LICHENS: THE CHALLENGE FOR ROCK ART CONSERVATION

A Dissertation

by

DEBRA ELAINE DANDRIDGE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2006

Major Subject: Anthropology

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ABSTRACT

Lichens: The Challenge for Rock Art Conservation. (December 2006)

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This study investigates the effects that lichens have on rock surfaces in which ancient rock art (petroglyphs and pictographs) may be found. The study area includes four sites in the United States: one quartzite site in southwest Minnesota, two sandstone sites in Wyoming, and one volcanic site in Central New Mexico. One additional granitic site studied is located northeast Queensland, Australia. The questions driving the pursuit of this dissertation research are:

1. How does the chemistry of the rock change with weathering and how deep is the profile?
2. Do lichens cause differential chemical changes?
3. How does the chemistry of the unaltered rock influence these changes?
4. Do lichens strip the patina or “desert varnish” from the rock surfaces?

The results of this research confirm from elemental chemical analyses that geochemical changes do take place in the presence of lichens. The combined mechanical and chemical processes contribute to the degradation and greater erodability of all the rock surfaces studied. Chemically, we have demonstrated that cements that hold grains of rocks together can be dissoluble by lichen byproducts in the presence of an aqueous environment whether the rocks are sandstone or granite. This information regarding the mechanical and geochemical processes at work in natural environments has significant practical benefit for the management, conservation, and preservation of rock art sites everywhere.

DEDICATION

This dissertation thesis is dedicated to the memory of Lee and Clint who never waivered in their support and faith.

ACKNOWLEDGEMENTS

The research and completion of this dissertation was accomplished only through the support of many people and organizations. Dr. Mary Striegel’s support in providing a fellowship sponsored by the National Center for Preservation Technology and Training was invaluable as was her unending patience. Certainly, the flexibility of the Texas A&M Department of Anthropology and the University of Houston Texas Center for Superconductivity in allowing a unique research partnership to move forward was instrumental in fostering the academic climate needed for success. The cooperation of many organizations was essential for field research and laboratory analysis without which this research could not have taken place. Instrumental in providing unparalleled support were Hilti, Inc. and Honda Corporation who provided essential field equipment and Exxon-Mobil Corporation who shared a macro that saved hundreds of hours of conversion time. I am indebted to the employees of USDI Bureau of Land Management, USDI National Park Service, the USDA Forest Service, State of Minnesota, State of Wyoming, and Texas Parks and Wildlife who worked with the researchers to provide permits, guides, and access to the study areas. Where it was not possible to remove samples from public lands, private landowners generously allowed access to immediately adjacent properties. An extraordinary relationship with the conservation staff at the Museum of Queensland, Townsville, Australia, the Wuluguruba Aboriginal community, and the National Park staff on Magnetic Island, as well as a private construction contractor provided field assistance, and they were responsible for the international aspect of this research.

Dr. James K. Meen and the students in his group at the University of Houston Texas Center for Superconductivity earned well deserved gratitude. Each person demonstrated extraordinary patience and tolerance for teaching the tasks and skills needed to carry out the analysis for this research. The Socratic style practiced by this group embodies the research ideal of exploration, questioning, testing, more questioning, and final resolution.

The Texas A&M thesis office provided extraordinarily valuable support and assistance to ensure this dissertation met the high standards set by the University.

Last, J. Clair Dean is responsible for patiently explaining archaeological conservation in the uncontrolled environment and opening our minds to the many crises found in rock art conservation.

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CHAPTER I

INTRODUCTION

Ancient Rock Art

Rock art is a term that ubiquitously describes images that are pecked, engraved, abraded, painted, daubed, or otherwise applied by humans to the surface of rocks—both portable and non-portable. Petroglyphs and pictographs are terms also used to distinguish those images that, respectively, are carved into a rock surface or are applied to a rock surface (the terms 'rock art' and 'rock glyph' are used interchangeably in this dissertation). Rock art images are found worldwide at thousands of archaeological sites as components of the artifact assemblage. Prehistoric humans from at least as early as 30,000 years ago through the present have used ever present rock faces—like those found in deep caves, at cliff-faces, in shallow rock shelters, and on exposed horizontal rock formations—to leave expressions of a culture's identity, spiritual beliefs, or for other communicative purposes (Bahn 1998). Archaeologists, however, tend not to include interpretation of rock glyph images in the overall analysis of an archaeological site. The reasons for this omission may be varied, but frequently the reason is the 'art' is difficult to relate to other objects in a heuristic manner relevant to the overall significance of the archaeological site.

Efforts by late 20th century researchers have proven that the rock art images are, indeed, relevant to archaeological interpretation. Research by Boyd (1998), Francis and

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The style and format for this dissertation follow that of *American Antiquity.*

Loendorf (2002), Lewis-Williams & Dowson (1989), Sundstrom (2004), and others have demonstrated that rock art is significant and that it can be analyzed and interpreted with valid assumptions. Though archaeological researchers have come late in recognizing the significance of these cultural artifacts, rock art images have engaged the curiosity of the general populous for decades. Venues that contain these often mysterious ancient writings, such as the painted caves at Lascaux (France) and Altamira (Spain), the painted murals at Kakadu National Park (Australia) and, carved or pecked images such as those at El Morro National Park (New Mexico, USA) or Picketwire Canyonlands (Colorado, USA), attract thousands of visitors each year who are curious about the rock glyphs and about the human cultures that were compelled to leave messages on stone.

Though it may be perceived that rocks themselves are interminable, rock art images are deteriorating and being lost at an alarming rate. Visitors to rock art sites are themselves agents of deterioration through intentional thoughtless acts of vandalism like theft, painting over images, or carving new messages around the ancient images. Often the simple act of people viewing the images onsite in large numbers can alter the immediate environment through transrespiration or by increasing the dust accumulation on the glyph images (Van Grieken, Delalieux, and Gysels 1998; Brunet, Vouvé, Malaurent, and Lacazedieu 1995). Rock glyphs are also adversely affected by the natural elements of wind, rain, and fire as well as some not so obvious factors such as microbiological presences and chemical changes taking place within the rock itself. An important agent of destruction that is rarely recognized is the impact that lichens have on the rock surfaces where rock art is found.

This study focuses on the deterioration potential of lichens. Lichens are found worldwide in almost every known environment from rural landscapes to urban cityscapes. These resilient biomes populate nearly any type of surface both porous and non-porous. As components of archaeological sites, rock art is quite often the most obvious and visual of artifacts exposed to many erosive elements including the growth of lichens. Schiffer (1987) addressed the presence of lichens in his discussion of environmental formation processes that affect archaeological sites in which he offered the rather cryptic comment that little damage is effected by lichens on artifacts. Contrary to Schiffer’s statement, lichens do affect the surfaces they populate both mechanically and chemically (Berthelin 1988; Chen, Blume, and Beyer 2000; Syers and Iskander 1973), albeit at a microscopic level. Many species of lichens, which are symbiotic relationships of fungus and algae, develop root-like elements called hyphae and rhizines. They also produce many metabolic byproducts including a variety of organic acids. Through normal growth processes, lichens have a deleterious effect on populated surfaces by establishing a foundation, seeking nutrients, and releasing byproducts.

Rock art sites are archaeological features/artifacts that have been protected and preserved in national and state parks and other monitored sites. In many instances, managers and conservators have little-to-no knowledge of the destructive forces of lichens and thus have no protocol in place for controlling, managing, or ameliorating damage caused by lichens. In an effort to delineate how lichens contribute to the deterioration of rock art, four objectives were developed for this research:

1. How does the chemistry of the rock change with weathering and how deep is the profile?
2. Do lichens cause differential chemical changes?
3. How does the chemistry of the unaltered rock influence these changes?
4. Do lichens strip the patina or ‘desert varnish’ from the rock surface?

CHAPTER II

BACKGROUND RESEARCH

Rock art images and the rock surfaces upon which they are found are a class of archaeological artifacts immediately at risk of loss or transformation by weathering and deterioration from biological growths. The processes of chemical and physical alteration of rock surfaces are collectively referred to as weathering. Bates and Jackson (1980:697) describe weathering as the "destructive process by which rocky materials on exposure to atmospheric agents are changed in color, texture, composition, firmness, or form … specifically the physical disintegration and chemical decomposition of rock." This definition of geological weathering illustrates Schiffer's (1987) discussion of environmental formation processes in which he describes archaeological formation processes as any agent that causes change in "the physical or chemical property including color, surface texture … shape, chemical composition … and hardness or tensile strength" (Schiffer 1987:143). Schiffer uses environmental formation processes to explain the transformation of artifacts from their original state at the time of construction to the current state within an archaeological context. Artifacts can be described as "objects found in archaeological sites that exhibit features which are the result of human activity" (Fagan 1978:32). By definition then rock art images are appropriately classed as artifacts that are affected by environmental formation processes.

For this research, it is significant to note that weathering both stabilizes and destabilizes rock surfaces thereby effectively transforming rock surfaces and potentially affecting the context of rock art imagery. Geochemically, this is important within the context of the weathering zone of a rock surface. This is an area in which free water (such as rain and groundwater) is an abundant, if ephemeral, commodity. Initially, free water is uncommon in the deep earth in which rocks develop mineralogical assemblages. Through the process of continual hydration and dehydration of the rock substrate in the presence of free water, cementation and recrystallization of sedimentary rocks takes place creating surfaces that are metastable and resistant to erosion.

A naturally weathered surface exhibits an assemblage of minerals that are less reactive with the environment than a fresh or unweathered surface. This is a situation which, in many cases, minerals form from or are relict from, the original rock. The naturally occurring series of steps of weathering evolution is, therefore, recorded throughout the rock substrate profile. An important aspect of rock weathering is that the reaction of an unweathered rock surface with the environment may be quite rapid—a few years or decades in some cases—and involve extensive destabilization of the rock and loss of material from the surface. Though destabilization initially may result in loss of surficial material, once a weathering profile is established under constant environmental conditions, the surface then has greater stability so that loss of material is greatly reduced as the weathered zone migrates into the rock. The rate of loss is dependent upon prevailing conditions and on the energy of the environment.

The creation of a weathered zone, or front, at the surface of a rock renders the rock surface resistant to erosion. When the weathered front is breached, either mechanically or chemically, the now fresh rock surface is vulnerable once again to loss from erosive elements such as wind, rain, frost/freezing, or other events. It is in the face of such deteriorating factors that the craft of rock art conservation seeks to stabilize ancient rock glyphs.

Two underlying tenets of artifact (including rock art) conservation are: (a) do no more intervention than is absolutely necessary to stabilize the artifact from further deterioration and (b) understand the processes influencing the artifact in order to devise the best possible treatments needed to inhibit further deterioration. The conservation of rock art poses particular problems for the manager and conservator alike. Native stone surfaces exposed in an unprotected natural environment have challenges that are unlike those found in dressed stones that may be found in similar situations because of the formation of weather rinds on natural rock surfaces. In addition, the majority of the time artifact conservators have the luxury of practicing their craft in a controlled environment. For reasons of scale and context, rock art conservators must devise effective treatments in exposed and uncontrolled environments. Next, knowledge of the construction of the artifact (i.e., the rock substrates of rock art) is required to understand what treatments will be effective and which treatments may contribute to deterioration of the rock surface. Many rock art conservators have sufficient training in chemistry to address most agents of deterioration; but, that same training does not necessarily extend to geochemistry and an understanding of how rocks are altered chemically and physically in a natural environment. Thus, there is an incomplete understanding of how best to address the issue of lichen-impacted rock art sites.

Rock art researchers around the world generally agree that ancient rock glyphs, in post-modern society, are being lost at an alarming rate through vandalism and environmental deterioration. Weathering and natural deterioration of *in situ* rock art, however, is inevitable. Part of the conservation challenge in such circumstances is to ameliorate deterioration, not hasten deterioration (Haydock and MacLeod 1987). With that thought in mind, it benefits conservators and managers alike to have at least a general understanding of how lichens, one of the most ubiquitous and yet least understood agents of degradation and deterioration, affect rock surfaces at sites where engraved, incised, carved, painted, or pigmented images are found on rock formations.

Previous Conservation Research

Needless to say, there are a multitude of environmental factors that affect the stone substrates where rock art is found. A representative sample of research that includes lichens is presented here for background.

Taylor, Myers, and Wainwright (1974) acknowledged the importance of rock art in Canadian archaeological research and lamented the poor state of sufficient research to understand the imagery symbolism found on natural stones. These observations spurred research for appropriate conservation practices at lichen impacted rock art sites. The researchers discussed briefly that water and organic acids from lichens tend to weather seemingly impervious rock to dissoluble clay “by leaching away the more soluble mineral element” (1974:28). The mechanical action of erosion, such as freeze-thaw cycles which can exfoliate rock surfaces, was also mentioned. Their article elaborates cooperative research conducted by the Canadian Conservation Institute and the Trent University Rock Art Project. This study removed rock samples from a rock art substrate for comparison purposes. The methodologies employed for analysis, in general, were described well. While they stated that a substrate sample one inch in diameter was removed from non-pigmented rock surfaces, they do not specify the overall dimensions of the sample, i.e., from how deep into the rock the samples were removed. They employed X-ray diffraction (XRD) and scanning electron microscopy (SEM) technology in their analyses. This study was not directed toward the effects of lichen but rather weathering in general. Thus, it lacks a direct correlation between lichenated rock surfaces and those surfaces not covered by lichen.

Investigative efforts by Laver and Wainwright (1995) at a petroglyph site where images were engraved in native marble assessed the effects of acid rain on rock substrates. The substrate understudy was identified as a coarse grained marble. Mechanical and chemical actions were identified as contributing to cracking and exfoliation of the rock. The mechanical mechanisms were frost weathering and micropitting by algae. An euendolithic (boring) algae populating the rock created pathways into the rock surface that facilitated frost weathering. It was thought that the presence of acid rain was instrumental in effecting chemical changes in the rock substrate. For this study, acid was defined as a pH value less than 5.6. The possibility of dry deposition of pollutants containing sulfates that could contribute to chemical deterioration was also considered. Core samples of the rock substrate were removed for study with an unweathered rock sample utilized as a control. The objective of the experiment was to determine the effect of pH on the marble in a controlled environment. The study concluded that to have an effect on the marble substrate, acid precipitation would have to reach a pH level of 3.0. The pH level of acid rain at the time of the study was estimated to be 4.0. Acid rain was determined to be the least significant erosive factor affecting the surface in the presence of other factors such as euendolithic algae and frost weathering.

For research conducted in Australia, Clarke (1976; 1977a:89) advised conservators and managers that a site must be "thoroughly investigate[d] … so that there is an understanding of the materials which make up the site and the relationship between these materials and the environment." He added emphasis, as have other researchers, that lichens both mechanically and chemically affect rocks and therefore lichens "should always be removed" (1977a:90). Several mechanical and chemical means to remove or kill lichens were described. His conclusions stated that many of the suggested treatments will "greatly prolong the life of a rock art site" (1977a:94). Unfortunately, he failed to consider lichen processes that affect rock surfaces and any ramifications that mechanical or chemical conservation treatments may have in the long-term on existing rock art images.

Another study by Clarke (1977b) discussed factors that contribute to the deterioration of rock art pigments at sites in Western Australia. In this study, a pertinent observation was that addressing the effect that airborne pollutants have on rock art. His observation was that natural salt weathering was accelerated by a combination of lower pH in rainwater and the introduction of sulfate and nitrate soluble salts from polluting sources.

Kennedy and Lundy (1976) briefly describe conservation efforts at a rock art site on Vancouver Island, B.C. in which moss lichens and other biological growths were described as growing on the rock surface. Two activities were described that effectively removed the offending growths: (a) casting the petroglyphs with silastic molds and (b) the use of trowels along with wire and bristle brushes to remove both mud and organic material. These researchers state their belief that "the situation was not at all damaging" (1976:9). Though it is clear that they intended to remove lichens from the rock host, it is also apparent that they did not address the effect that lichens have on rocks and the ramifications to the host rock of removing lichens.

Beverly Booth Childers (unpublished report, *Fremont County, Wyoming, Ranch Petroglyph Site: Updated Report,* 1997, personal papers author) described her 14-year experimentation with the removal of lichens at rock art sites on private property in Wyoming. Childers described at length chemicals believed to be efficacious in destroying lichen colonies that cover ancient carved and pecked rock art (petroglyphs) images. Chemicals utilized in her study included solutions of ortho phenylphenol (^{R}Lysol) as well as solutions of sodium hypochlorite (bleach). She mentioned spalling, chemical weathering, and lichen growths as the primary means of rock surface deterioration within her study area. Crustose and foliose forms of lichens were cited as being principally responsible for the deterioration of rock art imagery as well as the tendency of lichens to hold moisture on the rock surface were cited as erosive factors. The objective of the research was to "remove lichens for the purpose of preservation [and] more complete recording of the petroglyphs" (1997:3). Interaction of the chemicals used in treating the lichens and the potential long-term effects of chemical treatments on the rock surfaces were not addressed. Childers claimed success of the chemical eradication of lichens from treated rock art panels. The objective of treating lichens chemically at *in situ* rock art sites to effect a more complete recording of panels within a known site area and to “protect the petroglyphs … [from] further damage by the lichens” (1997:3) is questionable. Although the lichens were apparently eradicated, damage to the rock surface had already been effected by lichen growths and this situation was not addressed.

In a well-rounded discussion of rock art conservation, Loubser (1991) addressed removal of micro flora, including lichens, from rock surfaces. His recommendation was for removal of lichens by mechanical or chemical means. He did not, however, address the effect lichens have on the rock host and the potential of accelerated erosion of the rock surface after removal of the infringing biological colonies.

The studies cited here are a few instances in which rock art managers and conservators have attempted to address the issue of encroaching lichen growths at rock art sites. In each case, the management decision was to remove lichens. In all cases the suggested treatments were implemented without considering the potential long-term effect on the rock surfaces and hence the effect on irreplaceable rock glyph imagery.

What Are the Gaps—What Are the Needs?

Again, we ask the question “Why consider lichens in regard to conservation and management of ancient rock art?” The few qualified rock art conservators in the United States are typically trained first as fine arts conservators. As such, they rely on monument conservation literature for guidance when addressing similar issues at open air, *in situ* rock art sites. The problem then is two fold. First, dressed stone is not likely to react to conservation treatments in the same manner as native stone surfaces simply because native rocks have established weathering profiles that dressed stone assemblages do not have. Second, even though there are numerous references in art conservation literature that address lichen growths on monuments, statues, and buildings, rarely do monument conservation researchers address the microenvironment at the surface and the subsurface at depths of one mm or more below the surface. Unfortunately, the availability of research that specifically addresses the effect lichens have on ancient rock glyphs found *in situ* on a plethora of rock substrates is lacking and, in particular, research that includes pollutants.

Conjunct to research regarding the effects lichens have on buildings and monuments are the many studies in conservation literature on how to eliminate biological infestations such as mold, fungus, and other types of microflora from archaeological contexts (see Dandridge 2000 for literature review). The literature is sparse, however, concerning the long-term effects that these strategies (including the use of chemicals, enzymes, and mechanical methods) have on rock substrates in a natural environment. Hence, there is an incomplete understanding of how best to address the issue of lichen-impacted rock art sites.

As with projects undertaken by fine art conservators, rock art conservators also employ a standard that requires knowledge of the materials that one is conserving so as to devise the least intrusive, most effective treatment regimen. Ian Wainwright (personal communication 2000) with the Canadian Conservation Institute has discussed several additional concerns that site managers and conservators should consider when they are confronted with sites impacted by lichens. Most important among the concerns are:

1. Can the lichens be removed safely?
2. How deep into the rock have the lichens penetrated?
3. Will the rock be subjected to accelerated weathering after the lichens are removed?

While rock art conservation literature is sparse regarding lichens, researchers from various disciplines have addressed the presence of lichens at cultural monuments for several decades. Additionally, the morphology and physiology as well as general growth requirements of lichens are well known (Berthelin 1988; Bjelland and Thorseth 2002; Chen, Blume, and Beyer 2000; Krumbein 2002; St. Clair 1999; Syers and Iskander 1973). Thus, while there is ample information regarding the physiology of lichens, it is incumbent upon rock art conservators to recognize the effect lichens exert on host substrates not only at the surface level but also the subsurface level. Such information can mediate and guide the formulation of preservation treatments proposed for rock glyphs. An understanding of the geochemical processes taking place on rock surfaces colonized by lichens is clearly important so that conservators and site managers can make informed, evaluative decisions regarding the potential effects of conservation or preservation treatments on the underlying rock surface on which irreplaceable ancient rock art images may be found.

The present research seeks to fill the void in which rock art conservators and managers alike can benefit from a better understanding of how lichens and lichen byproducts affect rock surfaces. Thus, with knowledge of the geochemical processes at work in the presence of lichens, conservation treatments that are proposed to remove or alter lichens can be made with a better view of the potential short-term and long-term consequences on rock art images. Informed decisions concerning best management practices for conservation of rock can then be formulated at rock art archaeological sites affected by lichens.

CHAPTER III

LICHENS

Lichens are complex biomes that are versatile and resilient demonstrating the ability to be highly adaptable while exhibiting slow growth patterns that favor sustainability over production. A brief description of lichen morphology is presented here to aid in understanding how rock surfaces can be affected by their presence.

Lichens are symbioses of fungi and algae. The fungus is the mycobiant and provides structural support, mineral nutrients, and a growth medium for the alga (St. Clair 1999:1). The alga is the photobiont, which chemically fixes atmospheric carbon and synthesizes organics such as carbohydrates, amino acids, and vitamins. About 10% of lichen species are known to contain cyanobacteria that can fix atmospheric nitrogen (St. Claire 1999:1), thus, providing a critical element for lichen growth. Both the fungus and alga appear to contribute to the relationship—neither seems to be parasitic to the other. Under optimal conditions, and optimal varies diversely by situation, lichens thrive and grow. When environmental conditions are not optimal for growth, lichens may lie dormant for many years until environmental conditions again provide a situation in which the biome may thrive.

A growing medium for lichens is not limited to rock surfaces. They are found on many different media since this biome is not particular about what manner of host it populates. They are found on trees, glass, ceramics, and metal objects, as well as soil and deep within rocks. Over 15,000 species of lichens have been identified and catalogued worldwide (Ahmadjian and Hale 1973; St. Clair 1999). Lichens are found from arctic to desert to tropical environments. Natural landscapes and highly urbanized cityscapes can provide media for growth. Why and how these two symbionts come together and thrive remains a mystery to science.

Gilbert’s (2000) discussion of lichens found in and around stone and masonry edifices in England illustrates the versatility of lichen species. It is most interesting to note from his detailed discourse of lichen species the ability of lichens to tolerate extreme changes in their living environment. Conditions described that are conducive to lichen colonization on stone buildings included moisture, light, pH levels, pollution, decay, and aging masonry. Considerable attention was given to some species ability to adapt to toxic metal conditions (e.g., copper, zinc, and lead) and thriving at the boundary of toxic toleration and lethal toxicity. He further described the apparent condition where some species of lichens succumb to lethal levels of atmospheric pollution (typically due to lowered pH levels) while other species thrive on the changed conditions and fill the void left by less tolerant species. Mention is given to the ability of lichens to tolerate pH conditions ranging from a basic 8.0 to less than 5.0 acid levels. Special attention was given to the study of lichens on graveyard monuments in which lichens were noted on nearly all substrate types including granite, sandstone, slate, and limestone. Cultural objects such as clay bricks, pottery, and various timber products including gates, fences, and barns that exhibited lichen growths were also discussed. Gilbert further observed that while wood preservatives tended to discourage lichen growths, some species of lichens apparently find friendly habitat in close proximity to rusting nails even in the presence of the same wood preservatives. His research noted that lichens thrived on iron rich stone works only when the iron reached an oxidized state similar to the oxidation of iron in the rusting (ferric iron) nails. To further illustrate the flexible nature of lichens, Gilbert (2000) documented evidence of lichens thriving on asbestos-painted (hydrated Mg-Al-Silicate) surfaces in urban environments. He further found that in rural areas, lichens were apparently nurtured by animal manure and dust dispersed into the air by road traffic. Among the many environments to which lichens have adapted include situations in which some species thrive on dust accumulations in stone crevices.

Lichens were described as having the remarkable ability to find a home in diverse environments ranging from bonfire sites, discarded metal, and mine waste dumps including furnace slag, discarded fragments of rock, mortar, and broken masonry. An element common to most situations, but not always, was the presence of moisture in a sheltered situation. He further described what appears to be species succession whereby as environmental conditions change, the extant species also changed. That is, when one species can no longer thrive in a current environment, another species will take its place in succession. In this diverse study, Gilbert (2000) addressed the difficulty in accurately documenting long-term trends regarding the effects that atmospheric pollution had on lichens due to the lack of pre-industrial age data.

How lichens survive is almost as much a mystery as how the lichen symbiosis is created. Like all living organisms, lichens require water, light, and nutrients. The amount and quality depends on the local environment. Lichens are opportunistic in obtaining life-sustaining nutrients, which may come from a rock host (or other type host) or life-sustaining nutrients may be claimed from the ambient atmosphere. It is evident from

Gilbert’s (2000) study that lichens need enough life-sustaining elements but not too much.

Lichen metabolic processes can produce a host of organic acids including oxalic acid (Jones, Wilson, and McHardy 1981). Metabolic and growth processes may result in situations where grains from the rock surface are ‘mined’ or excavated as lichens proliferate and seek nutrients for survival. Growth is typically counted in millimeters per year; though occasionally, when all conditions are optimal (and dependent upon the species), one half centimeter or more may be achieved in one growing cycle.

The biological process of sending out rhizines that anchor the biome to the surface, as well as to garner nutrients and water, causes mechanical alteration of the surface. This ‘rooting’ of the lichen body may result in lichen byproducts such as organic acids to indurate the rock surface. In this way, lichen species can be responsible for mechanical and chemical changes, not only to a rock surface, but also to the extent that lichen byproducts may be transported into the rock interior either by biological growth or from aqueous transport (Chen, Blume, and Beyer 2000; Jones 1988; St. Clair 1999).

Lichens are broadly classified by the growth forms described as crustose, foliose, or fruticose species. In general, the morphological components of lichens are comprised of a thallus, cortex, medulla, and possibly rhizines or hyphae (see Figure 1). However, not all lichens support all these components. The thallus generally can be considered the body of the lichen. When a cortex is present, it is composed primarily of fungal hyphae. If a medulla is present, it is comprised of fungal filaments entwined in a layer of algal cells and found immediately beneath the cortex. A second, or lower, cortex may be present beneath the medulla which, when present, will use hyphae to attach itself to the host surface. Foliose species may also have root-like rhizines present in the lower cortex which are utilized to anchor the lichen to the rock host.

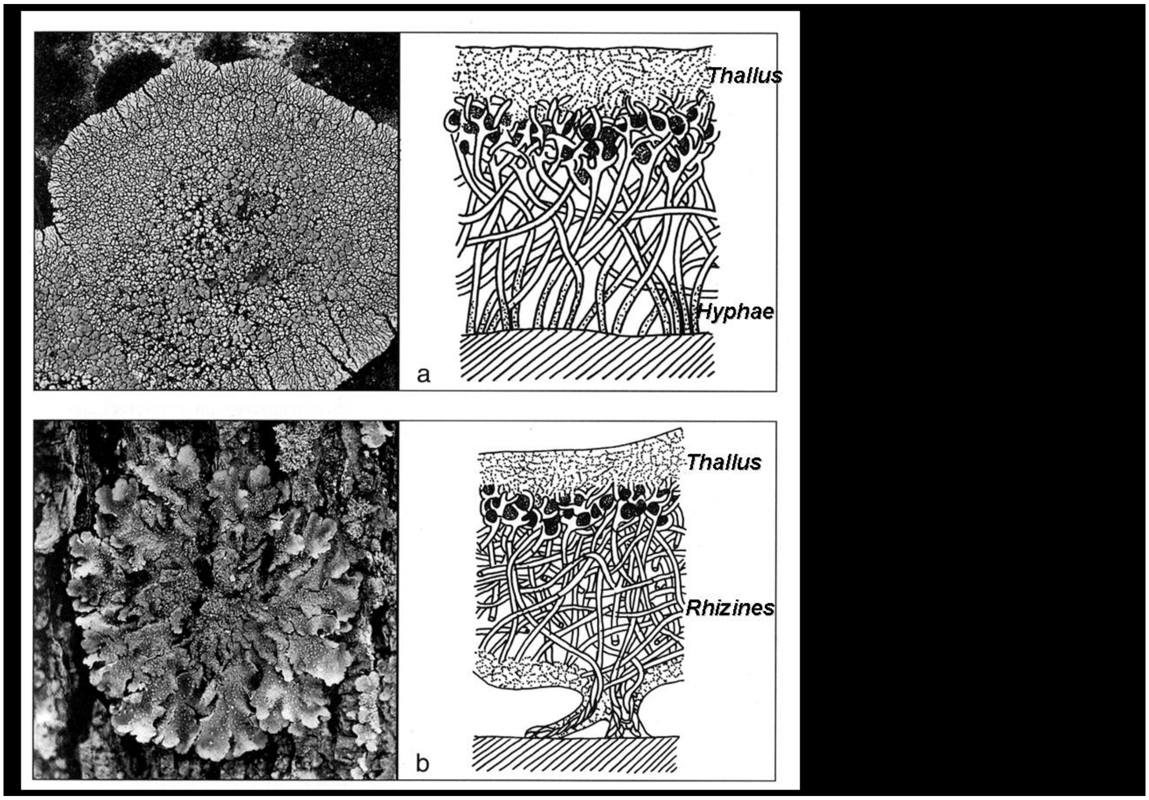

Figure 1. Lichen morphology (after St. Clair 1999): a. Crustose form, b. Foliose form.

Through the growth of hyphae or rhizines, lichens affect the rock surface mechanically and lichen metabolic byproducts effect chemical consequences as well. As lichen biomes grow and proliferate, root-like structures work their way in between mineral grains that comprise the rock matrix. Thus, mechanically, the rock surface is disaggregated by the simple act of an invasive root-like structure separating cemented grains and thereby breaking the rock apart, albeit microscopically. As the disaggregation proceeds, geochemical changes are taking place that include the reaction of present minerals and elements with lichenic acids (Bjelland 2005; St. Clair 1999; Syers and Iskander 1973). It must be noted that these geochemical alterations may be exacerbated in the presence of pollutants captured at the surface and incorporated into the lichen body.

Geochemical reactions can eventually result in the deterioration of cements that connect individual grains within the rock matrix. The internal structure of the host is changed and the surface becomes less stable than the surrounding matrix that has weathered to a metastable state over the course of millennia of environmental forces (National Center for Preservation Technology and Training [NCPTT] 2001:10-11). When lichen hyphae or rhizines are present, it has been speculated that organic acids are introduced into the rock matrix through the hyphae or rhizines. As organic acids are introduced into the rock matrix, they will react chemically with present mineral species thereby effectively destabilizing the rock matrix. The introduction of acids can effect phase changes in present mineral species—changing them from a relatively stable state to more easily erodable products. For instance, weathering processes can effect a change in feldspars and micas of granitic rocks to secondary illite, kaolinite, smectite, or other clays (Gerrard 1994). In this manner, stable minerals are altered to more readily erodable clay. The combined mechanical action of ‘root’ growth and geochemical reactions work together to create instability of weathered rock surfaces that enhance the erodibility of the surface (Dandridge and Meen 2003).

Lichens have historically focused in pollution research since they are considered a leading indicator of the presence of acid rain in that they “accumulate many different pollutants from atmospheric outwash” (St. Clair 1999:8). While lichens are quite resilient, they are at the same time quite sensitive to changes in optimal growth conditions such as a reduced pH environment brought about by the presence of pollutants that create acid rain. It is due to this sensitivity that lichens are a leading indicator that pollution is taking place even when polluting effects may not be perceptible in other contexts (St. Clair 1999).

This is a very general and gross representation of a highly complex organism of thousands of known species (Ahmadjian and Hale 1973; St. Clair 1999) that apparently is capable of adapting its growth response to nearly any environmental situation. Of particular interest to this research is the characteristic of some species to (a) send out hyphae or rhizines to anchor to the host surface, (b) the ability of some species to produce organic acids, and (c) the apparent capability to synthesize organic and inorganic elements from the ambient atmosphere as well as from the host substrate.

Background Research

Contributing to the complicated study of the effects that lichens have on rock substrates is that research studies tend to contradict one another. The following pertinent research articles targeting lichen physiology and growth requirements summarize the literature concerning the effect lichens may have on rock art.

In 1991, Brown and Brown compared various researchers’ statements that lichen species metabolized minerals from the host substrate and the environment versus results that concluded with uncertainty that lichens have the ability to take up minerals in diverse situations. Six years later, Seaward's (1997) research expanded on Brown and Brown's observations and described the effects lichens have regarding pedogenesis and bio-deterioration in natural environments. He particularly noted that lichen byproducts degraded substrata along with having the capacity to accumulate nitrogen, phosphorus, and sulphur which increase such element availability for various other plant forms. He acknowledged that lichens contribute to the weathering of rocks mechanically by rhizine penetration into the substrate as well as the physical action of expansion and contraction of thalli. Further, chemical weathering of rock substrates was attributed to carbon dioxide, oxalic acid, and the complexation effected by lichen byproducts. He pointed to studies that demonstrate lichens' contribution to the biodeterioration of historic monuments, frescoes, and other art works within a "short time-scale" (Seaward 1997:270). Although Nash (1996) discussed lichens' ability to take up nutrients from atmospheric sources, he significantly concluded that much remains unknown about the interaction of lichens with local ecosystems regarding nutrient and energy expenditures and needs.

Gries (1996:240-244) advised that lichens' supposed sensitivity to toxic pollutants be considered with caution, stating that not all lichens are equally sensitive to air pollutants. Though lichens have been used to indicate the presence of environmental pollutants for over 20 years, Gries points out that the study of lichens as pollution indicators is complicated by the fact that lichens can only be maintained under laboratory conditions for a few weeks.

Rock Art and Lichens

Why consider lichens in regard to conservation and management of ancient rock art? The few qualified rock art conservators in the United States are typically trained first as fine arts conservators. As such, they rely on fine art conservation literature for guidance when addressing similar issues at rock art sites. The problem then is twofold. First, dressed stone is not likely to react in the same manner as native stone surfaces simply because native rocks have established weathering surfaces that dressed stone typically does not have. Second, art monument conservation researchers rarely address the environment not only at the surface but also the subsurface from 1 mm or more below the surface. While it is known that lichens affect surfaces mechanically and chemically and there are numerous references in art conservation literature that address lichen growths on monuments, statues, and buildings, the literature is comparatively scarce regarding the role that lichens play in the degradation of rock substrates at the subsurface level.

Lichen Studies and Monuments

Rock art conservators typically rely on fine art conservation literature for guidance when addressing similar issues at rock art sites. The following references are examples of the literature that rock art conservators rely on for guidance.

Arino and Saiz-Jimenez (1996) studied lichens on the monuments at the second century B.C. Roman archaeological site of Baelo Cladia that had been excavated and conserved. This study attempted to determine the effects of biodeterioration on stone monuments through the study of lichens. Samples of lichens were removed from selected structures and examined by scanning electron microscopy (SEM) after being fixed, dried, and coated with gold. The authors did not clearly define the size of the samples taken for study nor was the methodology for sampling identified. They determined that the species of lichens colonizing the subject monuments incorporated grains of the substrate surface into the lichen thalli and thus effected mechanical deterioration of the monument surface.

Prieto, Seaward, Edwards, Rivas, and Silva (1998:59) studied the biodeterioration of granite monuments using Fourier transform Raman (FTR) spectroscopy to analyze the effects of lichens on 20 churches around Galicia, Spain. FT Raman spectroscopy was utilized because it "nondestructively" analyzes small samples, and/or, *in situ* organic materials. This technique was also used by Edwards, Edwards, Farwell, Lewis, and Seaward (1993:99) to examine deterioration induced by lichens on 16th century Renaissance frescoes at the Palazzo Farnese located in Caprarola, Italy. Due to the culturally sensitive nature of the artifacts under study, the researchers could not obtain "large quantities of substratum with lichens still attached," but they fail to quantify the amount of substratum that was removed. Both the Prieto et al. and Edwards et al. studies determined that lichens contribute to weathering of the host substrate, but they failed to clearly define the deterioration mechanisms involved.

Pinna (2000) stated that it is "well known" that epilithic (i.e., growing on the surface) lichens affect monuments with deleterious results. She highlights the fact that literature addressing the effects of endolithic (i.e., growing within the stone matrix, often with no outward visibility) lichens is not well known. Her research examined comparative samples taken from one church in central Italy and a natural limestone outcrop. Neither the methodology used to remove samples, nor the size of the samples is expressed in her article. The technology utilized for sample analysis included optical microscopy, X-ray diffraction (XRD) analysis, scanning electron microscopy, and Fourier transform infrared spectroscopy (FTIR) analysis. Emphasis was placed on lichen morphology, growth patterns, and the physical (i.e., mechanical) effects of endolithic species found at the architectural monument. Pinna concluded that more study is needed concerning the effects that endolithic lichen species have on cultural monuments so as to provide effective information to conservators regarding appropriate treatment methods.

In a 1999 article addressing the effects of *Ochrolechia parella* species of lichen on granite monuments in northwest Spain, Prieto, Seaward, Edwards, Rivas, and Silva stated that there is insufficient information concerning the relationship between chemical deterioration effected by the presence of lichens and environmental conditions. These researchers used FTIR to carry out research on lichen samples removed from monuments in four locations. They did not describe the sample sizes or the methods used to remove the lichens. It is presumed that Prieto, Seaward, Edwards, Rivas, and Silva only removed lichen growths and nothing of the stone host. The results of their study indicated that (a) the stone substrate was incorporated into the lichens' thallus body, (b) that there was a metabolic response to environmental changes, and, (c) that calcium oxalate monohydrate was produced.

An aggressive pollution-tolerant species of lichens found on Roman terracotta pots at the Museo Nationale Romano in Rome was studied by Seaward (1988). In this article he postulated that environmental pollution contributed to the proliferation of some species of lichens on monuments around Rome. This biological activity significantly contributed to the surface deterioration of cultural monuments including blistering and exfoliation of the surface. A brief mention was made that removing the lichens by mechanical or chemical means without damaging the host substrate presented a challenge to conservators.

Piterans, Indriksone, Spricis, and Actins (1997) studied the chemical effects of lichens on monuments in Latvia with the aim of evaluating the potential effectiveness of biocide treatments. The study areas were located in diverse areas of Latvia including cemetery monuments (tuff, sandstone, travertine, and dolomite stones) and memorial sculptures (also tuff, diorite, dolomite, travertine, and granite stones). Samples of crustose and foliose type lichens were removed from selected monuments with a steel scalpel. They failed to specify the size of the samples used for analysis in their article. The samples were dried and finely ground. Mineralogical content was determined by XRD analysis. Air pollution was addressed as an important factor of this study. The research highlighted the point that some organisms resistant to pollution can thrive in toxic conditions versus less resistant organisms which die off in the presence of changing pH conditions. In particular, they singled out several species of lichens as having this tolerance to air pollution in Latvia. In addition to their speculation that presence of lichens in a polluting environment was apparently contributing to the deterioration of monuments, they also list the amount of water present in the substrate contributed to the deterioration exhibited on these lichen colonized substrates. Tuff and travertine surfaces, as well as other porous surfaces which were colonized by lichens, contained calcium oxalates allegedly derived from lichens' production of oxalic acid.

They did not recommend mechanical removal of lichens from stone monuments as it appeared to do so would exacerbate weathering of an already weakened surface. removal of the lichens. They failed to mention, however, the effects that the proposed chemical treatment—$CuSO_4$—might have on the host substrate.

Richardson (1975) cited a study in England that discussed chemicals that effectively eliminate biological growths on stone structures and cemetery gravestones. Richardson's objective in his research was to address the removal of lichens for both aesthetic and deterioration reasons. He observed that biological growth contributing to stone degradation is dependent upon the ability of stone surfaces to retain moisture. A further observation was that lichens produce acids which deteriorate stone, particularly carbonaceous stone (e.g., limestone). In combination with atmospheric pollution (specifically sulphur dioxide, reacting with rainwater, present minerals in the host substrate sulfates were chelated and complexed resulting in accelerated erosion of the stone surfaces. In discussing specific chemicals used in his study to treat lichen colonies on stone buildings and monuments, Richardson mentioned the potential of chemical treatments to interact with the host substrate causing further deterioration. He also provided cautions about the potential for applied chemicals to accumulate in the treated stone possibly causing the stone faces to spall.

Martin and Johnson (1992) provided a comprehensive table of treatments that were determined to be effective in inhibiting the growth of lichens, mosses, and algae on both native and anthropomorphically altered stone. While this was a compilation of chemicals used in controlling lichens on stone, there was no mention of the effects that lichens have on the host substrate or the short- or long-term effects of removing lichens from the host surface. The potential for applied chemicals to interact with the stone substrate also was not mentioned.

All the studies mentioned here commonly address lichens on the surface of cultural stone works and some address treatments to eradicate the offending biomes. As with many such studies, the mechanical effects of lichens beyond the first mm are insufficiently addressed. The biochemical changes effected by the presence of lichens beyond the surface are also insufficiently addressed. Only a very small percentage of the citations presented in this research addressed the potential for chemicals used to eliminate lichens to react with minerals present in the stone. Few studies discussed conservation measures that could be implemented with the intent to prevent or at least slow the colonization of lichens on stone surfaces as an alternative to mechanical or chemical treatments.

CHAPTER IV

METHODS

Essential to finding a definitive answer to the questions central to this dissertation is the need to ascertain chemical, mineralogical, and physical alterations of rock substrates from the surface through the natural weathering rind (which forms on all exposed rock surfaces) through to unaltered native rock. To address the questions guiding this research relevant data needed to be obtained from: (a) the rock surface, (b) immediately below the surface, and (c) into the interior of the rock to include unaltered matrix. As it was impossible to ascertain the depth of a weathering rind at any given geographical location prior to acquiring a study sample, a decision was made to remove rock core samples at predetermined locations where rock art is located. Critical to this decision was a conscious effort *NOT* to remove core samples from any panel that contained rock art images, whether painted, pecked, engraved, incised, or otherwise culturally executed. It was also decided that core samples could be obtained from similar substrates within a 0.5-km radius of the rock art images. However, samples from immediately adjacent, similar substrates were preferable.

Control samples were needed to compare data differences between lichen-covered rock matrices and rock matrices that were not obviously impacted by lichen growth. Therefore, sample pairs were removed from each area selected for this research. The sample pairs were typically removed from the same rock surface that exhibited both areas of lichen growth and areas evidently lacking such growths. The distance between the pairs averaged 25 cm; occasionally the pairs were closer together and or farther apart.

An effort was made to locate some sites that were potentially affected by pollutants and sites that would be less affected by pollutants for comparison purposes.

Core samples measuring approximately 2.5 cm in diameter and approximately three to five cm in length were removed from rock substrates in the immediate vicinity of rock art images. As mentioned earlier, every effort was made to ensure that core samples were *not* removed from panels containing actual glyph images. Identification of lichen species was attempted but not always successful (Table 1).

Permission to remove samples was granted from the landowner and/or land-managing agency. Sample pairs from five locales were advanced for analyses (Table 1). The five locales include four in the United States—southwest Minnesota, west-central Wyoming, northeast Wyoming, and central New Mexico; and, one in northeastern Queensland, Australia (Figures 2 and 3). These areas were chosen based on their proximity, or lack of proximity, to known sources of pollutants; proximity to rock art; and proximity to public use lands. Queensland, Australia and New Mexico were areas where airborne pollutants were to be expected; agricultural pollutants were expected for Minnesota; and, no pollutants were expected for Wyoming. Public land access was highly desirable because of the potential benefit this research could be to managers.

Hilti, Inc. loaned appropriate field equipment including an electric drill, diamond-tipped titanium bits, and a water canister (see Figure 4) for removal of the rock core samples. The Honda Corporation loaned a portable generator to power the drill.

Table 1. Rock Core Samples Locations, Substrate Type, and Lichen Type

Location	Sample No.	Sample No.	Rock Substrate	Lichen Type/Species
	No lichen	With lichen		
SW Minnesota	1b 2b 3b	1a 2a 3a	Orthoquartzite	Squamulose; not identified
West-Central Wyoming	1b 2b 3b	1a 2a 3a	Sandstone	Crustose; sp. unidentifiable Squamulose, cf. Psora sp.; cf. Toninia sp. Squamulose; sp. unidentifiable
NE Wyoming	1a 2a 3a	1b 2b 3b	Sandstone	Crustose; unidentifiable
Magnetic Island Australia	1a 2a 3a	1b 2b 3b	Igneous Granite	Crustose; not identified
Central New Mexico	10C 16D 16H	1a 2a 3a	Basalt	Crustose; not identified

Note. Highlighted samples were advanced for analyses.

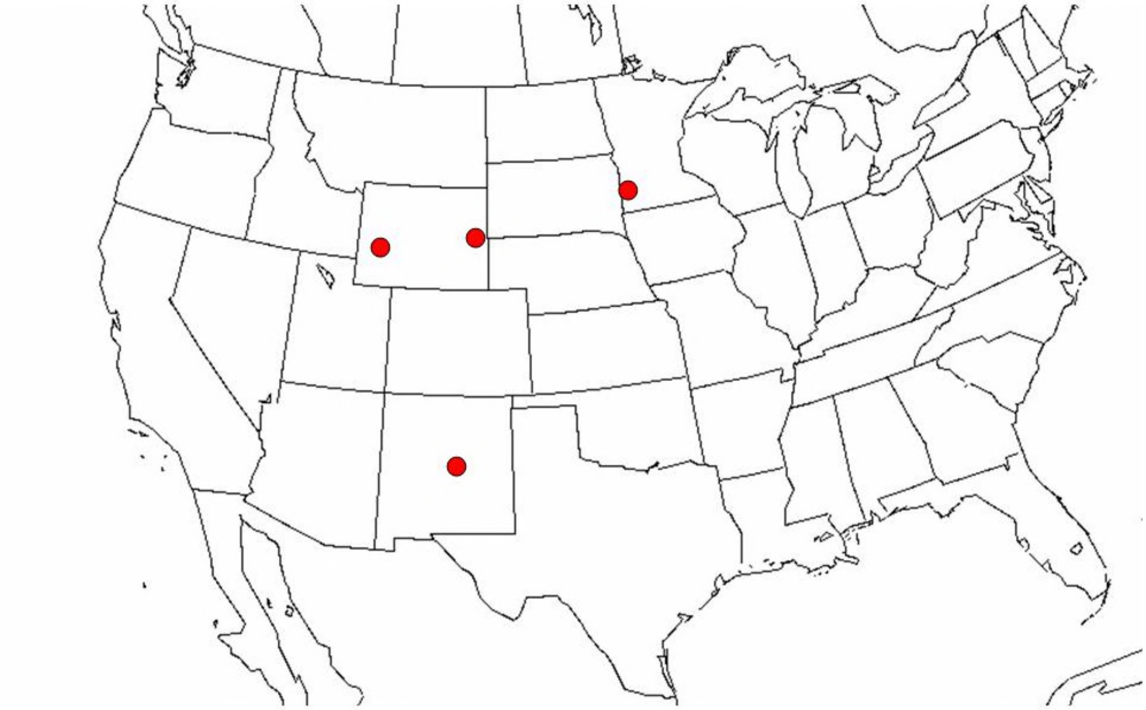

Figure 2. Map of sampling locales in the United States.

Figure 3. Map of Australia—Red dot indicates Townsville and general vicinity of Magnetic Island sampling area.

Figure 4. Field equipment loaned by Hilti, Inc. and the Honda Corporation.

In the laboratory, sample preparation and analysis methods were common to all samples. Each sample type had unique characteristics that required handling not specific to the other samples. Methods common to all samples are described here and methods specific only to one sample are found in the descriptions of each sample area. Rock core samples for this research were analyzed using field emission scanning electron microscopy (SEM) and X-ray diffraction (XRD) technology to map elemental chemical and mineralogical changes in the rock substrates due to the presence of lichens. The rock core samples were cut in half along the vertical axis and examined under a JEOL JSM6330F field emission scanning electron microscope. Specific mineral species identification was undertaken using a Siemens D5000 Diffractometer. SEM analysis provided general information about the geochemical elemental content of the rock samples. Chemical analysis of ~2 to 5 micron areas was performed by energy dispersive X-ray spectrometry (EDS). The analyses were then entered into a database to ascertain patterns of chemical changes within the sample.

Exxon-Mobil Corporation of Houston, Texas, provided a software macro that transformed SEM data into a spreadsheet. This facilitated ascertaining patterns of elemental chemical difference between sample pairs. Not all samples were prepared for analysis. It became apparent after the first samples were analyzed that comparison of each set of sample pairs would provide redundant information that did not enhance information obtainable from only one sample pair. Thus, it was possible to reserve some samples for future analysis. Due to the highly intrusive nature of the sampling methodology, this was a desirable course of action.

Specific mineral species identification was undertaken by XRD analysis. Samples were finely ground in millimeter increments from the surface down to the unaltered matrix utilizing diamond-surfaced files and/or carbide powder. The samples were centrifuged in a solution of deionized water and acetone to separate quartz grains from other minerals and clays. The typical analysis protocol for collecting x-ray diffraction data is to expose prepared samples for approximately 45 minutes, a protocol that has been used with limited results by researchers such as Chiari and Cossio (2004). However, experimentation for this research determined that due to the small sample size, longer exposure periods were required to detect microscopic mineralogical species. Therefore, this research exposed both powdered samples and smear samples for two- to four-hour time periods to ensure that mineralogic differences that may be present had a high probability of being detected.

The supernatant fluid was air-dried and the resultant residue was analyzed. Once the crystallographic data were gathered, it was transformed into visual peak patterns using ©EVA software. Peaks were then compared against a global Joint Committee for Powder Diffraction Studies (JCPDS) database to identify specific mineral species. Differences in mineral species present in lichen covered and non-lichen affected surfaces were thus compared.

Results from SEM elemental analyses and XRD analyses were used to determine the mineral species that were present in the samples. This information was compared against published petrological information for each locale. This methodology allowed for comparisons against what we could expect to find to what was actually present in the samples.

Dr. Lawrence St. Clair, at the Monte L. Bean Life Science Museum, Brigham Young University, assisted in identification of some species of lichens (Table 1). When it was not possible to identify a specific species, lichens were identified by general class, i.e., squamulose (intermediate species) or crustose. No fructicose lichens were identified in this research. Identification of lichen species was attempted but not possible for all species due to degradation of samples during transport to the lab, or in the case of the Australia samples, expertise was not available. The identification of lichen species can help provide information regarding the known morphology and metabolic byproducts of lichens (Tratebas and Chapman 1994). For instance, the hyphae of some crustose and squamulose lichen species, under specific conditions, can penetrate the rock substrate for the remarkable distance of 5 to 10 mm or more (Aghamiri and Schwartzman 2002:250). This is important as chemical changes in rock matrices near the hyphae can be attributed to lichen substances (National Center for Preservation Technology and Training [NCPTT] 200l:11).

Field samples for the research were acquired during the summers of 2000 and 2003. Determining best methods for analyses, sample preparation, and collecting analyses data from the samples took place between 2001 and 2004 as time and equipment availability allowed. Initial interpretation of laboratory data was undertaken in late 2001, with final interpretation undertaken during 2004-2005. Support for the research was provided by the National Center for Preservation Technology and Training (NCPTT-NPS). Dr. James K. Meen, Materials Characterization Laboratory at the Texas Center for Superconductivity, University of Houston, was instrumental in guiding the research and providing advice regarding geochemical analytical methods.

CHAPTER V

ANALYSIS

Overview

The rock art images in close proximity to the sampling areas are both pictographs and petroglyphs ranging in age from unknown to an estimated 10,000 years old. The substrates for the rock art include several varieties of sandstone types, i.e., Sioux orthoquartzite from Minnesota; Lakota sandstone and Tensleep sandstone from Wyoming; one igneous granite type from Australia; and one basalt type from the volcano fields in New Mexico. The modern environments of the study locales are diverse ranging from a moist tropical environment to high desert dry landscape. Origins of the rock substrates are just as diverse as the modern day climates. The orthoquartzite found in southwest Minnesota formed as sedimentation about 1.6 billion years ago. Outcroppings of this formation are due to eons of erosion. The granites of Australia are the result of igneous intrusions over 125 million years ago. Sandstones in northeast Wyoming, formed *in situ,* were deposited fluvial events perhaps 70 million years ago. Sandstones in northeast Wyoming, formed *in situ*, were deposited fulival events perhaps 70 million years ago. In stark contrast to the above formations, the basalt lava flows around Albuquerque are quite young having formed only about 190,000 years ago and sandstones from Torrey Valley are erratics from an outwash plain resulting from the Pinedale glaciation, 70,000 to 15,000 years ago. Locating differing substrates were desirable for this research to determine if lichens affected all rock surfaces in a similar manner.

Current elevations for the study locations presented in this thesis range from approximately sea level to over 2,100 m above sea level. Local environments include close proximity to a seashore, a tall grass prairie, and intermontane zones. Rock varnish or a very dark brown to black appearing surface, has formed on some of the substrates (Wyoming and New Mexico) presumably due to presence of cyanobacteria. The present lichen types are predominantly crustose or squamulose but also include endolithic species. Sources of pollution, when present, include agricultural fertilizers, smelter emissions, road dust, and vehicle emissions.

All the rock substrates demonstrate a weathering profile that has resulted in a metastable state of mineralization across the undisturbed surface. In some instances, such as the orthoquartzite, Australian granite, and the basalt, the weathering rind is quite shallow of 1 mm or less. In comparison, the weathering rind found in the samples from Wyoming are ~3 mm deep. For all the samples examined the effects of lichen processes were evident. Elemental analyses demonstrate that the presence of lichens, regardless of species or environment, has a distinctive geochemical footprint.

Individual Site Descriptions

Southwest Minnesota—Jeffers Petroglyphs Site

Jeffers Petroglyphs *[sic]* Historic Site, owned by the Minnesota Historical Society, is a four acre site located in Cottonwood County at the southwestern corner of Minnesota. This site encompasses approximately 2000 petroglyph images. While petroglyphs are found elsewhere along this quartzite formation, the greatest concentration is at the Jeffers Petroglyphs site. Purchased by the historical society from

Mr. Tom Jeffers in 1966, the site currently features a visitor center and marked trails to the petroglyphs. The site is managed in consultation with a number of Native American groups and has been awarded the Trustee Emeritus Award for Excellence in the Stewardship of Historic Sites by the National Trust for Historic Places. Ranging in age from 5000 years old to several hundred years old (based on relational evidence), the rock glyphs were discovered by European immigrants in the 1860s. Cultural affinity of the glyphs is attributed to Dakota speaking and possibly Algonquin speaking cultural groups (Lothson 1976; Roefer, English, and Lothson 1973).

This is perhaps the most geologically interesting area of the site locales visited for the present research due to the great depth of geological age for the region. The glyphs are pecked and carved into a pink to red colored orthoquartzite[1] commonly referred to as Sioux quartzite, which is part of a 23-mile long ridge extending into counties to the north and east. Orthoquartzite is commonly a sedimentary rock formed primarily of quartz sand in a fine-grained matrix. Substrates of this type are typically cemented with silica. The Sioux quartzite at this location was most probably formed by sands deposited in braided streams (Southwick and Lively 1984) where cross-bedding is common and chemical weathering of minerals other than quartz takes place (Ojankangas and Weber 1984). Stable minerals such as magnetite are commonly found in the rock.

Jeffers Petroglyphs Site is located approximately 140 miles south of Minneapolis/St.Paul in a rolling farmland landscape. The primary industry is farming.

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[1] Orthoquartzite is a sedimentary rock composed almost entirely of quartz. Quartz has a hardness of 7 on Mohs's scale of harness, which is a 1 to 10 scale with diamond having a hardness of 10. Orthoquartzite is thus among the hardest of all rocks.

Light industry such as an ethanol plant is important to the local economy, though some tourism also contributes to the local economy. The climate is moderately extreme with daytime temperatures dropping to 16℃ in the winter and rising to the mid-20's C in the summer. Night time temperatures reach well below freezing during the winter months. Precipitation averages 74 cm annually. There is no overstory in the immediate vicinity of the Sioux formation in this area and since the quartz outcrops are surrounded by farm fields, there is little or no native plant understory.

Lichen growth is extremely common on the quartzite rock outcrops in this area. All exposed quartzite outcroppings observed in the immediate vicinity of Jeffers Petroglyphs demonstrated an abundance of live lichens.

Methodology

As the Jeffers Petroglyphs site is an area of only approximately four acres, there were no appropriate rock outcrops from which to remove samples. However, an adjacent landowner volunteered access to private land for sample collection. This was an acceptable alternative since the location offered is an outcrop of the Sioux formation within 0.5 km of the Jeffers site. Removal of these samples was particularly challenging due to the hardness of the rock substrate. Ultimately, three sets of sample pairs were obtained following the methodology described in the General Methodology section. Samples 1a with lichen and samples 1b and 3b without obvious lichen were advanced for the present analysis (Table 2). Two samples without lichen were utilized for analysis so as to validate the absence of significantly detectable elements (specifically sodium). X-ray powder diffraction mineralogical analysis was not utilized because of the difficulty in obtaining material harder than the quartzite to render the rock core samples into a powder form. Mineralogy was, therefore, inferred from the chemical components obtained from SEM analyses as well as comparison with published descriptions of regional geology (Southwick 1984).

Results

Table 2. Jeffers Petroglyphs Site Sample Comparisons

Depth	Samples 1b, 3b—No Lichen	Sample 1a—Lichen
Surface	Clay, AlO, magnetite, unidentifiable mineral products, Na, FeO (cement)	AlO, magnetite, rutile
1 mm	Clay, chlorite, magnetite, AlO unidentifiable mineral products	Clay, rutile, magnetite
2 mm	Clay, chlorite, magnetite, AlO, unidentifiable mineral products	Rutile, magnetite, AlO
3-4 mm	Clay, magnetite, AlO, chlorite, unidentifiable mineral products	Rutile, magnetite
Distal end	Chlorite, FeO (cement), clay, Rutile, unidentifiable mineral products	Magnetite, AlO, clay

Samples 1b/3b—No Lichen

The unaltered distal end of the samples exhibits mineral content expected of quartzite rock types with the exception of the specifically unidentifiable components which have equivalent Al:Si, significant phosphorus (P) and sulphur (S), detectable calcium (Ca), and iron (Fe). This mineralogical composition is unexpected as it is characteristic in the presence of lichen and yet is found at all levels of the samples. Rutile

(TiO_2), chlorite (characterized by high amounts of Si, Al, and Fe) and silica clay, possibly illite, are common within the sample. Iron cements are at detectable levels.

Sample 1a—With Lichen

In this sample, very little clay is noted throughout the sample. At the distal end of the sample magnetite, a stable mineralization product, is significantly present as it is throughout the sample. Aluminum-oxide and clay are also significantly noted. Moving up through the sample closer to the surface, at 3 mm below the surface, the presence of rutile tends to dominate the analyses up to and including the surface and lichen biome. From 3 mm to the surface and into the lichen mass, aluminum-oxide is present. Magnetite is significantly present throughout the sample except in the lichen mass.

At the surface, little or no clay is noted. The presence of kaolinite is indicated as well as quite a bit of silica. Calcium is especially notable at the surface and may be present as an oxide (unlikely), hydroxide, or carbonate (most likely). At some data points, K appears to be associated with Ca. As seems to be typical in the presence of lichens, there are several analyses points with Na, Al, Si, P, S, K, Ca, and Fe. This content occasionally varies with the inclusion of Ti in place of P. One such data point includes Cu at significant levels. Fe is sometimes associated with Ca, sometimes with Si, and sometimes with S. There is no apatite and no zircon observed.

Comparison of samples. The characteristic footprint combination of Na, Al, Si, P, S, K, Ca, and Fe was expected in sample 1a. However, it was not expected in the samples supposedly lacking in lichen growths. This unexpected association of elements was noted not only at the surface but also at the distal end of samples 1b/3b. Clays are more dominant in samples 1b and 3b; and nearly absent in sample 1a. Chlorides, which are easily dissoluble, are freely present from the perceived unaltered rock up to 1 mm from the surface in samples 1b/3b. Similar chlorides are noticeably lacking in 1a. Magnetite seems to be consistently present in all samples from the unaltered rock up to 1 mm from the surface. Iron cements are apparent in samples 1b/3b without lichen, but are not apparent in sample 1a with lichen.

Discussion

Magnetite is not uncommon in detrital phases in sandstones, particularly in environments like Minnesota where there is an abundance of old high-grade rock. While the presence of magnetite is the result of a reducing environment, it is not surprising to find rather different compositions as there are numerous provenances for the mineral. So some magnetites have high Ti and others have low Ti but high Cr+Al. Any composition with very high Fe and some other elements (Mg, Al, Cr, Ti will be dominant) is detrital magnetite. Further, hot waters (acid) will dissolve magnetite with iron being reduced to Fe^{2+}. Waters inside any sedimentary rock tend to be reduced because of the presence of organic material. When the waters get near the surface and thus an oxidizing environment, the Fe is oxidized to Fe^{3+}, which is essentially insoluble. It is then precipitated as iron hydroxide or carbonate or oxy-hydroxide but mostly as hydroxide. Spot analyses for these samples have no Ti or Cr. But, spot analyses will rarely find only the $Fe(OH)_3$ since it is fine-grained and usually is intimately associated with $Al (OH)_3$ or clays. The cementatious materials present have high Fe, Al, and Si. These samples did have differing geochemistry in that there is evidence for detrital magnetite in some sample analyses while redistributed Fe is more apparent in other analyses. Lichens can be partly responsible for the redistribution of Fe as the body masses can foster a reduced environment.

Conclusion

As was expected, based on the known geology, the parent rock is dominated by SiO_2 grains and has some interstitial material of various sorts acting as cement. The cement includes iron silicate (hence the red color of the rock) which is most probably hydrated. The quartzite is very fine grained and the cement may not be crystalline or only poorly crystalline. There are crystals of Fe,Cu oxide that may have been precipitated as sulfide and oxidized during diagenesis. There is comparatively little sulphur in the rock. There are a few crystals of NaCl (halite) and KCl (sylvite) which were undoubtedly left over from seawater over 150 million years ago. Some of the cement is aluminum silicate (no other cations present) most probably $Al_4Si_4O_{10}(OH)_8$. i.e., kaolinite. Comparison of the samples can be found in Table 2.

Our conclusion is that all the samples under study from the Jeffers Petroglyphs area were host to lichens at some point in their recent histories. This is based on unusual elemental associations in some parts of the rocks. Further, the first impression is that quartzite is a poor host for lichen biomes. There are, however, sufficient clays and iron hydroxide cements in the rock to allow lichens to follow these paths of least resistance to infiltrate the rock, proliferate, and ultimately degrade the rock surface.

West-Central Wyoming—Torrey Valley

Two sites were chosen in Wyoming for this research. The first site, described here, is located in west-central Wyoming on state-managed lands in Torrey Valley, Fremont County, south of Dubois. Torrey Valley is a tributary to the upper Wind River and was shaped by the Bull Lake Glaciation between 200,000 and 130,000 years ago. The subsequent Pinedale Glaciation deposited moraine material in the Late Wisconsin Period, approximately 70,000 to 15,000 years ago. Northwest trending lateral moraines are parallel to Torrey Creek. Prominent features of the moraines are large, well-rounded boulders. Many of these boulders are Pre-Cambrian granite while others are Paleozoic (543-248 mya) sandstone known as Tensleep (Brockman 1985). Core samples that were removed for study are from these sandstone boulders. This sandstone is predominantly buff, tan, cream-colored, and white with fine-grained massive to cross-bedded sandstone. It tends to be porous and friable though it can also be hard and quartzitic. Sandstone outcrops tend to weather to brown and rusty-brown desert varnish, appearing nearly black from a distance (Keefer and Van Lieu 1966:B40-41).

At an elevation of 2218 m, the overstory in this mountainous region, is comprised of ponderosa pine and spruce interspersed with aspen. The understory includes sage and a variety of grasses. The valley landscape features two small lakes also resulting from glaciation. Average annual precipitation is 16 cm and daytime temperatures range from the low 20's C in the summer to -10°C in the winter. Lichens that were identified include a squamulose type, Psora, though the exact species could not be determined.

The numerous rock glyphs in Torrey Valley are thought to be evidence of indigenous cultures that preceded the historically known cultures such as Shoshone, Arapaho, Dakota, and Crow among others. These petroglyph images, pecked into Tensleep sandstone boulders, are known as Dinwoody or *en toto pecked* estimated to range in age from 850 to 2000 years old (Francis and Loendorf 2002:69-70, 79-82). While the modern Shoshone culture considers locales where Dinwoody glyphs are concentrated to be sacred landscapes (Francis and Loendorf 2002:69), historic interviews with Shoshone and Arapaho tribe members in 1873 by Dr. William Corbusier (U.S. Army) indicated that the glyph images were already in place when Shoshonean groups entered the area (Bureau of Ethnology 1882-1883:24).

Methodology

Sample collection followed the protocol established in the General Methodology section of this thesis. The rock core samples were set in epoxy prior to analysis due to the somewhat loose structure of the rock type. Multiple analysis points were examined from the surface to below the weathering rind and across the core sample from side-to-side. The analyses results were then entered into a database to ascertain patterns of chemical changes within the sample (see Appendix A for specific data point analyses).

Results

Samples 1b, 2b, 3b—No Lichen

Three sets of samples were analyzed from Torrey Valley. The samples believed to be free from lichens, 1b, 2b, and 3b, all demonstrated elemental combinations indicative of silica, calcite and feldspar cements (Table 3). Three to five mm from the surface, Si and Al are relatively abundant as in the 2 mm level. There are sporadic concentrations of Na, Mg, K, Mn, and Fe. Titanium (Ti) is undetectable. Calcium is found in abundance. While sporadic, Mn is essentially not detectable. Two and one half mm from the surface of the samples Na, P, and S are nearly undetectable; Mg, Cl, Ti, Mn, and Fe are not detectable; Si is still abundant; Al is less abundant. Barium (Ba) is sporadically detectable. At the 1 mm depth, Si and Al are still abundant but in lesser amounts than at the surface. Sulphur is in greater abundance at this level; Na, Mg, P, K, Ca, Ti, and Fe are sporadic. Chlorine is not detectable nor is Mn. The presence of Ba is abundant. Mature clay elements are noted close to the surface (less than 1 mm) while immature clay elements are noted deeper in the samples. Manganese is noted near the surface in these samples. At the surface there are Si, Al, Fe, Mn, and Na in higher abundance, with lesser amounts of Mg, P, S, Cl, K, Ca, and Ti.

Table 3. Torrey Valley Sample Comparisons

Depth	Samples 1b, 2b, 3b —No Lichen	Sample 2a —Lichen
Surface	Rutile, apatite, quartz, Mg, phyllosilicates (clays & micas)	Quartz, Na, Mg, S, Cl, K, Fe^{2+}
1 mm	Zircon, phyllosilicates, quartz	Phyllosilicates, quartz
2-3 mm	Lichen hyphae(2b),quartz	Phyllosilicates, quartz
5 mm	No data	Xenotime, lichen hyphae, zircon
Distal end	FeTi,O, Fe cement	Zircon, quartz, phyllosilicates

Samples 1a, 2a, 3a—With Lichen

The samples with obvious lichen growths demonstrate chemical differences from the non-lichen samples. Calcite (calcium carbonate, $CaCO_3$), feldspar, and barite (barium sulphate) cements were noted in these core samples, as were mature and immature clay species similar to the samples without lichens. Also, there is a demonstrable *lack* of Mn close to the surface in the samples with lichens, though Mn becomes more evident beyond the zone of weathering at the distal end of the sample as are concentrations of Ti and Fe. In the weathered zone, chemical analyses indicate an abundance of Si and Al with significantly reduced amounts of Cl, Mg, and Ca overall. There are sporadic concentrations of abundant Cl, Ca, and Cu. Other elements are not at detectable levels except in sporadic positions.

Comparison of samples. The Torrey Valley samples without lichen, samples 1b, 2b, 3b, show systematic chemical changes in the cement from the unweathered rock to the surface. The unweathered rock is poorly cemented with silica, calcite, authigenic feldspars, and potassium-bearing clays. The calcite, feldspar, and clay cements are not noted within 3 mm of the surface. In comparison, the samples with lichens show that the cement-rich areas have largely been replaced by lichen hyphae although many of the elements that were concentrated in the cement are now associated with the hyphae. The high manganese concentrations present at the surface in samples 1b, 2b, 3b are absent from the surface in the comparison samples (see Table 3 for comparison).

The clays that are present without lichens contain little or no potassium. Carbonates are absent. Notably, iron contents are elevated—consistent with the color changes in the rocks. For the samples with lichens present, the weathered outer surface of the rock, while not highly indurated, is much more heartily cemented than the interior. The nature of the cement has changed, presumably under the influence of oxidized, and probably acidic, water derived from the surface. The cement in the weathering rind is extremely fine-grained, variable in character, and low in abundance (a few percent of a 3 mm thick “cap”). It seems reasonable to suggest that it includes aluminum-silica clays or aluminum oxide-hydroxides, or both, and iron oxide-hydroxides. For the samples without lichens, manganese may have been concentrated by bacteriological action in hydroxides at the surface.

Rock surfaces in the lichen crusts have rather different chemical and, presumably, mineralogic characteristics from those without lichens. Cement-rich areas have largely been replaced by lichen hyphae although many of the elements that were concentrated in the cement are now associated with the hyphae. The one constant is the quartz, which seems impervious to the lichens; but, the lichens appear to have replaced many of the mineral grains that held the quartz together with their own hyphae and with biologically-mediated mineral phases.

Discussion

Chemical analysis of lichens on the surface by SEM-EDS, demonstrates, in addition to organic components, an abundance of Si and Al with lesser amounts of K and Fe. The lichen/rock interface shows high abundances of Si, K, and Fe. Lichen hyphae, which have penetrated into the rock substrate at least 1-2 mm, demonstrate concentrations of Si, Al, K, with significant, but lesser, amounts of Na, S, Ca, Cl, and

Fe. The rock matrix near the surface consists of Si, Al, K, S, Na, Mg, Cl, P, and some Fe (which is less abundant than concentrations in or immediately around lichen hyphae). These samples have demonstrably less mature clays near the surface.

Conclusion

The process of chelating and complexing[2] of minerals is exhibited in these samples. They are examples of the evolution of a cemented, pristine rock matrix where the cements are reduced and replaced with other distinctive materials. For example, manganese oxide forming on the surface is reduced to a dissolvable state by lichen products, thereby removing a hard crust that protects the rock surface from erosive elements. Thus, when the protective crust is removed, calcite cements, which are easily dissolved, are highly susceptible to erosion. The sandstone grains with cements and clays reduced will now slough off the surface to the extent that chemical reduction is taking place in the rock matrix (see Figure 5 for visual comparison of these effects).

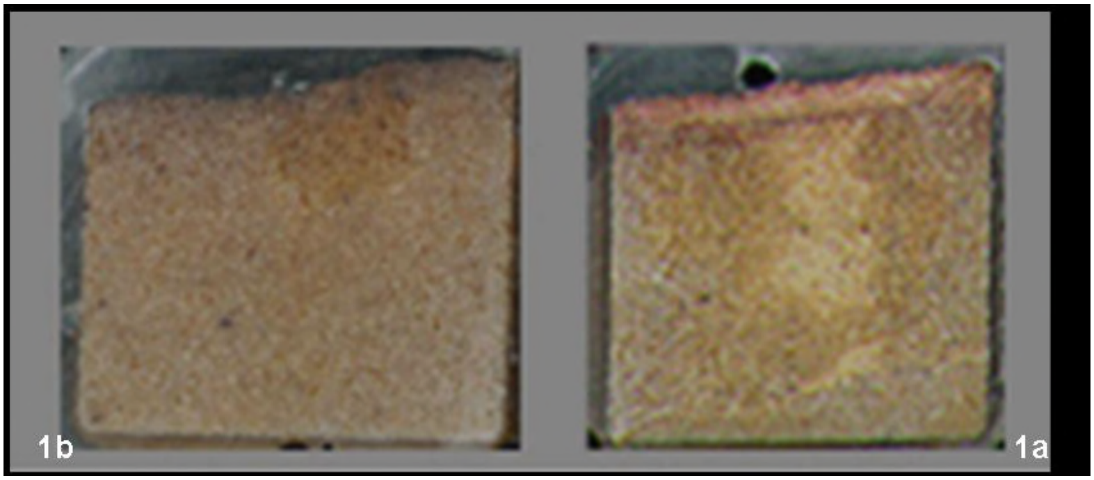

Figure 5. Torrey Valley samples 1b with lichen and 1a without lichen.

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[2] Chelating and complexing, simply stated, are processes whereby mineral lattices are broken apart and their constituent atoms are incorporated into other mineral species in aqueous solution.

Northeast Wyoming

The second site that was sampled in Wyoming is located on private property in Northeastern Wyoming, Niobrara County southeast of Newcastle. This area is located at the western periphery of the Black Hills uplift dome. The geologic setting for this area includes the Lakota (lower two-thirds) and Fall River formations (upper one-third) that comprise the Inyan Kara Group, which is Upper Cretaceous in age (70 mya to 90 mya). Pertinent to this investigation is the Chilson member of the Lakota formation. It is primarily formed of fluvial channel deposits composed of sandstone, shale, siltstone, and mudstone. The Fall River formation tends to be a heterogeneous group of laminate carbonaceous siltstones and fine-grained sandstones.

The climate today is semiarid. Day time temperatures range from a low of 30^{o}F in January to an average high of 90°F in July. Average annual precipitation is 13-15 inches per year (Daly and Taylor 1998). The vegetative understory is comprised of grasses, sedges, forbs, and shrubs; and the overstory is a mix of coniferous and deciduous species such as juniper and aspen.

Rock art imagery that is found in this area is commonly carved, pecked, or abraded onto the sandstone surface by prehistoric indigenous cultures. Petroglyphs are found on both the sandstone cliff walls and large boulders lining the creek bed along an intermittent drainage. Some of these glyph images are believed to be more than 10,000 years old and others as young as 150 years old (Sundstrom 2004:54; Tratebas 1993). Typically, the sandstone substrate has a black or nearly black ‘desert varnish’ on exposed surfaces. Desert varnish is thought to be created by biological activity, such as cyanobacteria and dust (Dorn and Oberlander 1981; Liu and Broecker 2000; McKeown and Post 2001; Perry and Kolb 2003) (Figure 6).

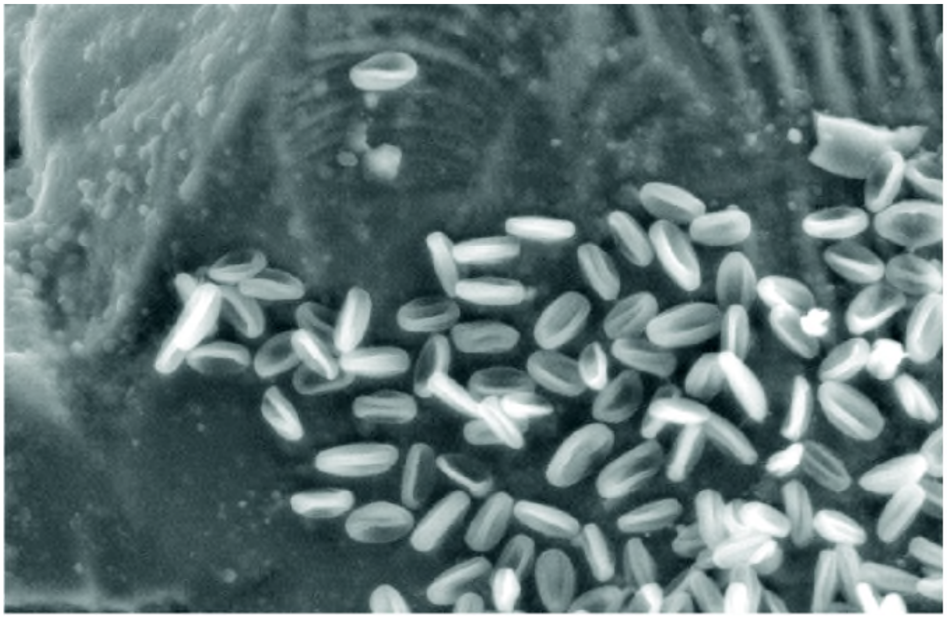

Figure 6. SEM image of cyanobacteria on surface of sample WB1b.

Methodology

Rock core samples for this research were analyzed following the methodology described in the General Methodology section of this thesis. The rock core samples were cut in half along the vertical axis, and set in epoxy similar to the Torrey Valley samples.

Results

Samples 1a, 2a, 3a—No Lichen

On rock core samples taken from nonlichenated surfaces a weathered rind has developed on the rock in this sampling area, as was expected. Several features serve to distinguish the weathered and unweathered sandstone. The weathered rind is better cemented than the interior of the rock. The weathered rind, without lichen, is dark reddish brown on the surface. There is a distinctive red layer within 1 mm from the surface similar to the samples without lichen from Torrey Valley. This layer is dominated by quartz but cement, although still intermittently present, is in higher abundance than in the unweathered distal portion of the rock samples. The cement is comprised of very finely grained material that could not be optically identified. The composition of the cement in this region of the sample differs markedly from that deeper in the rock. Iron is at a much higher level, Ca and Mg are both sporadically abundant at the more distal end, and elements such as Cl and S are at detectable levels (see Appendix A for raw analyses results; Table 4 for side-by-side comparison).

Table 4. Comparison of Samples From Northeastern Wyoming

Depth	Samples 1a, 2a, 3a —No Lichen	Samples 1b, 2b, 3b —Lichen
Surface	Quartzite Ca, Al, Ba, Fe, S, Mg	Quartzite, Fe, Al, Ti, V, P, S
1 mm	Quartzite, Ca, Fe, Al, Cu, Cl, K, Mg, Na S	Assemblage similar to surface
2 mm	Data similar to 1 mm	Quartzite, Cu, Cl, Na
3 mm	Data similar to 1 mm	Quartzite, Al, Cu, Cl, Mg, Ca
Distal end	Quartzite, Al, Cu, Fe, Zn, Cl, S	Quartzite, Al, Fe, K, Mg, Na, Cl, P, Cu, S

In general, throughout the samples, Al and Cl are present in roughly equivalent amounts, with Fe at nearly twice the concentration. Sodium (Na) is a constant presence, but at lower concentrations. There are sporadic, but distinct, concentrations of Ca rich regions that also contain small amounts of Si and lesser amounts of Mg. Some regions of the cement show elevated levels of K, S, or Mg in addition to the aforementioned elements.

Samples 1b, 2b, 3b—With Lichen

These core samples demonstrate evidence of lichen hyphae penetrating the rock matrix to a depth of 5.5 mm. Below 3 mm, the unaltered rock chemistry reflects abundances of Si, Al, Fe, K, and Mg. Also present are lesser, but detectable, amounts of Cl, Cu, Na, P, S, and Ti. In addition, at 3 mm, Si remains in abundance as well as Al and Cu. Detectable amounts of Cl, Mg and S are also present. An abundance of Si is present with detectable levels of Cl, Cu, and Na at the 2 mm depth. Closer to the surface, at the 1 mm depth, Si is abundant with detectable amounts of Cl.

At the contact of the rock surface and lichens, abundances of Si, Al, and Fe are high. Detectable amounts of Ca, Cl, K, Mg, Na, P, S, V, Ti, and Cr are present. Particularly noteworthy is that Ca is present, but in noticeably lesser quantities than in the comparative samples without lichens.

Comparison of samples. The unweathered rock in both samples is poorly cemented and is even less consolidated than samples from Torrey Valley, Wyoming. It is highly porous and has limited amounts of cement that may be either alkali-rich clays or some iron-rich minerals. The weathered rind of this rock is better cemented than is the interior. X-ray diffraction analysis of concentrated cement fractions establishes the presence of lepidocrocite, FeO(OH), as a cement. Other areas of cement are plausibly clays reduced in modal abundance. Many of the elements concentrated in the cements in the lichen-free samples are associated with the lichen hyphae in these samples. The hyphae penetrate some millimeters into the rock, thus piercing through the entirety of the original weathering rind (see Figure 7 below). Samples *with* lichen demonstrated a *lack* of FeO(OH).

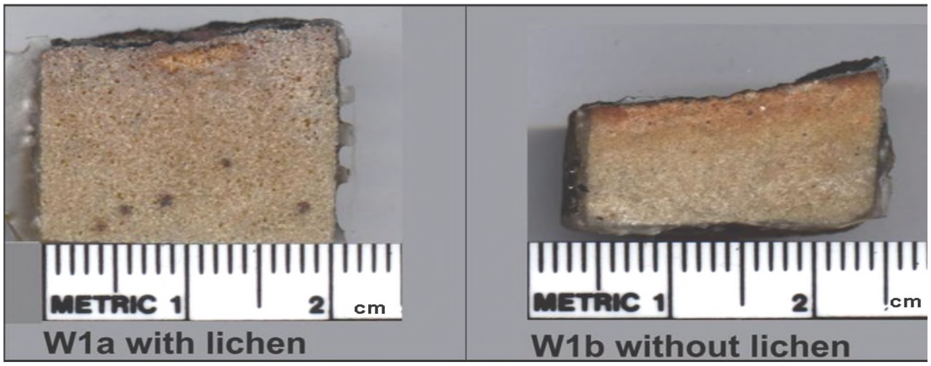

Figure 7. Visual comparison of Northeast Wyoming samples.

Discussion

The sample with lichens is very different visually as well as chemically from the sample without lichens. At the surface on the sample with lichens, there is a dark brown layer. Below the surface, there is no definitive banding such as is found in the samples that do not have lichens. From the surface to the interior of the core, there is a gradation in color from dark reddish brown to tan on the samples without lichen that is not seen on the samples with lichen (see Figure 7 above).

Conclusion

Data from the northeastern Wyoming sample sets demonstrate that chemical changes are taking place in the rock substrate that may be attributable to the presence of lichen. The unweathered sandstone is even less consolidated than that for Torrey Valley. The noted cement, lepidocrocite, is being replaced in lichen-encrusted areas with an assemblage of phases containing higher contents of iron, potassium, chlorine, and phosphorus. This may be attributed to the presence of one or more organic acids contributed by normal lichen processes that are chelating and complexing mineral and organic substances. Lepidocrocite is soluble in organic acids. Lichens obtain nutrients, and open spaces within the rock matrix, by exuding fumaric and oxalic acid then chelating available elements. Lepidocrocite is assumed to be providing some metabolic need for lichens as lepidocrocite is a natural adsorber of many elements (Dandridge and Meen 2003).

Australia—Geoffrey Creek Site

Core samples for this research were taken from the immediate vicinity of an aboriginal rock art site adjacent to Geoffrey Creek on Magnetic Island, Townsville, Queensland, Australia. Magnetic Island is located off the eastern coast of Queensland, Australia, just outside of the Townsville shipping port in the Coral Sea and well inside the Great Barrier Reef (Figure 3—map of Australia). Annual average rainfall is 1200 mm with temperatures ranging from 17°C (62°F) in the winter to 31°C (88°F) in the summer.

The island is an igneous granitic relic substrate as opposed to being a coral atoll. The island takes its name from Capt. James Cook who sailed close to the island during his voyage of discovery to Australia. At the time Cook was exploring the coastline, his shipboard compass was not properly functional. He attributed the malfunction to a supposed magnetic property of the island. This has since proved to be unfounded. But, nonetheless, the European name, Magnetic Island, remains today. The Wuluguruba Traditional Aboriginal Community claims the area as traditional lands and struggles to maintain an identity in the face of increasing Euro-Australian developments. Access to this site was granted by Magnetic Island National Park with permission from the Wuluguruba Traditional Community.

The primary industries on the island are tourism and recreation. Year round residency on the island has an ever-increasing appeal as an alternative to residing in nearby Townsville. Historically, the island was an important Allied post during World War II. The ruins of significant occupation sites capable of supporting a military outpost can still be seen today. A national park has been designated on the island to protect important koala bear habitat and the heritage resources found on the island.

Modern day activities that potentially affect the environment, and thus growth of lichens, are located on the mainland as well as the island itself. Activities on Magnetic Island that increase hydrocarbon pollutants come from commercial and residential housing construction. Vehicle use related to tourism and residential development contributes to pollution. There are seaborne pollutants from recreational boating, passenger ferries, and ships using the mainland port. Last, but perhaps most important, emissions from a nickel processing plant on the coast outside of Townsville, as well as at two other metals refineries within 40 km of the island, contribute to airborne pollutants.

These three known metals refineries/smelters appear to be the primary sources of pollution near Magnetic Island. Situated on the coast in and around Townsville, there is (a) the Townsville Copper Refinery, which has been in operation since 1959; (b) the Yabulu Nickel Refinery, one of the largest nickel and cobalt refineries in the world, which started operation in 1974; and, (c) Sun Metals Zinc Refinery, which produces sulphuric acid as a byproduct and has been operating since 1999 (Townsville City Council, 2005). Metals refineries inevitably produce airborne pollutants from smokestack emissions. These pollutants are carried on air currents and are either dry deposited on ground surfaces or combine with rainfall (H_2O) and result in aqueous acidic depositions. The pollutants, whether dry or wet, are inevitably incorporated into the thallus body of lichens.

According to Spenceley (1982), and as indicated by maps published by the Geological Survey of Queensland (1975), Magnetic Island is comprised of late Palaeozoic age plutonic rocks. The granitoids of the Townsville area (and by association Magnetic Island based on proximity) can be expected to have high K_2O, high and variable Rb, low $_{Fe2O3,}$ and tend to be silicic acid end-members. Quartz-K-feldspar-plagioclase are found in the rock matrix. Biotite adamellite/granite[3] can be expected within the granitic composition (Richards 1980:23 8). As demonstrated by the boulders at the present sampling area, the substrate is a homogenous, relatively coarse-grained granite *s.l.* (Geological Survey of Queensland, 1975). This granite type is similar to intrusive igneous granite found inland on the eastern edge of the Bowen Basin and is considered to be a felsic rock type.

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[3] Adamellite is described by the U.S. Bureau of Mines as being characterized by plagioclase, orthoclase and quartz with minor biotite, hornblende and accessory apatite, zircon and opaque oxides (1968).

The immediate microenvironment influencing the growth of lichens is comprised of overstory vegetation that is predominantly eucalyptus, while native grasses comprise the understory. Geoffrey Creek, the area designated for the present research, is found on the south end of the island. The sampling site is less than 1 km from a residential area and approximately 1.5 km inland on the island and situated on a west facing slope.

Traditional peoples utilized the area historically as evidenced by images painted on one surface of the boulder outcrop central to this study. The age of the pictographs is not known, nor is it apparent that the site is still in use, unlike many traditional rock art sites in Australia. The granitic outcrop being sampled is almost completely covered by lichens with the exception of the aboriginally painted surface. The pictographic surface could possibly have been prepared by smoothing the surface prior to application of the painted images, which may account for the lack of lichens on this particular face of the boulder outcrop. This situation could not be confirmed. Lichens, however, are encroaching on this surface following the water drip line.

Methodology

The rock substrate sampled at the Geoffrey Creek site is located on the south side of the island on a west facing slope. The sampling area is a cluster of granite boulders outcropping on the edge of an ephemeral stream drainage inland from Geoffrey Bay.

The protocol used for removing sample pairs for analysis is similar to that established for all other samples (see General Methodology section). In this case, one core was taken from an area on the rock surface that was heavily colonized by lichen (sample 1a). The control sample was taken from an area less than 30 cm away that visually appeared to have less lichen growth (sample 1b). Due to lack of specialized expertise in the Townsville area, it was not possible to get specific species identification of the lichens colonizing the outcrop. The lichens at this site, however, fall within the category of crustose types. In addition to surface growth, endolithic growth is in evidence as could be seen in SEM images and by the appearance of carbon peaks on SEM analysis points approximately 5 mm below the surface.

After removing rock core samples from the substrate, they were irradiated by exposure in a museum X-ray machine to render the lichen non-viable so as to facilitate transporting the samples through U.S. customs. This method was very effective in killing the lichen without apparently adversely affecting the rock host. In the laboratory at the University of Houston, one sample pair was prepared for analysis similarly to all samples collected at other locations.

At this point, a brief discussion of Bowen's Reaction Series will help the reader better understand the interpretation of the analysis of samples taken at Geoffrey Creek and the relation to weathering of igneous rocks. In the early part of the 20th century, N. L. Bowen theorized that "basalt magma is the parent of all igneous rocks, and the many varieties have arisen through crystallization differentiation" (Gilluly, Waters, and Woodford 1957:461). Laboratory experiments conducted by Bowen revealed that there is a specific ordering of mineral crystallization as basalt magma cooled. This is known today as Bowen's Reaction Series. (A diagrammatic representation of Bowen's Reaction Series is found in Figure 8).

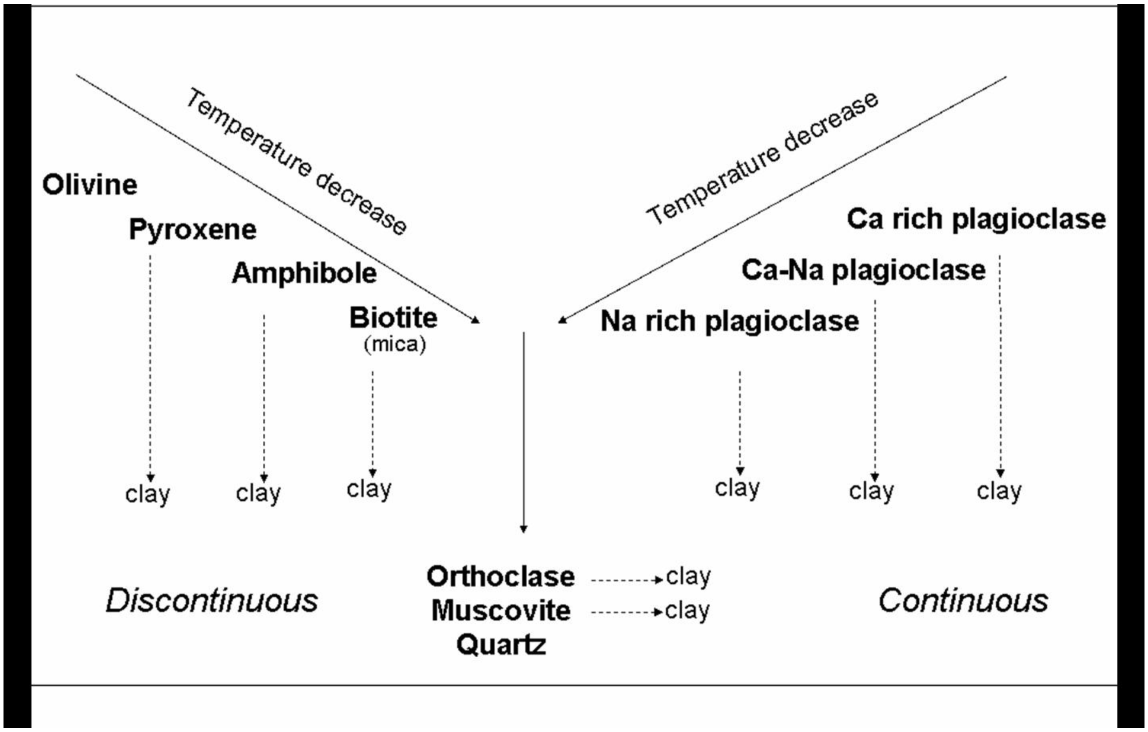

Figure 8. Diagrammatic representation of Bowen’s Reaction Series.

This pattern of crystallization appears at different stages in the cooling process. Olivine, a primary mineral in magma, is highly susceptible to weathering. It will break down in two stages to smectite (a clay species) and then to iron hydroxides (goethite) in tropical regimes (Colman and Dethier 1986) such as Magnetic Island. The minerals that form in Bowen’s Series are the pyroxenes and amphiboles such as hornblend, which in contrast to olivine are more stable. They weather to talc and iron oxides. In tropical climates, orthopyroxenes weather faster than clinopyroxenes (Colman and Dethier 1986). The formation of biotite, also known as black mica, is next in the series. A weathering characteristic of biotite is the loss of potassium and the oxidation of iron. Typical weathering products of biotite include hydrobiotite and magnesian vermiculite, which weathers to brucite, a clay. Hydrobiotite may weather to kaolinite, goethetite, gibbsite, and/or hematite. All these minerals are susceptible to chemical weathering like that induced by the presence of acid-producing lichens. It is notable that clay minerals such as the smectities tend to be stable products of weathering processes (Krauskopf 1967) though vulnerable to erosion.

In tandem with crystallization of these minerals, magmas crystallize to plagioclase feldspars. The right side of Figure 8 reflects the continuous series (as opposed to the discontinuous series on the left) because plagioclase has a continuous solid solution from high-temperature calsic composition to lower-temperature sodic ones. All feldspars can weather through loss of Ca and Na to form clays. Clays with higher Ca content are more susceptible to such weathering. At the lowest temperatures of crystallization, orthoclase (which is potassic feldspar), muscovite (white mica), and quartz join the crystallizing assemblage. These minerals are very resistant to weathering. Orthoclase and muscovite ultimately weather to clays. Quartz generally resists weathering and erodes to contribute to the sand in sediments.

Results

The rock core sample pair that was removed from the Geoffrey Creek site and advanced for analysis was labeled 1a and 1b. Sample 1a was heavily encrusted with lichen. The comparative sample, labeled 1b, also exhibited lichen growth, but in a lesser amount. The only rock surface not covered with lichen growth in the immediate vicinity of the site is the pictograph (painted rock art) panel, which was not sampled at the specific request of the Wuluguraba Traditional Community. Observations from SEM data point analyses are summarized in Table 5.

Table 5. Side-by-Side Comparison of Observed Differences From Analyses for Geoffrey Creek Samples

Depth	Sample 1b—No (or less) Lichen	Sample 1a—Abundant Lichen
Surface	S nominally present (<0-2%)	S is noted at the surface and in the first mm
Surface	K-feldspars	K-feldspars
1 mm	Na throughout the sample	Na less abundant than in 1b; Mn; S; FeO; K-feldspars
2 mm	No biotite is specifically noted	Mn; Biotite (breaking-down); FeO; K-feldspars
Distal end	Mn; FeO	Mn; FeO

Sample 1b—No Lichen

While the bottom 3 mm of the sample exhibits some evidence of weathering, it still contains the full mineral assemblage anticipated for the expected adamellite mineral, i.e., quartz, strongly potassic alkali feldspar (K-feldspar), plagioclase, biotite, iron-titanium oxide (FeTiO), and zircon (see Appendix A for data analysis). Biotite does not appear closer to the surface than 3 mm, suggesting that it is removed by weathering at relatively shallow levels. Iron-titanium oxides are present to within 2 mm of the surface but absent from the rock nearer the surface. Point analyses that yield compositions consistent with the presence of feldspars were obtained throughout the rock section; however, upon closer analysis, points that appear to be plagioclase are actually altering through the apparent leaching of calcium (see Figure 9 below for diagram of general leaching process). Points with elevated Na contents are noted throughout the rock. Plagioclase at the 3 mm depth from the surface has a Ca to Na range of .70 to .20, which presumably reflects natural variations of composition of plagioclase within the adamellite mineral.

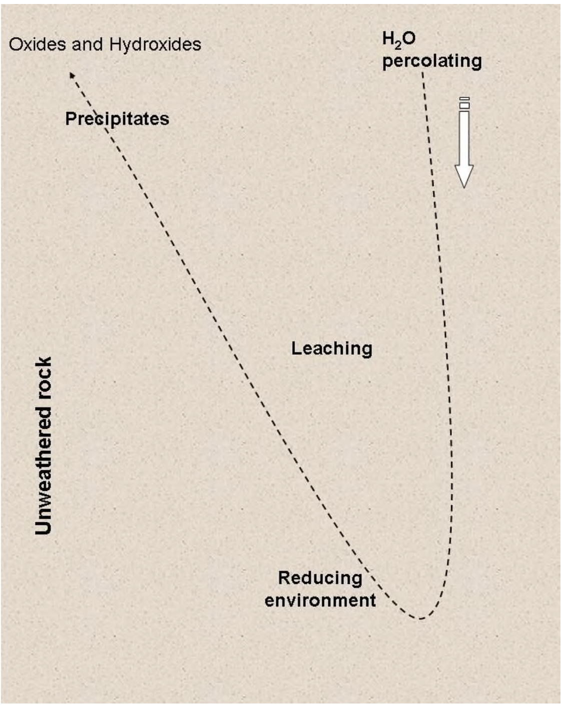

Figure 9. Diagram of general leaching process.

Conversely, analyses with elevated Na, Al, and Si contents from the 2 mm nearest the surface have lower Ca contents (Ca to Na of .13 to .01), which indicates that the plagioclase has undergone alteration with preferential leaching of Ca from the rock structure. Thus, consistent with Bowen’s Reaction Series discussed above, Ca plagioclase, biotite, and iron-titanium oxide are removed from the top 2 mm of the rock leaving a residue of potassic feldspar, quartz, and Na-rich alteration products of plagioclase. No highly aluminous materials or Fe-Mn oxide/hydroxides were encountered in the sample 1b analyses such as found in sample 1a (see Figure 10).

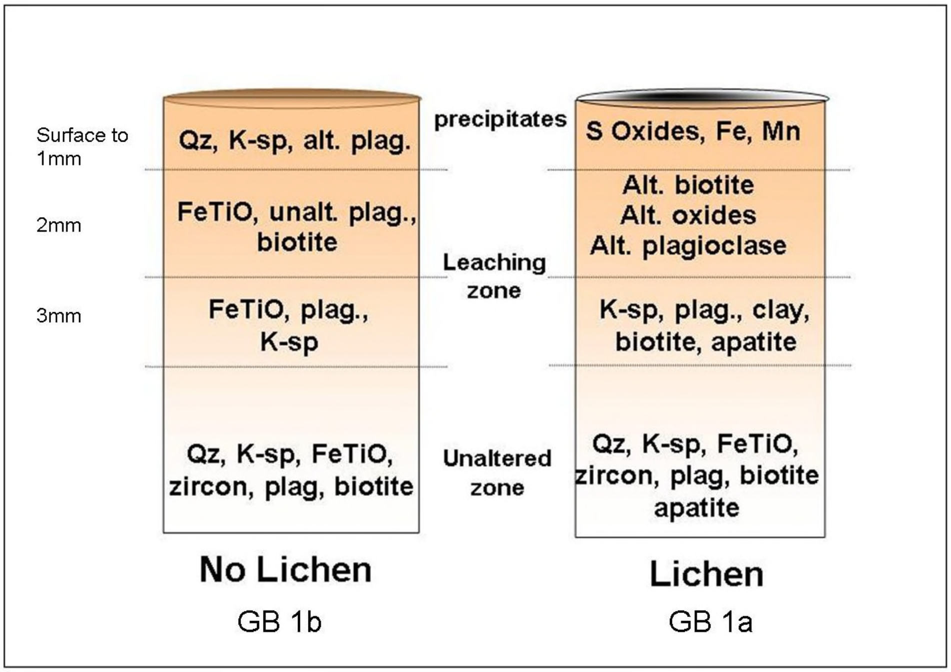

Figure 10. Mineral assemblage of Geoffrey Creek samples.

One analysis point of a Cu-rich phase associated with a sodium aluminum silicate near the surface and one analysis point of a Ni-Cr rich phase 3 mm deep in the sample are inconsistent with the geochemistry of a felsic rock and may reflect contamination from atmospheric borne pollutants, most probably from the nearby smelters in and around Townsville.

Sample 1a—With Lichen

The deepest part of this sample section is also made up of minerals expected in the unaltered rock, i.e., quartz, alkali feldspar, plagioclase, biotite, iron-titanium oxide, apatite, and zircon. The slight differences in mineral composition and abundance of minor minerals (especially apatite) are most plausibly explained as natural variations in the composition of a coarse-grained rock.

Chemically, the simple stratification observed in sample 1b is not replicated in sample 1a. Point analyses that provide compositions corresponding to unaltered biotite were not obtained in the top 2 mm of the rock. There are, however, point analyses with elevated Mg+Fe (15 wt. %), Al (5 wt. %) and with Ca and Na below detection—all of which are consistent with the presence of biotite. Potassium contents are severely depressed relative to biotite analyses, i.e., 1% as opposed to 5%. This is consistent with phases formed by the breakdown of biotite largely due to the removal of K, most probably due to chemical weathering. No analogous point analyses were obtained for sample 1b, without lichen.

Iron-titanium oxide (ilmenite) grains occur throughout sample 1a in contrast to 1b. In fact, ilmenite and magnetite ($Fe^{2+}Fe_2^{3+}O_4$), occur almost at the surface of the rock. The spinel group (as represented by the magnetite) are insoluble or only slowly soluble in the presence of acids. Just as in sample 1b, plagioclase that is found in the upper 2 mm of this sample is very poor in Ca and is presumed to be alteration products derived from plagioclase. Also, as in sample 1b, quartz and potassium feldspar are present throughout and have similar compositions at the surface as at depth.

Some point analyses in sample 1a provide compositions not similarly observed in sample 1b. There are regions at the surface and at depths as great as 3 mm below the surface which show significant concentrations of either alumina alone or alumina and silica. These areas are presumably residues of extreme cation leaching of igneous minerals (feldspar or mica). Other regions in the lichen itself and up to 1 mm below the surface contain a large number of elements that are not consistent with incorporation into a single mineral lattice. Typically, the areas have high Al and Si (in many cases Al > Si) and detectable amounts of Na, Mg, K, Ca, P, and S. Such areas are associated with lichen and are certainly mixtures of submicron grains of different lichen-mediated phases. An obvious source of the phosphorus is apatite in the granite that forms grains many microns long. Thus, the conclusion is that lichens generate acidic solutions that dissolve apatite and incorporate the chelated material in the lichen thallus or along rhizines.

The previously mentioned Al-rich regions that occur up to 3 mm below the surface are interpreted as clayey residues of feldspar, biotite, or both. It is plausible that the Na, K, Ca, Mg, and Fe in such primary phases are being removed by lichen-excreted acids. These elements are then stored in the biomass. Similar intense leaching is not observed in sample 1b. The high Al and Si presence around the lichens indicates that clay-like minerals also occupy these regions. Whether this material is deposited in solution by the lichens or represents pieces of residual mineral that have been mechanically disrupted is not known.

There is no apparent source of sulphur in the granitic rock and the origin of sulphur in the lichens remains speculative. The original presence of sulfide or sulfate in the granite cannot be ruled out; but it is more reasonable to expect that the sulfur is introduced from external sources. One possible source is from relatively nearby ocean waves as spray. The absence of chlorine from any analyses of either sample tends to argue against significant brine involvement, however. Other potential sources of anthropogenic pollutants can be fire retardant chemicals used to suppress wildfires or the emissions of nearby metal smelters.

Areas of the rock substrate around the lichens may be composed of mosaics of sub-micron grains that include sulfates, phosphates, and silicates. The silicates certainly include clays and, perhaps, oxides, hydroxides, carbonates, and oxalates. At least some of these, and probably all, are generated by the action of lichen metabolic processes.

Manganese is concentrated in some regions near the surface at ratios of Mn to Fe of approximately .69 to .25. Conversely, the Mn to Fe ratio is ~1 to 10 in sample 1b. The presence of the higher ratio of Mn to Fe is considered to be due to biological action since Mn and Fe are not fractionated from each other by inorganic activity.

Comparison of samples. A single interface in sample 1b separates rock (2 mm below the surface) in which the mineral assemblage is broadly granitic from one with a modified assemblage. In this modified assemblage iron oxide and biotite are absent and there is extremely leached plagioclase. Sample 1a has no such interface in that the iron oxides and biotite, or phases found by partial alteration of those minerals, occur throughout the sample. The mineral content of sample 1a could not have developed by growth of lichens directly on a rock surface identical to that of sample 1b. Either lichens were established on a fresh granite surface so biotite was present throughout the rock before lichens grew; or, the lichens disrupted and destroyed any weathered surface analogous to the top 2 mm of sample 1a before becoming stabilized at the position of the old front described in sample 1b above (also see Table 5 and Figure 10).

Lichens are providential biome systems accessing nutrients from both the ambient atmosphere as well as the petrologic host, anthropogenic pollutants, such as automobile and marine craft emissions, effluents discharged into the sea, and concentrations of particulates from nickel ore processing. They have the potential to affect rock surfaces as lichens metabolize or otherwise cache such polluting elements.

Discussion

Several accepted characteristics of the minerals mentioned in the Results section need to be emphasized to better understand the significance that lichens have on Magnetic Island rock surfaces. Mica minerals, such as biotite and muscovite, are more readily weathered than feldspar and quartz (Wright 1988). Plagioclase feldspars (Na, Ca) Al (Si, Al) Si_2O_8 are among the most common rock-forming minerals and are susceptible to deterioration when exposed to a hydrous environment (rain, flood, or other). Alkali feldspars [(K, Na) $AlSi_3O_8$] are feldspars that contain alkali metals but relatively little Ca. Minerals representative of this class include orthoclase, anorthoclase, sodic plagioclase, and albite. Significant to this discussion, also, is that the higher the ratio (Na+K) to Ca of a feldspar, the more readily it is weathered in temperate to tropical environments. Further, as feldspars decompose, the principal product is clay. Amphiboles, pyroxenes and other aluminum containing minerals decompose to clay also (Longwell, Knopf, and Flint, 1956:33-34). Weathering alters biotite to the clay species montmorillonite or vermiculite (Deer, Howie, and Zussman 1992:304), which are clays. All these clays are known to be products of natural weathering processes.

Conclusion

Chemical analysis from SEM revealed that in the Geoffrey Creek rocks, chemical weathering is facilitated by the presence of lichens. At the surface, on the core sample with abundant lichen growth, feldspars and plagioclase are absent within the lichen matrix. Manganese is concentrated; sulphur is noticeably present; potassium and calcium are present in roughly equivalent amounts. This information demonstrates that minerals present in the rock are being dissembled within the lichen body.

Petroglyph National Monument

Petroglyph National Monument (PNM) was established in 1990 primarily to protect the numerous petroglyph images found on the basalt boulders from encroaching residential developments. Thousands of sacred images are carved into the basalt boulders and formations dotting the landscape of the Llano de Albuquerque. These volcanic formations and landscape are considered spiritually significant to modern Puebloan groups who maintain traditional recognition of the sacred relationship between medicinal plants, rocks, and mountains (USDI 1995:10). The many glyph images, which may be representative of traditional beliefs, are thought to be 400 to 700 years old (Figure 11). The dark black surface coating on the basalt outcropping, commonly referred to as desert varnish, provides a dramatic canvas for the inscribing of glyph images.

Figure 11. Example of basalt boulders with petroglyph images—Petroglyph National Monument.

The geologic setting of Petroglyph National Monument is comprised of a high terrace where five volcano cones, active in the Pleistocene, rise from the current landscape (Chronic 1987). This terrace known as the Llano de Albuquerque is an upland plain considered to be part of the Santa Fe geologic formation. Volcano cones, Figure 12, of porphyritic basalt emerge from the 76 m thick Ceja Member of interbedded pinkish-gray sandy gravel. The current Llano surface is believed to be middle-Pleistocene in age based on fossil evidence, K-Ar dating of volcanic materials, pedologic dating of soil, geomorphic sequences, and uranium-series dating. The volcanic formations of the Llano de Albuquerque feature at least ten basalt flows of which one flow of olivine basalt has been ascertained to be the oldest at an estimated 190,000 years ± 40,000 years by K-Ar dating (Lambert, Hawley, and Wells 1982:102-3, 117). Kudo (1982:288) describes the rocks of the Albuquerque volcano cones as being comprised of “olivine tholeiite with phenocrysts of plagioclase and olivine and a ground mass composed of opaques, plagioclase, olivine, augite, and low Ca augite and pigeonite.” The volcanic rocks are characterized by lower alkalis, lower $A_{l2}O_3$ and high normative hypersthene. Two pyroxenes are apparent. Soils tend to be “well developed, polygenetic calcic” (Pazzaglia and Lucas 1999:109).

Figure 12. Samples with lichens were removed from boulders in foreground; volcano cones can be seen in background.

The 7,244 acre monument was at one time a remote distance from the New Mexico town of Albuquerque. Today, Petroglyph National Monument is encircled by residential and commercial developments including associated public works infrastructures, such as roadways, that support the surrounding community. Significant levels of air pollution were visually present in and around Albuquerque at the time of this study. Environmental Protection Agency records, however, for the period 1990-1999 indicate that overall averages of pollution counts, though still significant, demonstrate a downward trend in part per million (ppm) levels of carbon monoxide (CO) and nitrous oxide (NO_2). Data for sulphur dioxide (SO_2) levels were not available (Environmental Protection Agency 1999).

Methodology

The collection of core samples for this study was governed by parameters established by the USDI National Park Service, the agency charged with stewardship of the monument. Samples that obviously exhibited lichen growth were taken from near the base of a volcanic cone on the west-side of the monument (Figure 12). The actual removal of core samples follows the protocol described in the General Methodology section. A National Park Service employee was onsite while samples were collected after consultation with appropriate Native American groups. At the request of the National Park Service, the needed comparative samples without lichen were selected from core samples removed from PNM in the 1980s by a University of New Mexico geological research team. Access to this collection of rock core samples was generously extended by Dr. John Geissman, University of New Mexico.

After the core samples with lichen were set in epoxy and cut in half on the vertical axis, they were analyzed for chemical composition using scanning electron microscopy. One sample was then analyzed for mineralogical identification utilizing X-ray diffraction. Samples that did not exhibit lichen growth were not set in epoxy, but were also cut along the vertical axis and analyzed similarly to the comparative samples that displayed lichen growth, i.e., data points from SEM and X-ray powder diffraction (XRD) analyses.

Results

The samples advanced for analysis were labeled 1a for the sample with lichen and 10c for the sample without lichen. Detailed analyses for each sample are found in Appendix A. Observations from SEM data point and XRD analyses are summarized in Table 6.

Table 6. Comparison of Samples From Petroglyph National Monument

Depth	Samples 10c—No Lichen	Sample 1a—Lichen
Surface	Spinel, olivine, alteration products of olivine, clay, chlorite, plagioclase, alumina	Labradorite, augite, pigeonite, spinels, plagioclase feldspars, quartz, olvine, lichen mediated phases
1 mm	Clinopyroxenes, (augite, pigeonite), labradorite, ilmenite, clay	Same as surface plus glass/ground mass
2 mm	Spinels, labradorite, plagioclase, olivine, homeblend, quartz, clinopyroxenes, FeTiO	Ambiguous clay, labradorite, pigeonite, spinels, ilmenite, olivine, clinoproxenes, ilmenite, FeTiO
3 mm	Spinels, labradorite, plagioclase, quartz, olivine, clinopyroxenes (barite), FeTiO	Barite, spinels, olivine, plagioclase, labradorite, clinopyroxenes, ilmenite, FeTiO

Table 6 (continued)

Depth	Samples 10c—No Lichen	Sample 1a—Lichen
Distal end	Labradorite, spinels (magnetite, maghemite), clinopyroxenses, hornblende, olivine, alumina	Labradorite, spinels, magnetite, clinopyroxenes, ilmenite, olivine, hornblende, plagilclase, FeTiO

Sample 10c—No Lichen

The unaltered rock at the distal end of sample 10c exhibits analyses that reflect the development of mineral phases following Bowen's Reaction Series (Figure 7). Easily weathered olivines and clinopyroxenes on the discontinuous branch, and similarly Ca-rich plagioclase (labradorite) on the continuous branch, are present as one would expect. There were detectable amounts of olivine, hornblende, and an unexplained analysis point of alumina. Also at the distal end, the presence of the spinel magnetite was noted. Maghemite is presumably an alteration product of magnetite. Working progressively toward the surface, at the third mm from the surface, point analyses reveal barite, $FeTiO_3$ (ilmenite), plagioclase, and quartz. Spinels are more noticeably present at the 3 mm depth as is an increasing abundance of labradorite. There are phases of plagioclase that are intermediate Ca-Na plagioclase and Na-rich plagioclase. Olivines are still present and clinopyroxenes are more evident. At the second mm from the surface, the changes seen in the mineral assemblage display a greater frequency of hornblende, Na-rich plagioclase, clinopyroxenes, FeTiO and an unexpected appearance of quartz. There are also clinopyroxenes and olivine. Ilmenite appears in the second mm with some amounts of clay.

Alteration from inorganic weathering is in evidence through the presence of iron oxides, alumina, and spinels at the surface. Alteration products of olivine are also present at the surface. From the surface to 1 mm deep there are clinopyroxenes, olivine, plagioclase, alumina, spinel, possible chlorite or serpentine, iron oxide, and other alteration products of olivine. Chlorite is specifically noted in the first mm and down to at least the second mm. Plagioclase is minimally present in the first mm with increasing presence deeper into the sample. The pyroxenes augite and pigeonite are minimally present in the first mm, with increasing abundance in the remainder of the sample. Labradorite (plagioclase feldspar) is noted throughout the sample. Spinel and olivine are present and, in fact, olivine is noticeably present throughout the sample. Some clay is noted at the surface, but not in abundance. At the surface and first mm in sample 10c, some microscopic evidence of lichen growth was found.

Almost all the minerals present in the basalt are readily weathered in the near-surface environment. This is particularly true of the groundmass, which is composed of the same minerals that are present as phenocrysts. Their small size, however, renders them more susceptible to dissolution. Once the ground mass, a significant proportion of phenocrysts, or both, have been replaced or removed, the rock is no longer viable and disintegrates. The thickness of the weathering rind is, therefore, rather slight. Within this thin zone, however, we see that the order of the reaction of minerals follows Bowen’s Reaction Series. Olivine is replaced with chlorite or serpentine first. Pyroxenes and labradorite disappear next. More sodic plagioclase and iron titanium oxides are preserved near the surface. Throughout the sample P, S, Cl, and K are non-existent or minimal in content.

Sample 1a—With Lichen

It is more difficult to define the mineral species present in the sample exhibiting obvious lichen mass. However, XRD analysis supplementing SEM point analyses indicates that at the distal end of the sample labradorite and spinels as well as magnetite are present. Clinopyroxenes and ilmenite are also noted along with olivine. SEM point analyses demonstrate the unaltered aspect of the rock to have olivine, ilmenite, magnetite, pyroxenes, plagioclase, spinels, clinopyroxene, FeTiO, and hornblende. On sample 1a, the unaltered rock is similar to sample 10c in that there is a mineral assemblage that is to be expected for the unaltered rock including Ca-rich plagioclase.

At the third mm from the surface, changes in the mineral assemblage include the appearance of barite and ilmenite while Ca-rich plagioclase remains present. Spinels, olivine, and plagioclase minerals are present. Labradorite is a constant presence throughout the sample. Data points indicating barite, ilmenite, magnetite, olivine, clinopyroxene, plagioclase, and spinels are noted. The mineral assemblage noted in the second mm is not much changed from the third mm. In the second mm, clay minerals are observed along with labradorite, pigeonite, and spinels. Ilmenite is present and olivines are quite noticeable. Analysis points at this depth from the surface reveal plagioclase, quartz, pyroxenes, hornblende, and glass (ground mass) with detectable amounts of P, S, Cl, and K.

Point analyses at the surface and first mm, however, demonstrate interesting changes to the assemblage. Plagioclase remains Ca-rich and indeterminate mineral phases mediated by lichen byproducts are abundantly evident. The presence of P, S, Cl, and K is clear as is the presence of olivine. Labradorite, augite, pigeonite, spinels, and plagioclase feldspars are noted at the surface and first mm. The surface with lichens contains analyses points of plagioclase, olivine, quartz, and mineral phases that cannot be specifically attributed to inorganic weathering, and thus are attributed to the presence of lichens.

Comparison of samples. One of the most notable differences between the lichen sample 1a, and unlichenated sample 10c, is the presence of P, S, Cl and K at the surface on sample 1a. Lack of similar minerals at the surface on sample 10c is indicative of minerals introduced from sources external to the rock matrix, which are being held at the surface by lichens. Atmospheric pollution from the Albuquerque area may account for the presence of these minerals. The continued presence of olivine at the surface on sample la is a conundrum. Olivine generally is one of the most susceptible minerals to weathering, and therefore, it is expected to be among the first minerals to be displaced in the presence of mechanically and chemically induced lichen changes. Ca-rich plagioclase is present throughout sample 1a changing to intermediate Na-Ca composition only at the surface compared to the compositional changes found in sample 10c. This is typical of the changes demonstrated on the continuous branch of Bowen’s Series where Ca-rich plagioclase is displaced by intermediate species (equivalent Na-Ca) then by Na-rich plagioclase at the surface.

At the surface of sample 1a, there are a number of analyses points that are not recognizable as minerals. This anomaly is not similarly present in sample 10c, and therefore the presence of unrecognizable minerals in 1a is attributed to lichen-mediated processes as well as externally introduced elements. Labradorite, identified by XRD analysis, is a plagioclase and is present throughout both samples. Plagioclase is one of the most common rock forming-minerals and thus Ca-rich labradorite presence is not unusual.

On sample 1a the unaltered aspect of the core sample is similar to sample 10c in that there is found a mineral assemblage that is to be expected including Ca-rich plagioclase. Then at the third mm from the surface, changes in the mineral assemblage include the appearance of barite and ilmenite, while Ca-rich plagioclase remains present. The mineral assemblage noted in the second mm is not much changed from the third mm. Point analyses at the surface and first mm, however, demonstrate interesting changes to the assemblage. Plagioclase remains Ca-rich and indeterminate mineral phases mediated by lichen byproducts are abundantly evident. The presence of P, S, Cl, and K is notable as is the presence of olivine.

The presence of quartz in both samples is not what is normally expected in a basalt rock. The probable explanation can be found in Smith et al. who describe melted sandstone inclusions containing “quartz grains in a glass groundmass” (1999:2 13). Therefore, the identification of quartz in both samples and glass in sample 1a are consistent and not attributable to biological processes.

Discussion

At this point, a brief description of mineralogical processes may be helpful in understanding the effects of lichen on the rock surfaces found at Petroglyph National Monument. Mineral classes that are found higher on the branches of Bowen's Reaction Series are more easily weathered than those found lower on both branches. So, on the discontinuous branch, olivine and pyroxenes are more easily weathered than minerals found lower on the Reaction Series (i.e., amphiboles and biotites) (Figure 7). Calcium rich plagioclase, on the continuous branch, will weather more easily than sodium rich plagioclase or orthoclase.

In an oxidizing hydrous environment, $Fe^{3}+$ replaces $Fe^{2}+$ in olivine; and, olivine becomes gelatinous in the presence of acid (Deer, Howie, Zussman 1992). The minerals magnetite, magehemite, augite, and pigeonite are insoluble in most acids. Ilmenite is only slowly soluble in the presence of acid. Labradorite, a plagioclase feldspar, is soluble in acid. Fine-grained chlorite is a clay mineral readily attacked by acid (Deer, Howie, Zussman, 1992).

Rock surfaces that exhibit 'desert varnish' seem to be a highly prized surface in which Native American occupants inscribed glyph images. Several studies have concluded that the dark brown/black desert varnish may have an organic origin. A number of research teams including Dorn and Oberlander 1981; Palmer, Staley, Murray, Counsell, and Adams. 1986; McKeown and Post 2001; and, Perry and Kolb 2003, have concluded that the presence of bacteria is instrumental in the formation of desert varnish in arid and semi-arid environments. Additionally, at least one research team, Liu and

Broecker 2000, have concluded that it takes an average of 1000 years for varnish to be fully formed on a rock surface. At PNM, in particular, desert varnish has developed at the rate of approximately 7.6 microns/1000 years (Liu 1999).

Conclusion

The basalt that comprises the sample area for this research is relatively young on a geological scale. A weathered rind found on samples of basalt for this research is noticeably shallow and may be indicative of ‘desert varnish.’ Atmospheric pollutants are being assimilated by lichen growths and contribute to the mineralogic changes in the rock surface.

Sample 10c (without lichen) has a thin weathered rind in which olivine and Ca-plagioclase are replaced; pyroxenes are absent from the upper part of the rind; Na plagioclase and iron titanium oxide occur throughout. Conversely, sample 1a (with lichen) has Ca-plagioclase and olivine present at all levels. Thus, the rock surface of 1a was not formed by growth of lichens on the surface of a sample like 10c. Lichens have undoubtedly altered the basalt but preservation of easily weathered minerals at the surface of 1a indicates that the lichen-rock interface was initially fresh (unaltered) rock. The lichen mass may have colonized a surface that had just become exposed; or alternatively, the equivalent to the thin weathered rind of 10c was stripped away by lichen metabolic processes.

CHAPTER VI

INTERPRETATION OF ANALYSIS

> First, of course, there's the things you don't know;
> Then there's the things you do know but don't understand;
> There there's the things you do understand but which don't matter.
> -A. E. Coppard, "Simple Simon"

The samples analyzed for this research can be placed in two broad categories. The Wyoming samples and the orthoquartzite from Minnesota are essentially sandstone materials that formed in place. The granite from Australia and the basalt in New Mexico both formed as a result of igneous processes. Though the basic materials of sandstone and igneous formation differ in origination, there are similarities in how lichens affect the surfaces. It is evident that the presence of lichens can be identified by a geochemical footprint that includes the elements of Na, Mg, P, S, Cl, K, Ca, Ti, Cr and/or Ba in varying combinations. In the presence of lichens, minerals present are chelated due, at least in part, to the production of lichenic acids. This is particularly evident in the samples from Wyoming. The release of elemental ions is demonstrated in the loss of manganese on these samples.

In all the samples, desert varnish, or at least a patina, is evident in varying degrees—this is most visually evident on the basalt and least visually evident on the granite. The loss of the weathered surfaces in the presence of lichens may be mediated, at least in part, by the antibacterial properties of lichen compounds (Syers and Iskander 1973). Whether from acids or other lichen metabolites, the result is the same. The presence of lichens at the surface and the introduction of metabolites, through either the aqueous transport of free water, or through hyphae and rhizines, results in lichenic products (presumed to be principally acids) chelating present mineral compounds and complexing them into different phases of existing minerals, or altogether new compounds as the aqueous solute changes the internal rock environment from base to acid or possibly acid to base depending upon the elemental constituents of the rock matrix.

This movement is responsible for redox (oxidation and reduction) environments that force mineral compounds to move from one phase to another such as the alteration of ferrous iron (Fe^{3+}) to ferric iron (Fe^{2+}) (Figure 13). An aqueous environment must be present for the redox process to take place as well as environmental circumstances such as temperature, pressure, or introduction of constituents that force the movement from base to acid (Berthelin 1988; Garrels and Christ 1965). As the aqueous solute passes through the rock mass, leaching of minerals occurs so that when the solute evaporates to the rock surface, the precipitates from the leaching process react with oxygen to form oxides and hydroxides which contribute to a weathered surface. However, the production of a hardened weathered zone requires a significant timeframe of at least 100 years (Liu and Broecker 2000). For desert varnish to form, there is an apparent need for manganese and cyanobacteria to be present at the rock surface (Dorn and Oberlander 1981; Palmer et al. 1986). The lack of manganese at the surface of the NE Wyoming samples exhibiting lichen growths would argue that lichen metabolites are responsible for the loss of the previously hardened surface. This is, in addition to the loss of cements, demonstrated by chemical analysis. To a lesser extent, this situation could also be seen in the other samples but not as dramatically, and it is unclear whether the patina on the granite and orthoquartzite were mediated by the presence of bacteria.

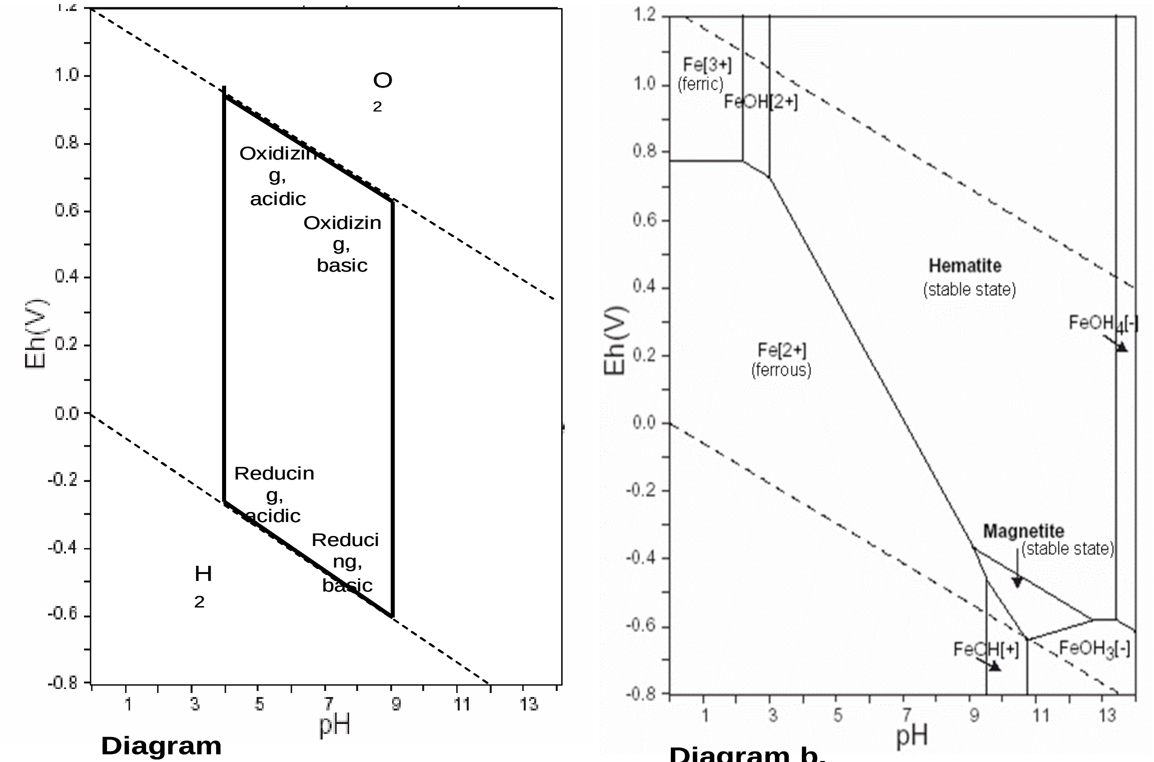

Diagram a.

Diagram b.

Figure 13. Diagram a. Example of oxidation and reduction. Diagram b. Example of Fe^{3+} to Fe^{2+} (after Garrels and Christ 1965).

CHAPTER VII

CONCLUSIONS AND IMPLICATIONS

Conclusions

As already established in the literature, the metabolic processes of lichens affect rock surfaces by mechanically breaking apart grains in the rock matrix and by chemical alteration of minerals present. This research demonstrates that the acids may then be conveyed from the lichen body on the surface into the rock by aqueous transport or possibly through the presence of hyphae or rhizines. As acids are produced by the lichens, minerals in the rock are chelated, that is, the elemental constituents are dissembled. We believe that organic acids then are conveyed, at least in part, through the root-like hyphae and/or rhizine structures. These organic acids attack the least resistant minerals first which include cements and clays. Thus, as these mineral structures are broken apart, microscopic conduits are opened within the rock matrix for hyphae or rhizines to penetrate. As they indurate the rock, the matrix is mechanically disaggregated (Figure 14), and surface material is incorporated in lichen thalli. The chelating process is thus moved ever deeper into the rock structure.

As this process is taking place, chelated minerals are being complexed, i.e., recombining, into new, or rather, different mineral structures that are more erodable than the original rock. This process is in evidence for each rock substrate type in this study. The extent to which lichen hyphae or rhizines penetrate into the rock determines the depth of the lichen-mediated degradation. For example, for the orthoquartzite in this study, which has a very tight structure with comparatively few minerals in the composition and with a high quartz content, the effects of lichens are contained at the surface. In contrast, the rather loosely aggregated sandstone in Torrey Valley, which is easily penetrated by lichen hyphae, demonstrates degradation as deep as 5 mm or more. Thus, the sandstone surface is more highly susceptible to erosive factors.

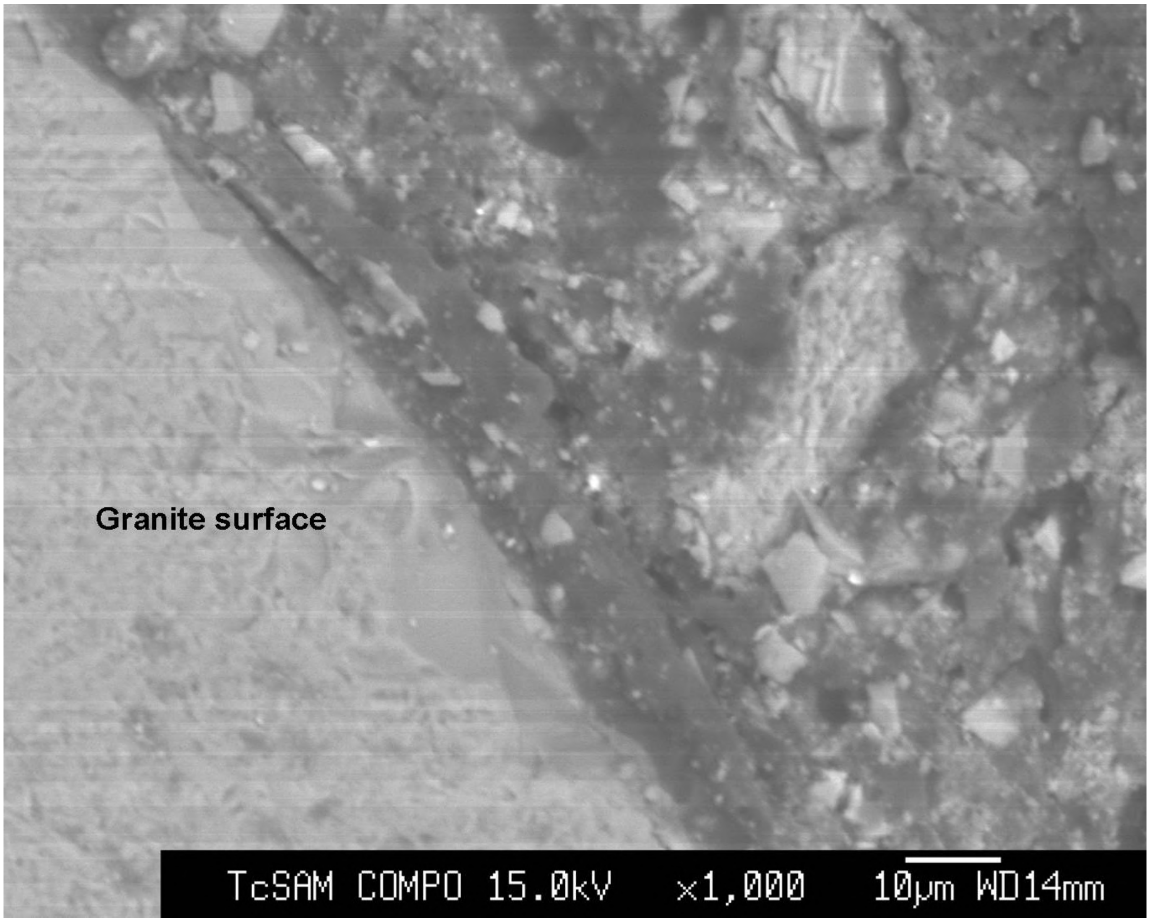

Figure 14. Example of granite surface-lichen interface with rock grains incorporated into lichen thalli. SEM image magnified x1,000 (Geoffrey Bay specimen).

This research has demonstrated that the presence of lichens does indeed facilitate a change in the weathering of rock profiles. The production of acids, other metabolites, and the introduction of those products into the rock surface reacts, in the presence of an aqueous environment, with present minerals through redox processes bringing about the change in the mineralogical constituencies that result in a more erodable surface than one without lichens present. Differential chemical changes are apparent dependent upon the rock substrate and the mineral assemblage contained therein and the presence and amount of moisture present. The chelation and complexing of minerals in the presence of lichens was evident in all the samples analyzed for this study. The manner in which the chelation process is facilitated is dependent upon the rock type and mineral make-up as well as the local environment. Factors such as anthropogenically introduced pollutants either from industrial manufacturing, agricultural applications, or simply increased particulates from dust can be taken up by lichens and incorporated into their metabolism Pollutants are thus reintroduced to the rock matrix in a different form such as organic acids. The chemistry of the unaltered rock can provide a medium in which the redox process takes place influencing phase changes in mineral compounds that may result in minerals less resistant to erosion. It is highly evident that the presence of lichens will influence the loss of desert varnish or other surface patina on rock surfaces by mediating the oxidized surface to a less consolidated medium (through mechanical disaggregation of the surface and chemical alteration) that is more susceptible to erosion while providing a more desirable host environment for lichens.

Practical Implications for Conservators and Managers

The present research, as well as past studies, establishes the degenerative effects that lichens have on rock surfaces. Rock art site managers and rock art conservators can apply this knowledge to develop informed decisions regarding the issue of treating lichens that are infringing on irreplaceable ancient rock art images. The decision of whether or not to remove lichens needs to be undertaken thoughtfully within the context of management objectives established for a site. Should lichens be treated with the intent of removing the biome for either recording or visitor viewing, the long-term consequences must be considered. Lichenic processes work on a microscopic scale both degrading the rock surface while at the same time providing a means to protect the now-weakened surface from erosive natural effects such as wind and rain. In instances where lichens have been removed from rocks, there is an obvious visual difference between the treated surface and adjacent untreated surfaces. Some observers remark that the surface formerly occupied by lichens has a ‘clean’ appearance, meaning that it is lighter in color than the surrounding surfaces (Figure 15). Indeed, this can be accurate in that the newly exposed surface is fresh rock, or rather, a surface that is now destabilized since lichen processes have chemically and mechanically reduced the surface that previously was in equilibrium (metastable) with the environment. The naturally metastable surface that was resistant to erosion is reduced to a more vulnerable state susceptible to loss that will likely proceed at a rate faster than the surrounding surfaces. At what rate this differential erosion will take place is a difficult question to answer as it depends on local environmental factors.

Figure 15. Example of “clean” appearance after lichen has been removed from the rock surface with tweezers.

Decisions to treat lichens must be made within the context of a holistic management schema. The first consideration is to define the objective in treating lichens. There may be several reasons, but typical reasons are: (a) recordation, (b) research objectives adjunct to recordation, and (c) enhanced visitor viewing.

If rock surfaces are treated to remove lichen growths, then activities to thoroughly document and record the glyph images *must* be in place *prior* to treating lichens. Protection of the newly exposed fresh rock surface must be considered. While there are, as yet, no satisfactory methods of rock surface consolidation, other techniques may be considered to at least limit the potential for accelerated loss. If the rock art is to be made available for visitor viewing, ensure that visitors are discouraged from touching the rock surface. Passive actions such as providing walking or viewing trails that are well marked and distanced so that visitors cannot touch the rock surface should be considered along with visually unobtrusive barriers such as low rails or buck and pole fencing. Trails should include interpretation that encourages photography and discourages rubbings, tracings, molds, etc.

Managers also need to consider the physical environment and give thought to those factors that encourage the growth of lichens with the objective of preventing or at least limiting growth. Lichens, like all living organisms, need water and nutrients to thrive. Modifications to the immediate environment should be considered so as to constrain regrowth. The ideal solution is one that inhibits regrowth or prevents initial colonization. Actions such as removing vegetation, which enhances moisture retention, should be considered especially if such vegetation is not indigenous to the environment or was not historically present. If natural resource habitat enhancements for other resources, such as livestock needs, are proposed that could increase moisture retention and/or vegetation cover (e.g., stock tanks, ponds for wildlife, vegetative species for grazing, etc.), or that will add to atmospheric particulates, then consideration should be given to placing such developments outside of a zone that directly affects rock art images.

The following is a summary of recommendations when lichens are considered for removal from rock surfaces.

1. What are the reason(s) for lichen removal? Is the risk of loss greater than the immediate desire to see glyph images beneath lichen growths?

2. DO NOT treat lichen growths with chemicals such as Lysol or bleach.
3. DO NOT scrub rock surface with wire brushes.
4. Prior to removal and immediately after removal of lichens, record all petroglyphs or pictograph images in detail.
5. Establish regular photo monitoring of the site to immediately assess any deterioration.
6. Protect the newly exposed surface, if possible, such as keeping visitors from touching the newly exposed and unstable surface(s).
7. Implement onsite landscape modifications that discourages lichen growth.
8. Develop proactive management plans.
9. Encourage and support research.

Managers should give serious consideration to preventing the growth and/or spread of lichens. While this may be an impossible mission since little is known about why and how the lichen symbosis occurs, landscape modifications as mentioned above may be helpful. Paying attention to the onset of lichen growth and assessing the immediate environment for modifications that will make the environment less hospitable in terms of moisture and ambient sources of nutrients, such as dust, may help at least slow lichen growth. Supporting research that considers the use of toxic amounts (toxic to lichens not humans) of minerals such as silica to the rock surface should be given serious consideration. Silica is suggested as it is not likely to adversely affect known dating techniques; it is not toxic to humans; and while it may be toxic to lichens in saturated solution, it is not toxic to the environment. Most importantly, the rock surface will still retain expansion and contraction capabilities without spalling. Use of silanes to consolidate native stone surfaces requires additional research (Grisafe and Nickens 1991; Miller 2001).

However, additional research is clearly indicated in a number of areas. Methods to record rock art images for research without removing lichens needs to be addressed. Technology such as infrared photography, portable X-ray devices, or technology that utilizes sound waves that could facilitate the researcher's need to know without contributing to the loss of images is essential. More managers must consider and implement modifications to onsite environmental conditions to successfully discourage colonization of rock surfaces. However, since a biological connection to a metastable weathered surface has been established in the scientific literature, due consideration to the long-term consequences of environmental alterations to inhibit microbiological growths such as lichens would be of paramount importance. Additional study into applied treatments that will kill lichens at the surface and the subsurface is needed so as to limit potentially harmful chemical reactions with rock substrates. Giving consideration to removing life-giving elements by the using chemicals such as ethanol (Bjelland 2005) needs additional assessment. Alternative means of visually presenting rock glyph images to the interested public should be explored. Providing virtual three-dimensional electronic representations in off-site venues can help to satisfy the curiosity of the viewing public while alleviating use that inadvertently may foster lichen growth.

Lichens are a ubiquitous presence having exceptional capability to adapt, survive, and thrive. Conserving irreplaceable ancient rock images for the information they can provide about past life ways and providing an enriching experience for thoughtful visitors in the presence of this remarkably resilient biome is a challenge for managers and conservators. Best management practices must be devised that consider the preservation of the potential knowledge rock art images can provide if not the images themselves.

The following is a glossary of terms pertinent to this study:

Adsorption – adherence of ions in solution to the surface of solids with which they are in contact.

Chelation and complexation – retention of a metallic ion by two atoms of a single organic molecule; decomposition or disintegration of rocks or minerals resulting from the action of organism or organic substances.

Crustose lichens – a type of lichen species that adheres tightly to the substrate and does not have a lower cortex attaching itself to the substrate by hyphae from the medulla (Jahns 1973:21).

Diagenesis – any change occurring within sediments subsequent to deposition and before complete lithification that alters the mineral content and physical properties of the sediments (Thrush 1968:320).

Eh – oxidation potential; Eh-pH diagrams are useful for summarizing. chemical information and for making predictions about reactions and associations among minerals.

Erosion – materials are worn away and simultaneously moved elsewhere

Felsic – igneous rock having abundant light-colored minerals, i.e., quartz, feldspars, muscovite.

Fixing – the process of stabilizing, in the solid products of metabolism, elements derived from aqueous (rain) or atmospheric (dust, etc) sources.

Front – metamorphic zone of changing mineralization developed outward from an igneous mass (Bates and Jackson 1980:247).

Groundmass – material between the phenocrysts of a porphyritic igneous rock; relatively fine grained and may be crystalline, glassy or both (Bates and Jackson 1980).

Hypersthene basalt – a common rock forming mineral of the orthopyroxenes group (Mg,Fe)SiO; specifically, basalt that is silica-saturated without quartz or olivine.

Hyphae – fungal filaments which help secure the lichen body to a substrate; and which may or may not serve as a conduit for nutrients and/or water (after Jahns 1973 and St. Clair 1999).

Interstitial – mineral deposit in which minerals fill the pores of the host rock.

Leaching – separation or dissolving-out of soluble constituents from a rock by the natural action of percolating water.

Metastable minerals – substances, or mixtures of substances, that react very slowly or are apparently stable (Krauskopf 1967:22).

Modal – adj. of mode; actual mineral composition of a rock; the most typical observation (Bates and Jackson 1980).

Phenocrysts – relatively large, conspicuous crystal in porphyritic rock (Bates and Jackson 1980).

Plutonic rocks - igneous rocks formed at great depth by crystallization of magma and/or chemical alteration.

Precipitate - separation of a solid phase in an aqueous solution.

Redox potential – measure of the ability of an environment to supply electrons to an oxidizing agent, or to take up electrons from a reducing agent; determined by the number of reactions.

Reduction – in general, a gain in electrons, versus a loss of electrons as in oxidation.

Rhizines – root like structure produced primarily on the lower surface of foliose lichens which may or may not serve as a conduit for nutrients and/or water (after Jahns 1973; and St. Clair 1999).

Silastic – silicone rubber

Squamulose lichens – intermediate form between crustose and foliose lichens. Elongated lobes can be attached to the substrate by the entire lower surface or the margin may be free and ascending (Jahns 1973).

Stable mineral – a mineral that coexists in equilibrium with other minerals and chemical compounds (Wenk and Bulakh 2004:290); one that does not react readily in a particular environment; i.e. stable with respect to equilibrium (Krauskopf 1967:21).

Sulfide – mineral compound characterized by the linkage of sulfur with a metal or semi-metal.

Sustainability – development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (Brundtland 1987).

Weather – to undergo changes brought about by exposure to the atmosphere

Weathering – process(es) by which rocky materials on exposure to atmospheric agents at or near the Earth's surface are changed in color, texture, composition, or form with little or no transport of the altered material.: destructive process by which rocky material on exposure to atmospheric agents are changed in color, texture, composition, firmness, or form … specifically the physical disintegration and chemical decomposition of rock (Bates and Jackson 1980).

Xenoliths – a foreign inclusion in igneous rock (Bates and Jackson 1980)

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APPENDIX A

SPECIFIC DATA POINT ANALYSES

NEWy2bL ich	Al	Ca	Cl	Cu	Fe	K	Mg	Mn	Na	P	Si	S	V	Ti	Cr
1 Srf/lich	5.50	0.44	nd	0.40	57.10	nd	0.57	nd	0.54	0.78	4.40	nd	1.20	nd	nd
2 Srf/lich	12.90	0.34	nd	nd	37.20	nd	0.21	nd	nd	1.40	10.50	nd	0.70	nd	nd
3 Srf/lich	7.90	0.54	nd	nd	51.90	nd	0.40	nd	nd	0.87	6.90	nd	nd	0.13	nd
4 Srf/lich	3.60	0.86	0.15	nd	59.60	nd	0.80	nd	nd	0.64	3.70	0.18	2.31	nd	nd
5 srf/lich	4.20	0.39	0.12	nd	61.70	nd	0.40	nd	nd	0.89	2.90	0.25	1.44	nd	nd
6 Srf/lich	4.30	0.43	0.33	0.82	49.30	0.40	0.70	nd	0.50	0.88	3.97	0.16	nd	7.60	0.38
7 Srf/lich	3.10	0.39	0.04	nd	66.50	0.02	0.40	nd	nd	1.10	1.75	0.90	nd	0.11	0.40
8 Srf/lich	5.70	0.46	0.14	nd	59.40	0.10	0.40	nd	nd	0.81	3.70	0.33	nd	0.21	0.32
9 Matrix	nd	nd	nd	nd	0.50	nd	nd	nd	nd	nd	46.60	nd	nd	0.04	nd
10 gy area	13.20	0.31	0.29	0.30	26.20	0.12	nd	nd	nd	0.30	18.20	nd	nd	0.18	0.11
11-1mm	nd	nd	0.17	nd	nd	nd	nd	nd	nd	nd	46.70	nd	nd	nd	nd
12-2mm	nd	nd	0.10	nd	nd	nd	nd	nd	nd	nd	46.70	nd	nd	nd	nd
13 """""	nd	nd	0.27	0.60	nd	nd	nd	nd	0.25	nd	46.10	nd	nd	nd	nd
14-3mm d	1.60	nd	1.50	10.20	nd	nd	3.10	nd	nd	nd	35.90	0.37	nd	nd	nd
15 """"""	nd	nd	0.22	0.41	nd	nd	0.20	nd	nd	nd	46.20	0.03	nd	nd	nd
16 """"""	31.20	nd	nd	7.80	nd	nd	0.70	nd	nd	nd	14.10	nd	nd	nd	nd
17-bottom	15.60	nd	0.44	0.50	3.70	7.40	1.96	nd	0.84	nd	23.70	nd	nd	0.45	nd
18 """"""	13.70	nd	0.14	nd	25.50	0.50	2.04	nd	0.53	0.54	15.80	0.25	nd	0.44	nd
19 """"""	12.60	0.45	0.50	nd	7.40	2.20	1.20	nd	nd	nd	28.30		nd	0.26	nd

NEWy2a NoLichen	**Al**	**Ca**	**Cl**	**Cu**	**Fe**	**K**	**Mg**	**Mn**	**Na**	**P**	**Si**	**S**	**Zn**	**Ba**	**Ti**
1 GySpot	nd	59.80	nd	nd	nd	nd	0.40	nd	nd	0.30	6.60	0.30	nd	nd	nd
2 Spt Srf	nd	0.30	nd	nd	nd	nd	0.10	nd	nd	nd	46.50	nd	nd	nd	nd
3 Spt Srf	4.70	nd	nd	nd	9.80	nd	0.40	nd	nd	0.10	22.70	4.50	nd	15.90	nd
4 Grvly Spt	12.90	2.90	nd	nd	nd	0.90	1.40	nd	nd	nd	24.50	nd	nd		nd
5 Matrix	nd	nd	0.99	nd	nd	nd	0.12	nd	nd	0.13	98.80	nd	nd	nd	nd
6 Matrix	nd	nd	0.99	nd	nd	nd	0.12	nd	nd	0.13	98.80	nd	nd	nd	nd
7-1mm dwn	1.60	nd	1.40	nd	2.50	nd	1.30	nd	0.20	nd	93.20	nd	nd	nd	nd
8-gy blob	nd	69.30	nd	nd	nd	nd	0.72	nd	nd	nd	0.88	nd	nd	nd	nd
9 gy blob	7.80	1.00	nd	nd	16.90	0.65	nd	nd	0.30	nd	26.80	1.10	nd	nd	nd
10 Matrix	nd	nd	0.50	1.10	nd	nd	0.30	nd	0.70	nd	45.20	nd	nd	nd	nd
11 Gy Blob	1.80	0.61	1.40	9.10	0.67	nd	2.60	nd	3.60	nd	33.50	0.60	nd	nd	nd
12 """""	14.10	nd	nd	nd	nd	3.90	1.80	nd	0.96	nd	29.90	0.93	nd	nd	nd
13 mid-btm	0.83	nd	nd	20.10	19.30	1.20		nd	nd	nd	14.10	nd	13.50	nd	nd
14 dk gy	2.50	0.75	8.10	14.80	2.30	0.91	1.50	nd	nd	nd	22.50	1.20	8.20	nd	nd

WyTV 1a, cross sec, lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
1 Lichen, surf	nd	nd	20.1	80.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2 lich/rock interface, surf	nd	nd	nd	52.5	nd	nd	nd	13.3	nd	nd	nd	34.1	nd	nd	nd	nd	nd	nd	nd
3 fluffy stuff, surf	nd	nd	nd	78.0	nd	nd	nd	21.1	nd	nd	nd	1.4	nd	nd	nd	nd	nd	nd	nd
6 lichen hyphae, surf	nd	nd	7.0	75.0	nd	nd	nd	8.4	nd	nd	nd	1.0	nd	nd	nd	nd	nd	nd	nd
pt 7, surf	2.6	nd	8.0	63.0	nd	5.3	3.0	10.0	9.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
10 br arc lich hyp, surf	11.0	nd	12.5	22.0	nd	15.0	13.4	18.0	8.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
11 br arc lich hyp, surf	nd	nd	15.2	38.1	nd	6.0	10.0	23.5	7.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt 12, surf	4.2	nd	4.6	60.0	nd	5.0	8.0	8.0	7.1	nd	nd	4.0	nd	nd	nd	nd	nd	nd	nd
pt13, surf	5.5	2.0	6.4	64.5	nd	4.8	2.3	7.2	7.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
14 dk mass between grains Si, surf	nd	nd	9.0	75.0	nd	nd	2.0	12.0	nd	nd	nd	3.0	nd	nd	nd	nd	nd	nd	nd
15 dk mass between grains Si, surf	nd	nd	14.1	60.4	nd	nd	4.1	17.2	nd	nd	nd	4.4	nd	nd	nd	nd	nd	nd	nd
pt 16, surf	nd	nd	6.0	26.0	nd	25.0	3.0	7.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Epofix, surf	nd	nd	nd	nd	nd	nd	79.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
16a new analy sec, surf	nd	nd	nd	26.0	nd	3.0	3.0	1.6	3.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt17, surf	nd	nd	2.1	27.0	nd	nd	nd	3.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
19 ltgry bridge between grains Si, surf	6.3	3.2	2.2	13.3	nd	7.3	2.1	nd	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
20 med gry blade, surf	10.3	5.0	2.4	8.1	nd	7.5	3.2	nd	6.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
21 br spot, surf	4.4	nd	nd	21.3	nd	3.4	nd	nd	3.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
22 br spot, surf	2.5	0.8	0.9	27.0	nd	1.8	nd	nd	2.0	nd	nd	0.6	nd	nd	nd	nd	nd	nd	nd
23 zircon, surf	nd	nd	1.0	16.0	14.0	nd	nd	nd	0.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
24 dk gry mass between grain Si, surf	nd	nd	nd	31.0	nd	nd	4.1	1.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
25 dk gry mass between grain Si, surf	nd	nd	nd	19.1	nd	nd	22.0	nd	11.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 1a, cross sec, lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
26 new area, br spot, surf	nd	nd	3.1	12.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	11.5	nd	nd	nd	nd	nd
4.11 pt 10 sm round spot, surf	nd	nd	12.7	22.2	nd	nd	nd	0.3	nd	nd	nd	0.7	nd	nd	nd	nd	nd	nd	nd
pt11 dk black areas between grains, surf	nd	nd	nd	32.5	nd	nd	1.5	nd	0.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt12 bright grey spot bridging between med gry grains, surf	nd	1.3	2.2	29.4	nd	nd	nd	1.3	0.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt13 med grey smudge, surf	nd	nd	nd	33.0	0.1	0.1	0.0	nd	0.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt14 dk black area between grains, surf	nd	nd	6.1	24.8	nd	nd	4.9	3.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt15 Band of more loosly consolidated grains - dk blk area between grains	nd	nd	nd	15.8	nd	nd	nd	nd	6.2	nd	nd	20.2	nd	nd	nd	nd	nd	nd	nd
pt16 Band med gry grainy areas	2.7	1.4	1.2	29.8	nd	nd	nd	0.4	nd	nd	nd	0.3	nd	nd	nd	nd	nd	nd	nd
pt17 Band same as above	0.9	0.6	0.7	12.4	nd	1.0	nd	2.0	25.1	nd	nd	0.6	nd	nd	nd	nd	nd	nd	nd
pt18 Band med gry grain in midle of black area	nd	nd	nd	31.7	nd	nd	nd	nd	2.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt19 gry granular area in dk black area	nd	nd	nd	11.3	nd	nd	nd	1.6	31.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt20 Band med gry meander	nd	nd	0.7	28.7	nd	2.0	nd	nd	2.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt21 3 mm from surf oval bright spot	nd	1.0	8.2	15.3	nd	4.1	nd	2.6	4.6	nd	nd	1.1	nd	nd	nd	nd	nd	nd	nd
pt22 3 mm from surf med gry area adjacent to oval spot above	nd	nd	nd	0.9	nd	15.9	nd	nd	16.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt23 3mm from surf grey grain	nd	nd	nd	23.4	nd	5.1	nd	nd	4.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt24 3mm from surf	nd	2.5	nd	5.9	nd	0.4	nd	nd	37.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 1a, cross sec, lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
pt25 3mm from surf calcium sulphate - gypsum	nd	0.2	nd	6.4	nd	12.8	nd	nd	14.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt26 bright oval smudge appx 2mm from surface	nd	nd	nd	2.5	nd	nd	nd	nd	nd	30.9	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt27med grey grain 2mm from surf	nd	nd	nd	33.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt28 uncon grain 2 mm from surf	nd	nd	7.4	22.9	nd	0.3	nd	7.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt29 lt gry grain 2 mm from surf	nd	nd	4.5	27.2	nd	nd	nd	4.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt30 sm oval lt gry grain 2 mm from surf	1.8	1.2	5.8	23.4	nd	0.9	nd	2.3	0.8	nd	nd	0.8	nd	nd	nd	nd	nd	nd	nd
pt31 uncon grain 2 mm from surf	nd	nd	7.2	22.9	nd	0.4	nd	7.3	0.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt32 nest lt gry unconsold 2 mm from surf	4.2	2.2	5.1	16.5	1.3	nd	nd	0.4	1.0	nd	1.5	8.6	nd	nd	nd	nd	nd	nd	nd
pt33 dk blk area 2 mm from surf	nd	nd	nd	10.3	nd	nd	nd	nd	34.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt34 br spot 2 mm from surf	nd	1.6	4.4	16.3	nd	nd	nd	nd	0.9	nd	4.8	12.8	nd	nd	nd	nd	nd	nd	nd
pt35 br spot 2 mm from surf	nd	nd	1.2	19.4	nd	nd	nd	nd	nd	1.0	nd	nd	nd	14.5	nd	2.4	nd	nd	nd
pt36 br spot 2 mm from surf	4.6	2.4	4.0	15.4	nd	nd	nd	nd	0.9	nd	3.9	11.1	nd	nd	nd	nd	nd	nd	nd
4/12 last 1 mm													nd						nd
pt1 last 1mm	0.4	nd	7.3	23.3	nd	nd	nd	7.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt2 last 1mm	nd	9.5	nd	24.6	nd	0.3	nd	nd	0.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt3 last 1 mm	nd	nd	6.9	23.3	nd	nd	nd	8.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt4 last 1mm	nd	nd	10.6	24.4	nd	nd	nd	0.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt5 last 1mm	0.7	1.8	1.9	7.3	nd	nd	nd	nd	nd	19.2	nd	5.3	nd	nd	nd	nd	nd	nd	nd
pt6 last 1mm	nd	nd	6.9	23.1	nd	nd	nd	7.5	nd	nd	nd	0.1	nd	nd	nd	nd	nd	nd	nd
pt7 last 1mm	nd	nd	7.4	23.4	nd	nd	nd	7.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt8 last 1 mm	nd	nd	1.2	7.5	nd	nd	nd	0.6	nd	24.0	nd	0.8	nd	nd	nd	nd	nd	nd	nd

WyTV 2bs - no lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
Pt1 rutile & apatite surface	nd	nd	nd	0.6	0.8	nd	nd	nd	1.5	30.8	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt2 matrix	nd	nd	nd	33.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt3 surface	nd	nd	8.4	22.6	nd	nd	nd	4.2	0.5	nd	nd	2.1	nd	nd	nd	nd	nd	nd	nd
pt 4 surface	nd	0.6	9.4	19.1	0.8	nd	nd	2.7	0.6	0.6	nd	4.1	nd	nd	nd	nd	nd	nd	nd
pt 5 <1 mm below surf	0.8	1.2	8.0	16.7	2.9	nd	nd	2.3	5.3	nd	nd	0.9	nd	nd	nd	nd	nd	nd	nd
pt6 <1mm below surf	0.9	0.7	2.8	29.0	nd	nd	nd	1.1	0.6	nd	nd	0.3	nd	nd	nd	nd	nd	nd	nd
pt7 <1mm below surf	nd	0.8	7.2	17.1	1.7	nd	nd	3.1	4.6	nd	nd	4.7	nd	nd	nd	nd	nd	nd	nd
pt8 tiny zircon <1mm below surf	nd	nd	nd	20.3	1.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	10.9	nd	nd	nd	nd
pt9 br spot <1mm below surf	nd	nd	0.7	19.9	nd	5.7	nd	0.3	0.6	nd	nd	nd	nd	nd	nd	nd	7.5	nd	nd
pt10 <1mm below surface	0.5	nd	7.4	22.7	nd	nd	nd	8.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt11 <1mm below surf	nd	1.1	9.0	21.4	nd	nd	nd	4.7	0.8	nd	nd	1.3	nd	nd	nd	nd	nd	nd	nd
pt12 <1mm below surf	nd	nd	10.1	17.9	nd	3.1	nd	0.3	0.3	nd	nd	nd	nd	nd	nd	nd	3.9	nd	nd
pt13 lt gry grains <1mm below	nd	nd	7.1	23.4	nd	nd	nd	8.0	0.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt14 <1mm below surf	0.4	nd	7.4	22.9	nd	nd	nd	8.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt15 <1mm below surf	1.3	1.5	8.0	21.0	0.8	nd	nd	3.5	1.4	nd	nd	0.6	nd	nd	nd	nd	nd	nd	nd
pt16 <1mm below surf	0.2	nd	7.5	22.9	nd	nd	nd	8.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt17 <1mm below surf	nd	nd	6.1	18.6	3.2	nd	nd	1.9	6.3	nd	nd	1.2	nd	nd	nd	nd	nd	nd	nd
pt18 <1mm below surf	nd	nd	7.5	23.1	nd	nd	nd	8.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt19 <1mm below surf	nd	0.9	7.0	16.9	3.5	nd	nd	2.0	6.3	nd	nd	1.1	nd	nd	nd	nd	nd	nd	nd
pt20 <1mm below surf	nd	nd	8.9	16.5	nd	3.7	nd	0.6	0.8	3.7	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt21 <1mm below surf	nd	nd	7.5	23.1	nd	nd	nd	8.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt22 band plus 1mm	nd	13.3	nd	22.6	nd	0.7	nd	nd	1.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt23 plus 1mm	nd	nd	7.3	23.2	nd	nd	nd	6.8	1.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt24 plus 1mm	nd	13.2	nd	21.5	nd	1.6	nd	nd	1.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 2bs - no lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
pt25 plus 1mm	nd	0.4	6.6	22.1	1.2	nd	nd	6.2	1.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt26 br spot plus 1mm	nd	1.5	3.0	23.0	nd	2.8	nd	1.2	1.2	nd	nd	nd	nd	nd	nd	nd	2.6	nd	nd
pt27plus 1mm	nd	0.9	3.7	20.4	4.0	nd	nd	1.0	6.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt28 plus 1mm	nd	nd	16.9	19.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt29 plus 1mm	nd	nd	7.3	22.8	nd	nd	nd	8.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt30 plus 1mm	nd	nd	7.8	21.4	nd	2.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3.0	nd	nd
pt31 plus 1mm	nd	0.5	6.0	24.3	nd	nd	nd	5.5	1.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt32 plus 1mm	nd	1.4	6.6	17.9	3.7	nd	nd	1.6	5.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 1b - no lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
pt1 surf	nd	1.3	9.5	16.3	1.3	nd	nd	1.7	nd	0.3	nd	8.3	nd	nd	nd	nd	nd	nd	nd
pt2 surf	2.2	0.5	7.8	16.1	1.8	nd	nd	0.5	1.1	0.5	2.7	5.8	nd	nd	nd	nd	nd	nd	nd
pt3 surf	1.0	1.4	10.0	17.8	0.3	nd	nd	2.5	0.2	0.3	nd	5.5	nd	nd	nd	nd	nd	nd	nd
pt4 surf	-0.1	0.2	1.4	31.6	0.2	nd	nd	0.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt5 surf	nd	0.8	8.3	24.2	.51.2	nd	nd	nd	0.3	0.2	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt6 surf	nd	0.4	2.5	30.6	0.2	nd	nd	0.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt7 surf	nd	0.4	2.5	30.6	0.2	nd	nd	0.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt8 surf	nd	nd	nd	33.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt9 surf	1.6	1.9	10.9	17.1	0.5	nd	nd	0.9	0.3	0.4	1.1	4.1	nd	nd	nd	nd	nd	nd	nd
pt10 surf	1.3	0.9	4.0	25.8	0.3	nd	nd	0.6	0.2	0.2	0.9	2.1	nd	nd	nd	nd	nd	nd	nd
pt11 surf	1.6	1.8	8.0	14.0	0.9	nd	nd	0.9	1.1	nd	7.5	5.2	nd	nd	nd	nd	nd	nd	nd
pt12 surf	2.2.	nd	9.4	11.3	0.9	nd	0.2	0.9	1.4	nd	10.7	3.2	nd	nd	nd	nd	nd	nd	nd
pt13 surf	2.7	0.9	8.3	18.9	0.7	0.3	nd	0.7	0.6	nd	2.8	2.4	nd	nd	nd	nd	nd	nd	nd
pt15 surf	1.2	1.2	8.4	16.7	0.5	nd	0.4	1.1	0.7	0.4	3.7	5.4	nd	nd	nd	nd	nd	nd	nd
pt16br spot surf	nd	nd	4.9	nd	nd	nd	nd	nd	nd	28.4	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt17 at surface	nd	0.8	10.2	18.3	nd	nd	nd	1.9	0.7	0.3	2.1	4.4	nd	nd	nd	nd	nd	nd	nd
pt18 at surface	1.5	1.8	7.9	15.3	1.0	nd	0.2	0.9	1.1	nd	4.5	6.1	nd	nd	nd	nd	nd	nd	nd
pt19 at surface	1.2	1.9	9.2	14.1	1.2	nd	nd	0.8	0.8	nd	2.6	8.5	nd	nd	nd	nd	nd	nd	nd
pt20 surf	nd	1.2	11.5	15.6	1.1	nd	nd	1.5	0.6	nd	2.5	4.9	nd	nd	nd	nd	nd	nd	nd
pt21 surf	nd	1.0	9.6	13.4	1.6	nd	nd	1.2	0.8	0.3	1.4	10.6	nd	nd	nd	nd	nd	nd	nd
pt22 surf	nd	nd	9.6	6.4	2.1	0.3	nd	nd	1.4	nd	13.5	9.2	nd	nd	nd	nd	nd	nd	nd
pt23 br spot <1/2 mm from surf	nd	nd	2.9	17.9	1.6	nd	nd	nd	1.0	0.3	7.2	8.0	nd	nd	nd	nd	nd	nd	nd
pt24 lt gry globs 1st mm	nd	nd	7.4	22.8	nd	nd	nd	8.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt26n lt gry globs 1st mm	0.5	nd	7.7	22.9	nd	nd	nd	7.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt27 br spt 1st mm	nd	nd	0.5	1.1	nd	nd	nd	nd	nd	31.8	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt28	nd	nd	nd	16.1	14.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt29 br spot 1st mm	19.7	nd	nd	nd	nd	6.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	7.7	nd	nd
pt30 bri spot 1st mm	nd	0.5	1.8	19.1	nd	4.4	nd	0.7	0.4	nd	nd	0.8	nd	nd	nd	nd	8.1	nd	nd
pt30a br spot 1st mm	nd	nd	1.6	14.4	nd	7.1	nd	0.4	1.3	nd	nd	0.6	nd	nd	nd	nd	10.1	nd	nd

WyTV 1b - no lichen	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Co	Cu	Zr	Sn	Ba	La	Ce
pt31 br spot 1 mm	nd	nd	0.5	13.0	nd	nd	nd	nd	12.0	11.9	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt32 br spot 1st mm	nd	3.8	nd	14.3	nd	8.1	nd	nd	0.6	nd	nd	nd	nd	nd	nd	nd	8.0	nd	nd
pt33 bri spot 1st mm	nd	nd	nd	14.1	nd	9.0	nd	nd	0.9	nd	nd	nd	nd	nd	nd	nd	9.8	nd	nd
pt34 2.5mm below surf - band	nd	nd	nd	15.3	nd	nd	nd	nd	0.9	nd	nd	nd	nd	nd	17.4	nd	nd	nd	nd
pt35 2.5 mm below surf	nd	nd	nd	nd	nd	nd	nd	nd	50.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt36 2.5 mm below surf	nd	nd	nd	1.2	nd	nd	nd	nd	48.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt37 2.5 mm below surf	nd	nd	nd	26.6	5.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt38 2.5 mm below surf	nd	nd	7.2	23.1	nd	nd	nd	8.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt39 2.5 mm below surf	nd	nd	nd	nd	nd	nd	nd	nd	50.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt40 2.5 mm below surf	nd	nd	7.7	23.0	nd	nd	nd	7.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt41 2.5 mm below surf	0.9	nd	7.1	22.8	nd	nd	nd	7.2	0.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt42 2.5 mm below surf	nd	nd	6.6	23.5	nd	nd	nd	8.6	0.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt43 2.5 mm below surf	nd	nd	nd	1.0	nd	nd	nd	nd	48.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt44 2.5 mm below surf	nd	nd	nd	0.6	nd	nd	nd	nd	49.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt45 2.5 mm below surf	nd	nd	8.9	10.3	nd	4.5	nd	nd	10.7	nd	nd	nd	nd	nd	nd	nd	4.0	nd	nd
pt46 3-5 mm below surf	nd	nd	nd	0.8	nd	nd	nd	nd	nd	17.9	1.2	20.8	nd	nd	nd	nd	nd	nd	nd
pt47 3-5 mm below surf	nd	nd	7.1	22.4	nd	nd	nd	8.4	1.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt48 3-5 mm below surf	nd	nd	0.3	1.6	nd	nd	nd	nd	47.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt49 3-5 mm below surf	nd	nd	nd	2.9	nd	18.1	nd	nd	nd	nd	nd	9.5	nd	nd	nd	nd	nd	nd	nd
pt50 3-5 mm below surf	nd	nd	1.7	15.4	nd	7.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	9.0	nd	nd
pt51 3-5 mm below surf oval gry grain	0.5	nd	7.6	22.9	nd	nd	nd	7.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt52 irreg oval, 3-5	0.4	nd	7.3	22.8	nd	nd	nd	8.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt53 irregular shape, 3-5	nd	0.6	0.3	0.8	nd	nd	nd	nd	47.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt54 bri spot, 3-5	nd	nd	nd	31.7	nd	0.8	nd	nd	nd	0.7	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt55 bri spot, 3-5	1.5	1.0	12.2	19.6	nd	nd	nd	3.7	nd	nd	nd	0.4	nd	nd	nd	nd	nd	nd	nd
pt56 gry irreg shape, 3-5	nd	nd	7.5	22.9	nd	nd	nd	8.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt57 nest of irg blobs, 3-5	0.4	nd	7.4	22.9	nd	nd	nd	8.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 1b - no lichen	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Co	Cu	Zr	Sn	Ba	La	Ce
pt58 irreg gry shape, 3-5	nd	nd	nd	1.8	nd	nd	nd	nd	47.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt59 connect silica grains, 3-5	nd	1.4	0.8	7.0	nd	nd	nd	nd	37.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt60 gry connect, 3-5	nd	0.2	nd	11.4	nd	nd	nd	nd	32.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt61 connect grain, 3-5	nd	0.6	nd	2.6	nd	0.2	nd	nd	45.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt62 nest irreg gry grans, 3-5	nd	nd	7.3	22.9	nd	nd	nd	8.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt63 nest of br spots, 3-5	nd	0.5	6.0	14.9	nd	0.4	nd	nd	0.5	nd	3.0	15.2	nd	nd	nd	nd	nd	nd	nd
pt64 3-5	nd	nd	12.4	20.1	nd	0.2	nd	0.3	.1.3	nd	0.9	2.3	nd	nd	nd	nd	nd	nd	nd
pt65 3-5	nd	0.3	1.4	29.9	nd	nd	nd	0.6	0.2	nd	nd	2.5	nd	nd	nd	nd	nd	nd	nd
pt66 br spot 3-5	1.0	nd	7.1	23.2	nd	nd	nd	7.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt67 3-5	0.2	nd	7.4	23.1	nd	nd	nd	8.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt68 3-5	0.4	nd	7.2	23.1	nd	nd	nd	7.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt69 ch of bri spots 3-5	nd	0.9	2.3	10.6	nd	1.7	nd	2.3	1.0	nd	nd	24.2	nd	nd	nd	nd	nd	nd	nd
pt70 br irreg blob 3-5	nd	2.2	6.9	21.7	nd	nd	nd	2.2	0.7	nd	nd	4.3	nd	nd	nd	nd	nd	nd	nd
pt71 3-5	nd	nd	6.7	22.6	nd	nd	nd	10.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt72 3-5	1.5	1.7	4.4	12.1	0.3	4.8	nd	4.2	0.3	0.2	nd	9.7	nd	nd	nd	nd	nd	nd	nd
pt73 3-5	nd	1.0	3.0	22.1	nd	nd	nd	1.8	0.8	nd	nd	9.8	nd	nd	nd	nd	nd	nd	nd
pt74 3-5	nd	1.9	4.2	13.3	nd	nd	nd	5.6	0.5	nd	nd	18.2	nd	nd	nd	nd	nd	nd	nd
pt75 3-5	nd	nd	6.5	23.0	nd	nd	nd	9.3	nd	nd	nd	0.4	nd	nd	nd	nd	nd	nd	nd
pt76 br area on Si grain 3-5	nd	0.8	1.4	5.1	nd	nd	nd	0.8	38.9	nd	nd	0.3	nd	nd	nd	nd	nd	nd	nd
pt77 br anular gr 3-5	nd	nd	5.6	22.8	nd	nd	nd	11.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt78 lt gry grain 3-5	1.1	0.7	7.3	20.0	nd	nd	nd	6.4	3.2	nd	nd	1.3	nd	nd	nd	nd	nd	nd	nd
pt79 lt fry area on Si grain 3-5	nd	0.7	.63.	nd	nd	nd	nd	nd	44.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt80 3-5	nd	nd	nd	5.3	nd	0.8	nd	nd	40.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt81 3-5	nd	0.8	nd	1.3	nd	nd	nd	nd	47.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt82 br spot 3-5	nd	nd	nd	15.8	2.8	nd	nd	nd	0.6	nd	nd	nd	nd	nd	13.8	nd	nd	nd	nd
pt83 lt gry spot 3-5	nd	0.1	3.2	19.8	nd	nd	nd	6.5	11.1	nd	nd	nd	nd	nd	0.1	nd	nd	nd	nd
pt84 br spot 3-5	nd	nd	0.3	10.7	nd	nd	nd	Nd	nd	22.4	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt85 3-5	nd	0.7	2.8	18.3	nd	nd	nd	0.7	17.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 1b - no lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
pt86 3-5	nd	0.6	3.6	27.9	nd	nd	nd	2.9	0.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt87 3-5	nd	0.7	0.3	0.7	nd	nd	nd	nd	47.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt88 3-5	nd	nd	7.3	23.2	nd	nd	nd	8.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt89 3-5	nd	0.4	1.6	5.2	nd	10.2	nd	5.1	nd	nd	nd	15.7	nd	nd	nd	nd	nd	nd	nd
pt90 3-5	nd	0.5	0.1	4.5	nd	nd	nd	nd	42.8	nd	nd	-0.1	nd	nd	nd	nd	nd	nd	nd
pt91 3-5	nd	0.4	nd	0.9	nd	nd	nd	nd	48.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt92 1mm from bottom	nd	nd	nd	15.8	15.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt93 br spot, last 1mm	nd	nd	nd	14.9	15.3	nd	nd	nd	0.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt94 lt gry blob last 1mm	0.8	nd	7.4	23.1	nd	nd	nd	7.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt95 last 1mm	0.2	nd	7.4	22.8	nd	nd	nd	8.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt96 last 1mm	nd	nd	7.4	22.8	nd	nd	nd	8.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt 97 connecting grains last 1mm	nd	1.2	2.3	27.5	nd	0.8	nd	1.5	nd	nd	nd	1.9	nd	nd	nd	nd	nd	nd	nd
pt98 last 1mm	nd	2.5	8.9	17.0	nd	1.8	nd	1.9	nd	nd	nd	5.7	nd	nd	nd	nd	nd	nd	nd
pt99 lt gry grain last 1mm	0.7	nd	7.5	23.0	nd	nd	nd	7.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt100 matrix last 1mm	nd	0.2	3.8	28.9	nd	nd	nd	2.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt101 last 1mm	nd	nd	nd	33.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt102 last 1mm	0.4	nd	7.4	23.0	nd	nd	nd	8.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt103 last 1mm	nd	nd	7.6	23.0	nd	nd	nd	8.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt104 last 1mm	0.1	nd	7.2	22.4	nd	nd	nd	9.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt105 last 1mm	0.5	nd	7.2	23.2	nd	nd	nd	7.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt106 last 1mm	nd	nd	17.1	19.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt107 last 1mm	nd	nd	16.6	18.8	nd	nd	nd	nd	1.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt108 last 1mm	1.3	0.9	13.0	17.6	nd	nd	nd	5.3	nd	0.2	nd	1.1	nd	nd	nd	nd	nd	nd	nd
pt109 last 1mm	1.1	1.8	9.7	20.0	nd	nd	nd	3.6	nd	0.4	nd	2.0	nd	nd	nd	nd	nd	nd	nd

WyTV 2a cross sec, lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
pt1 lichen surf	nd	0.9	5.0	26.3	nd	nd	nd	3.1	nd	nd	nd	1.0	nd	nd	nd	nd	nd	nd	nd
pt2 lichen surf	nd	0.9	nd	5.0	nd	nd	nd	3.1	nd	nd	nd	1.0	nd	nd	nd	nd	nd	nd	nd
pt3 lichen surf	nd	0.4	4.2	27.6	nd	0.2	0.3	1.5	0.2	nd	nd	1.0	nd	nd	nd	nd	nd	nd	nd
pt4 lichen surf	nd	1.5	3.0	28.5	nd	nd	nd	1.4	nd	nd	nd	1.0	nd	nd	nd	nd	nd	nd	nd
pt5 lichen surf	nd	nd	nd	nd	nd	nd	20.0	53.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt6 lichen surf	nd	nd	2.8	29.4	nd	nd	nd	1.8	0.1	nd	nd	0.9	nd	nd	nd	nd	nd	nd	nd
pt7 lichen surf	nd	0.8	5.8	25.7	nd	nd	nd	1.4	0.5	nd	nd	1.8	nd	nd	nd	nd	nd	nd	nd
pt9 lichen surf	1.4	1.2	5.0	25.8	nd	nd	nd	1.3	0.5	nd	nd	1.4	nd	nd	nd	nd	nd	nd	nd
pt10 lichen surf	1.0	0.9	3.7	20.1	3.3	0.4	nd	1.1	4.1	0.3	nd	1.7	nd	nd	nd	nd	nd	nd	nd
pt11 lichen surf	1.0	1.0	3.7	20.1	3.3	0.4	nd	1.1	4.1	0.3	nd	1.7	nd	nd	nd	nd	nd	nd	nd
pt12 lichen surf	1.8	1.8	7.7	22.5	nd	nd	nd	1.7	0.3	nd	nd	1.9	nd	nd	nd	nd	nd	nd	nd
pt13 x950 surf	nd	nd	6.9	23.2	nd	nd	13.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt14 surf	nd	nd	0.4	32.7	nd	nd	nd	0.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt15 surf	nd	nd	1.1	32.3	nd	nd	nd	0.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt16 surf	nd	0.8	4.0	9.7	nd	nd	nd	nd	0.9	0.3	nd	28.4	nd	nd	nd	nd	nd	nd	nd
pt17 surf	nd	nd	1.7	3.5	nd	nd	nd	0.4	0.4	14.7	0.9	19.1	nd	nd	nd	nd	nd	nd	nd
pt18 surf	1.5	0.7	8.0	21.5	nd	nd	nd	6.5	nd	0.5	nd	0.9	nd	nd	nd	nd	nd	nd	nd
med grey mass surf	1.8	1.6	5.2	18.1	1.7	1.1	2.2	0.7	1.5	nd	nd	1.5	nd	nd	nd	nd	nd	nd	nd
hyphae ph8	nd	1.5	1.9	29.3	nd	nd	nd	nd	2.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
lich overview	nd	nd	5.5	24.1	nd	nd	nd	1.9	4.2	nd	nd	1.3	nd	nd	nd	nd	nd	nd	nd
pt1 lichen surf	nd	nd	9.0	22.5	nd	nd	nd	2.7	nd	nd	nd	3.1	nd	nd	nd	nd	nd	nd	nd
pt2 lt gry grain in lich surf	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	50.0	nd	nd	nd	nd	nd	nd	nd
pt3 elongated grain lich surf	nd	6.7	8.2	16.0	nd	nd	nd	3.2	nd	0.5	nd	5.9	nd	nd	nd	nd	nd	nd	nd
pt4 dk area betwn grains in lich surf	nd	0.5	3.8	28.4	nd	0.2	nd	1.0	nd	nd	nd	1.1	nd	nd	nd	nd	nd	nd	nd
pt5 brt spot surf	nd	nd	1.8	5.9	nd	nd	nd	nd	nd	nd	nd	38.9	nd	nd	nd	nd	nd	nd	nd
pt1 ph9 surf	nd	nd	3.7	18.1	nd	5.9	13.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 2a cross sec, lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
pt2 ph9	nd	nd	5.5	19.3	nd	2.7	17.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt3 ph9	nd	nd	6.1	21.3	nd	2.4	11.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt4 ph9	nd	nd	7.5	21.9	nd	1.2	5.2	2.2	1.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt5 ph9	nd	nd	1.5	31.7	nd	0.1	nd	0.4	0.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt6 ph9	nd	nd	9.5	19.4	0.7	0.2	nd	1.8	0.4	nd	2.9	2.9	nd	nd	nd	nd	nd	nd	nd
pt7 ph9	1.0	1.0	6.6	17.4	0.9	0.3	nd	2.2	2.3	nd	3.0	4.9	nd	nd	nd	nd	nd	nd	nd
pt8 ph9	1.8	1.8	8.0	13.1	1.5	0.7	nd	1.6	2.1	nd	6.1	3.9	nd	nd	nd	nd	nd	nd	nd
pt9 ph9	2.1	1.1	5.1	20.6	0.6	0.1	nd	0.8	0.5	nd	5.8	1.9	nd	nd	nd	nd	nd	nd	nd
pt10 ph9	1.7	1.2	9.2	18.8	0.7	1.0	nd	3.2	0.3	nd	0.8	2.7	nd	nd	nd	nd	nd	nd	nd
pt11 ph9	1.3	0.5	0.6	31.2	0.1	0.1	nd	0.2	nd	nd	0.1	0.3	nd	nd	nd	nd	nd	nd	nd
pt12 ph9	nd	nd	nd	33.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt13 ph9	nd	nd	3.0	15.4	3.8	nd	4.2	nd	11.2	nd	nd	3.2	nd	nd	nd	nd	nd	nd	nd
pt14 ph9	nd	nd	3.2	15.4	nd	nd	nd	7.8	2.2	1.0	nd	13.4	nd	nd	nd	nd	nd	nd	nd
pt15 ph9	nd	nd	0.1	32.3	nd	nd	nd	nd	nd	0.9	nd	nd	nd	nd	nd	nd	nd	nd	nd
1 1st mm	nd	nd	5.8	24.1	nd	nd	nd	6.5	0.2	nd	nd	1.5	nd	nd	nd	nd	nd	nd	nd
2 1st mm	nd	nd	16.9	19.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
3 1st mm	nd	nd	1.5	3.9	nd	nd	nd	0.3	nd	27.9	nd	0.3	nd	nd	nd	nd	nd	nd	nd
4 1st mm	nd	nd	2.5	20.0	nd	nd	nd	0.4	7.1	6.0	nd	0.5	nd	nd	nd	nd	nd	nd	nd
5 1st mm	nd	nd	5.3	27.5	nd	nd	nd	2.3	0.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
6 1st mm blk (hole)	nd	nd	nd	21.8	nd	nd	34.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
7	nd	nd	6.3	25.4	nd	nd	nd	4.4	0.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
8 1st mm	nd	nd	7.6	22.9	nd	nd	nd	8.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
9 1st mm	nd	nd	4.9	25.5	nd	nd	11.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1 2nd mm	nd	nd	7.5	23.1	nd	nd	nd	7.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2 2nd mm	nd	nd	2.4	29.7	nd	nd	nd	0.8	1.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
3 2nd mm bridge betwn grains	1.1	nd	3.8	21.8	2.3	nd	nd	3.6	4.5	nd	nd	0.5	nd	nd	nd	nd	nd	nd	nd
4 2nd mm	nd	nd	2.2	19.6	5.3	nd	nd	0.7	7.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
5 2nd mm	0.7	nd	7.5	22.8	nd	nd	nd	7.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 2a cross sec, lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
6 2nd mm zircon	nd	nd	nd	17.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	15.9	nd	nd	nd	nd
7 2nd mm	nd	nd	nd	2.6	nd	nd	nd	nd	nd	2.7	nd	42.1	nd	nd	nd	nd	nd	nd	nd
8 2nd mm	nd	nd	nd	5.0	nd	nd	nd	nd	nd	28.3	nd	nd	nd	nd	nd	nd	nd	nd	nd
9 2nd mm	0.5	nd	7.1	22.5	nd	nd	nd	9.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
10 2nd mm	nd	nd	0.6	1.2	nd	nd	nd	nd	nd	31.6	nd	nd	nd	nd	nd	nd	nd	nd	nd
11 2nd mm	nd	nd	0.1	4.1	nd	nd	nd	nd	nd	29.2	nd	nd	nd	nd	nd	nd	nd	nd	nd
12 2nd mm	nd	nd	4.7	13.5	nd	nd	nd	0.6	nd	15.6	nd	nd	nd	nd	nd	nd	nd	nd	nd
13 2nd mm	0.6	nd	6.1	18.6	3.0	nd	nd	2.6	3.2	1.5	nd	1.3	nd	nd	nd	nd	nd	nd	nd
14 2nd mm	nd	nd	1.5	14.3	7.8	nd	nd	0.5	12.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
15 2nd mm	nd	nd	nd	31.4	1.2	nd	nd	nd	0.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
16 2nd mm	nd	nd	4.2	16.6	5.4	nd	nd	1.9	9.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
lich hyph 2.8 mm below surface	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
brite spot zircon plus 2.8 mm	nd	nd	nd	15.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	18.2	nd	nd	nd	nd
cement around zircon plus 2.8 mm	nd	nd	7.0	22.7	nd	nd	nd	9.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
zircon plus 2.8 mm	nd	nd	nd	15.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	18.2	nd	nd	nd	nd
lich hyph 1.5 mm below	nd	nd	0.5	32.1	nd	nd	nd	1.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
lich hyph plus 1.5 mm	nd	nd	6.3	23.9	nd	nd	nd	5.9	1.7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
plus 3mm below surf	nd	nd	nd	4.0	nd	nd	nd	nd	nd	29.3	nd	nd	nd	nd	nd	nd	nd	nd	nd
plus 3mm	nd	nd	nd	33.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
plus 3 mm	nd	nd	7.3	22.9	nd	nd	nd	8.7	nd	nd	nd	0.9	nd	nd	nd	nd	nd	nd	nd
plus 3 mm med gry mass	1.8	1.6	8.2	18.1	1.7	1.1	2.2	0.7	1.5	nd	nd	1.5	nd	nd	nd	nd	nd	nd	nd
plus 3mm	1.7	1.6	6.5	18.4	0.7	0.6	0.4	1.3	0.8	nd	nd	6.9	nd	nd	nd	nd	nd	nd	nd
plus 3mm	2.1	1.4	4.1	19.4	0.9	1.0	0.9	1.1	1.2	nd	3.5	3.1	nd	nd	nd	nd	nd	nd	nd
plus 3mm	nd	nd	7.2	23.0	nd	nd	nd	8.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
plus 3mm	nd	nd	7.4	22.9	nd	nd	nd	8.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 2a cross sec, lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
plud 3mm	nd	nd	nd	4.8	nd	nd	nd	nd	nd	28.3	nd	0.5	nd	nd	nd	nd	nd	nd	nd
plus 3mm	nd	nd	0.5	13.8	nd	nd	nd	nd	nd	16.7	nd	3.8	nd	nd	nd	nd	nd	nd	nd
plus 3mm	nd	nd	nd	15.1	2.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	15.9	nd	nd	nd	nd
plus 3mm	nd	nd	7.1	22.7	nd	nd	nd	9.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
plus 3mm	0.3	nd	7.4	22.6	nd	nd	nd	8.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
plus 3mm	nd	nd	16.8	19.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
plus 3mm	nd	nd	16.8	19.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
lich hyph 5.5 mm below surf	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Xenotime plus 5.5 mm	nd	nd	16.0	3.6	8.9	0.8	nd	0.4	1.5	nd	nd	nd	nd	nd	nd	nd	nd	1.5	3.0
pt2 plus 5.5 mm	nd	nd	1.0	1.8	nd	nd	nd	0.3	0.5	30.3	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt3 plus 5.5 mm	1.4	1.0	8.5	22.7	nd	nd	nd	3.2	nd	nd	nd	0.9	nd	nd	nd	nd	nd	nd	nd
pt4 plus 5.5 mm	nd	nd	3.9	11.2	nd	nd	nd	1.6	0.6	nd	nd	0.6	nd	nd	nd	nd	nd	nd	nd
pt5 plus 5.5 mm	nd	nd	7.1	22.9	nd	nd	nd	9.0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt6 plus 5.5 mm	nd	nd	nd	14.9	nd	nd	nd	nd	nd	18.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt7 plus 5.5 mm	nd	nd	nd	0.5	nd	nd	nd	nd	nd	32.9	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt8 plus 5.5 mm	nd	nd	7.5	23.0	nd	nd	nd	8.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt9 plus 5.5 mm	nd	nd	0.3	7.9	nd	11.9	1.2	nd	12.0	nd	nd	nd	1.5	nd	nd	nd	nd	nd	nd
pt10 plus 5.5 mm	nd	nd	1.1	10.0	nd	nd	nd	1.1	31.1	nd	nd	1.7	nd	nd	nd	nd	nd	nd	nd
pt11 plus 5.5 mm	nd	nd	8.0	23.0	nd	nd	nd	6.8	nd	nd	nd	0.4	nd	nd	nd	nd	nd	nd	nd
pt12 plus 5.5 mm	nd	nd	7.5	23.0	nd	nd	nd	8.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt13 Zircon plus 5.5 mm	nd	nd	nd	19.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	14.2	nd	nd	nd	nd
pt14 plus 5.5 mm	nd	nd	0.6	6.6	nd	nd	nd	nd	nd	26.3	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt15 plus 5.5 mm	nd	nd	16.2	19.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt16 zircon plus 5.5 mm	nd	nd	nd	14.4	3.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	14.5	nd	nd	nd	nd
pt17 plus 5.5 mm	nd	nd	5.9	21.2	nd	nd	nd	nd	6.6	0.7	nd	3.2	nd	nd	nd	nd	nd	nd	nd
last 1mm pt1	0.4	nd	7.3	23.3	nd	nd	nd	7.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt 3 granular area betwn grains last 1mm	nd	nd	9.5	24.6	nd	0.3	nd	nd	0.6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

WyTV 2a cross sec, lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Co**	**Cu**	**Zr**	**Sn**	**Ba**	**La**	**Ce**
pt3 lt gry grain last 1mm	nd	nd	6.9	23.3	nd	nd	nd	8.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt4 med dk gry granular last 1mm	nd	nd	10.6	24.4	nd	nd	nd	0.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt 5 last 1mm	0.7	1.8	1.97.3	nd	nd	nd	nd	nd	nd	19.4	nd	5.3	nd	nd	nd	nd	nd	nd	nd
pt 6 last 1mm	1.4	nd	6.9	23.1	nd	nd	nd	7.5	nd	nd	nd	0.1	nd	nd	nd	nd	nd	nd	nd
pt 7 last 1 mm	nd	nd	7.4	23.4	nd	nd	nd	7.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt 8 last 1 mm	nd	nd	1.2	7.5	nd	nd	nd	0.6	nd	23.9	nd	0.8	nd	nd	nd	nd	nd	nd	nd

Petroglyph NM 1a lichen															
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**	**Ba**
surface-1st mm	61.06	1.92	1.06	9.56	17.90	0.25	0.09	0.20	0.26	4.04	0.17	nd	0.63	2.85	nd
lichen	66.34	nd	0.10	0.33	32.78	nd	nd	0.27	nd	0.19	nd	nd	nd	nd	nd
pt	60.66	1.15	0.99	8.49	17.46	nd	nd	nd	0.50	4.99	0.44	nd	0.72	4.60	nd
lichen	58.55	nd	5.03	2.20	20.98	nd	nd	4.97	nd	4.92	nd	nd	nd	3.35	nd
lichen-see\photo	59.53	nd	nd	7.06	21.87	nd	nd	6.35	nd	3.02	nd	nd	nd	2.17	nd
incorporated\surface	61.50	0.35	1.47	9.37	18.87	0.22	nd	0.13	1.80	0.53	0.30	nd	1.88	3.58	nd
matrix	61.81	2.50	0.36	10.12	18.75	0.70	nd	0.11	0.42	3.01	0.33	nd	nd	1.91	nd
matrix	63.45	0.21	1.71	5.97	20.59	2.10	0.22	nd	0.33	4.60	nd	nd	nd	0.81	nd
matrix	59.86	1.92	1.32	7.38	14.72	nd	nd	nd	0.30	4.19	2.42	nd	nd	7.89	nd
pt	57.27	nd	20.75		14.54	nd	nd	nd	nd	0.20	nd	nd	nd	7.23	nd
pt	62.92	0.71	4.88	7.12	10.09	nd	6.27	nd	nd	0.38	nd	nd	nd	1.66	5.97
pt	59.86	nd	8.86	6.21	11.74	nd	2.44	nd	nd		nd	nd	nd	6.37	4.54
pt	58.85	nd	10.43	nd	12.00	nd	2.85	nd	nd	2.79	nd	nd	0.21	12.89	nd
pt	59.94	nd	2.30	2.78	12.08	3.11	1.09	0.44	nd	17.19	nd	nd	nd	1.06	nd
lichen-surface	62.02	0.80	2.58	6.76	19.46	nd	1.26	0.36	1.11	1.71	nd	nd	nd	3.94	nd
just\beneath\lichen	60.56	0.99	4.75	5.63	18.47	nd	nd	nd	nd	6.52	0.32	nd	nd	2.75	nd
2nd\mm	61.04	0.75	1.15	5.78	15.01	2.61	0.48	0.47	0.67	9.07	0.49	nd	nd	2.47	nd
pt	60.55	0.67	6.06	2.90	18.17	nd	0.82	0.13	nd	7.45	0.28	nd	nd	2.97	nd
pt	61.65	1.79	nd	12.17	17.58	nd	0.26	nd	nd	6.20	nd	nd	nd	0.36	nd
pt	61.78	1.87	nd	11.93	17.99	nd	0.27	nd	nd	5.95	nd	nd	nd	0.21	nd
pt	57.36	nd	13.11	0.29	14.57	nd	nd	nd	nd	0.39	nd	nd	0.35	13.93	nd
pt	57.20	nd	11.91	nd	14.39	nd	nd	nd	nd	0.36	nd	nd	nd	16.14	nd
pt	62.70	1.24	nd	9.59	16.13	nd	2.55	nd	nd	7.79	nd	nd	nd		nd
pt	60.17	nd	5.64	1.50	18.42	nd	nd	nd	nd	5.47	1.17	nd	nd	7.64	nd
pt	66.42	nd	0.11	0.58	31.89	nd	0.33	nd	nd	0.68	nd	nd	nd		nd
pt	57.18	nd	18.41		14.36	nd	nd	nd	nd	0.17	nd	nd	nd	9.88	nd
pt	57.13	nd	21.20	nd	14.27	nd	nd	nd	nd	0.26	nd	nd	nd	7.15	nd
pt	61.68	2.80	nd	11.39	19.06	nd	nd	nd	nd	4.71	nd	nd	nd	0.36	nd

Petroglyph NM 1a lichen														
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**	**Ba**
pt	59.05	0.39	1.04	0.78	1.51	nd		nd	nd	0.47	16.39	nd	nd	20.37	nd
3rd-mm	61.63	1.85	0.54	8.58	17.54	nd	1.38	0.28	0.25	4.90	nd	nd	nd	3.05	nd
pt	61.50	1.11	0.83	6.40	14.61	nd	2.85	nd	0.25	10.32	0.18	nd	nd	1.95	nd
pt	61.53	0.55	1.94	7.34	13.77	1.02	2.18	nd	0.36	4.21	0.20	nd	nd	6.89	nd
lichen	56.92	2.32	1.38	5.99	16.75	nd	nd	4.75	nd	1.80	nd	nd	nd	10.10	nd
pt	60.00	2.01	0.34	5.07	8.08	nd	nd	nd	nd	1.74	10.39	nd	nd	12.37	nd
pt	56.11	nd	3.03	6.89	0.67	nd	nd	nd	nd	0.29	2.05	12.13	nd	18.83	nd
pt	61.37	1.94	nd	12.34	17.55	nd	nd	nd	nd	6.45	nd	nd	nd	0.35	nd
pt	57.08	nd	9.21		14.16	nd	nd	nd	nd	0.20	nd	nd	0.39	18.97	nd
pt	59.97	0.23	8.20	1.04	19.24	nd	nd	nd	nd	7.59	0.29	nd	nd	3.45	nd
pt	56.74	nd	9.60	nd	13.49	nd	nd	nd	nd	0.29	nd	nd	0.32	19.56	nd
pt	52.98	nd	3.99	1.23	5.36	nd	nd	nd	nd	2.09	nd	nd	nd	34.35	nd
pt	63.47	0.86	0.61	1.27	3.17	nd	11.79	nd	nd	1.68	nd	nd	0.84	2.24	14.08
pt	59.66	0.82	0.91	2.08	2.81	1.48	nd	nd	nd	2.28	13.67	nd	nd	16.30	nd
pt	64.30	0.88	1.01	1.44	4.95	nd	11.68	nd	nd	2.30	nd	nd	nd	1.78	11.66
last-mm matrix	61.83	2.51	nd	11.26	18.97	nd	0.16	nd	nd	4.86	nd	nd	nd	0.41	nd
pt	61.76	2.58	nd	10.84	18.59	nd	0.40	nd	nd	5.35	nd	nd	nd	0.47	nd
pt	59.96	nd	7.51	1.37	18.87	nd	nd	nd	nd	7.74	0.36	nd	nd	4.18	nd
lichen	60.17	1.60	2.54	4.03	18.82	nd	1.37	2.42	nd	3.04	nd	nd	nd	6.02	nd
pt	55.50	nd	1.75	2.88	0.27	nd	nd	nd	nd	nd	4.96	8.67	nd	25.97	nd
pt	57.14	nd	15.32	nd	14.29	nd	nd	nd	nd	nd	nd	nd	nd	13.25	nd
pt	59.88	nd	6.68	1.51	18.43	nd	nd	nd	nd	8.32	0.57	nd	nd	4.62	nd
pt	59.38	nd	0.56	1.03	3.62		nd	nd	0.39	0.43	14.83	nd	nd	19.76	nd
pt	61.81	2.97	nd	10.11	19.27	0.53	nd	nd	nd	5.09	nd	nd	nd	0.23	nd
pt	54.39	nd	1.07	0.94	0.88		nd	nd	nd	0.73	7.44	nd	nd	34.54	nd
pt	55.30	nd	5.47		10.60	nd	nd	nd	nd	1.26	nd	nd	0.48	26.89	nd
pt	59.26	nd	0.28	0.66	1.94	nd	nd	nd	nd	0.36	16.25	nd	nd	21.24	nd
pt	57.18	nd	20.20	nd	14.35	nd	nd	nd	nd	nd	nd	nd	nd	8.27	nd
pt	57.27	nd	21.13	nd	14.54	nd	nd	nd	nd	0.14	nd	nd	nd	6.93	ne

Petroglyph NM - 2a lichen 9/12/03														
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**
lichen - sp 1	61.17	2.71	0.34	10.18	16.67	0.25	0.88	1.05	1.04	3.86	1.39			0.46
lichen - sp 11	61.03	2.79	0.38	10.07	16.83		0.77	0.83	1.04	4.24	1.41			0.61
matrix outside of lichen sp 1 & sp 11 (see spe 12)	61.62	2.08		12.09	18.24					5.74				0.24
surface	62.42	0.61	1.64	12.40	15.74				0.41	2.76	3.42			0.60
surface	61.37	1.35		11.67	17.58					5.72			0.58	1.72
surface	62.03	1.68	0.27	12.89	18.65				0.39	2.97			0.44	0.69
Lichen on surface	62.42	2.00	0.43	10.98	16.66		2.00	0.53	0.42	4.14	0.43			
Lichen on surface - 2a_3 image	62.45	1.09	2.33	7.15	15.38		0.62	0.41	0.43	4.27	5.87			
lt grey rectangle - surface	61.82	0.51	0.77	2.92	21.33				1.09	3.37	1.63			6.56
surface	61.56	2.03		12.66	17.81					5.72				0.21
surface-1mm	57.53	0.56	4.14	9.70	4.66					1.48	0.86	9.91		11.16
med gry matrix	61.92	3.04		10.56	20.24				0.30	3.95				
med/lt gry rectang	57.01		11.72		14.03									17.24
pt	57.00			0.32	13.85									18.82
pt	59.95			1.02	18.95					7.26	0.45			6.35
pt	58.62			0.59	1.02						15.92			22.53
lichen .5 mm	59.59	5.51		10.65	16.92		0.99	1.59	1.42	2.93				0.40
dk grey area near lich above	60.18	0.20		33.16	3.85	0.13	0.22	0.48	0.20	1.05				0.54
matrix near above	61.65	2.62		11.59	18.80	0.10			0.24	4.76				0.24
lichen trail .5 mm from surface	60.86	1.89	1.78	11.24	15.98		0.77	0.39	0.15	5.46				1.48
lt grey area adjacent to lich above	60.06		7.94	0.77	19.38					6.95	0.35			4.55
med/dk gry area near lich above	60.99	1.68		21.53	11.88		0.24	0.23	0.16	3.00				0.28

Petroglyph NM - 2a lichen 9/12/03														
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**
med grey area adjacent to lich above	62.50		0.36	12.56	15.86	1.93			0.52	3.45	0.21			2.61
lt/med gry ovoid	59.72	0.30	6.21	0.99	18.47					7.15	0.62			6.54
lt grey grain	57.54		7.63	0.29	14.94					0.48				19.12
dk grey ribbon	61.17	1.22		22.05	12.19			0.26		2.52				0.59
med gry grain	59.87		7.63	0.93	19.27					8.63				3.68
pt	60.83			32.98	5.51				0.64					
pt	64.17				24.02	0.63		0.32	0.54	1.17				1.20
lichen 2mm below surface	55.57	5.46	1.41	7.53	4.73		4.54	4.80	3.13	10.18	2.66			
lichen 2mm below surface	56.91	5.28		8.44	4.87		7.20	8.68	3.50	1.72	3.40			
lichen 2mm below surface	58.58	5.96		7.25	6.06		8.10	6.12	3.14	2.83	1.96			
dk gry gravelly area adjacent to lich above	59.85			36.82	1.90			0.60		0.43				0.41
lt grey area around gravelly area above	58.37	-0.43	18.57	1.04	13.35		0.46				1.73			6.91
rec grain in gravelly area above	58.01		6.83	0.41	15.81					0.25				18.69
dk grey area	59.63	0.47		36.21	1.90			0.51		0.65				0.63
pt	59.39		4.52	1.06	18.20					8.54	0.37			7.28
pt	61.69			11.37	18.88					5.38				0.33
pt	56.93			0.32	13.70									18.40
pt	56.63			1.02	1.06					0.86	11.70			27.33

Petroglyph NM - 2a lichen 9/12/03														
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**
pt	57.20				14.40									7.55
pt	61.58			10.14	20.13				0.25	3.56				0.49
pt	60.12				2.50			0.18		0.98				0.40
pt	61.99			10.79	20.05					4.26				
pt	61.51			11.62	18.64				0.16	4.98				0.39
pt	57.07				14.15									16.09
pt	59.91			0.92	18.80					7.04	0.55			6.43
pt	61.59			11.46	18.76					5.23				0.31
pt	58.71			0.55	7.93					0.15	9.22			17.83
3mm - lichen	64.44			5.71	5.04	4.58	8.16	2.20		7.93				1.94
bottom 1mm	57.16		21.08		14.32					0.09				7.35
pt	61.57			12.22	18.05					5.78				0.32
pt	56.96				13.91									17.25
pt	59.94			0.98	19.01					8.33	0.37			3.87
pt	61.66			2.47	21.55	0.63			0.79	3.15				1.64
pt	58.81		1.53	8.38	19.78			5.60		4.43				
pt	59.83			0.92	18.75					7.87	0.45			4.79
pt	59.82			1.68	18.19					8.33	0.61			4.23
pt	62.76			5.80	22.59	0.43			1.25	1.11				1.21
pt	59.96			6.32	17.07				0.61	11.79				2.45
pt	57.89		9.87	0.22	16.80					1.02				11.95
pt	61.29				1.59					0.40	20.59			15.34
pt	59.98			1.29	18.75					7.87	0.56			4.32
pt	60.98			25.29	9.97			0.16		2.63				
pt	57.82		11.93		16.76					0.58			0.25	10.44
pt	55.42			2.61	7.26	0.76				1.92	1.15			27.76
pt	60.23		1.15	1.38	4.23				0.37	1.03	16.02			14.98
pt	61.24			19.78	13.89				0.60	1.89				0.59
pt	59.02			1.41	2.18					1.30	15.16			18.65

Petroglyph NM - 2a lichen 9/12/03														
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**
pt	57.37				14.74									7.10
pt	66.06				31.31					1.00				
pt	61.95			9.04	21.09	0.22			0.44	3.23				0.37
pt	59.89			0.87	18.99					8.24	0.35			3.79
pt	52.64			2.31							3.91	0.44		39.79
pt	61.72			9.64	20.54				0.27	3.69				0.58
pt	61.68			10.60	19.86				0.31	3.94				0.33
pt	61.57			0.31	21.69		0.65			2.43				

Petroglyph NM Sample 10c no lichen -															
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**	**Ba**	**Bi**
1stmm - ltgry grain	56.12	nd	3.88	6.47		nd	nd	nd	nd	0.85	16.32	nd	16.36	nd	nd
matrix	57.24	nd	22.20	nd	14.48	nd	nd	nd	nd	nd	nd	nd	6.09	nd	nd
matrix	58.87	nd	15.35	5.13	15.17	nd	nd	nd	0.22	nd	nd	nd	5.27	nd	nd
br spot	50.93	nd	2.40	0.41	1.66	nd	nd	nd	nd	nd	nd	nd	44.59	nd	nd
gravellyareas	60.13	0.96	0.25	32.37	4.55	nd	nd	nd	1.01	nd	nd	nd	0.73	nd	nd
pt	57.17	nd	13.25		14.34	nd	nd	nd	0.21	nd	nd	nd	15.03	nd	nd
med/dkconnectingribbon	59.42	nd	11.44	7.49	14.82	nd	nd	nd	0.55	0.27		0.95	5.06	nd	nd
ltgrygrain	56.12		5.00	8.46		nd	nd	nd		0.95	14.10	nd	15.37	nd	nd
ltgreygrain	59.76	0.28	5.39	1.37	18.20	nd	nd	nd	7.63	0.77	nd	nd	6.61	nd	nd
dkgryspot	60.05	1.19	nd	32.15	4.24	nd	nd	nd	1.04	0.39	nd	nd	0.93	nd	nd
matrix	61.74	3.05	nd	11.20	19.41	nd	nd	nd	4.28		nd	nd	0.31	nd	nd
Brspot---contamination???	59.73	nd	0.54	6.23	1.27	nd	nd	nd	0.68	nd	nd	nd	1.39	nd	30.16
pt	59.83	0.38	7.10	1.51	18.59	nd	nd	nd	7.74	0.52	nd	nd	4.33	nd	
ltgrygrain	57.14	nd	11.57	0.20	14.18	nd	nd	nd	0.25	nd	nd	0.25	16.42	nd	nd
pt	57.20	nd	15.01	nd	14.40	nd	nd	nd	nd	nd	nd	nd	13.40	nd	nd
pt	59.85	0.18	7.46	1.25	18.62	nd	nd	nd	7.30	0.55	nd	nd	4.78	nd	nd
2ndmm	60.25	1.56	nd	10.78	15.88	nd	nd	nd	10.88	nd	nd	nd	0.65	nd	nd
pt	60.03	nd	nd	39.81	0.16	nd	nd	nd	nd	nd	nd	nd		nd	nd
ltgrygrain	57.28	0.39	10.52	2.17	13.68	nd	nd	nd	nd	nd	nd	nd	15.96	nd	nd
pt	57.54	0.97	9.31	6.43	12.21	nd	nd	nd	0.41	0.13	nd	0.14	12.86	nd	nd
pt	60.93	1.17	nd	6.73	6.44	nd	1.01	nd	2.45		nd	nd		nd	21.27
pt	60.50	1.49	2.84	6.51	17.41	0.12	nd	nd	5.37	0.90	nd	nd	4.87	nd	nd
pt	59.76	0.28	6.56	1.79	18.15	nd	nd	nd	8.35	0.60	nd	nd	4.50	nd	nd
pt	56.99	0.19	15.73	0.65	13.76	nd	nd	nd	0.24		nd	0.23	12.19	nd	nd
pt	59.66	0.38	5.97	1.08	18.32	nd	nd	nd	6.08	0.65	nd	nd	7.86	nd	nd
pt	61.64	2.06	nd	12.28	18.16	nd	nd	nd	5.87		nd	nd		nd	nd
pt	59.84	nd	7.17	1.80	18.79	nd	nd	nd	7.57		nd	nd	4.83	nd	nd
pt	58.47	0.37	3.01	1.55	10.78	nd	nd	nd	3.85	5.56	nd	nd	16.41	nd	nd

Petroglyph NM Sample 10c no lichen -														
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**	**Ba**	**Bi**
pt	60.22	0.38	5.86	3.83	18.12	nd	nd	nd	7.11	0.59	nd	nd	3.89	nd	nd
3rdmm	61.72	2.08	nd	12.16	18.40	nd	nd	nd	5.65	nd	nd	nd	nd	nd	nd
pt	61.66	4.50	nd	10.01	20.56	nd	nd	nd	2.90	nd	nd	nd	0.37	nd	nd
pt	59.97	nd	8.37	1.42	18.72	nd	nd	nd	6.28	0.50	nd	nd	4.74	nd	nd
pt	60.01	0.32	nd	38.73	0.81	nd	nd	nd	0.13	nd	nd	nd	nd	nd	nd
pt	61.71	3.21	nd	10.47	19.89	nd	nd	0.20	4.08	nd	nd	nd	0.43	nd	nd
pt	59.78	0.25	6.49	1.21	18.54	nd	nd	nd	6.19	0.55	nd	0.16	6.83	nd	nd
pt	60.03	nd	nd	39.84	0.14	nd	nd	nd	nd	nd	nd	nd		nd	nd
pt	58.10	nd	2.34	1.26	9.73	nd	nd	nd	3.62	5.84	nd	nd	19.12	nd	nd
pt	61.79	2.42	nd	11.50	19.05	nd	nd	nd	5.25	nd	nd	nd	nd	nd	nd
pt	61.69	2.41	nd	11.89	18.63	nd	nd	nd	5.38	nd	nd	nd	nd	nd	nd
pt	58.77	0.66	0.90	1.21	6.05	0.18	3.36	nd	7.09	4.21	nd	nd	14.76	2.82	nd
pt	57.11	nd	7.36	0.29	14.08	nd	nd	nd	nd	nd	nd	nd	21.16	nd	nd
pt	57.09	nd	13.01	nd	14.18	nd	nd	nd	nd	nd	nd	nd	15.72	nd	nd
bottommm	61.55	2.20	nd	12.29	18.06	nd	nd	nd	5.64	nd	nd	nd	0.26	nd	nd
pt	59.75	0.27	7.37	1.58	18.22	nd	nd	nd	7.57	0.63	nd	nd	4.61	nd	nd
pt	56.91	nd	8.24	nd	13.82	nd	nd	nd	0.21	nd	nd	0.29	20.54	nd	nd
pt	57.14	nd	0.34	1.64	4.52	nd	nd	nd		8.95	nd	nd	27.41	nd	nd
pt	61.39	1.83	0.43	14.51	16.43	nd	nd	nd	5.41	nd	nd	nd		nd	nd
pt	57.00	0.66	8.70	1.71	13.28	nd	nd	nd	0.41	0.21	nd	nd	18.04	nd	nd
pt	60.29	nd		31.95	4.22	nd	nd	nd	1.52	0.39	nd	nd	1.63	nd	nd
pt	59.84	nd	0.38	2.12	14.12	nd	nd	0.72	1.76	4.70	nd	nd	16.27	nd	nd
pt	57.28	nd	0.48	2.07	5.47	nd	nd	0.41	0.56	8.27	nd	nd	25.47	nd	nd
pt	57.44	nd	0.27	2.00	5.55	0.43	nd	0.34	1.37	7.86	nd	nd	24.75	nd	nd
pt	56.68	nd	nd	1.55	3.56	nd	nd	nd		9.02	nd	0.30	28.90	nd	nd
pt	59.96	nd	7.41	1.69	18.52	nd	nd	nd	7.61	0.55	nd	nd	4.27	nd	nd
pt	61.84	3.12	nd	10.75	19.86	nd	nd	nd	4.43	nd	nd	nd	nd	nd	nd

Minnesota Mn1a Lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Fe**	**O**
Surface - pt1 dk gry	nd	nd	19.07	11.74	0.86	0.14	nd	0.35	0.19	2.91	nd	1.96	62.79
pt2 med gry	nd	nd	10.47	9.83	2.77	nd	nd	0.49	0.28	9.97	nd	1.72	64.47
pt3 med-lt gry	nd	nd	4.70	5.42	0.98	nd	nd	0.18	0.25	21.80	nd	1.19	65.48
pt3 med-lt gry	nd	nd	4.43	4.25	1.10	nd	0.29	0.19	0.50	11.27	nd	18.48	59.50
pt5 lt gry	nd	nd	6.64	14.55	6.11	nd	0.11	0.18	0.57	5.00	nd	0.90	65.92
pt6 dk gry	nd	nd	18.11	12.12	0.96	nd	nd	0.36	0.23	3.36	nd	1.96	62.90
pt7 med gry	nd	nd	5.07	11.18	0.38	nd	nd	0.20	0.11	6.46	nd	16.28	60.32
pt8 med gry	nd	nd	3.89	15.33	0.23	nd	nd	0.21	nd	14.00	nd	0.57	65.76
pt9 dk substrate	nd	nd	3.47	26.99	0.86	nd	nd	0.12	nd	2.09	nd	0.46	66.02
pt10 med gry	nd	nd	8.69	13.92	1.46	nd	nd	0.40	nd	9.60	nd	1.00	64.93
pt11 lt gry	nd	nd	6.63	14.15	6.16	nd	0.13	0.17	0.44	5.31	nd	1.11	65.90
Lich	nd	nd		1.28	1.45	1.18	nd	nd	43.18	nd	nd	nd	52.91
Lich	nd	nd	1.56	1.97	2.52	2.47	nd	nd	35.74	nd	nd	nd	55.74
Lich	nd	nd	1.06	7.16		1.30	nd	nd	35.34	nd	nd	nd	55.15
1st mm	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	
pt 12 Lich	nd	nd	4.03	10.08	1.59	2.07	0.70	nd	1.70	8.09	nd	8.74	63.01
pt 13 substrate	nd	nd	nd	33.33	nd	nd	nd	nd	nd	nd	nd	nd	66.67
pt14 looser substrate	nd	nd	20.55	16.21	nd	nd	nd	nd	nd	nd	nd	nd	63.24
pt15 lt gry	nd	nd	nd	nd	nd	nd	nd	nd	nd	12.76	nd	30.85	56.38
pt 16 ltr grey meandr	nd	nd	12.67	17.47	1.94	0.34	nd	1.53	0.40	0.90	nd	0.99	63.76
pt 17 med gry	nd	nd	4.27	8.52	nd	nd	nd	0.18	nd	20.76	nd	0.62	65.66
pt18 med gry	nd	nd	3.16	11.22	nd	nd	nd	nd	nd	19.38	nd	0.15	66.09
pt 19 lt grye	nd	nd	14.59	nd	15.86	nd	nd	nd	0.35	nd	nd	nd	69.19
pt20 ltgry angular	nd	nd	0.71	2.21	nd	nd	nd	nd	nd	0.36	nd	45.25	51.46
pt21 lt gry	nd	nd	3.34	2.61	nd	nd	nd	nd	nd	16.02	nd	17.88	60.15
pt22 lt grey	nd	nd	0.42	0.72	nd	nd	nd	nd	nd	32.04	nd	0.34	66.48
pt 23 lt grey	nd	nd	12.19	7.24	nd	nd	nd	nd	nd	5.30	nd	15.95	59.32
pt24 lt grey	nd	nd	6.24	3.07	0.47	nd	nd	nd	nd	11.79	nd	19.07	59.35

Minnesota Mn1a Lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Fe**	**O**
pt25 lt grey	nd	nd	10.76	10.34	11.44	nd	nd	nd	0.43	nd	nd	0.59	66.44
pt26 dk gry loose river	nd	nd	35.91	3.04	0.31	nd	nd	nd	nd	nd	nd	nd	60.73
pt27	nd	nd	1.56	0.97	nd	nd	nd	nd	nd	5.45		38.43	53.60
pt28 attached to	nd	nd	0.83	0.88	nd	nd	nd	nd	nd	3.52	0.22	42.10	52.46
pt29	nd	nd	14.34	4.73	4.92	2.22	nd	nd	1.15	5.54	nd	2.47	64.63
pt30 lt gry meandr	nd	nd	14.13	7.99	3.82	1.51	nd	nd	0.93	0.50	nd	8.95	62.16
pt31 lt grey nest	nd	nd	1.19	1.98	nd	nd	nd	nd	nd	2.43	nd	41.90	52.50
pt32 med grey	nd	nd	37.94	1.55	nd	nd	nd	nd	nd	nd	nd	nd	0.25
pt33	nd	nd	1.00	1.03	0.22	nd	nd	nd	nd	1.76	nd	44.19	51.81
pt34	nd	nd	15.79	6.50	5.50	2.44	nd	nd	1.60	0.44	nd	3.76	63.98
2nd mm	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt35 dk grey	nd	nd	40.00	nd	nd	nd	nd	nd	nd	nd	nd	nd	60.00
pt36 lt grey	nd	nd	1.99	0.61	nd	nd	nd	nd	nd	31.06	nd	nd	66.34
pt37	nd	nd	0.24	0.78	nd	nd	nd	nd	nd	32.16	nd	0.28	66.53
pt38	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.76	nd	48.86	50.38
pt39	nd	nd	2.80	nd	24.80	0.47	nd	nd	nd		nd	2.14	69.78
pt40	nd	nd	6.27	nd	nd	nd	nd	nd	nd	0.77	0.23	39.14	53.58
pt41	nd	nd	33.33	nd	nd	nd	nd	nd	nd	nd	nd	nd	66.67
pt42	nd	nd	6.81	0.60	nd	nd	nd	nd	nd	27.05	nd	nd	65.53
3rd mm	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt43	nd	nd	2.54	nd	nd	nd	nd	nd	nd	30.80	nd	nd	66.67
pt44	nd	nd	14.18	nd	nd	nd	nd	nd	nd	0.41	nd	28.12	57.29
pt45	nd	nd	4.71	nd	nd	nd	nd	nd	nd	28.21	nd	0.62	66.46
pt45	nd	nd	17.43	18.81	nd	nd	nd	nd	nd	nd	nd	nd	63.76
pt46	nd	nd	3.38	5.32	0.60	nd	nd	nd	nd	17.29	nd	10.81	62.60
pt47	nd	nd	13.12	nd	nd	nd	nd	nd	nd	nd	nd	30.31	56.56
pt48	1.54	nd	1.95	5.20	nd	nd	nd	nd	nd	0.41	nd	38.01	52.90

Minnesota Mn1a Lichen	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Fe**	**O**
pt49	1.36	nd	0.29		nd	nd	nd	nd	nd	0.51	nd	47.85	49.99
pt50 med grey adjac to lt gry	0.42	nd	0.24	0.30	nd	nd	nd	nd	nd	30.33	nd	3.44	65.27
pt51	1.41	0.45	0.27	0.26	nd	nd	nd	nd	nd	0.29	nd	47.32	49.99
pt52	0.75	nd	5.99	4.20	nd	nd	nd	nd	nd	23.37	nd	0.59	65.09
pt53 dk gry	0.81	nd	22.90	12.66	nd	nd	nd	nd	nd	0.99	nd	0.31	62.34
pt54 substrate	nd	nd	nd	33.14	0.17	nd	nd	nd	nd	nd	nd	nd	66.69
4th mm	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	
pt55	nd	nd	0.38	0.66	0.01	nd	nd	nd	nd	31.89	nd	0.70	66.37
pt56	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	50.00	50.00
pt57	nd	nd	nd	0.37	nd	nd	nd	nd	nd	32.97	nd	nd	66.67
pt58	nd	nd	7.71	2.87	nd	nd	nd	nd	nd	5.71	nd	27.49	56.22
pt59 dk grey	nd	nd	3.18	29.77	nd	nd	nd	nd	nd	0.37	nd	0.81	65.87
pt60	nd	nd	39.55		nd	nd	nd	nd	nd	nd	nd	0.57	59.89
pt61	nd	nd	15.51	20.12	nd	nd	nd	nd	nd	nd	nd	0.44	63.94
pt62 adj to pt63	nd	nd	0.30	0.25	nd	nd	nd	nd	nd	1.36	nd	47.20	50.88
pt63	nd	nd	0.18	0.66	nd	nd	nd	nd	nd	32.28	nd	0.36	66.52
pt64	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.41	nd	49.38	50.21
pt65 dk gry	nd	nd	39.47	0.44	nd	nd	nd	nd	nd	nd	nd	nd	60.09
Last mm	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt66	nd	nd	39.28	0.60	nd	nd	nd	nd	nd	nd	nd	nd	60.12
pt67	nd	nd			nd	nd	nd	nd	nd	0.92	nd	48.62	50.46
pt68	nd	nd	2.05	2.55	0.66	nd	nd	nd	nd	0.88	nd	41.13	nd

Minnesota MN1b No Lichen	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Cr	Fe	O
pt 1 surf substr	nd	nd		0.09	nd	nd	nd	nd	nd	nd	nd	nd	66.67
pt2 top surf	0.22	nd	14.29	17.24	0.43	0.10	0.05	0.05	0.08	3.20	nd	0.23	64.12
pt3 top surf	nd	nd	2.98	30.55	0.18	0.07	nd	nd	nd	nd	nd	nd	66.22
pt4 br spots at surf	0.27	nd	8.94	6.60	1.43	0.30	0.07	0.18	0.30	16.56	nd	0.30	65.04
pt5 loose dk gry	0.29	nd	19.19	16.67	0.19	nd	nd	nd	nd	nd	nd	0.46	63.20
pt6 med gry	0.13	nd	38.80	0.72	0.19	nd	nd	nd	nd	nd	nd	nd	60.17
pt7 br spot	12.14	nd	3.19	nd	nd	nd	nd	nd	nd	20.03	nd	nd	64.64
pt8 nest of br spots	0.23	nd	2.80	7.08	0.09	nd	nd	nd	nd	8.05	nd	23.48	58.27
pt9 blk spot	0.10	nd	3.04	29.99	0.14	0.25	0.10	0.27	0.14		nd	nd	65.96
pt10 big br spot	0.13	nd	0.36	1.45	nd	nd	nd	nd	nd	31.42	nd	0.16	66.49
pt11 blk spot	0.21	nd	1.16	31.40	0.19	0.44	0.15	nd	nd	nd	nd	nd	66.45
2nd mm	**Na**	nd	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Sc**	Cr	**Fe**	**O**
pt12 br spot	0.19	nd	1.54	13.20	15.15	nd	nd	nd	0.52	0.26	nd	0.77	68.37
pt13 br spto	nd	nd	0.48	0.33	nd	nd	nd	nd	nd	0.37	nd	48.36	50.47
pt14 br spto	0.67	nd	0.88	2.29	nd	nd	nd	nd	nd	4.45	nd	38.29	53.42
pt15 brt spot	nd	nd	0.90	0.61	0.12	nd	nd	nd	nd	1.25	nd	45.87	51.25
pt16 med gry strands	0.27	nd	38.79	0.71	nd	nd	nd	nd	nd	nd	nd	0.25	59.99
pt17 blk spot	0.09	nd	2.03	0.96	nd	0.11	0.02	0.03	nd	nd	nd		66.29
4th mm		nd									nd		
pt18 br spot	nd	nd	6.05	11.70	0.19	nd	nd	0.58	nd	0.96	nd	22.66	57.84
pt19 med gry loose	nd	nd	6.49	27.92	nd	nd	nd	nd	nd	nd	nd	nd	65.58
pt20 med grey loose	nd	nd	22.41	14.66	nd	nd	nd	nd	nd	nd	nd	nd	62.93
pt21 br spherre	nd	nd	2.94	1.19	nd	nd	nd	nd	nd	0.50	0.36	43.35	51.67
pt22 med grey cement	nd	nd	40.00	nd	nd	nd	nd	nd	nd	nd	nd	nd	60.00
last mm	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Cr**	**Fe**	**O**
pt23 med gry blobs	nd	nd	40.00	nd	nd	nd	nd	nd	nd	nd	nd	nd	60.00
pt24 granular med gry	nd	nd	16.83	18.53	nd	nd	nd	1.56	nd	nd	nd	nd	63.08
pt25 med grey	nd	nd	17.40	18.83	nd	nd	nd	nd	nd	nd	nd	nd	63.77
pt 26 brt spot	nd	nd	0.63	20.95	nd	nd	nd	nd	nd	nd	nd	17.79	60.63
pt27 brt spot	nd	nd	0.69	16.14	0.16	nd	nd	nd	nd	16.16	nd	0.40	66.45
pt28 brt spot	0.27	0.20	0.18	2.21	nd	nd	nd	nd	nd	8.47	nd	33.34	55.32
pt29 brit spt	0.95	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	48.58	50.47

Aus Geoffrey Bay - #1 - Less Lichen 11/13/04		Aus Geoffrey Bay No Lichen																		
	R-Value	**O**	**Na**	**Mg**	**Al**	**Si**	**S**	**Cl**	**P**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**	**Bi**	**Zr**	**Ag**	**La**	**Ce**
Surface Br Spots		58.99	nd	nd	8.63	2.52	nd	nd	nd	nd	0.34	5.82	nd	1.41	11.66	10.63	nd	nd	nd	nd
LtGryMatrix		50.52	nd	nd	0.35		nd	nd	nd	nd	nd	0.86	nd	nd	48.28	nd	nd	nd	nd	nd
MedGryMatrix	0.857	63.42	1.29	nd	7.87	23.85	nd	nd	nd	0.60	2.96	nd	nd	nd	nd	nd	nd	nd	nd	nd
Br Spots		61.13	0.35	nd	14.44	7.81	nd	nd	nd	nd	1.44	nd	nd	nd	nd	14.83	nd	nd	nd	nd
Br Spots		53.50	nd	nd	1.59	1.02	nd	nd	nd	nd	nd	1.91	nd	nd	35.44	6.54	nd	nd	nd	nd
Br Spots		50.67	nd	nd			nd	nd	nd	nd	nd	1.33	nd	nd	48.00	nd	nd	nd	nd	nd
LtGryMatrix		46.59	nd	nd	43.12	1.75	nd	nd	nd	nd	nd	0.77	nd	nd	7.77	nd	nd	nd	nd	nd
MedGryInclusion		59.68	nd	nd			nd	nd	nd	nd	nd	19.36	nd	5.06	15.89	nd	nd	nd	nd	nd
Grymatrix		59.31	nd	nd	4.46	18.47	nd	nd	nd	11.13	nd	3.50	nd	0.68	2.45	nd	nd	nd	nd	nd
MedGryRibbon		58.74	nd	nd	0.32	0.55	nd	nd	11.17	nd	29.22	nd	nd	nd	nd	nd	nd	nd	nd	nd
MedGry Inclusion		59.26	nd	nd	5.27	22.41	nd	nd	nd	13.06	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Medgry Matrix		64.73	1.70	nd	6.52	27.05	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
DkGry Matrix		64.01	1.71	nd	6.38	26.42	nd	nd	nd	1.47	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
DkGry Matrix		64.25	1.22	nd	6.85	25.68	nd	nd	nd	nd	2.01	nd	nd	nd	nd	nd	nd	nd	nd	nd
Matrix		65.97	nd	nd	1.28	29.85	nd	nd	nd	nd	nd	nd	nd	nd	nd	2.89	nd	nd	nd	nd
pt Brite spot		60.28	nd	nd	3.93	1.40	nd	nd	nd	nd	nd	nd	nd	nd	nd	34.39	nd	nd	nd	nd
Big brite spot	0.549	64.50	1.35	nd	7.02	26.33	nd	nd	nd	0.35	0.44	nd	nd	nd	nd	nd	nd	nd	nd	nd
Grymatrix		64.13	1.26	nd	7.31	25.24	nd	nd	nd	nd	2.07	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt grymatrix		66.67	nd	nd	nd	33.33	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt grymatrix		65.39	nd	nd	0.90	28.54	1.67	1.54		nd	1.96	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt dk grey inclusion Cpk		59.12	nd	nd	5.99	21.80	nd	nd	nd	13.09		nd	nd	nd	nd	nd	nd	nd	nd	nd
pt lt grey matrix		66.36	nd	nd	0.23	32.61	nd	nd	nd	nd	0.79	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt med grey matrix		50.61	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.23	nd	0.55	47.61	nd	nd	nd	nd	nd
pt lg brite crystal		66.67	nd	nd	nd	nd	nd	nd	nd	33.33	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
med gry matrix		59.35	nd	nd	5.22	22.54	nd	nd	nd	12.89	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
lt gry matrix		50.00	nd	nd	nd	nd	nd	nd	nd	nd	0.36	nd	nd		49.64	nd	nd	nd	nd	nd
pt lg brt crystal surf	1.911	63.12	0.95	nd	5.38	20.91	3.17	1.51	nd	3.41	1.54	nd	nd	nd	nd	nd	nd	nd	nd	nd
pt carbon pk dk gry	0.876	63.53	1.79	nd	7.84	24.54	nd	nd	nd	1.00	1.30	nd	nd	nd	nd	nd	nd	nd	nd	nd

Aus Geoffrey Bay - #1 - Less Lichen 11/13/04		Aus Geoffrey Bay No Lichen																		
	R-Value	O	Na	Mg	Al	Si	S	Cl	P	K	Ca	Ti	Cr	Mn	Fe	Bi	Zr	Ag	La	Ce
pt lt grey matrix		65.65	nd	0.58	nd	30.49	nd	nd	nd	nd	nd	nd	nd	nd	1.69	1.60	nd	nd	nd	nd
pt Brite spot		56.30	nd	2.59	3.83	12.89	nd	0.40	nd	7.93	nd	2.15	nd	0.79	13.12	nd	nd	nd	nd	nd
pt lt grey matrix;biotite		64.31	1.57	nd	6.74	26.04	nd	nd	nd		1.33	nd	nd	nd	nd	nd	nd	nd	nd	nd
med grey matrix		59.23	0.24	nd	5.41	22.29	nd	nd	nd	12.83	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
med gry matrix		63.54	1.91	nd	7.08	24.49	nd	nd	nd		2.16	nd	nd	nd	0.83	nd	nd	nd	nd	nd
med gry matrix		59.04	nd	nd	5.52	22.00	nd	nd	nd	13.36	0.08	nd	nd	nd	nd	nd	nd	nd	nd	nd
med gry matrix		79.59	nd	nd	0.30	0.66	nd	nd	nd	nd	19.45	nd	nd	nd	nd	nd	nd	nd	nd	nd
med gry inclusion		59.70	nd	nd	nd	nd	nd	nd	nd	nd	nd	19.40	nd	6.95	13.95	nd	nd	nd	nd	nd
2nd mm		64.34	nd	nd	nd	27.93	nd	nd	nd	1.68	0.66	1.11	nd	nd	3.31	0.97	nd	nd	nd	nd
brite spot		66.93	nd	nd	nd	14.01	nd	nd	1.55	nd	nd	nd	nd	nd	nd	nd	17.51	nd	nd	nd
brite crystal		59.88	nd	nd	0.15	0.33	nd	nd	nd	nd	nd	19.35	nd	5.73	14.56	nd	nd	nd	nd	nd
lt gry crystal		70.70	nd	nd	0.95	nd	nd	nd	26.19	nd	nd	1.18	nd	nd	0.99	nd	nd	nd	nd	nd
med grey inclusion		59.87	nd	nd	0.94	1.31	nd	nd	nd	0.60	0.78	18.26	nd	6.14	12.10	nd	nd	nd	nd	nd
blk round inclusion		56.53	nd	2.31	4.18	13.03	nd	nd	nd	7.97	nd	1.93	nd	0.76	13.29	nd	nd	nd	nd	nd
lt-med gry matrix	0.707	64.26	1.41	nd	6.68	26.03	nd	nd	nd	0.29	1.32	nd	nd	nd	nd	nd	nd	nd	nd	nd
dk gry matrix		33.10	nd	nd	nd	nd	nd	nd	18.39	0.52	47.99	nd	nd	nd	nd	nd	nd	nd	nd	nd
lt gry inclusion		60.03	nd	nd	5.32	22.13	nd	nd	nd	12.53	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
med gry matrix		60.22	nd	nd	0.16	0.21	nd	nd	nd	nd	nd	20.15	nd	6.73	12.51	nd	nd	nd	nd	nd
br long crystal		59.78	nd	nd		0.29	nd	nd	nd	nd	nd	19.27	nd	11.89	8.77	nd	nd	nd	nd	nd
br angular crystal		59.85	nd	nd	0.90	4.19	nd	nd	nd	2.52	nd	16.33	nd	8.93	7.28	nd	nd	nd	nd	nd
rec brt inclusion		60.03	nd	nd	0.54	1.67	nd	nd	nd	nd	nd	18.13	nd	7.34	12.29	nd	nd	nd	nd	nd
rec brt inclusion		59.21	nd	nd	0.56	1.73	nd	nd	9.82	nd	24.88	1.67	nd	0.68	1.45	nd	nd	nd	nd	nd
rhomboid shape	0.842	63.90	1.66		6.58	25.48	nd	nd	nd	0.28	1.66	nd	nd	nd	0.44	nd	nd	nd	nd	nd
dk gry matrix		57.46	nd	3.35	5.33	13.54	nd	0.21	nd	4.08	nd	0.95	nd	0.45	14.63	nd	nd	nd	nd	nd
med gry matrix		58.29	nd	2.34	5.11	12.51	1.62	1.93	nd	1.57	3.08	0.98	nd		12.58	nd	nd	nd	nd	nd
triangle blk inclusion		57.66	nd	4.11	5.81	12.72	nd	nd	nd	1.08	nd	0.23	nd	0.68	17.71	nd	nd	nd	nd	nd
Medgry striated matrix		59.12	nd	nd	5.29	22.09	nd	nd	nd	13.33	nd	0.17	nd			nd	nd	nd	nd	nd
med gry matrix		60.67	nd	nd	1.15	3.92	nd	nd	nd	nd	nd	16.93	nd	6.65	10.74	nd	nd	nd	nd	nd

Aus Geoffrey Bay - #1 - Less Lichen 11/13/04		Aus Geoffrey Bay No Lichen																		
	R-Value	**O**	**Na**	**Mg**	**Al**	**Si**	**S**	**Cl**	**P**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**	**Bi**	**Zr**	**Ag**	**La**	**Ce**
long brite ovals		64.67	1.87	nd	6.40	27.07	nd	nd	nd	nd			nd			nd	nd	nd	nd	nd
med gry matrix	0.44	61.12	0.85	nd	13.84	15.67	nd	nd	nd	2.02	0.39	1.09	nd	0.49	4.52	nd	nd	nd	nd	nd
med gry connector		50.93	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.87	nd	0.63	46.56	nd	nd	nd	nd	nd
brite crystal		59.39	nd	nd	nd	nd	nd	nd	nd	nd	nd	18.77	nd	2.40	19.44	nd	nd	nd	nd	nd
pt brt crystal		59.04	nd	nd	0.40	1.28	nd	nd	11.07	nd	28.22	nd	nd	nd	nd	nd	nd	nd	nd	nd
med gry circle		59.32	nd	nd	5.85	22.09	nd	nd		12.74		nd	nd	nd	nd	nd	nd	nd	nd	nd
dk-med grey inclusion	1.1	62.89	1.55	nd	7.77	22.97	nd	nd	nd	0.61	4.22	nd	nd	nd	nd	nd	nd	nd	nd	nd
dk gry matrix		55.18	nd	nd	7.04	5.24	nd	nd	nd	nd	3.09	nd	3.19	0.40	25.86	nd	nd	nd	nd	nd
brt spots - streak of	###	60.80	0.65	nd	10.01	14.37	nd	nd	nd	nd	9.07	nd	nd	nd	nd	5.11	nd	nd	nd	nd
brt spots - streak of	0.99	62.04	0.97	nd	8.14	18.23	nd	nd	nd	0.53	5.01	nd	nd	nd	nd	5.08	nd	nd	nd	nd
brt spots - streak of	0.87	63.10	1.15	nd	8.43	22.84	nd	nd	nd	0.58	3.91	nd	nd	nd	nd	nd	nd	nd	nd	nd
dk gry matrix		66.50	nd	nd	0.34	15.29	nd	nd	1.78	0.55	0.39	nd	nd	nd	nd	nd	15.15	nd	nd	nd
med gry inclusion		59.27	nd	nd	0.38	0.49	nd	nd	nd	nd	nd	17.85	nd	2.53	19.48	nd		nd	nd	nd
medgry round inclusions	1.17	63.47	0.86	nd	6.84	23.02	0.78	nd	nd	1.27	3.75	nd	nd	nd	nd	nd	nd	nd	nd	nd
blk round inclusion		59.32	0.19	nd	5.65	22.23	nd	nd	nd	12.61	nd		nd	nd	nd	nd	nd	nd	nd	nd
ltr dk grey matrix		59.52	nd	nd	nd	nd	nd	nd	nd	nd	nd	19.04	nd	5.77	15.68	nd	nd	nd	nd	nd
pt brt crystal		51.41	nd	nd	nd	0.52	nd	nd	nd	nd	nd	2.31	nd	0.87	44.88	nd	nd	nd	nd	nd
brite crystal		60.31	nd	nd	3.18	1.55	nd	nd	nd	nd	nd	nd	nd	nd	nd	34.96	nd	nd	nd	nd
last mm; brite spot		60.19	nd	nd	1.67	0.94	nd	nd	nd	nd	nd	nd	nd	nd	nd	37.21	nd	nd	nd	nd
brite spot	0.89	63.62	1.45	nd	7.40	24.64	nd	nd	nd	0.77	2.12	nd	nd	nd	nd	nd	nd	nd	nd	nd
dk gry matrix		60.41	nd	nd	36.36	2.64	nd	nd	nd	nd	0.59	nd	nd	nd	nd	nd	nd	nd	nd	nd
med gry rubble		59.19	nd	nd	5.20	22.40	nd	nd	nd	13.21	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
ltr dk grey matrix		66.67	nd	nd	nd	33.33	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
dk gry matrix		58.77	nd	nd	5.58	21.71	nd	nd	nd	13.93	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
ltr dk grey matrix		61.87	nd	nd	5.71	9.34	nd	nd	nd	nd	nd	nd	nd	nd	nd	23.08	nd	nd	nd	nd
last mm brt spot		59.31	0.28	nd	5.43	22.36	nd	nd	nd	12.61	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
dk gry matrix		66.67	nd	nd	nd	33.33	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
dk gry matrix		61.24	nd	nd	11.77	16.71	3.39	6.89	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
blk round inclusion		66.67	nd	nd	nd	33.33	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
dk gry matrix		62.54	nd	nd	1.93	12.72	nd	nd	nd	nd	nd	nd	nd	nd	nd	22.81	nd	nd	nd	nd

Aus Geoffrey Bay - #1 - Less Lichen 11/13/04		Aus Geoffrey Bay No Lichen																		
	R-Value	**O**	**Na**	**Mg**	**Al**	**Si**	**S**	**Cl**	**P**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**	**Bi**	**Zr**	**Ag**	**La**	**Ce**
brt spot		63.94	nd	nd	nd	19.71	nd	nd	nd	nd	nd	nd	nd	nd	nd	16.35	nd	nd	nd	nd
brt spot		59.05	nd	nd	5.24	22.22	nd	nd	nd	13.49	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
ltr dk grey matrix		62.05	nd	nd	4.91	21.72	nd	nd	nd	5.06	0.60	2.46	nd	0.82	2.38	nd	nd	nd	nd	nd
pt med gry oval/mixed		64.19	nd	nd	0.75	2.08	nd	nd	10.85	nd	nd	nd	nd	nd	nd	nd	nd	1.41	6.20	14.51
spots on oval		63.82	nd	nd	6.19	21.86	nd	nd	nd	0.36	1.52	2.86	nd	0.95	2.43	nd	nd	nd	nd	nd
spots on oval		58.67	nd	nd	nd	nd	nd	nd	11.44	0.25	29.33	0.30	nd	nd	nd	nd	nd	nd	nd	nd
spots on oval		65.59	nd	nd	nd	29.06	nd	nd	nd	nd	nd	2.12	nd	0.55	2.68	nd	nd	nd	nd	nd
spots on oval		64.49	nd	nd	nd	1.30	nd	nd	12.77	nd	nd	8.52	nd	2.80	10.12	nd	nd	nd	nd	nd
spots on oval		58.96	nd	nd	nd	nd	nd	nd	11.95	nd	29.09	nd	nd	nd	nd	nd	nd	nd	nd	nd
spots on oval		66.67	nd	nd	nd	14.35	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	18.99	nd	nd	nd
spots on oval	0.815	63.95	1.28	nd	6.83	25.32	nd	nd	nd	0.38	2.25	nd	nd	nd	nd	nd	nd	nd	nd	nd
dk gry matrix		59.20	nd	nd	5.53	21.91	nd	nd	nd	12.57		nd	nd	nd	0.79	nd	nd	nd	nd	nd
ltr dk grey matrix		50.51	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.01		0.50	47.98	nd	nd	nd	nd	nd
pt lt grey inclusion		61.74	0.66	nd	5.92	24.46	nd	nd	nd	7.22	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
ltr dk grey matrix	0.9	63.83	1.75	nd	6.87	25.33	nd	nd	nd	0.46	1.75	nd	nd	nd	nd	nd	nd	nd	nd	nd
brite spot		60.00	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	40.00	nd	nd	nd	nd
blk inclusion		63.46	1.49	nd	4.80	19.96	3.55	2.83	nd	nd	2.88	1.04	nd	nd	nd	nd	nd	nd	nd	nd

Au Geoffrey Bay - 1a Lichen																	
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Zr**	**Ba**	**La**	**Ce**	**Bi**
surf-1 mm	63.64	1.02	nd	10.95	22.44	nd	nd	nd	0.28	1.25	nd	nd	0.42	nd	nd	nd	nd	nd
pt	62.87	0.67	nd	12.25	20.11	nd	nd	nd	0.31	2.32	nd	nd	1.48	nd	nd	nd	nd	nd
pt lich	63.13	0.36	nd	12.6	20.3	nd	nd	nd	0.31	0.56	nd	nd	2.73	nd	nd	nd	nd	nd
Brte spot	63.87	1.42	nd	6.67	21.3	nd	1.99	nd	0.34	1.77	nd	nd	nd	nd	2.64	nd	nd	nd
surf - lich	63.61	0.39	nd	14.43	20.38	nd	nd	nd	0.36	0.43	nd	nd	0.4	nd	nd	nd	nd	nd
matrix	63.71	1.67	nd	7.55	24.74	nd	nd	nd	0.51	1.81	nd	nd	nd	nd	nd	nd	nd	nd
brtspot-Lich	62.25	0.2	nd	13.35	16.33	1.14	nd	nd	0.23	nd	nd	0.54	5.79	nd	0.18	nd	nd	nd
brit spot	62.93	1.16	nd	6.68	21.05	nd	nd	nd	0.83	2.4	nd	nd	nd	nd		nd	nd	4.95
Lich	62.66	nd	nd	13.95	17.41	1.36	nd	nd	2.23	nd	nd	0.91	nd	nd	1.47	nd	nd	nd
brt spot	61.04	nd	nd	2.27	5.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	31.5
blk spot	61.04	nd	nd	2.27	5.2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	31.5
Matrix	59	nd	nd	5.46	22.03	nd	nd	nd	13.5	nd	nd	nd	nd	nd	nd	nd	nd	nd
Matrix	64.77	1.65	nd	6.43	27.15	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Lichen	63.88	1.09	nd	6.79	21.55	1.91	0.67	nd	1.7	2.41	nd	nd	nd	nd	nd	nd	nd	nd
brt spot	54.61	nd	nd	nd	nd	nd	2.53	nd	nd		nd	nd	nd	nd	nd	nd	nd	42.86
lichen ph1	2.19	nd	nd	nd	nd	nd	nd	95.62	nd	2.19	nd	nd	nd	nd	nd	nd	nd	nd
Lichen	63.93	nd	nd	8.22	20.63	2.89	nd	1.23	nd	3.1	nd	nd	nd	nd	nd	nd	nd	nd
Surface	63.57	1.39	nd	8.62	23.68	0.5	nd	nd	1.79	0.45	nd	nd	nd	nd	nd	nd	nd	nd
brt inclusion	50	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	50	nd	nd	nd	nd	nd
med gry matrix	63.25	0.89	nd	12.3	20.79	nd	nd	nd		nd	nd	nd	2.77	nd	nd	nd	nd	nd
ltr gry matrix	58.72	nd	nd	5.43	21.77	nd	nd	nd	14.08	nd	nd	nd	nd	nd	nd	nd	nd	nd
lichen	51.24	nd	nd		2.49	nd	nd	nd	nd	46.27	nd	nd	nd	nd	nd	nd	nd	nd
Matrix/ph3	57.19	nd	nd	5.09	20.46	nd	nd	nd	17.27		nd	nd	nd	nd	nd	nd	nd	nd
brit circle	52.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	5.59	2.18	39.43	nd	nd	nd	nd	nd
sm brite spot	65.3	nd	nd	nd	2.08	12.21	nd	nd	nd	nd	nd	nd	nd	nd	nd	6.68	10.5	nd
crumbly oval	65.11	0.71	nd	3.32	29.56	nd	nd	nd	1.31	nd	nd	nd	nd	nd	nd	nd	nd	nd
Med grey ribbon	66.53	nd	nd	0.81	32.66	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Au Geoffrey Bay - 1a Lichen

Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Zr**	**Ba**	**La**	**Ce**	**Bi**
2nd mm ltgry square	59.82	nd	nd	nd	nd	nd	nd	nd	nd	nd	19.64	4.49	16.05	nd	nd	nd	nd	nd
ltgry oval	66.21	nd	nd	nd	13.51	nd	nd	nd	nd	nd	0.93		1.37	17.99		nd	nd	nd
dkgry matrix	63.73	1.36	nd	6.82	25.03	nd			0.58	2.47				nd	nd	nd	nd	nd
med gry rec mass	56.03	nd	2.26	3.66	12.87	nd	nd	0.36	8.31	nd	1.87		14.64	nd	nd	nd	nd	nd
L shape inclusion	60.16	nd	0.35	0.96	1.62	nd	nd	nd	nd	nd	18.22	5.86	12.82	nd	nd	nd	nd	nd
matrix around L	64.57	1.15	nd	6.67	25.72	nd	nd	nd	nd	1.23	0.66			nd	nd	nd	nd	nd
gry sq	50	nd	nd	nd	nd	nd	nd	nd	nd	nd			50	nd	nd	nd	nd	nd
gry inclusion	59.62	nd	nd	nd	nd	nd	nd	nd	nd	nd	19.23	4.99	16.16	nd	nd	nd	nd	nd
3.5 mm below surf C-peak round blk circle ph3	60.77	0.99	nd	3.97	21.61	nd	1.56	nd	9.36	nd	nd	nd	1.73	nd	nd	nd	nd	nd
C-Peak blk oval	67.29	nd	nd		30.84	nd	1.87	nd	nd	nd	nd	nd	nd	nd	nd	nd		nd
thin gry ribbon	64.01	nd	nd	8.73	16.87	1.59	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	8.8	nd
C-peak black spot ph3/4	65.93	nd	nd	3.51	24.65	nd	3.79	2.12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
matrix	60	nd	nd	40		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
matrix	58.83	nd	nd	5.73	21.67	nd	nd	nd	13.77	nd	nd	nd	nd	nd	nd	nd	nd	nd
2nd mm C-Peak black circ	61.11	nd	nd	9.48	17.89	nd	2.41	1.34	7.77	nd	nd	nd	nd	nd	nd	nd	nd	nd
2mm C-Peak black cir	62.05	0.69	nd	5.04	22.03	nd	1.99		8.19	nd	nd	nd	nd	nd	nd	nd	nd	nd
C-Peak blk spot grouping ph5 (5mm below surf)	61.03	nd	nd	6.24	20.66	nd	1.73	nd	10.34	nd	nd	nd	nd	nd	nd	nd	nd	nd
bottom mm blk circ C-Peak	69.29	nd	nd	2.51	19.08	nd	9.12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
matrix	64.32	0.98	nd	6.71	25.77	nd	nd	nd	nd	2.22	nd	nd	nd	nd	nd	nd	nd	nd
matrix	59.63	nd	nd	5.47	22.65	nd	nd	nd	12.25		nd	nd	nd	nd	nd	nd	nd	nd
gry inclusion	57.78	nd	nd		16.37	nd	nd	nd	1.62	1.29	nd	22.94	nd	nd	nd	nd	nd	nd
gry spot	61.68	nd		4.12	12.1	nd	nd	nd		3.7	nd	nd	nd	nd	nd	11.98	nd	nd
med gry inclusion	57.16	nd	2.32	3.93	14.9	nd	nd	nd	8.07		1.5		12.12	nd	nd	nd	nd	nd
med gry inclusion	59.55	nd				nd	nd	nd	nd	nd	19.09	5.8	15.57	nd	nd	nd	nd	nd
blk oval inside above	66.67	nd	nd	nd	33.33	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Au Geoffrey Bay - 1a Lichen																		
Point Name	**O**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**K**	**Ca**	**Ti**	**Mn**	**Fe**	**Zr**	**Ba**	**La**	**Ce**	**Bi**
med gry circle	58.05	nd	nd	nd	nd	10.73	nd	nd	nd	31.22	nd	nd	nd	nd	nd	nd	nd	nd
gry square	50	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	50	nd	nd	nd	nd	nd
matrix	59.16	nd	nd	4.97	22.51	nd	nd	nd	13.35	nd	nd	nd	nd	nd	nd	nd	nd	nd
med grey inclusion	60.64	nd	nd		0.75	nd	nd	nd	0.4	nd	20.73	3.12	14.36	nd	nd	nd	nd	nd
gry spot	66.67	nd	nd	nd	33.33	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
crystal	59.25	nd	nd	nd	nd	nd	nd	nd	nd	nd	18.51	5.45	16.79	nd	nd	nd	nd	nd
crystal	66.67	nd	nd	nd	15.54	nd	nd	nd	nd	nd	nd	nd	nd	17.8	nd	nd	nd	nd
blk oval on crystal	58.38	nd	nd	nd	nd	11.17	nd	nd	nd	30.46	nd	nd	nd	nd	nd	nd	nd	nd
matrix	58.47	nd	nd	5.2	21.67		nd	nd	14.66	nd	nd	nd	nd	nd	nd	nd	nd	nd
matrix	62.06	1.03	nd	5.2	25.26	nd	nd	nd	6.44	nd	nd	nd	nd	nd	nd	nd	nd	nd
med grey sq	50.82	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.65	nd	47.53	nd	nd	nd	nd	nd
med grey crystal	50.37	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.74	nd	48.88	nd	nd	nd	nd	nd
med-dk grey matrix	57.01	nd	3.47	5.1	12.83	nd	nd	nd	2.74	nd	nd	0.95	17.9	nd	nd	nd	nd	nd
matrix	64.1	2.03	nd	6.74	25.85		nd	nd	nd	1.28	nd	nd	nd	nd	nd	nd	nd	nd

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2003-2005	Student Editor, Texas A&M University, Information Technology Issues Management, College Station, Texas.
2000-2003	Research Technician, University of Houston, Texas Center for Superconductivity and Materials Science Research.
1991-1998	Zone Archaeologist and Program Manager, Comanche and Cimarron National Grasslands, USDA Forest Service.
1988-1991	Zone Archaeologist, Black Hills National Forest, Custer, South Dakota.
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PUBLICATIONS

2006	First Lady of the New World: Arlington Springs Woman. *Mammoth Trumpet* 21:4, Center for the Study of First Americans, College Station, Texas.
2000	*Overview of Conservation Treatments Applied to Rock Glyph Archaeological Sites.* Master's Thesis, Department of Anthropology, Texas A&M University, College Station, Texas.
2003	The Degradation of Rock Art by Lichen Processes (with James K. Meen). In *American Indian Rock Art,* edited by A. Woody and J. T. O'Connor, 29:43-52. American Rock Art Association, Phoenix, Arizona.
1999	Vogel Canyon: A Case History of Federal Agency Rock Art Resource Management (with Allen E. Kane) in *Images Past, Images Present: The Conservation and Preservation of Rock Art,* edited by J. C. Dean, 2:27-32. American Rock Art Research Association, Tucson, Arizona.
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