 10, 2007

Photographs:

1.1
1.2
1.3

Samples Taken for Laboratory Analysis:

Sample 1.1. Road, bulk sample. Particle size analysis; mineral identification; and presence of magnesium chloride.

Sample 1.2. Stone taken from the base of the panel. Porosity study; nature of particulates on the surface; presence of magnesium chloride.

Particle Counts:

Particle Count taken at 10:20 AM, with no road traffic:

μ	Δ	Ft^3
0.3	10,658.4	
0.5	611.8	
1.0	146.8	
2.5	189.9	
5.0	41.7	
10.0	10.7	

Particle count taken at 10:30AM, during moderate road traffic:

μ	Δ	Ft^3
0.3	11,600.7	
0.5	643.6	
1.0	189.3	
2.5	222.5	
5.0	32.7	
10.0	5.9	

SITE 1
HARMON CANYON SITE
INTERPRETATION OF DATA

Particulates in the air were only slightly increased during the passing of vehicular traffic. This section of the road has been heavily treated for dust abatement and is constantly watered. These interventions clearly reduce the amount of dust that is generated by traffic.

The dust abatement material has been referred to generically as magnesium chloride. However, this section of the road is not within the purview of the BLM. Rather, it is subject to maintenance by the county, but exactly what that maintenance entails is not known at this time.

In fact, magnesium chloride can be used alone in powder or flake form for dust abatement purposes, but if this were the case on the road near site 42Dc162, the presence of magnesium chloride would be identifiable in the sample. The elemental analyses of the sample from the road are quite intriguing because they indicate the presence of both magnesium and chloride, but magnesium chloride itself could not be isolated nor identified during extensive laboratory tests. One possible explanation is that the road has not been treated and the magnesium and chloride are present as other naturally constituents of the sample. Another explanation may be that the road was not treated with magnesium chloride *per se*. Instead, it may have been treated with a mixture of hydrated magnesium oxide and magnesium chloride, to form a hard material that is called Sorel cement. In fact, the road is remarkably hard and permits little escape of dust into the air. At present, this critical anomaly cannot be explained and will require additional investigations.

4.3.2
SITE 2
COTTONWOOD CANYON SITE,
THE PANEL ABOVE THE "HUNT SCENE"
42Cb238

Description:
This is an outstanding petroglyph panel that is closely associated with the "Hunt Scene" panel, recognized as a major example of prehistoric rock art in the area.

This site was originally recorded in 1976 by Lindsay and Sargent and revisited in 1993 by USAS. It consists of four rock art panels on a large rock face above a 4-meter high ledge. Panel 1 consists of a possible shield motif, a zoomorph, historic initials (TJ) and a zoomorph and a deep groove. Panel 2 is a wide panel located to the left (south) of panel 1. It exhibits five zoomorphs, three snakes, nine dot group, one coiled circle, two bullseye designs, and one anthropomorph balanced atop a half pie design. Panel 3 is an isolated square-like element above and to the left of Panel 2. Panel 4 displays historic letters, numbers, and some very faint anthropomorphs.

Both panels have been visibly affected by a covering of light dust. The road near the panels has been worn down to a powdery consistency. When any vehicle passes, clouds of fine dust are generated. This dust from the road has settled on the rock art panel.

Date of Examination: July 10, 2007

Photographs:

2.1
2.2
2.3
2.4

Samples Taken for Laboratory Analysis:

2.1 Road, bulk sample. Particle size analysis; mineral identification; presence of magnesium chloride.

2.2 Petri dish collection, after 24 hours, taken from below the large panel. Particulate settling; particle size analysis; mineral identification; presence of magnesium chloride.

2.3 Rock sample taken from panel (below and to left of large panel). Porosity study; particle size analysis; mineral identification; presence of magnesium chloride.

Particle Counts:

Particle count taken July 10, 2007, 11:30AM, with no traffic on the road:

μ	Δ	Ft^3
0.3	9235.8	
0.5	3307.4	
1.0	2752.8	
2.5	4802.1	
5.0	1105.3	
10.0	682.4	

Particle count taken July 10, 2007, 11:40AM, during the passing of a wide-load truck and a large dumpster coming in opposite directions:

μ	Δ	Ft^3
0.3	13,093.6	
0.5	14,391.3	
1.0	13,059.5	
2.5	25,622.8	
5.0	5,750.8	
10.0	11,009.0	

SITE 2
COTTONWOOD CANYON SITE,
THE PANEL ABOVE THE "HUNTING SCENE"
INTERPRETATION

The road adjacent to the site has been reduced to fine powder. As the included photographs show, the powdery particulates are thrown into the air by traffic; the finest particles remain suspended until they settle in a surface. There is obvious heavy deposition of dust and fine particulates on the panel. The particle counts confirm these visual observations.

The elemental analysis of the sample from the road adjacent to site *42Cb238* raises several questions. It has been assumed that this section of road has never been treated with magnesium chloride. However, there is a clear indication for the presence of magnesium and chloride in the sample. Additionally, the spectra for sample 2.1 is quite similar to the spectra for sample 1.1, although there is the presence of traces of gold (Au) in the sample 2.1.

There are several possible explanations. First, the magnesium and chloride may be occurring naturally. Second, the road may have had an unauthorized treatment with magnesium chloride or a similar dust abatement material. Third, magnesium chloride may have been transported on the wheels of vehicle, contaminating the road and the adjacent rock art. The ability of magnesium chloride to cling to vehicles, be transported, and contaminate distant property has been noted and is a source of concern in many parts of the United States (Ucar 2000).

The spectra from the petri dish left at the site are quite interesting. There are some dissimilarities between the depositional spectra and the spectra from the road. Specifically, sodium (Na) is not present in the depositional spectra.

4.2.3
SITE 3
THE HUNT SCENE
42Cb239

Description:
This site was originally recorded in 1976 by Lindsay and Sargent and re-visited in 1993 by USAS. This is a famous rock art site in Nine Mile Canyon known as "The Great Hunt." The site is described as two components of rock art, petroglyphs and pictographs. Panel 1 consists of seven white daub pictographs, the southernmost, appears to be an outline of a shield containing four short lines hanging from the bottom and three vertical lines. There are several indiscernible white marks and a circle with three vertical lines inside.

Panel 2 exhibits three large red and chalked circle pictographs with underlying petroglyphs, zig-zag lines, oval shaped pictograph of grayish-white pigment, a yellowishgold pictograph, and a small circle of gray pigment, Below and above the pictographs are petroglyphs, including numerous sheep, deer, zoomorphs, and a buffalo. There are modern historic inscriptions present on the panel as well. The panel is along the back wall of a shallow overhang with an oxidized ceiling from campfires which were probably ancient and modern. Component B consists of six petroglyph panels including "The Great Hunt" (Comp B, Panel 1) which contains a total of 43 figures. The panels consist of anthropomorphs, bow and arrow hunters, numerous zoomorphs, sheep, and abstract designs.

The rock-art panel is located 125 feet from the road. The road has been reduced to a powdery surface. When large industrial vehicles passed, vast clouds of fine particulates were thrown at least 150 feet in the air and remained suspended until settling on nearby rock surfaces. There is obvious heavy deposition of fine particulates on the panel, as shown in the included photographs.

Date of Examination: July 10, 2007

Photographs:

3.1
3.2
3.3
3.4

Samples Taken for Laboratory Analysis:

3.1 Rock sample taken from panel below "T" of vandalism. Porosity study; particle size analysis on surface; mineral identification; presence of magnesium chloride.

3.2 Petri dish, particulate settling after 24 hours. Particle size distribution; mineral identification; presence of magnesium chloride.

3.3 Road, bulk sample. Particle size analysis; mineral identification; presence of magnesium chloride.

Particle Counts:

A particle count was taken with no traffic on the road, on July 10, 1007, at 1:25PM.

μ	Δ	Ft^3
0.3	10,475.9	
0.5	480.6	
1.0	52.7	
2.5	51.7	
5.0	7.4	
10.0	16.4	

A particle count taken at 1:45 PM, with 1 pickup truck and 3 heavy industrial trucks converging on the site:

μ	Δ	Ft^3
0.3	40,100.00	
0.5	10,108.0	
1.0	7,275.2	
2.5	14,334.6	
5.0	3,560.9	
10.0	2,028.6	

4.2.3
SITE 3
THE HUNT SCENE
INTERPRETATION

The road adjacent to the site 3 has been reduced to a powdery consistency. As the photographs show, when any vehicles pass large clouds of fine dust are thrown at least 150 feet into the air and linger for at least 10 minutes. When the vehicular traffic is especially heavy, the plume of dust visibly increases in size and density. This fine dust is blown against the nearest rock face and settles on it. There is no doubt that the dust has affected the rock art.

Sample 3.1 is a bulk sample that was taken from the road adjacent to the site. Sample 3.2 is a sample of depositional dust collected from a petri dish left at the site for 24 hours. The spectra of sample 3.1 and 3.2 are remarkably similar. The only conclusion is that the dust from the road is carried to and is deposited on the panel.

Spectra from samples 3.1 and 3.2 also indicate the presence of magnesium and chloride, but additional tests will be need to determine if the spectra indicate naturally occurring magnesium and chloride or the introduced presence of the salt magnesium chloride, either as a contaminant on vehicles or as unauthorized or unrecorded dust abatement treatments.

4.2.4
SITE 4.
DRY CANYON PETROGLYPHS
43Cb31

Description:
This is a Fremont rock art site with several structural elements located north of the Dry Canyon road and designated on the topographic map as "petroglyphs." The site was originally documented by the BLM over 30 years ago (Fike 1972) and re-recorded by MOAC in 2002 (Raney and Montgomery 2002), and again by the BLM in the same year (Maloney 2002). The site contains five petroglyph panels rendered on the cliff face, attributed to the Fremont culture. Panel 1 (12 ft ags) has a central spiral/serpent element

surrounded by about 24 smaller anthropomorphs (including a figure with a bow and arrow), zoomorphs, serpents, dot grids, and other abstract elements. Panel 2 (3 ft ags) displays a solid pecked 'horned' anthropomorph and two serpents. Panel 3 (9 ft ags) shows two spiral serpents and two dot grids. Panel 4 (6 ft ags) has three elements, two quadrupeds, and an abstract element. Panel 5 (6 ft ags) exhibits a series of dots. Maloney (2002) trowel tested two possible circular structural features to a depth of 20 cm below ground surface that failed to reveal cultural deposits. No artifacts were found at the site.

For this study, Dry Canyon served as a control because there is no development activity on the old access road that runs into the canyon. Unlike the main road of Nine Mile Canyon, the access road into Dry Canyon receives almost no traffic at all. For this reason, the road has retained its hard-pack gravel surface. The adjacent rock art is visibly free of depositional dust.

Date of Examination: July 11, 2007

Photographs:

4.1
4.2
4.3

Samples Taken for Laboratory Analysis:

4.1 Petri dish left at panel for particulate settling after 24 hours. Particle size distribution; mineral identification; presence of magnesium chloride.

4.2 Rock sample removed from panel below snake image. Porosity study; particle size analysis; mineral identification; presence of magnesium chloride.

4.3 Road, bulk sample. Particle size analysis; mineral identification; presence of magnesium chloride.

Particle Counts:

Particle count taken at 2:50PM:

μ	Δ	Ft^3
0.3	12,069.7	
0.5	517.1	
1.0	30.7	
2.5	26.4	
5.0	2.3	
10.0	0.6	

SITE 4
DRY CANYON PETROGLYPHS
INTREPRETATION

As the included photographs show, the lightly used road adjacent to the panel has retained a natural hard-packed surface. In this regard, it is interesting to note that the particle count quite closely resembles those taken at sites where the main road in Nine Mile Canyon has been treated with a dust abatement system and constant watering. However, the slightly elevated particulate count in the 0.3μ range could be due to other factors, such as naturally occurring particulates such as pollen or from smoke from the huge forest fires that burned nearby while the count was being taken.

Data generated from the laboratory analyses of the collected samples from Dry Canyon are intriguing. Sample 4.3 are spectra of a sample of the road adjacent to the rock art. The spectra closely resemble the spectra from the road adjacent to the Hunt Scene, in Nine Mile Canyon, with one critical exception: no magnesium chloride is present in the Dry Canyon sample, either naturally occurring or as an introduced material.

Sample 4.1 is the spectra of depositional material from the petri dish left at the site for 24 hours. The depositional material does not resemble the material of the road, suggesting that material deposited at the site is not generated from the road. Magnesium chloride is not present.

4.2.5
SITE 5
RASMUSSEN CAVE
42Cb16

Description:

The site is located in an overhang of a cliff face approximately 30 m north of Nine Mile Canyon road, due north across the canyon from the entrance to Dry Canyon. This site is commonly known as Rasmussen Cave. It was originally recorded as part of the Claflin-Emerson expeditions in the 1930s and details of the artifacts recovered and excavation are provided in *The Fremont Culture* authored by James Gunnerson in 1969. In 1991, the site was revisited as part of the Nine-Mile Canyon Survey (Report No U-91BL661). At that time, the site was reported as an overhang measuring 28 m wide and 7.5 m deep at its deepest point. The eastern half of the cave floor was littered with large boulders that fell from the ceiling in pre-occupation times. The western portion of the cave contained a flat area that may have served as the main activity area. Almost all surface boulders within the overhang contain petroglyphs and/or pictographs. The site has been vandalized extensively. The entire floor of the cave has been dug, and historic names, dates, etc. are superimposed over much of the rock art. Portions of panels 15 and 18 have been chiseled off. A total of 30 rock panels were described at the site. Three clefts (Clefts A, B, and C) were originally excavated within the cave. Some of the artifacts recovered include Emery Grayware sherds, ceramic figurines, clay blobs, a scraper, a mano, hide pieces, bone fragments, cord fragments, a reed tube, reed mat fragments, basket fragments, corn, a digging stick, stone points, a stone drill, one serrated bone tool, a spear foreshaft, and an atlatl. A Basketmaker-type burial was excavated in Cleft A. During the current inventory, a datum stamped with the permanent site number was placed at the site, and an updated topographic map was prepared; no further documentation was undertaken.

The road in front of the cave has been treated with a dust abatement material, assumed to be magnesium chloride. The road is often watered. Nevertheless, there is a substantial layer of fine dust on the rock fall in front of the panel. This dust was sampled to test the hypothesis that it might be from the road prior to its treatment with a dust abatement material.

Date of Examination: July 11, 2007

Photographs:

5.1
5.2
5.3

Samples Taken for Laboratory Analysis:

5.1 Petri dish left at the panel, particulates settling over 24 hours.
Particle size distribution; mineral identification; presence of magnesium chloride

5.2 Dust samples removed from rocks in front of the panel. Particle size analysis; mineral identification; presence of magnesium chloride.

5.3 Road, bulk sample. Particle size analysis; mineral identification, presence of magnesium chloride.

Particle Counts:

The particle count was taken at 12:05Pm on July 11, 2007, with no traffic on the road:

μ	Δ	Ft^3
0.3	10,176.5	
0.5	448.0	
1.0	79.2	
2.5	1,51.3	
5.0	40.0	
10.0	9.8	

The particle count was taken at 12:30PM with two vehicles passing in opposite directions:

μ	Δ	Ft^3
0.3	10,437.5	
0.5	693.0	
1.0	288.8	
2.5	723.2	
5.0	180.0	
10.0	58.0	

SITE 4
RASMUSSEN CAVE
INTERPRETATION

Only a slight increase in airborne particulates occurred with the passage of vehicles on the road, suggesting that dust abatement can greatly contain the genesis of dust.

The interior of the cave is heavily covered in dust, but it is not clear when and how this dust accumulated. The origin of this dust remains an interesting question. It may have been generated within the cave by the activity of unauthorized hikers, campers and illegal excavators; indeed, during the course of this study prehistoric corn cobs were observed strewn about the floor of the shelter, suggesting unauthorized "pot-hunting." However, the dust may have been generated from the road before dust abatement treatment. Data from the laboratory analyses are intriguing.

Sample 5.2 is the elemental spectra from the dust removed from the rock fall at the front of the cave. The spectra are so similar to the spectra for 4.3, the sample from the road in Dry Canyon, that they are almost identical. Indeed, there is no presence of possible magnesium chloride in sample 5.2, nor is there a possibility of magnesium chloride in sample 4.3.

The sample of depositional material collected in the petri dish, sample 5.1, is very similar to sample 5.2---and thus to sample 4.3, from the road in Dry Canyon---but there is a major difference: the depositional material contains spectra that indicate the possible presence of magnesium chloride.

The sample from the road in front of Rasmussen Cave, sample 5.3, shares many similarities with the depositional dust, including spectra that indicate the possible presence of magnesium chloride.

These data provide grist for an obvious---but still unproven---hypothesis. The dust on the rock fall was deposited from the road prior to fairly recent dust abatement treatments and thus closely resembles the undisturbed road of Dry Canyon---neither of which manifest any evidence for the presence of magnesium chloride. Following dust-abatement treatments, magnesium chloride was introduced and has found its way into the air as a particulate and has settled as such in the petri dish that was left at the site.

5
CONCLUSIONS AND RECOMMENDATIONS

Although the research described in this report remains in progress, it is possible to conclude that the degraded sections of road in Nine Mile Canyon are generating large amounts of dust as industrial traffic passes. These particulates are very fine and would appear to conform to the descriptions by Thomson: that the finest particles are the most dangerous for cultural property for many reasons, including their ability to remain suspended in air until they find a surface upon which to settle. In the case of Nine Mile Canyon, that surface can be a rock-art panel.

There is an on-going study of traffic in Nine Mile Canyon, supervised by the BLM, but on-site observations alone indicate that heavy industrial traffic has increased as energy-related work has increased. This traffic quickly cuts through any protective hardpack on the road and reaches and liberates the powdery substrate, which is thrown into the air as dust. In this regard, it should be recalled that the canyon was created by water-borne depositions, so fine silts and clays would not be unexpected. The heavy traffic further pulverizes these very fine particulates.

It is also clear that treatments that control the generation of dust from the road have been effective, although not perfect. In this regard, particle counts taken in Dry Canyon, where the road remains naturally hard-packed and receives little traffic, are very close to the particle counts taken at sites where the adjacent road sections have been treated with a dust abatement system and are watered continuously.

The analytical systems utilized in this study provided useful and verifiable data. These methods are especially useful because they are relatively inexpensive and simple to use, and the data are generated quite quickly. However, some refinements in use of these systems will be required. There is a discrepancy in the raw data from on-site readings with the particle counter, when compared with particle size distribution calculated from collected depositional material. One possible explanation is that the particle counter literally counts all particles in the air, including smoke, pollen and vegetal exudates, but these particulates are not calculated in the depositional analysis by laboratory systems.

To date the laboratory analyses, in combination with visual observations, confirmed that conditions at the control site, Dry Canyon, differ substantially from those at the sites in Nine Mile Canyon. In Nine Mile Canyon, the combination of raw road surfaces and heavy vehicular traffic produces large plumes of fine dust that settle on the adjacent rock art. Laboratory analyses provided spectra "signatures" of the depositional dust that confirm that it originates from the road at the Hunt Scene and Cottonwood Canyon panel. However, the depositional dust at the two sites adjacent to sections of road treated for dust abatement raises several questions about the origins of the dust overall on many sites in Nine Mile Canyon. Specifically, variations in the spectra suggest that some of the dust may have been deposited prior to the current industrial use of the road at Rasmussen Cave.

At all the study sites, the analyses raised an important, intriguing and totally unexpected question: what dust abatement system has been used on the road in Nine Mile Canyon? The dust abatement work on the road has occurred on sections that are under the purview of agencies not connected to the BLM. Consequently, the BLM does not have verifiable records of that road work. The anecdotal information is that magnesium chloride was used for dust abatement, but no documentation of its use has been provided.

In fact, magnesium chloride is widely used as flakes and as a powder for both dust abatement and for de-icing. Analyses confirm the presence of magnesium and chloride in samples from the road and in depositional dust in Nine Mile Canyon, but the actual salt, magnesium chloride, has not been isolated and identified. The presence and possible contamination of sites by magnesium chloride is a critical component of this study. Magnesium and chloride may be present naturally in the particulates of Nine Mile Canyon, although they are not present in Dry Canyon or in some of the dust at Rasmussen Cave.

The obvious source of magnesium chloride would be its application for dust control on the road. However, it has not been possible thus far to isolate and identify magnesium chloride from a section of treated road adjacent to the Harmon Canyon site. A possible explanation is that magnesium chloride was used with hydrated magnesium oxide to create a hard-pack surface material called Sorel cement. If this is the case, perhaps the magnesium chloride is transformed in the process, making its identification impossible.

The analytical mystery surrounding the use and presence of magnesium chloride in Nine Mile Canyon must be clarified. The presence of introduced magnesium chloride could serve as an effective marker as research in dust abatement and control continue in the canyon. Because of mounting concern about the environmental impacts caused by magnesium chloride, it is important to know if it is present and has contaminated the rock art. Continuing research will be required.

Finally, and most importantly, the need for refinement of analytical methods and additional research must not deflect from the need to act quickly to stop the generation of dust on the road in Nine Mile Canyon and to treat sites that have been affected. The final sections will examine these two critical issues.

5.1
DUST ABATEMENT ON THE ROAD AND CONCERNS ABOUT MAGNESIUM CHLORIDE

Increasingly, there is a body of scientific literature that is raising concerns about the use of magnesium chloride. Magnesium chloride is a salt that will deliquesce at a very low relative humidity; that is, it will pull ambient water out of the air and remain wet. A case history that reveals the potential for the deleterious effects of magnesium chloride occurred some years ago at the Metropolitan Museum. The Abbydos Frieze is an important work of art from dynastic Egypt, on display in the museum. It is made from carved limestone, which was constantly deteriorating. Eventually, it was determined that naturally occurring magnesium chloride in the stone was heavily deliquescing in the humid climate of New York City. The magnesium chloride could not be removed from the fabric of the stone. Therefore, the frieze had to be placed in a climate-controlled case.

It cannot be proved that particulate magnesium chloride landing on a rock-art panel in Nine Mile Canyon will produce the same damage as occurred on the Abbydos Frieze in the Metropolitan Museum. Nevertheless, the deterioration of a work of art by this salt does motivate concern for its use around any work of art.

More troubling data about the use of magnesium chloride is being raised from several agencies and organizations around the country following its introduction as a de-icing material (Cody 1996; Cody 2000; Leiser 1967). The work of these concerned scientists contrasts (not unexpectedly) with the benign pronouncements of the companies that make and market magnesium chloride (Peters Chemical Industry 2006).

A particularly focused and accessible paper has been written by Peter Snow of the American Concrete Institute (Snow 2002). Salient passages are quoted:

> During the winter of 2000-2001 scaling on concrete surfaces in the Idaho Falls region increased 10 times more than in all the previous 9 winters. The American Concrete Institute (AC1 302) and the National Ready Mix Concrete Association in their series "Concrete in Practice" define local flaking or peeling of a finished surface of hardened concrete as a result of freezing and thawing. A review of scientific and engineering literature indicated that chloride-containing deicing materials such as calcium chloride, potassium chloride and sodium chloride can exacerbate scaling as concrete goes through freeze-thaw cycles. By the winter of 2000-20001 there was a major change: governments had introduced a relatively new magnesium chloride-based deicing material.
>
> How does magnesium chloride damage concrete? One must have a fundamental knowledge of concrete in its hardened state. Concrete, when setting from a plastic to hardened condition, goes through a number of chemical reactions. Basically, hardened concrete consists of two major chemical compounds;

calcium-silicate-hydrate and calcium hydroxide. Actually, the reaction products from cement hydration with water are very chemically complex, but for the purposes of this review we will stick to the basics. When concrete is to be exposed to severe freezing, it is standard practice to entrain a system of microscopic air bubble in concrete mixtures typically occupying a volume of 5-8%. The purpose of this air-void system is to provide space for the increased volume that water will occupy as it becomes ice. If one were to look at concrete under a microscope in the range of 3000x this entrained air would look very much like a wasp nest. Magnesium chloride for deicing is effective in reducing the temperature at which water freezes. The problem begins as the magnesium chloride comes into contact with the now deiced concrete surface and remains contained in the melt water and permeates into the concrete. While deicing salts containing sodium, potassium and calcium are chemically innocuous to concrete, this is not true of magnesium. The magnesium ions accumulate and react with the cementitious compound calcium-silicate-hydrate converting it to magnesium-silicate-hydrate (or a mineral called brucite), which is non-cementitious in nature. In other word, a fundamental major mineralogical product of solidified concrete has now been chemically altered (completely changed). Formation of magnesium-silicate hydrate breaks down the "glue" that binds aggregates together and concrete surfaces begin to deteriorate. The net effect is we now have a chemical and physical attack that concrete is not designed to withstand, nor be subjected to.

The bad news is that the consequent damage to concrete and its financial impact upon the community at large is significant. Private property owners particularly suffer damage and are looking for someone to blame. A couple of essential points: The magnesium chloride adheres to vehicle tires and to the vehicle itself and is therefore contaminating private property owners' driveways and sidewalks and causing damage as previously outlined. Who is to pay for this?

The last essential point of this review is that this material is extremely corrosive, causing damage to plant and vegetable life, and greatly accelerating the destruction of most metals, primarily automobiles and their accessories. The producers of the magnesium chloride claim to have integrated a corrosion inhibitor to attempt to negate some of the auto damage, but a joint study of the Colorado Transportation Department and National Trucking Association (as a result of truckers' complaints about corrosion to their vehicle and electronics) has not borne out that this "corrosion inhibitor" is effective.

Again, there is no proof at present that magnesium chloride used for dust abatement in Nine Mile Canyon has---or will---become a vector of deterioration for the canyon's resources. However, it is important that all stewarding agencies be aware of the potential for damage that this material, and other dust abatement materials, may present.

5.2
RECOMMENDATIONS

Action needs to be taken to address the following problems:

1. Dust Abatement on the Road. Research needs to begin immediately to identify, develop and implement a treatment for the road that will be environmentally acceptable as well as effective. If at all possible, it would also be useful to implement a temporary dust abatement system adjacent to at-risk sites so that dust will not continue to build up on the panels.

2. Conservation Treatment for the Rock Art. Research needs to begin immediately to develop treatments for the removal of the dust from the rock art panels. Extensive dust removal from rock art has not been addressed in conservation literature, so the research will be innovative. Therefore, time and experimentation will be needed to develop an effective and safe treatment. Consequently, this research needs to begin immediately in order to have effective treatments in place in a timely manner.

3. Adjustment of Analytical Methods. As the dust abatement work continues in Nine Mile Canyon, analytical systems need to be employed in order to determine the success of the abatement and improvement in air-quality over the short-term and the long-term. A key research question is how much of the road---or how much of a given stretch of road near a site---needs to be treated to ensure that a rock art panel will not be impacted by dust. In this regard, the research now taking place at Burrup, Australia, may provide some prototypes of monitoring systems that could be installed in the canyon. Otherwise, the simpler and more conventional systems utilized in this study could be used if they are clarified and adjusted.

The mystery surrounding the presence or absence of magnesium chloride in Nine Mile Canyon needs to be resolved as soon as possible, as part of the continuing research.

4. Location of Impacted Sites. Nine Mile Canyon is replete with rock art panels, but it is not known how many have been affected by settlement of dust. For the purposes of long-term planning for both dust abatement on the road and conservation treatment, impacted sites need to be identified and evaluated.

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APPENDIX 1
LABORATORY ANALYSES

EMSL Analytical, Inc.

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Sample(s) Received: 08/13/2007
Date of Analysis: 09/26/2007
Date Printed: 09/26/2007
Reported By: D. D'Ulisse

-Preliminary-

- Laboratory Report -

Material Analysis

For

Project: Nine-Mile Canyon, Utah

Analyzed by: *Dana D'Ulisse*, *Materials Scientist* — September 26, 2007 (Date)

QA/QC: *John Newton*, *Laboratory Manager* — September 26, 2007 (Date)

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Conclusions:

- Magnesium Chloride with identified in sample 2.2
- Magnesium and/or chloride were identified in all of the remaining samples; however, they are not believed to be associated with each other.

Procurement of Samples and Analytical Overview:

The samples for analysis (15 bulk) arrived at EMSL Analytical's corporate laboratory in Westmont, NJ on August 13, 2007. The package arrived in satisfactory condition with no evidence of damage to the contents. The samples were submitted for the purpose of determining the particle sizes/distribution, porosity, mineral identification and presence of magnesium chloride. The samples reported herein have been analyzed using the following equipment and methodologies.

Methods & Equipment:
Stereo Microscopy
Scanning Electron Microscopy (SEM)
Energy Dispersive X-Ray Spectrometry (EDX)
X-Ray Diffraction (XRD)
Set of Sieves
Scale (0.01 g Sensitivity)

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Results and Discussion:

Table 1.1. Presents the percentage (by weight) of the particles obtained by sieving

Sample ID	**Site 1. Harmon Canyon**
Location	**1.1 Road. Bulk Sample**
Particle size range	
d > 20µm	100.00
10 µm< d ≤ 20 µm	0.00
d ≤ 10 µm	0.00

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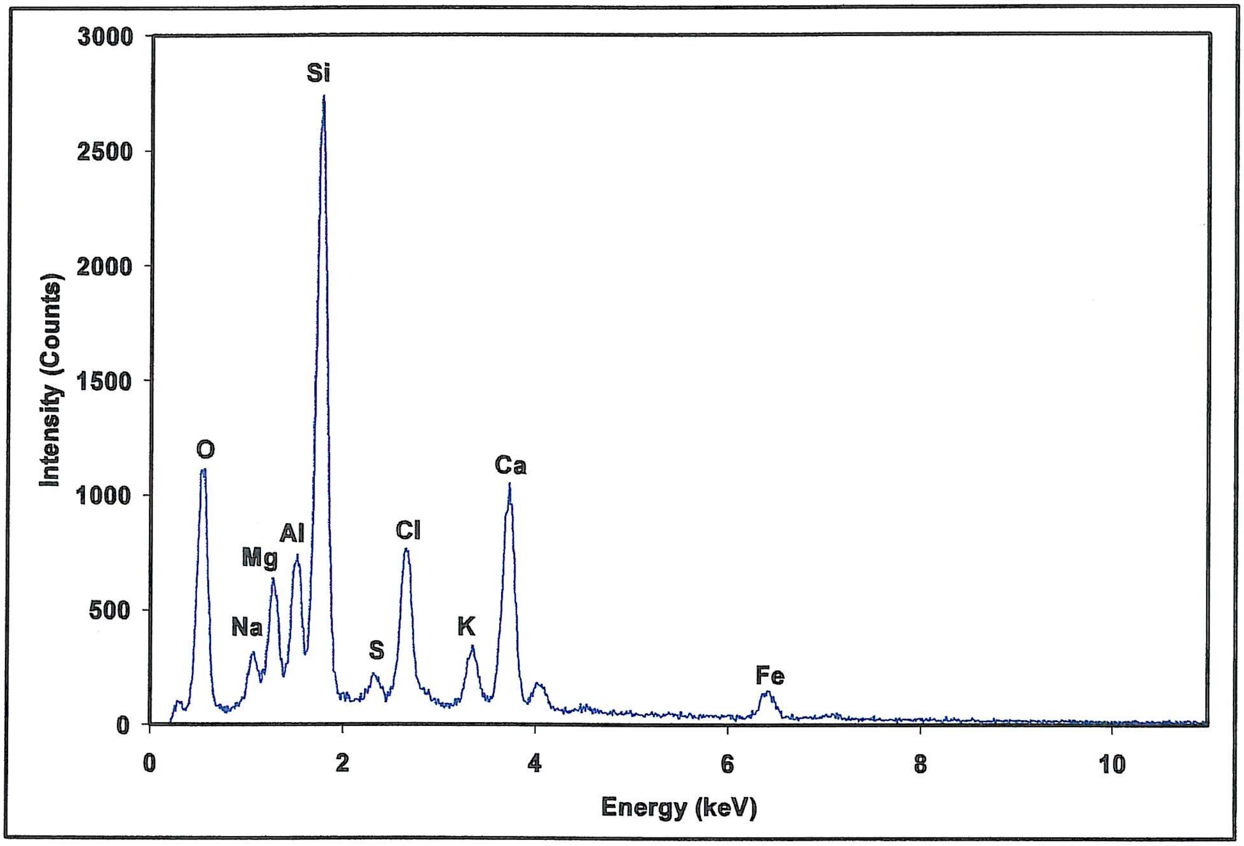

Figure 1.1: SEM/EDX elemental spectra of the particles in sample 1.1 indicating the presence of quartz (SiO_2), clays and feldspars (aluminum silicates), calcite ($CaCO_3$), gypsum ($CaSO_4$. $2H_2O$) and the possible presence of magnesium chloride; however, it is likely the magnesium is associated with aluminum and silica and the chloride is associated with sodium.

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Table 2.1. Presents the percentage (by weight) of the particles obtained by sieving

Sample ID	**Site 2. Cottonwood Canyon, Hunt Scene**
Location	**2.1 Road. Bulk Sample**
Particle size range	
d > 20μm	95.75
10 μm< d ≤ 20 μm	1.50
1 μm< d ≤ 10 μm	2.75
0.1 μm< d ≤ 1 μm	0.00

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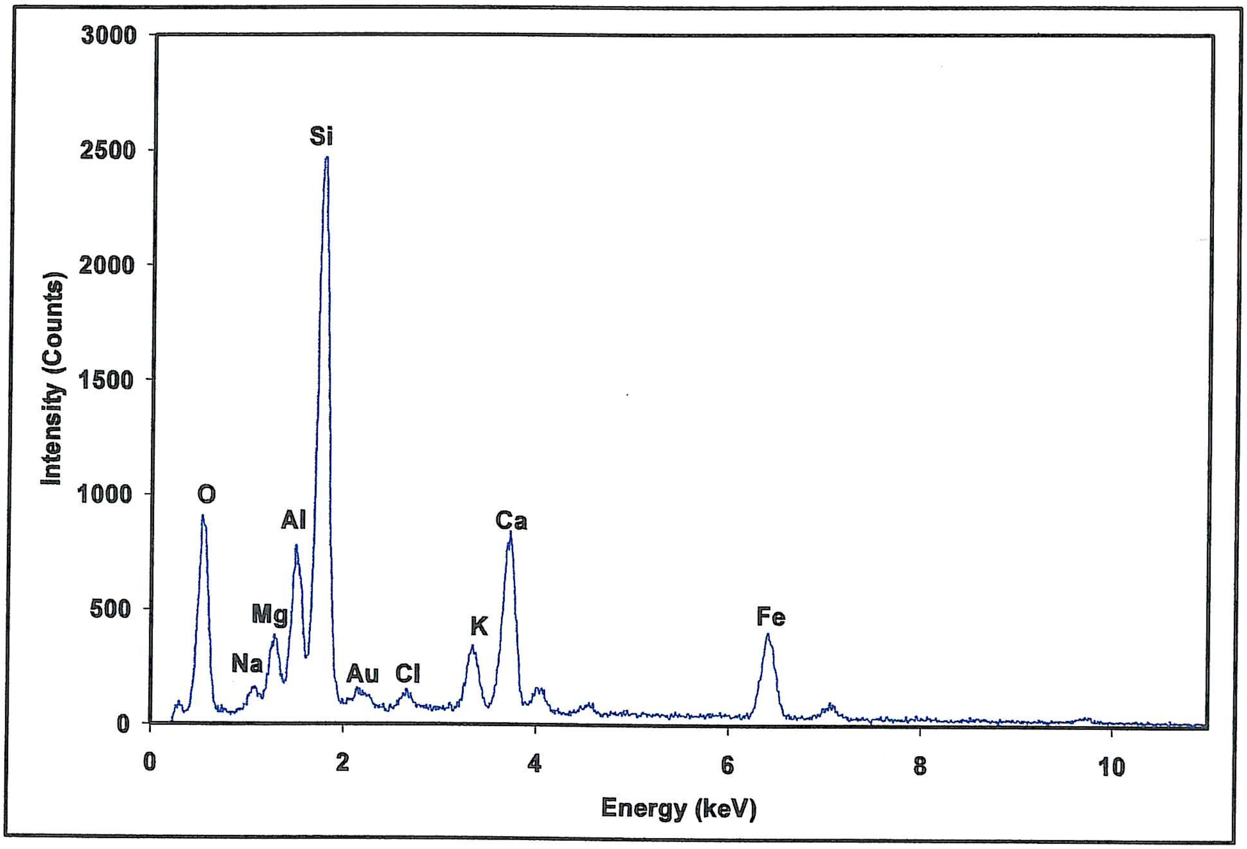

Figure 2.1: SEM/EDX elemental spectra of the particles in sample 2.1 indicating the presence of quartz (SiO_2), clays and feldspars (aluminum silicates) and calcite ($CaCO_3$). It is likely the magnesium is associated with aluminum and silica and the chloride is associated with sodium.

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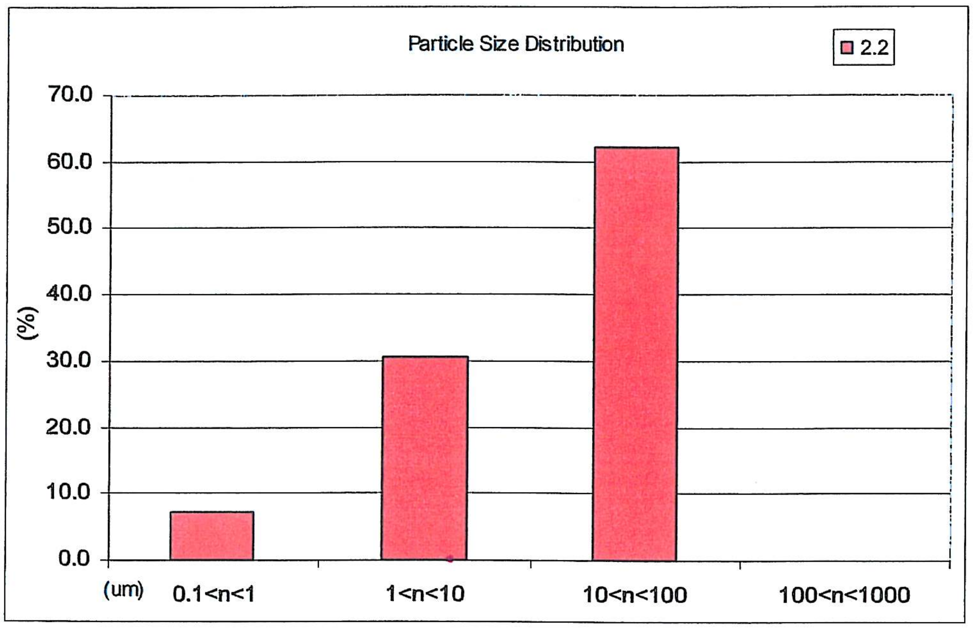

Table 2.2. Histogram of particle size and distribution for sample 2.2

		Range (um)	Count	(%)
Sample:	2.2			
Description:	From Under Large Panel	0.1<n<1	16	7.4
		1<n<10	66	30.6
		10<n<100	134	62.0
		100<n<1000	0	0.0

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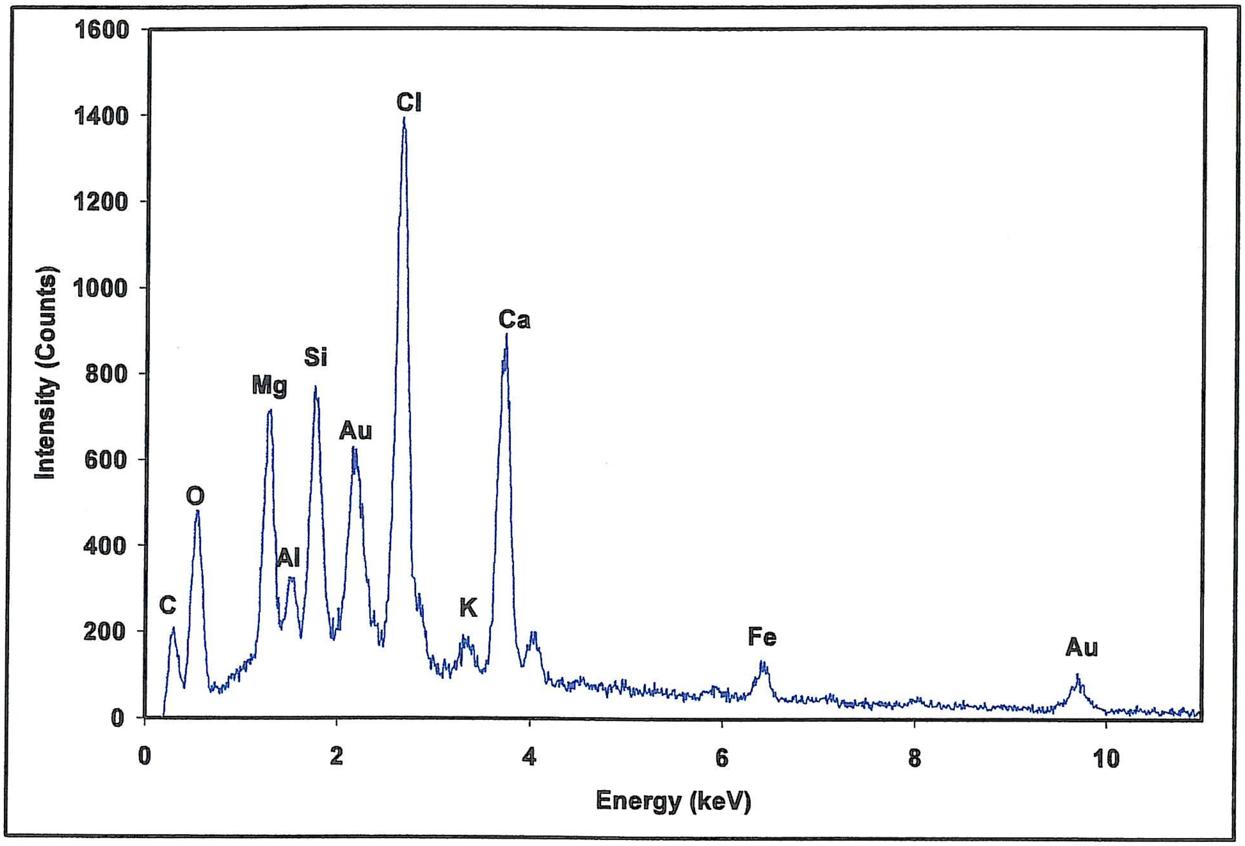

Figure 2.2: SEM/EDX elemental spectra of a single particle in sample 2.2 showing the possible presence of Magnesium Chloride.

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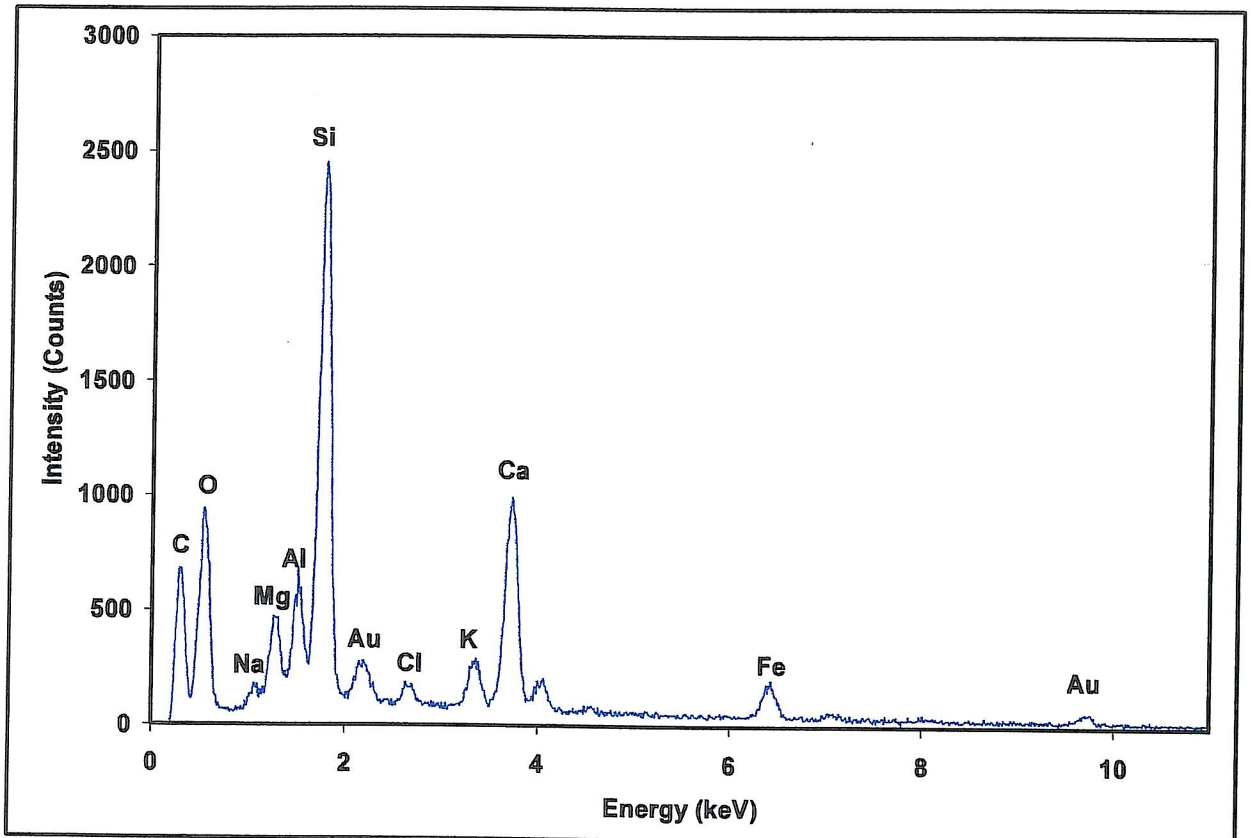

Figure 3.1: SEM/EDX elemental spectra of the particles in sample 3.3 indicating the presence of quartz (SiO_2), clays and feldspars (aluminum silicates) and calcite ($CaCO_3$). It is likely the magnesium is associated with aluminum and silica and the chloride is associated with sodium

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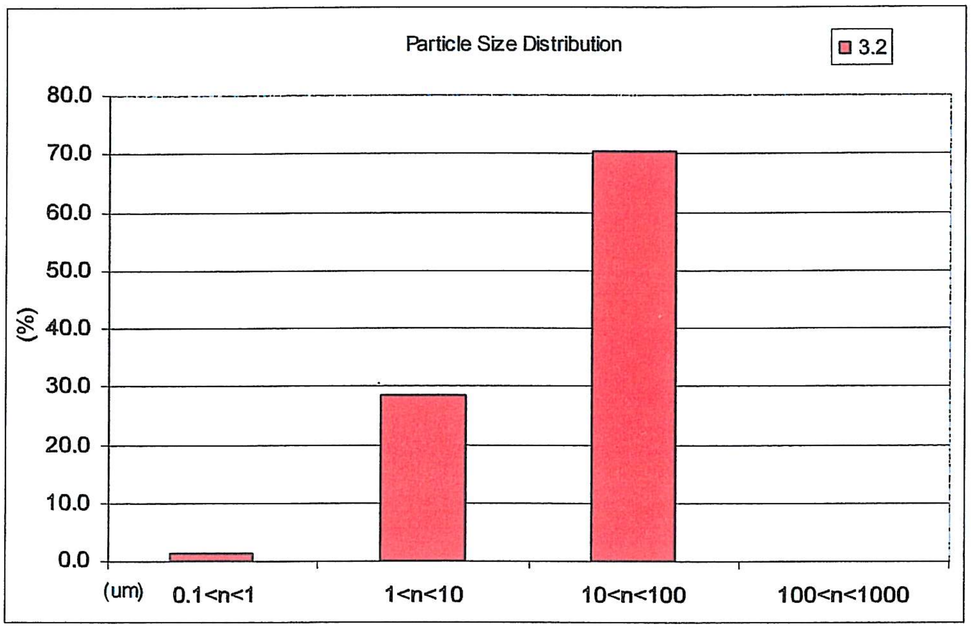

Table 3.2. Histogram of particle size and distribution for sample 3.2

		Range (um)	Count	(%)
Sample:	3.2			
Description:	Petri Dish Left at Panel	0.1<n<1	3	1.3
		1<n<10	68	28.3
		10<n<100	169	70.4
		100<n<1000	0	0.0

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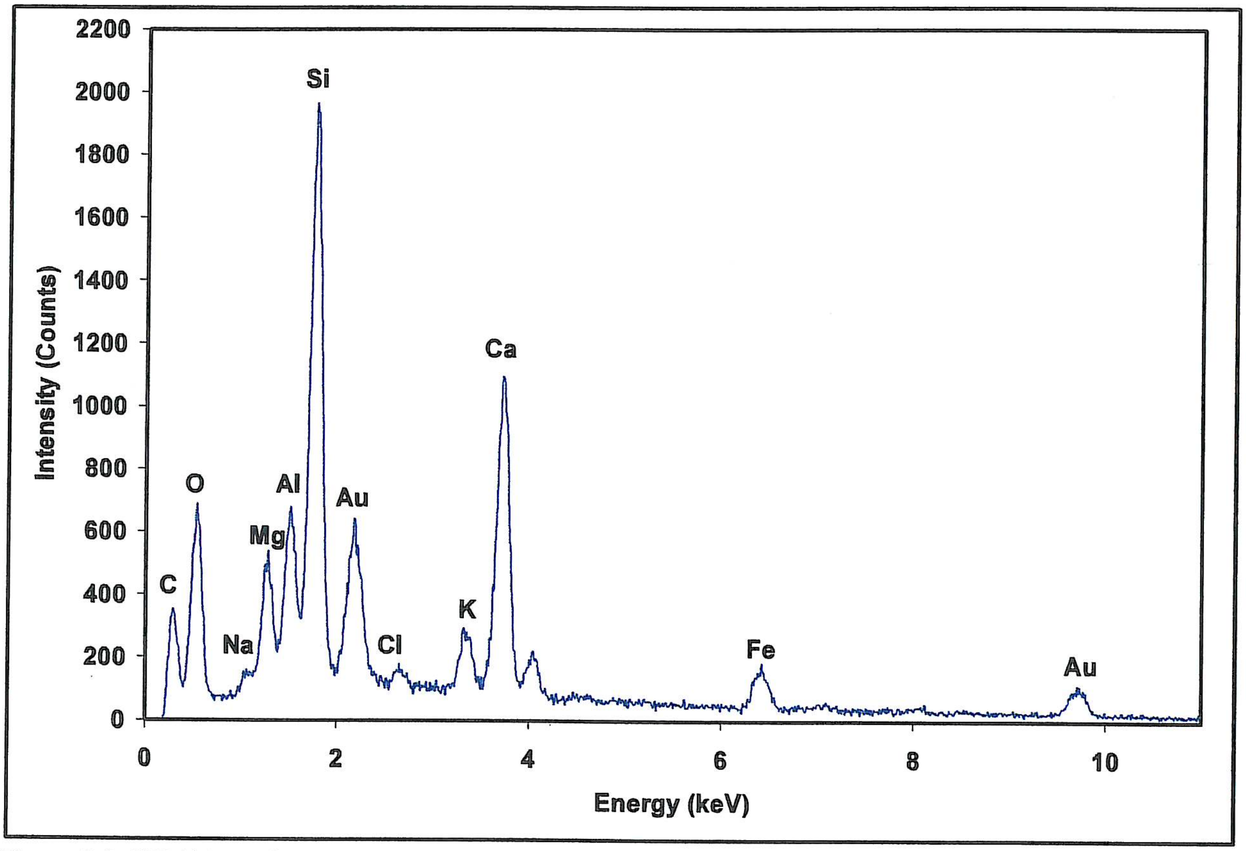

Figure 3.2: SEM/EDX elemental spectra of a cluster of particles in sample 3.2. Magnesium is associated with aluminum and silica and chloride is found in association with sodium. Remaining particles display similar spectra with respect to magnesium and chloride.

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Table 3.3. Presents the percentage (by weight) of the particles obtained by sieving

Sample ID	**Site 3. Hunt Scene**
Location	**3.3 Road. Bulk Sample**
Particle size range	
d > 20μm	98.18
10 μm< d ≤ 20 μm	1.57
1 μm< d ≤ 10 μm	0.24
0.1 μm< d ≤ 1 μm	0.01

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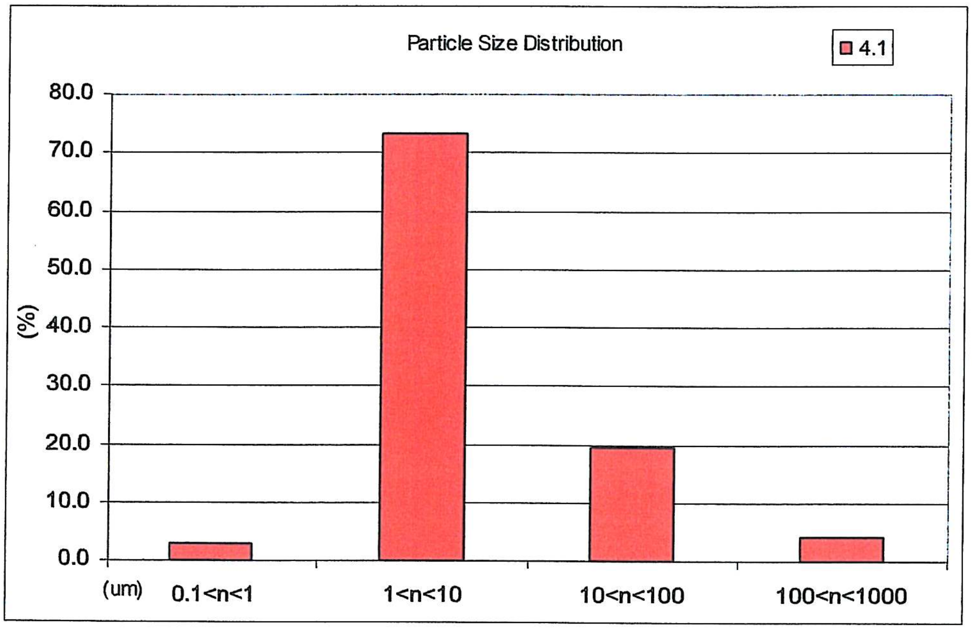

Table 4.1. Histogram of particle size and distribution for sample 4.1

		Range (um)	Count	(%)
Sample:	4.1			
Description:	Petri Dish Left at Panel	0.1<n<1	5	3.0
		1<n<10	121	73.3
		10<n<100	32	19.4
		100<n<1000	7	4.2

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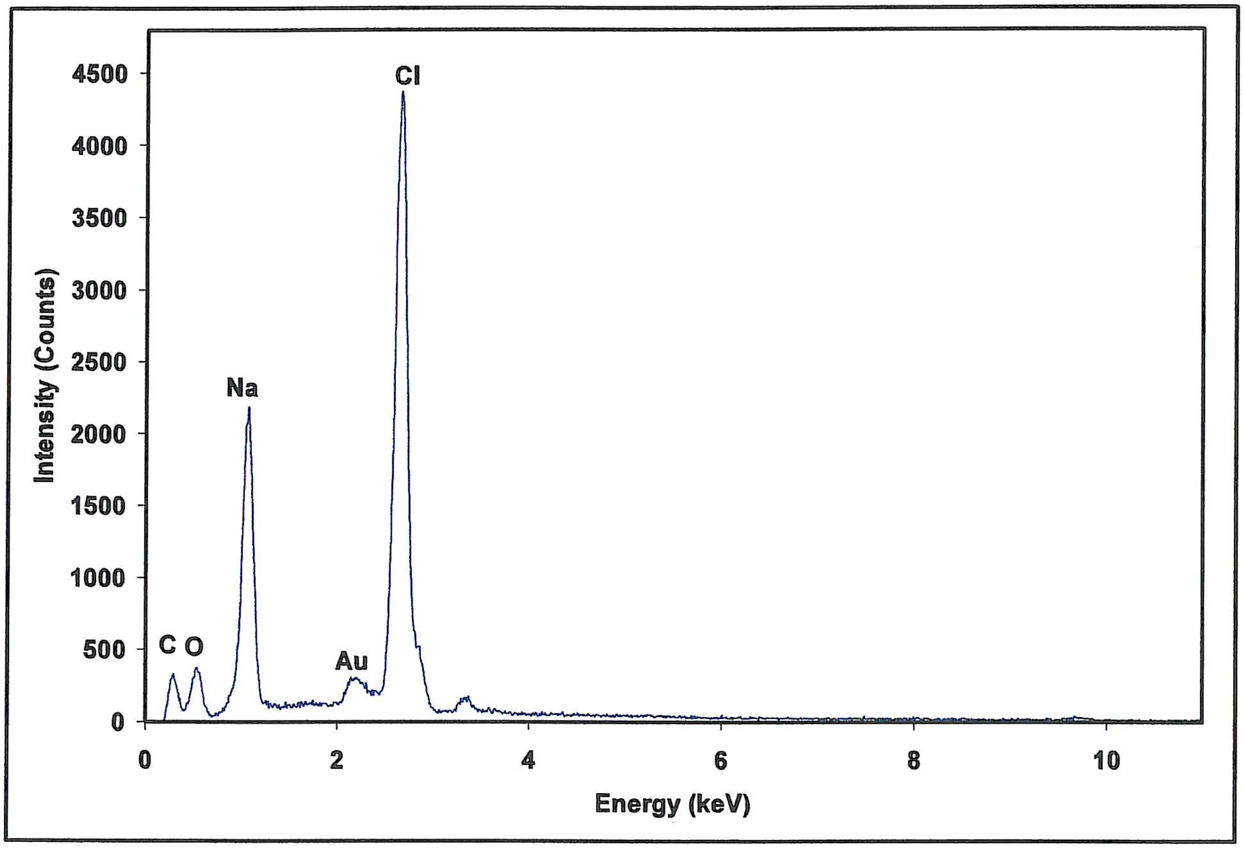

Figure 4.1: SEM/EDX elemental spectra of a single of sodium chloride identified in sample 4.1. chloride was not found with magnesium.

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Table 4.3. Presents the percentage (by weight) of the particles obtained by sieving

Sample ID	**Site 4.**
Location	**4.3 Road. Bulk Sample**
Particle size range	
$d > 20 \mu m$	97.90
$10 \mu m < d \leq 20 \mu m$	1.40
$d \leq 10 \mu m$	0.70

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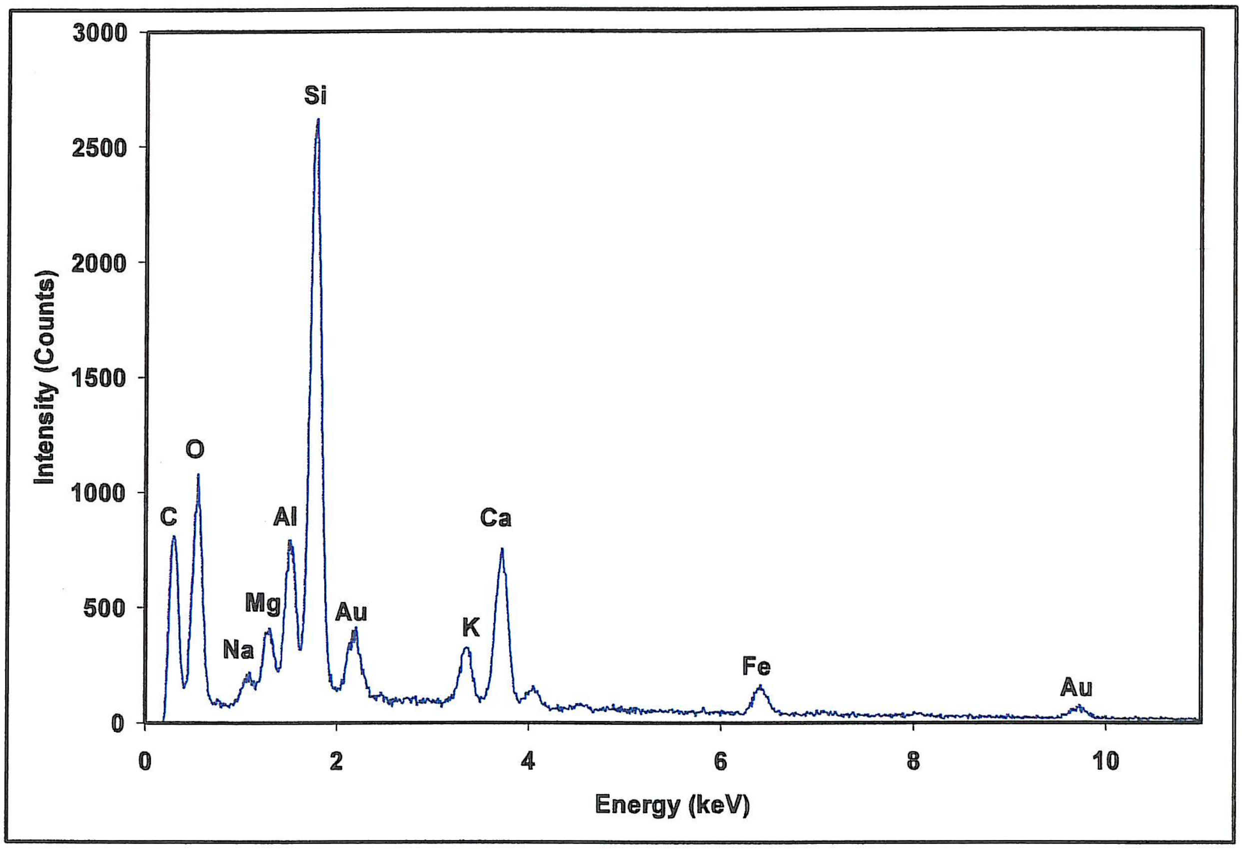

Figure 4.3: SEM/EDX elemental spectra of the particles in sample 4.3 showing no presence of magnesium chloride.

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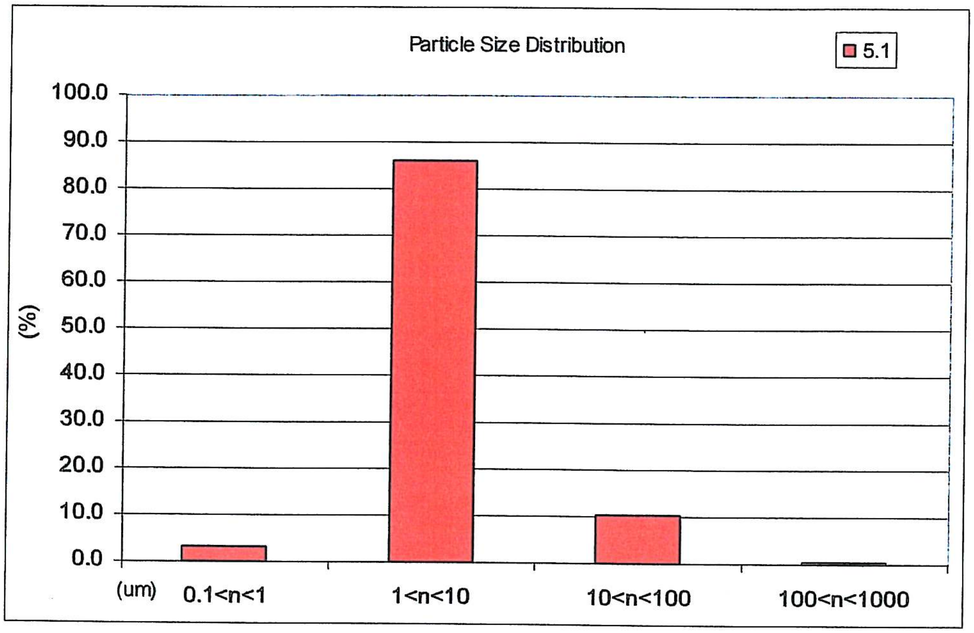

Table 5.1. Histogram of particle size and distribution for sample 5.1

		Range (um)	Count	(%)
Sample:	5.1			
Description:	Petri Dish Left at Panel	0.1<n<1	7	3.1
		1<n<10	193	86.2
		10<n<100	23	10.3
		100<n<1000	1	0.4

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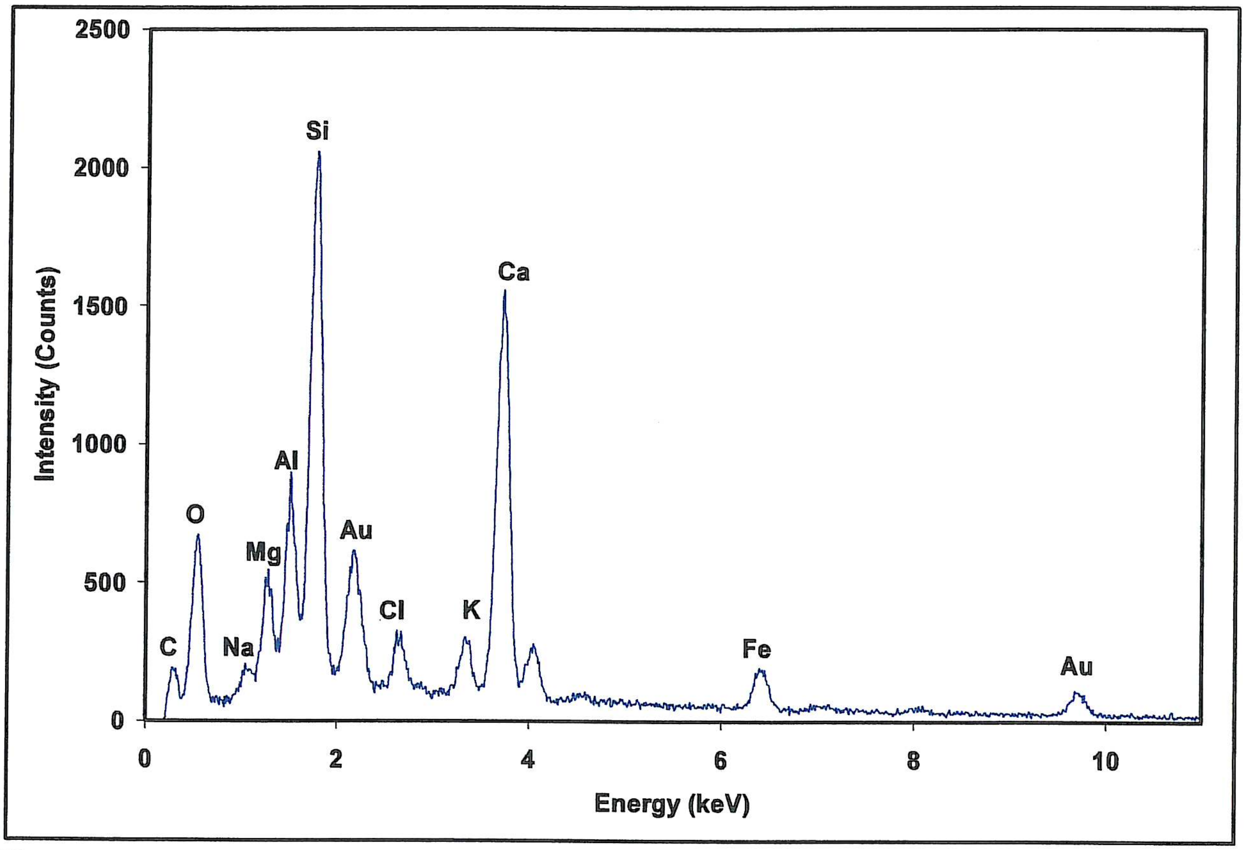

Figure 5.1: SEM/EDX elemental spectra of a cluster of particles in sample 5.1. Magnesium is associated with aluminum and silica and chloride is found in association with sodium.

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Table 5.2. Presents the percentage (by weight) of the particles obtained by sieving

Sample ID	**Site 5.**
Location	**5.2 Sample Rocks in Front of Panel**
Particle size range	
d > 20μm	99.78
10 μm< d ≤ 20 μm	0.20
d ≤ 10 μm	0.00

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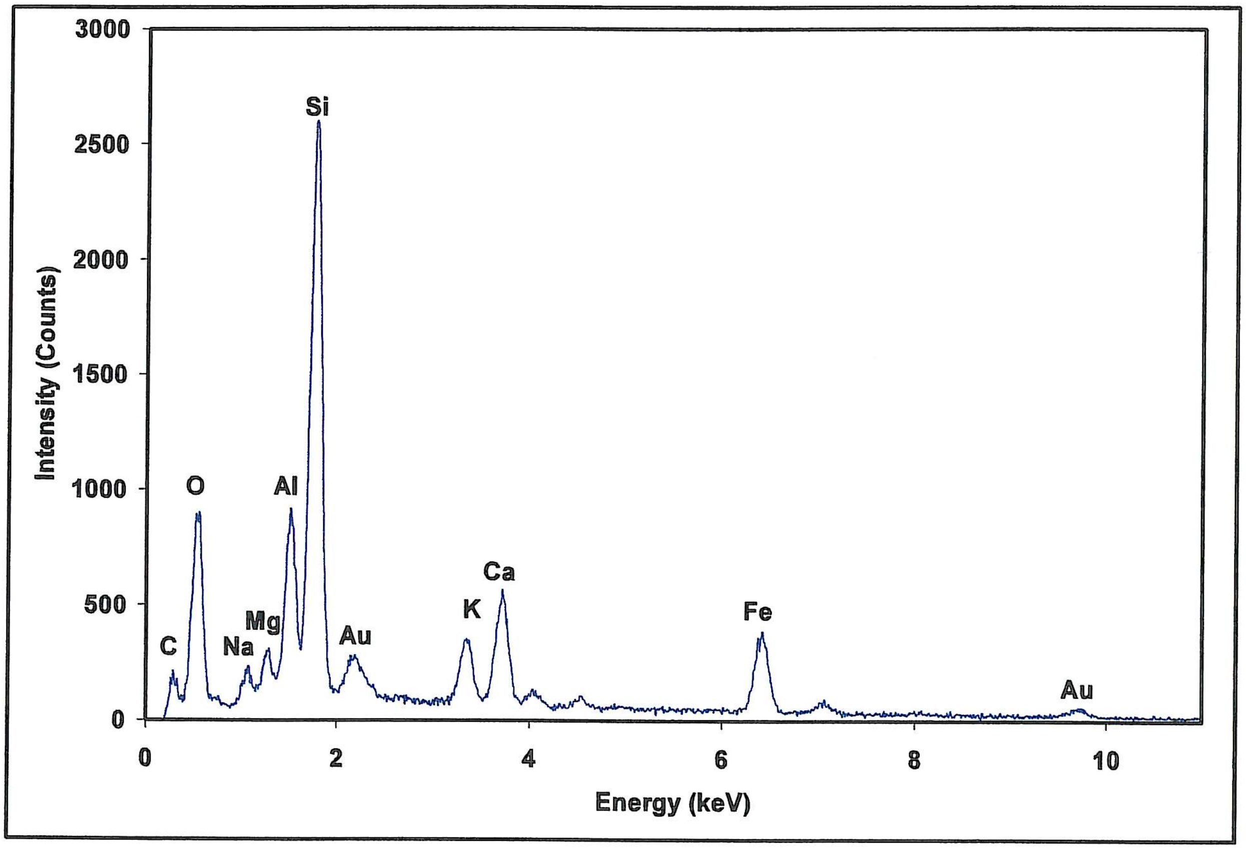

Figure 5.2: SEM/EDX elemental spectra of the particles in sample 5.2 showing no presence of magnesium chloride.

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Table 5.3. Presents the percentage (by weight) of the particles obtained by sieving

Sample ID	**Site 5.**
Location	**5.3 Road. Bulk Sample**
Particle size range	
d > 20μm	99.78
10 μm< d ≤ 20 μm	0.20
d ≤ 10 μm	0.00

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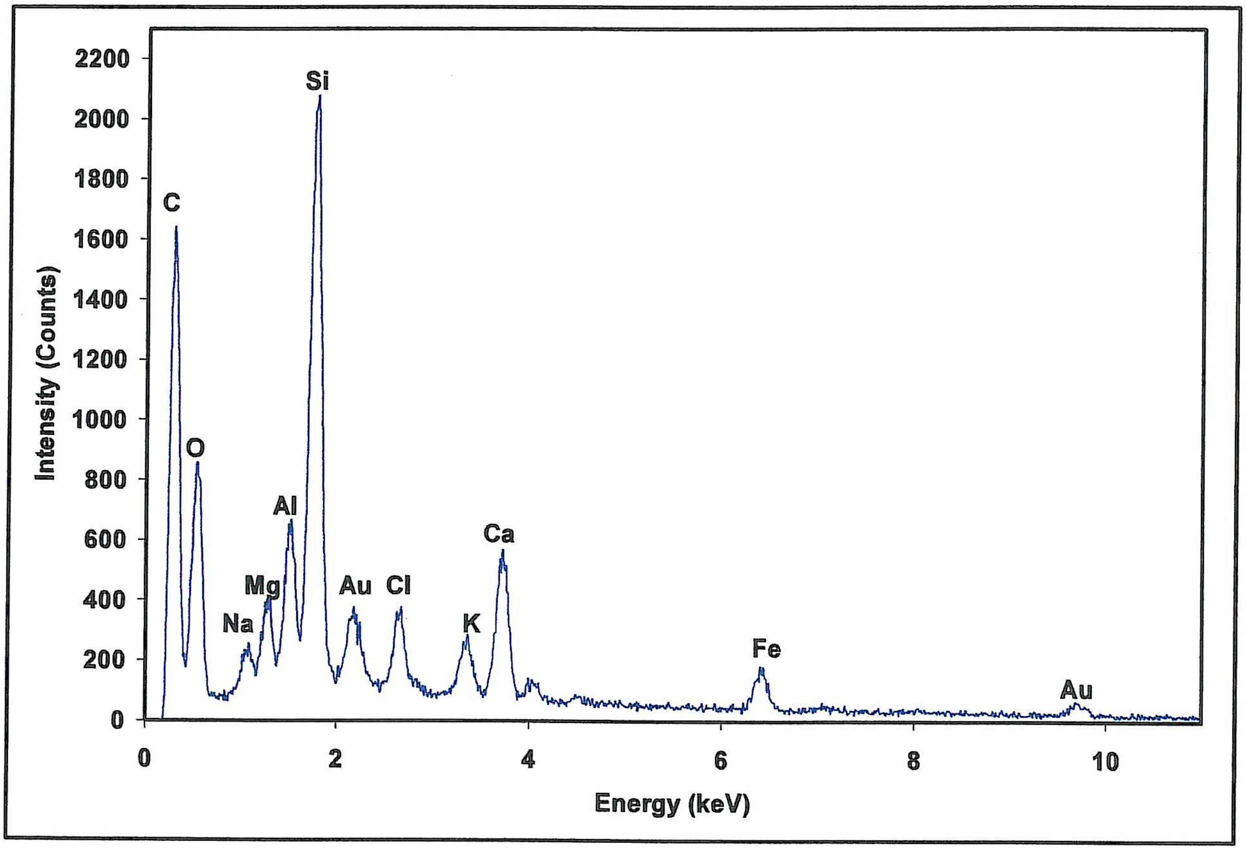

Figure 5.3: SEM/EDX elemental spectra of the particles in sample 5.3 showing the possible presence of magnesium chloride; however, it is likely that the magnesium is found in association with aluminum and silica and the chloride in association with sodium.

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Descriptions & Definitions:

None Detected (ND) denotes the absence of an analyte in the subsample analyzed. Trace levels of the analyte may be present in the sample below the limit of detection (LOD).

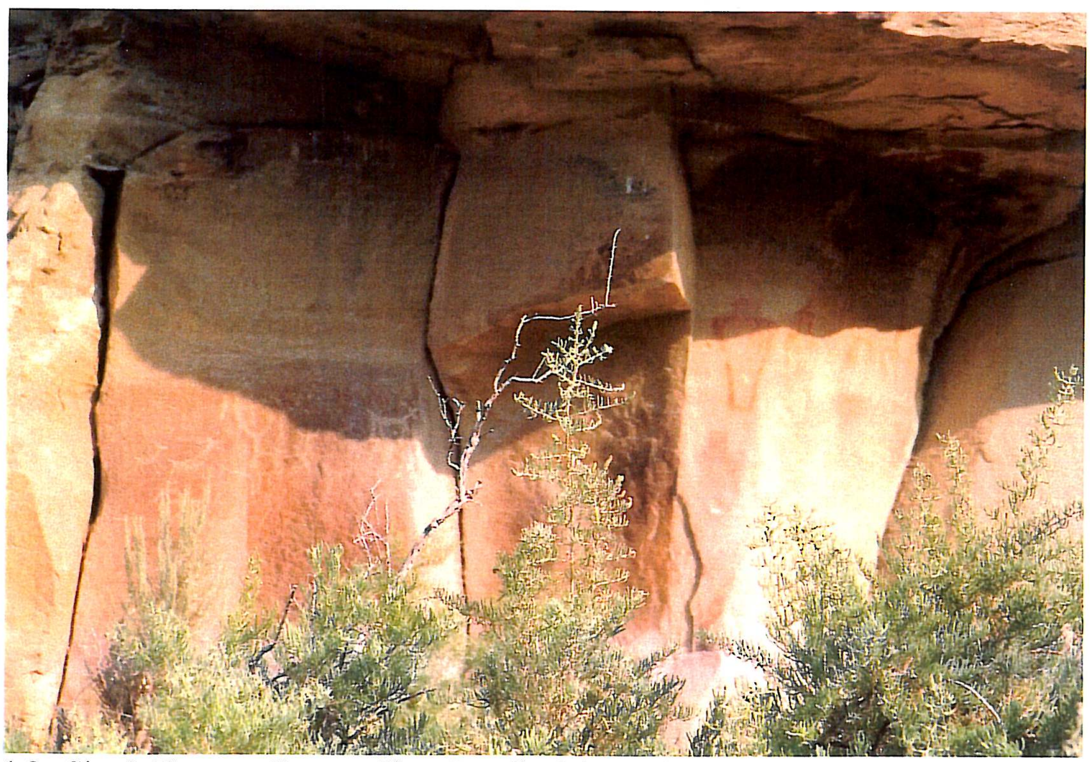
Limit of Detection (LOD): The minimum concentration that can be theoretically achieved for a given analytical procedure in the absence of matrix or sample processing effects. Particle analysis is limited to a single occurrence of an analyte particle in the sub-sample analyzed.

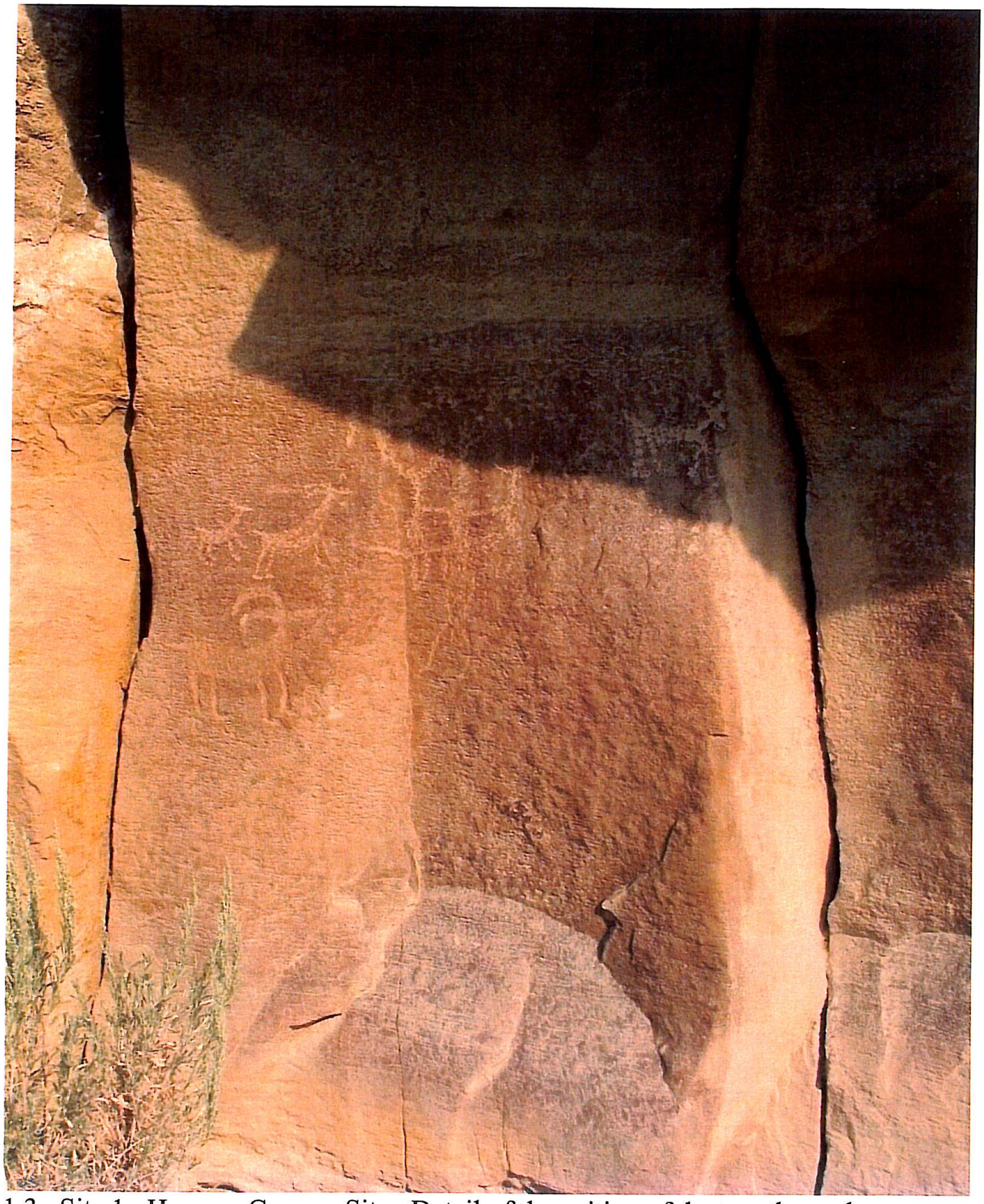
Concentrations for bulk samples are derived from Visual Area Estimation (VAE) unless otherwise noted. Air sample concentrations are calculated to particles per unit volume.

VAE technique estimates the relative projected area of a certain type of particulate from a mixture of particulate by comparison to data derived from analysis of calibration materials having similar texture and particulate content. Due to bi-dimensional nature of the measurements, in some cases the particle thickness could affect the results.

PHOTOGRAPHS


1.1. Site 1, Harmon Canyon Site. Overview from the road.


1.2. Site 1, Harmon Canyon Site. Detail of the rock art.

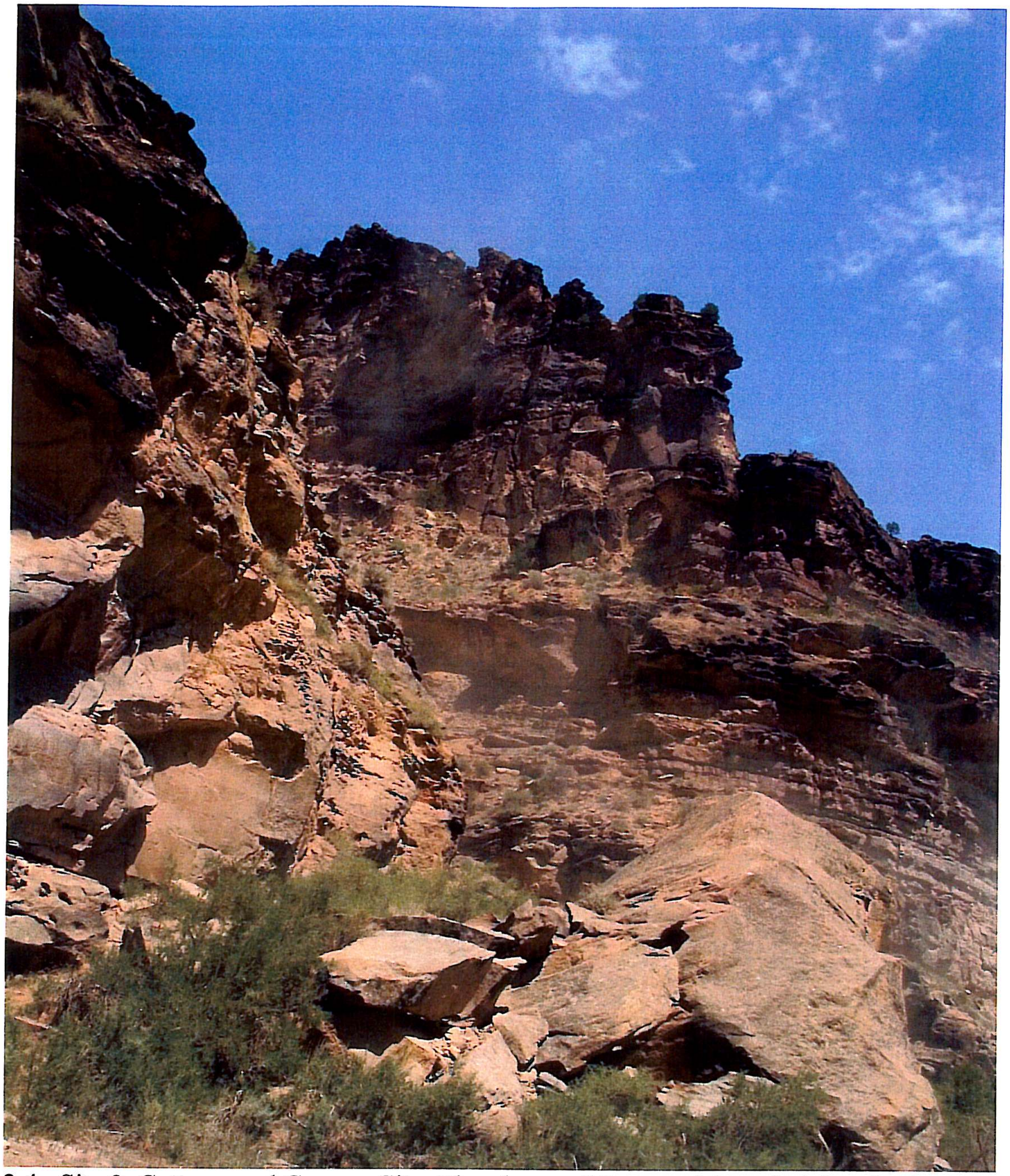


1.3. Site 1, Harmon Canyon Site. Detail of deposition of dust on the rock art.

2.1. Site 2, Cottonwood Canyon Site. Detail of the panel. Deposition of dust is evident.

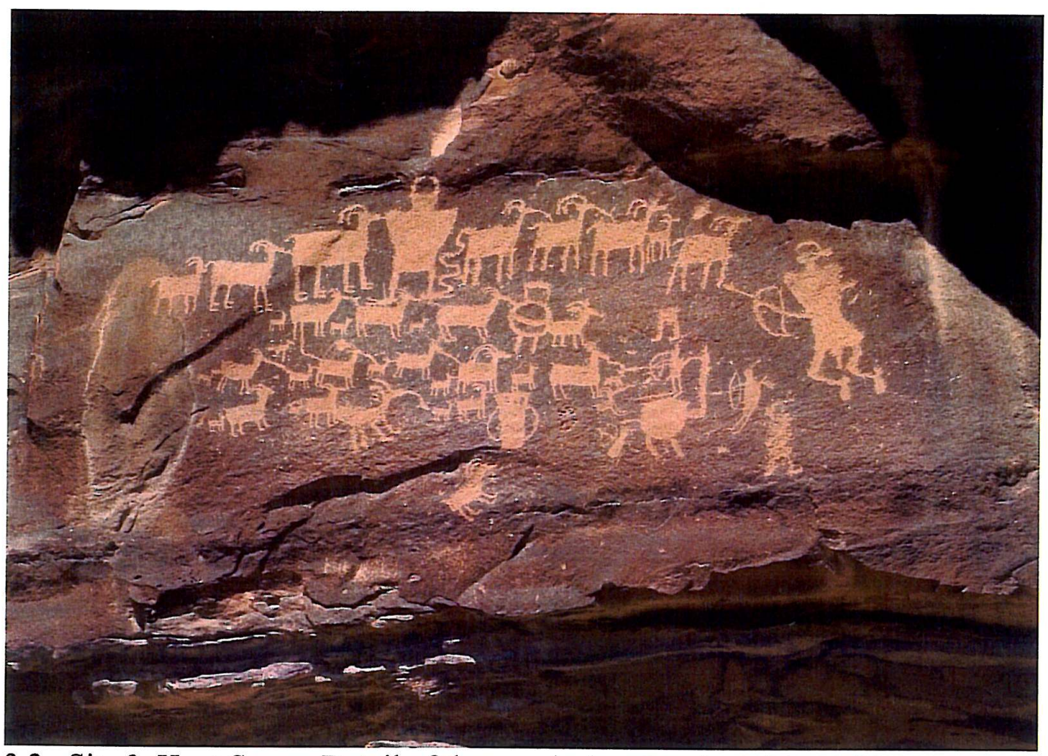
2.2. Site 2, Cottonwood Canyon Site. Deposition of dust is evident on the panel.

2.3. Site 2, Cottonwood Canyon Site. The road near the site and a plume of dust from passing traffic.



2.4. Site 2, Cottonwood Canyon Site. The plume of dust reaching a height of at least 150 feet and lingering for many minutes.

3.1. Site 3, Hunt Scene. The rock-art panel.



3.2. Site 3, Hunt Scene. Detail of the panel, showing deposition of dust.

3.3. Site 3, Hunt Scene. View of the road, with the development of dust from traffic.

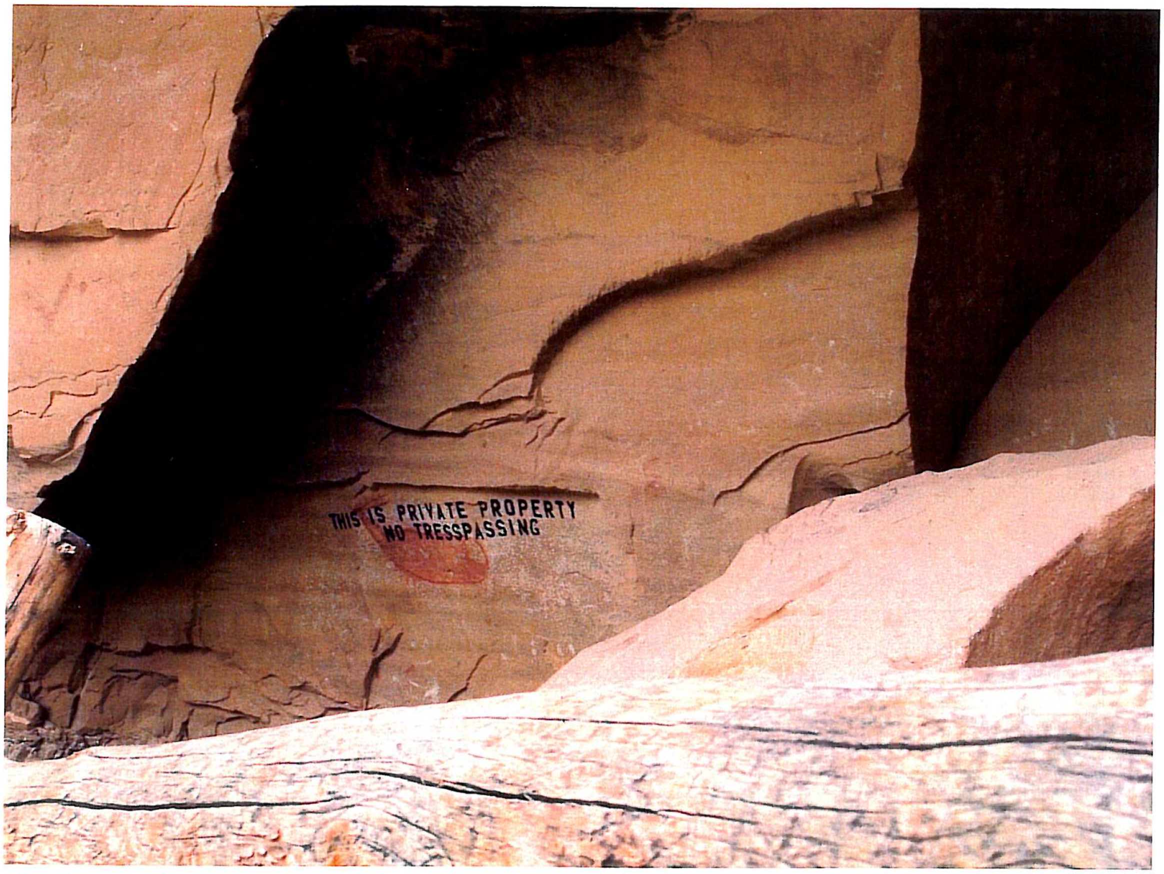
3.4. Site 3, Hunt Scene. The road near the site following heavy industrial traffic. The heavy plume of dust rose to a height of at least 150 feet and lingered for many minutes.

4.1. Site 4, Dry Canyon Site. Overview of the rock-art panel.

4.2. Site 4, Dry Canyon Site. Detail of the rock art panel, which remains in quite pristine condition and free from surface depositions like dust.

5.1. Site 5, Rasmussen Cave. Overview of the shelter from the road.

5.2. Site 5, Rasmussen Cave. Detail of the rock art panel



5.3. Site 5, Rasmussen Cave. Detail of the rock-art panel on the cave wall and heavy dust on rock fall in front of the panel.