

Utah State University

DigitalCommons@USU

All Graduate Theses and Dissertations

Graduate Studies

12-2008

Combining Environmental History and Soil Phytolith Analysis at the City of Rocks National Reserve: Developing New Methods in Historical Ecology

Lesley Morris
Utah State University

Follow this and additional works at: <https://digitalcommons.usu.edu/etd>

 Part of the [Biology Commons](#), [Botany Commons](#), and the [United States History Commons](#)

Recommended Citation

Morris, Lesley, "Combining Environmental History and Soil Phytolith Analysis at the City of Rocks National Reserve: Developing New Methods in Historical Ecology" (2008). *All Graduate Theses and Dissertations*. 35.

<https://digitalcommons.usu.edu/etd/35>

This Dissertation is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.



COMBINING ENVIRONMENTAL HISTORY AND SOIL PHYTOLITH ANALYSIS
AT THE CITY OF ROCKS NATIONAL RESERVE: DEVELOPING
NEW METHODS IN HISTORICAL ECOLOGY

by

Lesley R. Morris

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Ecology

Approved:

Dr. Ronald J. Ryel
Major Professor

Dr. Neil West
Committee Member

Dr. Fred Baker
Committee Member

Dr. John Malechek
Committee Member

Dr. Christopher Conte
Committee Member

Dr. Byron Burnham
Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2008

Copyright © Lesley R. Morris 2008

All Rights Reserved

ABSTRACT

Combining Environmental History and Soil Phytolith Analysis
at the City of Rocks National Reserve: Developing
New Methods in Historical Ecology

by

Lesley R. Morris, Doctor of Philosophy

Utah State University, 2008

Major Professor: Dr. Ronald J. Ryel
Department: Wildland Resources

Historical ecology is an emerging and interdisciplinary field that seeks to explain the changes in ecosystems over time through a synthesis of information derived from human records and biological data. The methods in historical ecology cover a wide range of temporal and spatial scales. However, methods for the more recent past (about 200 years) are largely limited to the human archive and dendrochronological evidence, which can be subject to human bias, limited in spatial extent or not appropriate for non-forested systems. There is a need to explore new methods by which biological data can be used to understand historic vegetation and disturbance regimes over the recent past especially in arid ecosystem types. Soil phytolith analysis has the potential to provide much needed information regarding historical conditions in both areas. Phytoliths are structures formed in plants through deposition and accumulation of silica within and around cell walls that are released from plants and preserved in sediments long after death and decay

of plant material. The City of Rocks National Reserve in southern Idaho was an excellent place to develop new methods in historical ecology because the human records of historic environmental conditions were so rich. There were two overarching and interconnected objectives for this dissertation research. The first was to reconstruct an ecological history of the City of Rocks National Reserve from the period of overland emigration to present. The second objective was to explore the utility of soil phytolith analysis for inferring vegetation and disturbance regime change over the recent past by testing its sensitivity to record known changes. I employed modern analogue studies, a multi-core approach and detailed core analysis to test for known changes through analysis of extraction weights, relative abundance of phytolith assemblages, microscopic charcoal and burned (darkened) phytoliths. My results showed that this combination of history and soil phytolith analysis can be useful for inferring vegetation changes (e.g. increases in introduced grasses) and disturbances (e.g. fire) in ecological histories.

(320 pages)

ACKNOWLEDGMENTS

This research was funded by a Doctoral Dissertation Improvement Grant from the National Science Foundation, the National Park Service, Idaho State Parks and Recreation, the Ecology Center at Utah State University, and a College of Natural Resources S.J. and Jessie E. Quinney Doctoral Fellowship.

I want to acknowledge the many people who helped with this project at Utah State University. I appreciated the commitment from both Neil West, who retired as my dissertation advisor part way into this project, and Ron Ryel, who guided me through to the end. Thank you to the rest of my dissertation committee: John Malecheck, Fred Baker, and Chris Conte. Many thanks to Marvin Bennett and Stephanie White, in the Ecology Center, and to Mary Barkworth and Michael Piep, at the Intermountain Herbarium. Helga Van Miegroet provided access to her laboratory and equipment. Darryl DeWald and Richard Mueller lent me microscopes. Chris and Ellie McGinty gave me patient assistance with maps and graphics. Field and laboratory assistance was provided by: Christo Morris, Jenny Wolfgram, Heather Wolfgram, Hayley Olsen, Jen Minnick, Stephanie Ashby, and Sean Kelly.

Special thanks to Wallace Keck, superintendent, Brad Shilling, Venna Ward, and Juanita Jones at the City of Rocks National Reserve. Special thanks also to the wonderful people of Almo and Elba! Special thanks to all of the oral history participants for hours of discussion, laughs, and hospitality! Marion and Buddy Ward, at the Old Homestead Bed and Breakfast, and Darla and Darwin Bywater, at the Almo Creek Outpost, treated me

like family. Special thanks to Mic Nicholson, Harold O. and Lorryne Ward, Bill and Phyllis Tracy, and J.R. Simplott for access to private property.

Thanks, also, to the many staff members, librarians, and archivists who assisted me including: Patty McNamee at the National Archives and Records Administration Pacific Alaska Regional Office in Seattle, the staff at the Idaho State Historical Society, Doug Misner from the Utah State Historical Society, Nancy Ady and Jim Tharp at the Burley District Office of the Bureau of Land Management, John Mark Lambertson at the Merrill Mattes Library, and Jim Riehl from Oregon California Trails Association.

Mikhail Blinnikov from St. Cloud State University, Minnesota, trained me in phytolith extraction and identification. Linda Scott-Cummings from the PaleoResearch Institute in Boulder, Colorado, visited me here in Logan.

And last but not least, thanks to family for all of their support. Especially my husband, Christo Morris, who has traveled with me, collected plants and soil cores, counted phytoliths, provided information on the introduction and extent of introduced plants, proofread chapters, offered his weed collection for phytolith analysis, and encouraged me the whole way. You're the best!

Lesley Morris

CONTENTS

	Page
ABSTRACT.....	iii
ACKNOWLEDGMENTS	v
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF PLATES	xiii
CHAPTER	
1. INTRODUCTION	1
Research objectives and questions.....	3
Research design and methodology.....	3
Chapter previews	4
References.....	10
2. PHYTOLITHS: “JEWELS OF THE PLANT WORLD”	12
Introduction.....	12
Physiology: production and function.....	13
Extraction, identification, and classification.....	15
Issues, theory, and use	18
Analysis and interpretation	25
Conclusion	26
References.....	27
3. THE “LAND WITNESS”: TEMPORARY LANDSCAPES OF THE CITY OF ROCKS NATIONAL RESERVE.....	31
Introduction.....	31
Study area.....	35
Native American use and occupation	38
European exploration and emigration.....	40
Period of survey and settlement.....	46
The beginning of regulation (1900-1929).....	56
Period of range management	64
Recognition, preservation, and changing uses.....	71

	Interpretation of vegetation changes	79
	Conclusion	84
4.	PHYTOLITH TYPES AND TYPE-FREQUENCIES IN NATIVE AND INTRODUCED SPECIES OF THE SAGEBRUSH STEPPE AND PINYON-JUNIPER WOODLANDS OF THE GREAT BASIN, USA ..	123
	Abstract	123
	Introduction	124
	Study area	125
	Methods	126
	Results and discussion	129
	Native forbs	130
	Native grasses, rushes, and sedges	138
	Native trees and shrubs	144
	Introduced forbs	145
	Introduced grasses	151
	Introduced trees	157
	Conclusion	158
	References	161
5.	DEVELOPING AN APPROACH FOR USING THE SOIL PHYTOLITH RECORD TO INFER VEGETATION AND DISTURBANCE REGIME CHANGES OVER THE PAST 200 YEARS CONCLUSION	183
	Abstract	183
	Introduction	184
	Regional setting	189
	Materials and methods	190
	Results	193
	Discussion	196
	Conclusion	200
	References	201
6.	CAN SOIL PHYTOLITH ANALYSIS AND CHARCOAL BE USED AS INDICATORS OF HISTORIC FIRE IN THE PINYON-JUNIPER AND SAGEBRUSH STEPPE ECOSYSTEM TYPES OF THE GREAT BASIN DESERT REGION, USA?	211
	Abstract	211
	Introduction	212
	Study area	215
	Methods	218
	Results	221

Discussion.....	223
Conclusion	228
References.....	229
7. TESTING SOIL PHYTOLITH ANALYSIS AS A TOOL TO UNDERSTAND VEGETATION CHANGE IN THE SAGEBRUSH STEPPE AND PINYON-JUNIPER WOODLANDS OF THE GREAT BASIN DESERT REGION	243
Abstract.....	243
Introduction	244
Study area.....	248
Methods.....	254
Results.....	260
Discussion.....	266
Conclusion	277
References.....	278
8. CONCLUSIONS AND FUTURE RESEARCH	296
Conclusions	296
Future research.....	298
Significance of this research	300
APPENDIX.....	301
CURRICULUM VITAE.....	304

LIST OF TABLES

Table	Page
4-1 List of all native species examined in this study.....	167
4-2 List of all introduced species examined in this study	169
4-3 Production frequency (in percent) of phytolith morphotypes found in common native Great Basin grasses	171
4-4 Production frequency (in percent) of phytolith morphotypes found in common introduced Great Basin grasses.....	172
5-1 Common grasses, trees and shrubs of the Great Basin analyzed for phytoliths ..	206
5-2 Common forbs of the Great Basin analyzed for phytoliths	207
6-1 Results from carbon dating segments from soil cores at Sites A, E, and H.....	234
7-1 Morphotype frequencies of the ten native and introduced grasses in CIRO	285
7-2 Results of radiocarbon dating	286
7-3 Detailed core analysis results from Site 1A.....	287
7-4 Detailed core analysis results from Site 3.....	288

LIST OF FIGURES

Figure	Page
3-1 Vicinity maps for the City of Rocks National Reserve.....	87
3-2 Five year running average precipitation for the study area.....	88
3-3 Homesteads in the City of Rocks National Reserve	89
3-4 City of Rocks National Reserve.....	90
3-5 Hectares burned per decade in the City of Rocks National Reserve	91
4-1 Map of the western portion of the United States showing the Great Basin Floristic Region.....	173
5-1 Map of the western United States showing the Great Basin ecoregion boundaries and the location of the City of Rocks National Reserve in southern Idaho.....	208
5-2 Phytoliths from <i>Alyssum desertorum</i>	209
5-3 Phytoliths from a) <i>Erigeron divergens</i> , 400x and b) <i>Mertensia oblongifolia</i> , 400x	209
5-4 Results from the Burned Phytolith Index analysis.....	210
6-1 City of Rocks National Reserve showing all mapped fires in study area over the last approximately 100 years (modified from Morris, 2006b).....	235
6-2 Photo of City of Rocks National Reserve taken in 1868	236
6-3 Charcoal abundance (number of charcoal x 10 ⁶ per 1 gram of soil) shown with increasing distance from burned Site A.....	237
6-4 Charcoal abundance (number of charcoal x 10 ⁶ per 1 gram of soil) by depth at a recently burned (Site A) and unburned site (Site H).....	238
6-5 Charcoal abundance (number of charcoal x 10 ⁶ per 1 gram of soil) by depth at the historic burn sites (Sites E-G) that burned over 150 years ago.....	239
6-6 Burned Phytolith Index (BPI) with increasing distance from the 2000 fire	240

		xii
6-7	Burned Phytolith Index (BPI) percentages by depth at a burned site (Site A) and unburned site (Site H)	241
6-8	Burned Phytolith Index (BPI) percentages by depth at the historic burn sites (Sites E-G)	242
7-1	Percent extraction weights for unburned sites	289
7-2	Percent extraction weights for burned sites	290
7-3	Percent rondels at four sites that were dominated by the introduced grass, <i>Bromus tectorum</i>	291
7-4	Percent extraction weights for detailed analysis cores	292
7-5	Phytolith percent diagram for detailed core at Site 1A.....	293
7-6	Phytolith percent diagram for detailed core at Site 3.....	294

LIST OF PLATES

Plates in Chapter 3	Page
1(a) Twin Sisters, 1868	93
1(b) Twin Sisters, 2005	93
2(a) City of Rocks View 1, 1868.....	95
2(b) City of Rocks View 1, 2005.....	95
3(a) City of Rocks View 2, 1868.....	97
3(b) City of Rocks View 2, 2005.....	97
4(a) Circle Creek 1868	99
4(b) Circle Creek 2007	99
5(a) Twin Sisters Road, 1940.....	101
5(b) Twin Sisters Road, 2005.....	101
6(a) Top of Camp Rock, 1900's.....	103
6(b) Top of Camp Rock, 2005.....	103
7(a) Mikesell Homestead	104
7(b) Mikesell Homestead, 1930.....	106
7(c) Mikesell Homestead, 2005.....	106
8(a) Top of Treasure Rock, early 1900's	108
8(b) Top of Treasure Rock, 2005	108
9(a) View from Turnout, 1963	110
9(b) View from Turnout, 2005	110
10(a) Circle Creek Basin, 1967	112

	xiv
10(b) Circle Creek Basin, 2005	112
11(a) Circle Creek Road, 1940.....	114
11(b) Circle Creek Road, 2005.....	114
12(a) Twin Sisters, 1923	116
12(b) Twin Sisters, 2005	116
13(a) Top of Bath Rock, 1950's.....	118
13(b) Top of Bath Rock, 2005.....	118
14(a) Road to Bread Loaves, 1940.....	120
14(b) Road to Bread Loaves, 1990's.....	120
14(c) Road to Bread Loaves, 1990's.....	122
14(d) Road to Bread Loaves, 2005.....	122
 Plates in Chapter 3	 Page
I Light micrographs of native forb morphotypes	176
II Light micrographs of native grass morphotypes.....	177
III Light micrographs of native and introduced tree and shrub morphotypes	178
IV Light micrographs of introduced forb morphotypes.....	180
V Light micrographs of introduced grass morphotypes	182
 Plates in Chapter 7	 Page
7-1 Morphotypes used in phytolith assemblage analysis.....	295

CHAPTER 1

INTRODUCTION

Historical ecology is an emerging and interdisciplinary field that seeks to explain the changes and the processes that have created current landscapes through a synthesis of information derived from human records and biological data (Russel, 1997). The human archive is the record of historic conditions contained within written, oral and photographic sources. The biological archive is the record of historic conditions contained within the natural environment and is discovered through dendrochronology, packrat middens, palynology, and soil phytolith analysis. The methods in historical ecology cover a wide range of temporal and spatial scales (Egan and Howell, 2001). However, methods for the more recent past (less than 200 years) are largely limited to the human archive and some dendrochronological evidence (Egan and Howell, 2001) which can be subject to human bias, limited in spatial extent and not appropriate in some forest types and non-forested systems (Swetnam et al., 1999).

Phytolith analysis is quickly becoming a popular method for determining historic vegetation (Piperno, 2006). Phytoliths are structures formed in plants through deposition and accumulation of silica within and around cell walls (Rovner, 1971; Fredlund, 2001). These phytoliths are released from plants into the soil through death and decay of plant material (Rovner, 1971). Phytoliths preserve well in terrestrial sediments while pollen grains are more stable in anaerobic lacustrine (lake) sediments (Golyeva, 2001). This is particularly important for arid and semi-arid environments where lacustrine evidence is not as common (Fredlund, 2001). These microfossils can remain stable in sediments from as early as the Eocene (Stromberg, 2004). There is a need to explore new methods

by which biological data can be used to determine historic vegetation and disturbance regimes over the past 200 years in arid and non-forested ecosystem types. Soil phytolith analysis has the potential to provide much needed information regarding historical conditions in both areas.

The City of Rocks National Reserve in southern Idaho is an excellent place to explore some unique combinations of the human and biological archive because the human records are rich with information regarding historical environmental conditions and it contains representative ecosystem types of the Great Basin Desert region. In return, an ecological history for the Reserve provides much needed historical information that assists in interpretation, management, planning and preservation of its unique cultural and natural resources. Deliverables from this dissertation to the City of Rocks National Reserve have included a written summary of the ecological history contained in the human archive (Morris, 2006a), a mapped fire history from 1926 to present (Morris, 2006b), 42 hours of oral history, a digital library of all archival documents used in the study, digital copies of 100 emigrant diaries and recollections from the period of overland emigration, 100 historical photos, a set of over 60 repeated historical photos, and a replica of a Holmes stereoscope with three stereographs of the Reserve taken in 1868. This rich human archive, in turn, allows for the exploration of new methods using soil phytolith analysis by providing useful information on vegetation that can be tested as modern analogues.

Research objectives and questions

There were two overarching and interconnected objectives for this dissertation research. The first was to reconstruct an ecological history of the City of Rocks National Reserve from the period of overland emigration to present, approximately the last 200 years. The second objective was to explore the utility of soil phytolith analysis for inferring vegetation and disturbance regime change over the past 200 years by testing its sensitivity to record known changes. These objectives were met by examining the following broad questions:

- 1) What does the human archive reveal about how the vegetation has changed at the City of Rocks since the period of overland emigration?
- 2) What are the characteristic phytolith types for dominant Great Basin native and introduced flora?
- 3) Is the phytolith record useful for investigating historical fire events?
- 4) Does the stratigraphy of the terrestrial soil phytolith assemblage record changes in vegetation and disturbance regimes over the more recent past?

Research design and methodology

This dissertation required two phases of research. The first phase involved gathering information from the human archive by collecting and examining written and oral documentation of historic conditions at the study site. The second phase involved gleaning information from the biological archive through soil phytolith analysis. In this two-phase design, the first step necessarily informed the second. Results from the human archive provided information about change and disturbance that were then used to

develop and test hypotheses about the sensitivity of the soil phytolith stratigraphy to record these events. Therefore, formulation of hypotheses, sampling strategy and sampling location depended heavily upon what was found in the human archive. A summary of how each of the four broad questions is addressed in the following chapters is offered below.

Chapter previews

Chapter 2 – Phytoliths: “jewels of the plant world.”

Even with the growing popularity and utility of phytolith analysis in historical fields of science, the topic is still fairly new and obscure to most researchers. Therefore, this chapter offers a brief overview of phytolith production, classification and identification, as well as the issues and theories behind phytolith analysis.

Chapter 3 – The “land witness”: temporary landscapes of the City of Rocks National Reserve.

Information regarding historic conditions of the City of Rocks National Reserve (CIRO) was collected from archival sources, federal land management records, emigrant diaries, oral histories, fire records and historic photography (Morris, 2006a). A comprehensive review of archival documents was undertaken to collect any available information concerning historic environmental conditions within CIRO and the surrounding area. Oral histories were gathered from existing sources and more than 30 interviews were conducted with longtime residents of the area. A collection of 100 emigrant diaries and recollections were examined for references to vegetation, fauna, fire and climatic conditions of the area (Morris, in press-b). More than 100 historic photos of

CIRO were also collected and most of these photos were retaken from the same vantage point (re-photography) (Morris, in press-a). In addition, a fire history of the CIRO was compiled and mapped from existing studies and historic fire reports from land management agencies (Morris, 2006b). Information was also gathered concerning fire from archival documents, emigrant diaries, oral histories and historical photographs. A digital map was created in ArcView/GIS 3.3 (ESRI, Redlands, CA, USA) of all mappable fires (Chapter 6).

This study revealed several important changes in the City of Rocks since settlement (Morris, 2006a). First, there has been an overall decrease in plant diversity in the valleys. This change was likely due to overlapping effects of heavy livestock grazing in the late 1800s, periodic droughts, land clearing during the dry-farming boom of the early 1900s, and additional cultivation after World War II to increase forage production with introduced crested wheatgrass (*Agropyron desertorum*) seeding. Second, there has been an overall increase in the woody species throughout the entire study area. This increase is most likely due to changes in land use and the fire regime as well as periodic droughts. Finally, there has been an increase in both the size and intensity of fires over the past 100 years. This is likely due to a combination of the fuel loads that accompany increasing density of woody species and climate change (Morris, 2006b). This historical land use and fire information was instrumental in formulating hypotheses, determining sampling sites and was crucial for ensuring that sample locations for soil cores have had a relatively stable soil profile during the time frame of interest (e.g. untilled land).

Chapter 4 – Phytolith types and type-frequencies
in native and introduced species of the sagebrush
steppe and pinyon-juniper woodlands of the
Great Basin, USA.

This chapter catalogued phytolith morphotypes and production from common native and introduced flora from two primary plant community types in the Great Basin Desert region of the USA – sagebrush steppe and pinyon-juniper woodlands. The reference collection included 143 species from 40 families including 68 introduced and 75 native plants. We examined 96 forbs, 33 grasses, sedges and rushes as well as 14 trees and shrubs. Over 100 of these species have not had their phytolith morphotypes or production described previously. We found that about 51% of the plants produced none or only trace amounts of phytoliths while the remaining 49% were common to abundant producers. All the grass species were abundant producers and our analysis revealed important differences in both morphotype and frequency production between native and introduced grass species. At least half of the forbs were also common phytolith producers and mostly generated the common dicotyledon morphotypes such as silicified epidermal cells and hairs. Our findings showed that several of the morphotypes in native and introduced forbs are unique for the genus and species within the reference collection. Finally, we found very little phytolith production in the woody species and no phytoliths for pinyon (*Pinus monophylla*) or juniper (*Juniperus osteosperma*). Therefore, there was no identifiable phytolith assemblage for pinyon-juniper woodlands in the Great Basin.

Chapter 5 - Developing an approach for using the soil phytolith record to infer vegetation and disturbance regime changes over the past 200 years.

This chapter presents the preliminary work to assess the approach of combining historical records and soil phytolith analysis. This paper was presented at the 6th bi-annual International Meeting on Phytolith Research in Barcelona, Spain in September 2006. It was later published in a special volume of the proceedings from that meeting by Quaternary International (Morris et al., in press) and is reprinted here with their permission. The goal of this study was to explore the development of an approach that combines the human archive and soil phytolith analysis to expand the biological evidence for inferring vegetation and disturbance regime changes in the this part of the Western United States since settlement in the 1800s. We reported on some of the results from the human archive concerning vegetation and disturbance regime change in the City of Rocks National Reserve, Idaho, US. In addition, we examined the phytoliths of native and introduced species from the study site and looked at how well the soil phytolith record reflects recent wildfires. This chapter presented results from the first modern day analogue of phytolith analysis in the United States comparing burned and unburned sites. Our results indicate that this combination of history and soil phytolith analysis would be a useful approach for inferring vegetation and disturbance change in ecological histories.

Chapter 6 - Can soil phytolith analysis and charcoal be used as indicators of historic fire in the pinyon-juniper and sagebrush steppe ecosystem types of the Great Basin Desert Region, USA?

Soil charcoal and phytolith analysis have been successfully employed in other regions to garner information about fire regimes through the Holocene. The modern

analogue study in Chapter 5 showed the potential utility of phytoliths for understanding historic fires at the study site. The purpose of this study was to further explore the utility of soil phytolith analysis in terrestrial soils from the study area. We tested if soil charcoal and burned phytoliths could be found in historic terrestrial sediments in these ecosystem types, quantified how their frequencies varied with distance and depth from a known fire, and assessed if a known historic fire could be detected within the soil stratigraphy. The results illustrated the difficulty of interpreting phytoliths and charcoal in terrestrial sediments after a fire. However, the soils in these ecosystem types were well stratified and contained both burned phytoliths and microscopic charcoal for examination. This research demonstrated that soil charcoal and phytolith analysis could be used to examine questions about historical fires in these two ecosystems of the Great Basin Desert region.

Chapter 7 - Testing soil phytolith analysis as a tool to understand vegetation change in the sagebrush steppe and pinyon-juniper woodlands of the Great Basin Desert region.

The objective in this chapter was to examine the utility of soil phytolith analysis to reflect vegetation changes over the period of about 200 years in two common ecosystem types of the Great Basin – sagebrush steppe and pinyon-juniper woodlands. Its sensitivity as a record for the more recent past was tested by sampling in locations where vegetation changes were known to have occurred based on human records. Results from previous human archive research (Chapter 3) showed that over the past two centuries, the vegetation has changed in two major ways in the study area. First, there are more woody species including denser sagebrush and increased cover and density of pinyon and juniper as these woodlands have encroached down slope and into the valleys.

Second, there has been a marked loss of native grasses and an increase in introduced grasses, particularly cheatgrass (*Bromus tectorum*) and crested wheatgrass (*Agropyron desertorum*). These known changes were used to test the sensitivity of the soil phytolith stratigraphy to record such events. We employed both a multi-core approach and detailed core analysis to test for these and other known changes through analysis of extraction weights, relative abundance of groups of phytoliths and detailed analysis of phytolith assemblages in the soils at a fine scale (one centimeter depth increments).

This is the first study to examine the use of soil phytoliths in a continuous core sampling method in these ecosystem types. We found that these soils can be stable and well stratified enough to record changes in the vegetation if the sampling is done with care to find sites that have not burned recently, have low slopes, and are outside of cultivated areas. The utility of soil phytolith analysis was tested by looking for known vegetation changes in the soil stratigraphy such as increased cover of woody species like sagebrush and pinyon-juniper woodlands. Our results show that extraction weights will track increases in pinyon-juniper woodland cover and density. Phytolith assemblages in the soil stratigraphy also reflect increasing dominance of invasive grass species like *Bromus tectorum*. Finally, detailed analysis at a fine scale of extraction in one centimeter depth increments revealed shifts in soil phytolith assemblages that suggest connection to known changes in climate, vegetation and land uses from the Little Ice Age to present. Soil phytolith analysis appears to hold promise as a biological proxy for understanding historic and prehistoric environmental conditions and deserves further exploration and research.

Chapter 8 – Conclusions and future research

This chapter provides an overall summary of the conclusions from this research, an assessment of the method and some important future directions.

References

- Egan, D., Howell, E.A. (Eds.), 2001. *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*. Island Press, Washington, DC.
- Fredlund, G.G., 2001. Inferring vegetation history from phytoliths. In: Egan, D. and Howell, E.A. (Eds.), *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*. Island Press, Washington, DC, pp. 335-362.
- Golyeva, A., 2001. Biomorphic analysis as a part of soil morphological investigations. *Catena* 43, 217-230.
- Morris, L., 2006a. Ecological history of the City of Rocks National Reserve, Part I: The Human Archive. National Park Service Pacific Northwest Region, Seattle, Washington.
- Morris, L., 2006b. Fire History of the City of Rocks National Reserve from 1926 to 2005. National Park Service Pacific Northwest Region, Seattle, Washington.
- Morris, L.R., in press-a. The changing California Trail: a journey in repeat photography in the City of Rocks National Reserve, Idaho. *Overland Journal*.
- Morris, L.R., in press-b. Using emigrant diaries to examine historic environmental conditions along the California Trail in the City of Rocks National Reserve, Idaho. *Overland Journal*.
- Morris, L.R., West, N.E., Baker, F.A., Van Miegroet, H., Ryel, R.J., in press. Developing an approach for using the soil phytolith record to infer vegetation and disturbance regime changes over the past 200 years. *Quaternary International* doi:10.1016/j.quaint.2007.08.040.
- Piperno, D.R., 2006. *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists*. AltaMira Press, Lanham, MD.
- Rovner, I., 1971. Potential of opal phytoliths for use in paleoecological reconstruction. *Quaternary Research* 1, 343-359.

Russel, E.W.B., 1997. *People and the Land Through Time: Linking Ecology and History*. Yale University Press, New Haven.

Stromberg, C.A.E., 2004. Using phytolith assemblages to reconstruct the origin and spread of grass-dominated habitats in the great plains of North America during the late Eocene to early Miocene. *Palaeogeography, Palaeoclimatology, Palaeoecology* 207, 239-275.

Swetnam, T.W., Allen, C.D., Betancourt, J.L., 1999. Applied historical ecology: using the past to manage for the future. *Ecological Applications* 9, 1189-1206.

CHAPTER 2

PHYTOLITHS: “JEWELS OF THE PLANT WORLD”

Introduction

Phytoliths have been called the “jewels of the plant world” (Fredlund, 2001, pp. 335). They were first discovered in living plants during the rise of microscopy in 1835 by a German scientist named Struve (Piperno, 1988). Christian Ehrenberg, another German scientist in the mid 1800s, was the first to recognize that siliceous formations in wind blown dust and soil samples were from plants (Fredlund, 2001). He called these silica bodies “phytolitharia” from the Greek meaning “plant stone” (Piperno, 1988; Fredlund, 2001). The name is fitting because these structures are formed within plants through the deposition and accumulation of silica within, around and between cell walls (Fredlund, 2001). Piperno (1988) divided the history of phytolith research into four periods: discovery and exploration from 1835 to about 1900, a botanical phase from 1900 to 1936, an ecological era with applications in soil science and vegetation history from 1955 to about 1975, and the modern period with new focus upon archaeological research, production, morphology and frequency in sediments.

Now, phytoliths are studied in nearly every major biome and from samples ranging from atmospheric dust to oceanic sediment cores (Fredlund, 2001). They are popular with the historical fields of archeology, palaeoecology, geology, and soil genesis. Even with their growing popularity in historical fields of research, phytoliths remain a relatively obscure topic for most people. Therefore, this chapter offers a brief overview of some of the basics in phytolith analysis that are not covered in the following chapters.

More complete reviews on the subject can be found in Piperno (1988, 2006), Pearsall (2000), Rapp and Mulholland (1992), or Fredlund (2001). The following sections will review the production and function of silica in plants, how phytoliths are identified and classified, and the use, issues and underlying theories of phytolith research in vegetation history.

Physiology: production and function

The precise mechanisms responsible for silica structures in plants are not well understood (Piperno, 1988). In general, however, phytoliths are produced by the concentration of silicon dioxide (SiO_2) within leaves and other plant tissues (Fredlund, 2001). Dissolved silica in the form of monosilicic acid ($\text{Si}(\text{OH})_4$) is absorbed through the roots and carried through the transpiration stream by the xylem (Piperno, 1988). With the reduction of water during transpiration, the dissolved silica is precipitated and deposited as a weakly hydrated silicon dioxide (SiO_2 with 5-15% H_2O) (Rovner, 1971; Bartoli and Wilding, 1980). The silicon dioxide found in plants is identical to the well known opal gemstone (Rovner, 1971). Therefore, they are also often referred to as “opal phytoliths,” “plant opal,” “biogenic opal,” “opaline silica,” or “grass opal” (Rovner, 1971; Piperno, 1988). These small incrustations range in size from 2 to 1000 microns with most around 20 to 200 microns (Rovner, 1971). They are found mostly within the leaf epidermal tissues, however, they also exist in woody tissues, seeds (Rovner, 1971; Fredlund, 2001) and even in roots (Sangster and Hodson, 1992). The silicon dioxide is deposited in several different ways: by filling in cells forming solid casts, cell linings, cell wall replacement, plant hairs, spines and other miscellaneous structures (Rovner, 1971).

These different types of silicification are used in identification and classification systems that will be discussed later.

Silica accumulation is variable between species, genus, family and even environmental conditions (Piperno, 1988; Fredlund, 2001). Monocots generally accumulate the most silica and produce the most phytoliths (Rovner, 1971). For comparison, needles from the family Pinaceae contain 0.08 to 1.37% silica (Klein and Geis, 1978) while shoots in the grasses contain from 5 to 20% silica by dry weight (Kaufman et al., 1985). Some families with high silica percent by dry weight include: Equisetaceae (horsetail), Poaceae (grasses), Palmae (palm), and Cyperaceae (sedges) (Fredlund, 2001). Piperno (2006) offers a review of known patterns, production, and percent of silica phytoliths generated by plant families. Phytolith production is variable but it is also patterned. Replication of certain shapes and types of phytoliths within family, subfamily and tribe may indicate some genetic control over silicification (Piperno, 1988). However, the proportion of silica in plants can also be influenced by the level of dissolved silica in the soil. Availability of dissolved silica is affected by soil pH, temperature and moisture (Piperno, 1988).

It is also not clearly understood why plants produce phytoliths or accumulate silica in their cells (Rovner, 1971; Kaufman et al., 1985; Massey et al., 2006). The processes can be either active (expending energy to absorb) or passive (no expending of energy) depending upon the taxon of plant (Piperno, 1988). Plants can exclude dissolved silica with cutin and/or suberin on their root surfaces (Parry and Winslow, 1977). Although silica is recognized as important to the normal development of grass shoots, it is not directly related to metabolism and, therefore, cannot be considered an “essential

element” (Kaufman et al., 1985, p. 487). However, silica accumulation may provide several benefits for the plant including: structural support for withstanding transpiration pressure (Rovner, 1971; Piperno, 1988), resistance to herbivory (Massey et al., 2006) and fungi, increasing incident solar radiation, and possibly temperature regulation (Rovner, 1971; Kaufman et al., 1985).

Extraction, identification, and classification

In order for phytoliths to be useful for research in vegetation history, there must be some means of both identification and classification. Identification can take place from both the extant plant tissues (*in situ*) and as disaggregated particles in sediments or other materials. Methods for extraction in both instances have been developed and refined over time. Complete descriptions and comparisons of the methods for extraction from plants are provided by Parr et al. (2001a; 2001b) and from soils by Pearsall (2000) and Piperno (2006).

Extraction from live plant tissue can be completed in one of two ways – chemical digestion or dry-ashing (Rovner, 1971; Piperno, 1988). Chemical digestive techniques require the use of strong acids to digest (or dissolve) organic material (Rovner, 1971; Pearsall, 2000). Dry-ashing involves heating plant material in a muffle furnace at temperatures from 400 °C to 500 °C (Fredlund, 2001). Although the melting point of silica is high (950 °C) (Piperno, 1988), this method is discouraged by some researchers because of its potential to disfigure the silica (Rovner, 1971). However, it is still very commonly and successfully employed (Piperno, 1988; Parr et al., 2001b). A recent

development for extraction from live plants, digestion via microwave oven, is reportedly even faster and better than dry-ashing techniques (Parr et al., 2001a).

Extraction of phytoliths from soils (or sediments) is accomplished through variations on several standardized steps: sieving sediments, dispersion of clays, removing organic material, and separating the phytoliths using density fractionation (Piperno, 2006). Some researchers prefer to separate sand, silt and clay sediments for analysis, others prefer to combine them, and most just analyze the silt fraction 5 to 50 μm (Piperno, 2006). There are also variations upon the type of heavy liquid used for floatation (e.g. zinc bromide or sodium polytungstate) but, whichever material is used, the silica is separated from the sediments using a specific gravity of 2.3 g m^{-3} . The phytoliths and extractant are rinsed, dried and stored either dry or in ethyl alcohol (Blinnikov, 2005; Piperno, 2006). The extracted phytoliths are mounted in a fluid to assist with three dimensional viewing (such as Canada Balsam or other oil) with a biological light microscope with magnification from 400x to 1000x (Fredlund, 2001; Piperno, 2006). The phytoliths can be documented with photomicroscopy and/or the use of SEM (scanning electron microscopes) (Wilding and Drees, 1971).

Once separated from the plant tissues or sediments, a system of classification is necessary to discuss the observed phytoliths. Mulholland and Rapp Jr. (1992a) describe three approaches used in classifying phytoliths – parataxonomic, botanical and morphological. The following is a summary from their discussion. The parataxonomic approach treats the phytoliths as separate objects to which the Linnean system of binomial naming is applied. Ehrenberg's ground breaking work in the mid 1800s was based upon this type of classification. Parataxonomic classification is acceptable under

the International Code of Botanical Nomenclature and is also used in palynology (the study of pollen and other microfossils). This approach is used when identification of the original plant may not be possible. The botanical approach, on the other hand, organizes phytoliths with information regarding their orientation and location within plant tissues. This system is only useful, however, if the phytoliths are observed *in situ* and is not as reliable or informative with disaggregated phytoliths in the sediments. The morphological approach applies a three dimensional descriptive system to phytoliths that are disaggregated from plant tissues. Within the morphological approach there are two methods. One describes and classifies the phytoliths purely upon their geometric characteristics. The other applies both geometric shape and an anatomical component (i.e. hair or hair base) (Mulholland and Rapp Jr., 1992b).

There has been very recent work to standardize the nomenclature among phytolith scientists by a group appointed by the Society for Phytolith Research (Piperno, 2006). Their efforts include formal protocols for describing and naming new types of phytoliths as well as redefining some and conserving other former nicknames (Madella et al., 2005). This new system, referred to as the International Code for Phytolith Nomenclature 1.0 uses three descriptors: shape, texture or ornamentation, and anatomical origin, if known. Former nicknames such as “dumbbell” are now known as “bilobates.” Some of the conserved names include “rondels,” “papillae,” and “dendritic” (see Plates in Chapter 4 for examples of these forms) (Madella et al., 2005). The lack of a formal naming system has made comparison across studies difficult at times unless good photographic evidence is provided (Blinnikov, 2005).

Herbaceous and woody species are now being examined more comprehensively after being ignored for sometime (Bozarth, 1992; Wallis, 2003). Therefore, differentiation between dicotyledons and monocotyledons, woody and herbaceous, grass and forbs, family, genus and even to species is beginning to open new windows for viewing historical vegetation. It has long been recognized that dicotyledons and monocotyledons consistently produce different types of phytoliths (Rovner, 1971; Piperno, 1988; Bozarth, 1992) (see Plates in Chapter 4 for examples). Grasses consistently form a variety of opal phytoliths (Mulholland and Rapp Jr., 1992a) and there are nine phytolith forms found only in dicotyledons (Bozarth, 1992). Relatively few plant taxa provide diagnostic phytoliths (Ollendorf, 1992). Cyperaceae (sedges) can be identified at least to the family level (Ollendorf, 1992). Some researchers have been able to establish diagnostic phytoliths at the genus (Klein and Geis, 1978) and even species level (Kerns, 2001) within the Pinaceae.

Issues, theory, and use

Palynology had already been well developed by the time researchers began using phytoliths to infer past vegetation (Piperno, 1988; Fredlund, 2001). Rovner (1971) is credited with bringing the utility of phytoliths to the forefront for archaeology and palaeoenvironmental study (Piperno, 1988; Wallis, 2003). Others credit Wilding (1967) for the first use of radiocarbon dating and opening the door to evidence from phytoliths in soils for vegetational history (Fredlund, 2001). Other major contributors have included Twiss (1992) for his pivotal study that paralleled phytolith analysis with that of palynology (Fredlund, 2001). Indeed, phytolith research shares a great deal in common

with palynology although it has advantages and disadvantages in comparison (Fredlund, 2001).

Phytoliths are touted as being particularly useful in paleoecological studies of grasslands because, in contrast to pollen, monocotyledons produce more and systematic forms (Rovner, 1971). Phytoliths preserve better in terrestrial sediments than pollen which persist better in anaerobic lacustrine (lake) sediments (Golyeva, 2001). This is particularly important for arid and semi-arid environments where lacustrine evidence is not as common (Fredlund, 2001). Phytoliths are also durable fossils that have been shown to date back to the late Pleistocene (Wilding, 1967) and even as early as the Eocene (Stromberg, 2004). Finally, many believe that phytoliths have the potential to provide a more localized record of plant community changes while pollen analysis tends to be regional (Blinnikov et al., 2002). On the other hand, phytolith analysis is also subject to many problems that are unique to this discipline including: classification, deposition and transportation and preservation (Fredlund, 2001).

Classification

As discussed previously, classification of phytoliths can be very complex and problematic. Classification is further confounded by issues of “redundancy” and “multiplicity.” While a single type of pollen may be produced by a plant taxon, this is not always the case with phytoliths (Fredlund and Tieszen, 1994). Redundancy occurs when the same phytolith type is produced by many taxa while multiplicity occurs when one plant generates many different types of phytoliths (Rovner, 1971). Redundancy and multiplicity clearly create problems for interpretation of past vegetation. Two methods

proposed for dealing with these issues are the “black box” and the “gray box” approaches (Powers, 1992; Fredlund and Tieszen, 1994). Under the black box method, phytoliths are assessed as entire “assemblages” or “suites” rather than attempting to identify the family or species of origin (Powers, 1992). Then, ancient suites can be compared with modern analogs of possible source vegetational assemblages (Powers, 1992). The gray box method is very similar in its emphasis upon vegetational rather than floristic reconstruction (Fredlund and Tieszen, 1994) but it attempts to link phytolith morphotypes to some “element” within its source (e.g. culm, leaf or physiological function) (Powers, 1992). For example, morphotypes from grass leaves have been used as indicators for predicting the distribution of C₃ and C₄ grasses (Twiss, 1992).

Deposition: release and transportation

Even beyond the issues with classification, there are questions and problems that arise with understanding the fossil record left behind by deposition of phytoliths into various sediments. Phytoliths are released from plants through death and decay of plant material (Rovner, 1971). Release can come in the form of litter fall as well as death of the organism in total. Therefore, the rate of deposition can vary for a single plant as well as between plants. For example, annually deposited phytoliths from leaves may be more concentrated in the soil record than those from woody tissues. These variations can lead to overrepresentation, underrepresentation or the complete absence of phytoliths in the fossil record (Piperno, 1988). This is particularly a problem when comparing grasslands and forests. Grasses not only produce more phytoliths but also release more of them annually. As a result, they may be over represented within the soil fossil record

(Fredlund, 2001). There are also other factors that influence the deposition rates of phytoliths such as fire and herbivory that can further complicate interpretation.

Transportation of released phytoliths is also a concern for interpretation. In early studies involving phytoliths, many researchers assumed a “decay in place” model of phytolith deposition and ignored issues of “taphonomy” (Fredlund, 2001). Taphonomy is the study of processes that intervene between the death of an organism and its inclusion into the fossil record (Shipman, 1981; Fredlund, 2001). Phytoliths are very small plant fossils that are easily transported by wind erosion, water erosion, fire and herbivory. In grasslands, for example, these processes are believed to horizontally transport 40 to 50% of the plant biomass (Fredlund, 2001). Very recently, researchers have worked to develop a conceptual model of taphonomy of phytoliths using modern analogues in similar soil types to archeological sediments in Tanzania (Albert et al., 2006). They recognized two primary filters that would bias phytolith preservation at two stages of incorporation into the sediments. The first was between death of plant and addition to the soils (e.g. herbivory) and the second was post depositional (e.g. pH of the sediments) (Albert et al., 2006). However, in areas where fire is a primary factor in the ecosystem processes, both of the filters Albert et al. (2006) proposed could be driven largely by this force. More work is needed to understand how fire relates to the taphonomy of phytoliths (Piperno, 2006).

Another issue regarding transportation of phytoliths is their potential for vertical movement within sediments, sometimes referred to as “illuviation” or “translocation” (Piperno, 2006). Given their size, some researchers argue that phytoliths are just as susceptible to vertical movement in the soil profile as silt (Fredlund, 2001). Others argue

that concentrations of phytoliths in the A horizons of soils indicates that the vertical movement is nominal (Piperno, 1988). Over the past 40 years, researchers have “made it clear, however, that vertical phytolith movement does not cause unique or distinctive problems in phytolith study” (Piperno, 2006, pp. 111). Phytoliths are known to be concentrated in the A horizons in soils and to decrease dramatically in the B horizons (Jones and Beavers, 1964; Piperno, 2006). Where accumulation was substantial in the lower sediments, the cause was more likely to have been development of soils on loess (Jones and Beavers, 1964) or soils with a high degree of shrinking and swelling (Hart and Humphreys, 2003). As further evidence, phytolith concentrations are typically used as an index for identifying buried A horizons (e.g. Hart and Humphreys, 2003; Piperno, 2006). Furthermore, vertical translocation would arguably cause homogenization across the profile as opposed to distinctive zonations of different assemblages as is observed most frequently (Fredlund et al., 1998). Soil phytoliths can also move up or down in the soil column through bioturbation (e.g. animal burrowing) (Piperno, 2006). In addition, post depositional erosion could remove whole portions of the soil profile and, therefore, truncate the vertical sedimentary record. Both of these issues make chronological understanding of the soil phytolith record important and difficult in terrestrial sediments (Piperno, 2006).

It is also important to understand that phytolith assemblages within soil sediments do not represent discrete “snapshots” in time (Kerns et al., 2001). Rather, the assemblages within the stratigraphy represent the sum of accumulation and losses over time and represent more of a long term average (Kerns et al., 2001). This notion of the incorporation of phytoliths into assemblages over hundreds of years was termed

“inheritance” by Fredlund and Tieszen (1994). The inheritance at a site is affected by both the rate of soil accumulation as well as the mean residence time of the phytoliths due to preservation (Fredlund and Tieszen, 1994). Therefore, interpretations of phytolith assemblages must include consideration of deposition and transportation in the inheritance at a site as well as preservation of those phytoliths.

Preservation

Finally, there are issues that arise with phytoliths due to their variable preservation across plant type and environmental conditions. The degree of phytolith preservation is linked to several factors including: soil pH (> pH 9 will lead to rapid dissolution), type of silicification (entire or just cell walls), iron and aluminum absorbed to the surface that protects it, characteristic of the sediment (e.g. slow decomposition rates), and phytolith surface area (Piperno, 2006). For example, the silicified epidermal sheets formed commonly by herbaceous plants and in leaves of woody taxa are often thin and weakly preserved in comparison to the phytoliths of grasses that almost completely fill in cells (Fredlund, 2001; Piperno, 2006). Again, this has the potential to bias the fossil record with more representation by certain types of plants. However, some researchers have been quite successful in recovering phytoliths thought to be poorly preserved such as hairs and silicified epidermal sheets from a variety of sediments (e.g. Albert and Weiner, 2000; Blinnikov, 2005). Modern analogs can also help determine the differences in preservation of different phytoliths (Fredlund, 2001). The combination of variable preservation and environment means that this problem may have to be addressed on a site-by site basis (Piperno, 2006).

Counting procedures and presentation

The number of phytoliths counted per slide for analysis is a balance between the number needed to carry out either statistical or abundance analysis and a level of practicality (Piperno, 2006). However, typically between 200-250 particle counts per slide are adequate even within studies with highly diverse flora (Piperno, 2006). As with pollen counts, there can be little variation in percentages beyond counts of 200 (Colinvaux et al., 1999). When statistical analysis is applied to the data to create transfer functions, minimum counts of 300-400 particles may be employed (Piperno, 2006). Counting is carried out in a systematic linear fashion on the slide to the predetermined count. Sometimes, additional scans of the slide are carried out to note the presence of rare taxa morphotypes (Piperno, 2006). Conversely, the overrepresented taxa can be tallied to a predetermined amount and then excluded in the remainder of the count (Piperno, 2006).

The results are usually presented in phytolith diagrams that plot the percent of each type in the assemblage against the depth and/or age of the stratigraphy (Piperno, 2006). The percents, in this case, represent a relative abundance of the sum counted and are not an absolute abundance of total particles on the slide. As with palynological results, there are some researchers who apply any number of statistical analyses to the relative abundance counts (e.g. Kerns et al., 2001; Blinnikov, 2005) and there are just as many who interpret the information based upon knowledge of the site, radiocarbon dating, history, and other information contained in the geologic record (e.g. Blinnikov, 1994; Piperno and Becker, 1996). Radiocarbon dating for phytolith analysis can be

accomplished through bulk sediment dates or from the occluded carbon contained within the phytoliths (Wilding, 1967; Iriarte, 2006).

Analysis and interpretation

While diagnostic forms can be of great use in inferring past vegetation, there need not be an identification of specific taxon for phytolith analysis to be useful (Piperno, 1988; Powers, 1992; Fredlund and Tieszen, 1994; Blinnikov et al., 2002). For example, if the phytolith form is known to be from a woody species as opposed to a grass, this information is useful in identifying past community types (Piperno, 1988). Phytolith researchers have used the differences between the morphotypes of the two growth forms to follow the cyclical changes from arboreal to grass taxa in archeological sediments (Grave and Kealhofer, 1999) and with ratios (or indexes) to compare changes the woody component density to grasslands (e.g. Alexandre et al., 1997). Another method involves using overall phytolith assemblages discovered in modern analogue studies of sediments under current vegetation as a way of interpreting phytolith assemblages recovered in historic sediments (e.g. Blinnikov et al., 2002; Delhon et al., 2003). More and more, researchers are discovering the importance of comparing the phytolith record to modern day analogues for better inference to the past (Piperno, 1988; Fredlund and Tieszen, 1994; Fredlund, 2001; Blinnikov et al., 2002).

Also, frequency analyses of morphotypes within extant vegetation are used to help interpret historic phytolith assemblages (Blinnikov, 1994; Kerns et al., 2001; Carnelli et al., 2004). Finally, some have used known production differences between grasses and woody species to test the overall weight of the extracted phytoliths or some

count of total grass phytoliths expressed as percent by volume in soils to examine the stability of forests and grasslands (e.g. Witty and Knox, 1964; Miles and Singleton, 1975; Fisher et al., 1987).

Conclusion

Interest in phytoliths and their potential uses in many fields of science has gone through several historical phases and a great deal of development in the past 20 years (Piperno, 1988; Piperno, 2006). The potential for phytolith analysis in historic vegetation studies has been recognized for some thirty years already. Yet, there is still a great deal of work to be done to better understand all aspects of phytolith research including production, function, identification, classification, transportation, deposition and preservation (Fredlund and Tieszen, 1994). Historically, the emphasis upon phytoliths in grasses and grassland research in its earliest stages created the impression that dicots do not form as many phytoliths or useful diagnostic forms (Fisher et al., 1995; Piperno, 2006). In fact, quite often the fossil record will hold distinctive forms of phytoliths that cannot be identified because they have not yet been catalogued (Fredlund, 2001). Therefore, the most recent push in this field is in the examination, identification and cataloguing of herbaceous and woody species across a number of plant communities. For example, Wallis (2003) has just recently systematically examined phytoliths in the Australian flora. However, even with its limitations and remaining questions, phytolith analysis has demonstrated its potential in inferring past vegetation across a broad range of environments and time scales. As more research is done with these “jewels of the plant world,” perhaps they will exhibit an even greater value than expected.

References

- Albert, R., Bamford, M.K., Cabanes, D., 2006. Taphonomy of phytoliths and macroplants in different soils from Olduvai Gorge (Tanzania) and the application to Plio-Pleistocene palaeoanthropological samples. *Quaternary Research* 148, 78-94.
- Albert, R.M., Weiner, S., 2000. Phytoliths in the Middle Palaeolithic deposits of Kebara Cave, Mt Carmel, Israel: study of the plant materials used for fuel and other purposes. *Journal of Archaeological Science* 27, 931-947.
- Alexandre, A., Meunier, J.D., Lezine, A.M., Vincens, A., Schwarts, D., 1997. Phytoliths: indicators of grassland dynamics during the late Holocene in intertropical Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* 136, 213-229.
- Bartoli, F., Wilding, L.P., 1980. Dissolution of biogenic opal as a function of its physical and chemical properties. *Soil Science Society of America Proceedings* 55, 487-507.
- Blinnikov, M.S., 1994. Phytolith analysis and Holocene dynamics of alpine vegetation. In: Onipchenko, V.G. and Blinnikov, M.S. (Eds.), *Experimental Investigation of Alpine Plant Communities in the North-western Caucasus*. Veröffentlichungen des Geobotanischen Institutes der ETH, Stiftung Rubel, Zurich, pp. 23-40.
- Blinnikov, M.S., 2005. Phytoliths in plants and soils of the interior Pacific Northwest, USA. *Review of Palaeobotany & Palynology* 135, 71-98.
- Blinnikov, M.S., Busacca, A., Whitlock, C., 2002. Reconstruction of late Pleistocene grassland of the Columbia Basin, Washington, USA, based on phytolith records in loess. *Palaeogeography, Palaeoclimatology, Palaeoecology* 177, 77-101.
- Bozarth, S.R., 1992. Classification of opal phytoliths formed in selected dicotyledons native to the Great Plains. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics: Emerging Issues*, Plenum Press, New York, pp. 192-214.
- Carnelli, A.L., Theurillat, J.P., Madella, M., 2004. Phytolith types and type-frequencies in the subalpine-alpine plant species of the European Alps. *Review of Palaeobotany & Palynology* 129, 39-65.
- Colinvaux, P.A., De Oliveira, P.E., Moreno, J.E., 1999. *Amazon Pollen Manual and Atlas*. Hardwood Academic Publishers, Amsterdam.
- Delhon, C., Alexandre, A., Berger, J.F., Thiebault, S., Brochier, J.L., Meunier, J.D., 2003. Phytolith assemblages as a promising tool for reconstructing Mediterranean Holocene vegetation. *Quaternary Research* 59, 48-60.

- Fisher, R.F., Jenkins, M.J., Fisher, W.F., 1987. Fire and prairie-forest mosaic of Devils Tower National Monument. *American Midland Naturalist* 117, 250-257.
- Fisher, R.F., Newell Bourne, C., Fisher, W.F., 1995. Opal phytoliths as an indicator of the floristics of prehistoric grasslands. *Geoderma* 68(4), 243-255.
- Fredlund, G.G., 2001. Inferring vegetation history from phytoliths. In: Egan, D. and Howell, E.A. (Eds.), *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*. Island Press, Washington, DC, pp. 335-362.
- Fredlund, G.G., Bousman, C.B., Boyd, D., 1998. The Holocene phytolith record from Morgan Playa in the rolling plains of Texas. *Plains Anthropologist* 43, 187-200.
- Fredlund, G.G., Tieszen, L.T., 1994. Modern phytolith assemblages from the North American Great Plains. *Journal of Biogeography* 21, 321-335.
- Golyeva, A., 2001. Biomorphic analysis as a part of soil morphological investigations. *Catena* 43, 217-230.
- Grave, P., Kealhofer, L., 1999. Assessing bioturbation in archaeological sediments using soil morphology and phytolith analysis. *Journal of Archaeological Science* 26, 1239-1248.
- Hart, D.M., Humphreys, G.S., 2003. Phytolith depth functions in surface regolith materials. In: Roach, I.C. (Ed.), *Advances in Regolith*. CRC LEME, Bentley, pp. 159-163.
- Iriarte, J., 2006. Vegetation and climate change since 14,810 ^{14}C yr B.P. in southeastern Uruguay and implications for the rise of early formative societies. *Quaternary Research* 65, 20-32.
- Jones, R.L., Beavers, A.H., 1964. Aspects of catenary and depth distribution of opal phytoliths in Illinois soils. *Soil Science Society of America Proceedings* 28, 413-416.
- Kaufman, P.B., Dayanandan, P., Franklin, C.I., Takeoka, Y., 1985. Structure and function of silica bodies in the epidermal system of grass shoots. *Annals of Botany* 55, 487-507.
- Kerns, B.K., 2001. Diagnostic phytoliths for a ponderosa pine-bunchgrass community near Flagstaff, Arizona. *The Southwestern Naturalist* 46, 282-294.
- Kerns, B.K., Moore, M.M., Hart, S.C., 2001. Estimating forest-grassland dynamics using soil phytolith assemblages and $\delta^{13}\text{C}$ of soil organic matter. *Ecoscience* 8(4), 478-488.

- Klein, R.L., Geis, J.W., 1978. Biogenic silica in the Pinaceae. *Soil Science* 126(3), 145-156.
- Madella, M., Alexandre, A., Ball, T., 2005. International code of phytolith nomenclature 1.0. *Annals of Botany* 96, 253-260.
- Massey, F.P., Ennos, A.R., Hartley, S.E., 2006. Silica in grasses as a defense against insect herbivores: contrasting effects on folivores and a phloem feeder. *Journal of Animal Ecology* 75, 595-603.
- Miles, S.R., Singleton, P.C., 1975. Vegetative history of Cinnabar Park in Medicine Bow National Forest, Wyoming. *Soil Science Society of America Proceedings* 39, 1204-1208.
- Mulholland, S.C., Rapp Jr., G., 1992a. A morphological classification of grass silica-bodies. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics: Emerging Issues*. Plenum Press, New York, pp. 65-90.
- Mulholland, S.C., Rapp Jr., G., 1992b. Phytolith systematics: an introduction. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics: Emerging Issues*. Plenum Press, New York, pp. 1-14.
- Ollendorf, A.L., 1992. Toward a classification scheme of sedge (Cyperaceae) phytoliths. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics: Emerging Issues*. Plenum Press, New York, pp. 91-111.
- Parr, J.F., Dolic, V., Lancaster, G., Boyd, W.E., 2001a. A microwave digestion method for the extraction of phytoliths from herbarium specimens. *Review of Palaeobotany & Palynology* 116, 203-212.
- Parr, J.F., Lentfer, C.J., Boyd, W.E., 2001b. A comparative analysis of wet and dry ashing techniques for the extraction of phytoliths from plant material. *Journal of Archaeological Science* 28, 875-886.
- Parry, D.W., Winslow, A., 1977. Electron-probe microanalysis of silicon accumulation in the leaves and tendrils of *Pisum sativum* (L.) following root severance. *Annals of Botany* 41, 275-278.
- Pearsall, D.M., 2000. *Paleoethnobotany: A Handbook of Procedures*. Academic Press, San Diego.
- Piperno, D.R., 1988. *Phytolith Analysis: An Archaeological and Geological Perspective*. Academic Press, San Diego.

- Piperno, D.R., 2006. *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists*. AltaMira Press, Lanham, MD.
- Piperno, D.R., Becker, P., 1996. Vegetational history of a site in the central Amazon basin derived from phytolith and charcoal records from natural soils. *Quaternary Research* 45, 202-209.
- Powers, A.H., 1992. Great expectations: a short historical review of European phytolith systematics. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics: Emerging Issues*. Plenum Press, New York, pp. 15-36.
- Rapp Jr., G., Mulholland, S.C., 1992. *Phytolith Systematics: Emerging Issues*. Plenum Press, New York.
- Rovner, I., 1971. Potential of opal phytoliths for use in paleoecological reconstruction. *Quaternary Research* 1, 343-359.
- Sangster, A.G., Hodson, M.J., 1992. Silica deposition in subterranean organs. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics: Emerging Issues*. Plenum Press, New York, pp. 15-36.
- Shipman, P., 1981. *Life History of a Fossil: An Introduction to Taphonomy and Paleoecology*. Harvard University Press, Cambridge.
- Stromberg, C.A.E., 2004. Using phytolith assemblages to reconstruct the origin and spread of grass-dominated habitats in the great plains of North America during the late Eocene to early Miocene. *Palaeogeography, Palaeoclimatology, Palaeoecology* 207, 239-275.
- Twiss, P.C., 1992. Predicted world distribution of C₃ and C₄ grass phytoliths. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics*. Plenum Press, New York, pp. 113-128.
- Wallis, L., 2003. An overview of leaf phytolith production patterns in selected northwest Australian flora. *Review of Palaeobotany & Palynology* 125, 201-248.
- Wilding, L.P., 1967. Radiocarbon dating of biogenetic opal. *Science* 156, 66-67.
- Wilding, L.P., Drees, L.R., 1971. Biogenic opal in Ohio soils. *Soil Science Society of America Proceedings* 35, 1004-1010.
- Witty, J.E., Knox, E.G., 1964. Grass opal in some chestnut and forested soils in north central Oregon. *Soil Science Society of America Proceedings* 28, 685-688.

CHAPTER 3

THE “LAND WITNESS”: TEMPORARY LANDSCAPES OF THE
CITY OF ROCKS NATIONAL RESERVE

Introduction

And, in 1988, Congress established the City of Rocks National Reserve, an area encompassing the city and the California Trail ruts as *land witness* to the Kelton-Boise stage route, the free-range cattle industry, range wars, the birth of forest reserves, dryland and irrigated farming, and the growth of stable communities.¹

The City of Rocks has held several titles over the years. It has been called the “City of Rocks,” “Pyramid Rocks,” “City of Castles,” “Pyramid Circle,” “Steeple Rocks,” “The Rock City,” and the “Silent City of Rocks” by several different diarists during the period of overland emigration. It was designated a National Historic Landmark, as a National Natural Landmark, and then a National Reserve. Each of these titles has brought increasing levels of recognition, protection and preservation for the cultural and natural landscapes within this unique area.

A cultural landscape can be defined as the “totality of resources that formed a system of land use or that now form a multiple-layer depiction of use overtime.”² Many people seek out such cultural landscapes as a way to understand history. As David Henige argues, “Just as chronologists attempt to make history real by placing it at a particular point in time, site-identifiers do the same by attempting to locate events

¹ Quote (emphasis added) is taken from Historical Research Associates [HRA], *Historic Resources Study: City of Rocks National Reserve Southcentral Idaho*, National Park Service Pacific West Field Area Columbia-Cascade System Support Office Seattle, Washington, 1996, 1.

² HRA, *Historic Resources Study*, 2 (note 1).

spatially.” The landscape of the City of Rocks contains the viewshed and even identifiable ruts from the California Trail era that fulfill the “lure of the tactile relationship with the past” for California Trail enthusiasts.³ Many visit this special area in search of experiencing history and for experiencing the unique natural environment. As either a cultural landscape or as a natural landscape, these unbuilt spaces become something that city dwellers seek to hold constant with designations as though a museum piece.⁴ Our idea about our national public lands and especially our natural parks is that they are to be held as “vignettes of primitive America.”⁵ But the law creating the City of Rocks National Reserve recognized both the historical and natural spaces within it for preservation.

While assessing its qualification for the National Register of Historic Places in 1996, Historic Research Associates provided it the most interesting title yet – “land witness”. This description of the Reserve can be carried through as an analogy. If it is a land witness, we want it to talk. Tell us what has happened. Tell us what went wrong, how to get back to where we were before. Western writers, historians, geographers, ecologists, and conservationists also seem to want the land witness to tell us who to blame for the degradation of land in the West. For some, it was the European settlers who were so out of step with the environment and with the “natural ecological native”. Others argue that the native people did not live in “harmony” with the land either, and

³ D. Henige, ‘This is the place:’ putting the past on the map, *Journal of Historical Geography* 33 (2007) 237-253.

⁴ E.W.B Russell, *People and the Land through Time: Linking Ecology and History*, New Haven, 1997, 171.

⁵ A.S. Leopold, S.A Cain, C.M. Cottam, I.N. Gabrielson and T.T. Kimball, *Wildlife Management in the National Parks: The Leopold Report*, National Park Service, 1963.

were also potentially overexploiting the resources. But, it seems as though there is one architect of rangeland degradation that authors feel most comfortable indicting – livestock.⁶

Many authors and researchers in the Intermountain West tend to characterize livestock grazing as the sole agent of change on Western rangelands. Some research has begun to increase awareness about other legacies of land use such as wood harvesting for the mines, charcoal production and even fencing.⁷ In the reports for the City of Rocks, however, there is a common assertion that cattle are the sole mechanism for soil degradation and fish losses and the main driver of vegetation change within the Reserve. One claim, for example, is that the “rivers and creeks once supported abundant populations of native Cutthroat trout and other small fish before they were ruined by

⁶ Westerners have, after all, grown up with the description of cattle from Edward Abby as “ugly, clumsy, stupid, bawling, stinking, fly-covered, shit-smeared, disease-spreading brutes” in his writings in E. Abby, *One Life at a Time, Please*, New York, 1988, 15; John Muir offered no better description of sheep calling them “hooved locust” in J. Muir, *The wild sheep of California*, *Overland Monthly*, 12 (1874), 359; From these and other famous conservationist writings, Americans have been taught to see western rangelands as a “cow-burnt wasteland”. Donald Worster describes the rangelands as “torched, chained, plowed, herbicided, desertified, and eaten down to the roots”. This attitude can be seen in writings about the western rangelands from D. Worster, *Under Western Skies: Nature and History in the American West*, New York, 1992; Environmental organizations such as Western Watersheds have taken up the cause and put out publications such as the oversized book edited by G. Wuerthner and M. Matteson, *Welfare Ranching: The Subsidized Destruction of the American West*, Washington, DC, 2002.

⁷ See J.A. Young, and J. D. Budy, Historical use of Nevada’s pinyon-juniper woodlands, *Journal of Forest History* 28 (1979) 113-121; J.A. Creque, N.E. West, and J.P. Dobrowolski, Methods in historical ecology: a case study of Tintic Valley, Utah, in: S.B. Monsen and R. Stevens (Eds), *Proceedings: Ecology and Management of Pinyon-Juniper Communities within the Interior West*, 1997, Provo, Utah, USDA Forest Service, Rocky Mountain Research Station, RMRS-P-9, (1999) 121-133.

livestock.”⁸ A more comprehensive study of the impacts of land use history and landscape change within the Reserve, therefore, is very much needed to provide a broader context for understanding the environmental changes and management implications. A fuller understanding of the causes of change can illuminate the inherent limits within a system that are important for assisting agencies in setting management priorities and goals.⁹

The story of this landscape is different from areas that are rapidly changing under urbanization.¹⁰ The alterations of this land have been slower and more subtle in many ways. There are many factors that influence vegetation change and they are all occurring simultaneously throughout time. Therefore, the causes are difficult to tease apart and very rarely is there a single factor for vegetation change. Variables that may influence vegetation dynamics include: climate, soils, herbivory, land use (such as dry farming or herbicide treatments), recreation, erosion, fire and the lack of fire, insects and parasites, soil microbial communities and nutrients, road building and other disturbances. The historic information gathered for this research revealed that the City of Rocks has multiple layers of historic land uses which, coupled with a changing climate and

⁸ D.H. Chance, and J.V. Chance, *Archaeology at the City of Rocks: The Investigations of 1991*, prepared for National Park Service Pacific West Field Area Columbia-Cascade System Support Office, Seattle, WA., 1992, 3; See also W. J. Little, *A Historical Overview of Livestock Use in the Area of City of Rocks National Reserve from Introduction to 1907*, unpublished report for the National Park Service, copy on file at the City of Rocks National Reserve, 1994; Chance and Chance, *Archeology at the City of Rocks*, 3 (note 8).

⁹ T.W. Swetnam, C.D. Allen, and J.L. Betancourt, Applied historical ecology: using the past to manage for the future, *Ecological Applications* 9 (1999) 1189-1206.

¹⁰ S.W. Trimble, Historical hydrographic and hydrologic changes in the San Diego creek watershed, Newport Bay, California, *Journal of Historical Geography* 29 (2003) 422-444.

combinations of the variables listed above, have brought about a great deal of vegetation change since the era of the California Trail. This paper looks at how the landscape today is a product of all these historic variables acting in concert.

Study area

The City of Rocks National Reserve is jointly managed under a cooperative agreement between the National Park Service and Idaho Department of Parks and Recreation. Prior to becoming a National Reserve in 1988, the City of Rocks consisted of approximately 28% Bureau of Land Management, 4% State, 21% US Forest Service and 47% private land.¹¹ A recent federal purchase of the private land has increased the Reserve's portion, but private in-holdings still make up a large portion (about 30%) of the City of Rocks National Reserve.¹² The City of Rocks National Reserve contains approximately 5,795 ha of the Great Basin Desert region in southern Idaho near the town of Almo, nestled within the Albion Mountains (Figure 3-1). The elevation reaches from 1,646 m in the valley floors to 2,702 m on Graham Peak.¹³ The vegetation includes sagebrush steppe, pinyon-juniper woodlands, mountain mahogany chaparral and limber pine forest with riparian habitat traversing all of these zones.

Climate can be one of the most influential factors driving vegetation change.

Vegetation is very sensitive to climate and even small variations can create large changes

¹¹ R.E. Daugherty, *Legislative Land Cost Estimate for City of Rocks National Reserve Cassia County, Idaho*, prepared for National Park Service Pacific Northwest Region, Seattle, WA, 1988.

¹² National Park Service acreage for the Reserve as of December 31, 2006; Wallace Keck, City of Rocks National Reserve Superintendent, personal communication, 2005.

¹³ Daugherty, *Legislative Land Cost Estimate for City of Rocks National Reserve* (note 11).

in plant communities and structure.¹⁴ However, climate also has a confounding influence in analysis of historical vegetation because it, too, is changing over time. This is particularly true when looking at long lived species of trees or when there were significant regional or global climatic changes. This type of climatic change is an issue for the time period of this history because of the impacts from the end of the Little Ice Age. The Little Ice Age was a generally cooler and wetter period in the Northern Hemisphere from approximately 1400-1900 AD.¹⁵ Though the drop in average temperature was estimated to be only 1° C, it had marked impacts upon ecosystems in North American, Europe and other parts of the globe.¹⁶ This Little Ice Age plays an important role in the interpretation of vegetation change over the last 200 years because it ended coincidentally with European exploration and settlement in most of the Intermountain West. It is difficult to tease apart the influence of humans from the climate in historic vegetation studies.¹⁷

Precipitation trends in the Great Basin generally show a marked pattern of winter maximum and summer minimum due to influence of winter storms that develop off the Pacific coast in the winter.¹⁸ The City of Rocks, however, is part of the eastern portion of

¹⁴ D.G. Sprugel, Disturbance, equilibrium, and environmental variability: what is 'natural' vegetation in a changing environment? *Biological Conservation* 58 (1991) 1-18; C.D. Allen and D.D. Breshears, Drought-induced shift of a forest-woodland ecotone: rapid landscape response to climate variation, *Proceedings of the National Academy of Sciences of the United States of America* 95 (1998) 14839-14842.

¹⁵ C.I. Millar and W.B. Woolfenden, The role of climate change in interpreting historical variability, *Ecological Applications* 9 (1999) 1207-1216.

¹⁶ N. Roberts, *The Holocene: An Environmental History*, Oxford, 1998.

¹⁷ Millar and Woolfenden, The role of climate change (note 15).

¹⁸ R.F. Miller, T.J. Svejcar, and N.E. West, Implications of livestock grazing in the

Idaho that shows maximum monthly amounts in summer and minimums in the winter due to influence of moisture from storms originating from the south in the Gulf of Mexico and the Caribbean region.¹⁹ The average total monthly precipitation in the area peaks during the months of April, May and June. This increased proportion of April-September precipitation in the eastern portion of the sagebrush steppe region has been used to explain the predominance of grass species in some areas.²⁰

The mean annual precipitation over the period of record (1914-2005) was 276 mm. Peaks in precipitation occurred in the 1910s and into the early 1920s when it began to decline rapidly (Figure 3-2).²¹ This period of lower than average precipitation lasted from the early 1920s until the early 1930s when annual precipitation began to climb. It did not, however, rise to average precipitation again until about 1942. There was a short (two year) period of above average precipitation and then it dipped back below average

Intermountain sagebrush region: plant composition, in: M. Vavra, W.A. Laycock, and R.D. Pieper (Eds.), *Ecological Implications of Livestock Herbivory in the West*, Society for Range Management Publications, 1994, 101-146; Western Regional Climate Center [WRCC], *Climate of Idaho*, 2006, accessed on line at <http://www.wrcc.dri.edu>.

¹⁹ There are no long term climate data stations within the City of Rocks National Reserve. Data from the Oakley station is used here because it offers the best proxy for climate information given its proximity to the Reserve, similarity in elevation of the valleys (4,584 feet in Oakley and 5,400 feet in City of Rocks), and positioning among mountain ranges. Its approximation for higher elevations is, of course, less reliable but there are no long-term weather data stations available at those locations. Furthermore, the Oakley climate data contains the longest running data set for the area. Climate data for Oakley, Idaho was obtained from the Western Regional Climate Center (note 18). This dataset represents 92 years of measurements both monthly and annually from 1914 to 2005.

²⁰ L.A. Stoddart, The Palouse grassland association in northern Utah, *Ecology* 22 (1941) 158-163.

²¹ Graphs of annual precipitation can be very “noisy” and difficult to interpret. Therefore, a common method for identifying trends is the 5 year running average. The 5 year running average for the Oakley dataset was calculated and graphed using methods found in C.J. Bahre and M.L. Shelton, Historic vegetation change, mesquite increases, and climate in southeastern Arizona, *Journal of Biogeography* 20 (1993) 489-504.

again from about 1944 through to 1960. The decade of the 1960s enjoyed above average levels of precipitation with a short slump in the early 1970s. The first half of the 1980s was marked by above average peaks in precipitation followed with below average levels in the latter part of the decade. The 1990s, once again, received precipitation not seen since the 1960s. Temperatures can also be highly variable in the region. The annual mean temperature is 9° C with a maximum of 41° C and a minimum of -33° C.²²

Native American use and occupation

Even though there have been several archaeological studies commissioned by the City of Rocks National Reserve to research the cultural history of the Native Americans in the area, there are still many unanswered questions about the land use of the first human inhabitants at the Reserve.²³ The earliest identified cultural materials within the City of Rocks date back to 4,000 years ago, but most information about the peoples inhabiting the area comes from contact with fur trappers, explorers and emigrants.²⁴ By that time (about 150 years ago) there were two overlapping Shoshoni cultures around the City of Rocks described as the “pedestrian” desert peoples and the “mounted” northern

²² L. Morris, *Ecological History of the City of Rocks National Reserve, Part I: The Human Archive*, National Park Service Pacific Northwest Region, 2006.

²³ D.H Chance, *The Tubaduka and the Kamuduka Shoshoni of the City of Rocks and Surrounding Country*, prepared for National Park Service Pacific West Field Area Columbia-Cascade System Support Office Seattle, WA, 1989; D.H. Chance and J.V. Chance, *The Archaeological Reconnaissance of the City of Rocks Reserve*, prepared for National Park Service Pacific West Field Area Columbia-Cascade System Support Office, Seattle, WA, 1990; Chance and Chance, *Archaeology at the City of Rocks* (note 3); D.H. Chance and J.V. Chance, *Riddles of a Stagecoach Station and Other Questions at the City of Rocks*, prepared for National Park Service Pacific West Field Area Columbia-Cascade System Support Office, Seattle, WA, 1993.

²⁴ Chance and Chance, *The Archaeological Reconnaissance* (note 23).

groups who hunted buffalo (*Bison bison*) on horses.²⁵ The “Northwestern Shoshoni” near the City of Rocks used the area for pinyon pine (*Pinus monophylla*) nut harvesting and hunting in the autumn, even after being forced onto the Fort Hall Indian Reservation in 1869.²⁶ In addition, the Northwestern Shoshoni were also believed to have been collecting many harvestable berries and plants, fishing and grazing horses and some cattle within and around the City of Rocks prior to Euro-American settlement.²⁷

It is now widely accepted that many Native Americans were “managing” grazing lands and food resources with fire before European settlement in the United States.²⁸ However, there were no specific accounts found of the Northwestern Shoshoni burning the land within the City of Rocks.²⁹ Given that the pinyon nuts were so important in the Northwestern Shoshoni diet, it seems counterintuitive to set fire near these trees because they do not typically survive burning. However, recent work from the Sierra Nevada region in California suggests that the Timbisha Shoshoni were managing the pinyon trees by pruning low branches and thinning stands of trees to prevent loss by fire.³⁰ There is no evidence yet to suggest that this occurred in the City of Rocks; however, it deserves consideration given how little is known about the fire history and the Native American use in the Reserve.

²⁵ Chance, *The Tubaduka and the Kamuduka Shoshoni* (note 23).

²⁶ Chance, *The Tubaduka and the Kamuduka Shoshoni* (note 23); B.D Madsen, *The Northern Shoshoni*, Caldwell, 1980.

²⁷ Chance and Chance, *Archaeology at the City of Rocks* (note 3); Chance, *The Tubaduka and the Kamuduka Shoshoni* (note 23); Little, *A Historical Overview of Livestock Use* (note 8).

²⁸ Miller, Svejcar, West, Implications of livestock grazing (note 18).

²⁹ Chance provides only one story by a Gosiute Shoshone woman, Maude Moon, about when a fire went out of control. See Chance, *The Tubaduka and the Kamuduka* (note 23).

³⁰ M.K. Anderson, *Tending the Wild: Native American Knowledge and the Management of California's Natural Resources*, Berkeley, 2005.

There were regional reports of elk (*Cervus canadensis*) and bighorn sheep (*Ovis canadensis*) in the Albion Mountain Range and surrounding areas the City of Rocks in the 1820s and 1830s.³¹ Yet, the archeological studies thus far have not found any bone or tooth evidence of these species in the City of Rocks. Instead, faunal remains of eight different species were recovered including: mountain cottontail (*Sylvilagus nuttallii*), yellow-bellied marmot (*Marmota flaviventris*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), mink (*Mustela vison*) mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), and bison. There were also bones that could only be identified to genus including: jackrabbit (*Lepus* sp.), ground squirrel (*Spermophilus* sp.), and dog (*Canis* sp.).³² In addition to elk and bighorn sheep, beaver (*Castor canadensis*) were remarkably absent from any of the fossil remains. Its absence was remarkable because it was the lure of fur bearing animals (such as beaver) that pulled the first European people into the West.

European exploration and emigration

Fur trappers

The first European people to have potentially entered the City of Rocks were the fur trappers in the early 1800s. Thomas Hunt speculated that Joseph Redford Walker may have made his way through the City of Rocks as early as 1834.³³ Unfortunately, many of these trappers either did not make it into the City of Rocks or did not describe

³¹ Chance and Chance, *The Archaeological Reconnaissance*, 37-38 (note 23).

³² Chance and Chance, *Archaeology at the City of Rocks*, 87 (note 8).

³³ T.H. Hunt, Silent City of Rocks, *Overland Journal* 7 (1989) 13-23.

their trips into the Reserve.³⁴ Similarly, there is no record of the exact route that Joseph Chiles followed in 1842, although he very likely could have passed through the City of Rocks. The honor of being the first to open the route from Fort Hall through the City of Rocks, therefore, goes to Joseph Walker in 1843. The Salt Lake Alternate trail was opened in 1848 almost by happenstance when returning members of the Mormon Battalion met up with the party of Samuel Hensley that had just cut into the City of Rocks due to a bad storm (Figure 3-1).³⁵ These earliest wagon trains did not leave behind descriptive records of their journeys. Instead, it was the emigrants who followed by the thousands through these newly opened wagon routes who left the best record of the conditions along these historic trails.

Overland emigration

The California Trail era lasted from about 1843 until 1869 when the transcontinental railroad was completed.³⁶ Emigration peaked in the early 1850s, and then waned in the following decades.³⁷ Overland emigration brought and estimated 200,000 people and their livestock to California between 1849 and 1860. The estimates for livestock trailed along with these emigrants were staggering. In 1849, there were reportedly 40,000 draft animals brought through the trail. By the next year, an estimated 7,500 mules, 31,000 oxen, 23,000 horses and over 5,000 cows were on their way to the golden state. In 1852, a year of peak travel, 90,340 cattle were said to be en route from

³⁴ HRA, *Historic Resources Study* (note 1); Hunt, *Silent City of Rocks* (note 33).

³⁵ Hunt, *Silent City of Rocks* (note 33).

³⁶ HRA, *Historic Resources Study* (note 1).

³⁷ J. Unruh, *The Plains Across: The Overland Emigrants and the Trans-Mississippi West, 1840-1860*, Urbana, 1979.

Nebraska.³⁸ The pure numerical consideration of livestock and human use along the California Trail has led to several assumptions regarding the detrimental and devastating impact the emigration had on the vegetation in and around the City of Rocks.³⁹

With the exhausted and very hungry emigrants came thousands of cattle, horses, mules, and domestic sheep. The livestock ate off the prime grass seed-growing areas in the river bottoms. Dead cattle filled the creeks, and every stick of available firewood, dry or green, was cut and burned along the emigration routes.⁴⁰

Many of these intrepid emigrants left behind journals, diaries and other written recollections of their journey. The diarists frequently described the things which made their journey possible such as animals for food, grass for forage, wood for fuel, and water. They also discussed events that broke the monotony of the day such as animal sightings, weather, and the scenery. From these accounts, it is possible to find descriptions of the City of Rocks over seasons as well as over many decades of travel.⁴¹ Even when the diarists do not refer to it by name, their descriptions of the “rocks jutting out near the road of peculiar shapes from 5 to 100 ft high” and meeting up with the “road from Salt Lake” or the “Mormon Road” makes it very easy to determine their location.⁴²

There was no evidence from the emigrant diaries, travel guide books or reports of the time to indicate that the nearly twenty-five years of emigration altered the plant

³⁸ Livestock estimates were compiled by Little, *A Historical Overview of Livestock Use* (note 8).

³⁹ Several different reports prepared for the City of Rocks National Reserve describe utter devastation following the era of emigration without any citation or evidence provided.

⁴⁰ Chance, *The Tubaduka and the Kamuduka Shoshoni*, 6 (note 23).

⁴¹ Morris, *Ecological History of the City of Rocks National Reserve* (note 22); L. Morris, Using emigrant diaries to examine historic environmental conditions along the California Trail in the City of Rocks National Reserve, Idaho, *Overland Journal* in press.

⁴² H.S. Giffen, *The Diaries of Peter Decker: Overland to California in 1849 and Life in the Mines, 1850-1851*, Santa Barbara, 1966.

communities in the City of Rocks.⁴³ Most of the emigrant groups traveled through the City of Rocks in the late summer and fall. Great Basin bunchgrasses are most vulnerable to overgrazing in the early spring and have mostly seeded by late summer. Although there was reportedly less forage toward the end of a season of use, there was no indication that the use was reducing the overall availability of forage grasses or the plant communities over the decades.

The diaries did provide excellent anecdotal evidence of the generally cooler and wetter climate during the era of overland emigration that coincided with the ending Little Ice Age. Out of a collection of one hundred diaries spanning twenty-five years, twelve mentioned either being cold or experiencing freezing temperatures while they were around the City of Rocks from the end of June through the end of August. For example, J. Goldsborough Bruff reported on his morning of August 29th, 1849.

Temp. 28° (frost early) Patches of snow on the adjacent mountains. We were all white this morning on awakening, with frost, and my hair being very long, the ends were froze to the saddle and ground, so that I had to pull it loose, but had to leave some, as a memento for the wolves to examine.⁴⁴

In addition, there were several descriptions of the snow-capped mountains from May through September. On July 25th of 1850, Jones said that the snow was nearby and plants were still vigorous such that you could “gather ice with one hand and flowers with the other”.⁴⁵ Even the most extreme temperatures from 1914 to 2005 did not reach below

⁴³ Morris, *Ecological History of the City of Rocks National Reserve* (note 22).

⁴⁴ G.W. Read and R. Gaines, *Gold Rush: The Journals, Drawings, and Other Papers of J. Goldsborough Bruff*, New York, 1949.

⁴⁵ J. C. Jones, unpublished diary on file at the Merrill Mattes Library (OCTA-MS-Jones), 1850.

freezing in these months.⁴⁶ Cooler temperatures could have meant less evaporation of soil moisture. They could imply that there was more soil moisture available over the growing season as the snow slowly melted and percolated into the groundwater and through the streams. The colder and potentially wetter conditions could have supported more grass and herbaceous vegetation than today.

The diaries also offer a better idea of what animals were in the area than what was previously known from ethnographic and archeological studies. While it was only surmised that the Northwestern Shoshoni fished in the areas surrounding the City of Rocks, it was clear from the diaries that the emigrants were fishing successfully. They referred to catching fish in the Raft River and its tributaries, although not specifically within Circle Creek in the City of Rocks. Most frequently, they wrote of catching fish in the Raft River and in the “the narrows” (Figure 3-1). The emigrants also described several other very interesting meals.

In the camps along the Raft River fresh-water lobsters are boiled and eaten by many, said to be good. They are about four inches long. The emigrants, or some of them, cook and eat rattlesnakes. They call them *bush fish*. Prairie dogs are nice eating...Marmots are used for food. They are very fat and good. Rabbits are abundant here.⁴⁷

There are no longer any crayfish in these portions of the Raft River. Presently, the Raft River is mostly a dry wash in summer months and no fish inhabit its main stem although some still occur in the upper tributaries.⁴⁸

⁴⁶ Morris, *Ecological History of the City of Rocks National Reserve* (note 22).

⁴⁷ Diary excerpt of William Swain, 1849, found in J.S. Holliday, *The World Rushed In: The California Gold Rush Experience*, Norman, 1981.

⁴⁸ Wallace Keck, personal communication, 2008 (note 12). There are three native crayfish in the state of Idaho, all three are in the genus *Pacifastacus*. Idaho Department of Fish and Game, *Idaho Fish and Game Management Plan 2007-2012*, available on line at

The King survey

Clarence King was commissioned by Congress to conduct the exploration and survey of the Fortieth Parallel in 1867. The fortieth parallel actually runs south of the Idaho border through the upper two thirds of Utah.⁴⁹ Even so, it appears that King and at least some of his crew made it into the Reserve because a set of six photos taken by the survey photographer, Timothy O’Sullivan, in the City of Rocks were a part of the official record for 1868. Although King and his party did not leave behind any written description of this trip, they were most likely in the Reserve around September of 1868 when they went to explore the “supposed coal beds along Goose Creek”.⁵⁰ King mentioned taking the stage from Rock Creek back to his Salt Lake valley camp in October of that year, but he provided no further detail or description in his letters and reports from the expedition.⁵¹

Therefore, the only information about the environmental conditions during their visit to the City of Rocks was the startlingly vivid images by O’Sullivan (Plates 1-4). These images are the first photographic evidence of what the land was like in the City of Rocks prior to European settlement. These images reveal places where there has been a change in plant species (Plate 1) and show what appear to be fire scars along hillsides within the City of Rocks (Plates 3 and 4). King mentioned difficulty with triangulation

http://fishandgame.idaho.gov/fish/programs/fish_plan.pdf ; Idaho Department of Fish and Game, *Management Plan for Conservation of Yellowstone Cutthroat Trout in Idaho*, April 2007, available on line at <http://fishandgame.idaho.gov/>.

⁴⁹ T. Wilkins, *Clarence King: A Biography*, Albuquerque, 1988.

⁵⁰ Records of the King Survey, 1867-81, letters sent to the Chief of Army Engineers, Mar. 28, 1867-Jan. 18, 1879, vol. 1, National Archives Microfilm Publication M622, roll 3, Records of the U.S. Geological Survey, Record Group 57, National Archives at College Park; Wilkins, *Clarence King* (note 49).

⁵¹ Records of the King Survey, 1867-1871 (note 50).

work on the survey during late summer months in Northern Utah due to problems with haze and smoke from fires filling the valleys.⁵² These photos capture an important time of transition between the end of the California Trail as the major route for overland emigration and transportation (the railroad was completed in 1869) and the time just before the City of Rocks was settled. But before the City of Rocks would be homesteaded, the land had to be surveyed.

Period of survey and settlement

As acquisition of new US territories progressed, the federal government required an account of the lands with the most potential for settlement. The General Land Office was created in 1812 to survey the national lands for settlement and disposal.⁵³ A standard survey consisted of a Township (36 mi² block of land) containing 36 Sections (1 mi² blocks of land) that were aligned north-south on meridians and east-west on baselines. The Township boundaries were surveyed first and then the interior section lines. In Idaho, these surveys were conducted from 1866 through 1925. For the City of Rocks, the earliest survey was conducted by Allen Thompson in 1878 of the township boundaries that bisect the Reserve into four quadrants (northwest, northeast, southwest and southeast; Figure 3-3). The earliest section line survey was also conducted in 1878 by Allen Thompson, with the others completed in 1880s and into the early 1890s.⁵⁴

⁵² Records of the King Survey, 1867-1871 (note 50).

⁵³ S.M. Galatowitsch, Using the original land survey notes to reconstruct pre-settlement landscapes in the American West, *Great Basin Naturalist* 50 (1990) 181-191.

⁵⁴ The survey notes for the City of Rocks are described in detail in Morris, *Ecological History of the City of Rocks National Reserve* (note 22).

The two northern townships in the City Rocks were not rated equally for settlement by the surveyors. Allen Thompson concluded from his survey of the northwestern quadrant that it “contains but very little land suitable for farming, is generally hilly and mountainous”.⁵⁵ He believed that the township was mostly “well adapted for grazing.”⁵⁶ In 1884, J.R. Glover surveyed the same locations as Thompson and he concluded, “The soil is 2nd rate, producing sagebrush and in the valley, excellent bunchgrass.”⁵⁷ The northeastern quadrant that included the area known as the Circle Creek Basin was different from the northwestern quadrant. Here, Thompson concluded that the township, “contains a fair proportion of first rate land for farming, is well watered by numerous (illegible) streams which plenish (?) water for irrigation. The Township is well adapted for grazing, will advise of a large settlement and should therefore be subdivided.”⁵⁸ Oscar Sonnenkalb surveyed the remaining inner section lines in the Circle Creek basin area in October of 1886. He described “dense cedars, pines and undergrowth of the same” along the mountain tops and into the lower hills while a “sagebrush plain” covered the valley with willow brush growing along the creek.⁵⁹

The southern townships were generally described as less desirable for farming than the land within Circle Creek Basin but fairly good range for livestock. Thompson described the boundary between the two southern portions as having “good grass” but

⁵⁵ Description from General Land Office survey notes on file at the State Bureau of Land Management Office in Boise, Idaho under, A. Thompson, 1878, vol. 21, 655.

⁵⁶ A. Thompson, 1878, vol. 21, 655 (note 55).

⁵⁷ See note 55, J.R. Glover, 1884, vol 34, 462.

⁵⁸ A. Thompson, 1878 vol. 35, 647 (note 55).

⁵⁹ See note 55, O. Sonnenkalb, 1886, vol. 93, 348-388. There are no true cedar trees in the City of Rocks. However, “cedar” was a common name applied to junipers (*Juniperus osteosperma*). This common name is still used in the local western vernacular.

only “scattering juniper and scrubby pine”.⁶⁰ Frank Riblett surveyed the interior section lines in the southwestern quadrant of the Reserve in 1892. He mentioned some aspen (*Populus tremuloides*) and mountain mahogany (*Cercocarpus ledifolius*) but generally found no “timber” along the western edge of the Reserve except dense junipers (*Juniperus osteosperma*) and pinyon pine.⁶¹ In the southeastern section, Oscar Sonnenkalb completed the section line surveys in 1886. This area contained “small creeks in narrow canons (sic)” where the only soils considered “1st and 2nd rate” were found in “small spots”. He believed the mountains had “sufficient grasses and herbs to render this part of the township a good range for stock.” He remarked that the hills were “covered with a dense growth of cedars, mahoganies and pinion (sic) pines of smaller size and produce here and there heavy timber of cedars with dense undergrowth of the same.” All this “timber”, however, was described as only good for “fencing and as fire wood for house use.”⁶²

The original survey markers, usually piles of rocks or pits, have all long since been replaced by new brass post markers and plastic vertical tags in subsequent surveys. But the legacy of the survey system is visible upon the landscape in a number of ways including the road system. The only roads described in the survey records were the wagon and stage routes. But after the surveys were completed, the old California Trail wagon routes gave way to roads that followed the new section lines as people began

⁶⁰ A. Thompson, 1878 vol. 35 pgs. 638-663 (note 55).

⁶¹ See note 55, F. Riblett, 1892, vol. 112, 524-557.

⁶² Oscar Sonnenkalb, 1886, vol. 93, 502-504 (note 55).

fencing their homesteads.⁶³ The adjustment of roads to the section lines is still part of the transportation system in the Reserve today in many areas. For example, the road takes an abrupt right angle in the southern section of the City of Rocks to follow the section lines (Figure 3-4). The igneous parent material of the soils in the City of Rocks makes all roads highly susceptible to erosion. Even if the vegetation covers the tracks of an old road, whether it be the California Trail or along a section line, the eroded swale left behind can still be located today (Plates 5 and 6).

Homesteads

Another way that the surveying system influenced the Reserve was through patterns of development and homesteading. Those properties described as most suitable for farming in the Circle Creek basin were those claimed first. Settlement within the City of Rocks began just after the establishment of the nearby town of Almo in the late 1870s.⁶⁴ The first land entry was George Lunsford who reported building a house and moving onto the land in 1882 and patented his claim in 1888 (Figure 3-3). There were only three land patents filed under the original Homestead Act and two under the Desert Homesteads Act. It was not until the Forest Homestead Act of 1906 and when the Enlarged Homestead Act came to Idaho in 1909 that settlement really began to spread within the Reserve.⁶⁵ The era of homesteading ushered in a whole new suite of land uses

⁶³ Oral history with Jim Lloyd, long time local resident, recorded by Lesley Morris, October 16, 2005, on file at the City of Rocks National Reserve; M. Wells, *History of the City of Rocks*, prepared for National Park Service Pacific West Field Area Columbia-Cascade System Support Office Seattle, WA., 1990.

⁶⁴ Little, *A Historical Overview of Livestock Use* (note 8); HRA, *Historic Resources Study* (note 1); Wells, *History of the City of Rocks* (note 63); and others.

⁶⁵ HRA, *Historic Resources Study* (note 1).

including dry farming, land clearing, fence post cutting, irrigation work and livestock grazing.

The increase in settlement after the turn of the century was largely due to the spread of dry farming into the region. Dry farming is the practice of cultivation without irrigation.⁶⁶ General guidelines from the period when the practice was first employed called for alternately plowing to a depth of 18 to 25 cm so as to avoid creating a hardpan. All vegetation except the crop was removed to minimize competition for water. Rotation of summer fallowing was said to store the water in the soil from the previous year for crop production during the following season.⁶⁷ Early books on the subject encouraged people to locate their dry farms where there were vigorous stands of native grass and tall sagebrush.⁶⁸ In other words, they were encouraged to plow under the most productive areas of sagebrush steppe.

Most of these homesteaders put at least part of their land into cultivation, cropping winter wheat, barley, or oats, and had some areas of irrigated garden production. These and other kinds of improvements were used as part of the “proving up” for the patent.⁶⁹ By the time all the patents were filed, the homesteaders had collectively cleared and/or cultivated approximately 1,266 acres of land within the City

⁶⁶ J.A. Widtsoe, *Dry-Farming: A System of Agriculture for Countries under Low Rainfall*, New York, 1911.

⁶⁷ W. MacDonald, *Dry-Farming: Its Principles and Practice*, New York, 1911; Widtsoe, *Dry-Farming* (note 66).

⁶⁸ Widtsoe, *Dry-Farming* (note 66).

⁶⁹ “Proving up” was a term used for the process of declaring improvements to the General Land Office representative at the time the patent for ownership on the land was filed.

of Rocks National Reserve (Plate 7).⁷⁰ They likely cleared and cultivated even more land after filing. Cultivation can be the most drastic disturbance of sagebrush steppe areas with recovery of sagebrush taking nearly a half century and restoration of many perennial forbs still not accomplished.⁷¹ Dry farming can influence vegetation through declining soil fertility, increasing erosion, and aiding in the introduction of invasive and weedy plant species.⁷² Areas of historic cultivation often have altered plant diversity and lowered potential for reoccupation of the site by native species.⁷³ Many of the areas that were historically cultivated and repeatedly plowed in the Reserve contain little native vegetation beyond the sagebrush.⁷⁴ The effects of this land use are visible on the landscape even today (Plates 7-10).

Another form of “proving up” on a patent was to “improve” the property by fencing. The homesteaders in the City of Rocks made good use of the timber described in the General Land Office Surveys for fence posts. According to the Minidoka National

⁷⁰ Calculated from copies of the homestead records for the Reserve on file at the City of Rocks National Reserve headquarters in Almo, ID; Morris, *Ecological History of the City of Rocks National Reserve* (note 22).

⁷¹ E.W. Tisdale, and M. Hironaka, *The Sagebrush-Grass Region: A Review of the Ecological Literature*, USDA Forest, Wildlife and Range Experiment Station, University of Idaho, Bulletin No. 33, 1981.

⁷² A. F Bracken, Extent and condition of the range lands for Utah, in: *Utah Agricultural Experimental Station Agricultural Adjustment Survey for Utah*, 1935, 37-42; H. Bolton, J.L. Smith, and S.O. Link, Soil microbial biomass and activity of a disturbed and undisturbed shrub-steppe ecosystem, *Soil Biology and Biochemistry* 25 (1993) 545-552; R. L. Piemeisel, *Changes in Weedy Plant Cover on Cleared Sagebrush Land and their Probable Causes*, USDA Technical Bulletin No. 654, 1938.

⁷³ Piemeisel, *Changes in Weedy Plant Cover* (note 72); K.D. Sanders, S.C. Bunting and R.G. Wright, *Grazing Management Plan: City of Rocks National Reserve*, prepared for the Pacific Northwest Region of National Park Service, on file at the City of Rocks National Reserve, 1996.

⁷⁴ Sanders, Bunting and Wright, *Grazing Management Plan* (note 73); personal observation of the author, 2005.

Forest History, “large quantities of posts and poles” were given away under free use permits to hundreds of settlers during the height of the dry-farming era about 1914.⁷⁵ Using descriptions from the Homestead Patents in the City of Rocks, around 140 km of fencing was erected in the Reserve during this era. Most of the patents described fencing with posts one rod apart (5.3 m) and only two claimed fences at two rods distance (10.1 m). Given these approximations, some 16,520 posts would have been needed for fencing in the Reserve alone. A good juniper tree for a post was approximately 2 m tall and at least 10 cm in diameter.⁷⁶ This former land use was spotted by a surveyor for the Bureau of Land Management in 1952 when he described an area that was “...cut over for posts (approximately 10% of volume) and many small openings containing air within the stand”.⁷⁷

The era of homesteading and settlement likely had an impact on the wildlife as well. Several of the earliest settlers in the City of Rocks made a living by trapping including Walter Mooso, Samuel P. Mikesell and Torrey Campbell.⁷⁸ Walter Mooso, a homesteader west of the Twin Sisters said he bought most of his traps from Mikesell who had homesteaded on the east side of the Twin Sisters (Plate 7). Mikesell was said to be

⁷⁵ Minidoka National Forest Personnel, *History of the Minidoka National Forest* [MNF History 1941], USDA Forest Service Intermountain Region, Sawtooth National Forest, on file at the City of Rocks National Reserve, 1941.

⁷⁶ Malta Civilian Conservation Corps Report, Cotterel Mt. Post Cutting Project, on file at the National Archives and Records Administration Pacific Alaska Regional Office, Seattle, WA, 1941, RG 49 BLM Burley District Office SMC and Range Improvement case files, G-141 Malta CCC camp.

⁷⁷ Bureau of Land Management Range Surveys, on file at the Bureau of Land Management Burley District Office, Burley, ID, 1952.

⁷⁸ Oral history with homesteader, Walter Mooso, interviewed by A.W. and Lillian Dawson, March 4, 1975, transcription on file at Cassia County Historical Society and Museum, Burley, ID; Chance and Chance, *Riddles of a Stagecoach Station*, 100 (note 23).

employed by the Australian government as a trapper.⁷⁹ He and other early trappers caught coyotes, muskrats (*Ondatra zibethicus*), badgers (*Taxidea taxus*), skunks (probably *Mephitis mephitis* or *Spilogale gracilis*), mountain lions (*Puma concolor*), lynx (*Lynx* sp.), bobcats (*Lynx rufus*) and weasels (*Mustela* sp.).⁸⁰ There was no mention of them harvesting any beaver in the area.

The period of settlement was synchronous with the rise of the cattle barons and the subsequent conflicts between cattlemen, sheep growers and farmers known as the range wars. Cattle and sheep had been trailed through the City of Rocks beginning in the California Trail era. The earliest known cattle drive was documented by Cyrus Loveland in 1850.⁸¹ Kit Carson trailed sheep through the City of Rocks in 1853, and Mrs. Benjamin Ferris reported a band of 4,000 sheep in the same year.⁸² The cattle industry in the area was believed to have initiated in 1869 when James Q. Shirley summered a herd near the City of Rocks. The settlers in the City of Rocks and Almo area had smaller herds of cattle that did not compare to the number of livestock that came out of the bigger ranches in Nevada and Utah. For example, the consolidated ranches of Sparks and Tinnin in 1881 ran an estimated 175,000 head of cattle “from Junction Valley in the east to the Bruneau River on the west and from Snake River to the north to Humboldt Wells

⁷⁹ Chance and Chance, *Riddles of a Stagecoach Station*, 100 (note 23).

⁸⁰ Oral history transcription of Walter Mooso (note 78); B.T. Kimber, *Life Story of Bertha T. Kimber*, unpublished autobiography on file at the City of Rocks National Reserve, no date.

⁸¹ Little, *A Historical Overview of Livestock Use* (note 8); R.H. Dillon, *California Trail Herd: The 1850 Missouri to California Journal of Cyrus C. Loveland*, Los Gatos, 1961.

⁸² E. N. Wentworth, *America's Sheep Trails: History and Personalities*, Ames, 1948; B.G. Ferris, *The Mormons at Home: With Some Incidents of Travel from Missouri to California, 1852-3*, Brooklyn, 1971.

in Nevada". In Utah, the Bar M Ranch, owned by Charles Crocker, had 75,000 head of cattle that ranged into Idaho and the Raft River valley.⁸³

Mr. Taylor of Almo and many others say, when they came to the country [Almo area], their horses or cattle could be turned any place and would fill up in short time. Then came the large herds of cattle, so numerous that no one counted them.⁸⁴

Some estimated, however, that there were as many as 230,000 head of cattle and several thousand horses in the mid 1880s on the lands in and surrounding the City of Rocks.⁸⁵

Mining in Idaho and continued development of the railroads in the 1870s and 1880s opened new markets and fed the growth of the livestock industry in the region. The livestock industry during these early years engaged in year-round grazing and did not supplement their feed in the winter.⁸⁶ In the winter months in the Great Basin, large herds of cattle were moved into the desert valleys of Nevada for grazing there.⁸⁷ This level and season of use reportedly took a toll on the range around the City of Rocks:

...the range began to show signs of overcrowding; there were thousands of five and six-year old steers on the range, and too many breeding animals.⁸⁸

According to statements of old-timers, the sagebrush plains and foothills were densely carpeted with bunchgrass.....Overgrazing, together with the

⁸³ Little, *A Historical Overview of Livestock Use*, 18 (note 8).

⁸⁴ Minidoka National Forest [MNF Report 1949], Albion Ranger District Management Plan, National Archives and Records Administration Pacific Alaska Region, Seattle, WA, RG 95, Box 1, Sawtooth National Forest, Range Management Records, 1949, section VIII.

⁸⁵ MNF History 1941, 13 (note 75).

⁸⁶ Little, *A Historical Overview of Livestock Use* (note 8); J.A. Young and B.A. Sparks, *Cattle in the Cold Desert*, Reno, 2002.

⁸⁷ Young and Sparks, *Cattle in the Cold Desert* (note 86).

⁸⁸ Walgamot, quoted in MNF History 1941, 4 (note 75).

droughts of 1886 and 1891 seriously depleted these valuable forage plants which were in many cases supplanted by sage.⁸⁹ Great Basin bunchgrasses do not fair well under the combination of high stocking rates and early spring use when they are most vulnerable.⁹⁰ Jim Young and B. Abbott Sparks argued that this intense use before the turn of the century began to kill off the grasses in the Great Basin that rely on seed for reproduction. Over the decades of heavy use, the seed bank became depleted and could not replenish the populations.⁹¹ Based on the above descriptions, this was likely the case in the City of Rocks as well.

The harsh winters and droughts in the late 1800s took a toll on the local livestock industry.⁹² From 1886 until 1891, there was a reported drought that “dried up creeks” and left “vegetation wilted to the ground.”⁹³ Local residents recalled hearing stories that the drought of the 1890s lasted for several years and turned the land into a “dust bowl.” Some of the ranchers skinned the dead cows and sold the hides for 50 cents a piece. The livestock had reportedly eaten down all the vegetation in the valleys during that drought, and it took several years before there was good grazing again.⁹⁴

On top of the droughts, the “devastating winter” of 1889-1890 brought losses that many say crippled the cattlemen. William Little called it the great “equalizer” because it

⁸⁹ MNF History 1941, 4 (note 75).

⁹⁰ Tisdale and Hironaka, *The Sagebrush-Grass Region* (note 71); Miller, Svejcar, West, Implications of livestock grazing (note 18).

⁹¹ Young and Sparks, *Cattle in the Cold Desert* (note 86).

⁹² MNF History 1941 (note 75); Little, *A Historical Overview of Livestock Use* (note 8); E. Durfee, *Remembrances of Almo Community*, unpublished autobiography, on file at City of Rocks National Reserve, no date, may have been between 1970 and 1975.

⁹³ Durfee, *Remembrances of Almo Community* (note 92).

⁹⁴ Oral history with Jay Black, long time local resident, interviewed by Lesley Morris, May 28, 2005, on file at the City of Rocks National Reserve; Oral history with Ned Jackson, former City of Rocks Superintendent, interviewed by Lesley Morris, September 5, 2005, on file at the City of Rocks National Reserve.

elevated the sheep growers whose flocks had better survived the winter because the sheep could utilize more browse in the deserts and on the steep terrain. Beginning in 1891, sheep herds began to increase, and there were reportedly 85,000 head of sheep in the area around the City of Rocks by 1895. Sheep trails through the City of Rocks are visible in early photographs (Plate 6). Although they never regained the pre-1891 numbers, cattle and sheep had both increased by 1900 and overgrazing was prevalent once again.⁹⁵

That devastating winter of 1889-1890 influenced the rangelands as well. Jim Young and B. Abbott Sparks speculated that this period following the great white winter strongly favored shrub production in the Great Basin because two decades of heavy grazing on the perennial grasses had largely depleted their seed banks, and the grasses could not take advantage of the 1890-1893 increase in precipitation. Woody species such as juniper and sagebrush, on the other hand, had already become established and were poised to make further gains from the increase in precipitation. This winter also ushered in another change in land use as it was clearly necessary to begin supplementing livestock with hay in the winters.⁹⁶

The beginning of regulation (1900-1929)

The impacts of these multiple uses brought by settlement helped to initiate the system of the Forest Reserves in the early 1900s. The Raft River Forest Reserve was created in 1906. It contained what was later known as the Albion Division. In 1907 the

⁹⁵ Called a “devastating winter” in Young and Sparks, *Cattle in the Cold Desert* (note 86); called the “equalizer” by Little, *A Historical Overview of Livestock Use* (note 8); MNF History 1941 (note 75).

⁹⁶ Young and Sparks, *Cattle in the Cold Desert* (note 86).

National Forests were created from the Forest Reserves and the Raft River and Cassia Forest Reserves were combined into the Minidoka National Forest by 1908.⁹⁷ The very large Minidoka National Forest stretched from Idaho into Northern Utah and just the Albion Ranger District (including part of the City of Rocks) alone contained 32,358 hectares.⁹⁸ The portion within the City of Rocks that was historically managed by the Forest Service made up only 21% of the total area of the Reserve when it was created. However, the US Forest Service records provide very good insight into the conditions and concerns of the time.⁹⁹

The new Forest Reserve managers (and later the National Forest Rangers) were not only responsible for timber management but also livestock grazing and wildlife resources. For the Minidoka Forests, livestock grazing was one of the primary issues the agency faced. Their very first attempt at regulation was a permit system initiated in 1906. In 1907, what was then known as the Raft River National Forest, reported permits for 3,042 cattle and horses and 14,665 sheep.¹⁰⁰ Seasonal use was from April 1 through November 30 for cattle and June 15 to October 31 for sheep. In a 1909 report, Forest Supervisor William McCoy lamented that, “control was 20 years late, and the effects of forest fires, wasteful cutting of timber, and overgrazing of the range will be felt for years”. He stated that the range would accommodate “only 50% of the number of stock it

⁹⁷ MNF History 1941 (note 75).

⁹⁸ MNF Report 1949 (note 84).

⁹⁹ Historical records of the Minidoka National Forest are housed at the National Archives and Records Administration Pacific Alaska Regional Office in Seattle, WA, and in the USDA Forest Service Region 4 Office in Ogden, UT. Historical records from the Twin Falls Supervisors office could not be located.

¹⁰⁰ US Forest Service, Report on Grazing, Raft River National Forest, 1907, found in Little, *A Historical Overview of Livestock Use*, Appendix E (note 8).

would years ago.”¹⁰¹ Despite their efforts, overgrazing was still an issue in the early 1920s.¹⁰² The impacts were also still visible in the valleys. A long-time resident who ran sheep in the City of Rocks as a child recalled that, in the 1920s, the land on the southern end of the Reserve was so overgrazed there was nothing but “sagebrush and dust.”¹⁰³

In addition to livestock, wild horses were also believed to have contributed to the overall downward trend in range conditions in the National Forests.¹⁰⁴ Wild horses are a lasting part of the community’s memory in the area. Locals remembered chasing and “rounding up” the wild horses. Sometimes they corralled the ponies into the rocks and “practiced branding them.” The horses were also a source of income for adults. The sale of about 20-25 wild horses helped at least one young couple afford to buy their first house.¹⁰⁵ The military was said to have released stallions into the wild horse herds on the nearby Jim Sage Mountains to improve the stock, and then they harvested close to 2,000 animals from that area (Figure 3-1). A massive effort to rid the range of wild horses was initiated in the 1920s. Some 3,000 horses were rounded up from the foothills surrounding the Minidoka National Forest, and several thousand were removed from US Forest Service lands in 1928.¹⁰⁶ Since 1924, 300 horses were eliminated from a grazing

¹⁰¹ Minidoka National Forest Report [MNF Report 1909], Report for Forest, on file at the City of Rocks National Reserve, 12.

¹⁰² MNF History 1941 (note 75).

¹⁰³ Oral history with Jim Lloyd (note 63).

¹⁰⁴ MNF Report 1949 (note 84).

¹⁰⁵ Oral history with Leona Jones, long time local resident, interviewed by Lesley Morris, August 10, 2004, on file at the City of Rocks National Reserve.

¹⁰⁶ MNF History 1941 (note 75); Oral history with Delmar Vail, interviewed by Linda Morton-Keithley, November 6, 1995, on file at the Idaho State Historical Society (IDSHS #1428a-c).

allotment that included portions of the City of Rocks.¹⁰⁷ The wild horses were reportedly “taken care of” by 1930, and there are no longer any found in the City of Rocks.¹⁰⁸

The new Forest Service was also concerned with wildlife and, in particular, protecting their devastated deer population on the Minidoka National Forest.¹⁰⁹ Deer were reportedly “killed and hauled like cordwood” in the late 1890s and were, therefore, depleted by the time the Forest Reserve was created. In 1918, they believed there were only 20 deer left. They were successful at increasing the herd by closing the forest to hunting from 1910 through 1929 but there were concerns over other game animals as well including birds and elk. Game birds were a concern as early as 1918. The “grouse” and “sage hens” decreased alternately in the early 1910s and 1920s as they were alternately protected from or listed for open hunting.¹¹⁰ Elk were introduced on the Albion Division in 1915 but they reportedly “did not prosper.”¹¹¹ Deer were not the only

¹⁰⁷ Minidoka National Forest Report [MNF Report 1929], Individual Grazing Allotment Plan, on file at the National Archives and Records Administration Pacific Alaska Region, Seattle, WA, RG 95, Box 1, Sawtooth National Forest, Range Management Records.

¹⁰⁸ MNF Report 1949 (note 84).

¹⁰⁹ Wildlife Management reports for the Minidoka National Forest from 1918 to 1950 were found at the National Archives and Records Administration Pacific Alaska Regional Office in Seattle, WA, Record Group 95, Box 1, Sawtooth National Forest, Wildlife Management Records 1917-1939 and Box 2, Sawtooth National Forest, Wildlife Management Records 1940-1953. The reporting was not consistent or thorough enough for quantitative analysis; however, it did provide a qualitative glimpse at what was happening with several important species over time in the area. Information from these reports is used throughout the paper.

¹¹⁰ Only common names are given for these birds through out the reports. However, “sage hens” most likely refers to the greater sage-grouse (*Centrocercus urophasianus*). The term “grouse” is eventually refined to “pine hen” and “blue grouse” in later reports. Therefore, it is likely that the grouse referred to in the reports were blue grouse (*Dendragapus obscurus*).

¹¹¹ Information on wildlife comes from Wildlife Reports from 1918-1950 (See note 109).

animal to go through drastic changes on the Minidoka National Forest. In 1925, six beavers were reported on the forest. By 1936, beaver were reportedly “numerous” but there was still no mention of them within the Reserve. The last report of wolves (*Canis lupus*) in the Albion Division was in 1924. They are now locally extinct.

There were bounties on several animals considered to be pests. Magpies (*Pica hudsonia*), which were a problem because they were nest robbers and would get into the chickens and eat the eggs, carried a bounty of about 1-5 cents per bird and 2 cents for an egg at the local store in Almo.¹¹² Gophers (probably *Thomomys talpoides*) and ground squirrels were considered a problem because they would get into the fields, and their mounds would plug up the hay swather. There was a bounty on squirrels from about 1912-1920, and since people could get a penny a tail, some people would put out poisoned oats to kill them.¹¹³ Many people recalled having rabbit drives when the populations would get large.¹¹⁴

¹¹² Oral history with Larry Edwards, long time resident, interviewed by Lesley Morris, March 5, 2005, on file at the City of Rocks National Reserve; Oral history with Jay Black (note 94); Oral history with Jack and Kathryn Erickson, long time local residents, interviewed by Lesley Morris, October 16, 2005, on file at the City of Rocks National Reserve; Oral history with Jim Lloyd (note 63).

¹¹³ Oral history with Grace Durfee, long time local resident, interviewed by Lesley Morris, August 9 and 11, 2004, on file at the City of Rocks National Reserve; Oral history with William and Annalee Jones, interviewed by Lesley Morris, August 9, 2004, on file at the City of Rocks National Reserve; Oral history with Jim Lloyd (note 63).

¹¹⁴ Oral history with Jack and Kathryn Erickson (note 112); Oral history with Juanita Jones, City of Rocks Employee and local resident, interviewed by Lesley Morris, September 13, 2005, on file at the City of Rocks National Reserve; Oral history with Stan Lloyd, local resident, interviewed by Lesley Morris, October 16, 2005, on file at City of Rocks National Reserve; Oral history with Kent and Janis Durfee, local residents, interviewed by Lesley Morris, May 6, 2005, on file at the City of Rocks National Reserve.

The Forest Service also made an effort to increase fishing opportunities in the Minidoka National Forest. Nearby Almo Creek was stocked with 5,000 fry in 1920 and 1924.¹¹⁵ Immediately, there was concern that fish were getting into irrigation ditches and being destroyed. In 1921, Forest Ranger Henry Smith reported, “The canals in the vicinity of this Division are badly in need of screening and seem to be the most important factor to be considered in maintaining normal supply of fish.” The reports were unclear as to when this stocking was discontinued, but there was an indication that local residents complained about fish getting in their canals. There were no specific reports on stocking fish in South Creek, Center Creek or North Creek that flow directly into Circle Creek in the City of Rocks.

People living in Almo and in the City of Rocks made use of all the local natural resources including wildlife, wood, and water. They used the wood from local woodlands and forests for building fences, homes and for fuel. The original families got their timber out of the Albion Mountains for building their homes.¹¹⁶ A variety of fuel wood was used by the communities surrounding the City of Rocks. Many liked to use mountain mahogany because it burned hot like coal, lasted the longest, and made a good nighttime wood. People also said they used a lot of aspen, some pinyon pine, some juniper, and even lodge pole pine (*Pinus contorta*), limber pine (*Pinus flexilis*), and Douglas-fir (*Pseudotsuga menziesii*). Aspen was said to be the easiest to cut and made a

¹¹⁵ As with the birds, no species names for the fish were used in these reports, only “trout” or sometimes “rainbow trout.”

¹¹⁶ Oral history with Grace Durfee (note 113); Oral history Kent and Janis Durfee (note 114); Oral history with James and Dorothy Sheridan, long time local residents, interviewed by Lesley Morris, September 14, 2005, on file at the City of Rocks National Reserve.

good fire for cooking because it did not produce much ash. Residents cut wood to heat their homes, the school house and the church. They went all over the Albion Mountains and into the City of Rocks cutting both live and dead wood. There were at least two wood roads in the Reserve, one was just before Bath Rock and the other was the old road around the Circle Creek basin (Plate 11).¹¹⁷ After World War II, many residents stopped using as much fuel wood, and many installed oil burning stoves or coal furnaces.¹¹⁸

Local settlers also collected pine nuts along side the Native Americans, who continued to visit from Fort Hall Reservation in the fall to camp, harvest pine nuts and trade hides for the beaded deer skin gloves they made.¹¹⁹ A typical family could collect close to twenty-five pounds without the cones and about fifty pounds in sacks with the cones still on them in one day.¹²⁰ Very few local families reported collecting pine nuts anymore.

Even though they were mostly dry farming, the homesteaders dug wells and developed water for culinary use, gardening and for their livestock. One homesteader,

¹¹⁷ Oral history with Buddy and Marion Ward, local residents, interviewed by Lesley Morris, August 8, 2004, on file at the City of Rocks National Reserve; Oral history with Jack and Annalee Erickson (note 112); Oral history with Kent and Janis Durfee (note 114); Oral history with Jay Black (note 94); Oral history with Jim and Dorothy Sheridan (note 116); Oral history with Klint and June Lloyd, local residents, interviewed by Lesley Morris, October 15, 2005, on file at the City of Rocks National Reserve; Oral history with Jim Lloyd (note 63); Oral history with William and Annalee Jones (note 113); Oral history with Richard Bruesch, local resident, interviewed by Lesley Morris, August 12, 2004, on file at the City of Rocks National Reserve; Vinola Archibald, grew up in the area, personal communication, 2005.

¹¹⁸ Oral history with Leona Jones (note 105); Oral history with Bob and Nancy Ward, local residents, interviewed by Lesley Morris, October 15, 2005, on file at the City of Rocks National Reserve.

¹¹⁹ Chance and Chance, *The Archaeological Reconnaissance* (note 23).

¹²⁰ Oral history with Grace Durfee (note 113); Oral history with Buddy and Marion Ward (note 117).

Mrs. Mikesell, said their land had an abundance of water where she lived and that men hit water with their shovels when they were digging post holes (Plate 7).¹²¹ Walter Mooso also described finding a spring site easy enough to develop with just a shovel:

....I got a hold of this piece of wood and it was as hard as anything I ever tried to carry. And it happened to be mahogany and I didn't know anything about mahogany. But it was like carrying iron. Well I carried it along and I got a little tired. I stopped and stood it up there and I looked around. And the clouds separated and the moon shined right on the spot. Almost to my feet and it was little soft before I had got to it. And it shined there before I got to it and it shined there and I could see it was bare.....So I rolled my sleeves up and I started to digging and I dug down there about twelve inches and I run into a nice bunch of water there. That was the spring that I developed there. They can call it developing or what ever they want to. But it was there and I just looked up from the shovel and I took off to the house with my shovel. It wasn't a shovel but an ax. I took off up to the shack and I got the shovel then I com back. And the clouds had moved away and I didn't have much trouble and that was about eleven o'clock at night. And by gosh, by two thirty I had me a nice well just about up to my...just above my hips a ways.¹²²

They installed check dams, created small reservoirs and some piped water out in flood irrigation systems.¹²³ All that changed beginning in 1920 when the “underground water suddenly disappeared...drying up the springs and stopping irrigation.”¹²⁴ The climate records clearly show that the average annual precipitation began dropping in the 1920s and kept declining until the mid 1930s (Figure 3-2). During this drought in the 1920 and 1930s, the homesteaders who relied upon dry farming were “starved out” because they could not pay their taxes. At that time, people went the way of the water. If the water

¹²¹ South Idaho Press, 1955.

¹²² Oral history transcript of Walter Mooso (note 78).

¹²³ Oral history with Jim Lloyd (note 63); Oral history with Stan Lloyd (note 114); homestead records for City of Rocks in the Circle Creek basin also show irrigation ditches.

¹²⁴ Southern Idaho Press, 1955.

was gone, so were they. Many of the early settlers moved to Almo, Oakley, or to Burley, Idaho.¹²⁵

Period of range management (1934-1960)

After abandonment of the dry farms in the 1920s, much of this land was slow to revert back to natural vegetation and the forage production was very limited.¹²⁶ Drought in the 1930s further exacerbated the declining range conditions (Figure 3-2).¹²⁷ The drought in the 1930s was particularly hard on the communities surrounding the City of Rocks. Jim Lloyd, who grew up herding sheep in the City of Rocks during the drought years of the 1920s and into the 1930s, said it was terribly dusty. Stan Lloyd, also a long-time local resident, said his parents told him that the depression was bad, but the drought was worse. The people in nearby Almo and other local communities were pretty self-sufficient for food, but they needed the money they could get from selling a cow to purchase other supplies, and that affected the community the worst. Several people recalled the federal government bought cattle just to help people out financially and destroyed the animals because there was no market for them during the 1930s drought and depression.¹²⁸ Locals recalled that their once boggy meadows turned to dust and,

¹²⁵ Oral history transcription of Walter Mooso (note 78).

¹²⁶ Sanders, Bunting and Wright, *Grazing Management Plan* (note 73).

¹²⁷ MNF History 1941 (note 75).

¹²⁸ E. Durfee, *Remembrances of Almo Community* (note 92); Oral history with Jack and Kathryn Erickson (note 112); Oral history with William and Annalee Jones (note 113).

because they did not have wells to compensate for irrigation needs, the community really suffered.¹²⁹

Land that was not patented remained under the General Land Office jurisdiction, and was open to unregulated livestock grazing until passage of the Taylor Grazing Act in 1934. Under this new system, land within the City of Rocks that was not within the National Forests, privately owned, or state property was managed by the Grazing Service as the Raft River Grazing District No. 2.¹³⁰ The management of these lands was turned over to the newly created Bureau of Land Management (BLM) in 1946 and has been managed by the Burley District Office since that time.

The BLM range surveys were not completed until 1952, but the records from the USFS describe the land conditions just as the BLM was being organized.¹³¹ The Albion Division reported 4,225 cattle and horses, 2,080 sheep and 2,200 deer around that time.¹³² The sagebrush areas on the Albion Division were in fair to poor condition with “increasing annual weeds and grasses, lessening plant vigor in the accessible (sic) plants, loss of top soil, and in some cases the appearance of shoestring and gully erosion”. Aspen stands were reportedly in very poor condition, “denuded of all palatable species of grasses and weeds,” and some stands were “dying out” including some in the upper reaches of Almo Creek just outside the boundary of the Reserve. They also reported that

¹²⁹ Oral history with Venna Ward, employee of City of Rocks National Reserve and local resident, interviewed by Lesley Morris, September 11, 2005, on file at the City of Rocks National Reserve.

¹³⁰ Grazing District Map, on file at the Bureau of Land Management Burley District Office, 1939.

¹³¹ BLM Range Surveys 1952 (note 77); Oral history transcription of Delmar Vail (note 106).

¹³² MNF Report 1949 (note 84).

sheet erosion and weed invasions indicated an urgent need for corrective measures.

The “timber” range type was listed as poor to fair condition. All range types were reported to have erosion of up to four inches judged by pedestaled plants. There seemed to be a general concern about the loss of top soil and productivity. Stockmen complained that the deer were overusing the forage as well. The US Forest Service believed the district was best adapted to cattle rather than sheep grazing and there was a push to switch permits from sheep to cows.¹³³

As with the National Forests, by the 1940s, many new, introduced and invasive plant species had established in the valleys surrounding the City of Rocks. A particularly troublesome one was the poisonous forb, halogeton (*Halogeton glomeratus*). In 1945, both John Ward and Oscar Jones together lost over 1,500 sheep to halogeton poisoning after they moved their bands onto winter range in the Raft River Valley (Figure 3-1).¹³⁴

The cause of death was described by John Ward:

I had lost a few sheep for several years in and around the area west of the Bridge school house. On a day in November, 1945, a band of 1,300 of my sheep were moved into this halogeton area about noon. By 2 or 3 o'clock that afternoon, the sheep were sick and began to die immediately, of the 1,300 head, 1,000 died that afternoon in that area and the remainder died later on.¹³⁵

Other weedy species that thrived in areas of soil disturbances (such as roadsides, heavily grazed lands and fallow agricultural fields) had likely already made their way into the Reserve. These included such species as Russian thistle (*Salsola iberica*), tumble

¹³³ MNF Report 1949, 4-5 (note 84).

¹³⁴ J.A. Young, P.C. Martinelli, R.E. Eckert and R.A. Evans, *Halogeton: A History of Mid-20th Century Range Conservation in the Intermountain Area*, USDA Agricultural Research Service Miscellaneous Publication No. 1553, 1999.

¹³⁵ Quoted in Young, Martinelli, Eckert and Evans, *Halogeton*, 14 (note 134).

mustard (*Sysymbrium altissimum*), flixweed (*Descurainia sophia*) and cheatgrass (*Bromus tectorum*) (Plate 12).¹³⁶ Cheatgrass was already on the Minidoka National Forest by the 1920s.¹³⁷ Bulbous bluegrass (*Poa bulbosa*) was recommended in reseeding efforts and was used for aerial seeding in nearby Gooding in 1943.¹³⁸ This grass species was reported in the Reserve by at least 1995.¹³⁹

The people and the rangelands had suffered many losses during the droughts and the Great Depression. By the time World War II ended, there was very little good feed left, weeds had taken over the fallow fields and a new widespread effort to “regrass” the rangelands began to take shape.¹⁴⁰ A good deal of previously dry farmed land was “re-cleared of brush and seeded to crested wheatgrass” (Plates 8 and 10).¹⁴¹ Much like dry farming, the seeding projects were slated for areas where “vigorous stands of sagebrush” could be found because it was an indication the site was “productive and generally favorable for seeding.”¹⁴² It was suggested that seeding be carried out using seed drills or other equipment at depths from 0.5 to 1.25 cm.¹⁴³ Land management agencies and many private land owners in the area and in the City of Rocks employed this method of

¹³⁶ Piemeisel, *Changes in Weedy Plant Cover* (note 72); Morris, *Ecological History of the City of Rocks National Reserve* (note 22).

¹³⁷ M.H. Deming, *Period Study Report: Minidoka National Forest*, unpublished report prepared for the USDA Forest Service, on file at City of Rocks National Reserve, 1923.

¹³⁸ A.C. Hull, *Regrassing Southern Idaho Range Lands*, University of Idaho College of Agriculture Extension Division, Extension Bulletin No. 146, 1973.

¹³⁹ Bulbous bluegrass was included in the plant list created for the City of Rocks in T. John, *Vascular Plants of the City of Rocks: An Annotated Checklist*, prepared for the National Parks Service, on file at the City of Rocks National Reserve, 1995.

¹⁴⁰ Oral history transcription of Delmar Vail (note 106); Hull, *Regrassing Southern Idaho Range Lands* (note 138); Miller, Svejcar, West, Implications of livestock grazing (note 18).

¹⁴¹ Sanders, Bunting and Wright, *Grazing Management Plan*, 3 (note 73).

¹⁴² Hull, *Regrassing Southern Idaho Range Lands* (note 138).

¹⁴³ Hull, *Regrassing Southern Idaho Range Lands* (note 138).

seeding.¹⁴⁴ Despite all of the problems, some say the 1930s drought may have been the best thing that happened to the area because it got them to start planting crested wheatgrass.¹⁴⁵

The Forest Supervisor, S. Stewart, recognized in the 1930s that, “Sheep growers individually and thru their county predatory animal control boards have reduced coyotes, bobcats, lynx and mountain lion very materially the past three or four years.”¹⁴⁶ It is this feature which appears largely responsible for the apparent increase in deer the last year or two”. Deer were said to number close to 6,000 on the forest by 1935 and a special hunt was initiated in 1936 to cut the numbers.¹⁴⁷ By 1946, some adjacent ranchers were complaining about damaged crops and competition for feed on the ranges. High concentrations of deer in 1948 were becoming a concern in the Almo Park area where there was evidence of “highlining” (eating the browse off to the maximum height an animal can reach) on the mahogany, bitterbrush (*Purshia tridentata*), juniper, wild cherry (*Prunus virginiana*), and other browse species. That same year there was 84% hunter success. By 1949, “mahogany above the City of Rocks” had been “seriously highlined” as well. The Range Report from that same year confirmed deep concerns about the condition of all range types within the forests. By 1950, they estimated 3,000 deer were on the Albion Division alone.

¹⁴⁴ Bureau of Land Management Allotment Files, on file at the Bureau of Land Management Burley District Office, Burley, ID; Morris, *Ecological History of the City of Rocks National Reserve* (note 22).

¹⁴⁵ Oral history with William and Annalee Jones (note 113).

¹⁴⁶ USFS Wildlife Reports (note 109).

¹⁴⁷ MNF History 1941 (note 75).

As mentioned previously, predator control of mountain lion, coyote, bobcat and lynx was widely praised in the late 1920s and early 1930s. In 1944, there was an expressed desire to “maintain state bounty on [mountain] lion because they are taking a heavy toll on deer and sheep.”¹⁴⁸ There were reports of about 5 black bear (likely *Ursus americanus*) on the Albion division in the 1940s. Coyotes were reportedly “getting bad again” in 1942. By 1947, baiting stations with “1080” (or Thallium) were put out for coyotes. The baiting effort was recorded as successful in 1948 since there were little or no sheep losses reported and “no coyote signs around deer herds.” The decrease in predators was again attributed to assisting in the rapid increase of deer over the next two years.

Interestingly, porcupines (*Erethizon dorsatum*) were included on the list of predatory animals starting in the early 1930s. An estimated 274 porcupine were killed in 1934 on the entire Minidoka National Forest. There were reportedly 125 porcupines killed on the Albion Division in 1940. In 1945, “an intensive campaign against porcupines was conducted” and the ranger suggested that control work should continue. Porcupines were reported to be a prevalent problem where the USFS had planted trees.¹⁴⁹ Porcupine did not kill the trees by barking them unless they stripped it all the way around, but they were considered a threat to the trees and hunters were encouraged to shoot them. Local residents recalled that there used to be lot of porcupine, and people worried about them because they were “unpleasant” and they would get up into the

¹⁴⁸ MNF History 1941 (note 75); Oral history with Larry Edwards (note 112); Oral history with Jay Black (note 94); Oral history with Jack and Kathryn Erickson (note 112).

¹⁴⁹ MNF History 1941 (note 75).

orchards and strip bark from the trees.¹⁵⁰ Porcupines were generally shot when they were encountered and residents say there does not seem to be as many of them now.¹⁵¹

The Minidoka National Forest Service also continued the effort to transplant wildlife and encourage growth of important game species well into the 1950s. In 1942, the Forest Ranger recommended that stocking of fish in mountain streams should be reinstated well above the irrigation intakes. One report mentioned the need to build small reservoirs or dams along the streams to keep the fish alive through the season, but said the locals did not like the idea of blocking irrigation water. It was unclear from the reports if this initiative was ever revisited. There was no indication from the reports that cattle destroyed the streams or contributed to the disappearance of the fish. In 1944, a Forest Ranger suggested that it would be “good to see some beaver planted in Almo creek.” The number slowly climbed over two decades until 100 beavers were reported in 1945. By 1947, beavers were “becoming established in most of the drainages over the entire district...Almo Creek above the Forest Boundary to the mouth of Piney Creek shows much beaver activity.” By this time, there were 200 beavers and a growing concern that they would kill the few remaining aspen stands. An effort was started in 1948 to remove beavers, but the reports did not specify where on the forest.

By 1930, Forest Rangers reported that grouse were “very rarely seen anymore.” The reduced populations became so much of a concern that the Idaho portion of the Minidoka National Forest was declared a bird sanctuary in 1931 and all forms of hunting

¹⁵⁰ Oral history with Leona Jones (note 105); Oral history with Grace Durfee (note 113).

¹⁵¹ Oral history with Jim Lloyd (note 63); Oral history with Alan Bruesch, local resident, interviewed by Lesley Morris, September 12, 2005, on file at the City of Rocks National Reserve; Morris, *Ecological History of the City of Rocks National Reserve* (note 22).

were prohibited.¹⁵² Some of the foresters reported that crows (probably *Corvus corax*) and magpies were having an impact on the birds' nests in the early 1930s. Still, by 1945, there was no recovery in the game bird populations. Some of the problem was attributed to cold wet springs in the 1940s that were bad for the nests and hatches. Increases in game birds on the Albion Division were not reported until 1948. It was concern over wildlife, such as birds and deer, that brought the Albion Division under protection from hunting, but it was concerns over a different resource that brought the City of Rocks into preservation status.

Recognition, preservation, and changing uses

Formal recognition of the unique granite formations and the City of Rock's historical significance to America's westward expansion began in 1957 when the school section was classified as an Idaho State Park.¹⁵³ At the same time, a new use of the woodlands was added by the BLM in 1957 when it decided to sell pinyon pine for Christmas trees to the public. Prior to this program, tree sales were exclusively to commercial cutters. Commercial cutting was discontinued in 1961 due to popularity of the Christmas tree sales, and an estimated 600 trees were cut annually (based on permit sales) during the Christmas tree program.¹⁵⁴ In 1961, there was already concern about the current level of use:

¹⁵² MNF History 1941 (note 75).

¹⁵³ HRA, *Historic Resources Study* (note 1).

¹⁵⁴ Bureau of Land Management Christmas Tree Management Plan [BLM-CTMP], on file at the Bureau of Land Management Burley District Office, Burley, ID, 1981.

The lack of replanting and stand improvement has deprived the area to a point where future Xmas tree cuttings would, in a short time, eliminate the area of pinyon pine and leave it open for complete invasion of junipers.¹⁵⁵

The Burley District pursued some experimental plot thinning and improvements in the early 1960s to try to increase the yield and quality of the smaller pinyon pines favored for Christmas trees.¹⁵⁶ The program proved very popular but the tree sales were discontinued in 1968 due to concerns with over-harvesting and a need for inventory data.¹⁵⁷

Starting about the same time as the creation of the new Idaho State Park in the City of Rocks, the area began to experience increases in annual precipitation. In fact, the 1960s were some of the wettest years on record (Figure 3-2). This wetter than usual period caused some flooding, washed out reservoirs, and began down-cutting the streambeds in the riparian areas. This, in turn, lowered the water table, drained the meadows and provided even more opportunity for sagebrush to flourish.¹⁵⁸ Cultivation practices, in the 1960s and earlier, as well as herbicides may have also played a part in reducing the level of native herbaceous understory and increasing erosion.¹⁵⁹ Crested wheatgrass seeding continued through at least the 1960s (Plates 9 and 10). Many of the old seeded areas are still visible and producing.¹⁶⁰ In fact, the big sagebrush/crested

¹⁵⁵ Quote from John F. Kenny in Bureau of Land Management Burley District Report, on file at the Bureau of Land Management Burley District Office, Burley, ID, 1961, 1.

¹⁵⁶ Bureau of Land Management Memo, on file at the Bureau of Land Management Burley District Office, Burley, ID, 1965.

¹⁵⁷ BLM-CTMP 1981 (note 154).

¹⁵⁸ Oral history with Jim Lloyd (note 63); Oral history with Stan Lloyd (note 114).

¹⁵⁹ J.P. Blaisdell and W.F. Mueggler, Effect of 2,4-D on forbs and shrubs associated with big sagebrush, *Journal of Range Management* 9 (1956) 38-40.

¹⁶⁰ Sanders, Bunting and Wright, *Grazing Management Plan* (note 73); and personal observation of the author.

wheatgrass type covered an estimated 1,996 ha in 2005, and was the largest cover type recorded in the Reserve.¹⁶¹

Sagebrush was not the only plant targeted by rangeland managers for removal to increase forage production. Starting in the 1950s and following well into the 1960s, pinyon-juniper woodlands were viewed as a “king-size weed patch” in “need of eradication”.¹⁶² Land managers across the Intermountain West engaged in chaining, herbicide spraying and reseeding pinyon-juniper woodlands to increase forage production.¹⁶³ In the 1970s, environmentalists began to challenge these drastic mechanical removals of pinyon-juniper woodlands.¹⁶⁴ Additionally, the energy crisis and fuel costs in the 1970s refocused some attention on these woodlands as a good source of heating fuel.¹⁶⁵ There was no evidence that this recurrent land use of wood fuel harvesting increased again in the City of Rocks. Nor were there any large scale manipulations of the woodlands within the Reserve during this time. However, local residents and land managers did notice the trees had been spreading further down the hill slopes into the valleys and increasing in cover and density (Plate 13).¹⁶⁶ The Grazing

¹⁶¹ G.M Wilson, *Landcover Classification of the City of Rocks National Reserve Using ASTER Satellite Imagery*, produced through the National Park Service Upper Columbia Basin Network Inventory and Monitoring Program, on file at the City of Rocks National Reserve, 2005.

¹⁶² D. Tidwell, Multi-resource management of pinyon-juniper woodlands: times have changed, but do we know it? in: *Proceedings: Pinyon-Juniper Conference*, Reno, NV, 1986, R.L. Everett (Ed), Intermountain Research Station, 1986, 5-8; N.E. West and J.A. Young, Intermountain valleys and lower mountain slopes. In: M.G. Barbour and W.D. Billings (Eds), *North American Terrestrial Vegetation*, 2nd ed., Cambridge, 256-284.

¹⁶³ West and J.A. Young, Intermountain valleys and lower mountain slopes (note 162).

¹⁶⁴ Tidwell, Multi-resource management of pinyon-juniper woodlands (note 162).

¹⁶⁵ Tidwell, Multi-resource management of pinyon-juniper woodlands (note 162).

¹⁶⁶ Morris, *Ecological History of the City of Rocks National Reserve* (note 22).

Evaluation Summary for the Circle Creek Allotment 1984-1988 showed a 300% increase in pinyon pine in just four years. This Grazing Summary further demonstrated the trend:

As for unpalatable and undesirable forbs, a quick comparison will show an increase in forbs that are not generally grazed at all. As for the larger species, large increases can be seen in Pimo [pinyon pine] as well as shrubs that are unpalatable to cattle and others that can be utilized by deer.¹⁶⁷

Livestock grazing had been working to select against the species most desirable for forage and in favor of the forbs and woody species cattle and sheep found unpalatable. But, it may not have been just livestock grazing that was influencing the loss of the understory species. Overstory crown cover has been clearly linked to the reduction of perennial grasses as well as associate forb and shrub species.¹⁶⁸ Even if the trees are not yet touching, “the root systems [of juniper] extend two to three times wider than the crown canopy” and they can easily dominate the scarce water and nutrient resources in the soil.¹⁶⁹ Research into mechanisms for the expansion of woodlands have also included historic fuel wood consumption, altered fire regimes, climate change, increasing atmospheric CO₂ levels, competitive ability and interactions with seed

¹⁶⁷ Grazing Evaluation Summary from 1984 to 1988 for Circle Creek Allotment, Bureau of Land Management Allotment Files, on file at the Bureau of Land Management Burley District Office, Burley, ID.

¹⁶⁸ N.E. West, Successional patterns and productivity potentials of pinyon-juniper ecosystems, in: National Research Council, *Developing Strategies for Rangeland Management*, Boulder, 1984, 1301-1332.

¹⁶⁹ N.E. West, Junipers of the Western U.S.: classification, distribution, ecology, and control, in: L.F. James, J.O. Evans, M.H. Ralphs and R.D. Child (Eds), *Noxious Range Weeds*, Boulder, 1991, 326-333, 328.

dispersing animals.¹⁷⁰ This expansion has been noted for causing several land management issues across the western US including loss of wildlife habitat, soil erosion, lower water yield and quality, and catastrophic stand replacing crown fires.¹⁷¹

In 1981, the BLM considered options for reinstating the Christmas tree sales due to increased pressure from the public and in an attempt to get control of illegal cutting.¹⁷² Following a 1981 inventory and analysis, the program switched to bi-annual sales of about 500 pinyon pine alternating with juniper tree sales in the early 1980s to “ensure good management and availability in the years to come.”¹⁷³ In 1983, a multi-agency meeting was held between the Burley BLM District, the Sawtooth National Forest, the Salt Lake BLM District, and the Idaho State BLM office to discuss Christmas tree management programs, ways to “curb the theft of pinyon,” and how to coordinate yield to meet the public demand.¹⁷⁴ At the time the Burley District’s inventory had been completed and an allowable cut of an estimated 250 trees per year had been established. After a study determined that Christmas-tree-size pinyon trees were nearly 200 years old,

¹⁷⁰ N.E. West, Spatial pattern-functional interactions in shrub-dominated plant communities, In: McKell, C.M. (Ed), *The Biology and Utilization of Shrubs*, Burlington, 1989, 283-305; Miller, Svejcar, West, Implications of livestock grazing (note 18).

¹⁷¹ West, Spatial pattern-functional interactions in shrub-dominated plant communities (note 170); R.A. Evans, *Management of Pinyon-Juniper Woodlands*, USDA Forest Service, Intermountain Research Station, General Technical Report, INT-249, 1988; Miller, Svejcar, West, Implications of livestock grazing (note 18).

¹⁷² BLM-CTMP 1981 (note 154).

¹⁷³ Bureau of Land Management Press Release, on file at the Bureau of Land Management Burley District Office, Burley, ID, 1986.

¹⁷⁴ Bureau of Land Management Report of Meeting, on file at the Bureau of Land Management Burley District Office, Burley, ID, 1983.

the program was abandoned for a few years. It has since been reinstated with about 100 to 120 trees cut per year.¹⁷⁵

In the mid 1980s, another concern emerged over the pinyon pine in the City of Rocks and surrounding area. The black stain fungus (*Verticicladiella spp.*) had infected some of the pinyon pine. According to a BLM report in 1986, the black stain spread radially through root contact from the center of the infected cluster of trees. It tends to kill older trees and affected pinyons are often invaded by the Ips beetle (*Ips spp.*) prior to death.¹⁷⁶ At that time, it was also reported that the aspen were “suffering from a foliar pathogen and insects” because they were “overmature and need to be regenerated.” However, a recent assessment of the aspen in the City of Rocks National Reserve suggested that regeneration in the stands was not being suppressed by the lack fire or by overgrazing and that there was a “relative absence” of invasion and overtopping by other trees.¹⁷⁷

The expansion of woodland and sagebrush cover is especially noticeable in the City of Rocks in photographs since the 1950s (Plate 13). Another impressive increase followed this same trend. There has been a pronounced increase in the number of hectares burned in the Reserve since the 1950s (Figure 3-5). In the 1950s, only about 3% of the Reserve burned. Throughout the 1960s, 1970s and 1980s, less than 1% was

¹⁷⁵ Jim Tharp, BLM Burley District Ecologist, personal communication, 2006.

¹⁷⁶ Bureau of Land Management Condition Report, on file at the Bureau of Land Management Burley District Office, Burley, ID, 1986.

¹⁷⁷ N. Batten, M. Case, J. Collette, B. Cram, H. Hill, E. Hoffnagle, N. Mullens, T. Rodhouse, J. Steele, J. Vincent, P. Wolken, and M. Wyse, *Baseline Survey of Quaking Aspen (Populus tremuloides) in City of Rocks National Reserve*, produced for City of Rocks National Reserve through the OMSI Botany Research Team, on file at the City of Rocks, 2005, 7.

burned. Then, from the 4% burned during the 1990s, there was a large jump when 14% of the Reserve was blackened in just one fire in 2000. Of the 5,795 ha within the City of Rocks, an estimated 1,442 ha or at least 25% of the Reserve burned over the reporting period from 1926 to 2005. Fires in the Reserve not only got larger but also more difficult, time consuming and costly to control.¹⁷⁸

The City of Rocks was designated as a National Historic Landmark in 1964 and as a National Natural Landmark in 1974.¹⁷⁹ Reports of “vandalism” and “indiscriminate use of off road vehicles and firearms, hiking and camping and poor climbing practices” were said to have damaged the rocks as well.¹⁸⁰ The current boundaries of the City of Rocks National Reserve were established in 1988.¹⁸¹ A number of recreational activities are available in the Reserve including camping, hiking, birding, horseback riding, mountain biking, hunting and historical trail sightseeing. The most popular reason for visiting, however, seems to be the world class rock climbing.¹⁸² The Reserve was well on its way to international recognition in the late 1970s and surely peaked as a rock climbing destination in the late 1980s with the publication of the first City of Rocks climber’s guide.¹⁸³ Under concurrent status as a unit in the National Park System and Idaho State Parks, the City of Rocks National Reserve has received 80,000 to 97,000

¹⁷⁸ L. Morris, *Fire History of the City of Rocks National Reserve from 1926 to 2006*, National Park Service Pacific Northwest Region, 2006.

¹⁷⁹ HRA, *Historic Resources Study* (note 1).

¹⁸⁰ G. Wolf, Idaho Senators want area Protected, City of Rocks study prompts action, *Pocatello-Chubbuk*, Idaho, Thursday, June 25, Idaho State Journal Section, 1987, 8.

¹⁸¹ Public Law 100-696, Arizona-Idaho Conservation Act of 1988.

¹⁸² United States Department of the Interior, National Park System (USDI-NPS), *City of Rocks National Reserve Comprehensive Management Plan, Development Concept Plan and Environmental Impact Statement*, 1994.

¹⁸³ HRA, *Historic Resources Study* (note 1).

visitors annually during the early to mid 1990s.¹⁸⁴ Over the last sixteen years, average annual visitation was 76,617 people.¹⁸⁵

Many of the residents in the local communities have stopped going into the City of Rocks because they say there are too many other people up there now. In the past, the City of Rocks was mostly used by local people.¹⁸⁶ It was a popular place for the locals to go for picnics, family reunions or just to play. From what the community described in oral histories, people have been climbing, rolling and moving rocks out there since as long as there have been people coming into this valley (Plate 8). The memories as well as the signatures are beginning to fade and you cannot even see the emigrants' inscriptions from the road anymore.¹⁸⁷ There is now a whole generation of kids in the community that have only known the City of Rocks as a National Reserve.¹⁸⁸

The increasing visitation at the Reserve has changed the community as well as the landscape. New campgrounds, water facilities, restrooms and trails have been constructed to accommodate its gaining popularity. The Reserve purchased new property within the City of Rocks, and began construction of an equestrian campground on the east side of the Smokey Mountains in cooperation with the BLM.¹⁸⁹ Some of the most vivid and rapid changes in the last few decades have been from soil erosion and roads,

¹⁸⁴ USDI –NPS 1994 (note 182).

¹⁸⁵ Sixteen year average calculated from yearly visitation numbers for 1995 through 2006 reported by the National Park Service on its Operations Formulation System (online at <http://www.nps.gov/ciro>) only sixteen years are included because the data for 1994 was incomplete.

¹⁸⁶ Oral history transcription with Delmar Vail (note 106).

¹⁸⁷ Oral history with Venna Ward (note 129).

¹⁸⁸ Oral history with Wallace Keck, Superintendent of City of Rocks National Reserve, interviewed by Lesley Morris, September 12, 2005, on file at the City of Rocks National Reserve.

¹⁸⁹ Oral history with Wallace Keck (note 188).

which often go together. The nature of the decomposed, granitic soil in the City of Rocks makes it very susceptible to erosion. So much so, it could “practically be eroded using an eye dropper.”¹⁹⁰ Several projects were initiated in the 1990s to control erosion of roads, trails and staging areas for rock climbers (Plate 14).¹⁹¹ There was a lot of culvert work completed in the 1990s in the Reserve to move the water off the roads.¹⁹²

Castle Rocks State Park, just a few miles from the Reserve, is also experiencing increased development as it is prepared by managers to off-set the density of climbers and other visitors to the Reserve in the peak summer months.¹⁹³ A new road into Castles State Park was constructed in 2007. The popularity of these two parks, in conjunction with the Back Country Byway status for the route leading into the Reserve, helped gain state funds to redirect and resurface the highway leading into the City of Rocks National Reserve. Now, relieved of difficulties with road travel and access, people are once again streaming into these valleys from May through August in even greater numbers than during the peak of overland emigration.

Interpretation of the vegetation changes

The earliest photos of the City of Rocks National Reserve from 1868 illustrate very well that the vegetation has changed in the sagebrush steppe dominated valley and along the hillslopes now thick with pinyon-juniper woodlands (Plates 1-4). The change in plant species shown in (Plate 1) the valley bottoms is a product of multiple and

¹⁹⁰ Oral history with Ned Jackson (note 94); Oral history with Wallace Keck (note 188); Oral history with Brad Shilling, employee at City of Rocks National Reserve, interviewed by Lesley Morris, September 13, 2005, on file at the City of Rocks National Reserve.

¹⁹¹ Oral history with Brad Shilling (note 190).

¹⁹² Oral history with Wallace Keck (note 188).

¹⁹³ Oral history with Wallace Keck (note 188); Oral history with Brad Shilling (note 190).

overlapping factors since European settlement. The bunchgrasses of these sagebrush steppe areas were likely already heavily grazed and trampled by the end of the California Trail era, even if this use did not change the overall vegetation. Perhaps the cooler and wetter climate during the Little Ice Age helped these cool season grasses recover. But the droughts of late 1880s, as well as the severe overgrazing and improper timing of use by the cattle barons, precipitated a decline in grasses and herbaceous plant species.

The era of dry farming followed, and any remaining vigorous stands of native grass and healthy sagebrush steppe in low slope areas were targeted for plowing. In addition, many hectares of the valley bottom were cleared and fenced to “prove up” and gain patent on the land. Clearing and plowing are all known to have severe impacts on sagebrush steppe that can take decades to recover.¹⁹⁴ Fallow dry-farm plots were left exposed during the droughts of the 1920s and 1930s and many weedy species, such as cheatgrass, began to establish and spread. Unregulated livestock grazing continued until at least the 1950s, when the new Bureau of Land Management allotments were adjudicated. This institution of grazing management also meant that, instead of decades to recover from plowing, many of these same valley lands were again cleared and seeded with the introduced forage grass, crested wheatgrass. The fallow dry farming lots were infested with weeds and many of these introduced species likely spread further with this repeated soil disturbance. Grazing pressure from cattle, horses, sheep, and deer also

¹⁹⁴ Bracken, Extent and condition of the range lands for Utah (note 72); Bolton, Smith, and Link, Soil microbial biomass (note 72); Piemeisel, *Changes in Weedy Plant Cover* (note 72); Sanders, Bunting and Wright, *Grazing Management Plan* (note 73); and personal observation of the author, 2005.

likely enhanced the populations of unpalatable species (like sagebrush) by reducing the vigor and cover of the palatable ones (like grasses and forbs).

Even though crested wheatgrass was an improvement in livestock forage and it sustained the local ranching economy, this management effort did not help increase the other native bunch grasses, forbs or keep the sagebrush from reestablishing. In fact, continual soil disturbance, as well as spraying herbicide to maintain crested wheatgrass stands, probably had a devastating impact on forbs that were also already strained under historic sheep grazing and drought pressures. Sagebrush has apparently had no problem reoccupying disturbed, cleared and plowed sites, as can be seen in many of the repeated images in the Plates. Interestingly, however, pinyon-juniper woodland encroachment into the valleys seems to be excluded from areas that were historically plowed multiple times. The most recent plow/seeding line is visible as a stark coloration contrast in between the grayish sagebrush in valleys and the darker woodlands on the slopes (Plates 7, 12, 13, and 14). Today, some areas have more grasses than were visible in earlier photos but much of the valley is dominated by stands of sagebrush, the invasive cheat grass and remnants of the introduced crested wheatgrass.

Likewise, the pinyon-juniper woodlands have clearly been expanding down the slopes and increasing in cover and density since the earliest records and photos in the Reserve. Multiple factors were likely involved in these increasing woodland densities as well. Most residents did not recall a lot of fires during their lifetime. There was some fire suppression, but there also could have been a low incidence of fire because of the lack of fine fuels (e.g. grasses) to carry fires through sagebrush steppe and into the adjacent woodlands. Now, fire carries across the closed canopy of the woodlands and

across the sagebrush. A lack of fire, in conjunction with a whole history of drought and land use changes, seems likely to have encouraged this encroachment. In contrast to grasses and forbs, sagebrush, pinyon pine and junipers are more resistant to periodic droughts because of physiological and morphological differences. For example, woody species do not have to rebuild their above-ground tissues each year and their deep roots give them access to more soil moisture.¹⁹⁵

In addition to drought and lack of fire, there has been a decreasing demand for these tree species for fuel wood as local residents switched to oil, coal and electric heating. There was also decreased demand for use of juniper fence posts after the homesteaders left in the 1920s and as people began to use metal posts instead. There was also a decrease in pressure on the pinyon pine seeds since people were no longer dependent upon them as a food source and collected them less as a community. The one potential “predator” of pinyon or juniper, porcupine, has been significantly reduced through hunting. And finally, there was no evidence of any major insect or pathogen outbreaks that would have controlled the populations of either tree species until very recently.¹⁹⁶

The vegetation changes in the City of Rocks National Reserve since settlement are not different in many ways than what has been described across the rest of the Great Basin desert region. There has been an overall “lignification” or increase in the woody cover of sagebrush, pinyon and juniper reported across the Intermountain West. As well

¹⁹⁵ West and Young, Intermountain valleys and lower mountain slopes (note 162); Brown, Ecophysiology and water relations research in the pinyon-juniper vegetation type, in: R.L. Everett (Ed), *Proceedings – Pinyon-juniper Conference*, USDA Forest Service, Intermountain Research Station, General Technical Report INT-215, 1987, 398-405.

¹⁹⁶ BLM Condition Report 1986 (note 176).

as decreasing overall plant diversity through loss of native perennial bunch grasses, decreasing native forbs, and the spread of introduced and invasive grasses.¹⁹⁷ Many of the same factors are at play as well such as previous Native American land uses, historic dry farming, heavy livestock overgrazing, homesteader clearing and fence building, changing fire regimes and forage seeding projects.¹⁹⁸ There are, however, at least two very unique aspects to the changes within the Reserve. The first was that the City of Rocks did not appear to have woodland cutting for use in mines. In other areas of the Great Basin, particularly in Nevada, the pinyon-juniper woodlands were harvested as cordwood for fuel and for making charcoal to run equipment in mining operations. This historical cutting left many recent observers with the impression that the woodlands were new instead of recovering their historic ranges.¹⁹⁹ The second was that the City of Rocks National Reserve has not yet experienced the frequent fire return intervals that have accompanied cheatgrass in other parts of the Great Basin.²⁰⁰ Unfortunately, recurrent wildfires and monocultures of invasive annual grasses may be in the future for the Reserve.

¹⁹⁷ West and Young, Intermountain valleys and lower mountain slopes (note 162).

¹⁹⁸ West and Young, Intermountain valleys and lower mountain slopes (note 162); Miller, Svejcar, West, Implications of livestock grazing (note 18); R.F. Miller and R.J. Tausch, The role of fire in juniper and pinyon woodlands: a descriptive analysis, in: K.E.M. Galley and T.P. Wilson (Eds), *Proceedings of the Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species*, Tall Timbers Research Station, Miscellaneous publication no. 11, 2000, 15-30.

¹⁹⁹ Young and Budy, Historical use of Nevada's pinyon-juniper (note 7).

²⁰⁰ West and Young, Intermountain valleys and lower mountain slopes (note 162).

Conclusion

The earliest people to settle in the City of Rocks and the surrounding communities seem to have experienced a land that was very different than today. There was reportedly more grass, more water, more snow and more harsh winters. Those earliest settlers, however, also experienced a land very similar to the one today. There were droughts that turned boggy areas to dust, impacted their livestock, their culinary water supplies, and the vegetation. Part of the difference between then and now is the technology available to people for coping with droughts. For example, people can now feed livestock over the winter with alfalfa grown with the assistance of wells and center pivot sprinkler systems.

Clearly there were a number of overlapping factors such as climate, stocking rates and timing of use, seed bank availability, fuel wood cutting, fence post cutting, land clearing, forage seeding, wildlife populations, agricultural developments and recreational activities that have all contributed to the changing vegetation over time in and around the City of Rocks. Having gone more deeply into the testimony of our land witness, we find strong evidence of multiple causes for the changes in these treasured landscapes. In fact, the causal links were overlapping, synchronous, dynamic and complex. Certainly, livestock overgrazing has had a far reaching and negative impact upon western rangelands and in the City of Rocks National Reserve. But if that plot line is incomplete, why does it continue to dominate the story? I argue that it is because blaming livestock as the one cause is easier. If there is only one cause for ecological degradation then those changes become alluringly easy to understand and seemingly easy to solve. After all, if it is just the livestock that are damaging rangelands, then take the livestock off! This belief has become the rangeland equivalent of the Smokey the Bear phenomenon. For years,

the National Forests promoted the idea and the public believed that if we could just keep fire out, the forest was well protected.²⁰¹ Likewise, the public has been led to believe that if we can just get the livestock off the land, the range will somehow be protected and restored.

It is time to look more closely into the complexities of the ecological history of landscapes. This history is important for understanding the range of variability on this landscape and what may be its future potential. If restoration is what we seek, we must follow each one of the threads in the whole knot that is the dynamic ecosystem. A more complete history provides more than just a reference site as a goal for restoration. It tells us what the potential may be for reaching that goal. The idea that ecosystems are dynamic and that there are “multiple states” and “transitions” in which they can exist is gaining acceptance for rangeland managers and scientists. Some of our rangelands may have crossed thresholds into new stable states that they are not going to transition out of easily, particularly with just the removal of livestock grazing. We may be facing new ecosystem domains within which we must learn to manage, preserve and protect.²⁰²

Both the natural and the cultural landscapes of the City of Rocks are temporary. And yet, it is interesting to see how many things do not change over time. Yes, the

²⁰¹ For a discussion of how US Forest Service policy and Smokey the Bear influenced wildlands see S. Pyne, *America's Fires: Management of Wildlands and Forests*, Durham, 1997; and S. Pyne, *Fire in America: A Cultural History of Wildland and Rural Fire*, Princeton, 1987; for fire policy and impacts in the National Park Service see H. Rothman, *Blazing Heritage: A history of Wildland Fire in the National Parks*, Oxford, 2007.

²⁰² A more detailed discussion of the “State-and-Transition” model, thresholds and multiple stable states can be found in W.A. Laycock, Stable states and threshold of range condition on North American rangelands: a viewpoint, *Journal of Range Management* 44 (1991) 427-433.

clothes change from fedoras to spandex, but people still climb the rocks. Yes, the wagons change from prairie schooners to station wagons, but people still travel through looking. Yes, the axle grease changes to spray paint, but people still want to leave their mark. Visitors draw it, photograph it, scramble over it and explore it. Everyone envisions shapes in the rocks, names them and searches them for traces of the past. People still rush in by the thousands during its most accessible seasons and then leave it. It is a temporary landscape – visited and abandoned. A temporary landscape – never remaining the same. *A land witness to change.*

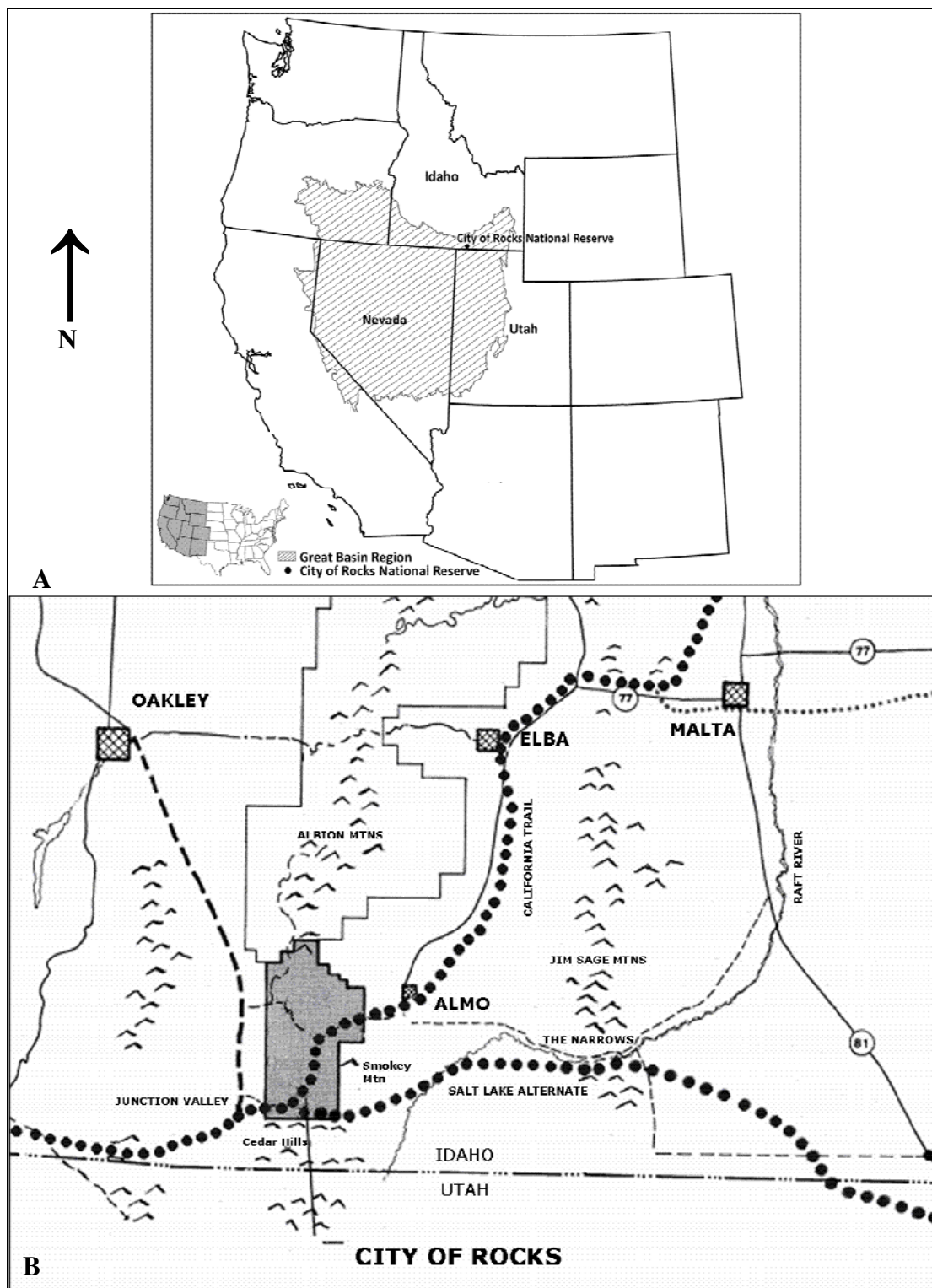


Figure 3.1 Vicinity maps for the City of Rocks National Reserve. Map A shows location of Reserve in the Western US. Map B shows local landmarks of the area. Source: HRA, Historic Resources Study (see Notes).

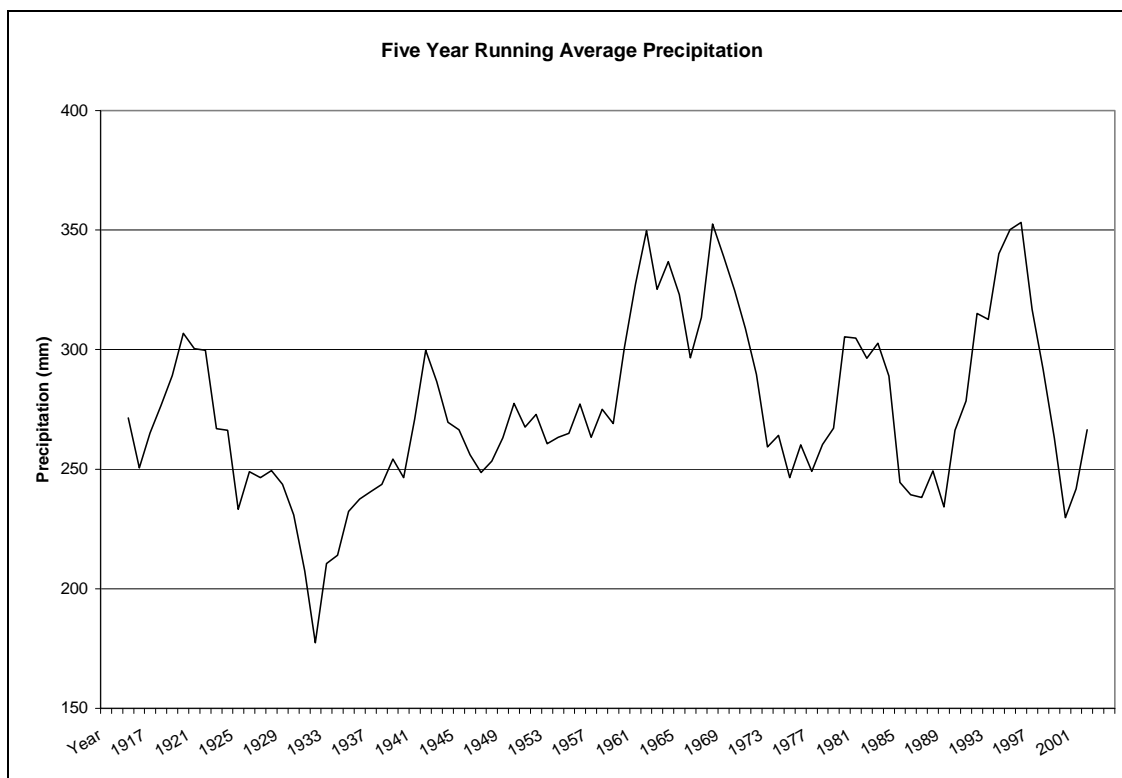


Figure 3-2 Five year running average precipitation for the study area.

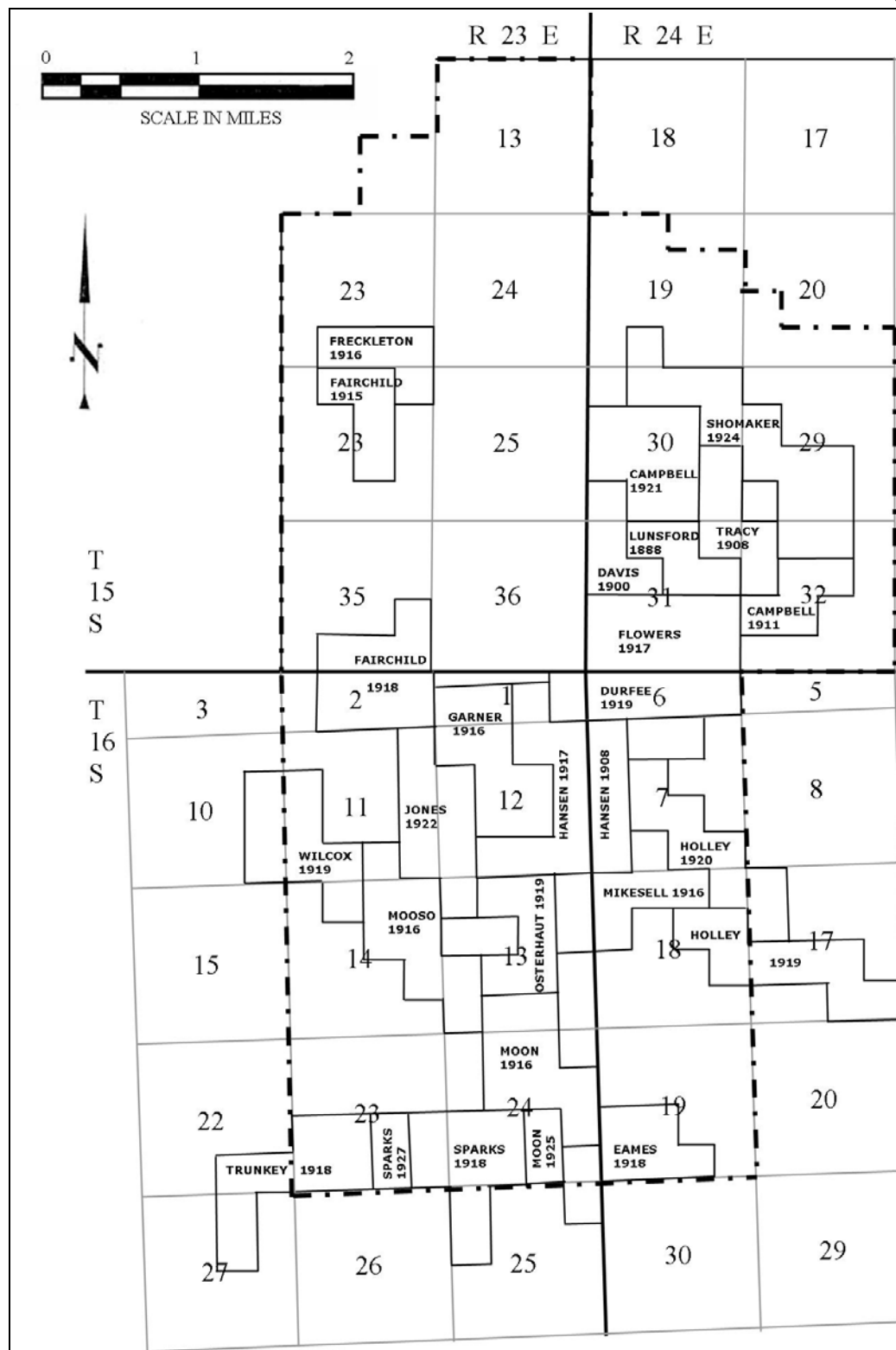


Figure 3-3 Homesteads in the City of Rocks National Reserve. Source: Adapted from HRA, Historic Resources Study (see Notes).

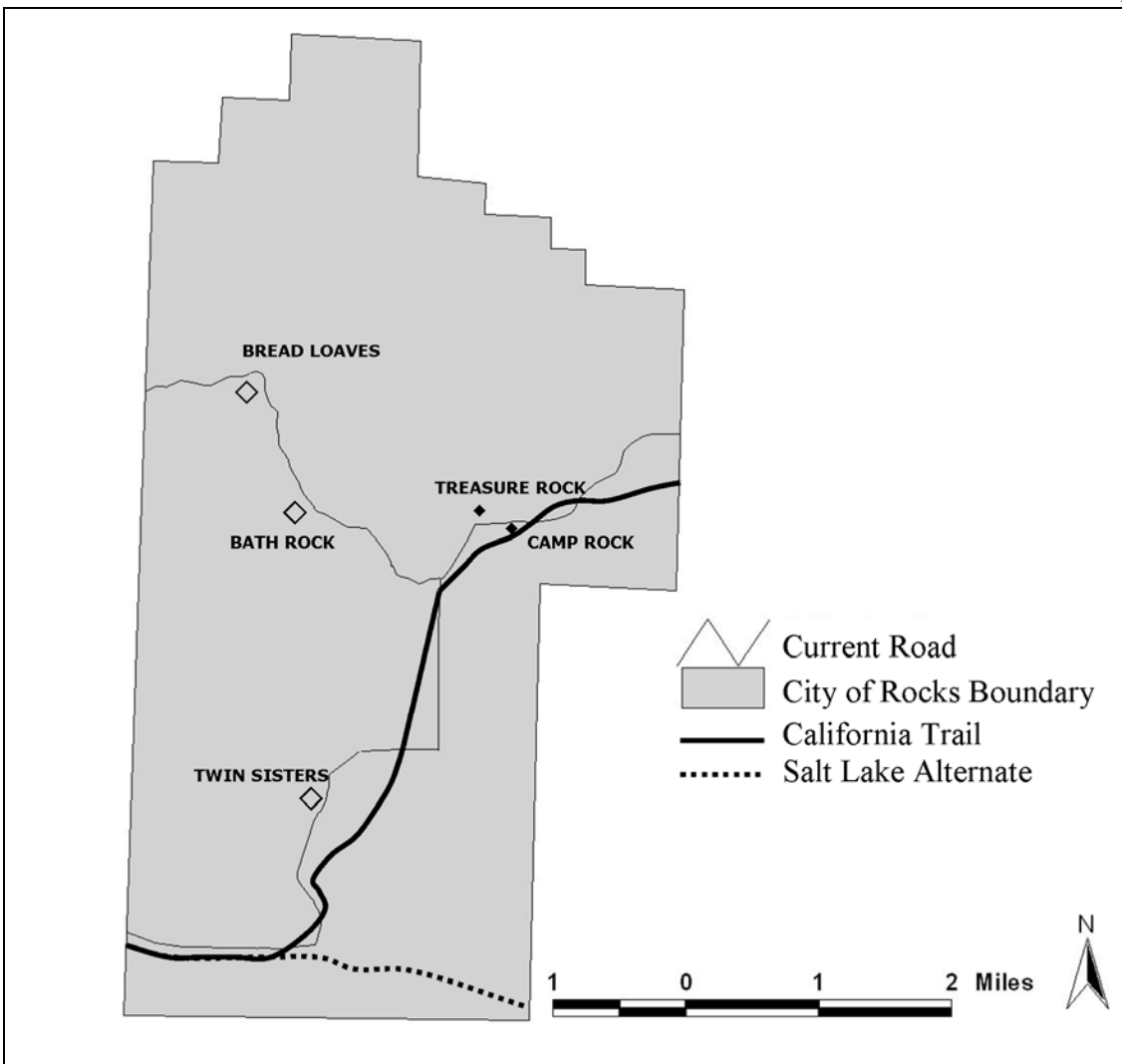


Figure 3-4 City of Rocks National Reserve. Map showing roads, trails and rocks mentioned in the text.

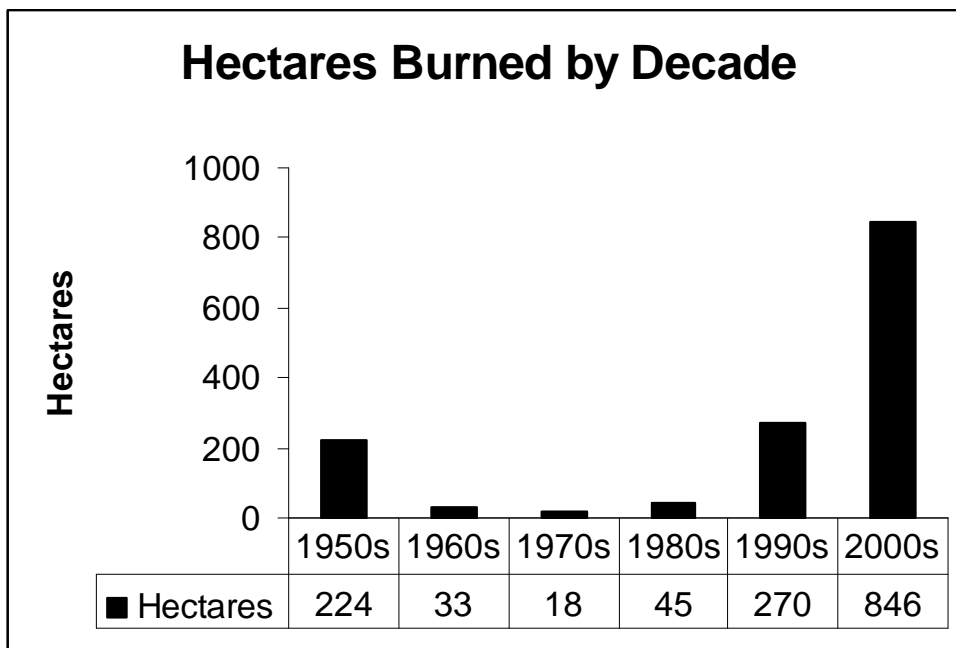


Figure 3-5 Hectares burned per decade in the City of Rocks National Reserve.

Plate 1(a) Twin Sisters, 1868

This photo was taken looking north toward the “Twin Sisters”. The vegetation in the foreground includes: arrowleaf balsamroot (*Balsamorhiza sagittata*), rabbit brush (*Chrysothamnus viscidiflorus*), antelope bitterbrush (*Purshia tridentata*), some sagebrush (*Artemisia tridentata*) and likely bluebunch wheatgrass (*Pseudoroegneria spicata*).

Photo: Timothy O’Sullivan, National Archives and Records Administration, 1868

Plate 1(b) Twin Sisters, 2005

About 130 years later, species diversity in the foreground is limited to sagebrush and crested wheatgrass (*Agropyron desertorum*). Pinyon (*Pinus monophylla*) and juniper (*Juniperus osteosperma*) now occupy the granite apron. Photo: Lesley Morris, 2005



Plate 1(a) Twin Sisters, 1868



Plate 1(b) Twin Sisters, 2005

Plate 2(a) City of Rocks View 1, 1868

This photo was taken looking northwest. The area is now part of the Box Top Trail.

Photo: Timothy O'Sullivan, National Archives and Records Administration, 1868

Plate 2(b) City of Rocks View 1, 2005

This repeat about 130 years later shows the increase in pinyon and juniper in both the foreground and along the low slopes in background. Photo: Lesley Morris, 2005



Plate 2(a) City of Rocks View 1, 1868



Plate 2(b) City of Rocks View 1, 2005

Plate 3(a) City of Rocks View 2, 1868

This photo was damaged in the left corner because the original glass negative had started to peel. It was taken looking northwest from near the top of Box Top Trail. The distant slopes in upper right corner show signs of past fire (indicated by arrow). Photo: Timothy O'Sullivan, National Archives and Records Administration, 1868

Plate 3(b) City of Rocks View 2, 2005

The damage to the original photo made it difficult to find a better match in the foreground for this photo, but the ridgeline was very similar. About 130 years later, the fire scar is no longer visible on distant slopes in upper right hand corner due to infilling by conifer trees. In addition, the pinyon and juniper woodlands increased on low slopes and into the valley bottom. Photo: Lesley Morris, 2005



Plate 3(a) City of Rocks View 2, 1868



Plate 3(b) City of Rocks View 2, 2005

Plate 4(a) Circle Creek, 1868

This photo was taken looking east through the Circle Creek basin in the City of Rocks National Reserve. Note the fire scar going up the hill slope in the background (indicated with arrow). This low hill is known as Smokey Mountain. The trees in the foreground where a human figure is seen are mountain mahogany (*Cercocarpus ledifolius*). Photo: Timothy O'Sullivan, National Archives and Records Administration, 1868

Plate 4(b) Circle Creek, 2007

Taken about 130 years later, the fire scar and the slopes on all of the hillsides have filled in with pinyon-juniper woodlands. Pinyon and juniper are also obstructing most of the view in the foreground. Mountain mahogany trees are still present in the left foreground. Photo: Lesley Morris, 2007

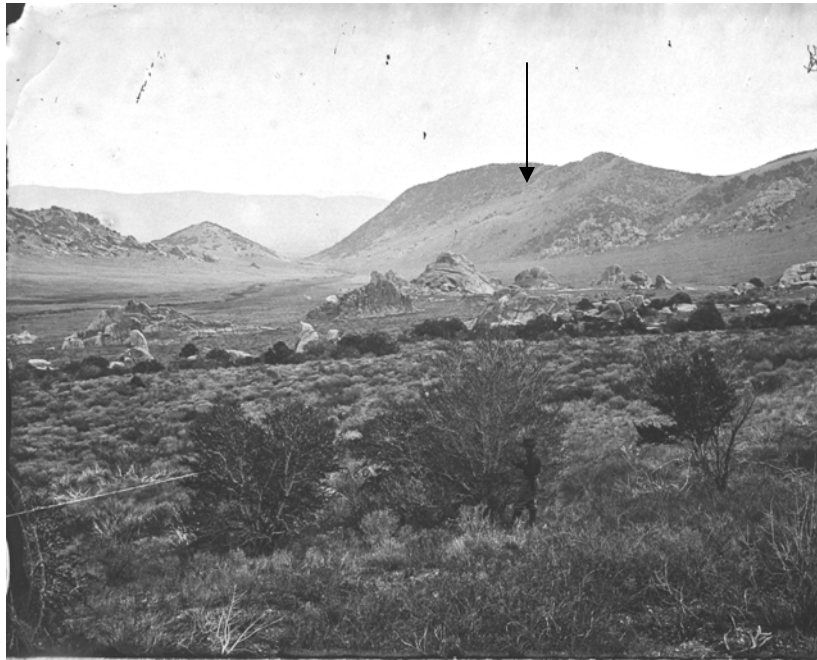


Plate 4(a) Circle Creek, 1868



Plate 4(b) Circle Creek, 2007

Plate 5(a) Twin Sisters Road, 1940

This image was taken from the southwest side of the Twin Sisters. This road used to follow the section lines from the northeastern side of the Twin Sisters and cut through the rocks. Photo: Idaho State Historical Society, 1940

Plate 5(b) Twin Sisters Road, 2005

This repeated image, about sixty-five years later, shows that the old road is grown over with sagebrush and the introduced crested wheatgrass. Although not visible in the photo, locating this old road is still possible using the eroded swale it left behind. Photo: Lesley Morris, 2005



Plate 5(a) Twin Sisters Road, 1940



Plate 5(b) Twin Sisters Road, 2005

Plate 6(a) Top of Camp Rock, early 1900's

This photo was taken looking west from on top of Camp Rock. This photo is likely from the early 1900s because a part of the California Trail (visible in the foreground) still appears to be the only real road, and there is no evidence of homesteading activity. The smaller paths are likely sheep trails. Photo: Utah State Historical Society, no date

Plate 6(b) Top of Camp Rock, 2005

Nearly 100 years later, the trails are no longer visible. This area around Camp Rock was seed with crested wheatgrass by the 1960s (Plate 10). Sagebrush has re-occupied the site, and has grown to nearly 3 m tall in some areas. Photo: Brad Shilling, Climbing Ranger, City of Rocks National Reserve, 2005



Plate 6(a) Top of Camp Rock, early 1900's



Plate 6(b) Top of Camp Rock, 2005

Plate 7(a) Mikesell Homestead, no date

This was the best reproduction of this photo that could be obtained from the South Idaho Press newspaper archives. The Mikesell's homesteaded this land by the Twin Sisters in 1910 and lived here until 1920. Clearly, the photo is prior to the one in Plate 7(b) from 1930 since the windmill and the house are still intact. Therefore, it is believed that the photo is probably taken in the early 1910s. The California Trail ran across their property in front of the house. It can be seen as the light streak in the foreground of the image. Their sheep camp is to the right of the house. Mrs. Mikesell described their land as having sagebrush "like tall trees with blue grass growing among it". The area around the house and in the foreground was likely cleared for dry farming or for "proving up" on their patent. Photo: South Idaho Press, 1955, no date given for photo

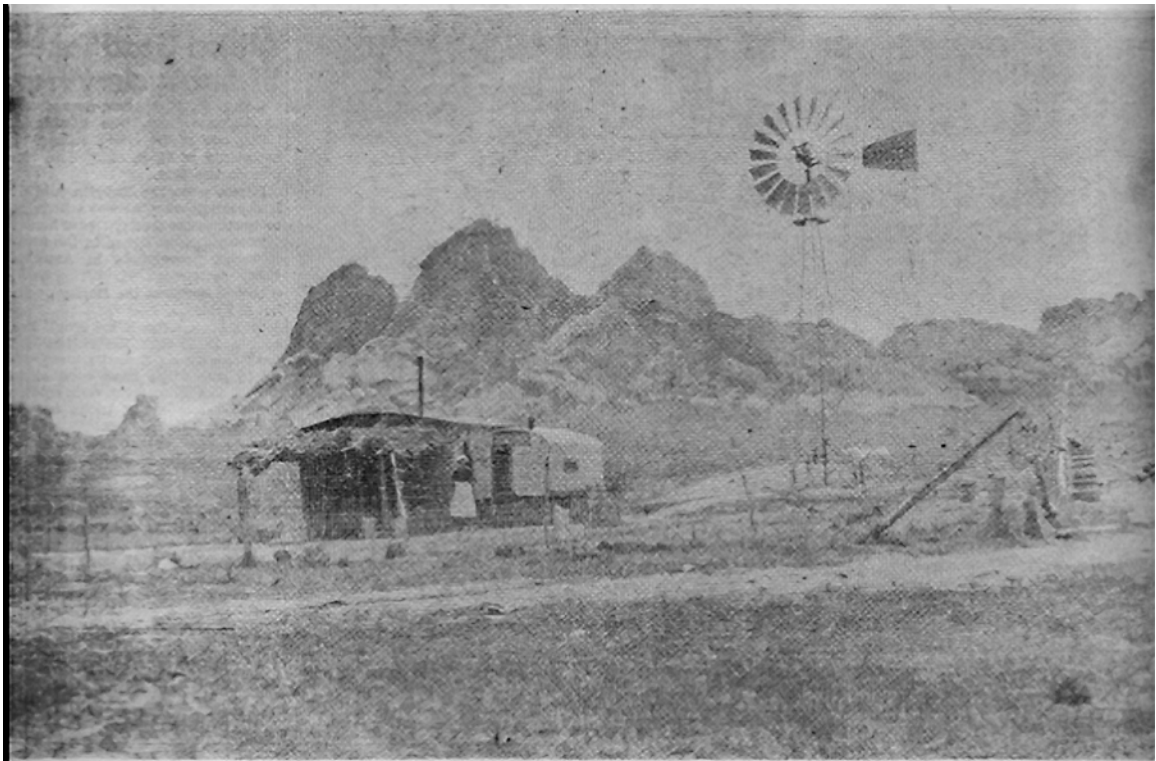


Plate 7(b) Mikesell Homestead, 1930

This photo was taken looking west from what was the Mikesell's homestead. The building in this picture, according to oral histories, is a shed and not the Mikesell's home. Remnants of the old windmill and corral are visible on the right side of the photo. Photo: Utah State Historical Society, 1930

Plate 7(c) Mikesell Homestead, 2005

Seventy five years after the photo in Plate 7(b), all of the structures are gone. The sagebrush is not quite as dense as it appears in the 1930s photo. There is more grass (mostly crested wheatgrass) visible as well. Photo: Lesley Morris, 2005



Plate 7(b) Mikesell Homestead, 1930



Plate 7(c) Mikesell Homestead, 2005

Plate 8(a) Top of Treasure Rock, early 1900's

This photo was taken from on top of Treasure Rock looking east toward Smokey Mountain. Judging from clothing and no visible homesteading activity on the site, it was probably taken in the early 1900s. The apparent fire scars on the hillside are even more evident in this view than in Plate 4. Photo: Cassia County Historical Society, no date

Plate 8(b) Top of Treasure Rock, 2005

Pinyon-juniper woodlands have completely filled in the apparent fire scar. The stark contrasting coloration from slope to valley is where pinyon-juniper woodlands meet the historic plow line. Photo: Brad Shilling, Climbing Ranger, City of Rocks National Reserve, 2005



Plate 8(a) Top of Treasure Rock, early 1900's



Plate 8(b) Top of Treasure Rock, 2005

Plate 9(a) View from Turnout, 1963

This photo was taken looking east near a turnout at the boundary of what was the USDA Forest Service land prior to the creation of the City of Rocks National Reserve. The apparent old fire scar on the north slope of Smokey Mountain was still visible in the 1960s. Also, the signs of agricultural development are evident in the Circle Creek basin. These are likely areas where the land was cleared for crested wheatgrass seeding. Photo: Idaho State Historical Society, 1963

Plate 9(b) View from Turnout, 2005

About forty years later, the old fire scar has nearly disappeared as have the signs of agricultural fields in the valley. The vegetation along the riparian corridor is not as prominent as it appears in the 1960s. This may be due to incision of the creek bed over time. Photo: Lesley Morris, 2005



Plate 9(a) View from Turnout, 1963



Plate 9(b) View from Turnout, 2005

Plate 10(a) Circle Creek Basin, 1967

This photo was taken from in the road entering the Circle Creek Basin looking southwest. The fields of crested wheatgrass are clearly visible in the left side of the photo. Cattle are grazing in the first field to the left of the road. Photo: USDA Forest Service photo, on file at City of Rocks National Reserve, 1967

Plate 10(b) Circle Creek Basin, 2005

Nearly 40 years later, the crested wheatgrass seedings have been re-occupied by sagebrush. The formerly seeded area is still detectable by the visible lack of pinyon or juniper. On the slopes, where the ground was not plowed for the seeding, there has been an increase in density of the woodland. This legacy can also be seen in Plate 8. Photo: Lesley Morris, 2005



Plate 10(a) Circle Creek Basin, 1967



Plate 10(b) Circle Creek Basin, 2005

Plate 11(a) Circle Creek Road, 1940

This photo was taken looking west into the Circle Creek basin from the Almo road into the City of Rocks. The building is a shed or a barn on the Circle Creek Ranch, but the house is not visible from this angle. The sagebrush in the foreground is abundant. There are no recognizable grasses in the understory. Photo: Idaho State Historical Society, 1940

Plate 11(b) Circle Creek Road, 2005

Sixty five years later, the Circle Creek Ranch building is gone, but two new structures have been added to the scene – a fence and telephone/power poles. More grasses are visible in the foreground. The road has been reclaimed by vegetation. Pinyon and juniper now block the view of the rocks on the right. Photo: Lesley Morris, 2005



Plate 11(a) Circle Creek Road, 1940



Plate 11(b) Circle Creek Road, 2005

Plate 12(a) Twin Sisters, 1923

This photo was taken from the road (visible in left hand corner of the photo) looking northeast toward the Twin Sisters. The vegetation from the foreground to the distance is mostly sagebrush with no recognizable grass species present. Many young junipers are growing in the valley. Photo: Idaho State Historical Society, 1923

Plate 12(b) Twin Sisters, 2005

About 80 years later, fire burned a portion of the vegetation in the foreground at this site. The current vegetation along the roadside is largely invasive species such as tumble mustard (*Sisymbrium altissimum*) and cheatgrass (*Bromus tectorum*). The City of Rocks seeded this area following the fire in 2000. Photo: Lesley Morris, 2005

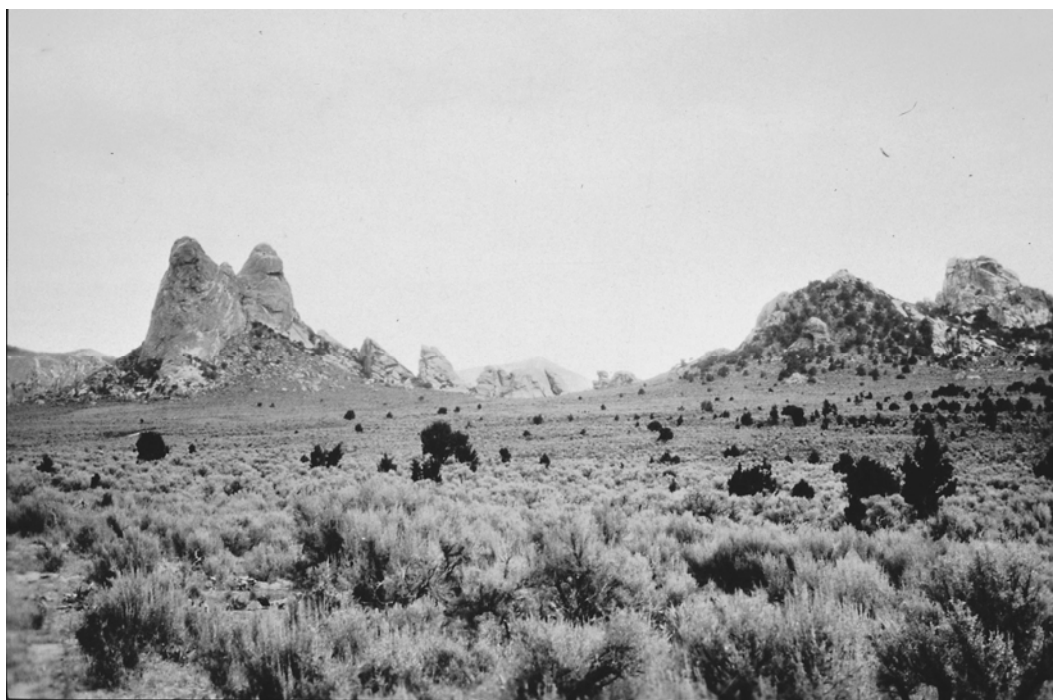


Plate 12(a) Twin Sisters, 1923



Plate 12(b) Twin Sisters, 2005

Plate 13(a) Top of Bath Rock, 1950's

This photo was taken from on top of Bath Rock looking southeast toward Smokey Mountain. The apparent fire scars are still visible along the north slopes of Smokey Mountain in the distance on the left. Photo: Courtesy of the Bruesch Family, 1950s

Plate 13(b) Top of Bath Rock, 2005

About fifty five years later, the apparent fire scars have filled in the slope on the far left of the image. Pinyon and juniper have also moved down slope and increased density on the east slope of the Smokey Mountain in the upper right corner. The tree, encircled by a road, on the lower left portion of the 1950s photo is still present. Photo: Brad Shilling, Climbing Ranger, City of Rocks National Reserve, 2005



Plate 13(a) Top of Bath Rock, 1950's



Plate 13(b) Top of Bath Rock, 2005

Plate 14(a) Road to Bread Loaves, 1940

This photo was taken looking north from the Emery Canyon Road toward the “Bread Loaves”. At the time, the road was mostly just a two-track. The drainage to the left of the road is barely visible. The vegetation in the foreground is unrecognizable. Photo: Idaho State Historical Society, 1940

Plate 14(b) Road to Bread Loaves, 1990's

This file photo from the City of Rocks shows how much the road has cut and eroded by the 1990s. Photo: City of Rocks National Reserve, mid 1990s



Plate 14(a) Road to Bread Loaves, 1940

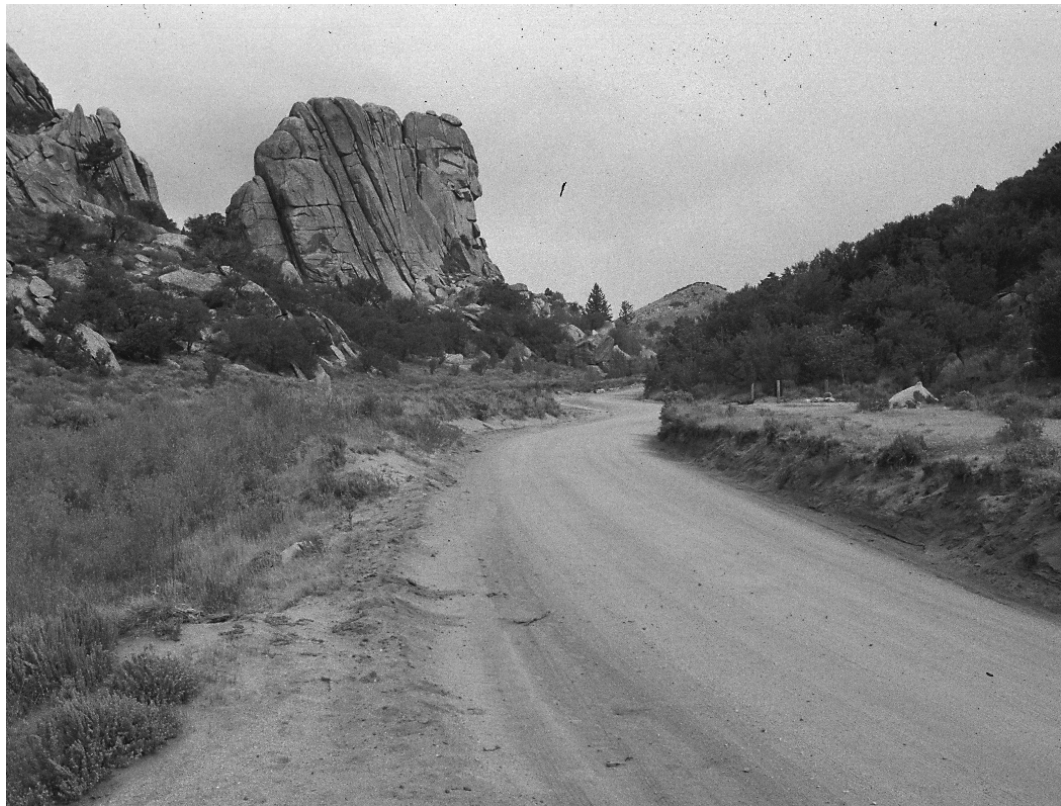


Plate 14(b) Road to Bread Loaves, 1990's

Plate 14(c) Road to Bread Loaves, 1990's

Same photo as Plate 14(b). Photo: City of Rocks National Reserve, mid 1990's

Plate 14(d) Road to Bread Loaves, 2005

Sixty five years after the original photo, the road and the vegetation have changed a great deal. Emery Canyon Road is now bladed and maintained. Erosion has been a large problem for the Reserve in this area. Several erosion projects, including planting these willows, were initiated in the 1990s. Photo: Lesley Morris, 2005

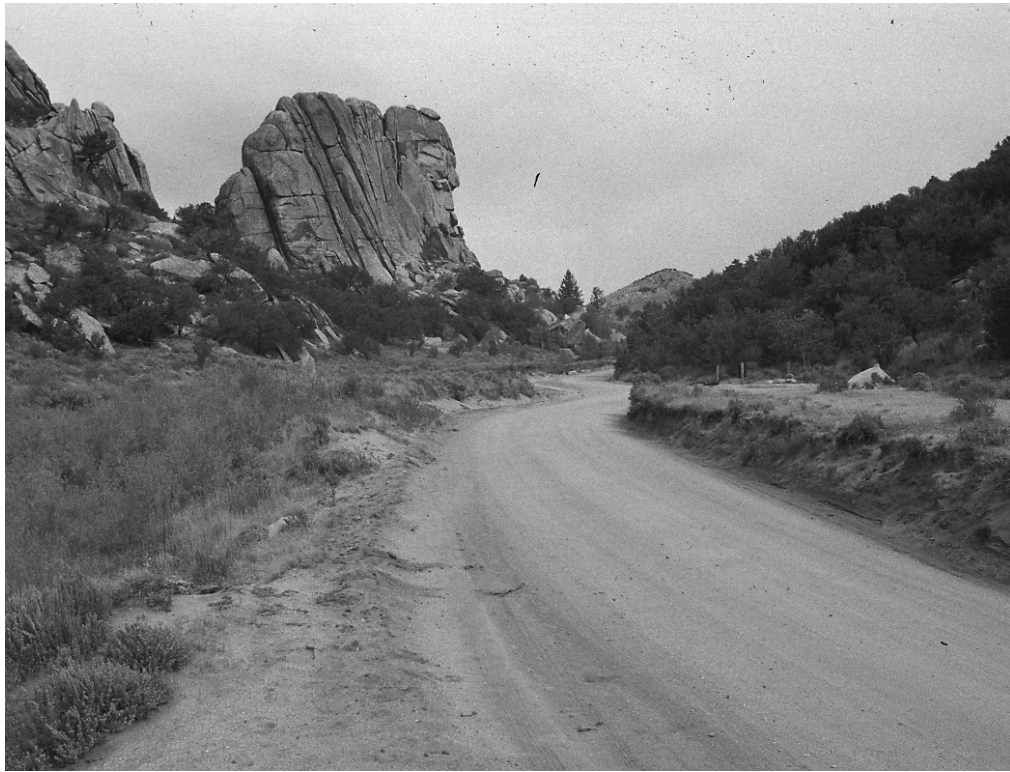


Plate 14(c) Road to Bread Loaves, 1990's



Plate 14(d) Road to Bread Loaves, 2005

CHAPTER 4

PHYTOLITH TYPES AND TYPE-FREQUENCIES IN NATIVE AND INTRODUCED
SPECIES OF THE SAGEBRUSH STEPPE AND PINYON-JUNIPER
WOODLANDS OF THE GREAT BASIN, USA¹

Abstract

This study catalogued phytolith morphotypes and production of common native and introduced flora from two primary plant community types in the Great Basin Desert region of the USA – sagebrush steppe and pinyon-juniper woodlands. The reference collection for this study included 143 species from 40 plant families, including 68 introduced and 75 native plants. We examined 96 forbs, 33 grasses, sedges and rushes as well as 14 trees and shrubs. The phytolith morphotypes of more than 100 of these species were previously not described. We found that about 51% of the plants produced none or only trace amounts of phytoliths, while the remaining 49% had common to abundant production. All the grass species produced abundant phytoliths. Morphotype and frequency of phytolith production differed between native and introduced grass species. At least half of the forbs had common phytolith production and most generated the common dicotyledon morphotypes such as silicified epidermal cells and hairs. Several morphotypes in native and introduced forbs were unique for the genus and species within the reference collection. There was very little phytolith production in the woody species we examined. We found no identifiable phytolith assemblage for pinyon-juniper woodlands in the Great Basin. These results will be useful for future research regarding historical ecology, palaeoecology, palaeoclimatology and ethnobotany.

¹Coauthored by Lesley R. Morris, Fred A. Baker, and Ronald J. Ryel.

Introduction

Phytolith analysis is an increasingly popular tool for revealing historic vegetation patterns and human uses across the fields of historical ecology, palaeoecology, palaeoethnobotany and archaeology (Meunier and Colin, 2001). Phytoliths are silica casts of plant cells created within living vegetation that can remain in sediments long after the living tissue has decayed (Rovner, 1971). Phytolith analysis is limited by a lack of catalogued phytoliths and a need to relate historic soil phytolith assemblages to modern day analogues (Fredlund, 2001; Piperno, 2006) particularly in North America (Blinnikov, 2005). Researchers often have to assemble a reference collection for an area prior to defining research questions. Previous research in the US has described phytoliths at the community level in ponderosa pine forests (Kerns, 2001) and at the regional level in the Pacific Northwest (Blinnikov, 2005). However, there are no described reference collections from two of the Great Basin region's most dominant community types – sagebrush steppe and pinyon-juniper woodlands. Soil phytolith research in these more arid areas is very important because few lakes are available for sedimentary analysis. Investigations into the potential for soil phytolith analysis to inform historic ecology and palaeoecology are currently underway in the Great Basin (Morris et al., in press).

While some species described in previous studies overlap with the flora of the Great Basin, no one has systematically examined and catalogued phytoliths of this region's forbs and introduced species. Phytolith morphotypes from introduced species may provide a key to interpreting the stratigraphy in the soil because the timeframe of their introduction is known. For instance, common phytolith morphotypes in the invasive

cheatgrass (*Bromus tectorum*) were noted as possible evidence of the arrival of the Euro-American settlers (Blinnikov et al., 2002; Blinnikov, 2005). Blinnikov (2005) analyzed and described 38 species (12 trees, 6 shrubs, 17 grasses, and 3 forbs). Forbs have been particularly overlooked in most cataloguing efforts. Furthermore, most of the regional studies and reports on dicotyledons have focused solely on the leaf material and have not explored phytolith production in wood (Bozarth, 1992; Kerns, 2001; Blinnikov, 2005). Notable exceptions to this have come from studies involving the Pinaceae family and other coniferous trees (Klein and Geis, 1978; Kerns, 2001). Here, we report upon the phytolith production and morphotypes of common Great Basin native and introduced species found in two wide spread ecosystem types – pinyon juniper woodlands and sagebrush-steppe.

Study area

There are several ways in which the Great Basin boundary can be defined including hydrographically, physiographically, and even culturally (Grayson, 1993). However, since this paper focuses on plant communities, it is most appropriately defined by the floristic boundary (Figure 4-1). Most of the Great Basin ecosystems are within the rain shadow of the Sierra Nevada Mountains in western Nevada and eastern California, which depletes the moisture from Pacific storms (Beatley, 1975). The Great Basin is known as a “cold” desert because the majority of its precipitation comes in the form of winter snow (MacMahon, 1988). Two major ecosystem types within the floristic Great Basin are the sagebrush steppe and pinyon-juniper woodlands.

The sagebrush steppe is the largest of the North American temperate semi-desert types (West, 1983). The ecosystem gets its name from the historically equal dominance of shrubs from the genus *Artemisia* and various species of bunchgrasses (West, 1983). Sagebrush steppe occurs in areas with precipitation varying from 150-400 mm (Flaschka et al., 1987). Around 60% of this precipitation arrives as snow from winter storms generated in the Pacific Oceans (Miller et al., 1994). European settlement into this portion of the interior western US did not begin until the 1860s (Miller et al., 1994). European settlement introduced livestock grazing, agriculture development and many exotic plant species to the region (Miller et al., 1994).

There are estimates of between 43 and 100 million acres of pinyon-juniper woodland in the southwestern United States (Tueller et al., 1979). Nearly 17.6 million acres of this ecosystem type occur in the Great Basin alone (West et al., 1998). In general, these woodlands are found in areas with 203-508 mm of annual precipitation (West et al., 1975). The major tree species in the Great Basin pinyon-juniper woodlands are *Pinus monophylla* (single leaf pinyon) and *Juniperus osteosperma* (Utah juniper). The understory species are highly variable across the region and can be found in adjacent forests, shrub steppes or grasslands (West et al., 1975).

Methods

We created a reference collection of 143 plant species representing native and introduced Great Basin flora from southern Idaho and northern Utah. Of the 143 plants, 68 introduced species and 75 native species were processed. We catalogued: 96 forbs; 33 grasses, sedges and rushes; and 14 tree and shrub species. The collection spans 40

families. There were 46 native forbs, 16 native grasses, 2 native rushes, 1 native sedge, and 10 native tree and shrub species. There were 50 introduced forbs, 14 introduced grasses, and 4 introduced tree species.

Phytoliths were extracted from the reference plants using dry-ashing techniques (Pearsall, 2000; Kerns, 2001). The plant material was divided into leaf, stem and seed/flower portions for analysis unless impractical. All forb and grass material was washed using deionized water and dried overnight. It was then weighed and placed into crucibles for dry-ashing. Forb and grass material was ashed in a muffle furnace at 450° C for 4-5 hours. Woody material from trees and shrubs was separated into leaf (needle), stem and seed/flowering parts. In addition, some tree bark material was examined separately. The stems and bark were washed in a sonic bath for ½ hour, air-dried overnight, weighed, placed in crucibles and then ashed in the muffle furnace for 5-6 hours at 450° C.

Phytolith morphotypes are redundant across many taxa within the Poaceae (Rovner, 1971). Therefore, procedures to identify phytolith types and their type frequencies within grasses are often used (Kerns, 2001; Carnelli et al., 2004; Blinnikov, 2005). These frequencies are usually expressed as a percentage of the total number of phytoliths counted on a slide. Following the methods of Blinnikov (2005) and Kerns (2001) we conducted cell counts of at least 100 morphotypes in the native and introduced grasses. We only counted disarticulated cells that were intact and recognizable, with the exception of broken hair bases. We did not include the distal portions of a broken hair. Since the most common morphotypes in our species assemblage were different than either Blinnikov (2005) or Kerns (2001), we included some different morphotypes than in

either previous study. However, we attempted to use common types and the modified classification system from Blinnikov (2005) as much as possible for comparison because his study had the most species overlap with ours. Finally, our type frequency analysis was conducted on the leaf and culm material only and, in most cases, inflorescences were examined separately. At least one photo for each counted morphotype is included in Plates II and V.

We employed the descriptive index developed by Wallis (2003) to estimate and rank phytolith production among the species in our reference collection. Slides of the material were viewed under 100-400x magnification and rated under the following four categories:

- 1) Non-producer (NP) – no phytoliths observed in any field of view
- 2) Trace (T) – a small number of phytoliths observed on the entire slide,
with none in most fields
- 3) Common (C) – a small number of phytoliths observed in the majority of
fields
- 4) Abundant (A) – a large number of phytoliths observed in the majority
of fields

We only described the phytoliths in detail that were from common or abundant producing species (Wallis, 2003). When possible, we described phytolith morphotypes using the International Code for Phytolith Nomenclature (Madella et al., 2005).

Identification of plant species in the reference collection was confirmed by the Intermountain Herbarium at Utah State University where the plant specimens and ashed

material are housed. Photographs of all the phytolith morphotypes from the complete reference collection may also be viewed on line (Morris, 2008).

Results and discussion

Out of the 143 species examined in this collection, only 6 had different abundance classes for leaf and stem material. All of these species were trees and shrubs. Of the 137 remaining species, 51% were non-producers or only trace producers of phytoliths, 24% were common, and 25% were abundant producers. The production indexes for all species are summarized in Tables 4-1 and 4-2.

Dicotyledons are known to produce at least nine distinct morphotypes (Bozarth, 1992). Most of these nine morphotypes were observed in both native and introduced forbs from the collection. Typical dicotyledon morphotypes include: silicification of the epidermal cells, known as polyhedral epidermal (Plate I, o) and jigsaw or anticlinal epidermal (Plate I, p), mesophyll (Plate IV, a), vascular tissues (e.g. tracheids) (Plate III, c), various hairs and hair bases (Bozarth, 1992; Plates I and IV). All of these dicotyledonous morphotypes are considered less useful than other types of phytoliths because they are redundant across taxonomic groups and typically do not preserve well in sediments (Piperno, 2006). However, dicotyledonous species are often neglected and many forbs have not been catalogued (Carnelli et al., 2004). Furthermore, groups of epidermal cells (called silica skeletons) have been extracted from modern soil sediments (Blinnikov, 2005) and in some archeological contexts (Albert and Weiner, 2000). We found a number of silica skeletons and hairs that we believe have unique characteristics

which may further aid researchers in understanding which taxa these morphotypes represent.

Woody species have received a little more attention than forbs in phytoliths studies. Several studies have examined the common families of trees and shrubs in the Great Basin including the Pinaceae, Cupressaceae, Asteraceae, and Rosaceae (Klein and Geis, 1978; Kerns, 2001; Blinnikov, 2005). Bozarth (1992) looked at 20 woody species; however, he only examined their leaves. In these, he found silicified epidermal cells similar to those in herbaceous dicotyledons. A few have looked specifically at the woody stems of several plant families (Scurfield et al., 1974; Kondo et al., 1994; Albert and Weiner, 2001). The Pinaceae, in particular, has received more attention in the literature because several species produce unique morphotypes (Klein and Geis, 1978; Kerns, 2001; Blinnikov, 2005). Several of our woody tree and shrub species have not been previously examined, and we also looked at the seeds, cones, and flowering parts. We did not find abundant silicification in our woody reference collection. However, many of the trees and shrubs produced calcium oxalate crystals. These calcium phytoliths are less likely to be recovered from natural and archaeological sediments because they are susceptible to dissolution in acids used in extractions (Coil et al., 2003). Therefore, we only describe them briefly for the woody species.

Native forbs

Of the 46 native forbs, 48% were only trace or non-producers of phytoliths while 52% of them were common producers (Table 4-1). There were no native forbs rated as abundant. The 24 species rated as common producers came from 9 different families:

Asteraceae, Boraginaceae, Brassicaceae, Euphorbiaceae, Polemoniaceae, Ranunculaceae, Rubiaceae, Scrophulariaceae, and Solonaceae.

Asteraceae

Eleven of the 15 native species of Asteraceae examined were common producers of phytoliths: *Achillea millefolium*, *Artemisia ludoviciana*, *Balsamorhiza sagittata*, *Erigeron divergens*, *Erigeron pumilus*, *Grindelia squarrosa*, *Haplopappus acaulis*, *Helianthus annuus*, *Iva axillaris*, *Iva xanthifolia*, and *Xanthium strumarium*. They commonly produced hairs, polyhedral epidermal sheets and tracheids. All of these species formed segmented hairs that were reported to be characteristic of the family (Bozarth, 1992) except *Achillea millefolium* and *Grindelia squarrosa*.

Achillea millefolium is a perennial forb found on both dry and mesic sites (Shaw, 1989). It is an important and resistant forage species for cattle and game species, and it recovers well on highly disturbed sites (Monsen et al., 2004). *Achillea millefolium* made the majority of its phytoliths in the leaves, while the stem was not highly silicified. Leaf phytoliths included acicular psilate unsegmented hairs (Plate I, a) and anticlinal epidermal sheets. We also observed striations on some of these anticlinal epidermal cells (Plate I, b).

Artemisia ludoviciana is an herbaceous aromatic perennial reaching up to 69 cm near riparian areas or in dry and rocky sites in the sagebrush steppe (USDA, 2007). It is considered an important ethnobotanical herb (USDA, 2007). *Artemisia ludoviciana* was reported to produce anticlinal epidermal sheets (Bozarth, 1992) and we observed striations on them as well (Plate I, c). This species also produced tracheids.

Balsamorhiza sagittata is a broadleaf perennial with a woody taproot. It is an important forage species for native grazers like deer and elk as well as cattle and sheep (Monsen et al., 2004). *Balsamorhiza sagittata* was previously described by Bozarth (1992) and Blinnikov (2005). We observed that the previously described segmented hairs were most common in the leaf and flowering head portions of the plant. The hairs appeared to be thinly silicified and they tended to break and disfigure during processing (Plate I, i). This species also produced many tracheids.

Two species in the *Erigeron* genus were both common producers of phytoliths. They are both low growing biennial herbs that favor moist places and partial shade (USDA, 2007). *Erigeron divergens* and *Erigeron pumilus* both generate very long (over 500 microns) acicular psilate segmented hairs (up to 4 smooth segments) in the leaf and stem (Plate I, d). The flower/seed portion contained several trichiary elements.

Although *Grindelia squarrosa* is a native species, it spreads along roadsides and disturbed areas and is sometimes considered an invasive weed (Young and Clements, 2005). *Grindelia squarrosa* had some very weakly silicified epidermal sheets and some acute acicular psilate unicellular hairs on the leaves (Plate I, f). In addition, we observed some weak silicification around cells in the stem that made half moon to circular shapes (Plate I, e). The seed head produced mostly charcoal but also had some trichiary elements.

Haplopappus acaulis is a perennial herbaceous species (sometimes considered a subshrub) that grows in dry open habitats (USDA, 2007). *Haplopappus acaulis* had some thinly silicified acicular psilate segmented hairs with very rounded or inflated

looking segments (Plate I, g). It also made a quite unique bifid hair base with striations along the sides (Plate I, h).

Helianthus annuus is a common sunflower that is widely distributed and can be found on disturbed sites (Shaw, 1989). The leaves and flowering head of *Helianthus annuus* were dominated by short segmented hairs that were heavily darkened by the processing and are covered with granulate processes. The stem produced a few hairs and some tracheids. Bozarth (1992) reported that this species also produced silicified polyhedral epidermal sheets and irregularly perforated opaque platelets in the achenes. Our flowering head may not have contained any developed seeds because we did not observe this type in our specimen.

Two species within the genus *Iva* were common producers. While *Iva axillaris* is perennial and *Iva xanthifolia* is an annual, both species are considered weedy and are common along roadsides and disturbed areas (Shaw, 1989). Both *Iva axillaris* and *Iva xanthifolia* are dominated by acicular psilate segmented hairs with and without bases still attached. They also both contained a few weakly silicified epidermal sheets.

Xanthium strumarium is considered to be of “questionable origin” (Shaw, 1989) by some botanists because there is debate over whether it is a native to North America or not. It is now commonly considered a noxious weed because its seedlings are poisonous to livestock and its seeds (cocklebur) infest wool and hair of animals (USDA, 2007). *Xanthium strumarium* leaves formed conical psilate segmented hairs with 3 rounded portions that occurred with and without bases attached (Plate I, q) and polyhedral epidermal cells. The hairs on the stems were also segmented with 3-4 sections but were longer and had no bases attached. The seed had extremely weakly silicified epidermal

portions and some hairs similar to the stem. Bozarth (1992) described silicified polyhedral epidermal cells and regularly perforated opaque cells in this species. He also described the hairs as having a rounded or oval shaped bases and a short apex (Bozarth, 1992).

Boraginaceae

All three native species of Boraginaceae (*Hackelia patens*, *Lithospermum ruderale* and *Mertensia oblongifolia*) in the collection were common producers of phytoliths. The phytolith production was mostly of unsegmented (or unicellular) hairs. This family only rarely produces segmented hairs (Bozarth, 1992). The hairs vary in length and ornamentation, but are always unicellular with round hair bases that often remain attached. *Hackelia patens* produced conical psilate hairs varying in length from 196 to almost 1000 microns with and without bases attached (Plate I, k and l). In *Lithospermum ruderale*, on the other hand, there were long (from 150 to over 700 microns) conical granulated hairs. These species are both common perennial forbs in sagebrush on dry open sites (Shaw, 1989). *Mertensia oblongifolia* was also dominated by conical psilate hairs (from 100 to 500 microns) with and without the hair bases attached. This perennial species is commonly found in sagebrush and pinyon juniper woodlands (Shaw, 1989).

Brassicaceae

There was only one native *Brassicaceae*, *Erysimum asperum*, in the collection. This species is a perennial forb common on open rocky sites (Shaw, 1989). It was a common producer of phytoliths due to the dominance of fusiform (Plate 1, j) and

bifurcated (y-shaped) hairs. These hairs have been described as medifixed and trifixed depending upon how they attach to the leaf surface (Khalik, 2005). This species produced fusiform tuberculate unicellular hairs that attached to the surface of the plant at the center (medifixed) and bifurcated tuberculate unicellular hairs that also attached at the center point (trifixed).

Euphorbiaceae

The only native *Euphorbiaceae* in the collection, *Chamaesyce maculata*, was also a common phytolith producer. This species is common among disturbed sites and is said to be a native but qualified as “probably a native of eastern North America” by Shaw (p. 152, 1989). We did not observe any hairs in *Chamaesyce maculata*. Instead, the common phytoliths were anticlinal epidermal sheets (some blackened from the processing) as well as long celled polyhedral epidermal sheets and several tracheids.

Polemoniaceae

Both native species of Polemoniaceae in the collection were common phytolith producers. They were also both in the genus *Phlox*. *Phlox hoodii* is a low-growing cushion like plant with very sharp tipped leaves that is found in open dry sites with sagebrush (Shaw, 1989). The tips of the leaves contained highly silicified cells. This species also has what could be characterized as anticlinal papillate epidermal cells. We observed similar phytoliths in *Phlox longifolia*. This herbaceous perennial forb has an upright growth form and occurs on dry open sites. In *Phlox longifolia*, we observed rectangular papillate striate epidermal cells (Plate I, t). They were somewhat similar to the papillae observed in *Bromus*, but could be distinguished by the anticlinal cells or the

striations from either *Phlox*. We did not observe any similar phytoliths produced in this collection and these may be unique phytolith morphotypes for this genus.

Ranunculaceae

We sampled one native species in this family, *Delphinium nuttallianum*.

Delphinium nuttallianum is a notable forb in both ecosystem types because it is poisonous to livestock (Whitson et al., 2000). It was found to be a common producer of epidermal and tracheid phytoliths. The anticlinal epidermal sheets appeared thinly silicified, however, each cell disarticulated individually (Plate I, n). This disarticulation was quite different from most epidermal silicified sheets that usually only break as smaller and smaller groups of cells. In addition, the charcoal or burned structures of this species created honeycombed shapes that were not entirely opaque.

Rubiaceae

The one native species of Rubiaceae, *Galium aparine*, was also a common producer of phytoliths. Although a native, this annual species is considered an agricultural pest because it creates difficulty in harvesting hay and because its bristly seeds cling to clothes and animal fur (Whitson et al., 2000). This species generated abrupt conical psilate hairs with hair base cells attached (Plate I, s) as well as anticlinal epidermal sheets.

Scrophulariaceae

We examined four native species of Scrophulariaceae, but only three were common producers of phytoliths: *Castilleja angustifolia*, *Castilleja flava* and *Collinsia*

parviflora. *Castilleja angustifolia* and *Castilleja flava* are semiparasitic perennials of sagebrush (Shaw, 1989). *Castilleja angustifolia* created long acicular granulate segmented hairs (3 sections) with and without bases still attached (Plate I, m). In addition, its polyhedral epidermal sheets were often darkened from the processing into blackened polyhedral epidermal sheets that were very weakly silicified. *Castilleja flava* also made long segmented hairs that were both psilate and granulate. All of the hairs were thinly silicified and curled or bent from the heat of processing. This species also produced extremely weakly silicified epidermal sheets with oblong cells. *Collinsia parviflora* is a diminutive annual herb that is most prolific in an early wet spring in the sagebrush steppe (personal observation). It produced long narrow acicular psilate unicellular hairs with out any hair base cells attached and weakly silicified anticlinal epidermal cells.

Solonaceae

We examined one native Solonaceae, *Physalis longifolia*, and found it to be a common phytolith producer. This plant is also considered a “native weed” (Shaw, 1989) because it is a native of North America but “naturalized” to its current distribution across the US West (USDA, 2007). It is a striking plant commonly called “Chinese lantern” because the inflated calyx that covers the berry looks like a paper lantern. The leaves of this species produced common epidermal or mesophyll structures. The stem contained an interesting suborbicular phytolith of unknown origin that seemed to be thinly silicified (Plate I, r). In addition, the stem created well silicified polyhedral epidermal sheets that were darkened from the processing and had roughened surfaces.

Native grasses, rushes, and sedges

All 16 of the native grasses, one scouring rush and one native sedge (95%) were abundant phytolith producers (Table 4-1). *Juncus balticus* was the only rush examined in this collection and it was a non-producer (5%). The results of our type frequency analysis were similar for most of the species that were analyzed in previous studies (Table 4-3). Most of the variability can probably be explained by the type of morphotypes counted and the preparation of plant material. Our morphotype descriptions and frequency results for the abundant producers are discussed below.

Achnatherum hymenoides, *Hesperostipa comata*, and *Achnatherum nevadense* are all species from the Stipeae tribe within the Poaceae. As such, they form the recognizable bilobate shape with a trapezoidal bottom known as the “stipa type” (Fredlund and Tieszen, 1994). *Achnatherum hymenoides* produced the most of this morphotype (39%) among these dominant native species (Plate II, a-b). *Achnatherum hymenoides* is one of the most common grasses in the arid and semiarid western US where it is highly palatable to livestock, and its seeds are an important food source for wildlife (Monsen et al., 2004). It was also a staple food for American Indians (USDA, 2007). It is generally found on drier sites, but can occupy more mesic zones as well (Monsen et al., 2004).

Hesperostipa comata generated fewer stipa types (8%) and more of the short cells known as rondels. As with Blinnikov (2005), we found frequencies over 30% for production of horned rondels (32%) by *Hesperostipa comata* (Plate II, f). *Hesperostipa comata* is a widely distributed cool season bunchgrass in the western US. It is highly

sensitive to overgrazing and is said to be the “first species to disappear from native pastures and range sites” under such conditions (Monsen et al., 2004, p. 418).

The common stipa type was rather thin in cross sectional view in *Achnatherum nevadense* (Plate II, d) and it produced more thin, weakly lobed pieces (47% other) than true stipa types (15%) (Plate II, e). *Achnatherum nevadense* is found in seven western states in the US in sagebrush and open woodlands (USDA, 2007).

Phytolith morphologies in the *Carex* genus have a wide variation even among the sedge cones that characterize the family Cyperaceae (Ollendorf, 1992). *Carex nebrascensis* produced many of the well known sedge cone morphotypes including rounded psilate and rounded apex with satellites as individuals and in platelets, and angular psilate and pointed apex without satellites in platelets and as individuals (Ollendorf, 1992). Some of the platelets take on a bilobate appearance in top view, but are easily distinguished from any grass morphotype by rotation to the cross sectional profile (Plate II, aa). Although not the diagnostic form for this family or genus, this species also produced elongated and rectangular forms similar to *Carex* that were described by Blinnikov (2005). In *Carex nebrascensis*, these elongated rectangular forms have many processes along the longest edge and are irregular at the ends (Plate II, bb). There were also unicellular hairs without bases that were similar to the ones found in the *Poaceae*.

The morphotypes in *Distichlis stricta* were heavily dominated by saddles (91%) and just a few long indented cells (6%). It did not appear to produce any of the bilobate morphotypes. *Distichlis stricta* is a dominant grass species in lower-elevation desert shrub communities where it can form pure stands in saline soils. It is not a preferred

forage species for cattle (Monsen et al., 2004). This species is one of the five native C₄ grasses we examined in this collection.

The morphotypes in the genus *Elymus* did not group together. The morphotypes of *Elymus elymoides* were made up of almost equal proportions of long wavy types (14%) (Plate II, g), deeply indented long cells (17%) round hair bases (14%) (e.g. Plate II, c) and other shapes consisting of round bottomed rondels (13%) (Plate II, h). We noted a large number of hairs in our sample; however, since they were broken, only the hair bases were counted. Blinnikov (2005) also remarked upon the high percentage of hairs in this species and he believed they may be a good indicator of the species presence in sediments. The waves were very shallow in this species compared to others such as *Festuca idahoensis* (Plate II, n). This loosely caespitose perennial species is often an early successional species on overgrazed and disturbed sites and is a common understory grass in sagebrush steppe (Monsen et al., 2004).

Elymus lanceolatus, on the other hand, was distinguishable by its high percentage of rondels including keeled (45%) (Plate II, i), horned (24%) and pyramidal (13%) (Plate II, j). *Elymus lanceolatus* is a cool season perennial bunchgrass that is often regarded as a disturbance tolerant species because it recovers quickly and flourishes in sagebrush and pinyon-juniper woodland communities after fire (Monsen et al., 2004).

Echinochloa muricata was dominated by the bilobate (39%) and cross forms (20%) commonly found in the C₄ grasses. These bilobates are easily distinguished from the native stipa type by their well defined shaft and the difference in their in cross sectional profile (Plate II, u-x). This plant, along with the taxonomically very similar *Echinochloa crus-galli*, have been controversial species for the genus because they are

difficult to distinguish and there are both native and “adventive populations” in North America (Gould et al., 1972). *Echinochloa muricata* var. *microstachya* is the most common of its genus found in the American West (Gould et al., 1972) and it could either be a native relict or possibly introduced with Europeans where it is found today (Barkworth, 2007; Piep, 2007). Today, *Echinochloa muricata* is a widely distributed C₄ grass throughout the lower 48 states and is generally found in wet areas (USDA, 2007).

Equisetum laevigatum was the only species of rush examined in the Equisetaceae family. This species produced the genus diagnostic stomata and the epidermal cells with granulate surfaces and “elevated projections along the edges” (Plate II, cc) (Piperno, 2006). In addition, there were many cylindrical bilobate and polylobate verrucate epidermal morphotypes that were distinguishable from those in the grasses by the verrucate surfaces (Plate II, dd).

Half of the morphotypes in *Festuca idahoensis* were long wavy plates (50%) (Plate II, n). Although it produced a fair amount of keeled rondels (18%) as well, the long wavy plates appeared to be the most important indicator morphotype for this species in our dataset. Our results differed from Blinnikov’s (2005) assessment of morphotypes in this species. He found a much higher frequency of horned rondels and he believed they distinguished this species from its codominant in sagebrush steppe, *Pseudoroegneria spicata*. *Festuca idahoensis* is an important perennial bunchgrass in the both ecosystems, particularly as a forage species for wildlife and livestock. In lower elevations, it can be restricted to more mesic sites (Monsen et al., 2004).

Hordeum brachyantherum was dominated by long deeply indented cells (33%) (Plate II, o) and keeled rondels (31%). This cool season perennial bunchgrass is best adapted to moist sites (USDA, 2007).

Leymus cinereus was dominated by the long deeply indented (18%) and long indented cells (21%) (Plate II, k). We found that it also generated a fair amount of oblong knobby hair bases (15%) (Plate II, l) and keeled rondels (17%). Blinnikov (2005) considered *Leymus cinereus* to be difficult to distinguish from other closely related *Agropyron* grasses. This is the largest of the native cool season bunchgrasses. It can be found mixed in mixed communities, in pure stands and in areas that receive runoff water, such as roadsides and washes (Monsen et al. 2004).

Muhlenbergia richardsonis also produced mostly saddle morphotypes (37%) and few long cells. Other morphotypes made up 21% of the count. These shapes included cells that looked very similar to those found in *Carex* species (Plate II, aa). In *Muhlenbergia richardsonis* these cells were rounded to sinuous platelets with processes and multiple (usually two) psilate apices (Plate II, s). *Muhlenbergia richardsonis* is a C₄ grass commonly found in wet areas in the western US (USDA, 2007).

There were two *Poa secunda* subspecies examined in this study, *Poa secunda* ssp. *juncifolia* and *Poa secunda* ssp. *secunda*. Both *Poa secunda* are small, densely tufted cool season perennials that are highly resistant to grazing and trampling (Monsen et al., 2004). Both of these species contained a high percentage of long smooth cells (14-22%) (e.g. Plate V, k). Keeled rondels dominated in the subspecies *secunda*. We observed that the rondels in the subspecies *juncifolia* were not well formed and were difficult to identify. Many of them ended up in the category “other” and could have also been

included as short wavy types that Blinnikov (2005) found dominated the *Poa* species in his study. *Poa secunda* ssp. *secunda* other shapes also included several irregularly shaped short cells and several (11 total) prickles (Plate II, q). The relatively high percentage of papillae cells (Plate II, r) is probably due to the fact that this subspecies was processed as a whole rather than separated into leaf and culm material.

Pseudoroegneria spicata is one of the most important, productive and palatable grasses in sagebrush and pinyon-juniper communities. It is very sensitive to the overgrazing and is lost from many sites due to poor grazing management (Monsen et al., 2004). We found *Pseudoroegneria spicata* generated mostly long wavy plates (15%), long smooth cells (22%) and square based hairs (18%). We observed nearly equal proportions of pyramidal (10%) and keeled (9%) rondels. Our results differed from Blinnikov's (2005) frequencies for this species. He observed more pyramidal rondels and less long wavy and smooth cells. Again, this difference may be because we counted a similar but not exactly the same set of morphotypes in our frequency analysis.

The morphotypes in *Sporobolus airoides* contained nearly even frequencies of saddles (12%), long indented cells (12%) and pyramidal rondels (14%). The majority of its shapes were considered to be in the other category (33%). These other shapes were bilobates without a long shaft that appeared very square and were thick in cross section (Plate II, t). *Sporobolus airoides* is a C₄ grass that can be found in higher elevations, but develops pure stands in lower elevation, moist and alkaline sites (Monsen et al., 2004).

Sporobolus cryptandrus, on the other hand, was dominated by saddle types (84%) (Plate II, y) and produced more typical bilobates (9%) (Plate II, z) and very few rondels at all (2%). This species is a component of many communities, including sagebrush

steppe and pinyon-juniper woodlands. This C₄ grass often invades disturbed sites and is grazing tolerant due to low desirability by livestock, late development and a protected root crown (Monsen et al., 2004).

Native trees and shrubs

There were 10 native trees and shrubs examined. The plant material was divided into leaves, stem, seed/flowering portion and bark (when available). None of these species were considered abundant producers of phytoliths. None of the bark, seeds, cones or flowering parts examined for these 10 species produced any phytoliths other than calcium phytoliths. In several cases, the leaf and stem material had different abundance classes. The vast majority of the woody species' material (79%) was categorized as trace to non-producers of phytoliths. The common producers made up 21% of the material. The only families with common phytolith producing plant material were *Asteraceae* and *Rosaceae*. The common producers, *Prunus virginiana* and *Rosa woodsii*, were from leaf material (Table 4-1). There was only one shrub, *Artemisia tridentata*, where stem material could be ranked as common. Most of the native trees and shrubs produced calcium oxalate (CaOx) crystals that we have not seen described previously for these species. Calcium oxalate crystals were not present in any of the *Juniperus* plant material, however, *Pinus monophylla* and *Cercocarpus ledifolius* both produced abundant blocky, prismatic and elongate rectangular styloid forms (Plate III) (Franceschi and Nakata, 2005).

Asteraceae

We examined two shrub species in the *Asteraceae* and only the stem of *Artemisia tridentata* can be considered a common producer of phytoliths. While the leaf material produced a few blocky shapes as well, the stem of this species created a common small blocky form usually <20 microns in length (Plate III, a). Blinnikov (2005) first described this blocky form in *Artemisia tridentata* and found it was a good indicator of sagebrush steppe in modern soils from the Columbia Basin. *Artemisia tridentata* is the dominant shrub species in the sagebrush steppe ecosystem type.

Rosaceae

Of the four species of native trees and shrubs examined in this family, only two, *Prunus virginiana* (tree) and *Rosa woodsii* (shrub) had material that commonly produced phytoliths. Both of these species are found in the moist sites, canyons and along streams (Shaw, 1989). *Prunus virginiana* leaves produced a silicified anticlinal epidermal cells (Plate III, f) and tracheids (e.g. Plate III, c). In addition, it produced rhombohedral calcium oxalate crystals (Plate III, g-h) that were unique among the species in this collection (Franceschi and Nakata, 2005).

Introduced forbs

Of the 50 introduced forbs in the collection, 78% were either non-producers or produced only trace amounts of phytoliths, and 22% were common to abundant producers (Table 4-2). The trace producers formed mostly very weak epidermal silica and some tracheids. The only two species rated as abundant producers were both from

the Brassicaceae family. The nine common producers were from five families: Asteraceae, Boraginaceae, Brassicaceae, Cucurbitaceae, and Ranunculaceae.

Asteraceae

Acroptilon repens formed what Bozarth (1992) described as honeycomb assemblages from clusters of the mesophyll cells (Plate IV, a), tracheids and silicified polyhedral epidermal shapes (Plate IV, b). *Acroptilon repens* was first introduced from Turkestan into Canada in the early 1900's in contaminated alfalfa seed (Watson, 1980). By 1985, it was reported in 21 out of the lower 48 states, prevalent in Canada, and could be found on every continent, except Antarctica (Maddox et al., 1985). It is currently found in 27 states in the US excluding some in the eastern and southern regions of the country (USDA, 2007). It is known to have been collected within the Great Basin state of Idaho as early as 1926 (Rice, 2007).

Cirsium vulgare formed several interesting phytoliths within the leaf and stem while the seed contained mostly blackened hairs. The tips of the leaf contained highly silicified polyhedral epidermal sheets (Plate IV, f) that disarticulated into separate cells (Plate IV, g) rather than only breaking together as smaller and smaller groups. It also produced cylindric psilate phytoliths of unknown origin, some with lanceolate tips. In the Pacific Northwest, *Cirsium vulgare* was first collected in the state of Washington in 1883 and was in Idaho by 1911 (Rice, 2007). It can now be found in all 50 US states (USDA, 2007).

Lactuca serriola formed polyhedral epidermal cells with some processes at the tips of the leaves. The stems produced a number of conical psilate prickles that were

unique to this species in the collection (Plate IV, d). The prickles disarticulated well, and had a rounded apex and concave base (Plate IV, e). There were no other phytolith morphotypes like this one in the collection and, therefore, it could represent a unique morphotype for this introduced species in the region. *Lactuca serriola* is a native of the Mediterranean and Central Asia and was first collected in North America in Massachusetts in 1863 (Weaver and Downs, 2003). It was in the western state of Montana by 1881 and collected in Idaho by 1897 (Rice, 2007). Its current distribution includes all 49 US states excluding only Alaska (USDA, 2007).

The leaf of the *Tragopogon dubius* was one of the few that contained silicified stomata cells. In addition, the leaves produced unique epidermal cells with irregular sinuated processes (Plate IV, j-k), polyhedral epidermal sheets and silicified mesophyll cells. *Tragopogon dubius* was used as food by early European settlers, and is believed to have escaped from cultivation (Clements et al., 1999). It is a common weed on roadsides and waste sites (Whitson et al., 2000). It was collected in Wyoming in 1900 and in Idaho in 1941 (Rice, 2007). It is currently found in 46 US states excluding the South (USDA, 2007).

Boraginaceae

Two species of Boraginaceae were common producers of phytoliths: *Asperugo procumbens* and *Myosotis micrantha*. *Asperugo procumbens* produced conical psilate unicellular hairs that separated easily from the hair bases (Plate IV, o). Some hairs were curved; however, that could be from the heat of the muffle furnace in processing. They also produced tracheids and some weakly silicified anticlinal epidermal cells (Bozarth,

1992). *Asperugo procumbens* was first collected on the ballast grounds of Philadelphia, Pennsylvania in 1877 (Martindale, 1877). In 1878, it was observed on newly constructed wharves in New York Harbor (Brown, 1878) where it was also believed to have been introduced from ballast water (Britton and Hollick, 1885). It was first collected in the western coastal state of Washington in 1897 and found in Idaho by 1938 (Rice, 2007). It is now found in 24 mostly western and northern states in the union (USDA, 2007).

Myosotis micrantha formed long conical granulate hairs with and without bases still attached (Plate IV, l-m). It produced polyhedral as well as anticlinal epidermal cells with squared edges (Plate IV, n). In the Pacific Northwest, it was first collected in Washington in 1880 and was found in Idaho by 1926 (Rice, 2007). *Myosotis micrantha* is also currently found in 24 northern and western states (USDA, 2007).

Brassicaceae

Two species of *Brassicaceae*, *Alyssum desertorum* and *Capsella bursa-pastoris*, produced abundant silica phytoliths. *Alyssum desertorum* produced an abundant amount of very large stellate granulate hairs (Morris et al., in press). *Capsella bursa-pastoris* produced an abundant amount of hairs including some similar to the stellate granulate hairs found in *Alyssum desertorum*. However, the stellate granulate hairs found in *Alyssum desertorum* typically had more than four arms, and most were dendriform (Plate IV, s). *Capsella bursa-pastoris* also generated a number of hairs that have been described as branched hairs, medifixed and simple hairs (Khalik, 2005). The branched hairs rise from a base and split into three or four arms while the medifixed hairs are

affixed to the plant in the center, lay flat with the surface of the leaf, and have two (fusiform granulate hair) or three arms (bifurcated granulate hair) (Khalik, 2005). The hairs on both of these species were granulate to tuberculate. All of these hairs were relatively large, ranging from 100-500 microns in length.

The fusiform and bifurcated granulate hairs of the *Capsella bursa-pastoris* (Plate IV, p-r) were similar to the native *Brassica*, *Erysimum asperum*. However, the stellate granulate hairs from both introduced Brassicas were not observed in the native *Brassicacae* from this family. This stellate granulate hair could be a unique indicator for these introduced mustards. Furthermore, *Alyssum desertorum* is a more widespread invasive plant in wildlands, while *Capsella bursa-pastoris* is more metropolitan and agricultural. Therefore, the stellate dendriform granulate hair morphotypes in a wildland setting could be even further indication of the species *Alyssum desertorum*. Finally, care should be used to interpret the usefulness of these morphotypes to indicate the introduced species based upon potential of other *Brassica* species to produce similar hairs and what can be expected in the flora of a particular study area. For example, several species, such as *Draba argyrea* and *Draba aurea*, generate some stellate like hairs, but the plants are usually found in alpine and subalpine areas (Hitchcock et al., 1969). *Draba densifolia*, on the other hand, contains some stellate hairs and can be found in middle elevations (Hitchcock et al., 1969).

There is little known about the introduction and spread of *Alyssum desertorum* (Young and Clements, 2005) except that, in the Pacific Northwest, it was first collected in Montana 1933, and first collected in Idaho in 1940 (Rice, 2007). Its current distribution spreads across 12, mostly western, US states (USDA, 2007). *Capsella bursa-*

pastoris, however, has a more rich history. There is genetic evidence for multiple introductions into North America. Populations from central California resemble populations from Spain, while populations from the rest of the United States are more similar to those from temperate regions in Europe (Neuffer and Hurka, 1999). The earliest report of *Capsella bursa-pastoris* in the US was from New England in 1663 (Crosby, 2000). It was later reported as a contaminant in agricultural seed in Delaware in 1889 (Mack and Erneberg, 2002). In the northwestern US, it was first collected in Oregon in 1880, and in Idaho in 1895 (Rice, 2007). It is now found in all 50 states in the US (USDA, 2007).

Cucurbitaceae

Only one species in the *Cucurbitaceae* was examined in this study. *Bryonia alba* produced acicular psilate segmented hairs with 3-4 sections, with and without hair base cells still attached. The hairs appeared to be deformed by the high temperatures during processing (Plate IV, h). This species also generated an interesting charcoal or blackened structure (Plate IV, i). There is genetic evidence for multiple introductions of *Bryonia alba* because of its use as a medicinal and ornamental plant (Novak and Mack, 1995). It is known to have been sold as an ornamental in Massachusetts (1860-1867), New York (1870-1899) and Illinois (1899) (Mack, 1991). It was not collected in the Pacific Northwest until it was found in Montana in 1953; much later than many of the other introduced species (Rice, 2007). However, this invasive herbaceous vine made up for its late introduction with a rapid growth rate that gained it the moniker, “kudzu of the Pacific

Northwest” (Stannard, 2002). Its current distribution now includes the states of Oregon, Washington, Idaho and Utah (USDA, 2007).

Ranunculaceae

Ceratocephala testiculata formed cylindrical granulated hairs (Plate IV, c) with no hair base cells and extremely weakly silicified polyhedron epidermal cells.

Ceratocephala testiculata was first collected in the US near Salt Lake City, Utah in 1932 (Buchanan et al., 1978). It was collected in Oregon in 1935, and in Idaho as early as 1940 (Rice, 2007). It is now found in 14 northern and western states in the US (USDA, 2007).

Introduced grasses

As would be expected from the literature and from the results of the native grasses, all 14 introduced *Poaceae* species were abundant phytolith producers (Table 4-3). Many of the introduced grass species produced morphotypes that were not redundant with the native *Poaceae* in this region. Blinnikov et al. (2002) noted that the appearance of typical *Bromus tectorum* phytoliths near the surface of his sediments could be an indication of the era of European settlement. He also used this widespread invasive species in his study of sagebrush steppe (Blinnikov, 2005). We found similar frequency types for *Bromus tectorum* in our analysis (Table 4-4). In addition, several of the introduced species to this region are C₄ grasses. The morphotype differences between C₄ and C₃ grasses have been known for some time, and used for understanding shifts in dominance of these grasses worldwide (Kaufman et al., 1985; Twiss, 1992; Fredlund and Tieszen, 1994). Northern portions of the Great Basin floristic region, which includes the

sagebrush steppe, have a relatively low percentage of C₄ grasses (Teeri and Stowe, 1976). In his study of phytoliths in the Pacific Northwest, Blinnikov (2005) noted that the only bilobate morphotypes in his collection were from the stipa type and the rare occurrence of a C₄ *Aristida longiseta*. Similarly, the sagebrush steppe region in our study is composed mostly of native C₃ grasses. We believe the distinctive C₄ morphotypes and the differences in frequency types of the introduced grasses may be useful indicators of climatic and vegetation changes, historical land uses and as time markers in the soil profile since their timeframe of introduction is known.

Agropyron desertorum contained equal percentages of long indented cells (22%) (Plate V, b) and long deeply indented cells (22%) (Plate V, a). Its rondels were also equally pyramidal as well as keeled (11%). It produced the most square based hairs (12%) (Plate V, e) of the introduced species, but only 2% of the oblong knobby hair base form (Plate V, c). The “other” morphotypes (11%) were mostly blocky forms with tuberculate processes (Plate V, d). *Agropyron desertorum* was widely planted in the Great Basin to increase forage production beginning after World War II (West, 1983). It is well adapted to the cold desert sagebrush steppe, and can establish well in plantings and in disturbed sites (Monsen et al., 2004).

Three species of introduced *Bromus* were examined in study, *Bromus inermis*, *Bromus japonicus* and *Bromus tectorum*. None of these species produced very many rondels of any kind (0-2%). *Bromus inermis* was processed whole and, therefore, was dominated (71%) by the papillae cells (e.g. Plate V, g) from the inflorescence this genus was known for producing (Blinnikov, 2005). *Bromus inermis* was introduced from Europe and extensively seeded to restore overgrazed rangelands (Monsen et al., 2004). It

was recommended and used for planting in southern Idaho (Hull, 1973). It now occurs throughout North America, and in 47 US states (USDA, 2007).

Bromus japonicus produced mostly long wavy cells (47%) and long smooth cells (26%) (Plate V, k). The waves on this species, however, were shallow and had mostly squared ends (Plate V, f). *Bromus japonicus* is a weed on rangelands and in hayfields (Whitson et al., 2000). It was first collected in Pacific Northwest in Washington state in 1903, and was collected in Idaho in 1913 (Rice, 2007). It now occurs throughout the lower 48 states (USDA, 2007).

Bromus tectorum phytoliths were made up of long wavy cells with variable ends (Plate V, j), long smooth cells, round based hairs (Plate V, h), and papillae (Plate V, g) in almost equal proportions (18-19%). The papillae percentage was high even though the inflorescences were processed separately. Blinnikov (2005) found very similar production in his study, except he reported a higher percentage of pyramidal rondels. *Bromus tectorum* was first collected in North America in Pennsylvania in 1790 (Vallient et al., 2007) and was found in Provo, Utah in 1894 (Knapp, 1996). It is considered a problem plant in both degraded rangelands and in winter wheat (Morrow and Stahlman, 1984). It is currently distributed throughout all 50 states (USDA, 2007).

Cynodon dactylon stands out from the other introduced (and native) species due to its production of bulliform cells (4%) (Plate V, l) and the predominance of the saddles (57%) (Plate V, m). The bilobate in this C₄ grass was distinguishable because of its well defined shaft in comparison to the native stipa type counterpart. This species is a common crop and turf weed that is believed to be introduced from Africa (Whitson et al.,

2000). It was first collected in the state of Washington in 1897, and in Idaho 1937 (Rice, 2007). It is currently found in 41 US states (USDA, 2007).

Dactylis glomerata was recognizable by its high percentage of long wavy plate cells (45%). Although described similarly to those in the *Bromus* and even some native species, they were, in fact, recognizably different. The long wavy cells in this species had extremely rounded, deeply formed multiple waves (Plate V, p) and were trapezoidal in cross sectional view (Plate V, q). Some were unevenly lobed on both sides. *Dactylis glomerata* was first collected in the Pacific Northwestern state of Washington in 1882, and in Idaho by 1890 (Rice, 2007). Introduced as a hay and pasture grass, multiple varieties have been bred (Monsen et al., 2004). It was highly recommended and useful for planting in southern Idaho (Hull, 1973). It is now distributed in all 50 US states (USDA, 2007).

Echinochloa crus-galli was dominated by bilobate (59%) (Plate V, n) and cross like (18%) morphotypes (Plate V, o). As mentioned above, the identity and nativity of this species has often been confused with *Echinochloa muricata* (Gould et al., 1972). Today, *Echinochloa crus-galli* is considered a common weed of irrigated and cultivated areas (Whitson et al., 2000), and is found in every state in the US, except Alaska (USDA, 2007).

Elytrigia repens generated mostly long deeply indented cells (23%), keeled rondels (25%) and pyramidal rondels (13%). Some of these long deeply indented types had one straight edge. This species is a common crop, pasture and rangeland weed in moist soils (Whitson et al., 2000). It was first collected in the Pacific Northwest state of

Washington in 1882, and was in Idaho by 1901 (Rice, 2007). It is now distributed throughout 44 states excluding the South (USDA, 2007).

Eragrostis cilianensis was also recognizable from its production of saddles (41%), bilobates (23%) and bulliform cells (1%). Even though bulliforms were a small percentage in the overall production in *Eragrostis cilianensis* and *Cynodon dactylon*, there were no other cells like them observed in any of the native C₃ grasses in this collection. This C₄ grass species is a common agricultural weed (Whitson et al., 2000). It was first collected in Pacific Northwest in Montana in 1887, and was collected in Idaho in 1911 (Rice, 2007). It is now widely distributed in every US state, except Alaska (USDA, 2007).

Phleum pratense also produced predominantly long deeply indented types (26%), papillae (32%) (Plate V, s), and keeled rondels (16%). We observed that this species was weakly silicified overall with the exception of the rondels and papillae. The long deeply indented types were very thin with squared-off waves that tended to stay together as sheets or break at the squared-off top of the waves together. In addition, this species formed a number of opaque pieces of variable form. The most recognizable of this opaque form was a rounded piece with a hole in the center (Plate V, r). This species was recommended for planting in southern Idaho (Hull, 1973), and was introduced for hay and forage production on ranges with wet sites (Monsen et al., 2004). It now occurs in all 50 US states (USDA, 2007).

Poa bulbosa produced mostly long wavy cells (23%), long smooth cells (34%) and long deeply indented types (17%). There were very few rondels (4-8%). We observed that the long smooth cells in this species were relatively large and long with

pitted edges (Plate V, t). *Poa bulbosa* was first collected in the Pacific Northwest state of Oregon in 1901, and was in Idaho by 1928 (Rice, 2007). It was also one of the many species recommended for planting to increase forage in southern Idaho (Hull, 1973). It is now in 42 states in the US (USDA, 2007).

Poa pratensis stood out from the other introduced grasses by its high production of both horned (23%) (Plate V, u) and keeled (19%) rondel types. We noted that the long wavy types in this species had many waves (9-10) with mostly squared ends. As with the other native *Poa* examined in this study, they created quite a few long smooth cells (16%). *Poa pratensis* was one of the earliest (1685) grass species deliberately introduced to the US, but it was restricted to wet, cool areas (Monsen et al., 2004). It is extremely tolerant of grazing and can be used as an indicator of overgrazing (Monsen et al., 2004). The first collection of *Poa pratensis* in the Pacific Northwest was in the state of Washington in 1876. It was first collected in Idaho in 1892 (Rice, 2007). Its current distribution includes all 50 US states (USDA, 2007).

Secale cereale was the highest producer of rondels in this collection including keeled (46%) (Plate V, v), pyramidal (8%) and horned (5%). Otherwise, there was very little difference in phytolith frequency. This species of ryegrass escaped cultivation to become a serious problem for wheat producers and on rangelands (Whitson et al., 2000). In the Pacific Northwest, it was first collected in Washington in 1897, where it is now listed as a state noxious weed (Rice, 2007; USDA, 2007). It was first collected in Idaho in 1941 (Rice, 2007). *Secale cereale* is now widespread through 48 states (USDA, 2007).

Setaria viridis made the most bilobates (50%) in this collection of all the introduced grasses. The bilobate shape (Plate V, x) and its frequency are enough to

distinguish it from the native grasses in this region. This C₄ grass is a common crop weed (Whitson et al., 2000), and is widely distributed in the lower 48 US states (USDA, 2007). It was first collected in the Pacific Northwest in Montana in 1887, and then in Idaho in 1912 (Rice, 2007).

Introduced trees

We examined four introduced tree species from four families for this study. None of the species produced abundant phytoliths. In several species, the leaf and stem material were different abundance classes. Phytoliths were common only in leaf material. Most of the introduced woody species' plant material (60%) classified as trace to non-producers of phytoliths. The common producers made up 40% of the material, and it was all from leaves. The only families with common producing leaf material were Salicaceae and Ulmaceae. Most of the woody introduced species formed calcium oxalate crystals. One species, *Elaeagnus angustifolia*, formed raphid calcium oxalate crystals worth noting (Plate III) (Franceschi and Nakata, 2005).

Salicaceae

The leaves from the introduced tree species in this family, *Populus alba*, contained silicified polyhedral epidermal sheets (Plate III, b) and tracheids (Plate III, c). This species was introduced to North America as early as 1748 as an ornamental tree (USDA, 2007).

Ulmaceae

We examined one species of introduced Ulmaceae, *Ulmus pumila*. The stems were non-producers and only the leaves generated common phytoliths. The leaf contained polyhedral epidermal sheets and abrupt conical psilate hairs with striations on their bases (Plate III, e). This tree was introduced to the US in the 1860s as a popular windbreak and shelter for homes (USDA, 2007).

Conclusion

We found many Great Basin native and introduced species that produced common or abundant phytoliths. In addition, we found that there are many useful phytoliths in the under evaluated forb group. The most common forb phytoliths we observed were hairs, hair base cells and anticlinal/polyhedral epidermal sheets. Although these phytoliths have been considered less useful due to poor preservation, they have been recovered from a variety of modern sediments (Blinnikov, 2005). Also, hairs and hair bases from plants introduced in the last century may be better preserved in sediments over this shorter timeframe. Several silicified epidermal cells were unique in comparison to the other plants in this collection. Again, recognition of these unique types could be useful for a number of questions in the realm of historical ecology, palaeoecology, palaeoethnobotany and archaeology. For example, the conical psilate prickles generated in *Lactuca serriola* could be a useful indicator of recent sediments and disturbance factors in an ecological context. They could also provide information for ethnobotanical and archeological studies since *Lactuca serriola* was introduced so early to North America and was used by Native Americans (Vestal, 1952). We believe the description of all of these morphotypes

will aid in the understanding of vegetation change and plant use if they are found in natural sediments or archeological contexts.

Our analysis of native and introduced grasses showed important differences in both morphotypes and production frequency. We have described here a number of morphotype differences between native and introduced species of grasses that should be useful indicators of more recent soils (approximately 100 years), and as a way to understand historic land use practices, such as agricultural development and grazing. Our morphotype findings are consistent with the literature and lend support to the idea of using differences in morphotypes between C₃ and C₄ grasses as an important way to study vegetation change. In addition, our production frequency analysis demonstrated several differences between native and introduced grasses that may be useful in vegetation histories. For example, introduced grasses in our collection produced fewer rondels than most of the native grasses. This difference is especially pronounced when dominance on the landscape and habitat are considered. Many areas that were once occupied by natives like *Elymus lanceolatus* and *Hesperostipa comata* are now susceptible to invasion by the introduced *Bromus tectorum* and *Agropyron desertorum*. Analysis based on frequency types of rondels between these groups of grasses could reflect this type of grassland species conversion.

We did not find a great deal of silicification in our collection of woody and tree species. However, the amorphous silica found in several of the tree species should be examined with scanning electron images *in situ* in the wood as others have done (Scurfield et al., 1974; Klein and Geis, 1978; Carnelli et al., 2004). There were several forbs and grasses with identifiable morphotypes that are associated with pinyon- juniper

woodlands. However, we did not identify any unique silica input from the two dominant tree species in this system. Therefore, there is apparently is no clear phytolith assemblage for pinyon-juniper woodlands in the Great Basin. Other plant communities also lack a diverse and recognizable phytolith assemblage. Two common US Mojave Desert plant communities, creosote-bursage scrub and Joshua tree woodlands apparently do not generate a characteristic phytolith assemblage (Lawlor, 1995; Piperno, 2006). It may be, therefore, that the lack of phytolith production demonstrated by comparisons of extraction weights between these woodlands and shrub-steppe or grasslands would be a better way to differentiate these plant communities. This type of analysis by phytolith mass has been used to differentiate between forests and prairie vegetation (Kalisz and Boettcher, 1990).

This study represents a first step in cataloguing phytoliths of the thousands of species found in the Great Basin Desert region. Many plants in this collection produce phytoliths and several species have potentially unique forms. While our study focused upon the aerial portions of herbaceous plants, underground portions of these plants should also be examined in future research. It was previously believed that the underground plant portions did not produce many useful phytolith types, but some recent work in rhizomes and tubers has shown otherwise (Piperno, 2006). We sampled one bulb from *Calochortus nuttallii*, but found no phytoliths. The native and introduced Great Basin flora deserve more study, and this cataloguing effort should continue.

References

- Albert, R., and Weiner, S., 2001. Study of phytoliths in prehistoric ash layers using a quantitative approach. In: Meunier, J. and Colin, F. (Eds.), *Phytoliths: Applications in Earth Science and Human History*. A.A. Balkema Publishers, Lisse, pp. 251-266.
- Albert, R.M., Weiner, S., 2000. Phytoliths in the Middle Palaeolithic deposits of Kebara Cave, Mt Carmel, Israel: study of the plant materials used for fuel and other purposes. *Journal of Archaeological Science* 27, 931-947.
- Barkworth, M., 2007. Personal communication. Director, Intermountain Herbarium, Utah State University, Logan, UT.
- Beatley, J.C., 1975. Climates and vegetation pattern across the Mojave/Great Basin Desert transition of southern Nevada. *American Midland Naturalist* 93(1), 53-70.
- Blinnikov, M.S., 2005. Phytoliths in plants and soils of the interior Pacific Northwest, USA. *Review of Palaeobotany & Palynology* 135, 71-98.
- Blinnikov, M.S., Busacca, A., Whitlock, C., 2002. Reconstruction of late Pleistocene grassland of the Columbia Basin, Washington, USA, based on phytolith records in loess. *Palaeogeography, Palaeoclimatology, Palaeoecology* 177, 77-101.
- Bozarth, S.R., 1992. Classification of opal phytoliths formed in selected dicotyledons native to the Great Plains. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics: Emerging Issues*, Plenum Press, New York, pp. 192-214.
- Britton, N.L., Hollick, A., 1885. Flora of Richmond Co., N.Y. *Bulletin of the Torrey Botanical Club* 12(4), 38-40.
- Brown, A., 1878. Plants introduced with ballast and on made land. *Bulletin of the Torrey Botanical Club* 6(45), 255-258.
- Buchanan, B.A., Karper, K.T., Frischknecht, N.C., 1978. Allelopathic effects of bur buttercup tissue on germination and growth of various grasses and forbs *in vitro* and in soil. *Great Basin Naturalist* 38, 90-96.
- Carnelli, A.L., Theurillat, J.P., Madella, M., 2004. Phytolith types and type-frequencies in the subalpine-alpine plant species of the European Alps. *Review of Palaeobotany & Palynology* 129, 39-65.
- Clements, D.R., Upadhyaya, M.K., Bos, S.J., 1999. The biology of Canadian weeds. 110. *Tragopogon dubius* Scop., *Tragopogon pratensis* L., and *Tragopogon porrifolius*. *Canadian Journal of Plant Science* 79, 153-163.

- Coil, J., Korstanje, M.A., Archer, S., Hastorf, C.A., 2003. Laboratory goals and considerations for multiple microfossil extraction in archaeology. *Journal of Archaeological Science* 30, 991-1008.
- Crosby, A.W., 2000. *Ecological Imperialism: The Biological Expansion of Europe, 900-1900*. Cambridge University Press, Cambridge, UK.
- Flaschka, I., Stockton, C.W., Boggess, W.R., 1987. Climatic variation and surface water resources in the Great Basin. *Water Resources Bulletin* 23, 47-57.
- Franceschi, V.R., Nakata, P.A., 2005. Calcium oxalate in plants: formation and function. *Annual Review of Plant Biology* 56, 41-71.
- Fredlund, G.G., 2001. Inferring vegetation history from phytoliths. In: Egan, D. and Howell, E.A. (Eds.), *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*. Island Press, Washington, DC, pp. 335-362.
- Fredlund, G.G., Tieszen, L.T., 1994. Modern phytolith assemblages from the North American Great Plains. *Journal of Biogeography* 21, 321-335.
- Gould, F.W., Ali, M.A., Fairbrothers, D.E., 1972. A revision of *Echinochloa* in the United States. *The American Midland Naturalist* 87(1), 36-59.
- Grayson, D.K., 1993. *The Desert's Past: A Natural Prehistory of the Great Basin*. Smithsonian Institution Press, Washington, DC.
- Hitchcock, C.L., Cronquist, A., Ownbey, M., Thompson, J.W., 1969. *Vascular plants of the Pacific Northwest, 2*. University of Washington Press, Seattle, WA.
- Hull, A.C., 1973. *Regrassing southern Idaho range lands*. University of Idaho College of Agriculture Extension Division, Extension Bulletin No. 146.
- Kalisz, P.J., Boettcher, S.E., 1990. Phytolith analysis of soils at Buffalo Beats, a small forest opening in southeastern Ohio. *Bulletin of the Torrey Botanical Club* 117(4), 445-449.
- Kaufman, P.B., Dayanandan, P., Franklin, C.I., Takeoka, Y., 1985. Structure and function of silica bodies in the epidermal system of grass shoots. *Annals of Botany* 55, 487-507.
- Kerns, B.K., 2001. Diagnostic phytoliths for a ponderosa pine-bunchgrass community near Flagstaff, Arizona. *The Southwestern Naturalist* 46, 282-294.

- Khalik, K.A., 2005. Morphological studies on trichomes of Brassicaceae in Egypt and taxonomic significance. *Acta Botanica Croatica* 64, 57-73.
- Klein, R.L., Geis, J.W., 1978. Biogenic silica in the Pinaceae. *Soil Science* 126(3), 145-156.
- Knapp, P.A., 1996. Cheatgrass (*Bromus tectorum* L.) dominance in the Great Basin Desert. *Global Environmental Change* 6, 37-52.
- Kondo, R., Childs, C., Atkinson, I., 1994. *Opal Phytoliths of New Zealand*. Whenua Press, New Zealand.
- Lawlor, E.J., 1995. Archaeological site-formation processes affecting plant remains in the Mojave Desert. Unpublished Ph.D. dissertation, University of California, Riverside.
- Mack, R.N., 1991. The commercial seed trade: an early disperser of weeds in the United States. *Economic Botany* 45(2), 257-273.
- Mack, R.N., Erneberg, M., 2002. The United States naturalized flora: largely the product of deliberate introductions. *Annals of the Missouri Botanical Garden* 89(2), 176-189.
- MacMahon, J.A., 1988. Warm deserts. In: Barbour, M.G. and Billings, W.D. (Eds.), *North American Terrestrial Vegetation*. Cambridge University Press, New York, NY, pp. 232-260.
- Maddox, D.M., Mayfield, A., Poritz, N.H., 1985. Distribution of yellow starthistle (*Centaurea solstitialis*) and Russian knapweed (*Centaurea repens*). *Weed Science* 33, 315-327.
- Madella, M., Alexandre, A., Ball, T., 2005. International code of phytolith nomenclature 1.0. *Annals of Botany* 96, 253-260.
- Martindale, I.C., 1877. More about ballast plants. *Bulletin of the Torrey Botanical Club* 2(10), 127-128.
- Meunier, J., Colin, F., 2001. *Phytoliths: Applications in Earth Sciences and Human History*. A.A. Balkema Publishers, Lisse, Netherlands.
- Miller, R.F., Svejcar, T.J., West, N.E., 1994. Implications of livestock grazing in the Intermountain sagebrush region: plant composition. In: Vavra, M., Laycock, W.A. and Pieper, R.D. (Eds.), *Ecological Implications of Livestock Herbivory in the West*. Society for Range Management Publications, Denver, CO, pp. 101-146.

- Monsen, S.B., Stevens, R., Shaw, N.L., 2004. Restoring western ranges and wildlands. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-136-vol-2, 295-698 pp.
- Morris, L.R., 2008. Great Basin Phytolith Database. Intermountain Herbarium, Utah State University (<http://www.herbarium.usu.edu>).
- Morris, L.R., West, N.E., Baker, F.A., Van Miegroet, H., Ryel, R.J., in press. Developing an approach for using the soil phytolith record to infer vegetation and disturbance regime changes over the past 200 years. *Quaternary International*.
- Morrow, L.A., Stahlman, P.W., 1984. The history and distribution of downy brome (*Bromus tectorum*) in North America. *Weed Science* 32(Supplement 1), 2-6.
- Neuffer, B., Hurka, H., 1999. Colonization history and introduction dynamics of *Capsella bursa-pastoris* (Brassicaceae) in North America: isozymes and quantitative traits. *Molecular Ecology* 8, 1667-1681.
- Novak, S.J., Mack, R.N., 1995. Allozyme diversity in the apomictic vine *Bryonia alba* (Cucurbitaceae): potential consequences of multiple introductions. *American Journal of Botany* 82(9), 1153-1162.
- Ollendorf, A.L., 1992. Toward a classification scheme of sedge (Cyperaceae) phytoliths. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics: Emerging Issues*. Plenum Press, New York, pp. 91-111.
- Pearsall, D.M., 2000. *Paleoethnobotany: A Handbook of Procedures*. Academic Press, San Diego.
- Piep, M.B., 2007. Personal communication. Assistant Curator, Intermountain Herbarium, Utah State University, Logan, UT.
- Piperno, D.R., 2006. *Phytoliths: a comprehensive guide for archaeologists and paleoecologists*. AltaMira Press, Lanham, MD.
- Rice, P.M., 2007. INVADERS Database System (<http://invader.dbs.umt.edu>). Division of Biological Sciences, University of Montana, Missoula, MT.
- Rovner, I., 1971. Potential of opal phytoliths for use in paleoecological reconstruction. *Quaternary Research* 1, 343-359.
- Scurfield, G., Anderson, C.A., Segnit, E.R., 1974. Silica in woody stems. *Australian Journal of Botany* 22, 211-229.

- Shaw, R.J., 1989. Vascular plants of Northern Utah: an identification manual. Utah State University Press, Logan, UT.
- Stannard, M., 2002. White Bryony: "the Pacific Northwest kudzu." U.S. Department of Agriculture, Natural Resources Conservation Service, Pullman, WA and Moscow, ID, pp. 1-4.
- Teeri, J.A., Stowe, L.G., 1976. Climatic patterns and the distribution of C₄ grasses in North America. *Oecologia* 23, 1-12.
- Tueller, P.T., Beeson, C.D., Tausch, R.J., West, N.E., Rea, K.H., 1979. Pinyon-juniper woodlands of the Great Basin: distribution, flora, vegetal cover. USDA Forest Service, Intermountain Research Station, Research Paper INT-229.
- Twiss, P.C., 1992. Predicted world distribution of C₃ and C₄ grass phytoliths. In: Rapp Jr., G. and Mulholland, S.C. (Eds.), *Phytolith Systematics: Emerging Issues*. Plenum Press, New York, pp. 113-128.
- USDA, 2007. The PLANTS Database National Plant Data Center (<http://plants.usda.gov>), Baton Rouge, LA.
- Vallient, M.T., Mack, R.N., Novack, S.J., 2007. Introduction history and population genetics of the invasive grass *Bromus tectorum* (Poaceae) in Canada. *American Journal of Botany* 94, 1156-1169.
- Vestal, P.A., 1952. The ethnobotany of the Ramah Navaho. *Papers of the Peabody Museum of American Archaeology and Ethnology* 40(4), 1-94.
- Wallis, L., 2003. An overview of leaf phytolith production patterns in selected northwest Australian flora. *Review of Palaeobotany & Palynology* 125, 201-248.
- Watson, A.K., 1980. The biology of Canadian weeds. 43. *Acroptilon (Centaurea) repens* (L.) DC. *Canadian Journal of Plant Science* 60, 993-1004.
- Weaver, S.E., Downs, M.P., 2003. The biology of Canadian weeds. 122. *Lactuca serriola* L. *Canadian Journal of Plant Science* 83(3), 619-628.
- West, N.E., 1983. Western intermountain sagebrush steppe. In: West, N.E. (Ed.), *Temperate Deserts and Semi-Deserts*. Elsevier Scientific Publishing Company, Amsterdam, pp. 351-374.
- West, N.E., Rea, K.H., Tausch, R.J., 1975. Basic synecological relationships in juniper-pinyon woodlands. In: Gifford, G.F. and Busby, F.E. (Eds.), *The Pinyon-juniper Ecosystem: A Symposium*. Utah State University Logan, UT, pp. 41-53.

- West, N.E., Tausch, R.J., Tueller, P.T., 1998. A management-oriented classification of pinyon-juniper woodlands of the Great Basin. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-12.
- Whitson, T.D., Burrill, L.C., Dewey, S.A., Cudney, D.W., Nelson, B.E., Lee, R.D., Parker, R., 2000. Weeds of the West. Western Society of Weed Science, the Western United States Land Grant Universities Cooperative Extension Services and the University of Wyoming, Jackson, WY.
- Young, J.A., Clements, C.D., 2005. Exotic and invasive herbaceous range weeds. *Rangelands* 27, 10-16.

Table 4-1 List of all native species examined in this study. For Production Index (P.I.), NP = nonproducer, T = trace, C = common, and A = abundant.

Family	Common Name	Scientific Name	P. I.
<u>Grasses, Rushes and Sedges</u>			
Cyperaceae	Nebraska sedge	<i>Carex nebrascensis</i>	A
Equisetaceae	Scouring rush	<i>Equisetum laevigatum</i>	A
Juncaceae	Northern rush	<i>Juncus balticus</i>	NP
Poaceae	Indian ricegrass	<i>Achnatherum hymenoides</i>	A
	Nevada needlegrass	<i>Achnatherum nevadense</i>	A
	Saltgrass	<i>Distichlis stricta</i>	A
	Rough barnyardgrass	<i>Echinochloa muricata</i>	A
	Squirreltail	<i>Elymus elymoides</i>	A
	Thickspike wheatgrass	<i>Elymus lanceolatus</i>	A
	Idaho fescue	<i>Festuca idahoensis</i>	A
	Needle and thread grass	<i>Hesperostipa comata</i>	A
	Meadow barley	<i>Hordeum brachyantherum</i>	A
	Great Basin wildrye	<i>Leymus cinereus</i>	A
	Mat muhly	<i>Muhlenbergia richardsonis</i>	A
	Sandberg bluegrass ²	<i>Poa secunda</i> ssp. <i>juncifolia</i>	A
	Sandberg bluegrass	<i>Poa secunda</i> ssp. <i>secunda</i>	A
	Bluebunch wheatgrass	<i>Pseudoroegneria spicata</i>	A
	Sand dropseed	<i>Sporobolus cryptandrus</i>	A
	Alkalai sacaton	<i>Sporobolus airoides</i>	A
<u>Forbs</u>			
Amaranthaceae	Prostrate pigweed	<i>Amaranthus blitoides</i>	T
Apiaceae	Narrowleaf lomatium	<i>Lomatium triternatum</i>	T
Asteraceae	Yarrow	<i>Achillea millefolium</i>	C
	Mountain dandelion	<i>Agoseris glauca</i>	T
	Pussy toes	<i>Antennaria microphylla</i>	NP
	Western mugwort	<i>Artemisia ludoviciana</i>	C
	Arrowleaf balsamroot	<i>Balsamorhiza sagittata</i>	C
	Dusty maiden	<i>Chaenactis douglasii</i>	T
	Spreading fleabane	<i>Erigeron divergens</i>	C
	Low Fleabane	<i>Erigeron pumilus</i>	C
	Sawtooth gumweed	<i>Grindelia squarrosa</i>	C
	Broom snakeweed	<i>Gutierrezia sarothrae</i>	T
	Stemless goldenweed	<i>Haplopappus acaulis</i>	C
	Annual sunflower	<i>Helianthus annuus</i>	C
	Poverty sumpweed	<i>Iva axillaris</i>	C
	Marshelder	<i>Iva xanthifolia</i>	C
	Hoary aster	<i>Machaeranthera canescens</i>	T
	Cockleburr	<i>Xanthium strumarium</i>	C
Brassicaceae	Wall flower	<i>Erysimum asperum</i>	C

Table 4-1 Continued

Family	Common Name	Scientific Name	P.I.
<u>Forbs Continued</u>			
Boraginaceae	Spotted forget-me-not	<i>Hackelia patens</i>	C
	Stoneseed	<i>Lithospermum ruderale</i>	C
	Sagebrush bluebell	<i>Mertensia oblongifolia</i>	C
Euphorbiaceae	Prostrate spurge	<i>Chamaesyce maculata</i>	C
Fabaceae	Beckwith milkvetch	<i>Astragalus beckwithii</i>	T
	Wild licorice	<i>Glycyrrhiza lepidota</i>	T
	Silver lupine	<i>Lupinus argenteus</i>	T
Liliaceae	Wild onion	<i>Allium brandegei</i>	T
	Sego lily	<i>Calochortus nuttallii</i>	T
	Death camas	<i>Zigadenus paniculatus</i>	NP
Linaceae	Flax	<i>Linum lewisii</i>	T
Malvaceae	Gooseberry-leaf mallow	<i>Sphaeralcea grossulariifolia</i>	T
Onagraceae	Willowweed	<i>Epilobium brachycarpum</i>	NP
Plantaginaceae	Broadleaf plantain	<i>Plantago major</i>	T
Polemoniaceae	Carpet phlox	<i>Phlox hoodii</i>	C
	Longleaf phlox	<i>Phlox longifolia</i>	C
Polygonaceae	Whorled buckwheat	<i>Eriogonum heracleoides</i>	T
	Slender buckwheat	<i>Eriogonum microthecum</i>	T
	Cushion buckwheat	<i>Eriogonum ovalifolium</i>	T
Ranunculaceae	Larkspur	<i>Delphinium nuttallianum</i>	C
Rubiaceae	Bedstraw catchweed	<i>Galium aparine</i>	C
Santalaceae	Bastard toadflax	<i>Comandra umbellata</i>	T
Scrophulariaceae	Desert paintbrush	<i>Castilleja angustifolia</i>	C
	Yellow paintbrush	<i>Castilleja flava</i>	C
	Blue-eyed Mary	<i>Collinsia parviflora</i>	C
	Matroot penstemon	<i>Penstemon radicosus</i>	T
Solonaceae	Wright groundcherry	<i>Physalis longifolia</i>	C
<u>Trees/Shrubs</u>			
Asteraceae	Big sagebrush	<i>Artemisia tridentata</i>	T/C*
	Rabbit brush	<i>Chrysothamnus viscidiflorus</i>	T
Caprifoliaceae	Snowberry	<i>Symphoricarpos oreophilus</i>	NP
Cupressaceae	Utah juniper	<i>Juniperus osteosperma</i>	NP
Pinaceae	Pinyon pine	<i>Pinus monophylla</i>	T
Rosaceae	Mountain mahogany	<i>Cercocarpus ledifolius</i>	T
	Chokecherry	<i>Prunus virginiana</i>	C/T
	Antelope bitterbrush	<i>Purshia tridentata</i>	T/NP
	Wild rose	<i>Rosa woodsii</i>	C/NP
Salicaceae	Yellow willow	<i>Salix lutea</i>	NP

* Dual abundance classes are expressed as leaf/stem

Table 4-2 List of all introduced species examined in this study. For Production Index (P.I.), NP = nonproducer, T = trace, C = common, and A = abundant.

Family	Common Name	Scientific Name	P.I.
<u>Grasses</u>			
Poaceae	Crested wheatgrass	<i>Agropyron desertorum</i>	A
	Smooth brome	<i>Bromus inermis</i>	A
	Japanese brome	<i>Bromus japonicus</i>	A
	Cheatgrass	<i>Bromus tectorum</i>	A
	Orchardgrass	<i>Dactylis glomerata</i>	A
	Barnyardgrass	<i>Echinochloa crus-galli</i>	A
	Quackgrass	<i>Elytrigia repens</i>	A
	Timothygrass	<i>Phleum pratense</i>	A
	Bulbous bluegrass	<i>Poa bulbosa</i>	A
	Kentucky bluegrass	<i>Poa pratensis</i>	A
	Bermuda grass	<i>Cynodon dactylon</i>	A
	Stinkgrass	<i>Eragrostis cilianensis</i>	A
	Feral rye	<i>Secale cereale</i>	A
	Green foxtail	<i>Setaria viridis</i>	A
<u>Forbs</u>			
Amaranthaceae	Tumble pigweed	<i>Amaranthus albus</i>	T
	Redroot pigweed	<i>Amaranthus retroflexus</i>	T
Asteraceae	Russian knapweed	<i>Acroptilon repens</i>	T
	Ragweed	<i>Ambrosia artemisiifolia</i>	C
	Musk thistle	<i>Carduus nutans</i>	T
	Chicory	<i>Cichorium intybus</i>	T
	Canada thistle	<i>Cirsium arvense</i>	T
	Bull thistle	<i>Cirsium vulgare</i>	C
	Prickly lettuce	<i>Lactuca serriola</i>	C
	Scotch thistle	<i>Onopordum acanthium</i>	T
	Dandelion	<i>Taraxacum officinale</i>	T
	Yellow salsify	<i>Tragopogon dubius</i>	C
Boraginaceae	Catchweed	<i>Asperugo procumbens</i>	C
	Forget-me-not	<i>Myosotis micrantha</i>	C
Brassicaceae	Desert Alyssum	<i>Alyssum desertorum</i>	A
	Shepard's purse	<i>Capsella bursa-pastoris</i>	A
	Hoary cress	<i>Cardaria draba</i>	T
	Purple mustard	<i>Chorispora tenella</i>	T
	Flixweed tansy mustard	<i>Descurainia sophia</i>	C
	Dyers woad	<i>Isatis tinctoria</i>	T
	Clasping pepperweed	<i>Lepidium perfoliatum</i>	NP
	Tumble mustard	<i>Sisymbrium altissimum</i>	T
Chenopodiaceae	Lambsquarter	<i>Chenopodium album</i>	NP
	Halogeton	<i>Halogeton glomeratus</i>	T

Table 4-2 Continued

Family	Common Name	Scientific Name	P.I.
<u>Forbs Continued</u>			
Chenopodiaceae	Kochia	<i>Kochia scoparia</i>	T
	Russian thistle	<i>Salsola iberica</i>	NP
Convolvulaceae	Field bindweed	<i>Convolvulus arvensis</i>	T
Cucurbitaceae	White bryony	<i>Bryonia alba</i>	C
Dipsacaceae	Common teasel	<i>Dipsacus sylvestris</i>	NP
Euphorbiaceae	Blue spurge	<i>Euphorbia myrsinites</i>	T
Fabaceae	Goats rue	<i>Galega officinalis</i>	NP
	Black medic	<i>Medicago lupulina</i>	NP
	White sweetclover	<i>Melilotus albus</i>	T
	Sweet clover	<i>Melilotus officinalis</i>	T
Geraniaceae	Redstem fillaree	<i>Erodium cicutarium</i>	T
Lamiaceae	White horehound	<i>Marrubium vulgare</i>	NP
	Catnip	<i>Nepeta cataria</i>	T
Malvaceae	Common mallow	<i>Malva neglecta</i>	T
Oxalidaceae	Yellow woodsorrel	<i>Oxalis corniculata</i>	NP
Plantaginaceae	Narrowleaf plantain	<i>Plantago lanceolata</i>	NP
Polygonaceae	Prostrate knotweed	<i>Polygonum aviculare</i>	NP
	Curly dock	<i>Rumex crispus</i>	T
Portulacaceae	Common purselane	<i>Portulaca oleracea</i>	NP
Ranunculaceae	Bur buttercup	<i>Ceratocephala testiculata</i>	C
Scrophulariaceae	Common mullein	<i>Verbascum thapsus</i>	T
	Speedwell	<i>Veronica biloba</i>	T
Solonaceae	Black henbane	<i>Hyoscyamus niger</i>	NP
	Bitter nightshade	<i>Solanum dulcamara</i>	T
	Hairy nightshade	<i>Solanum sarrachoides</i>	T
Zygophyllaceae	Puncturevine	<i>Tribulus terrestris</i>	T
<u>Trees and shrubs</u>			
Eleagnaceae	Russian olive	<i>Elaeagnus angustifolia</i>	NP
Salicaceae	White poplar	<i>Populus alba</i>	T/C*
Tamaricaceae	Saltcedar	<i>Tamarix chinensis</i>	NP
Ulmaceae	Siberian elm	<i>Ulmus pumila</i>	NP/C

* Dual abundance classes expressed as leaf/stem

Table 4-3 Production frequency (in percent) of phytolith morphotypes found in common native Great Basin grasses.

	Saddle	Bilobate	Stipa Type	Plate wavy short	Plate wavy long	Long cell smooth	Long deeply indented	Long cell indented	Plate rectangular	Square-based hair	Round-based hair	Trichome	Oblong knobby hair	Papillae	Pyramidal rondel	Keeled rondel	Horned rondel	Other	Total
<i>Achnatherum hymenoides</i>	0	0	39	1	0	28	1	1	5	1	8	0	0	0	1	1	10	1	136
<i>Achnatherum nevadense</i>	0	0	15	13	1	4	0	0	1	1	1	0	3	1	0	0	0	47	165
<i>Elymus elymoides</i>	0	0	0	6	14	9	17	2	4	1	14	0	0	1	14	6	0	13	112
<i>Elymus lanceolatus</i>	0	0	0	0	0	6	1	6	1	1	2	0	0	0	13	45	24	3	120
<i>Hesperostipa comata</i>	0	0	8	0	0	3	3	1	0	0	5	1	16	2	11	12	32	2	130
<i>Leymus cinereus</i>	0	0	0	0	0	6	18	21	1	0	8	0	15	0	9	17	0	4	156
<i>Poa secunda ssp. juncifolia</i>	0	0	0	2	6	20	6	13	1	6	1	3	0	0	8	7	4	25	109
<i>Poa secunda ssp. secunda</i>	0	0	0	5	1	14	5	9	1	0	11	0	0	15	4	21	0	14	111
<i>Pseudoroegneria spicata</i>	0	0	0	2	15	22	1	11	0	18	4	1	0	0	10	9	0	8	123
<i>Festuca idahoensis</i>	0	0	0	0	50	10	15	3	1	0	0	0	1	0	0	18	3	0	120
<i>Hordeum brachyantherum</i>	0	0	0	0	5	7	33	0	2	0	11	0	2	0	4	31	5	0	132
<i>Distichlis stricta</i>	91	0	0	0	0	0	0	6	1	0	0	0	1	0	0	0	0	0	109
<i>Muhlenbergia richardsonis</i>	37	0	0	0	0	4	5	4	0	0	0	0	0	0	4	4	0	21	112
<i>Sporobolus cryptandrus</i>	84	9	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4	118
<i>Sporobolus airoides</i>	12	1	0	0	0	1	0	12	0	0	1	6	0	0	0	14	5	33	138
<i>Echinochloa muricata</i>	0	39	0	10	0	8	5	5	0	0	0	0	0	0	1	0	0	12	117

Table 4-4 Production frequency (in percent) of phytolith morphotypes found in common introduced Great Basin grasses.

Species Name	Bulliform	Saddle	Bilobate	Cross	Stipa type	Plate wavy	Plate wavy long	Long cell smooth	Long deeply indented	Long cell indented	Plate rectangular	Square-based hair	Round-based hair	Trichome	Oblong knobby hair	Quadrilateral (blocky)	Papillae	Pyramdial rondel	Keeled rondel	Horned rondel	Other	Total
<i>Agropyron desertorum</i>	0	0	0	0	0	0	0	0	22	22	0	12	2	0	2	0	0	10	11	1	11	139
<i>Bromus inermis</i>	0	0	0	0	0	0	0	6	1	0	0	1	3	0	0	0	71	2	2	1	14	126
<i>Bromus japonicus</i>	0	0	0	0	0	1	47	26	0	2	1	0	3	2	2	0	0	1	2	0	7	124
<i>Bromus tectorum</i>	0	0	0	0	0	0	18	18	9	1	1	1	19	0	0	0	19	1	2	0	10	136
<i>Dactylis glomerata</i>	0	0	0	0	4	7	45	18	2	2	0	0	0	1	0	0	0	2	5	0	15	130
<i>Echinochloa crus-galli</i>	0	0	59	18	0	11	0	3	0	8	0	0	0	0	0	0	0	2	0	0	0	111
<i>Elytrigia repens</i>	0	0	0	0	0	0	0	7	23	10	3	0	8	4	6	0	0	13	25	0	0	126
<i>Phleum pratense</i>	0	0	0	0	0	0	0	1	26	14	1	0	0	0	0	0	32	3	16	0	7	107
<i>Poa bulbosa</i>	0	0	1	0	0	3	23	34	17	4	2	0	1	4	0	0	0	8	4	0	0	113
<i>Poa pratensis</i>	0	0	0	0	0	1	7	16	13	0	1	0	6	2	0	0	0	2	19	23	8	119
<i>Cynodon dactylon</i>	4	57	10	0	0	0	0	1	6	10	2	0	0	0	0	8	0	1	2	0	1	104
<i>Eragrostis cilianensis</i>	1	41	23	2	0	0	0	0	16	11	0	0	0	2	0	4	0	0	0	0	0	105
<i>Secale cereale</i>	0	0	0	0	0	0	3	11	7	8	4	1	6	1	0	0	0	8	46	5	2	119
<i>Setaria viridis</i>	0	0	50	2	0	0	0	5	15	13	2	2	4	5	0	0	2	1	0	0	0	112



Figure 4-1 Map of the western portion of the United States showing the Great Basin Floristic Region.

Plate I. Light micrographs of native forb morphotypes. Some of these images have been altered using a graphics program to enhance their features and size. (a) *Achillea millefolium* acicular psilate unsegmented hair with hair base cells (b) *Achillea millefolium* anticlinal epidermal with striations (c) *Artemisia ludoviciana* anticlinal epidermal cells with striations (d) *Erigeron pumilus* acicular psilate segmented hairs (e) *Grindelia squarrosa* unknown origin (f) *Grindelia squarrosa* acute acicular psilate unicellular hair with base (g) *Haplopappus acaulis* acicular psilate segmented hair (h) *Haplopappus acaulis* bifid striate hair base (i) *Balsamorhiza sagittata* acicular psilate segmented contorted hair (j) *Erysimum asperum* fusiform tuberculate unicellular hair (k) *Hackelia patens* conical psilate unicellular hair (l) *Hackelia patens* conical psilate unicellular hair (m) *Castilleja angustifolia* long acicular granulate segmented hair with base (n) *Delphinium nuttallianum* disarticulated anticlinal epidermal cell (o) *Physalis longifolia* polyhedral epidermal cells (p) *Artemisia ludoviciana* anticlinal epidermal cells (q) *Xanthium strumarium* conical rounded psilate segmented hair with base (r) *Physalis longifolia* suborbicular form of unknown origin (s) *Galium aparine* abrupt conical psilate unicellular hair with base (t) *Phlox longifolia* rectangular papillate striate epidermal cells.

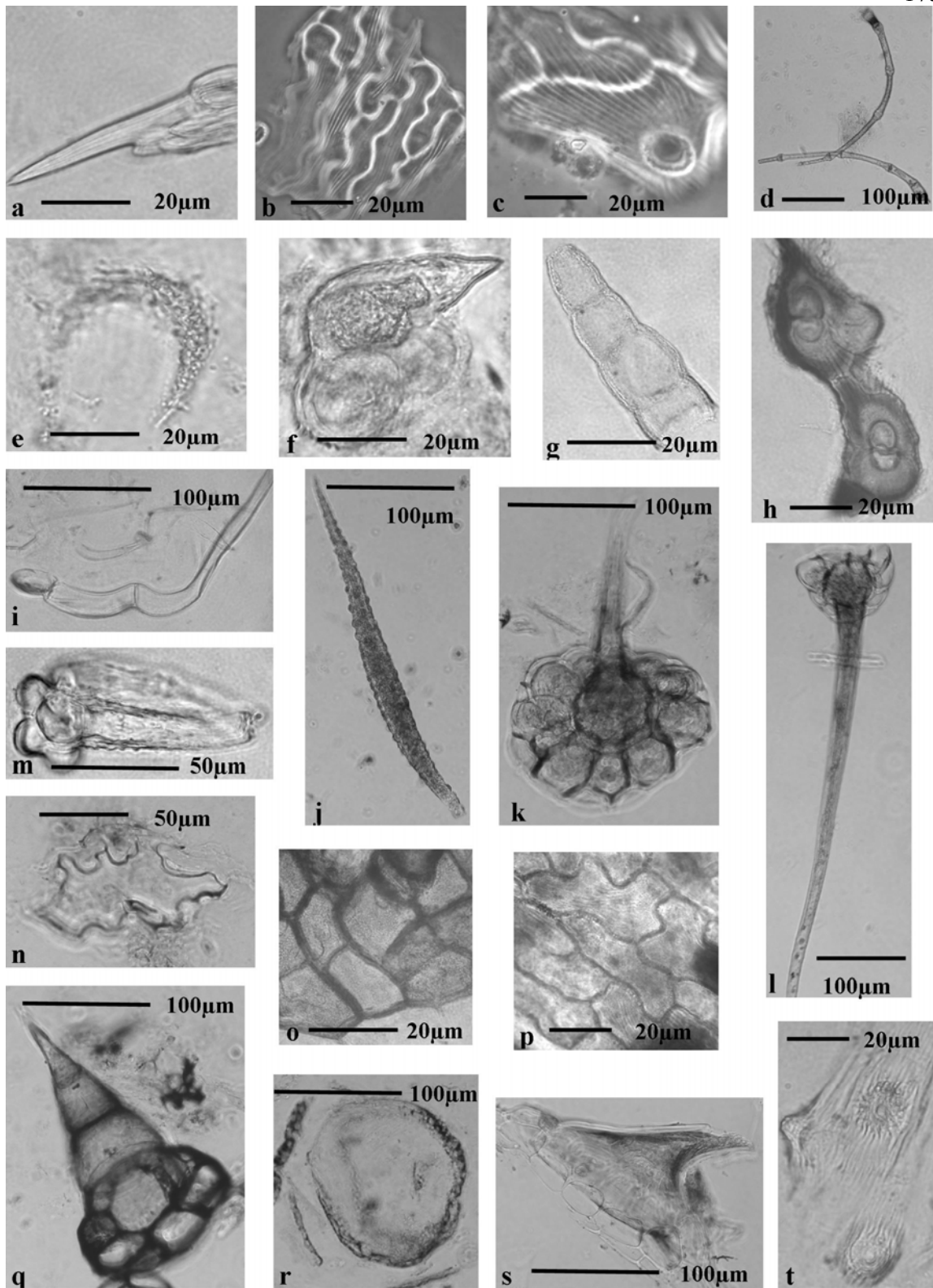


Plate I. Light micrographs of native forb morphotypes.

Plate II. Light micrographs of native grass morphotypes. Some of these images have been altered using a graphics program to enhance their features and size. (a)

Achnatherum hymenoides stipa type in top view (b) *Achnatherum hymenoides* stipa type

in cross sectional view (c) *Achnatherum hymenoides* round based hair (d) *Achnatherum*

nevadense stipa type in top view (e) *Achnatherum nevadense* thin weakly lobed type in

top view (f) *Hesperostipa comata* horned rondel in cross sectional view (g) *Elymus*

elymoides long wavy plate (h) *Elymus elymoides* round bottomed rondel (i) *Elymus*

lanceolatus keeled rondel (j) *Elymus lanceolatus* pyramidal rondel (k) *Leymus cinereus*

long indented (l) *Leymus cinereus* oblong knobby hair (m) *Festuca idahoensis* keeled (n)

Festuca idahoensis long wavy (o) *Hordeum brachyantherum* long deeply indented (p)

Poa secunda long wavy plate (q) *Poa secunda* prickle (r) *Poa secunda* papillae (s)

Muhlenbergia richardsonis sinuous platelets with two psilate apices in cross sectional

view (t) *Sporobolus airoides* bilobate in top view (u) *Echinochloa muricata* bilobate in

top view (v) *Echinochloa muricata* bilobate cross sectional view (w) *Echinochloa*

muricata plate wavy short in top view (x) *Echinochloa muricata* plate wavy short in cross

sectional view (y) *Sporobolus cryptandrus* saddle in top view (z) *Sporobolus cryptandrus*

bilobate in top view (aa) *Carex nebrascensis* angular psilate pointed apex without

satellites in platelets in cross sectional view (bb) *Carex nebrascensis* elongated

rectangular with irregular ends (cc) *Equisetum laevigatum* epidermal cells with elevated

projections on edges, stomata and cylindrical polylobate verrucate cells *in situ* (dd)

Equisetum laevigatum disarticulated cylindrical polylobate verrucate in cross sectional

view.

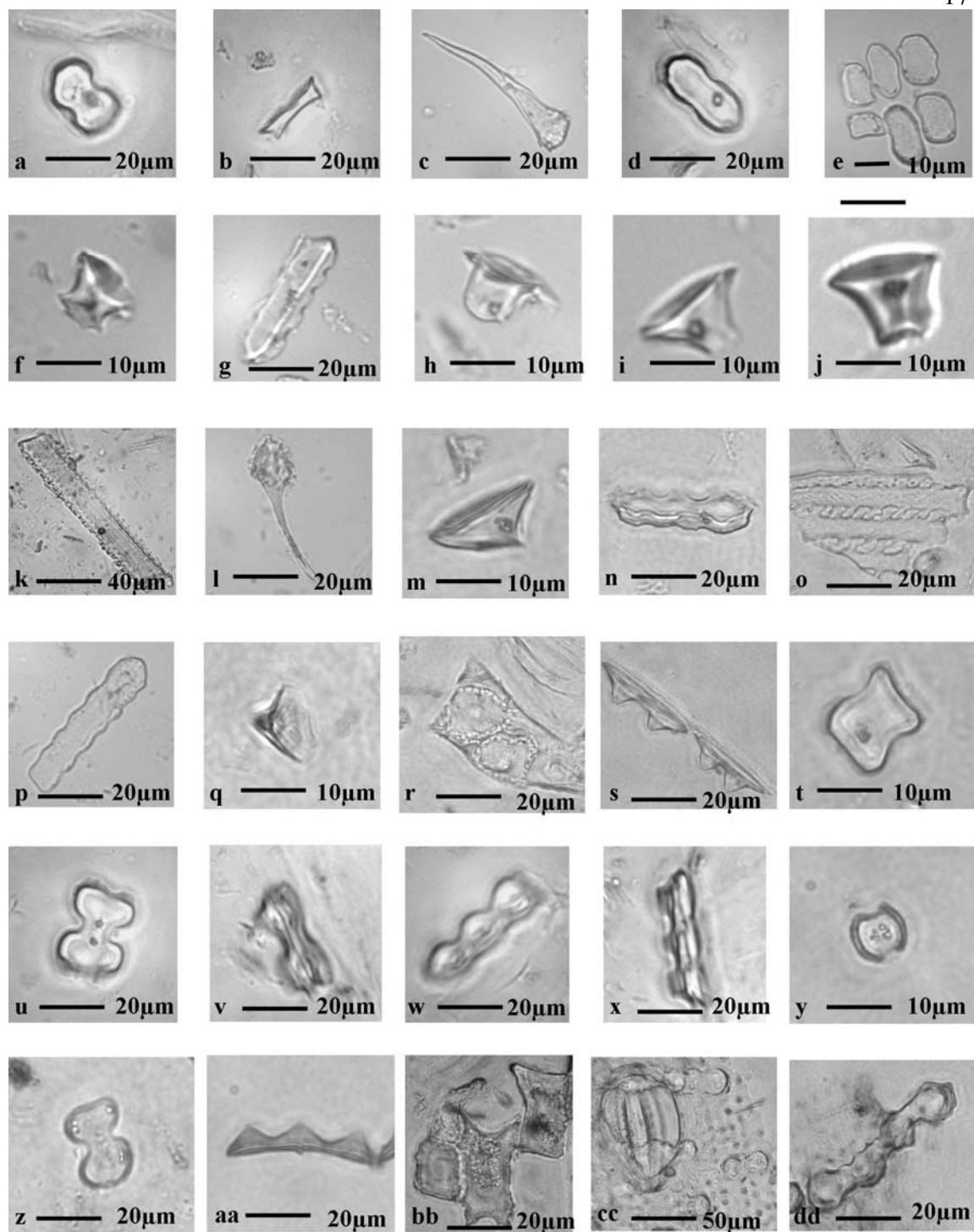


Plate II. Light micrographs of native grass morphotypes.

Plate III. Light micrographs of native and introduced tree and shrub morphotypes.

Some of these images have been altered using a graphics program to enhance their features and size. (a) *Artemisia tridentata* blocky (b) *Populus alba* polyhedral epidermal (c) *Populus alba* tracheid (d) *Rosa woodsii* polyhedral epidermal (e) *Ulmus pumila* hair base with striations (f) *Prunus virginiana* anticlinal epidermal (g) *Prunus virginiana* rhombohedral CaOx crystals (h) *Prunus virginiana* rhombohedral CaOx crystals (i) *Cercocarpus ledifolius* blocky and rectangular CaOx crystals (j) *Pinus monophylla* blocky CaOx crystals (k) *Elaeagnus angustifolia* raphide CaOx crystals

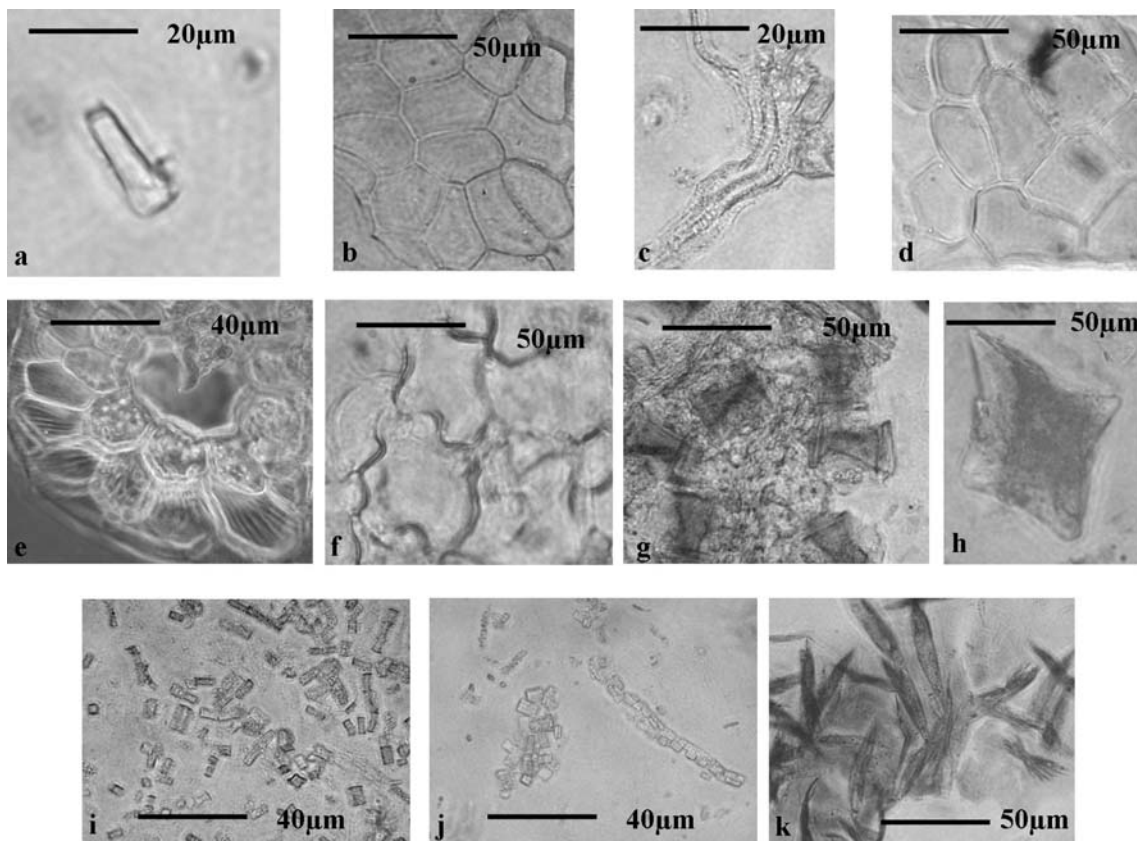


Plate IV. Light micrographs of introduced forb morphotypes. Some of these images have been altered using a graphics program to enhance their features and size. (a) *Acroptilon repens* mesophyll cells (b) *Acroptilon repens* epidermal cells (c) *Ceratocephala testiculata* cylindrical granulate segmented hair with no base (d) *Lactuca serriola* conical psilate prickles (e) *Lactuca serriola* conical psilate prickle (f) *Cirsium vulgare* polyhedral epidermal cells (g) *Cirsium vulgare* disarticulated polyhedral epidermal cell (h) *Bryonia alba* acicular psilate segmented hair without base (i) *Bryonia alba* charcoal (j) *Tragopogon dubius* epidermal cells with irregularly sinuated processes (k) *Tragopogon dubius* epidermal cells with irregular sinuated processes (l) *Myosotis micrantha* long conical granulate unicellular hair with base (m) detail of *Myosotis micrantha* granulated hair surface (n) *Myosotis micrantha* anticlinal epidermal cells with squared edges (o) *Asperugo procumbens* conical psilate unicellular hair detached from base (p) *Capsella bursa-pastoris* stellate tuberculate hair (q) *Capsella bursa-pastoris* bifurcated granulate hairs (r) detail of *Capsella bursa-pastoris* tuberculate hair surface (s) *Alyssum desertorum* stellate dendriform granulate hair.

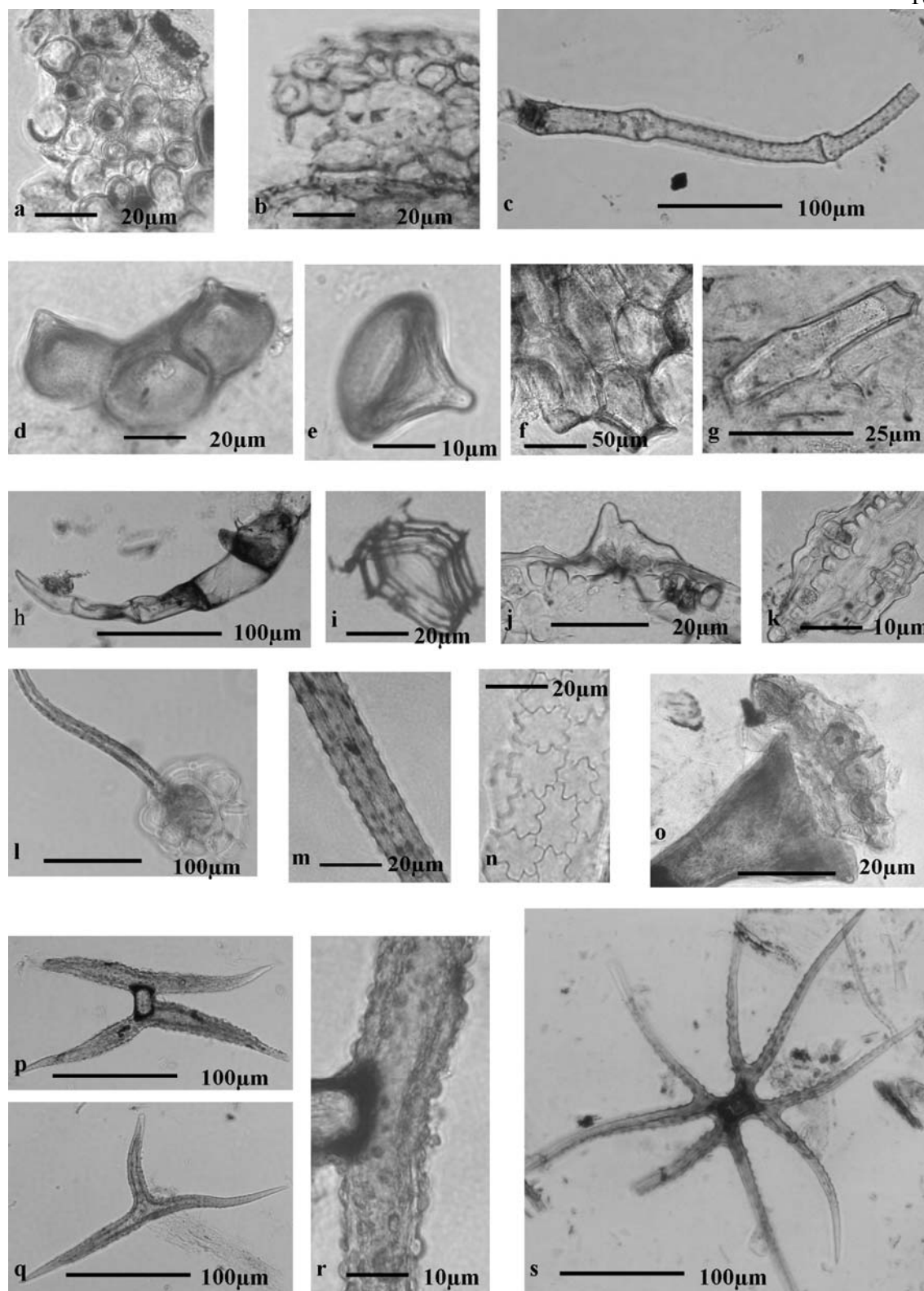


Plate IV. Light micrographs of introduced forb morphotypes.

Plate V. Light micrographs of introduced grass morphotypes. Some of these images have been altered using a graphics program to enhance their features and size. (a) *Agropyron desertorum* long deeply indented morphotype (b) *Agropyron desertorum* long cell indented (c) *Agropyron desertorum* oblong knobby hair (d) *Agropyron desertorum* cubic tuberculate (e) *Agropyron desertorum* square-based hair (f) *Bromus japonicus* plate wavy long (g) *Bromus tectorum* papillae (h) *Bromus tectorum* round-based hair (i) *Bromus tectorum* dendritic (j) *Bromus tectorum* long wavy plate variable ends (k) *Bromus japonicus* long cell smooth (l) *Cynodon dactylon* bulliform cell (m) *Cynodon dactylon* saddle (n) *Echinochloa crus-galli* bilobate (o) *Echinochloa crus-galli* cross (p) *Dactylis glomerata* long wavy plate deeply lobed in top view (q) *Dactylis glomerata* long wavy plate in cross sectional view (r) *Phleum pretense* opaque pieces (s) *Phleum pretense* papillae (t) *Poa bulbosa* long cell smooth with perforated edges (u) *Poa pratensis* horned rondel (v) *Secale cereale* keeled rondel (w) *Setaria viridis* bilobate (x) *Setaria viridis* bilobates and cross types.

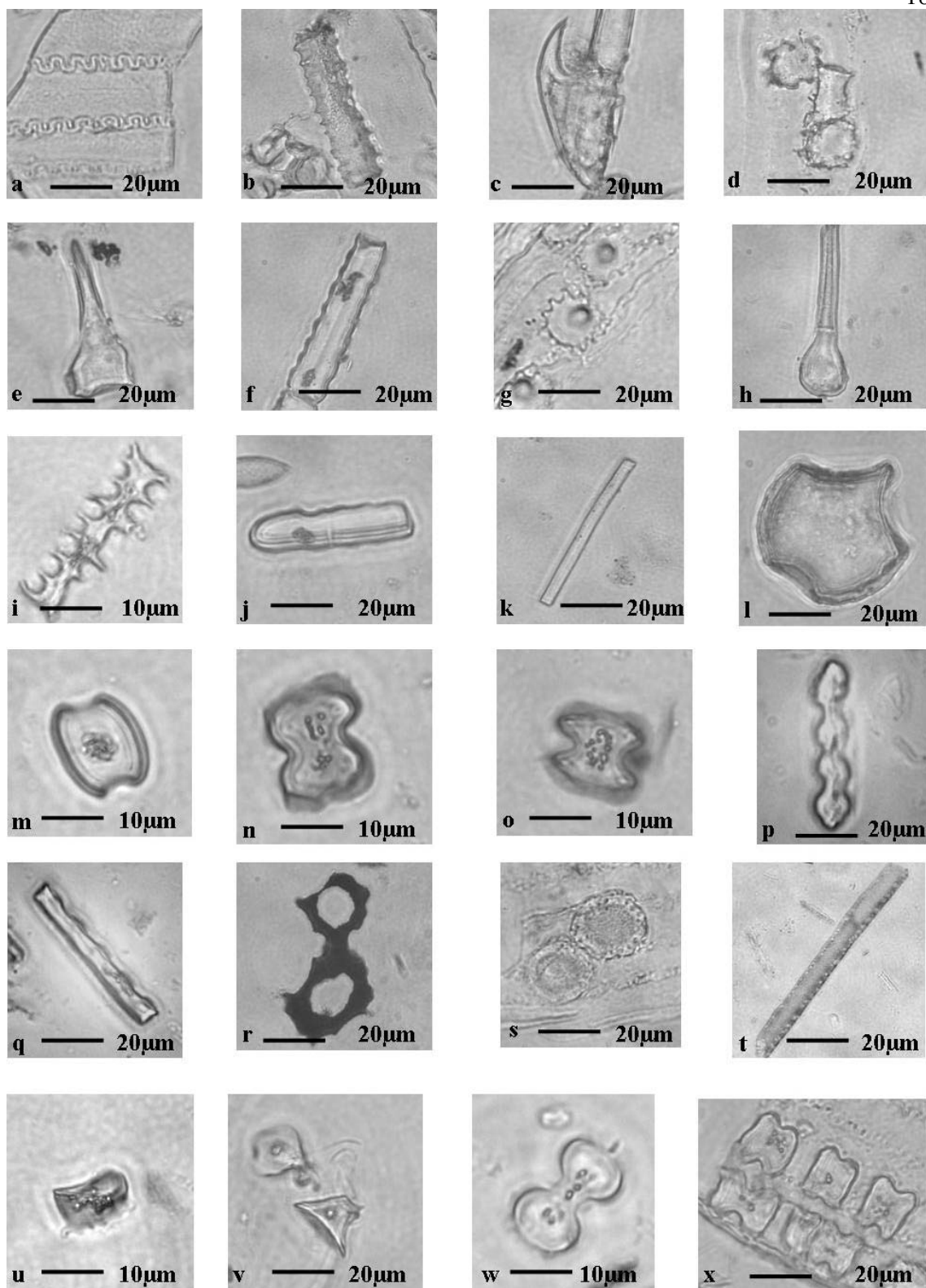


Plate V. Light micrographs of introduced grass morphotypes.

CHAPTER 5

DEVELOPING AN APPROACH FOR USING THE SOIL PHYTOLITH RECORD TO
INFER VEGETATION AND DISTURBANCE REGIME CHANGES
OVER THE PAST 200 YEARS¹

Abstract

Historical ecology is a field of research that seeks to explain how ecosystem change is manifest upon the landscape over time. This interdisciplinary synthesis of information draws from the human and the biological archive. Historical ecology helps characterize reference conditions and the historic range of variability in ecosystem structure that is useful in understanding ecosystem dynamics and function, provides input to resource managers, and guides restoration efforts. The methods in historical ecology cover a wide range of temporal and spatial scales. However, the evidence for time scales of less than 200 years is largely limited to the human archive and dendrochronology. Additional approaches for this more recent time period could provide important information for understanding the vegetation changes in the past 200 years especially where dendrochronology is not applicable. This research seeks to expand the biological evidence for inferring vegetation and disturbance regime changes in the Western United States since settlement in the 1800s by developing an approach that combines the human archive and soil phytolith analysis. We examined the human archive for vegetation and disturbance regimes change in the City of Rocks National Reserve, Idaho, US. In addition, we examined the phytoliths of native and introduced species in the area and looked at how well the soil phytolith record reflects recent wildfires. Our results indicate

¹ Coauthored by Lesley R. Morris, Neil E. West, Fred A. Baker, Helga Van Miegroet, and Ronald J. Ryel.

that this combination of history and soil phytolith analysis will be a useful approach for inferring vegetation and disturbance change in ecological histories.

Introduction

Across the Intermountain West of the United States, land management agencies are struggling with the issues of landscape change. In the Great Basin region, woody species are reported to be increasing in dominance at the expense of the grass and herbaceous understory in both sagebrush steppe (Miller et al., 1994) and pinyon-juniper woodlands (West and Young, 2000). Changes in ecosystem function, such as water relations (Ryel et al. 2003, 2004; Brown et al., 2005; Ponton et al., 2006), may also be affected. Invasive plant species, such as annual grasses, are further altering landscape dynamics (Miller et al., 1994) and many question the causes of what seem to be increasingly frequent and devastating wildfires (Miller and Tausch, 2001). Land managers often seek information about the past to understand how to manage for the future (Swetnam et al., 1999). In addition, knowledge of past plant community assemblages and historic dynamics are important for ecologists in studying ecosystem function.

Historical ecology is an emerging and interdisciplinary field of study that seeks to describe and explain the changes and processes that have created current landscapes through a synthesis of information derived from human records and biological data (Russell, 1997). The resulting ecological histories of landscapes provide an understanding of historic conditions, the range of variability and “reference conditions” that are particularly useful in restoration efforts (Egan and Howell, 2001) and for setting

management priorities and goals (Swetnam et al., 1999). Historical ecology requires synthesis of information from the human and biological archives. The human archive records historic conditions within written, oral and photographic sources. The biological archive is the record of historic conditions contained within the natural environment and is investigated through dendrochronology, packrat middens, palynology and soil phytolith analysis. The methods in historical ecology cover a wide range of temporal and spatial scales. However, the methods for time scales less than 200 years are largely limited to the human archive and some dendrochronological evidence that may be subject to human bias, limited in spatial extent or inappropriate for non-forested systems.

The goal of this research was to develop an approach that expands the biological evidence for inferring vegetation and disturbance regime change within the past 200 years by exploring ways in which the combination of the human archive and soil phytolith analysis can address these issues. We examined this combination of human and biological evidence at a site in the western US with a rich human archive by addressing three broad questions: (1) How have the vegetation and the disturbance regimes in the study area changed within the past 200 years? (2) Are there characteristic phytolith types for dominant Great Basin native and introduced flora? (3) How well does the soil phytolith record reflect recent wildland fire? Using the results from these three questions, we present an evaluation of the potential for this approach to provide additional biological evidence in historical ecology for more recent time scales.

The need for expanding the methodology

The human archive can be very useful for illustrating changes in historic conditions over time. Use of written, oral and photographic evidence often reveals amazing changes and their potential causes. For example, historic records from the General Land Office surveys that laid out the township and range boundaries systematically across the western US in the mid 1800s is a rich source of vegetation description (Galatowitsch, 1990). Oral histories reveal land and resource uses that were otherwise unrecorded or poorly understood. Finally, photographic evidence offers some of the clearest evidence for exactly what the land looked like at a particular point in time. Each of these sources, however, has limitations. Both written and oral documentation are subject to a cultural filter or bias (Edmonds, 2001; Swetnam et al., 1999). For example, often only vegetation and wildlife that are of economic value are described. Photographic evidence is also subject to bias because people record what is of interest at a particular time. Photographs are also spatially limited (Swetnam et al., 1999). Efforts to counteract these limitations by examining the biological archive are constrained by the available methodology. Dendrochronology is the most widely employed tool, but it is largely limited to forested systems. Examining pollen or phytoliths deposited in lakes is of limited use in the drier regions of the Intermountain West. In addition, lake sediments represent regional rather than local patterns.

Part of the problem with using biological evidence in the recent past is the lack of a sufficient dating technique. Paleoecological evidence of historic vegetation is well developed for much of the West including the Great Basin (Grayson, 1993). The biological evidence from the deep past from dendroecology, packrat middens, palynology

and phytoliths is corroborated by the use of radio carbon dating. Use of this biological evidence for determining more recent vegetation change, however, has been limited by the fact that radio carbon dating is less exact for the past 400 years (Rhode, 2001). Several relatively new methods involving the use of lead (^{210}Pb) and Cesium (^{137}Cs) have been used for dating sediments within the past 150 years from lakes and wetlands (Slate and Stevenson, 2000). These chronological methods, however, have not been developed for terrestrial soils. As a result, there are gaps in methods and biological evidence for reconstructing vegetation change in the more recent past from terrestrial soils. Understanding the changes during this time period is an important scientific task because it would reveal pre-settlement conditions, effects of the “Little Ice Age” and novel land uses brought by the European settlers in the western US (Rhode, 2001).

Soil phytolith analysis also needs further development. Phytolith analysis is limited by a lack of catalogued phytoliths and a need to relate historic soil phytolith assemblages to modern day analogs (Fredlund, 2001; Piperno, 1988; Piperno, 2006) particularly in North America (Blinnikov, 2005). Phytoliths have been catalogued at the community level in ponderosa pine forests (Kerns, 2001a) and at the regional level in the Pacific Northwest (Blinnikov, 2005). While some species described in these studies overlap with the Great Basin, there is no full examination of this region’s most dominant species. In addition, no one has examined and catalogued phytoliths of this region’s introduced species. Phytolith morphotypes from introduced species may provide a key to interpreting the stratigraphy in the soil because the timeframe of their introduction is known. For instance, phytolith morphotypes common in the invasive cheatgrass (*Bromus tectorum*) were considered as evidence of “the arrival of the Euro-American settlers”

(Blinnikov et al., 2002; Blinnikov 2005). Kealhofer (1996) applied agricultural weed phytoliths in her study of human and environmental interactions in Thailand. However, no one has further explored the potential morphotypes or applications of introduced species to provide time context in the soil stratigraphy in the US. Such an application would open up the field of phytolith analysis to interpretation of the more recent past. In addition, it would aide in identifying areas with disturbances to the soil profile from animal burrows or frost heaving that may have mixed the phytolith record.

A lack of fire scars creates difficulty in inferring fire regimes in pinyon-juniper and sagebrush steppe ecosystems (Baker and Shinneman, 2004; Mensing et al., 2006). Pinyon-juniper woodlands provide only limited fire scar records because most of the trees are killed by fire (Miller and Tausch, 2001). Thus, it is uncertain whether low severity fires were really a part of this system, if fire maintained open woodlands, or if stand replacing fires prevented woodlands from encroaching down slope (Baker and Shinneman, 2004). Therefore, dendrochronology alone does not provide a full picture of the fire in these systems.

Phytoliths have been used to infer historic fires in several studies outside of the US including Thailand (Kealhofer, 1996), Panama (Piperno, 1994), South Africa (Schiegl et al., 2004), and Canada (Boyd, 2002). Discoloration or darkening occurs during occlusion of carbon or oxidation of the phytoliths during a fire (Parr, 2006). In addition, fire darkens the silica aggregates (amorphous silica substances) found in wood ash (Schiegl et al., 2004). By comparing the percent of light versus dark phytoliths, or Burned Phytolith Index (BPI), in surface and buried A horizons, Boyd (2002) inferred

higher fire frequency in Holocene grasslands than in the present. This method has not been tested in a modern day analogue study or in a wildland context in the US.

Regional setting

Study area

The City of Rocks National Reserve (CIRO) contains approximately 5,800 ha of the northern Great Basin Desert Region in south central Idaho in the western US (Figure 5-1). The elevation ranges from 1,646 meters in the valley floors to 2,702 meters on Graham Peak (Daugherty, 1988). The vegetation includes sagebrush steppe, pinyon-juniper woodlands, mountain mahogany chaparral, and limber pine forest with riparian habitat traversing all of these zones. There are approximately 75 to 95 frost free days (Soil Conservation Service, 1994). The mean annual precipitation is 276 mm (Morris, 2006a). Temperatures in this region can be highly variable. The annual mean temperature is 9° C with extremes of 41° C and -33° C (Morris, 2006a). The Northwestern Shoshoni Native Americans historically used the area for fall pinyon nut harvesting and hunting prior to European settlement (Chance, 1989). The CIRO contains segments of both the California Trail and the Salt Lake Alternate route from the era of overland emigration (1843-1869) in the US (HRA, 1996). Homesteads and dryland farming were active in CIRO until the droughts of the 1920s when failing springs and crops forced many settlers off the land (HRA, 1996). These historic uses provide a rich human archive for examining historical environmental conditions.

Materials and methods

This project required two phases. The first phase involved gathering information from the human archive by collecting and examining written and oral documentation of historic conditions. The second phase involved examining the biological archive by looking at the phytoliths generated by the local flora and combining history with phytolith analysis.

The human archive

Information regarding historic conditions was collected from archival sources, emigrant diaries, oral histories, fire records and historic photography. A comprehensive review of archival documents was undertaken to collect any available information concerning historic environmental conditions within the CIRO and the surrounding area. Existing oral histories were gathered and more than 30 interviews were conducted with longtime residents of the area. Discussion focused upon what the participant remembered or had been told about the historic environmental conditions within the CIRO. A collection of 100 emigrant diaries were examined for references to vegetation, fauna, fire and climatic conditions of the area. More than 100 historic photos of the CIRO were also collected and more than 60 of these photos were retaken from the same vantage point (re-photography).

A fire history of the CIRO was compiled and mapped from existing studies and historic fire reports from land management agencies. Previously digitized fire history records were obtained from the US Department of Agriculture Forest Service and the US Department of Interior Bureau of Land Management. Information was also gathered

concerning fire from archival documents searches, emigrant diaries, oral histories and historical photographs. When historical fire reports or records contained maps of fires, they were digitized on screen. A digital map of all such fires was created in ArcView/GIS 3.3. (ESRI, Redlands, CA, USA).

The biological archive

Characteristic phytoliths of Great Basin native and introduced flora

A modern reference collection was made of extant plants from the study area and region. Identification of the plants to species will be confirmed by and housed at the Intermountain Herbarium at Utah State University. Phytoliths from these plants were extracted using modified dry ashing techniques outlined in Pearsall (2000) and Kerns (2001a). Portions of the plant (e.g. leaf, stem and seed) were washed in deionized water to remove soil and dust particles, dried at 70° C for one hour to remove excess water and then heated to 450° C for five hours in a muffle furnace. The remaining ash was placed in vials and coded to its respective plant species. A small amount of the ash from each plant was mounted on microscopic slides in Canada Balsam oil and sealed with clear fingernail polish. Each slide was examined using an Olympus BH-2 phase contrast microscope with microphotograph capability. Phytoliths are described and classified using the International Code for Phytolith Nomenclature (Madella et al., 2005). In addition to examining the different parts of the plant (e.g. leaves, stems and seeds) we also examined the galls formed on *Juniperus osteosperma* for identifiable phytoliths. This was done assuming that a novel form of tissue may produce a novel morphotype.

Soil sampling and phytolith extraction

Six soil sampling sites were located using the mapped historical information gathered from the human archive. In addition to fires, historical land uses such as homesteads, dryland farming, and range improvement projects were digitized onto a map of the study area using ArcView/GIS to ensure that sample locations have had a relatively stable soil profile during the time frame of interest (e.g. untilled). Sampling locations included areas that were known to have burned in 2000 (three sites) and were known to have not burned in the last 100 years (three sites). Soil surface samples were collected from these sites in May and June, 2006.

Phytoliths were extracted from the soils using modified wet oxidation and heavy liquid flotation methods (Blinnikov, 1994; Pearsall, 2000). Approximately 5 g of soil was obtained through a #270 (52 μm) sieve and organics were digested using a heated 70% nitric acid bath for at least one hour. Defloculation was carried out using a 5% solution of sodium hexametaphosphate. A heavy liquid flotation with sodium polytungstate at 2.3 g/cm^3 density was used to remove phytoliths from the remaining material. The entire supernatant was decanted and phytoliths were sunk by adding distilled water at a ratio of three to one and centrifuging. This material was then washed, poured into vials and dried for twenty four hours at 65-80° C.

Phytolith counting

The dried phytolith material was mixed well inside the vials to ensure homogeneity within each sample. Using a dissecting needle, a small sample of the phytolith material was tapped onto a microscope slide. One drop of Canada Balsam oil

was added and mixed well using the same dissecting needle. After the mixed liquid spread across the entire cover slip, the slides were examined under a microscope. One hundred phytoliths were counted under 400x magnification from the center left and then center right of each slide for a total count of 200. The percentage of dark versus clear phytoliths and soil aggregates per 100 counted were averaged to generate the BPI for each sample site. The BPI here included all dark phytoliths and dark soil aggregates, a divergence from Boyd (2002) who only counted long cells from grasses.

Results

Historical vegetation and disturbance changes

The evidence from the human archive revealed several important changes in the vegetation and disturbance regimes of the CIRO since settlement. First, overall plant diversity in the valleys has decreased. The most striking evidence of this decline can be found in historic photographs. The earliest photo of the CIRO was taken in 1868 by Timothy O'Sullivan as part of the King Survey of the 40th parallel in the western US (US-NARA, 1868). These images show that the valley floor once supported multiple species of grasses, forbs and shrubs. Compared to a repeat photo from today, these same sites now consist of mainly sagebrush and crested wheatgrass. The change in the valley vegetation was likely due to the overlapping impacts of heavy livestock grazing in the late 1800s, land clearing during the dry-farming boom of the early 1900s, and cultivation of crested wheatgrass (*Agropyron desertorum*) after World War II in an effort to increase forage production, and multiple periods of drought.

Second, woody species have increased throughout the entire study area.

Descriptions from emigrant diaries and the field notes from the General Land Office surveys report that the pinyon-juniper woodlands have moved further down slope than they were in the past. In addition, oral histories and historical photos confirm that the both the woodlands and the forests have much higher tree density and cover than they did in the past. These same records show that sagebrush density and cover also increased in the valleys. In most areas, the rise in woody vegetation has come at the expense of native grasses and forbs. Causes for this increase in woody vegetation potentially include fire suppression policies in the last 100 years, heavy livestock grazing, multiple periods of drought, overall temperature increase and precipitation decrease and plant competition.

Finally, there has been an increase in the number and cover of non-native plant species in the study area. The human archive reveals that non-native plants were introduced to the CIRO both intentionally and unintentionally. Agricultural development and livestock grazing are both primary sources of introduction because of accompanying land disturbance for cultivation, seed and feed contamination, and seed spread on fur and dung of livestock. The spread of several of these introduced plant species has also been aided by recent fires in the area (e.g. *Bromus tectorum*). The fire regimes for the sagebrush steppe and pinyon-juniper woodlands have likely been altered by federal land agency fire suppression policies. In addition, fires have increased in both the size and intensity over the past 100 years. This is likely due to a combination of the fuel loads that accompany increasing density of woody species and climate change. Additional results from the human archive review and fire history are included in Morris (2006a, b).

*Characteristic phytoliths of Great Basin
native and introduced flora*

Sixty five common Great Basin species from 22 different families have been dry-ashed and examined under the microscope. This reference collection consisted of: 10 grass species, 10 tree and shrub species (Table 5-1) and 45 forbs (Table 5-2). Of these, 22 were introduced species. Almost all of the species examined demonstrated at least some silicification. Most of phytoliths were partially darkened from the burning in the muffle furnace. Consistent with the literature, the grasses formed the most phytoliths and many recognizable phytolith morphotypes. One of the ten processed grasses, *Achnatherum hymenoides*, formed a bilobate (or stipa-type) phytolith. Two others, *Acnatherum nevadensis* and *Hesperostipa comata*, formed trapeziform polylobates. Trees and shrubs formed cubic, parallelepipedal, and globular morphotypes. There was no unique phytolith formed in the gall tissue of *J. osteosperma*.

Several unique and potentially diagnostic phytoliths were discovered among the forbs. The most spectacular of these came from *Alyssum desertorum*, an introduced annual mustard that has spread across the western US. The leaves, stems and seeds of this species are covered with stellate granulate hairs that make recognizable phytoliths (Figure 5-2). These stellate granulate hairs range from 250-500 μm and are quite large in comparison to other phytoliths. No similar hairs were found on any of the other mustards or other forbs examined. It is possible, therefore, that this very interesting shape could provide a diagnostic morphotypes for the species (at least in this study area). In addition, there were several other species that produced distinct hairs and hair bases. For example, *Erigeron divergens* produced large (200-500 μm) segmented hairs with three and

sometimes more sections (Figure 5-3a). *Mertensia oblongifolia* makes many ovate irregular hair bases and acicular psilate hair cells (Figure 5-3b).

Modern day fire analogs

Darkened phytoliths and silica aggregates appear to reflect recent wildland fires. On average, the three sites that had burned in 2000 (“burned sites”) had a 38% BPI while the three sites that had not burned within the last 100 years (“unburned sites”) had a 17% BPI (Figure 5-4). The BPI varied from 30% to 49% at burned sites (Figure 5-4). At unburned sites, the BPI ranged between 10% to 22% (Figure 5-4).

Discussion

Historical vegetation and disturbance changes

In the two-phase research design applied here, the first step necessarily informed the second. The human archive provided information about change and disturbance that was useful for determining sampling sites and ensuring that these locations have had a relatively stable soil profile during the time frame of interest (e.g. untilled land). In addition, the human archive revealed vegetation changes that can be used to further test combinations of history and soil phytolith analysis. For example, frequency diagrams can be created to test the sensitivity of the soil phytolith stratigraphy to record such events over the past 200 years using the morphotypes of native grasses, non-native species and woody vegetation described here. The relative frequency of introduced species phytolith morphotypes should decrease with depth in the soil profile. Conversely, the relative frequency of grass and forb phytolith morphotypes should increase while

woody morphotypes decrease with depth in the soil profile as a reflection of higher grass cover and diversity in the past. Kerns (2001b) found higher frequencies of grass morphotypes in subsurface samples from species that were not common in her plots in the present. This suggests that the phytolith record may in fact be sensitive enough to record changes such as those found here.

Soil phytolith analysis has the potential to provide much needed biological evidence in historical ecology for the more recent past. Its sensitivity as a record for the past 200 years can be tested by sampling in locations where vegetation change is known to have occurred based on human records. Similarly, the combination of historical information and dendrochronology can be used to test whether soil phytolith analysis can provide useful insight into the occurrence of fire in pinyon-juniper woodlands and sagebrush steppe. The site at the CIRO is an excellent location for developing these sensitivity tests. The CIRO has a very long and well recorded history from European emigration and settlement in the mid-1800s to present. After recognizing the known historic changes within the phytolith record, soil phytolith analysis can be expanded in future research to help understand historic changes that were not identified in the human archive.

*Characteristic phytoliths in Great Basin
native and introduced flora*

This examination of potential characteristic phytoliths has begun to fill the need for a catalogue of morphotypes in the native and introduced flora of the Great Basin. The stellate hair found in the *Alyssum desertorum* is a potential diagnostic phytolith for this species in the study area. According to Khalik (2005), this particular form of trichome is

only found in the genera *Alyssum*, *Anastatica*, *Eremobium*, and in the species *Maresia nana*, and *Morettia canescens*. None of these other genera or species is present in the study area (John, 1995). *Alyssum desertorum* was introduced nearly a century ago and has apparently experienced a population and range explosion in the last few decades (Young and Clements, 2005). The unique stellate granulate hair from this species did not show up in any of the surface samples used for the modern day fire study. However, its size would have precluded it from inclusion due to sieving process used in this work. Typically, phytoliths range in size from 50-200 microns (Pearsall, 2000). The relatively large hairs from the other forbs were not found in the surface soil samples presumably for the same reasons. More exploration using an adapted methodology for larger phytoliths (up to 500 microns) is needed to determine if this unique phytolith will be useful within the soil phytolith assemblage.

The bilobate and trapeziform polylobate phytoliths found in the grasses will be useful for addressing hypotheses about vegetation change in the study area. Both of these native grasses have reportedly decreased over time due to livestock grazing pressure and replacement by non-native species (Morris, 2006a). In addition, the hair morphotypes associated with forbs of the sagebrush steppe may also be useful for tracking vegetation changes. The morphotypes from woody species may also be useful for tracking shrub and woodland encroachment into the valleys of the study area. Further testing on the woody morphotypes described here will be useful to determine if they are silica rather than calcium oxalate phytoliths. Silica phytoliths are better preserved in soils and would provide a longer record. Woody species have been reported to make useful cubic,

parallelepipedal, and globular morphotypes in other studies (Albert et al., 2001, 2003; Kondo et al., 1994; Piperno, 2006).

Modern day fire analogues

These results indicate that darkening in phytoliths and silica aggregates reflect modern fires and, therefore, may be a useful tool for identifying historic fires within the soil profile in this region. However, since the BPI of both burned and unburned sites is still relatively close, more areas need to be examined to assess the reliability of this index. There is relatively little known about the area of vegetation that the soil phytolith assemblage represents, however, some have estimated that it incorporates about one hectare of plant phytolith inputs (Blinnikov et al., 2002). It is possible that the relatively close range in BPI between sites is due to area of phytolith re-distribution and the inability of a site to retain all its microfossils. For example, a recently burned site has greater potential for wind and water borne soil erosion because of the sudden loss of vegetation. An unburned site nearby may contain a relatively higher BPI because phytoliths were deposited there during the fire event and were retained more readily in the soils by the stability offered from resident vegetation. In addition, the heat intensity, size of the fire, windspeed, and topography will all impact the size of fire particulates and the distance they can travel (Komarek et al., 1973). White ashed materials may fall closer to the ground after short distances because they are not “aerodynamic” but charcoal particulates have been observed over one-half mile from a fire (Komarek et al., 1973).

Conclusion

This research seeks to fill the gap in biological evidence for inferring vegetation and disturbance regime change over the past 200 years by developing an approach that combines the human archive evidence with the soil phytolith record to address these issues. Our examination of the human archive demonstrated that the vegetation and disturbance regimes have changed significantly during the period of study and that this knowledge will be useful for testing the sensitivity of the soil phytolith record to reflect these changes. Our results also demonstrate that there are potentially diagnostic phytoliths in introduced species (such as *Alyssum desertorum*) that may be useful as time markers for recent soil profiles. In addition, morphotypes from the native grasses and woody species will be useful in testing for vegetation changes in the study area due to changing disturbance regimes (e.g. livestock grazing), cultivation and competition from invasive plants. The results from the modern day fire analogues show that a BPI which includes darkened phytoliths and soil aggregates can distinguish between areas that burned recently and those that have not burned in at least 100 years. Developing this approach for expanding biological evidence will be beneficial for understanding sagebrush steppe and pinyon-juniper woodlands, two widespread and highly threatened systems in the Intermountain West of the US (West, 1983, 1999). The approach can be adapted to examine a variety of questions about vegetation and disturbance regime change in other systems as well.

References

- Albert, R.M., Weiner, S., 2001. Study of phytoliths in prehistoric ash layers using a quantitative approach. In: Meunier, J.D., Colin, F. (Eds.), *Phytoliths, Applications in Earth Science and Human History*. A.A. Balkema Publishers, Lisse, pp. 251-266.
- Albert, R.M., Bar-Yosef, O., Meignen, L., Weiner, S., 2003. Quantitative phytolith study of Hearths from the Natufian and middle palaeolith levels of Hayonim Cave (Galilee, Israel). *Journal of Archaeological Science* 30, 461-480.
- Baker, W.L., Shinneman, D.J., 2004. Fire and restoration in piñon-juniper woodlands in the western United States: a review. *Forest Ecology and Management* 189, 1-21.
- Blinnikov, M.S., 1994. Phytolith analysis and Holocene dynamics of alpine vegetation In: Onipchenko, V.G., Blinnikov, M.S. (Eds.), *Experimental investigation of alpine plant communities in the north-western Caucasus*. Veröffentlichungen des Geobotanischen Institutes der ETH, Stiftung Rubel, Zurich, pp. 23-40.
- Blinnikov, M.S., 2005. Phytoliths in plants and soils of the interior Pacific Northwest, USA. *Review of Palaeobotany & Palynology* 135, 71-98.
- Blinnikov, M.S., Busacca, A., Whitlock, C., 2002. Reconstruction of late Pleistocene grassland of the Columbia basin, Washington, USA, based on phytolith records in loess. *Palaeogeography, Palaeoclimatology, Palaeoecology* 177, 77-101.
- Boyd, M., 2002. Identification of anthropogenic burning in the palaeoecologic record of the Northern Prairies: a new approach. *Annals of the Association of American Geographers* 92, 471-487.
- Brown, A.E., Zhang, L., McMahon, T.A., Western, A.W., Vertessy, R.A., 2005. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Forest Hydrology* 310, 28-61.
- Chance, D.H., 1989. *The Tubaduka and the Kamuduka Shoshoni of the City of Rocks and Surrounding Country*. National Park Service Pacific West Field Area Columbia-Cascade System Support Office Seattle, Washington.
- Daugherty, R.E., 1988. *Legislative land cost estimate for City of Rocks National Reserve Cassia County, Idaho*. National Park Service Pacific Northwest Region, Seattle, Washington.
- Edmonds, M., 2001. Oral history: a guide to its creation and use. In: Egan, D., Howell, E.A. (Eds.), *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*. Island Press, Washington, DC, pp. 73-99.

- Egan, D., Howell, E.A., 2001. *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*. Island Press, Washington, DC.
- Fredlund, G.G., 2001. Inferring vegetation history from phytoliths. In: Egan, D., Howell, E.A. (Eds.), *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*. Island Press, Washington, DC, pp. 335-362.
- Galatowitsch, S.M., 1990. Using the original land survey notes to reconstruct presettlement landscapes in the American West. *Great Basin Naturalist* 50, 181-191.
- Grayson, D.K., 1993. *The Desert's Past: A Natural Prehistory of the Great Basin*. Smithsonian Institution Press, Washington, DC.
- Historical Research Associates (HRA), 1996. *Historic Resources Study: City of Rocks National Reserve Southcentral, Idaho*. National Park Service Pacific West Field Area Columbia-Cascade System Support Office, Seattle, Washington.
- John, T., 1995. Vascular plants of City of Rocks: An annotated checklist. National Parks Service, on file at the City of Rocks National Reserve.
- Kealhofer, L., 1996. The human environment during the terminal Pleistocene and Holocene in Northeastern Thailand: phytolith evidence from Lake Kumphawapi. *Asian Perspectives* 35, 229-254.
- Kerns, B.K., 2001a. Diagnostic phytoliths for a ponderosa pine-bunchgrass community near Flagstaff, Arizona. *The Southwestern Naturalist* 46, 282-294.
- Kerns, B.K., Moore, M.M, Hart, S.C., 2001b. Estimating forest-grassland dynamics using soil phytolith assemblages and $\delta^{13}\text{C}$ of soil organic matter. *Ecoscience* 8 (4), 478-488.
- Khalik, K.A., 2005. Morphological studies on trichomes of Brassicaceae in Egypt and taxonomic significance. *Acta Botanica Croatica* 64, 57-73.
- Komarek, E.V., Komarek, B.B., Carlisle, T.C., 1973. *The Ecology of smoke Particulates and Charcoal Residues from Forest and Grassland Fires: A Preliminary Atlas*. Miscellaneous publication Number 3, Tallahassee, Florida.
- Kondo, R., Childs, C., Atkinson, I., 1994. *Opal Phytoliths of New Zealand*. Manaaki Whenua Press, New Zealand.
- Madella, M., Alexandre, A., Ball, T., 2005. International code of phytolith nomenclature 1.0. *Annals of Botany* 96, 253-260.

- Mensing, S., Livingston, S., Barker, P., 2006. Long-term fire history in Great Basin sagebrush reconstructed from macroscopic charcoal in spring sediments. Newark Valley, Nevada. *Western North American Naturalist* 66, 64-77.
- Miller, R.F., Tausch, R.J., 2001. The role of fire in juniper and pinyon woodlands: a descriptive analysis. In: Galley, K.E.M., Wilson, T.P. (Eds.), *Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species, Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management*, Miscellaneous publication No. 11, Tall Timbers Research Station, Tallahassee, Florida, pp. 15-30.
- Miller, R.F., Svejcar, T.J., West, N.E., 1994. Implications of livestock grazing in the Intermountain sagebrush region: plant composition. In: Vavra, M., Laycock, W.A., Pieper, R.D. (Eds.), *Ecological Implications of Livestock Herbivory in the West*, Society for Range Management Publications, Denver, Colorado, pp. 101-146.
- Morris, L., 2006a. *Ecological History of the City of Rocks National Reserve, Part I: The Human Archive*. City of Rocks National Reserve, National Park Service Pacific Northwest Region, Seattle, Washington.
- Morris, L., 2006b. *Fire History of the City of Rocks National Reserve from 1926 to 2005*. City of Rocks National Reserve, National Park Service Pacific Northwest Region, Seattle, Washington.
- Parr, J.F., 2006. Effect of fire on phytolith coloration. *Geoarchaeology: An International Journal* 21, 171-185
- Pearsall, D.M., 2000. *Paleoethnobotany: A Handbook of Procedures*, second ed. Academic Press, San Diego.
- Piperno, D.R., 1994. Phytolith and charcoal evidence for prehistoric slash-and-burn agriculture in the Darien rain forest of Panama. *The Holocene* 4, 321-325.
- Piperno, D.R. 1988. *Phytolith Analysis: An Archaeological and Geological Perspective*. Academic Press, San Diego, CA.
- Piperno, D.R. 2006. *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists*. AltaMira Press, Lanham, MD.
- Ponton, S., Flanagan, L.B., Alstad, K.P., Johnson, B.G., Morgenstern, K., Kljun, N., Black, T.A., Barr, A.G., 2006. Comparison of ecosystem water-use efficiency among Douglas-fir forest, aspen forest and grassland using eddy covariance and carbon isotope techniques. *Global Change Biology* 12, 294-310.

- Rhode, D. 2001. Packrat middens as a tool for reconstructing historic ecosystems. In: Egan, D., Howell, E.A. (Eds.), *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*. Island Press, Washington, DC, pp. 257-294.
- Russell, E.W.B., 1997. *People and the Land through Time: Linking Ecology and History*. Yale University Press, New Haven.
- Ryel, R.J., Caldwell, M.M., Leffler, A.J., Yoder, C.K., 2003. Rapid soil moisture recharge to depth by roots in a stand of *Artemisia tridentata*. *Ecology* 84, 757-764.
- Ryel, R.J., Leffler, A.J., Peek, M.S., Ivans, C.Y., Caldwell, M.M., 2004. Water conservation in *Artemisia tridentata* through redistribution of precipitation. *Oecologia* 141, 335-345.
- Schiegl, S., Stockhammer, P., Scott, C., Wadley, L., 2004. A mineralogical and phytolith study of the middle stone age hearths in Sibudu Cave, KwaZulu-Natal, South Africa. *South African Journal of Science* 100, 185-194.
- Slate, J.E., Stevenson, J., 2000. Recent and abrupt environmental change in the Florida Everglades indicated from siliceous microfossils. *Wetlands* 20, 346-356.
- Soil Conservation Service, 1994. *Soil Survey of Cassia County, Idaho, Eastern Part*. US Department of Agriculture.
- Swetnam, T.W., Allen, C.D., Betancourt, J.L., 1999. Applied historical ecology: Using the past to manage for the future. *Ecological Applications* 9, 1189-1206.
- United States National Archives and Records Administration (US-NARA), Photograph no. 77-KW-189, "City of Rocks, ID", 1868. Timothy O'Sullivan, Records of the U.S. Geological Survey, Record Group 57, National Archives at College Park, College Park, MD
- West, N.E., 1983. Western Intermountain sagebrush steppe. In: West, N.E. (Ed.), *Temperate Deserts and Semi-Deserts*. Elsevier Scientific Publishing Company, Amsterdam, pp. 351-374.
- West, N.E., 1999. Juniper-pinyon savannas and woodlands of western North America. In: Anderson, R.C., Fralish, J.S., Baskin, J.M. (Eds.), *Savannas, Barrens, and Rock Outcrop Plant Communities of North America*. Cambridge University Press, London, pp. 288-308.

West, N.E., Young, J.A., 2000. Intermountain valleys and lower mountain slopes. In: Barbour, M.G., Billings, W.D. (Eds.), *North American Terrestrial Vegetation*, second ed. Cambridge University Press, New York, pp. 351-374.

Young, J.A., Clements, C.D., 2005. Exotic and invasive herbaceous range weeds. *Rangelands* 27, 10-16.

Table 5-1 Common Grasses, Trees and Shrubs of the Great Basin analyzed for phytoliths.

Family	Common Name	Scientific Name
<u>Grasses</u>		
Poaceae	Indian ricegrass	<i>Achnatherum hymenoides</i>
	Needlegrass	<i>Achnatherum nevadensis</i>
	Needle and thread grass	<i>Hesperostipa comata</i>
	+Bulbous bluegrass	<i>Poa bulbosa</i>
	+Crested wheatgrass	<i>Agropyron desertorum</i>
	+Cheat grass	<i>Bromus tectorum</i>
	Kentucky bluegrass	<i>Poa pratensis</i>
	Bluebunch wheatgrass	<i>Pseudoregneria spicatum</i>
	Great Basin wild rye	<i>Leymus cineris</i>
	Squirrel tail	<i>Elymus elymoides</i>
<u>Trees/Shrubs</u>		
Asteraceae	Rabbit brush	<i>Chrysothamnus viscidiflorus</i>
	Big sagebrush	<i>Artemisia tridentata</i>
Caryophyllaceae	Snowberry	<i>Symphoricarpos oreophilus</i>
Cupressaceae	Utah juniper	<i>Juniperus osteosperma</i>
Rosaceae	Chokecherry	<i>Prunus virginiana</i>
	Mountain mahogany	<i>Cercocarpus ledifolius</i>
	Antelope bitterbrush	<i>Purshia tridentata</i>
	Wild rose	<i>Rosa woodsii</i>
Salicaceae	Yellow Willow	<i>Salix lutea</i>
Pinaceae	Pinyon pine	<i>Pinus monophylla</i>

+ non-native/introduced

Table 5-2 Common Forbs of the Great Basin analyzed for phytoliths.

Family	Common Name	Scientific Name
Apiaceae	Narrowleaf lomatium	<i>Lomatium triternatum</i>
Asteraceae	+Dandelion	<i>Taraxacum officinale</i>
	+Yellow salsify	<i>Tragopogon dubius</i>
	Arrowleaf balsamroot	<i>Balsamorhiza sagittata</i>
	Sawtooth gumweed	<i>Grindelia squarrosa</i>
	Yarrow	<i>Achillea millefolium</i>
	Mountain dandelion	<i>Agoseris glauca</i>
	White aster	<i>Erigeron plumilus</i>
	Spreading fleabane	<i>Erigeron divergens</i>
	+Canada thistle	<i>Cirsium arvense</i>
	Dusty maiden	<i>Chaenactis douglasii</i>
	Hoary aster	<i>Machaeranthera canescens</i>
	Pussytoes	<i>Antennaria microphylla</i>
Brassicaceae	+Clasping pepperweed	<i>Lepidium perfoliatum</i>
	+Tumble mustard	<i>Sisymbrium altissimum</i>
	+Purple mustard	<i>Chorispora tenella</i>
	+Desert Alyssum	<i>Alyssum desertorum</i>
	+Flixweed tansy mustard	<i>Descurainea sophia</i>
	Wall flower	<i>Erysimum asperum</i>
	+*Dyerswoad	<i>Isatis tinctoria</i>
Boraginaceae	Spotted forget-me-not	<i>Hackelia patans</i>
	+Forget-me-not	<i>Myosotis micrantha</i>
	+Catchweed	<i>Asperugo procumbens</i>
	Sagebrush bluebell	<i>Mertensia oblongifolia</i>
	Stoneseed	<i>Lithospermum ruderales</i>
Chenopodiaceae	+Russian thistle	<i>Salsola iberica</i>
Convolvulaceae	+Field bindweed	<i>Convolvulus arvensis</i>
Fabaceae	Silver lupine	<i>Lupinus argenteus</i>
	+Sweet clover	<i>Melilotus officinalis</i>
	Beckwith milkvetch	<i>Astragalus beckwithii</i>
Lilliaceae	Wild onion	<i>Allium brandegei</i>
	Death camas	<i>Zigadenus paniculatus</i>
Linaceae	Flax	<i>Linum lewisii</i>
Plantaginaceae	+Plantago	<i>Plantago lanceolata</i>
Polygonaceae	Cushion buckwheat	<i>Eriogonum ovalifolium</i>
	Buckwheat	<i>Eriogonum sp.</i>
Polemoniaceae	Carpet phlox	<i>Phlox hoodii</i>
	Longleaf phlox	<i>Phlox longifolia</i>
Malvaceae	Gooseberry-leaf mallow	<i>Sphaeralcea grossulariifolia</i>
Ranunculaceae	+Bur buttercup	<i>Ceratocephalus testiculatus</i>
	Larkspur	<i>Delphinium sp.</i>
Scrophulariaceae	Blue-eyed Mary	<i>Collinsia parviflora</i>
	Yellow paintbrush	<i>Castilleja flava</i>
	+Speedwell	<i>Veronica biloba</i>
Solonaceae	+Black henbane	<i>Hyoscyamus niger</i>

+ non-native/introduced *not found in the study area



Figure 5-1 Map of the western United States showing the Great Basin ecoregion boundaries and the location of the City of Rocks National Reserve in southern Idaho.

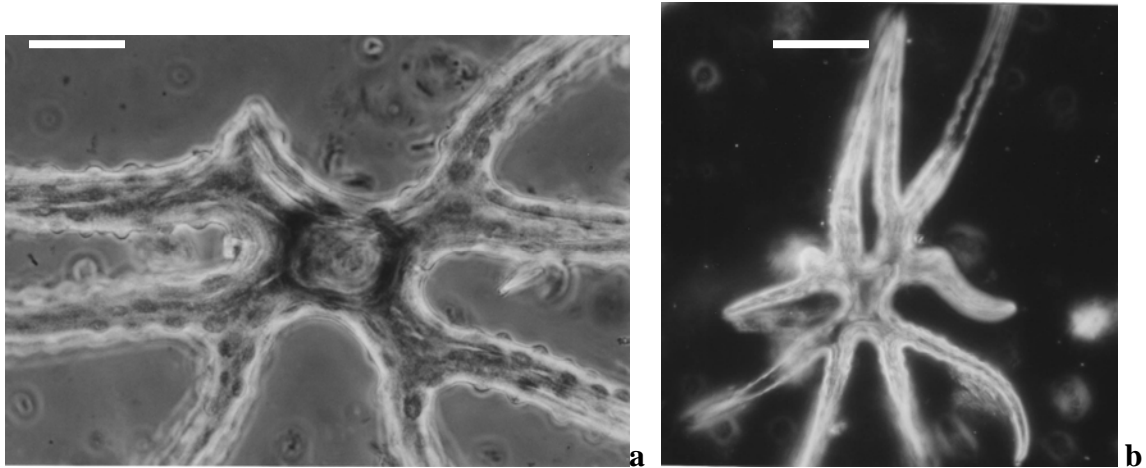


Figure 5-2 Phytoliths from *Alyssum desertorum* a) magnification 400x b) magnification 20x, bar is 20 μ m.

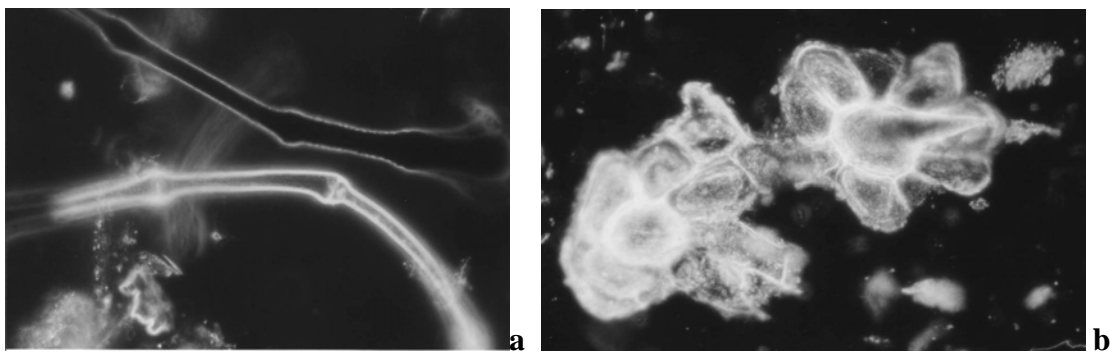


Figure 5-3 Phytoliths from a) *Erigeron divergens*, 400x and b) *Mertensia oblongifolia*, 400x.

Burned Phytolith Index (BPI)

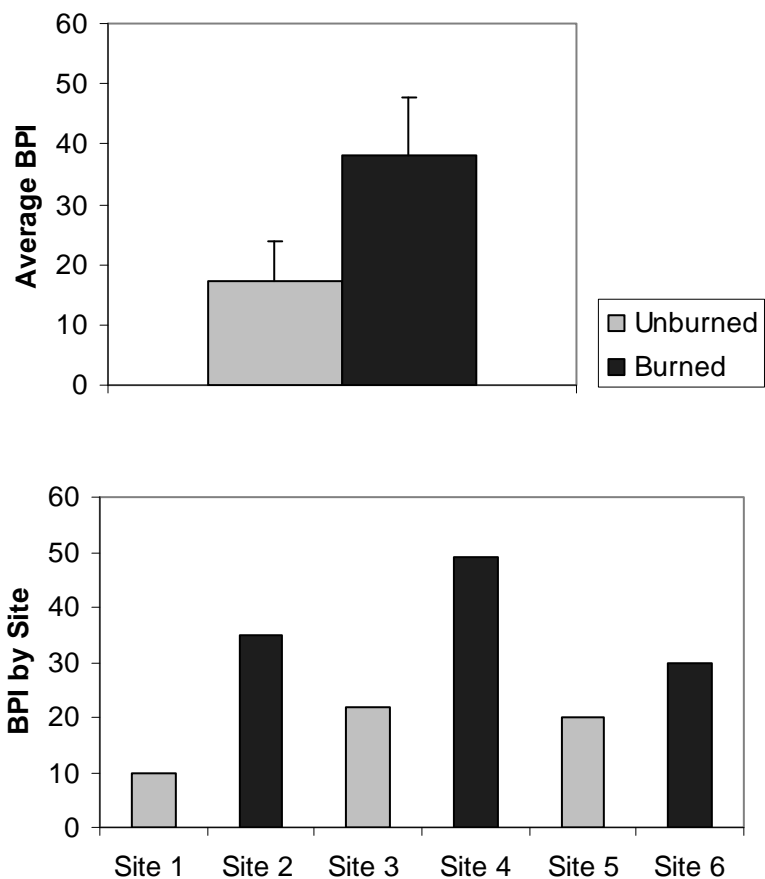


Figure 5-4 Results from the Burned Phytolith Index analysis. The bars represent standard error.

CHAPTER 6

CAN SOIL PHYTOLITH ANALYSIS AND CHARCOAL BE USED AS
INDICATORS OF HISTORIC FIRE IN THE PINYON-JUNIPER AND
SAGEBRUSH STEPPE ECOSYSTEM TYPES OF THE
GREAT BASIN DESERT REGION, USA?¹

Abstract

Wildland fire intensity and area are increasing across the Intermountain West, USA in a variety of ecosystem types including the pinyon-juniper woodlands and sagebrush steppe of the Great Basin Desert region. Unfortunately, we do not know if there were historic analogues for these high intensity stand replacing fires due to the lack of fire scars that record evidence of them. Soil charcoal and phytolith analysis have been successfully employed in other regions to garner information about fire regimes through the Holocene. We studied the utility and taphonomy of these methodologies in terrestrial soils in our region. Our results illustrated the difficulty of defining a clear taphonomy for phytoliths and microscopic charcoal in terrestrial sediments after a fire. However, the soils in these ecosystem types seem to be well stratified and contain both burned phytoliths and microscopic charcoal for examination. Soil-charcoal and phytolith analysis can be used to examine questions about historical fires in these two ecosystems of the Great Basin Desert region.

¹ Coauthored by Lesley R. Morris, Ronald J. Ryel, and Neil E. West.

Introduction

Across the Intermountain West of the United States, wildfires are believed to be increasing in size and intensity, attributed to historic land uses and climate (Westerling *et al.*, 2006). The ecosystem types of the Great Basin Desert region have not escaped this pattern. Both pinyon juniper woodlands and the sagebrush steppe have experienced a great deal of fire in recent decades (Miller and Tausch, 2001; Mensing *et al.*, 2006). It is unclear if these high severity fires were a part of the historic fire regime in this system (Baker and Shinneman, 2004). In addition to the size of these fires, the introduced annual grass *Bromus tectorum* has played a role in increasing the fire frequency, especially in the sagebrush steppe (Whisenant, 1990). Scientists and land managers need an historical context for fires in order to better understand them and make meaningful policy decisions (Gavin *et al.*, 2007).

Our understanding of the historic fire regimes in these two common ecosystem types of the Great Basin Desert region comes largely from indirect dendrochronological evidence of associated tree species (Miller and Rose, 1999; Miller and Tausch, 2001). Pinyon-juniper woodlands provide variable fire scar records because most of the trees are killed by fire (Miller and Tausch, 2001). This has raised questions about whether low severity fires were really a part of this system, if fire maintained open woodlands, or if stand replacing fires prevented woodlands from encroaching down slope (Baker and Shinneman, 2004). Similarly, fire in sagebrush steppe most often replaces the entire stand (Mensing *et al.*, 2006). Our understanding of fire regimes (Swetnam and Baisan, 1995) and the methods for inferring them in pinyon-juniper and sagebrush steppe need

further development due to lack of sufficient fire scars (Baker and Shinneman, 2004; Mensing *et al.*, 2006).

Sedimentary charcoal analysis has been used as a proxy for the study of historic fire regimes in a number of ecosystems where dendrochronological evidence may be limited and to extend the reference conditions beyond the life span of trees (Gavin *et al.*, 2007). Lacustrine sediments are the most common sources for charcoal analysis, and soil-charcoal is still a relatively new technique (Berg and Anderson, 2006). Several studies using soil-charcoal have been conducted in coastal temperate rain forest regions of Canada (Lertzman *et al.*, 2002; Gavin *et al.*, 2003; Sanborn *et al.*, 2006) Alaska (Berg and Anderson, 2006), in the northern ponderosa pine forests of the Western US in Idaho (Meyer and Pierce, 2003; Pierce *et al.*, 2004), the northern French Alps (Carcaillet, 1998) and in the Central Amazon Basin (Piperno and Becker, 1996). For the most part, these soil-charcoal studies have investigated macroscopic charcoal (>400 μm) in charcoal rich layers of the stratum and have used carbon dating of individual pieces of charcoal. This technique has not been examined in terrestrial soils from either the pinyon-juniper woodland or the sagebrush steppe ecosystems.

Phytoliths have been used to infer historic fires in several studies outside of the United States including Thailand (Kealhofer, 1996), Panama (Piperno, 1994), Brazil (Piperno and Becker, 1996) and Canada (Boyd 2002). Phytoliths can be darkened on the surface or by carbon inclusions that fill the cell as a result of fire (Boyd, 2002; Parr, 2006; Piperno, 2006). Phytoliths are often paired with charcoal and analyzed from samples of lacustrine sediments (Piperno, 1994, 2006). There are some, however, who have combined these methods in terrestrial soil sediments with success (Piperno and

Becker, 1996; Boyd, 2002). Piperno and Becker (1996) found soil phytolith analysis was a useful tool in the humid tropics. Boyd (2002) inferred higher fire frequency in Holocene grasslands by testing surface and buried A horizons. He compared the ratio of clear versus darkened phytoliths, or a Burned Phytolith Index (BPI).

Only one study has examined this BPI methodology using a modern day analogue in a wildland context in the United States (Morris *et al.*, in press). This study indicated that darkened phytoliths could be useful indicators of fire in pinyon-juniper woodlands and sagebrush steppe. While a body of literature addresses the distances and sizes of charcoal fragments for understanding regional versus local fire in lacustrine sediments (Clark and Hussey, 1996; Whitlock and Millspaugh, 1996) and some work has been done in soil sediments (Clark *et al.*, 1998; Ohlson and Tryterud, 2000; Eckmeier *et al.*, 2007), the taphonomy of phytoliths is still largely unknown. Albert *et al.* (2006) conducted one of the few taphonomic studies of phytoliths by comparing production in extant plants and preservation rates in differing soil types. They did not, however, include fire effects in their examination or model (Albert *et al.*, 2006). More work with microscopic charcoal and phytolith modern analogues is needed to better understand and interpret these fire proxy data in natural ecosystems in North America (Piperno, 2006).

In this study we explore the utility and taphonomy of these methodologies in terrestrial soils from pinyon-juniper woodlands and sagebrush steppe. We examined three questions: 1) Can soil charcoal and burned phytoliths be found in historic terrestrial sediments in these ecosystems? 2) How do soil charcoal and the darkened phytolith percentages vary with distance and depth from a known fire? 3) Can a known historic fire be detected within the soil stratigraphy on the site?

Study area

Our study area was located in the City of Rocks National Reserve in southcentral Idaho in the western US. This 5,800 ha Reserve sits at the northern edge of the Great Basin Desert region and contains both pinyon-juniper woodlands and sagebrush steppe. Elevations range from 1,646 m to 2,702 m (Daugherty, 1988). The Great Basin is known as a “cold desert” because it receives most of its precipitation as snow from winter storms (MacMahon, 1988). The Reserve averages 276 mm of precipitation a year with average temperatures of 9° C. However, temperature can be highly variable in this area with extremes from 41° C to -33° C (Morris, 2006a). The soils in the study area are classified as clayey-skeletal, montmorillonitic, frigid Typic and Lithic Argixerolls. The parent material is the alluvium and residuum of mica, schist and quartzite. The sampling sites were from three different soil mapping units including: Birchcreek-Itca complex, the Itca-Birchcreek complex and Poisonhol very stony loam (SCS, 1994).

Site selection

The City of Rocks has seen similar patterns of increasing size and intensity of wildfires as the rest of the Intermountain West (Morris, 2006b). Using a fire history for the City of Rocks National Reserve, we selected sampling sites that had burned in 1999 and 2000 (“burned sites”) and sites that had not burned within the last 100 years (“unburned sites”) (Morris, 2006b). A 2000 fire was the most recent and largest in the Reserve’s recorded history (Morris, 2006b). The fire started by lightning in August of 2000, consumed 7,125 ha and burned for five days before it was controlled. This wildfire started in Utah, moved north into Idaho and into the City of Rocks where it blackened

846 ha (Morris, 2006b). It was driven by a strong wind from the South and was finally contained within the Reserve through the use of backfiring and bulldozing fire breaks (BLM, 2000). Knowledge of this prevailing south wind was used in our selection of sites with an increasing northward distance from this fire.

We used a total of nine sites in this study: three burned sites (Sites A, B, C), one “safe site” of unburned vegetation within the 2000 fire boundary (Site I), and five other unburned sites (Sites D, E, F, G, and H) (Figure 6-1). Previously published Burned Phytolith Index (BPI) data from surface samples at five of our sites (Sites A, B, C, D, and H) are included in our analysis to show the variation across the landscape and within sites (Morris *et al.*, in press). In 2006 and 2007, we collected soil cores from five sites (A, E, F, G, and H) at 10 to 20 cm in total depth. The soil cores were divided into approximately 1cm increments for analysis.

We conducted a pilot carbon dating study on several soil cores in our study area in 2006 to determine which segments to use for analysis. The pilot study revealed information regarding the depth to which different sites should be cored in order to reach sediments that were not mostly “modern” carbon (>95% 1950 carbon ratios). Some sites were modern only to approximately 5 cm in depth and others were modern all the way to 10 cm in depth. Therefore, we cored only to 10 cm at some locations and to 20 cm at others based on pilot carbon dating. Each sampling site is discussed in more detail below. Since the sampling locations for the previously published data (Morris *et al.*, in press) were not described in detail before, we have included that information as well.

Sampling sites

Of the nine sites, A, B, C were located in burned areas (Morris, 2006b) (Figure 6-1). Site A was formerly a pinyon-juniper invaded sagebrush steppe area that burned in 1999. It was in a broad valley with a south facing aspect on an 8° slope. Our soil core at this location was at least 22 cm deep and we processed three segments for our analysis: the surface (0-1 cm), 14-15 cm, and 19-20 cm. We collected only surface samples from Sites B and C in the area that burned in the fall of 2000. Site B was formerly a pinyon-juniper woodland with a north facing aspect on a 10° slope. Site C was also formerly a pinyon-juniper woodland with a south facing aspect on a 10° slope. We collected surface samples from the safe site (a remnant of unburned pinyon-juniper) (Site I). Site I was sampled under a juniper tree on a 15° slope with a north facing aspect.

Site D was an unburned area in a pinyon-juniper woodland across a canyon about 402 m from the northern edge of the 2000 fire. It had a south facing aspect on an approximately 10° slope. We collected and processed only soil surface samples from this site.

Sites E through G were areas that had not burned in the last 100 years, but, from photo interpretation (Figure 6-2), we believe burned over 150 years ago (“historic burn sites”) (Morris, 2006a, b). Site E was located very near the top of the ridge on this historic burn site with a 25° slope and a northwest aspect. It was about 2.8 km from the northern edge of the 2000 fire. We collected a soil core from this location to a depth of 10 cm and we processed three segments: 0-1 cm, 4-5 cm, and 9-10 cm. The site was dominated by old growth pinyon pine. Site F was at a slightly lower elevation on that ridge, with a 60° slope and a north facing aspect within pinyon-juniper cover. It was

about 3.2 km from the edge of the 2000 fire. Our soil core at this site was 15 cm deep and we processed three segments: 0-1 cm, 4-5 cm, and 9-10 cm. Site G was lower in elevation where juniper begins to dominate over the pinyon pine on a 30° slope and a north facing aspect. It was about 4.0 km from the northern boundary of the 2000 fire. Our soil core at this location was 13 cm deep and we processed three segments: 0-1 cm, 4-5 cm, and 9-10 cm.

Site H represents two datasets in our analysis. We included BPI data from previous study conducted on surface samples collected at Site H within a pinyon-juniper community with a south facing aspect on a 10° slope about 4.8 km from the 2000 fire boundary. We also collected a soil core in a nearby sagebrush steppe community at about 4.8 km from the 2000 fire with a south facing aspect on a 5° slope. The soil core was approximately 13 cm deep and we processed two segments: 0-1 cm and 9-10 cm. This site had not burned in at least 100 years (Morris, 2006b).

Methods

Soil extractions

Both microscopic charcoal and phytoliths were extracted from the soil samples using a modified wet oxidation and heavy liquid flotation technique (Blinnikov, 1994; Pearsall, 2000). Microscopic charcoal and phytoliths have a similar specific density and can be extracted together using the standard methods for phytoliths (Piperno, 2006). The surface samples and soil core segments were ground with a mortar and pestle to ensure homogeneity and sifted through a 250 µm sieve. Acid digestion of organic material was carried out with a heated 70% HNO₃ solution for one hour using 2 g of sieved soil from

the core segments and surface samples. We dispersed clays with a 5% solution of sodium hexametaphosphate. Our heavy liquid for density separation was sodium polytungstate (2.3 g cm^{-3}). The extractant was placed in a vial and dried at 80° C for 1-2 days.

We radiocarbon dated five core segments in this study from Sites A, E, and H. We assumed the dates for Site F and Site G would be similar to those for Site E. The soils for radiocarbon dating were also ground with a mortar and pestle, sifted through a $250 \mu\text{m}$ sieve, weighed (between 3 to 5 g per sample), placed in glass vials and sent to the National Ocean Sciences AMS labs (NOSAMS) at the Woods Hole Oceanographic Institution for carbon dating. We did not observe any macroscopic charcoal pieces within the soil cores that could be sent for dating.

Counting procedures

For the charcoal analysis, we used a dissecting needle to place a very small amount ($<0.0015\text{g}$) of the extracted sample onto a slide. As with the phytolith analysis, a small portion of Canada Balsam oil was added to the slide, mixed well and then covered with a slip and sealed down using clear fingernail polish. The entire slide was systematically examined under 100x magnification using a BH-2 Olympus microscope. Starting at the top left hand corner of the slide, we counted all charcoal pieces on the entire slide. We identified charcoal as pieces that were opaque and angular or irregularly shaped (Clark, 1988; Piperno and Jones, 2003). To see if there were any interactions between distance from the fire and size of charcoal pieces, we counted three different size classifications: small ($5\text{-}56 \mu\text{m}$), medium ($56\text{-}120 \mu\text{m}$), and large ($\geq 120 \mu\text{m}$). A “local

fire” should be indicated by anything greater than 125 μm (Gardner and Whitlock, 2001). The final charcoal counts were expressed as total abundance (the number per 1 g of soil) by calculating up from the counts per weight of each slide sample.

Slides for counting phytoliths were made with the same methods as the charcoal except they were not weighed. We used modified counting procedures similar to those developed by Boyd (2002). We counted one hundred phytoliths under 400x magnification from the center top and center bottom of each slide for a total count of 200 per slide. The percentage of dark and light phytoliths per 100 count were averaged to generate the Burned Phytolith Index (BPI) for each sample. We included only clear or darkened recognizable phytoliths in our BPI counts. Boyd (2002) only used long cells from grasses and we used averaged percentages rather than ratios.

Pattern analysis

The BPI and charcoals counts were used to examine our three research questions. Our first two questions related to the existence and spatial distribution of phytoliths and microscopic charcoal in the soil. We predicted that both the charcoal abundance and the BPI would decrease in the surface samples with increasing distance from the fire in 2000. At burned Site A, we predicted that both the charcoal abundance and the BPI would decrease from the surface with depth to reflect the recent fires and lack of fire in the past. Our prediction for the unburned site H was that the charcoal abundance and the BPI would remain relatively constant with depth since it had not burned in at least 100 years. We predicted the BPI at the unburned safe site (Site I) would be at least as high or even higher than the burned sites for two reasons; because of its proximity to the fire and

because less erosion was expected in a place that retained vegetation cover. Our third question addressed whether a known historic fire could be detected within the soil stratigraphy and was examined on sites E through G on the historic burn. We hypothesized that there would be an identifiable increase in both the charcoal abundance and the BPI with depth in the soil profile that would reflect the historic wildfire.

Results

Charcoal analysis

The carbon dating results showed that the soils at our sites were well stratified (Table 6-1). In other words, we can assume from these dates that the younger soils are above the older soils in our cores.

No microscopic charcoal was observed in the large category, while only 51 pieces were medium, and 1,922 were small in the total 2,063 pieces of charcoal counted across all samples. Therefore, we did not continue to analyze charcoal size and used only the total counts for each sample. The charcoal abundances followed only part of our prediction. Charcoal in surface samples was most abundant on the burn site, but decreased dramatically and remained fairly consistent from 2.8 km to 4.8 km away from the edge of the burn (Figure 6-3). Charcoal abundances with depth followed our predictions fairly well at the burned versus unburned sites. The charcoal abundance decreased dramatically with depth to reflect the recent fire at Site A and remained fairly constant with depth at the unburned site H (Figure 6-4). At the depths we analyzed (0-1 cm, 4-5 cm, and 9-10 cm) on the historic burn sites (Site E, F, and G), we did not detect an increase in charcoal abundance that would indicate the historic fire at these sites. In

fact, the charcoal abundance remained relatively consistent within these depths at all three of the historic burn sites (Figure 6-5).

Burned phytolith analysis

Our BPI results followed fairly well with our prediction for change over distance from the recent fires. In general, the BPI of the surface samples decreased with distance from the recent fire (Figure 6-6). However, when compared with previously published data from surface samples, unburned sites appeared to have a greater amount of variability in BPI than did the burned sites. Previous data from Site A (35%) was almost exactly the same as the current BPI (36%). Burned sites in general ranged from 30% to 49% BPI with an average of 38% (n=4). The safe site, Site I, had a very low BPI of only 1%. Unburned sites, on the other hand, exhibited a great deal of variability. The highest BPI (20%) was from the pinyon-juniper woodland area at Site H. Our BPI from the sagebrush steppe community at this same site was only 3%. In addition, two samples from Site D, the closest unburned site to the recent fires, had a BPI of 0% and 10%. The BPI on all unburned sites ranged from 0% to 20% and averaged 6% (n=7).

The BPI analysis with depth only followed one of our predictions. The comparisons of burned Site A and unburned Site H met our expectation. The BPI, in fact, decreased between the surface and two depth samples (14-15 cm and 19-20 cm) at Site A and remained fairly constant between the surface and 9-10 cm in depth at Site H (Figure 6-7). However, on the historic burn (Sites E, F, and G), the BPI was low and remained relatively constant between the surface and the two depths (4-5 cm and 9-10 cm) for all three sites. We had expected to find an increase in the BPI between the

surface and/or 4-5 cm level and the 9-10 cm depth that would relate to the historic fire (Figure 6-8).

Discussion

Charcoal with distance and depth

Charcoal was most abundant at the location of the modern fire and decreased by 0.4 km from the edge of the burn. Clark *et al.* (1998) found in an experimental burn that the charcoal loads declined abruptly at the burn edge and then remained rather constant to distances of 1.0 km from their intense crown fire. Ohlson and Tryterud (2000) found a similar trend of abrupt decrease in their experimental burn. Our charcoal abundance followed this pattern over distances from 0.4 km to 4.8 km from the edge of the 2000 fire. We found no differentiation in size of charcoal with increasing distances from the recent fires as has been found in lacustrine sediments (Whitlock and Millspaugh, 1996). Our lack of size differentiation in the charcoal with distance from the fire sites could be a methodological issue created by grinding the sections with a mortar and pestle. However, we did not observe any macroscopic charcoal prior to this step, in the sieve or during soil core collection in the field.

Very little is known about the transportation and incorporation of charcoal into soil sediments following a fire (Ohlson and Tryterud, 2000; Eckmeier *et al.*, 2007). There is good evidence, however, for fragmentation and movement down through the mineral horizons (Preston and Schmidt, 2006). Piperno and Becker (1996) concluded that, in the tropics, the phytoliths were substantially older than the charcoal and that those occurring at the same stratigraphic level cannot be assumed to be the same age.

Caracaillet (2001) found that individual pieces of charcoal were not well stratified in alpine and subalpine soils but that charcoal concentrations were. He concluded that, in the Alps, charcoal particles can migrate through the profile to about 100 cm in less than 500 years (Caracaillet, 2001). Our radiocarbon dates were on bulk soil sediments and we do not know the exact age of the charcoal or the phytoliths within the soil matrix. However, it is interesting to note that the charcoal counts at depth did not differ much from counts at the surface in modern samples unless the site burned. Charcoal abundance was also similar in soil samples close in age. Future research should focus on analysis of soils exposed to fires of known dates to assess how charcoal is incorporated into the soil stratigraphy.

BPI with distance and depth

The range of our BPIs fall within the range reported for burned areas in other studies. Piperno (1994) reported burned phytolith percentages (burnt/sum of all grass phytoliths) as peaking at 35%. Similarly, Kealhofer (1996) reported burned phytolith percentages in Thailand from 5-29%. Both studies were using lacustrine sediments cores. Boyd's (2002) terrestrial surface samples had an average of 8.2% with the last known fire in the area being in the late 1940s. The buried sediment layer with substantial macroscopic charcoal that he used for comparison had a BPI of 73%. His study revealed peaks from 60-70% in the BPI with depth and declines all the way to 10% for the uppermost soil layer. The only other study from our region found that, on average, burned sites had a higher BPI (38%, n = 3) than unburned sites (17%, n = 3) (Morris *et al.*, in press). The BPI at our unburned sites was generally lower than reported by Morris

et al. (in press), which may be due to the difference in counting procedures. The study by Morris *et al.* (in press) included soil aggregates, while in this study we counted recognizable phytoliths. When combining results from both studies, surface samples from burned sites had an average 38% BPI (n=4) while unburned sites (n=7) averaged a 6% BPI. Our BPIs might vary from other studies because of vegetation type, topography, climate, and sediment type. For example, Boyd (2002), who worked in grasslands and counted grass phytoliths, had the highest BPIs. None of our sampling sites were in grasslands.

Our BPI for Site I on the safe site within the 2000 fire was surprising. Ohlson and Tryterud (2000) conducted an experimental fire to assess the distribution of large charcoal (500-2,000 μm and $>2,000 \mu\text{m}$) and found that the presence of charcoal was a good indicator of local fire while the absence had to be interpreted more carefully. Even within their experimental fire, some 38 of their 280 traps inside the burn contained no particles $>500 \mu\text{m}$. Many of the traps without charcoal were located in an area where there was a combination of low fuel loads, low charcoal producing fuels (e.g. grasses), and lower fire intensity. This may also be the case with our safe site where the majority of vegetation that burned around it produced few phytoliths. A recent study of phytolith production in Great Basin species has shown that pinyon pine (*Pinus monophylla*) and juniper (*Juniperus osteosperma*) form only trace amounts or no phytoliths at all (Chapter 4).

Because this is the first attempt to use BPI as an indicator of historic fires in these ecosystem types and soils, it is unclear what the threshold BPI should be to indicate an historic fire. Our results on modern fires and distances from them indicated that

characteristic BPI of a burn would be around 38%. No site had greater than 30% BPI at any depth. However, we cannot conclude that fire was absent during the time periods that these samples represent because, similar to other studies using charcoal, lower BPIs are actually more difficult to interpret. For example, our safe site within the fire had one of the lowest BPIs in the study. Also, our interpretations are limited because we do not know about the effects of time on this measure. For example, perhaps the BPI of a burned site decreases over time due to post depositional forces on the soil, such as wind and water. There are also issues of inheritance associated with the phytoliths. There were several fires in our study area over the last approximately 100 years (Figure 6-1) (Morris, 2006b). Each of them could have contributed to the BPI at our unburned sites as well, not just the 1999 and 2000 fires. Future research using BPI on soil profiles at burned sites of varying known ages would be useful.

The BPI of these sites prior to the 1999 and 2000 fires is also unknown. The BPI could be created by the deposition of burned vegetation onto the soils during the fire, by the charring of the phytoliths on the soil surface during the fire, or both. Sites with an accumulation of duff versus those without it could char more phytoliths within the mineral soil layer due to high heat. Temperatures at the ground surface in sagebrush fires can reach peaks of 150-500° C with sustained heating for 5-10 minutes at >100° C and 10-15 minutes at >200° C (Buenger, 2003). In pinyon-juniper woodland fires, ground surface temperatures can peak at 700-800° C with sustained heating at 200-400° C for more than an hour (Buenger, 2003). Large amounts of litter and duff can contribute to deeper soil temperatures up to 94° C (Klopatek *et al.*, 1988).

Finally, the BPI may also be dependent upon grass cover at the time of the fire. Charcoal is generated mostly by woody species while phytoliths in these two systems are mostly from the grasses and some of the herbaceous understory (Chapter 4). Junipers are known to decrease understory vegetation as the cover increases in these woodlands (West, 1991, 1999). Most of the fires in this study area occur in late summer and fall when livestock and wildlife have grazed over the grasses for the season (Morris, 2006b). Therefore, there may simply not be the enough grasses at the time of the fire to contribute to large numbers of phytoliths carried on the wind, but they may be present in the mineral soil. Therefore, they might char on site and not be as likely to disperse in the smoke and wind during the fire.

The historic burn site

We did not find a clear indication of the historic fire in our old burn site samples. It could be that the spike in BPI and charcoal on the historic burn site was simply not detected because we sampled modern core segments. Our pilot study dating results indicated that depths of around 9-10 cm could be approximately 190 ± 25 ^{14}C years before present. Therefore, we dated and analyzed core segments at 4-5 cm and 9-10 cm. However, the carbon dates of these segments were modern. We believe this fire occurred over 150 years ago (Morris, 2006b). Given that the soils in our study area have shown to be well stratified in this study, there is good reason to believe that the core segments between the surface and 4-5 cm and from 4-5 cm to 9-10 cm in depth are also modern. Perhaps the charcoal and BPI signal for this fire was deeper in the soil profile than we sampled. Being on a slope, it is likely that there are buried A horizons deeper in the

profile or that much of the soils following the fire in our photo (Figure 6-2) were eroded away. Also, the soils at this site could be mixed enough to result in a modern date. Finally, it is also possible that there was no fire at this site even though it appears there was one in the past from the photo. Given the ability of the phytolith record to reflect recent fires on lower degree slopes and the presence of both charcoal and burned phytoliths in very old soils, we believe that the method is sound, but it should be tested in a more stable location in future research.

Conclusion

We have documented that both charcoal and burned phytoliths are present in terrestrial soils dated as old as the late Holocene. We worked with both proxies in a modern analogue study to examine changes in their abundance with distance from modern fires and with depth at sites of modern fires. Our results show that burned phytoliths and charcoal in terrestrial sediments are potential sources for interpreting historic fires in sagebrush steppe and pinyon-juniper woodlands. Both of these important biological proxies were found in sediments dating back to the late Holocene. Information regarding fire from this time period, commonly known as the Little Ice Age, can be important for understanding the historic range of variability of these systems. This is the first attempt to examine these proxies in terrestrial sediments in this region. Our results illustrate the difficulty of defining a clear taphonomy for phytoliths and charcoal in terrestrial sediments after a fire in these two ecosystems. There are many unanswered questions left to explore in future research. However, this study does indicate that charcoal and phytolith analysis have the potential for use in examining questions related

to historical fires in pinyon-juniper and sagebrush steppe ecosystems of the Great Basin Desert region.

References

- Albert, R., Bamford, M. K., and Cabanes, D.** 2006: Taphonomy of phytoliths and macroplants in different soils from Olduvai Gorge (Tanzania) and the application to Plio-Pleistocene palaeoanthropological samples. *Quaternary Research* 148, 78-94.
- Baker, W., and Shinneman, D.** 2004: Fire and restoration in pinyon-juniper woodlands in the western United States: a review. *Forest Ecology and Management* 189, 1-21.
- Berg, E. E., and Anderson, R. S.** 2006: Fire history of white and Lutz spruce forest on the Kenai Peninsula, Alaska, over the last two millenia as determined from soil charcoal. *Forest Ecology and Management* 227, 275-283.
- Blinnikov, M. S.** 1994: Phytolith analysis and Holocene dynamics of alpine vegetation. In Onipchenko, V. G., and Blinnikov, M. S., editors, *Experimental investigation of alpine plant communities in the north-western Caucasus*. Veröffentlichungen des Geobotanischen Institutes der ETH, Stiftung Rubel, 23-40.
- BLM.** 2000: *Fire Report*. Bureau of Land Management, Southern Idaho District, on file at City of Rocks National Reserve Headquarters.
- Boyd, M.** 2002: Identification of anthropogenic burning in the palaeoecologic record of the northern prairies: a new approach. *Annals of the Association of American Geographers* 92, 471-487.
- Buenger, B. A.** 2003: *The impact of wildland and prescribed fire on archaeological resources*. Unpublished dissertation, University of Kansas.
- Carcaillet, C.** 2001: Soil particles reworking evidences by AMS ^{14}C dating of charcoal. *Sciences de la Terre et des planetes* 332, 21-28.
- Carcaillet, C.** 1998: A spatially precise study of Holocene fire history, climate and human impact within the Maurienne Valley, North French Alps. *Journal of Ecology* 86, 384-396.
- Clark, J. S.** 1988: Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. *Quaternary Research* 30, 81-91.

- Clark, J. S., and Hussey, T. C.** 1996: Estimating mass flux of charcoal from sedimentary records: effects of particle size, morphology and orientation. *The Holocene* 6, 129-144.
- Clark, J. S., Lynch, J., Stocks, B. J., and Goldammer, J. G.** 1998: Relationships between charcoal particles in air and sediments in west-central Siberia. *The Holocene* 8, 19-29.
- Daugherty, R. E.** 1988: *Legislative land cost estimate for City of Rocks National Reserve, Cassia County, Idaho*. National Park Service Pacific Northwest Region.
- Eckmeier, E., Gerlach, R., Skjemstad, J. O., Ehrmann, O., and Schmidt, M. W. I.** 2007: Minor changes in soil organic carbon and charcoal concentrations detected in a temperate deciduous forest a year after an experimental slash-and-burn. *Biogeosciences* 4, 377--383.
- Gardner, J. J., and Whitlock, C.** 2001: Charcoal accumulation following a recent fire in the Cascade Range, northwestern USA, and its relevance for fire-history studies. *The Holocene* 11, 541-549.
- Gavin, D., Hallett, D. J., Hu, F. S., Lertzman, K., Prichard, S. J., Brown, K. J., Lynch, J. A., Bartlein, P., and Peterson, D. L.** 2007: Forest fire and climate change in western North America: insights from sediment charcoal records. *Frontiers in Ecology and the Environment* 5, 499-506.
- Gavin, D. G., Brubaker, L. B., and Lertzman, K. P.** 2003: Holocene fire history of a coastal temperate rain forest based on soil charcoal radiocarbon dates. *Ecology* 84, 186-201.
- Kealhofer, L.** 1996: The human environment during the terminal Pleistocene and Holocene in northeastern Thailand: phytolith evidence from Lake Kumphawapi. *Asian Perspectives* 35, 229-254.
- Klopatek, C. C., Debano, L. F., and Klopatek, J. M.** 1988: Effects of simulated fire on vesicular-arbuscular mycorrhizae in pinyon-juniper woodland soil. *Plant and Soil* 109, 245-249.
- Lertzman, K., Gavin, D., Hallett, D., Brubaker, L., Lepofsky, D., and Mathewes, R.** 2002: Long-term fire regime estimated from soil charcoal in coastal temperate rainforests. *Conservation Ecology* 6, 5-18.
- MacMahon, J. A.** 1988: Warm deserts. In Barbour, M.G., and Billings, W. D., editors, *North American terrestrial vegetation*. Cambridge University Press, 232-260.

- Mensing, S., Livingston, S., and Barker, P.** 2006: Long-term fire history in Great Basin sagebrush reconstructed from macroscopic charcoal in spring sediments, Newark Valley, Nevada. *Western North American Naturalist* 66, 64-77.
- Meyer, G. A., and Pierce, J. L.** 2003: Climatic controls on fire-induced sediment pulses in Yellowstone National Park and central Idaho; a long-term perspective. *Forest Ecology and Management* 178, 89-104.
- Miller, R. F., and Rose, J. A.** 1999: Fire history and western juniper encroachment in sagebrush steppe. *Journal of Range Management* 52, 550-559.
- Miller, R. F., and Tausch, R. J.** 2001: The role of fire in juniper and pinyon woodlands: a descriptive analysis. In Galley, K. E. M., and Wilson, T. P., editors, *Proceedings of the invasive species workshop: the role of fire in the control and spread of invasive species, fire conference 2000: the first national congress on fire ecology, prevention, and management*. Miscellaneous publication number 11. Tall Timbers Research Station, 15-30.
- Morris, L.** 2006a: *Ecological history of the City of Rocks National Reserve, Part I: the human archive*. National Park Service Pacific Northwest Region.
- Morris, L.** 2006b: *Fire history of the City of Rocks National Reserve from 1926 to 2005*. National Park Service Pacific Northwest Region.
- Morris, L. R., West, N. E., Baker, F. A., Van Miegroet, H., and Ryel, R. J.** in press: Developing an approach for using the soil phytolith record to infer vegetation and disturbance regime changes over the past 200 years. *Quaternary International*.
- Ohlson, M., and Tryterud, E.** 2000: Interpretation of the charcoal record in forest soils: forest fires and their production and deposition of macroscopic charcoal. *The Holocene* 10, 519-525.
- Parr, J. F.** 2006: Effect of fire on phytolith coloration. *Geoarchaeology: An International Journal* 21, 171-185.
- Pearsall, D. M.** 2000: *Paleoethnobotany: a handbook of procedures*. Academic Press.
- Pierce, J. L., Meyer, G. A., and Jull, A. J. T.** 2004: Fire-induced erosion and millennial-scale climate change in northern ponderosa pine forests. *Nature* 432, 87-90.
- Piperno, D. R.** 1994: Phytolith and charcoal evidence for prehistoric slash-and-burn agriculture in the Darien rain forest of Panama. *The Holocene* 4, 321-325.

- Piperno, D. R.** 2006: *Phytoliths: a comprehensive guide for archaeologists and paleoecologists*. AltaMira Press.
- Piperno, D. R., and Becker, P.** 1996: Vegetational history of a site in the central Amazon basin derived from phytolith and charcoal records from natural soils. *Quaternary Research* 45, 202-209.
- Piperno, D. R., and Jones, J. G.** 2003: Paleoecological and archaeological implications of a Late Pleistocene/Early Holocene record of vegetation and climate from the Pacific coastal plain of Panama. *Quaternary Research* 59, 79-87.
- Preston, C. M., and Schmidt, M. W. I.** 2006: Black (pyrogenic) carbon: a synthesis of current knowledge and uncertainties with special consideration of boreal regions. *Biogeosciences* 3, 397-420.
- Sanborn, P., Geertsema, M., Jull, A. J. T., and Hawkes, B.** 2006: Soil and sedimentary charcoal evidence for Holocene forest fires in an inland temperate rainforest, east-central British Columbia, Canada. *The Holocene* 16, 415-427.
- SCS.** 1994: *Soil Conservation Service: soil survey of Cassia County, Idaho, eastern part*. US Department of Agriculture.
- Swetnam, T. W., and Baisan, C. H.** 1995: Historical fire regime patterns in the southwestern United States since AD 1700. In Allen, C. D., editor, *Fire effects in southwestern forests*. General Technical Report RM-GTR-286. US Department of Agriculture, Forest Service, Rocky Mountain Research Station.
- West, N. E.** 1991: Junipers of the Western US: classification, distribution, ecology and control. In James, L. F., Evans, J. O., Ralphs, M. H., and Child, R. D., editors, *Noxious range weeds*. Westview Press, 325-333.
- West, N. E.** 1999: Juniper-pinyon savannas and woodlands of western North America. In Anderson, R. C., Fralish, J. S., and Baskin, J. M., editors, *Savannas, barrens, and rock outcrop plant communities of North America*. Cambridge University Press, 288-308.
- Westerling, A. L., Hidalgo, H. G., Cayan, D. R., and Swetnam, T. W.** 2006: Warming and earlier spring increases western U.S. Forest wildfire activity. *Science* 313, 940-943.
- Whisenant, S. G.** 1990: Changing fire frequencies on Idaho's River Plains: ecological and management implications. In McArthur, E. D., Romney, E. M., Smith, S. D., and Tueller, P. T., editors, *Proceedings - symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management*. General

Technical Report INT-276. US Department of Agriculture, Forest Service, Intermountain Research Station.

Whitlock, C., and Millspaugh, S. H. 1996: Testing the assumptions of fire-history studies: an examination of modern charcoal accumulation in Yellowstone National Park, USA. *The Holocene* 6, 7-15.

Table 6-1 Results from carbon dating segments from soil cores at Sites A, E, and H.

Site	Depth	Radiocarbon Age	Calibrated Calendar Age (1 Sigma Ranges)	Calibrated Calendar Age (2 Sigma Ranges)
Site A	14-15cm	695 ± 30	Cal AD 1274-1298 Cal AD 1372-1378	Cal AD 1264-1310 Cal AD 1360-1387
	19-20cm	905 ± 35	Cal AD 1044-1098 Cal AD 1119-1142 Cal AD 1147-1174	Cal AD 1037-1209
Site E	4-5cm	>Modern		
	9-10cm	>Modern		
Site H	9-10cm	410 ± 35	Cal AD 1439-1491 Cal AD 1603-1611	Cal AD 1429-1522 Cal AD 1573-1628

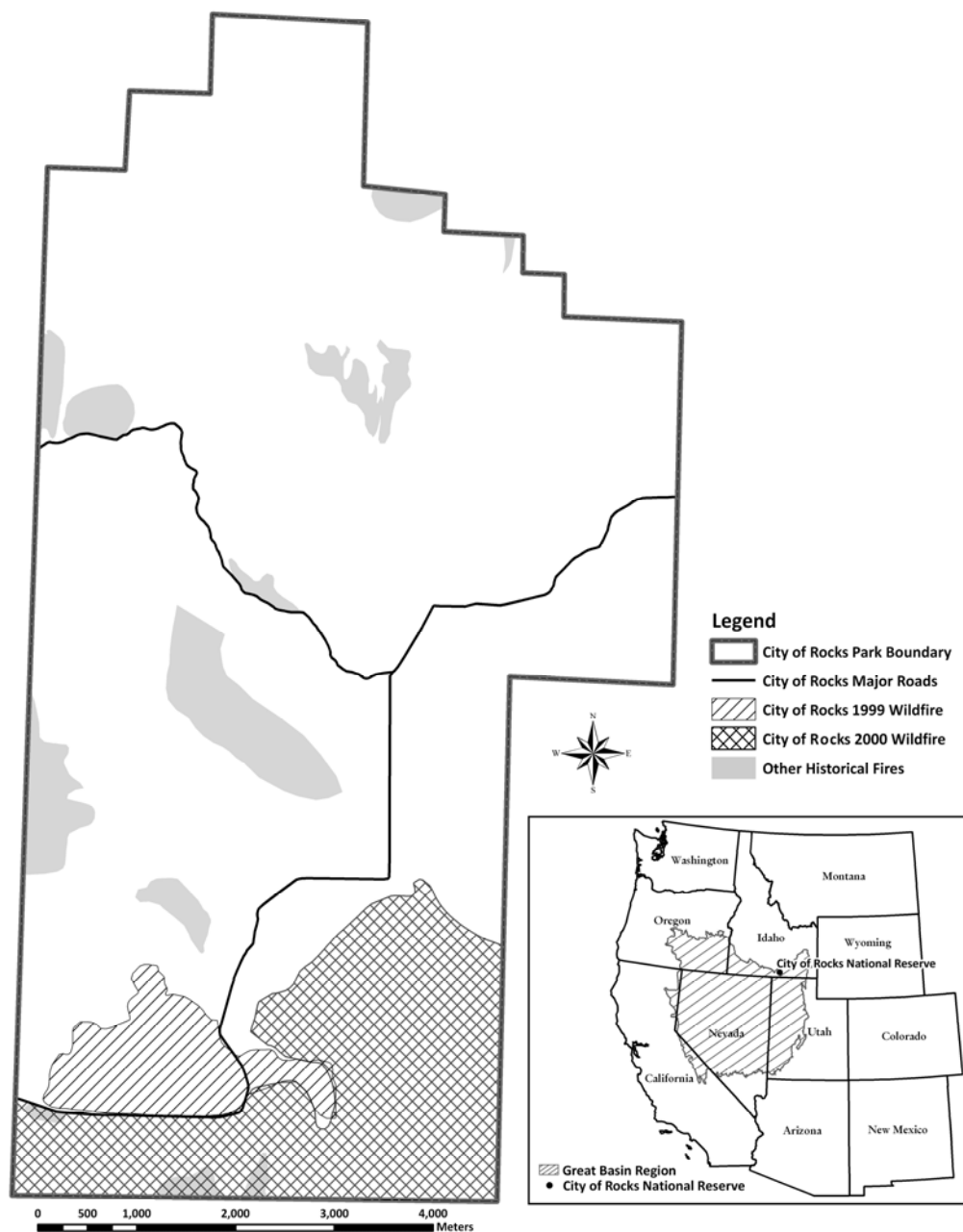


Figure 6-1 City of Rocks National Reserve showing all mapped fires in study area over the last approximately 100 years (modified from Morris, 2006b). A, B, C, indicate burned site locations from fires in 1999 and 2000. I indicates location of the safe site within the 2000 burn. D-H indicate unburned site locations.

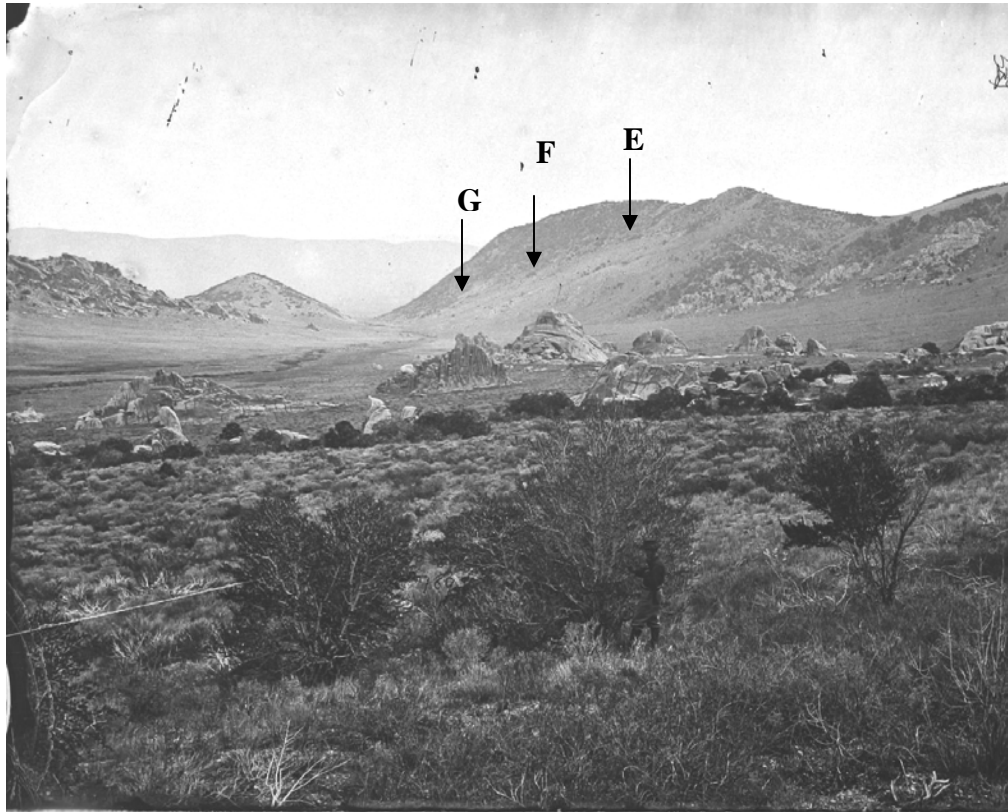


Figure 6-2 Photo of City of Rocks National Reserve taken in 1868. The old fire scar is on the distant slope in the right center background. The approximate locations of the historic burn sites (Site E, F, and G) are indicated with arrows. (Photo by Timothy O'Sullivan, 1868, Courtesy of the National Archives and Records Administration)



Figure 6-3 Charcoal abundance (number of charcoal $\times 10^6$ per 1 gram of soil) shown with increasing distance from burned Site A. Distances of Site E through H range from 2.8 km to 4.8 km from the boundary of the 2000 fire.

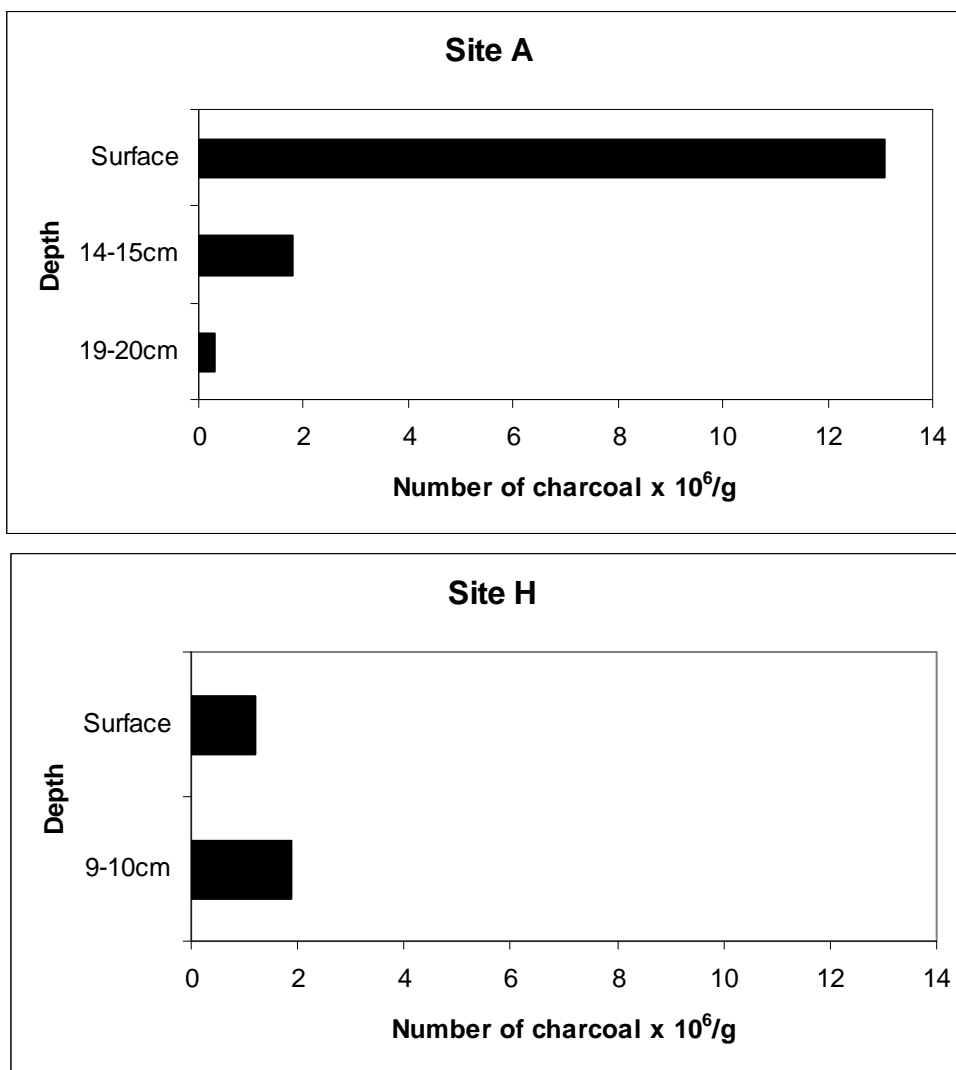


Figure 6-4 Charcoal abundance (number of charcoal x 10⁶ per 1 gram of soil) by depth at a recently burned (Site A) and unburned site (Site H).

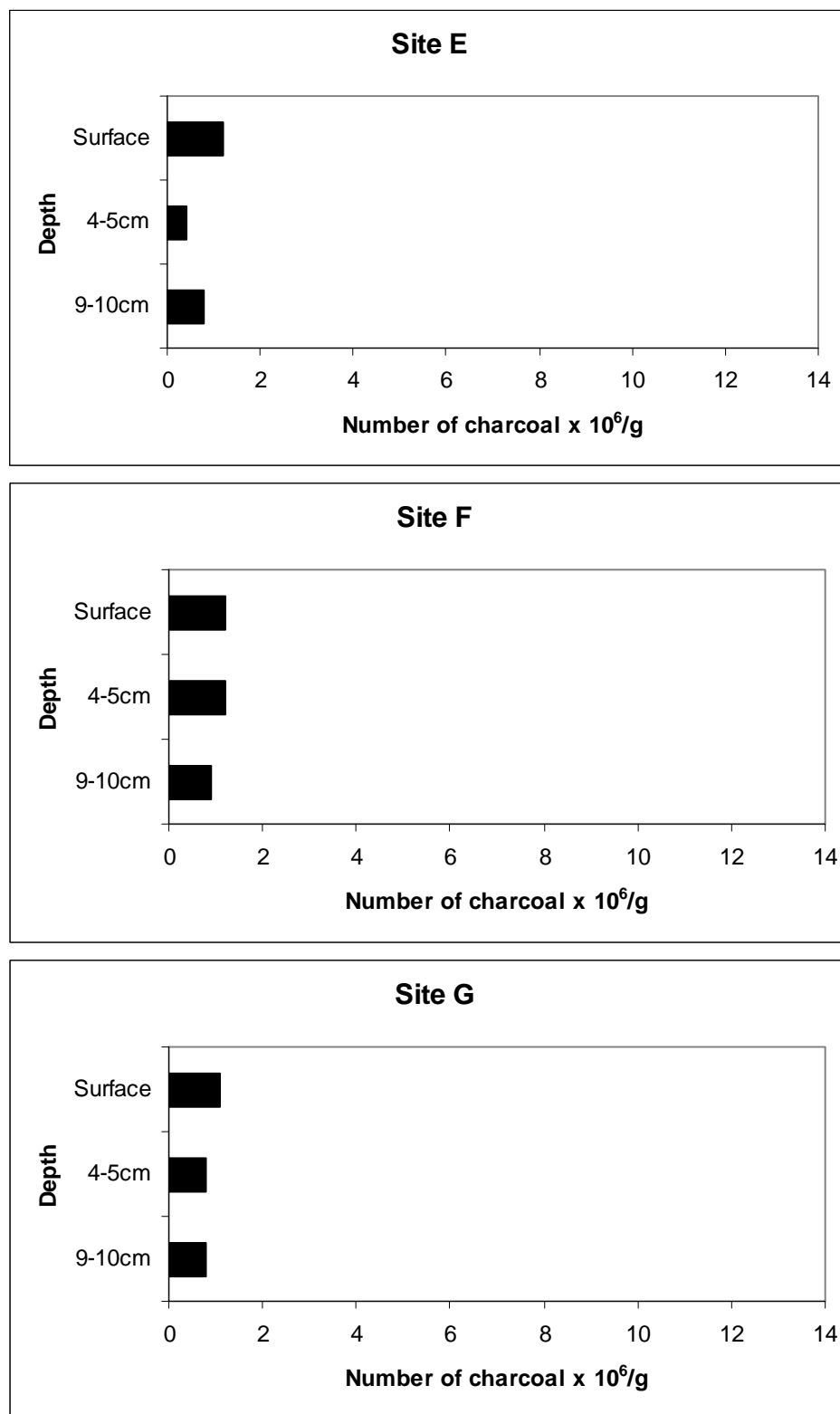


Figure 6-5 Charcoal abundance (number of charcoal $\times 10^6$ per 1 gram of soil) by depth at the historic burn sites (Sites E-G) that burned over 150 years ago.

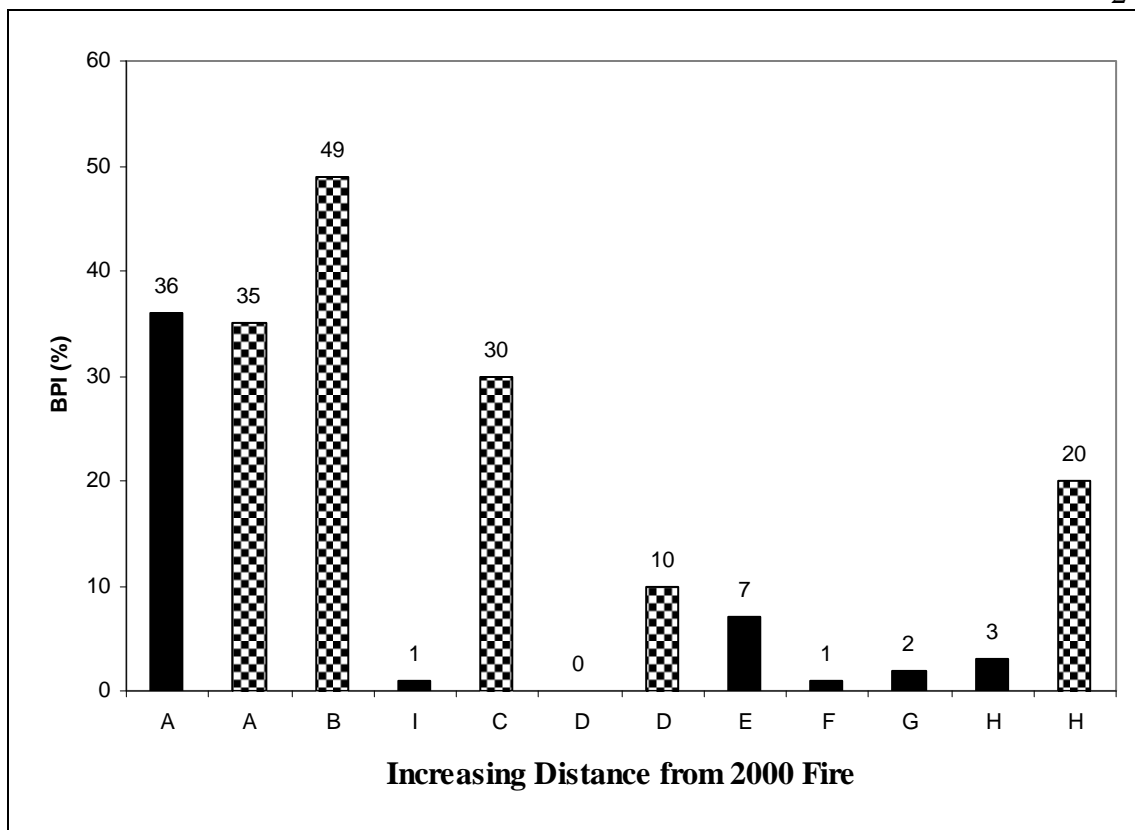


Figure 6-6 Burned Phytolith Index (BPI) with increasing distance from the 2000 fire. Distances from the nearest edge of the 2000 fire ranged from 0.4 km (Site D) to 4.8 km (Site H). Checkered bars are previously published data (Morris *et al.*, in press). A, B, and C burned in 1999 and 2000. Sites D-H had not burned in at least the last 100 years. I is the “safe” site of unburned vegetation within the 2000 burn area. A, D, and H are repeated because they were sampled twice. Previously published data from Site H (with checkered bar) was collected in pinyon-juniper site and the second sample from Site H (solid bar) was collected in sagebrush steppe.

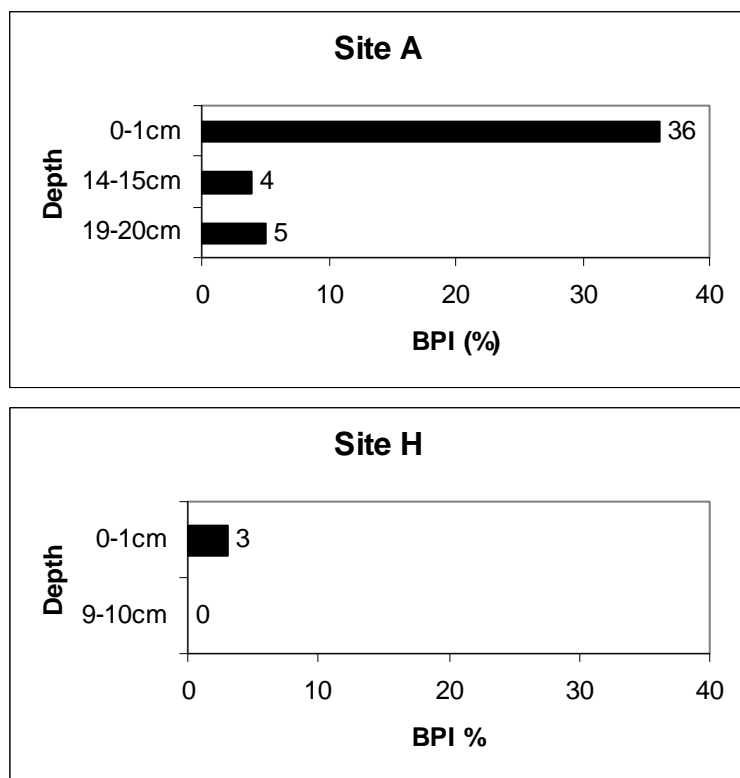


Figure 6-7 Burned Phytolith Index (BPI) percentages by depth at a burned site (Site A) and unburned site (Site H).

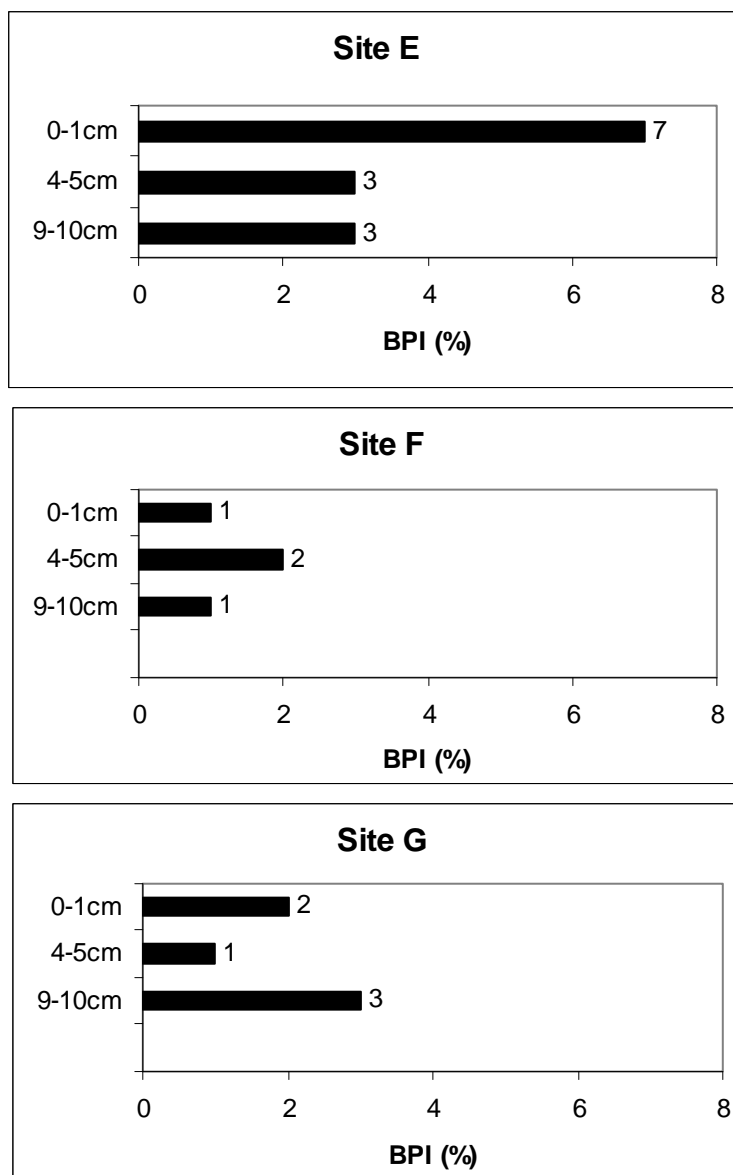


Figure 6-8 Burned Phytolith Index (BPI) percentages by depth at the historic burn sites (Sites E-G).

CHAPTER 7

TESTING SOIL PHYTOLITH ANALYSIS AS A TOOL TO UNDERSTAND
VEGETATION CHANGE IN THE SAGEBRUSH STEPPE AND
PINYON-JUNIPER WOODLANDS OF THE
GREAT BASIN DESERT REGION¹

Abstract

Phytolith analysis has been increasing in popularity over the past few decades. Most of the research with this important paleoecological tool has been done in lacustrine sediments, but these sites are limited in arid systems. Better development of biological proxy methods are needed to understand changes in more arid ecosystems over the recent past. Our objective in this study was to examine the utility of soil phytolith analysis to reflect vegetation changes over the past 200 years, from the end of the Little Ice Age to present. The sensitivity of phytoliths to record vegetation changes for this time period was tested by sampling in locations where vegetation changes were known to have occurred based on human records. This is the first study to examine the use of soil phytoliths in a continuous core sampling method in these ecosystem types. We found that these soils can be stable and well stratified enough to record changes in the vegetation on unburned, low sloped and uncultivated areas. We recommend combining site history with a multiple core sampling approach. Soil phytolith analysis has the potential to provide much needed biological proxy data for this time period in the Great Basin Desert region.

¹ Coauthored by Lesley R. Morris, Ronald J. Ryel, and Neil E. West.

Introduction

Phytolith analysis is becoming an increasingly popular method for determining historic vegetation (Piperno, 2006). Phytoliths are structures formed in plants through deposition and accumulation of silica within and around cell walls (Rovner, 1971; Fredlund, 2001). They are released from plants into sediments through death and decay of plant material where they have been recovered from as early as the Eocene (Stromberg, 2004). These microfossils are most often used along side pollen analysis from lacustrine sediments. However, phytoliths preserve better in terrestrial sediments than pollen grains which are more stable in anaerobic conditions (Golyeva, 2001). This is particularly important for arid and semi-arid environments where lacustrine evidence is not as common (Fredlund, 2001). In addition, biological proxies for the more recent past (less than 200 years) are largely limited to the human archive and some dendrochronological evidence (Egan and Howell, 2001) which can be subject to human bias, limited in spatial extent or not appropriate for non-forested systems (Swetnam *et al.*, 1999). Better development of biological proxy methods is needed to understand changes in more arid ecosystems over the recent past. Soil phytolith analysis has the potential to provide this much needed biological evidence.

Several studies have used the phytolith record from natural terrestrial sediments across a variety of regions from the Amazon basin (Piperno and Becker, 1996) to the Rhone valley in France (Delhon *et al.*, 2003). In North America, soil sediments have been used for phytolith studies from the northern prairies of Canada (Boyd, 2002) and in the United States' Columbia Basin in the northwest (Blinnikov *et al.*, 2002), the northern Rocky Mountains between Montana and Idaho (Stromberg, 2004), the Great Plains

(Kurmann, 1985; Fredlund and Tieszen, 1997; Stromberg, 2004) and the deserts of southwest US in Utah (Fisher *et al.*, 1995). In each of these studies, one or more buried soil horizons is used as a comparison. Research examining changes in the continuous soil stratigraphy with phytoliths is much more limited. Blinnikov (1994) employed this technique in studies of alpine soils. He sampled every 2 cm to a depth of 10 cm and then every 5 cm to a total depth of 25-40 cm into the lower limit of the soil B horizon. He was able to infer changes in the vegetation for the last half of the Holocene and could reportedly detect the phytolith signal of a severe grazing period in the last several hundred years. Similarly, Kerns (2001) examined changes between surface (0-2 cm) and subsurface (2-7 cm) soils of the ponderosa pine forests in the southern Rocky Mountains of Arizona.

Diagnostic phytolith morphotypes have been reported at varying taxonomic levels. For example, there are diagnostic phytoliths at the genus (Klein and Geis, 1978) and even species level (Kerns, 2001) within the family Pinaceae. However, there need not be a diagnostic form for each taxa for the method to be useful (Piperno, 2006). For example, frequency analysis of morphotypes found in the extant vegetation are often compared to each other as a way of determining which type or set of morphotypes provide a signal for a species, community or even a climate regime (Kerns, 2001; Carnelli *et al.*, 2004; Blinnikov, 2005). Furthermore, since many tree species do not produce diagnostic forms or many phytoliths overall, previous studies have used the mass or percent weight of extracted silica as a proxy for forb dominated vegetation (Kalisz and Boettcher, 1990) versus forest cover in the past or changes in grasslands over time (Fisher *et al.*, 1987). In areas where conifers or other forest species generate

recognizable phytolith morphotypes, relative abundance has been used (Blinnikov *et al.*, 2002). Blinnikov (2005) identified a blocky phytolith morphotype useful for signaling *Artemisia* and, therefore, sagebrush steppe ecosystems.

Recent analysis by Morris *et al.* (see Chapter 4) of the phytolith production and morphotype frequencies in native and introduced species of the Great Basin has demonstrated that pinyon-juniper woodlands do not have a recognizable phytolith assemblage due to the lack of production by the dominant woody species, *Pinus monophylla* (pinyon pine) and *Juniperus osteosperma* (Utah juniper). Their work suggested that extraction weights may be a more appropriate method for differentiating between these woodlands and grasslands or sagebrush steppe communities. In addition, this study demonstrated important differences in morphotype production frequency between native and introduced grass species as well as within these groups. In particular, the most common introduced grass species in their study area produced almost half the frequency of rondel morphotypes as native grass species (Chapter 4).

Our objective in this study was to examine the utility of soil phytolith analysis to reflect vegetation changes over the period of about 200 years in two common ecosystem types of the Great Basin, sagebrush steppe and pinyon-juniper woodlands. The sensitivity of phytoliths as a record for the more recent past can be tested by sampling in locations where vegetation changes are known to have occurred based on human records. Results from previous environmental history work in our study area (Chapter 3) show that over the past two centuries, the vegetation has changed in two major ways. First, there are more woody species including denser sagebrush and increased cover and density of pinyon and juniper as these woodlands have encroached down slope and into

the valleys. Second, there has been an overall loss of native grasses and an increase in introduced grasses, particularly *Bromus tectorum* (cheatgrass) and *Agropyron desertorum* (crested wheatgrass) (Morris, 2006a). These known changes are used to test the sensitivity of the soil phytolith stratigraphy to record such events. We employed both a multi-core approach and detailed core analysis to examine three questions.

- 1) Do extraction weights from soils reflect the reduction of grasses over time with an increase in woody vegetation either from sagebrush or pinyon-juniper woodlands across the landscape?
- 2) Do the relative abundances of total rondels from soil sediments reflect the change over time to dominance of introduced grasses over native grasses across the landscape?
- 3) Do phytolith assemblages change over time at a fine scale (1 cm increments) in continuous sampling analysis of cores?

We hypothesized that the extraction weights would be less in the surface segments due to the historic reduction of grasses with high phytolith production being replaced by woody species with very low phytolith production. In addition, we predicted that total rondel percentages would be less in the surface segments than in deeper segments within multiple cores due to the increasing dominance of introduced grasses. Finally, we hypothesized that the overall phytolith assemblage would change with depth over time along continuous sampling of 1 cm segments in a core and reflect known vegetation changes.

Study area

City of Rocks National Reserve

The City of Rocks National Reserve (CIRO) contains approximately 5,800 ha of the Great Basin Desert Region in the Albion Mountains of southern Idaho. The elevation reaches from 1,646 m in the valley to 2,702 m on Graham Peak (Daugherty, 1988). The vegetation includes sagebrush steppe in the valleys and pinyon-juniper woodlands along the slopes and lower mountains with mountain mahogany chaparral and limber pine forest at the highest elevations. The sagebrush steppe is the largest of the North American temperate semi-desert types (West, 1983). The ecosystem gets its name from the historically equal dominance of shrubs from the genus *Artemisia* and various species of bunchgrasses (West, 1983). The major tree species in the Great Basin pinyon-juniper woodlands are *P. monophylla* and *J. osteosperma*. The understory species are highly variable across the region but are usually made up of the flora found in adjacent forests, shrub steppes or grasslands (West *et al.*, 1975; West, 1999).

Precipitation trends in the Great Basin generally show a marked pattern of winter maximum and summer minimum due to winter storms that develop off the Pacific coast (Miller *et al.*, 1994; WRCC, 2006). The City of Rocks, however, is part of the eastern portion of Idaho that shows maximum monthly amounts in summer and minimums in the winter due to moisture from storms originating from the south in the Gulf of Mexico and the Caribbean region (WRCC, 2006). The average total monthly precipitation peaks during the months of April, May and June (Morris, 2006a). This increased proportion of April-September precipitation in the eastern portion of the sagebrush steppe region has

been used to explain the predominance of grass species in some areas (Stoddart, 1941). The mean annual precipitation is 276 mm (Morris, 2006a). Temperatures can be highly variable in this region. The annual mean temperatures at the site range from 41° C to -33° C with average temperatures of 9° C (Morris, 2006a).

CIRO has a very long and well recorded history from European emigration and settlement in the mid 1800s to present. The City of Rocks contains segments of two important routes of the California Trail from the era of overland emigration in the USA from the 1840s to the 1870s (HRA, 1996). CIRO has also been an important area for livestock grazing and homesteading. Commercial herds of sheep and cattle were trailed through the City of Rocks beginning in the 1850s (Little, 1994). The area was first used as a home base for a livestock grazing in the late 1860s (Little, 1994; HRA, 1996). By the late 1880s several large livestock operations from Nevada and Utah were grazing cattle through the Reserve and surrounding lands (Little, 1994). Extremely harsh winters and droughts in the 1890s devastated the cattle barons (Young and Sparks, 2002). After that, most of the livestock grazing in the area was from more local farms and ranches which supplemented livestock with hay or grain in the winter. The first homesteader arrived within the City of Rocks in 1882, but homesteading and dry land farming were most active in the CIRO from 1909 to 1920. Again, droughts in the 1920s and into the 1930s drove many out of business and the settlers began to move away, reportedly due to failing springs and other water sources (HRA, 1996). In the 1950s, there was a push to increase forage production in the most productive sagebrush steppe areas that were left fallow since the dry farming era and devastated from droughts and overgrazing. This meant clearing the land once again and drill seeding with the introduced forage grass,

Agropyron desertorum. More details concerning the environmental history of the study area are available in Morris (2006a) and Chapter 3.

European exploration and settlement of the American West coincided with the end of the period known as the Little Ice Age. The Little Ice Age was a generally cool period in the Northern Hemisphere from approximately 1300-1850 AD (Millar and Woolfenden, 1999; Miller and Tausch, 2001). Though the difference in average temperature was only estimated to be 1° C, it had marked impacts upon ecosystems in North American, Europe and other parts of the globe (Roberts, 1998). The Little Ice Age was the wettest and coolest period of the Late Holocene (Miller and Tausch, 2001). Since then, the general trend has been one of continual warming and aridity in the much of the Great Basin region (Miller and Wigand, 1994; Miller and Tausch, 2001). Because this climatic shift coincided with the arrival of European settlers and the introduction of new disturbances from agricultural development, livestock grazing and invasive plant species, it is difficult to tease apart the so called “natural” climatic shifts in vegetation from those driven by human influence (Millar and Woolfenden, 1999). Whatever the mechanism, the changes in the vegetation have been very distinct over this time period making the CIRO an excellent location for testing the sensitivity of the soil phytolith record.

Site descriptions

An understanding of the history and land uses in the study area was crucial for developing hypotheses to be tested as well as determining sampling sites that have had a relatively stable soil profile over the time period of interest (e.g. unplowed sites). The

widespread history of dry farming in the early 1900s and seeding projects later in the 1950s left very few valley locations that were potentially stable enough for sampling. Six soil sampling sites were located using the mapped historical information gathered from the human archive (Morris, 2006a, b). At each site, the following information was collected: GPS coordinates, slope, aspect, recently burned/unburned in the last 100 years, community type, and characterization of the present vegetation. The present character of the vegetation (percent cover) was assessed using point line transect method for shrub steppe and understory vegetation and line intercept method for woodlands (Bonham, 1989).

The soils in the study area are classified as clayey-skeletal, montmorillonitic, frigid Typic and Lithic Argixerolls. The parent material is the alluvium and residuum of mica, schist and quartzite. The pH ranges from 6.6-7.3 at all sampling locations. The sampling sites were from three different soil mapping units that included: Birchcreek-Itca complex, the Itca-Birchcreek-Rock outcrop complex and Poisonhol very stony loam (SCS, 1994). The Birchcreek-Itca complex soils are a mix of moderately deep to shallow well drained very stony loams on north-facing mountainsides with potential natural plant communities of *P. monophylla*, *J. osteosperma*, *Artemisia tridentata ssp. vaseyana* (mountain big sagebrush) and *Pseudoroegneria spicata* (bluebunch wheatgrass). The Itca-Birchcreek-Rock outcrop complex is composed of shallow to moderately deep well drained soils on south-facing mountainsides with potential natural vegetation of *P. monophylla*, *J. osteosperma*, *A. tridentata ssp. vaseyana*, *P. spicata* and *Festuca idahoensis* (Idaho fescue). The Poisonhol very stony loam units are typically moderately deep and well drained soils with a potential natural vegetation of *A. tridentata ssp.*

vaseyana and *P. spicata* (SCS, 1994). Each sampling location is described in detail below.

Site 1A was in a pinyon-juniper woodland within the Itca-Birchcreek-Rock outcrop complex with a south facing aspect on a 10° slope. The site had not burned in at least 100 years (Morris, 2006b). Total cover of the woodland was 47% with *J. osteosperma* making up 34% and *P. monophylla* was the remaining 13%. The understory cover was 38% grasses, 4% forbs, 9% shrubs and 49% bare ground. The dominant grasses remaining in the understory were *Poa secunda* (Sandberg bluegrass) and *Poa pratensis* (Kentucky bluegrass).

Site 1B was in a sagebrush steppe community with a south facing aspect on a 5° slope. The site had not burned in at least 100 years (Morris, 2006b). This was the only sampling location in the Poisonhol very stony loam unit. Total cover of the vegetation on site was 22% grasses, 6% forbs, 51% shrub and 21% bare ground. While dominated by the shrub, *A. tridentata*, the grasses at this site included *Hesperostipa comata* (needle and thread grass), *P. secunda* and *B. tectorum*.

Site 2 was in a pinyon juniper community within the Birchcreek-Itca complex a north facing aspect on a 2° slope. The site had not burned in at least 100 years (Morris, 2006b). Total cover of the woodland was 56% with 18% of the cover from *J. osteosperma* and 38% from *P. monophylla*. The understory cover was 27% grass, 29% forb, 13% shrub and 31% bare ground. This site had a substantial number of forbs in the understory in comparison to the other sites such as *Mertensia oblongifolia* (sagebrush bluebell), *Phlox longifolia* (longleaf phlox), and *Taraxacum officinale* (dandelion). The dominant grass was *P. secunda*.

Site 3 was in a burned pinyon-juniper woodland within the Itca-Birchcreek-Rock outcrop complex with a south facing aspect on an 8° slope. This site burned in 1999 (Morris, 2006b). Total cover of the former woodland could not be calculated as there were only scattered standing dead trees. The current cover at the site was 48% grasses, 23% forbs, 13% shrubs and 16% bare ground. Both forb and grass cover was dominated by introduced species such as *Alyssum desertorum* (desert alyssum) and *Descurainia sophia* (flixweed tansy mustard) as well as the introduced grass, *B. tectorum*.

Site 4 was formerly a pinyon-juniper woodland within the Birchcreek-Itca complex on a north facing aspect with a 10° slope. The site burned in 2000 and the previous woodland cover was unknown (Morris, 2006b). The current cover of the understory vegetation consisted of 38% grasses, 43% forbs, 6% shrubs and 13% bare ground. This site had a relatively diverse forb community in comparison to other sites. However, up to 29% of forb cover was from the introduced *Alyssum desertorum*. The introduced *B. tectorum* was the dominant grass and the shrub component was mainly the fire resistant *Chrysothamnus viscidiflorus* (rabbit brush).

Site 5 was formerly a pinyon-juniper woodland within the Itca-Birchcreek-Rock outcrop complex a south facing aspect on a 10° slope. The site burned in 2000 and the previous cover for the woodland was unknown (Morris, 2006b). The current cover of the understory vegetation consisted of 51% grass, 26% forbs, 1% shrubs and 22% bare ground. Although relatively high in grasses and forbs, this site was dominated by introduced and weedy species. The majority of grasses at this site were the introduced *B.*

tectorum and the site's forbs were mainly introduced mustards, *Alyssum desertorum* and *Sisymbrium altissimum* (tumble mustard).

Methods

Soil sampling

Soil sampling began in June 2006 and continued through October of 2007. At least two soil cores from the A horizon of the soil (approximately 10 to 20 cm in depth) were collected from each of the sites as near to vegetation transect tape as practical. Distance between cores was no more than 10 m and care was taken to core in locations that did not appear to be recently disturbed by burrowing animals. The soil cores were divided into approximately 1 cm increments. Given the relatively short time period of interest, we believed the small increments should better reflect changes in phytolith assemblage. We did not assume a constant rate of soil development over that time. The 1 cm increment was the smallest stable section that could be effectively obtained from the soil cores. Depths should be considered relative to each core rather than absolute because some compaction occurred during the sampling.

Carbon dating

One of the first assumptions we had to address was if the soils in our study area were stable and well stratified enough to examine questions of vegetation change over the period of interest. We conducted a carbon dating pilot study in 2006 on our initial soil cores. A set of four samples from two depths (5 cm and 10 cm) in two cores representing the two watersheds in the study area were sent to the National Ocean Sciences

Accelerator Mass Spectrometry Facility (Woods Hole, MA, USA) for radiocarbon dating. Carbon dating samples were prepared by grinding the core segment with a mortar and pestle, removing coarse material through a 250 μm sieve, weighing out between 3 to 5 grams of soil for each sample, and placing it in a labeled glass vial.

The results were useful indicators for locating the appropriate depth in our cores that would potentially represent our time period of interest. An additional set of eight samples were then sent to the same facility for radiocarbon dating. This additional radiocarbon dating was used to determine which soil segments to process and how to frame the time period of interest between the present and the Little Ice Age within our cores.

Extraction of phytoliths from soils

Phytoliths were extracted from soil core segments in the laboratory. We selected segments of the cores for processing based upon the carbon dating results so that surface segments could be compared with those from the Little Ice Age first. We then selected one site in each watershed in the study area that demonstrated overall site stability and that had more than one carbon date available to frame the timeline in the core for detailed processing of each 1 cm segment.

The phytoliths were extracted using a modified standard wet oxidation and heavy liquid flotation methods outlined by previous researchers (Blinnikov, 1994; Pearsall, 2000). Acid digestion of organic material was carried out with a heated 70% HNO_3 solution for one hour on 2 g of soil sifted through a 250 μm sieve. We dispersed clays with a 5% solution of sodium hexametaphosphate. Our heavy liquid for density

separation was sodium polytungstate (2.3 g cm^{-3}). The extractant was placed in a vial, dried at 80° C for 1-2 days. The extractant was stored dry in the vial.

The extracted material was weighed and recorded to four decimal points. Percent weight was determined by dividing the final extracted weight by the dry soil weight (2 g) and multiplying by 100 for each segment. The extractant weights are not solely from phytolith mass. The extractant includes some microscopic mica, quartz sand and charcoal because these materials have similar specific densities as phytoliths and float out with phytoliths during the extraction process (Piperno, 2006). The extractant also includes whole and broken portions of diatoms and sponge spicules that are also constructed of silica and, therefore, come out with the same density fraction as phytoliths. Some researchers have adjusted for the impurities in their sample weights by estimating the percentage of other material and subtracting that from the overall extractant weight (Evetts *et al.*, 2007). We did not apply any “correction estimations” to the extractant weights because we felt these could introduce error that could obscure the overall pattern revealed by the total weights. This pattern and reasoning are covered more thoroughly in the results and discussion sections.

We used multiple cores from all six sites in the extraction weight analysis. Part of the reason we sampled three recently burned (since 1999) areas and three unburned (in the last 100 years) areas was to make sure that extraction weights were not influenced by the one time massive deposition event during recent fires. Even though the sites that had burned were formerly pinyon-juniper woodlands which do not generate phytoliths, we wanted to see if the microscopic charcoal generated or phytolith deposition from all remaining grasses on the site during the fire would influence the weight.

Phytolith identification and counting

Identification of morphotypes used in this study was based on a reference collection of 143 species of common Great Basin native and introduced plants (Chapter 4). That study examined the relative frequencies of phytolith morphotypes in common native and introduced species of grasses (Table 7-1). Their frequency analysis showed that introduced grasses produced nearly half (15%) of the total rondel frequency compared to native grasses (28%). They also reported on the typical phytolith types found in forbs, shrubs and trees. Some common forms in forbs included hairs, hairbases, and silicified epidermal sheets. These forms are typically not well preserved in sediments (Piperno, 2006) although they have been recovered from soils in sagebrush steppe sites in the Columbia Basin by Blinnikov (2005). The dominant trees in our study site, pinyon and juniper do not produce identifiable phytoliths (Chapter 4). However, as mentioned previously, *Artemisia tridentata*, a very common shrub in our study area produces a recognizable “blocky” form (Blinnikov, 2005; Plate 7-1.n). Even so, grass phytoliths usually dominate phytolith counts even in sagebrush steppe sites (Blinnikov, 2005). “Stipa types” (Plate 7-1a) have a bilobate shape in top view with a trapezoidal bottom in cross section and are produced in the grasses from the Stipeae tribe (Fredlund and Tieszen, 1994; Blinnikov, 2005). Morris *et al.* (see Chapter 4) also noted that the long wavy plate morphotype in *F. idahoensis* usually had deep lobes (Plate 7-1.c).

Therefore, based upon previous morphotype frequency work in the Great Basin (Chapter 4) and the Columbia Basin sagebrush steppe ecosystem type (Blinnikov, 2005), we counted fourteen morphotypes that we believed would be useful for identifying

changes in the grass community, changes from native to introduced grass species, and representation of *Artemisia* (Plate 7-1). The nomenclature used for the fourteen morphotypes in this analysis follows the work of Morris *et al.* (see Chapter 4) and of Blinnikov (2005) who examined phytolith morphotypes in the nearby Columbia Basin. Their descriptions according to the International Code for Phytolith Nomenclature 1.0 were provided in Blinnikov (2005) and are not repeated here.

The morphotype differences between C₄ and C₃ grasses have been known for some time and used for understanding shifts in dominance of these grasses worldwide (Kaufman *et al.*, 1985; Twiss, 1992; Fredlund and Tieszen, 1994). Most of the grass species in the study area are cool season bunch grasses with a C₃ photosynthetic pathway. Of the 66 grass species known to exist in the study area (John, 1995), only 5 are C₄ grasses. One of those is the introduced *Echinochloa crus-galli* (John, 1995) which has had a controversial grouping with the native *Echinochloa muricata* in the past (Gould *et al.*, 1972) (Chapter 4). The only native C₄ grasses in the study area were: *Distichlis spicata*, *Muhlenbergia richardsonis*, *Sporobolus aeroides* and *Sporobolus cryptandrus*. None of our sampling sites contained these species presently or were typical sites where they would have occurred in the potential natural vegetation. We believe, therefore, that finding distinctive C₄ morphotypes (e.g. bilobates) may be useful indicators of introduced grasses, vegetation change, historical land uses and as time markers in the soil profile since their timeframe of introduction is known (Chapter 4). We scanned our slides for these types but did not include them in the sum.

A small standard amount of the soil phytolith extract was suspended in Canada Balsam oil to enable three dimensional viewing, placed under a cover slip and sealed

with clear fingernail polish for morphotype counting (Pearsall, 2000) using an Olympus BH-2 microscope. Typically, phytolith analysts count between 200 to 300 particles per slide (Piperno, 2006). We counted at least 200 phytoliths at 400x magnification by beginning at the left hand corner and working systematically down, across and up on each slide. We included the fourteen recognizable morphotypes in the total sum (Plate 7-1). We completed a full scan of the slides at 100x magnification to note any other morphotypes though they were not included in the sum (e.g. C₄ bilobates and forb hairs). We did not include phytoliths that were broken or partially dissolved so that the primary characteristic of identification could not be found. The level of dissolution was noted for each core.

We used the four sites (Sites 1B, Site 3, Site 4, and Site 5) that were dominated by introduced species (particularly *B. tectorum*) to test for the increase of rondels in older segments as a signal for native grass domination of the site in the past. We used the cores from Site 1A and at Site 3 for detailed analysis. These cores were selected for analysis because they were located on sites that appeared to be stable and well stratified. In addition, they shared several key characteristics such as soil type, slope, aspect, potential natural vegetation and recent invasion by pinyon-juniper woodlands. Both of these sites were also located in areas very near the historic overland emigration trail system and, therefore, shared similar grazing histories throughout the modern period (Morris, 2006a). One potentially important difference for phytolith composition was the current dominance of *Poa* species (with a moderately high total rondel frequency) at Site 1A and the current dominance of *B. tectorum* (with minimal total rondel frequency) at Site 3. The counting procedures and morphotypes were the same for both sets of analysis but

only the total percent rondel count is reported for the Sites 1B, Site 3, Site 4, and Site

5. The entire phytolith assemblage is reported for the detailed analysis in Sites 1A and Site 3.

Results

Carbon dating

Our carbon dating results demonstrated that the soils in these pinyon-juniper woodlands and sagebrush sites were well stratified and relatively stable over the period of interest (Table 7-2). In other words, based on these results we can assume that the youngest soils were on top and the oldest soils were below. A date of “>modern” was assigned by the lab to samples with at least 95% of the radiocarbon concentrations from calendar year 1950 to present. Kerns et al. (2001) referred to her surface samples as “modern” and her subsurface samples, that were also mostly modern carbon, as “pre-modern” to reflect the assumption of younger soils on top even if they were both “>modern.” This language seems appropriate for our results as well. We will, therefore, refer to the surface of the core (0-1 cm) as “modern” and the subsurface sections including the >modern dated segment as “pre-modern.” All of the other radiocarbon dates fell within the Little Ice Age (250 ± 35 to 905 ± 35 ^{14}C years B.P.). We can then frame our time period of interest between modern, pre-modern and Little Ice Age soil segments within the cores.

Extraction weights

The overall pattern across our multiple cores demonstrated a reduction in extraction weights in the modern core segments compared to the Little Ice Age segments. Both cores from each of the six sites were processed with the exception of Site 2 where one of the cores was found to be mislabeled. Therefore, a total of 11 cores with 32 core segments were processed. Twenty four of the segments were from 1 cm increments and eight of the segments came from 3-5 cm increments in the deepest part of the core.

There was variation in extraction weight between the sites as well as within sites from unburned (Figure 7-1) and burned sites (Figure 7-2). The burned areas tended to have more among site and within site variation as is shown in the differences in extraction weights at all three sites (3, 4, and 5). Site 5 had the most variation between cores. Even so, the modern segments had lower extraction weights than the Little Ice Age and deeper segments in 5 out of the 6 cores from burned sites. Only the first core from Site 5 was essentially unchanged in extraction weight between modern, Little Ice Age, and deeper segments. The unburned sites, on the other hand, had more consistent extraction weight patterns across and within sites. Typically, the lowest extraction percentage was in the modern segment, and it increased with depth to the dated Little Ice Age and deeper segments. The reduction in percent extractant weight was almost half of the highest weight in the oldest segments at most unburned sites.

Total rondel counts

The results from phytolith analysis of the total rondel counts were consistent with our prediction at only two of the four sites dominated by *B. tectorum* (Figure 7-3). Site

1B and Site 3 both showed a marked reduction in total rondel percentage in the modern segments compared to the Little Ice Age segments. In fact, total rondel percentages were reduced by nearly half at these two sites. Site 4 and Site 5, on the other hand, were not consistent with our prediction. The total rondel percentages at these sites were essentially unchanged between the modern and Little Ice Age segments.

Detailed core analysis

Detailed analysis of each centimeter segment between the dated portions of the two cores from Site 1A and Site 3 revealed additional information about extraction weights. The extraction weights at Site 1A varied throughout the core from 6-16% (Figure 7-4). There were two segments in the core where the extractant weights peaked: at 16-17cm (16%) and 12-13 cm (15%). The pattern seemed to follow our prediction that extraction weight would reflect the overall decrease in grasses at the site over time because the extraction weights dropped by nearly half from the 14-15 cm segment (370 ± 25 ^{14}C years B.P.) to the modern surface sample. By the beginning of the pre-modern segments (9-10 cm), the extractant weights had not gone below their historic range. However, the weights showed a steady decline through the sampled pre-modern segments beginning in the 8-9 cm segment (10%) and into the modern segment (6%).

The detailed analysis between these two cores also revealed additional information regarding total rondel counts and the soil phytolith assemblages. The total rondel percentages varied throughout the core in Site 1A (Table 7-3 and Figure 7-5). Total rondel percentages throughout the core ranged from 20% to 31%. The highest values for total rondels (25-31%) were in the four deepest segments (13-14 cm to 16-17

cm). Total rondel percentages declined abruptly between the 13-14 cm (31%) segment and the 12-13 cm segment (21%). The total rondel counts for the segments from the 12-13 cm and the 10-11 cm segment remained at lower percentages (20-22%) than the deepest four segments. Similarly, the pre-modern segments (9-10 cm to 4-5 cm) remained at percentages (20-24%) that were lower than the deepest segments. Site 5 and Site 1A were on similar soils with the same aspect and the same slope. The total rondel percentage at Site 1A from the 9-10 cm to 12-14 cm segments ranged from 20-22% where Site 5 at the 9-10 cm segment (250 ± 50 ^{14}C years B.P.) had 20% total rondels.

The soil phytolith assemblage at Site 1A also changed through each segment within the core and over time. Grass phytoliths dominate the record with blocky forms from *Artemisia* making up 1-7% of the total sum. The blocky forms of *Artemisia* fluctuated in the Little Ice Age segments (12-17 cm) from 1-4% and then dropped abruptly between 13-14 cm segment (6%) and the 12-13 cm segment (2%). The blocky forms increase just as abruptly back to 7% by the 11-12 cm segment and then remain consistent at 6% into the pre-modern and modern segments. As with the total rondel percentages, there were changes in the representation of several key morphotypes that began to shift between the 12-13 cm and 13-14 cm depths. It was here that the stipa type peaked, going from 1% to 4%, the wavy plates with deep lobes dropped from 12% to 5% and remained low, long wavy plates increased from 18% to 25%, keeled rondels decreased from 17% to 2%, horned rondels dropped from 9% to 6% and pyramidal rondels increased from 5% to 12%. Finally, it is at this 12-13 cm depth that the blocky morphotypes drop to a low of 2% and then quickly jump and maintain a higher level through to the modern segment. The long wavy plate with deep lobes, indicative of *F.*

idahoensis, was relatively more abundant in the deeper portions of the core (7-13%) and declined into the pre-modern segments. The long indented cells and keeled rondels also increased throughout the pre-modern segments from 10% to 16%. We observed a great deal of dissolution and breakage of the phytoliths in this core beginning with the surface segment and progressing through the core.

Site 3 also had variable extractant weights throughout the entire core (Figure 7-4). The extractant weights ranged from 8-25%. Extractant weights were the same between the modern surface segment and the 14-15 cm segment (695 ± 30 ^{14}C years B.P.). However, the oldest segment at 19-20 cm (950 ± 35 ^{14}C years B.P.) had nearly twice as much extractant weight (14%) than the modern surface segment (8%). The oldest segments did not have the greatest extraction weights in the core, and this pattern did not appear to support our prediction that the lowest extraction weights would be in the modern samples and the highest in the Little Ice Age segments. However, it does still appear to follow our prediction of loss of grasses at the site with pinyon-juniper woodland encroachment in the more recent sediments. In fact, the extractant weight peaked at the 11-12 cm segment (25%) and then declined again in the next segment (16%) and through the pre-modern segment (9-10 cm). The extraction weights dropped by nearly half between the oldest segment (19-20cm) (14%) and the modern surface (8%) and between the pre-modern segment (16%) to the modern surface (8%). This was similar to patterns in the multiple core weight analysis.

Site 3 also appeared to support our prediction regarding the reduction in total rondel percentages at sites that were dominated by the introduced species of grass, *B. tectorum* (Table 7-4 and Figure 7-6). Total rondel counts in this core ranged from 13% to

30%. The total rondel percentages were highest (27-30%) in the deepest three segments including the Little Ice Age segment (695 ± 30 ^{14}C years B.P.). Total rondel percentages declined from 30% to 23% between the 12-13 cm and 11-12 cm segments. They remained fairly consistent (23-26%) between 11-12 cm segment and the pre-modern segment at 9-10 cm. Then, they decreased by nearly half from the pre-modern segment (26%) to the modern surface segment (13%). Total rondel percentages declined by similar amounts across the different cores from Site 3 at the same depth (Figure 7-3 and Table 7-4). The detailed core total rondel percentage went from 27% at the 14-15 cm segment to 13% in the modern surface segment while the 14-15 cm segment from the multiple core study went from 19% to 12% in the modern surface segment.

The overall soil phytolith assemblage also changed over time throughout the core at Site 3. Grass phytoliths dominated the record with the blocky forms of *Artemisia* making up 3-8% of the total sum. Similar to the results in Site 1A, representation of several key morphotypes began to shift between the 11-12 cm and 12-13 cm segments. It was here that the stipa types reached a peak from 5% to 9%, keeled rondels declined 16% to 9%, and horned rondels increased slightly from 8% to 10% followed by a decline in the pre-modern and modern segments. Pyramidal rondels and wavy plate with deep lobes did not change as much as in Site 1A. In this core, the wavy plates with deep lobes were generally lower (6-8%) throughout all segments. However, like Site 1A, between the 11-12 and 12-13 cm segments, the total rondel percentage dropped by nearly 10% and blocky types for *Artemisia* also reached a low. The blocky types then jump to 8% in the pre-modern segment and drop again to 4% in the modern surface segment. Stipa types began declining into the pre-modern segment. Pyramidal rondels, keeled rondels and

horned rondels all declined from the pre-modern to modern segment. The phytoliths in this core become progressively broken and weathered with depth in the core.

We did not encounter any of the phytoliths typically associated with native or introduced forb species in the Great Basin (Chapter 4) including hairs, hair bases, and silicified epidermal cells in the detailed cores. Nor did we see any of papillae that were dominant in the frequency analysis. We observed the hairs of the introduced *Alyssum desertorum* (Chapter 4) in surface samples from Site 3 used in multiple core analysis. We also encountered two bilobate morphotypes that appeared to be from introduced C₄ grasses at the surface of Site 3 and at Site 1A in segment 12-13 cm. Other hairs (e.g. square-based and oblong knobby hairs) that were common in the frequency analysis were encountered and included in the sum. However, there were not any interpretable patterns associated with these hairs that we could detect.

Discussion

Extraction weights

The results from our extraction weight analysis appeared to support our prediction that increases in woody vegetation over grasses would be reflected in extraction weight due to limited production of phytoliths in the woody species. The extraction weights from the multiple core study showed decreases of nearly 50% in weight from the surface to the Little Ice Age layers at most sagebrush sites and those recently dominated by pinyon-juniper woodland. Since most of our sampling locations were in areas where pinyon-juniper woodlands had recently encroached and dominated the site, more sampling should be done to examine extraction weights and sagebrush cover. However,

the decrease in extraction weights seemed to be strongly linked to the recent increase in pinyon-juniper woodlands. Evidence for this claim comes from the multiple core results as well as connections with extraction weight coupled with the information from the detailed core analysis.

The extraction weights in the detailed core at Site 1A reached maximum in the segments where the blocky phytoliths indicating *Artemisia* were the lowest percent of the sum. As *Artemisia* representation increased, the extraction weight actually decreased. This would be expected if the increased in woody vegetation was replacing the grasses. However, the extraction weights continue to decrease even though the *Artemisia* percentages did not change in the pre-modern and modern segments of the core. What was likely represented in this pre-modern and modern timeframe was increasing cover and density of the pinyon-juniper woodlands as well as increased grazing pressure (Morris, 2006a).

Likewise, the detailed core analysis at Site 3 showed a similar connection with pinyon-juniper woodland density. The extraction weight in the core at Site 3 also peaked at the time in which *Artemisia* representation was the lowest in the sum. The extraction weights continually decreased with increasing *Artemisia* representation, but the lowest extraction weight does not correspond with the highest percentage of sagebrush. In addition, the extraction weights and the *Artemisia* representation currently match the Little Ice Age segment (695 ± 30 ^{14}C years B.P.). However, the extraction weights followed the same pattern as Site 1A and decreased over time in the pre-modern to modern segments. Again, this change seems to correspond to an increase in pinyon-juniper woodland cover and increasing livestock grazing pressure (Morris, 2006a).

Increasing pinyon and juniper cover is known to suppress understory vegetation including sagebrush (Everett *et al.*, 1983; West, 1991, 1999). Suppression comes not only from above ground cover and duff accumulation but also from dominance of the soil resources by the roots of *J. osteosperma* (Everett *et al.*, 1983; West, 1991, 1999).

The pattern of extraction weights is consistent with increasing pinyon-juniper woodland cover in the recent past. However, more information is still needed to interpret the fluctuating extraction weight patterns in the deepest portions of both cores. Although they may appear to represent alternating pinyon-juniper woodland and grass domination at the sites, there is no evidence to support woodland encroachment during the Little Ice Age. In fact, woodland densities over the past approximately 200 years are generally three times greater than they were at the end of the Little Ice Age (Tausch, 1999). Expansions of these woodlands in the just the last 130 years exceed anything that is found in other proxy records (e.g. woodrat middens and pollen) in the last 5,000 years (Miller and Wigand, 1994; Tausch, 1999). Since there are no recognizable phytoliths for *P. monophylla* or *J. osteosperma*, we cannot demonstrate that these were the cause of fluctuation in weight. Connections to other biological proxy records are needed for more interpretation in this matter.

Our extraction weights were higher than the “corrected” percent weights reported in other studies (Fisher *et al.*, 1987; Kerns *et al.*, 2001; Evett *et al.*, 2007). The soils in the City of Rocks are formed on granitic parent material containing mica, schist and quartzite that come out in the same density fraction as biogenic silica. We did not use counts or percent cover of impurity estimations as others have done because we did not want to introduce a potential estimation error into the data. Our uncorrected extraction

weights matched the ratios reported in other studies even if not their “corrected” values (Fisher *et al.*, 1987; Fredlund and Tieszen, 1997). For example, Fisher *et al.* (1987) reported corrected mean percent weights in their forested sites (0.53 ± 0.035 se) that were half of those in their prairie sites (1.05 ± 0.018 se). Although there are variations in soils types, deposition variables and preservation rates across ecosystem types, this was the closest analogue to our study using weight analysis. Furthermore, we examined the potential for a one time deposition event of fire to increase extraction weights. We found that fire did not increase extraction weights, and that microscopic charcoal impurities were not overshadowing the weights. Therefore, we believe that the higher values of our weights showed the influence of the soil parent material and that the ratios of our extractant weights were consistent with those reported in the literature.

Total rondel percents

We predicted that total rondel percentages would be less in the surface segments than in older subsurface segments across the multiple cores due to the increased dominance of introduced grasses. The relative abundances of total rondels do reflect the change in dominance from native to introduced grasses over time if the soils have been relatively stable. This pattern was especially pronounced at sites that were presently dominated by the invasive grass *B. tectorum*. This change was evident at two sites in the multiple core study. Total rondel percentages in the surface segments at Site 1B and Site 3 were nearly half those in the older, deeper segments. This change coincides with the frequency analysis of rondel production between native and introduced grasses showing native production is nearly twice that of introduced grasses. However, the pattern did not

hold for the other two sites. We believe that the surface soil segments at Site 4 and Site 5 experienced erosion and mixing following the recent fire in 2000. The variation of the extraction weights between cores and the lack of variation in total rondel counts support this conclusion. The similarity of total rondel counts at similar depths across the cores at Site 5 and Site 1A suggested that only the surface sediments mixed and the deeper portions remained stable.

The pattern of reduction in total rondel percentages was evident in the detailed core analysis as well. In the core used for detailed analysis at Site 3, the total rondel count decreased by 50% from the pre-modern segment to modern surface segment and was also nearly half of the total rondel percentages in all the deeper (and older) segments. Declines in total rondel percentages were also similar in the different cores from Site 3. The total rondel percentage declined in the detailed core at Site 1A but not as much as at sites dominated by *B. tectorum*. This was probably due to the fact that Site 1A is currently dominated by *Poa* species which also tend to produce moderately high percentages of rondels.

We observed that areas with the greatest cover of *Agropyron desertorum* had been seeded in the past (unpublished data). Since we had to sample from untilled areas, we did not directly test changes in total rondel percentages under dominance of this species. Even so, this and other species of introduced grass in the study area could influence the phytolith record through wind transport and livestock dung. This grass, as well as the other common introduced species will spread easily in these ecosystem types, but none has been as widespread dominant an invader as the *B. tectorum* (Bradley and Mustard,

2005). *Bromus tectorum* was the most common invasive grass species on sites with no cultivation (Morris, 2006a).

Evidence of vegetation change in the detailed core analysis

The detailed analysis of soil cores by one centimeter segments demonstrated that phytolith assemblages changed over time at a very fine scale with continuous sampling. These phytolith assemblages also appeared to be linked to known vegetation changes and they shared commonalities across cores.

The phytolith assemblages at Site 1A changed from the bottom of the core, representing the Little Ice Age (~ 500 cal. years B.P.), to the pre-modern and modern segments. The phytolith assemblages from approximately 13-17 cm in depth were consistent with what would be expected during generally cooler and wetter conditions of this time period. For example, the total rondel percentages were the highest we found (25-31%). Blinnikov (2002) reported that total rondel percentages in the Columbia Basin in the range of 30% were indicative of *F. idahoensis*, and also implied cooler, wetter conditions. The long wavy plates with deep lobes, also indicative of *F. idahoensis*, were also relatively more abundant in these deeper portions of the core. Finally, keeled rondels, also produced with relatively high frequency in *F. idahoensis*, were relatively high in the deeper portions of the core.

There was an apparent shift in the phytolith assemblage between the 12-13 cm and 13-14 cm segments at Site 1A where *Artemisia* blocky forms, deeply lobed (*Festuca*) morphotypes, keeled and horned rondels, and the total rondel percentage all decreased while the stipa types increased. This shift suggests a drying period at the site (Blinnikov

et al., 2002). The morphotypes for both *Festuca* (e.g. long wavy with deep lobes and keeled rondels) and Stipeae tribe grasses (*A. hymenoides*, *A. nevadense* and *H. comata*) declined after this segment. Long wavy plate morphotypes began to increase around the same time that the *Festuca* deep lobed wavy plates dropped. This could reflect an increase in the *P. spicata* at the site as it is also a common producer of this morphotypes. *Festuca idahoensis* is commonly replaced by *P. spicata* and Stipeae grasses when moisture decreases or there is strong grazing pressure (USDA, 2007).

Grass composition also changes in the pre-modern to modern segments. The stipa types peaked at 12-13 cm segment then decrease steadily into pre-modern and modern portions. Coincident with the decrease in Stipeae grasses were the indications of an increasing contribution of the *Poa* species from long indented cells and keeled rondels. This loss of the Stipeae grasses is consistent with what is known about both grazing pressure and increasing pinyon-juniper cover at the site. While Stipeae grasses (e.g. *H. comata* and *A. hymenoides*) and *Poa* species are all palatable to livestock, *P. secunda* is more resistant to grazing, trampling, and increasing cover and duff from of pinyon-juniper woodlands (Everett *et al.*, 1983; Monsen *et al.*, 2004). *Poa* species now dominate grass cover under the canopy at this site.

The phytolith assemblages at Site 3 also changed from the bottom of the core, representing the Little Ice Age (~ 700 cal. years B.P.) to the pre-modern and modern segments. In this core, the bottom three segments from 12-15 cm also seemed to reflect the generally cooler and wetter climate during the Little Ice Age. As in Site 1A, the total rondel percentage were much higher in these segments and were within the 30% range that Blinnikov (2002) said represented *Festuca* dominated, cooler and wetter sites. The

wavy plate with deep lobes, typical of *F. idahoensis*, remained fairly consistent in this core. Dissolution and breakage may have played a role here. The deep lobes on this morphotype can be broken or worn down. The deepest segments in this core were older and had a great deal of breakage and dissolution. However, the keeled rondel morphotypes, also produced in high frequency in this grass were highest in these lower sections of the core.

Similar to the core in Site 1A, there was an apparent shift in the phytolith assemblage that occurs between two segments. In Site 3, this shift occurred between the 11-12 cm and the 12-13 cm segments. As was observed at Site 1A, there was a drop in the total rondel percentage, keeled rondels and the *Artemisia* blocky types between these depths. In addition, the stipa types increased sharply. Horned rondels, also produced with great frequency in Stipeae grasses, began to rise. Again, this shift suggested a change to a drier climate at the site around this time. This could represent the end of the Little Ice Age.

Vegetation also changed in the time represented by the pre-modern segment and modern segments. After the spike in representation of the stipa type and horned rondels indicative of the Stipeae grasses, these types declined over time into the pre-modern segment. Across the same segments, the representation of the *Artemisia* blocky form increased. This pattern appeared to reflect the known increase in sagebrush cover, loss of native grasses, and then encroachment of pinyon-juniper onto the site. These changes could be from increasing grazing pressure, drought and encroachment of the pinyon-juniper woodland. The decline by 50% in the representation of the total rondels seemed

to support the increasing dominance of the invasive *B. tectorum* at the site. Unlike Site 1A, this site burned in 1999 and was dominated by invasive grasses and forbs.

Our interpretations of the changes in these phytolith assemblages were similar to other findings from soil sediments. Blinnikov (1994) was the only study that we are aware of in which fine scale continuous sampling (0-2 cm segments to 15-30 cm total depth) of natural soil sediments was used to examine vegetation change. His study was conducted in alpine soils of the Northwestern Caucasus, Russia (Blinnikov, 1994). He also found that the soil phytolith assemblages changed over time with fine scale continuous sampling. Increases in the morphotype associated with *Nardus stricta* in the upper segments, a grass typically avoided by sheep, was interpreted to reflect historic overgrazing. Kerns *et al.* (2001) found changes the phytolith assemblage between surface segments (0-2 cm) they called “modern” and subsurface segments (2-7 cm) they called “premodern”. They observed a decrease from surface to subsurface samples in a crenate morphotype (similar to our wavy types) that were typical of two native grasses, *Koeleria macrantha* and *Bromus ciliatus*. Because these grasses are palatable forage species, they suggested that the decrease could be related to excessive grazing. In addition, these researchers pointed to the negative impacts of duff buildup under forest canopies to grass production as a related cause. Their findings and explanations are consistent with ours.

Effectiveness of phytolith morphotypes in the detailed core analysis

Some of the morphotypes that made up a substantial portion of the frequency analysis were not useful in interpreting the soil phytolith assemblage. Although the

different types of grass hairs appeared to be important indicators for different native and introduced species in the frequency analysis, their patterns within the soil were not useful. For example, the oblong knobby hair was produced with great frequency by *H. comata*, but its representation within the sums did not fit with any of the other patterns demonstrated throughout the cores. Likewise, pyramidal rondels were not a useful indication of vegetation change. Long deeply indented cells that can be prevalent in the Triticeae tribe of grasses (e.g. *Hordeum brachyantherum* and *Elymus elymoides* and *Agropyron desertorum*) were negligible and not used in our interpretation.

Other researchers have pointed to morphotypes such as papillae (Blinnikov *et al.*, 2002) or long hairs (Fisher *et al.*, 1995) as indicative of the introduced grass species *B. tectorum*. Our frequency analysis also showed highest frequencies of papillae in *Bromus*. Fisher *et al.* (1995) reported significant decreases between surface samples and buried horizons in the long hair morphotypes as a sign of current dominance of this invasive grass. Blinnikov *et al.* (2002) also recovered hairs, hair bases and epidermal sheets typical of herbaceous plants from modern soils, loess, and paleosols. We did not count any papillae, long hairs or epidermal sheets in our samples. We observed hairs in our sediments but very few of the types found in herbaceous plants in our reference collection (Chapter 4). Our use of a 250 μm sieve should not have excluded all of them from our slides and our methods of extraction and counting closely followed Blinnikov *et al.* (2002). Perhaps differences in preservation rates in the soil types between our study sites were a factor in the absences of these phytoliths in our samples. Dissolution and breakage of the phytoliths seemed high in both cores, especially at the surface of the younger segments in Site 1A. It may also be more effective to separate the silt and sand

fractions as others do in forested systems to help increase counts of large, rare morphotypes like hairs (Piperno, 2006).

We did observe several of the bilobate morphotypes associated with introduced C₄ grasses at two sites at different depths. At Site 3, they were observed in the surface segments as would be expected if these morphotypes were an indication of introduced species. They were also observed at Site 1A in the 12-13 cm segment where the overall phytolith assemblage begins to shift and the extraction weight peaks. This observation could represent the beginning of overland emigration in the area or the introduction of livestock. Both could have transported C₄ grass morphotypes in dung, mud, fur, boots and the like. However, this is purely speculation at this point and should be explored in further sampling.

Evaluation of the method

In general, our results indicated that soils in pinyon-juniper woodlands and sagebrush steppe can be stable and stratified well enough to reflect changes in vegetation over time using soil phytolith analysis. This seemed to be the case for both the historic period (~200 years) and the Little Ice Age. However, an understanding of the site history was crucial for choosing a site sampling selection and interpretation with this method because many areas containing these ecosystem types have been plowed historically (Chapter 3). As can be seen from the variations in extraction weight between cores at burned sites and the insensitivity of total rondel percentages, areas that have not burned recently may be preferable sampling locations. This is particularly true if the analysis will include portions of the pre-modern soils because there could be more mixing from

erosion in the upper segments associated with the fire. We did not do any additional sampling between the pre-modern and modern surface segments at Site 3 because of this.

Our results also showed the importance of using multiple cores. This type of analysis helped locate more stable sites and provided more rigor for the interpretation as comparisons could be made within sites and across them. For example, comparing multiple cores helps rule out the potential interference of the pattern from current or historic animal burrows. It would be useful to test for a few known changes in the vegetation as we have done here before embarking on detailed core analysis. Also, our pilot study for carbon dating from several different cores was very useful for narrowing down the portions of the cores for further dating and analysis. The detailed core analysis of continuous segments in 1 cm increments was most useful for conducting detailed vegetation change studies. Clearly, there was more to be learned from the transitions in between the Little Ice Age, pre-modern and modern segments than 2-3 samples per core could provide.

Conclusion

This is the first study to examine the use of soil phytoliths in a continuous core sampling method in these ecosystem types. We found that these soils can be stable and well stratified enough to record changes in the vegetation if the sampling is done with care to find unburned sites with gentle slopes outside of cultivated areas. The utility of soil phytolith analysis was tested by looking for known vegetation changes in the soil stratigraphy such as increased cover of woody species like sagebrush and pinyon-juniper woodlands. Extraction weights tracked increases in pinyon-juniper woodland cover and

density in the recent past. Phytolith assemblages in the soil stratigraphy also reflected increasing dominance of invasive grass species like *B. tectorum*. Finally, detailed analysis at a fine scale of extraction (1 cm increments) revealed shifts in soil phytolith assemblages that suggested connections to changes in climate, vegetation and land uses from the Little Ice Age to present. Soil phytolith analysis appears to hold promise as a biological proxy for understanding historic and prehistoric environmental conditions, and it deserves further exploration and research.

We interpreted our phytolith assemblages from the detailed cores using frequency analysis of phytolith production in extant plants and from modern analogues in the literature that relate assemblages to present vegetation in reference areas. Future research should seek more information about historic plant communities in these ecosystem types through modern analogue studies of reference areas. Reference sites for this type of modern analogue study were not available in the City of Rocks, particularly in the valleys where a great deal of historic soil disturbance occurred with dry farming and forage seeding in the past. Based on our findings, soil phytolith analysis is a useful biological proxy for examining vegetation changes since European settlement as well as into the Little Ice Age. More work should be done combining the human archive and soil phytolith analysis as modern analogue studies from within the Great Basin region to explore its utility.

References

- Blinnikov, M. S.** 1994: Phytolith analysis and Holocene dynamics of alpine vegetation. In Onipchenko, V.G., and Blinnikov, M. S., editors, *Experimental investigation of alpine plant communities in the north-western Caucasus*. Veröffentlichungen des Geobotanischen Institutes der ETH, Stiftung Rubel, 23-40.

- Blinnikov, M. S.** 2005: Phytoliths in plants and soils of the interior Pacific Northwest, USA. *Review of Palaeobotany & Palynology* 135, 71-98.
- Blinnikov, M. S., Busacca, A., and Whitlock, C.** 2002: Reconstruction of late Pleistocene grassland of the Columbia Basin, Washington, USA, based on phytolith records in loess. *Palaeogeography, Palaeoclimatology, Palaeoecology* 177, 77-101.
- Bonham, C. D.** 1989: *Measurements for terrestrial vegetation*. John Wiley & Sons.
- Boyd, M.** 2002: Identification of anthropogenic burning in the palaeoecologic record of the northern prairies: a new approach. *Annals of the Association of American Geographers* 92, 471-487.
- Bradley, B. A., and Mustard, J. F.** 2005: Identifying land cover variability distinct from land cover change: cheatgrass in the Great Basin. *Remote Sensing Environment* 94, 204-213.
- Carnelli, A. L., Theurillat, J. P., and Madella, M.** 2004: Phytolith types and type-frequencies in the subalpine-alpine plant species of the European Alps. *Review of Palaeobotany & Palynology* 129, 39-65.
- Daugherty, R. E.** 1988: *Legislative land cost estimate for City of Rocks National Reserve, Cassia County, Idaho*. National Park Service Pacific Northwest Region.
- Delhon, C., Alexandre, A., Berger, J. F., Thiebault, S., Brochier, J. L., and Meunier, J. D.** 2003: Phytolith assemblages as a promising tool for reconstructing Mediterranean Holocene vegetation. *Quaternary Research* 59, 48-60.
- Egan, D., and Howell, E. A.** 2001: *The historical ecology handbook: a restorationist's guide to reference ecosystems*. Island Press.
- Everett, R. L., Sharrow, S. H., and Meeuwig, R. O.** 1983: Pinyon-juniper woodland understory distribution patterns and species associations. *Bulletin of the Torrey Botanical Club* 110, 454-463.
- Evet, R. R., Franco-Vizcaino, E., and Stephens, S. L.** 2007: Phytolith evidence for the absence of a prehistoric grass understory in a Jeffrey pine-mixed conifer forest in the Sierra San Pedro Martir, Mexico. *Canadian Journal of Forest Resources* 37, 306-317.
- Fisher, R. F., Jenkins, M. J., and Fisher, W. F.** 1987: Fire and prairie-forest mosaic of Devil's Tower National Monument. *American Midland Naturalist* 117, 250-257.

- Fisher, R. F., Newell Bourne, C., and Fisher, W. F.** 1995: Opal phytoliths as an indicator of the floristics of prehistoric grasslands. *Geoderma* 68, 243-255.
- Fredlund, G. G.** 2001: Inferring vegetation history from phytoliths. In Egan, D., and Howell, E. A., editors, *The historical ecology handbook: a restorationist's guide to reference ecosystems*. Island Press, 335-362.
- Fredlund, G. G., and Tieszen, L. T.** 1994: Modern phytolith assemblages from the North American Great Plains. *Journal of Biogeography* 21, 321-335.
- Fredlund, G. G., and Tieszen, L. T.** 1997: Phytolith and carbon isotope evidence for Late Quaternary vegetation and climate change in the Southern Black Hills, South Dakota. *Quaternary Research* 47, 206-217.
- Golyeva, A.** 2001: Biomorphic analysis as a part of soil morphological investigations. *Catena* 43, 217-230.
- Gould, F. W., Ali, M. A., and Fairbrothers, D. E.** 1972: A revision of *Echinochloa* in the United States. *The American Midland Naturalist* 87, 36-59.
- HRA, H. R. A.** 1996: *Historic resources study: City of Rocks National Reserve southcentral Idaho*. National Park Service Pacific West Field Area Columbia-Cascade System Support Office.
- John, T.** 1995: *Vascular plants of City of Rocks: an annotated checklist*. National Park Service.
- Kalisz, P. J., and Boettcher, S. E.** 1990: Phytolith analysis of soils at Buffalo Beats, a small forest opening in southeastern Ohio. *Bulletin of the Torrey Botanical Club* 117, 445-449.
- Kaufman, P. B., Dayanandan, P., Franklin, C. I., and Takeoka, Y.** 1985: Structure and function of silica bodies in the epidermal system of grass shoots. *Annals of Botany* 55, 487-507.
- Kerns, B. K.** 2001: Diagnostic phytoliths for a ponderosa pine-bunchgrass community near Flagstaff, Arizona. *The Southwestern Naturalist* 46, 282-294.
- Kerns, B. K., Moore, M. M., and Hart, S. C.** 2001: Estimating forest-grassland dynamics using soil phytolith assemblages and $\delta^{13}\text{C}$ of soil organic matter. *Ecoscience* 8, 478-488.
- Klein, R. L., and Geis, J. W.** 1978: Biogenic silica in the Pinaceae. *Soil Science* 126, 145-156.

- Kurmann, M. H.** 1985: An opal phytolith and palynomorph study of extant and fossil soils in Kansas (U.S.A). *Palaeogeography, Palaeoclimatology, Palaeoecology* 49, 217-235.
- Little, W. J.** 1994: *A historical overview of livestock use in the area of City of Rocks National Reserve from introduction to 1907*. Unpublished report for the National Park Service, copy on file at the City of Rocks National Reserve.
- Millar, C. I., and Woolfenden, W. B.** 1999: The role of climate change in interpreting historical variability. *Ecological Applications* 9, 1207-1216.
- Miller, R. F., Svejcar, T. J., and West, N. E.** 1994: Implications of livestock grazing in the Intermountain sagebrush region: plant composition. In Vavra, M., Laycock, W. A., and Pieper, R. D., editors. *Ecological implications of livestock herbivory in the west*, Society for Range Management Publications, 101-146.
- Miller, R. F., and Tausch, R. J.** 2001: The role of fire in juniper and pinyon woodlands: a descriptive analysis. In Galley, K. E. M., and Wilson, T. P., editors, *Proceedings of the invasive species workshop: The role of fire in the control and spread of invasive species, fire conference 2000: The first national congress on fire ecology, prevention, and management*. Miscellaneous publication number 11, Tall Timbers Research Station, 15-30.
- Miller, R. F., and Wigand, P. E.** 1994: Holocene changes in semiarid pinyon-juniper woodlands: response to climate, fire, and human activities in the US Great Basin. *BioScience* 44, 465-474.
- Monsen, S. B., Stevens, R., and Shaw, N. L.** 2004: *Restoring western ranges and wildlands*. General Technical Report RMRS-GTR-136-vol-2. USDA Forest Service, Rocky Mountain Research Station.
- Morris, L.** 2006a: *Ecological history of the City of Rocks National Reserve, Part I: the human archive*. National Park Service Pacific Northwest Region.
- Morris, L.** 2006b: *Fire history of the City of Rocks National Reserve from 1926 to 2005*. National Park Service Pacific Northwest Region.
- Pearsall, D. M.** 2000: *Paleoethnobotany: a handbook of procedures*. Academic Press.
- Piperno, D. R.** 2006: *Phytoliths: a comprehensive guide for archaeologists and paleoecologists*. AltaMira Press.
- Piperno, D. R., and Becker, P.** 1996: Vegetational history of a site in the central Amazon basin derived from phytolith and charcoal records from natural soils. *Quaternary Research* 45, 202-209.

- Roberts, N.** 1998: *The Holocene: an environmental history*. Blackwell Publishers.
- Rovner, I.** 1971: Potential of opal phytoliths for use in paleoecological reconstruction. *Quaternary Research* 1, 343-359.
- SCS.** 1994: *Soil Conservation Service: soil survey of Cassia County, Idaho, eastern part*. US Department of Agriculture.
- Stoddart, L. A.** 1941: The Palouse grassland association in northern Utah. *Ecology* 22.
- Stromberg, C. A. E.** 2004: Using phytolith assemblages to reconstruct the origin and spread of grass-dominated habitats in the great plains of North America during the late Eocene to early Miocene. *Palaeogeography, Palaeoclimatology, Palaeoecology* 207, 239-275.
- Swetnam, T. W., Allen, C. D., and Betancourt, J. L.** 1999: Applied historical ecology: using the past to manage for the future. *Ecological Applications* 9, 1189-1206.
- Tausch, R. J.** 1999: Historic pinyon and juniper woodland development. In Monsen, S. B., Stevens, R., Tausch, R. J., Miller, R. F., and Goodrich, S., editors, *Proceedings: ecology and management of pinyon-juniper communities within the Interior West*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, RMRS-P-9, 12-19.
- Twiss, P. C.** 1992: Predicted world distribution of C₃ and C₄ grass phytoliths. In Rapp Jr., G., and Mulholland, S. C., editors, *Phytoliths systematics: emerging issues*. Plenum Press, 113-128.
- USDA.** 2007: *The PLANTS Database* National Plant Data Center (<http://plants.usda.gov>).
- West, N. E.** 1983: Western intermountain sagebrush steppe. In West, N. E., editor, *Temperate deserts and semi-deserts*. Elsevier Scientific Publishing Company, 351-374.
- West, N. E.** 1991: Junipers of the Western US: classification, distribution, ecology and control. In James, L. F., Evans, J. O., Ralphs, M. H., and Child, R. D., editors, *Noxious range weeds*. Westview Press, 325-333.
- West, N. E.** 1999: Juniper-pinyon savannas and woodlands of western North America. In Anderson, R. C., Fralish, J. S., and Baskin, J. M., editors, *Savannas, barrens, and rock outcrop plant communities of North America*. Cambridge University Press, 288-308.

West, N. E., Rea, K. H., and Tausch, R. J. 1975: Basic synecological relationships in juniper-pinyon woodlands. In Gifford, G. F. and Busby, F. E., editors, *The pinyon-juniper ecosystem: a symposium*. Utah State University, 41-53.

WRCC, W. R. C. C. 2006: Climate of Idaho. <http://www.wrcc.dri.edu> accessed 2006.

Young, J. A., and Sparks, B. A. 2002: *Cattle in the cold desert, expanded edition*. University of Nevada Press.

Table 7-1 Morphotype frequencies of the ten native and introduced grasses in CIRO. Frequencies are expressed as a percent of total counted.

Species Name	Bilobate	Cross	Stipa Type	Plate wavy short	Plate wavy long	Long cell smooth	Long deeply indented	Long cell indented	Plate rectangular	Square-based hair	Round-based hair	Oblong knobby hair	Papillae	Pyramidal rondel	Keeled rondel	Horned rondel	Total Rondel	Other	Total
Native Grasses																	27		
<i>Achnatherum hymenoides</i>	0	0	39	1	0	28	1	1	5	1	8	0	0	1	1	10	13	1	136
<i>Achnatherum nevadense</i>	0	0	15	13	1	4	0	0	1	1	1	3	1	0	0	0	0	47	165
<i>Hesperostipa comata</i>	0	0	8	0	0	3	3	1	0	0	5	16	2	11	12	32	55	2	130
<i>Elymus lanceolatus</i>	0	0	0	0	0	6	1	6	1	1	2	0	0	13	45	24	82	3	120
<i>Poa secunda ssp. juncifolia</i>	0	0	0	2	6	20	6	13	1	6	1	0	0	8	7	4	18	25	109
<i>Poa secunda ssp. secunda</i>	0	0	0	5	1	14	5	9	1	0	11	0	15	4	21	0	24	14	111
<i>Pseudoroegneria spicata</i>	0	0	0	2	15	22	1	11	0	18	4	0	0	10	9	0	19	8	123
<i>Festuca idahoensis</i>	0	0	0	0	50	10	15	3	1	0	0	1	0	0	18	3	20	0	120
<i>Hordeum brachyantherum</i>	0	0	0	0	5	7	33	0	2	0	11	2	0	4	31	5	40	0	132
<i>Elymus elymoides</i>	0	0	0	6	14	9	17	2	4	1	14	0	1	14	6	0	20	13	112
<i>Leymus cinereus</i>	0	0	0	0	0	6	18	21	1	0	8	15	0	9	17	0	25	4	156
Introduced Grasses																	15		
<i>Agropyron desertorum</i>	0	0	0	0	0	0	22	22	0	12	2	2	0	10	11	1	22	11	139
<i>Bromus inermis</i>	0	0	0	0	0	6	1	0	0	1	3	0	71	2	2	1	4	14	126
<i>Bromus japonicus</i>	0	0	0	1	47	26	0	2	1	0	3	2	0	1	2	0	3	7	124
<i>Bromus tectorum</i>	0	0	0	0	18	18	9	1	1	1	19	0	19	1	2	0	3	10	136
<i>Dactylis glomerata</i>	0	0	4	7	45	18	2	2	0	0	0	0	0	2	5	0	7	15	130
<i>Echinochloa crus-galli</i>	59	18	0	11	0	3	0	8	0	0	0	0	0	2	0	0	1	0	111
<i>Elytrigia repens</i>	0	0	0	0	0	7	23	10	3	0	8	6	0	13	25	0	37	0	126
<i>Phleum pratense</i>	0	0	0	0	0	1	26	14	1	0	0	0	32	3	16	0	19	7	107
<i>Poa bulbosa</i>	1	0	0	3	23	34	17	4	2	0	1	0	0	8	4	0	12	0	113
<i>Poa pratensis</i>	0	0	0	1	7	16	13	0	1	0	6	0	0	2	19	23	44	8	119

Table 7-2 Results of radiocarbon dating. Dates are from bulk sediments soil cores segments at all sites. Calibration of calendar ages from Stuiver, M., Reimer, P. J., and Reimer, R. W. 2005. CALIB 5.0. (<http://calib.qub.ac.uk/calib/>). * Data from pilot study cores.

Site	Depth	Radiocarbon Age	Calibrated Calendar Age (1 Sigma Ranges)	Calibrated Calendar Age (2 Sigma Ranges)
Site 1A	9-10cm	> Modern		
	14-15cm	370 ± 25	Cal AD 1458-1515 Cal AD 1598-1617	Cal AD 1449-1524 Cal AD 1558-1631
Site 1B	9-10cm	410 ± 35	Cal AD 1439-1491 Cal AD 1603-1611	Cal AD 1429-1522 Cal AD 1573-1628
Site 2	4-5cm *	>Modern		
	9-10 cm	510 ± 30	Cal AD 1410-1435	Cal AD 1328-1341 Cal AD 1395-1445
Site 3	4-5 cm*	> Modern		
	9-10cm*	> Modern		
	14-15cm	695 ± 30	Cal AD 1274-1298 Cal AD 1372-1378	Cal AD 1264-1310 Cal AD 1360-1387
	19-20cm	905 ± 35	Cal AD 1044-1098 Cal AD 1119-1142 Cal AD 1147-1174	Cal AD 1037-1209
Site 4	9-10cm	540 ± 30	Cal AD 1329-1340 Cal AD 1396-1426	Cal AD 1317-1354 Cal AD 1389-1437
Site 5	9-10cm	250 ± 35	Cal AD 1529-1547 Cal AD 1634-1688 Cal AD 1781-1798	Cal AD 1519-1593 Cal AD 1619-1681 Cal AD 1738-1753 Cal AD 1762-1802

Table 7-3 Detailed core analysis results from Site 1A. Relative abundance of phytolith morphotypes expressed as a percent of the grass total for grass morphotypes. Relative abundance of the blocky morphotype (*Artemisia*) expressed as a percent of the sum.

Segment Age	Depth in centimeters	Extraction weight	Stipa type	Plate wavy short	Plate wavy deep lobes	Plate wavy long	Long cell smooth	Long deeply indented	Long cell indented	Square-based hair	Round-based hair	Oblong knobby hair	Pyramidal rondel	Keeled rondel	Horned rondel	Total rondel	Blocky (<i>Artemisia</i>)	Grass Total	Sum
Modern	0-1cm	6	1	4	5	18	23	2	16	3	2	4	10	10	3	23	6	215	228
	4-5cm	8	0	3	3	27	25	1	14	1	4	1	10	8	1	20	6	205	219
	8-9cm	10	3	4	3	20	28	0	12	2	3	1	6	12	6	24	6	212	226
Pre-Modern	9-10cm	11	2	2	3	27	31	0	10	0	3	1	15	5	2	22	6	213	227
	10-11cm	11	3	1	4	26	29	0	8	1	4	1	9	10	4	22	5	216	227
	11-12cm	11	3	4	7	22	26	0	13	1	2	1	9	7	4	20	7	216	233
	12-13cm	15	4	4	5	26	26	0	8	2	2	1	12	2	6	21	2	204	209
	13-14cm	12	1	3	12	25	18	0	7	0	1	0	5	17	9	31	6	204	217
	370 ± 25	14-15cm	11	3	7	13	18	19	0	10	1	3	0	6	10	9	25	4	211
	15-16cm	10	2	3	13	14	23	0	9	0	2	0	11	11	9	31	1	203	206
	16-17cm	16	2	2	7	18	24	1	10	1	4	1	9	14	7	30	2	221	226

Table 7-4 Detailed core analysis results from Site 3. Relative abundance of phytolith morphotypes expressed as a percent of the grass total for grass morphotypes. Relative abundance of the blocky morphotype (*Artemisia*) expressed as a percent of the sum. See Table 7-2 and text for details on segment ages. Extraction weights are expressed as percents of total sample weight (2 g).

Segment Age	Depth in centimeters	Extraction weights	Stipa Type	Plate wavy short	Plate wavy deep lobes	Plate wavy long	Long cell smooth	Long deeply indented	Long cell indented	Square-based hair	Round-based hair	Oblong knobby hair	Pyramidal rondel	Keeled rondel	Horned rondel	Total rondel	Blocky (<i>Artemisia</i>)	Grass total	Sum
Modern	0-1cm	8	2	2	6	33	26	0	11	2	2	3	3	7	3	13	4	214	222
Pre-Modern	9-10cm	16	2	2	6	22	29	0	10	2	2	0	8	9	8	26	8	202	220
	10-11cm	16	8	1	8	20	24	1	10	0	3	1	3	10	11	24	5	225	238
	11-12cm	25	9	3	8	18	23	0	10	1	4	1	5	9	10	23	3	222	228
	12-13cm	17	5	2	7	18	24	0	7	2	2	0	6	16	8	30	4	228	237
	13-14cm	17	4	1	8	25	24	0	5	2	1	1	8	12	8	28	5	212	222
695 ± 30	14-15cm	8	5	3	8	16	24	0	12	0	3	0	7	10	9	27	4	229	238

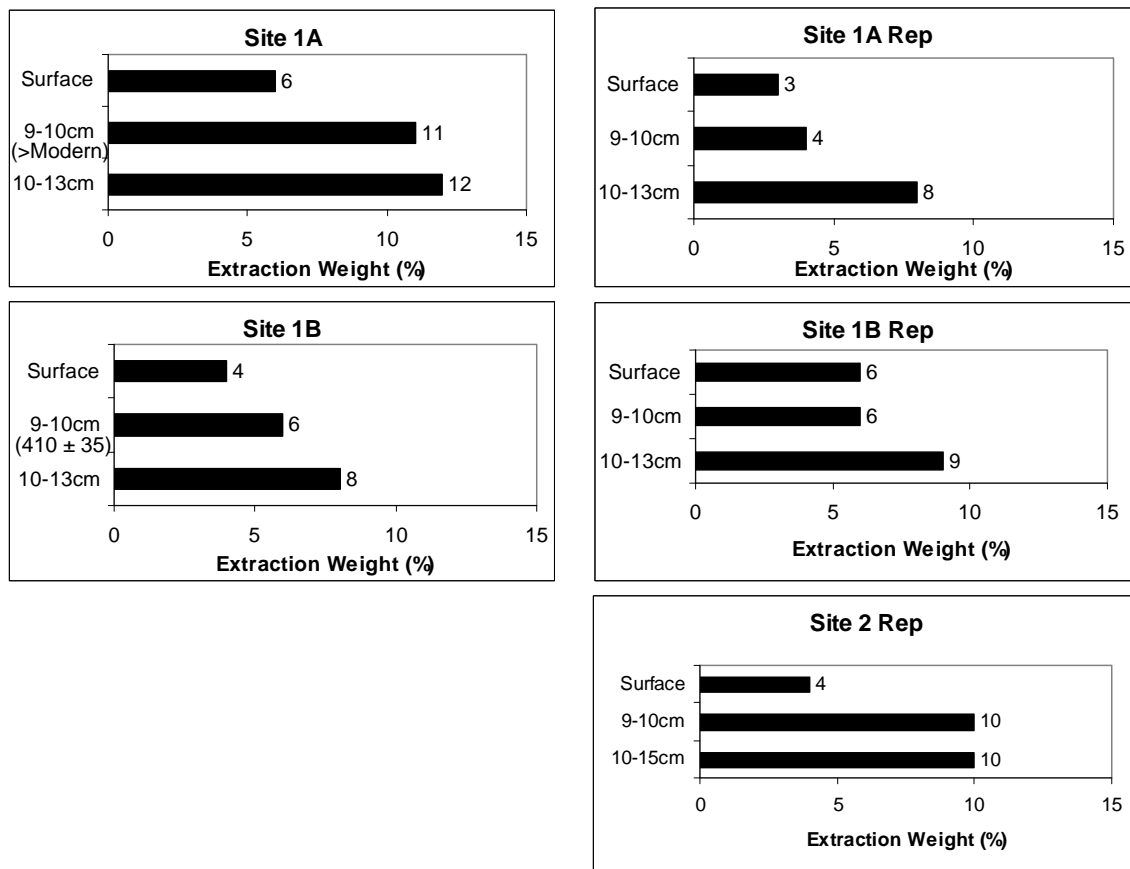


Figure 7-1 Percent extraction weights for unburned sites. Primary core and replicate core for sites that had not burned in at least 100 years (Morris, 2006b). The first core for Site 2 was destroyed during mishandling in the laboratory. Radiocarbon dates in years before present are presented parenthetically when available.

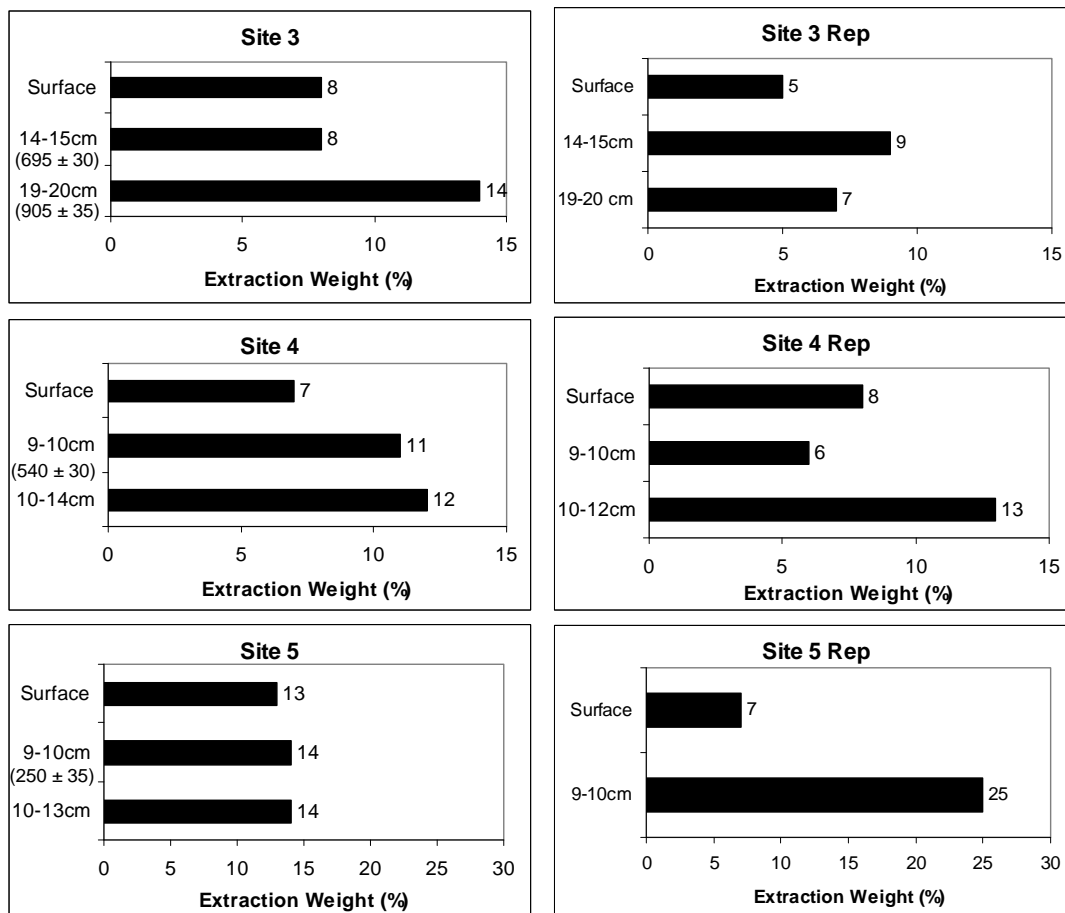


Figure 7-2 Percent extraction weights for burned sites. Primary and replicate cores are from sites that burned in 1999 and 2000 (Morris, 2006b). Radiocarbon dates in radiocarbon years before present are presented parenthetically where available.

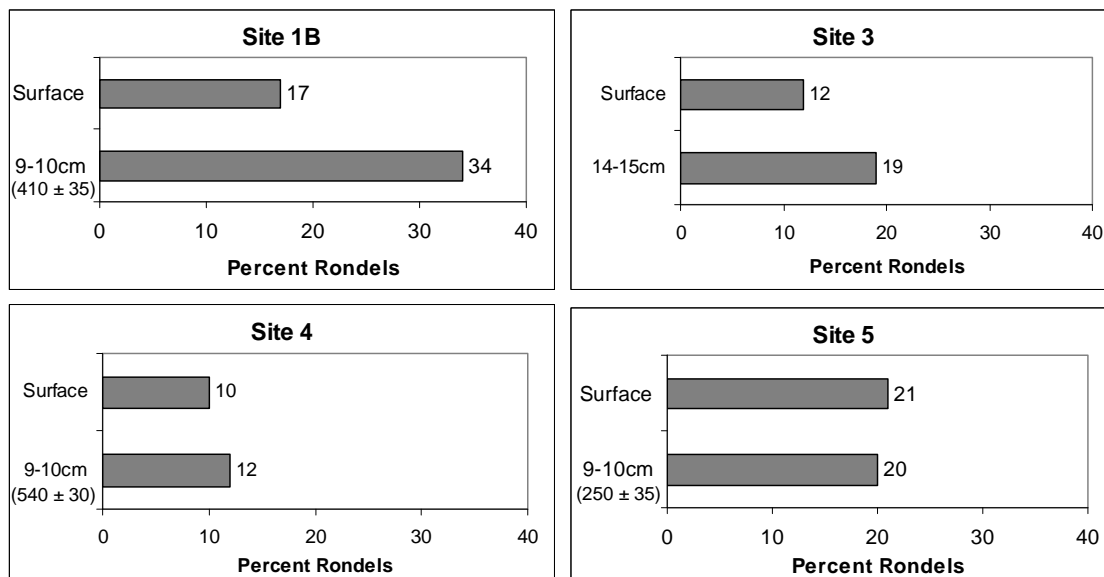


Figure 7-3 Percent rondels at four sites that were dominated by the introduced grass, *Bromus tectorum*. The information is expressed as all rondels counted, divided by the sum of all grass morphotypes multiplied by 100 to give percent rondels. Dates in radiocarbon years before present are presented parenthetically when available.

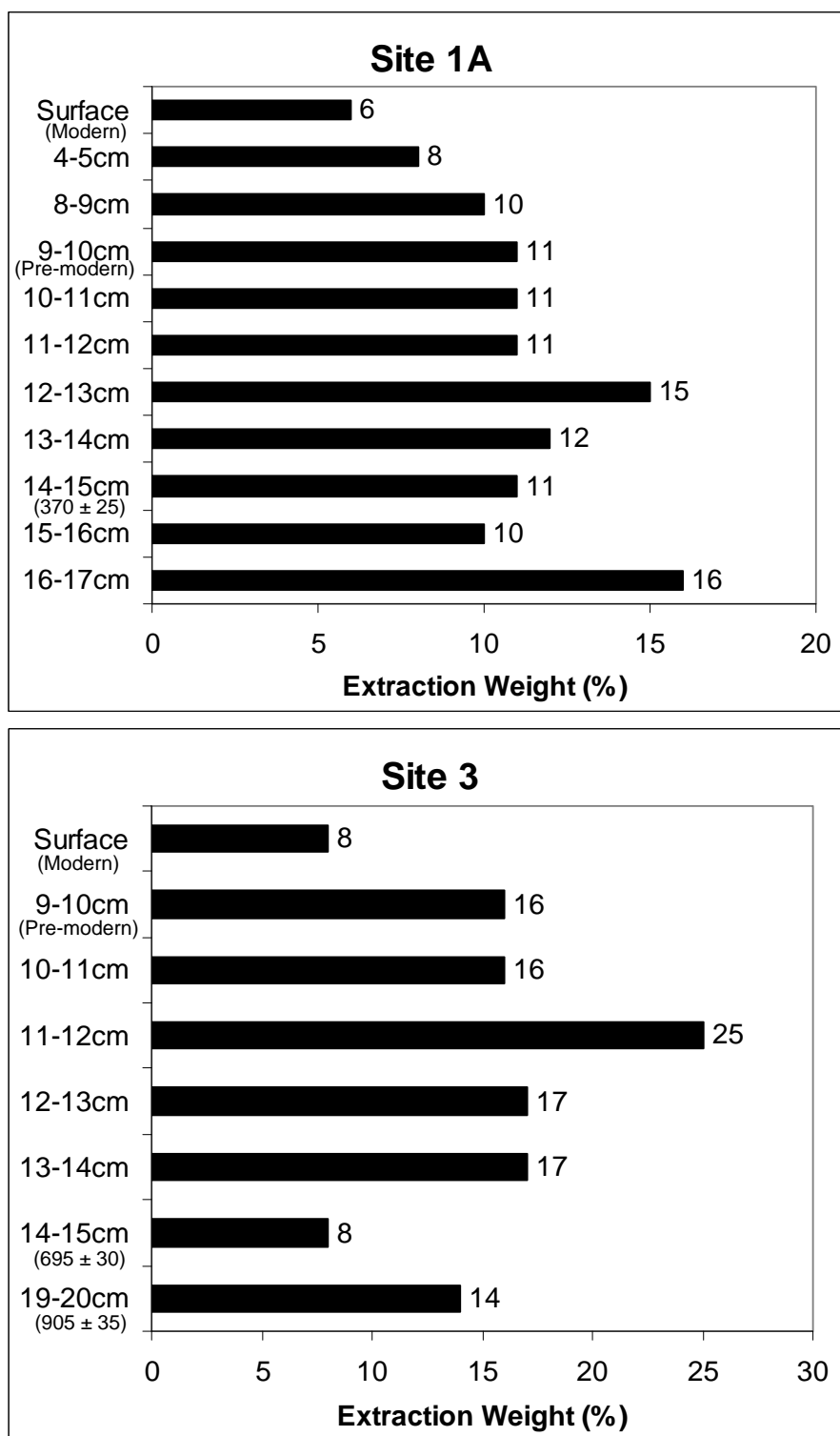


Figure 7-4 Percent extraction weights for detailed analysis cores. Site 1A is in a pinyon-juniper woodland and Site 3 is in a former pinyon juniper woodland that burned in 1999 and is now dominated by introduced grasses and forbs. Segment ages are provided parenthetically where available.

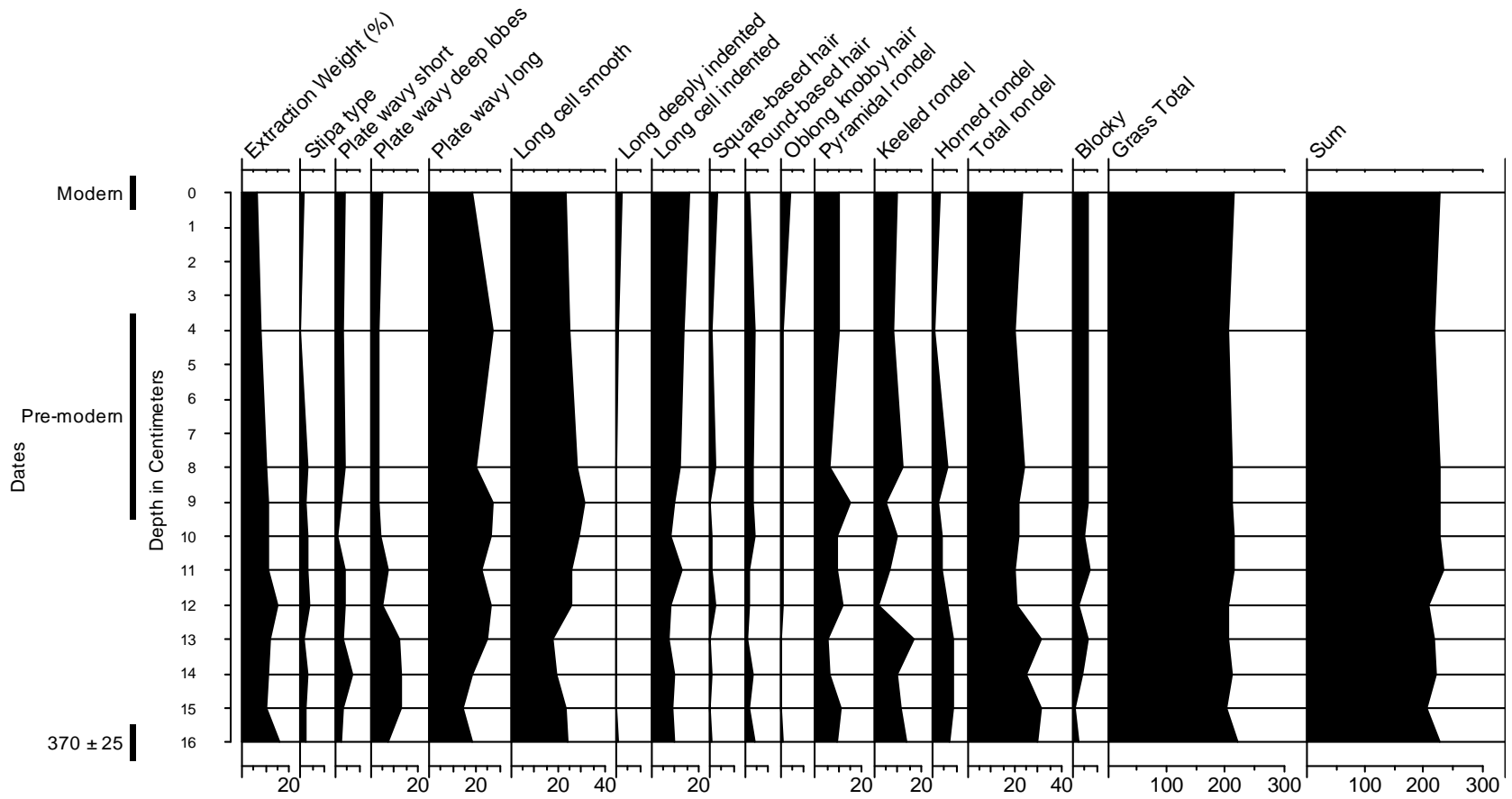


Figure 7-5 Phytolith percent diagram for detailed core at Site 1A.

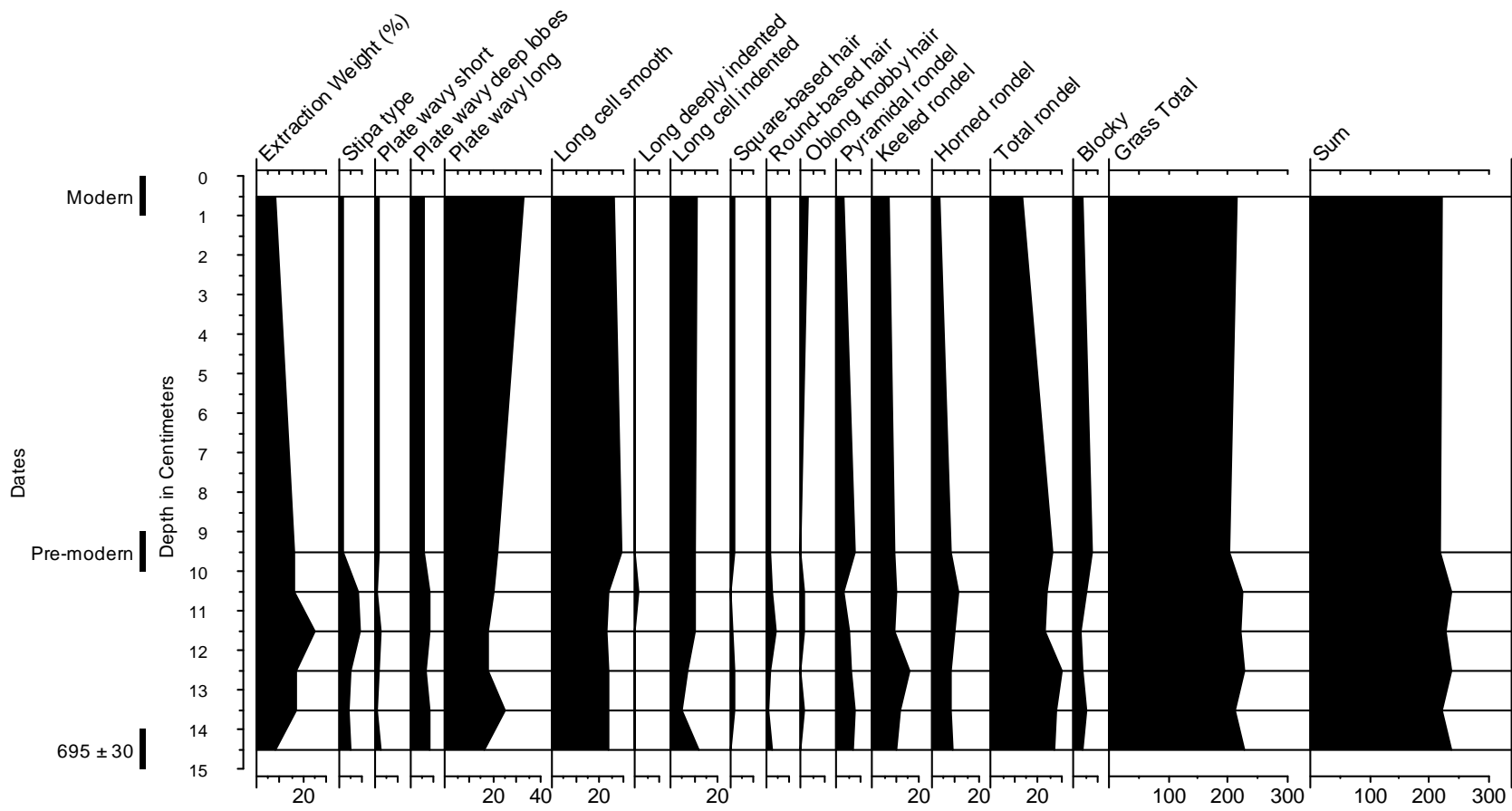
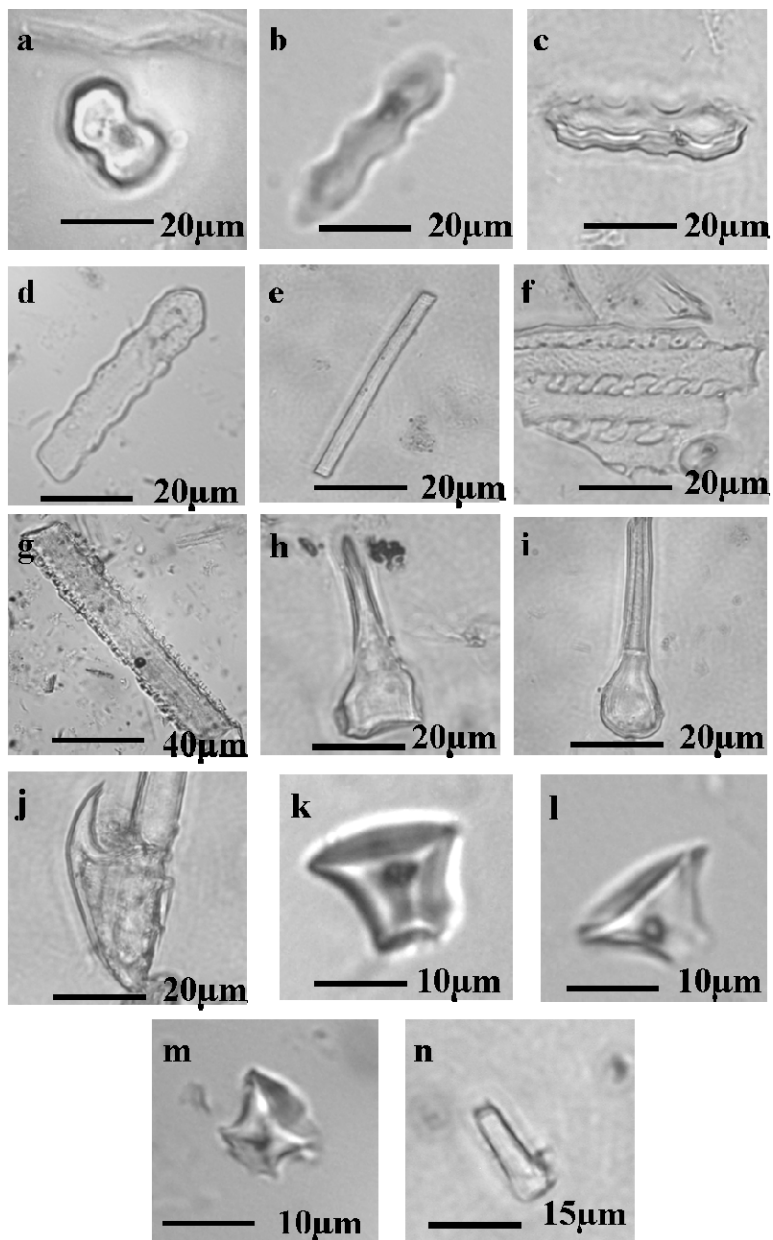


Figure 7-6 Phytolith percent diagram for detailed core at Site 3.

Plate 7-1 Morphotypes used in phytolith assemblage analysis; (a) stipa type (b) plate wavy short (c) plate wavy deep lobes (d) plate wavy long (e) long cell smooth (f) long deeply indented (g) long cell indented (h) square-based hair (i) round-based hair (j) oblong knobby hair (k) pyramidal rondel (l) keeled rondel (m) horned rondel (n) blocky



CHAPTER 8

CONCLUSIONS AND FUTURE RESEARCH

Conclusions

There were two interconnected objectives for this dissertation research. The first was to reconstruct an ecological history of the City of Rocks National Reserve from the period of overland emigration to present, approximately the last 200 years. The second objective was to explore the utility of soil phytolith analysis for inferring vegetation and disturbance regime change over the past 200 years by testing its sensitivity to record known changes. These objectives were addressed by examining the human archive for evidence of ecological change, particularly in vegetation. Then, using these known changes, I developed hypotheses and tested if the soil phytolith stratigraphy recorded them. The results demonstrated that the multiple land use changes, coupled with changes in climate and fire have resulted in vegetation that is different in many ways from what it was approximately 200 years ago. Soil phytolith analysis appears to hold promise as a biological proxy for understanding historic and prehistoric environmental conditions and fire histories. By testing for and finding a pattern suggesting the similarity to the changes from the human archive, biological data was added to support the claims summarized by historical documents.

In addition to the findings from each of the four general questions that we addressed to meet the objectives, there is another important conclusion that can be drawn from the culmination of this work. Much of the historic land use impacts are still visible on the landscape. Based on this, we can assume that the influence of those historic land

uses have had lasting impacts that deserve deeper consideration. These land uses are the stage upon which the dynamics of competition, facilitation, plant soil interactions or other mechanisms are acting. Therefore, in addition to demonstrating how important it is to consider the multiple causes of change, the ecological history at the City of Rocks National Reserve demonstrated very clearly that land use history should be included in all projects seeking to understand ecological dynamics, conservation, preservation, or restoration. The history of an area influences every part of the ecosystem and cannot be separated from it if we seek knowledge of its function for management or theory. History is important for management actions directed at the landscape as well as the people who visit it. In fact, interpretative programs for the public regarding the dynamics of ecosystems and the legacies of all types of land uses are the most immediate application of this study and others like it.

Of course, there are limitations to the soil phytolith analysis methods explored in this dissertation, such as location and sampling. Interpretation of the soil phytolith record in these chapters was linked to known changes in vegetation and modern analogue studies. Until more work has been done to refine the interpretation of the soil assemblages, this method is limited to areas with a rich human archive. Even with carbon dating, the human archive was essential in locating areas with a relatively stable soil profile. It is also limited to the sagebrush steppe and pinyon-juniper woodlands. Continuous sampling has not been tested in other ecosystem types and there is reason to believe that it may not be portable. For example, grassland soils have faster soil turnover and development and more soil fauna than these more arid systems. In addition, the fires that sweep across grasslands happen more frequently and have a higher transportation

potential. Therefore, buried A horizon comparison may be a better method in grasslands rather than the continuous sampling developed here.

Continuous sampling and multiple core soil phytolith analysis is also limited by sampling issues. Soil cores with stable one centimeter segments are difficult to obtain in the field. Once the cores are collected, the segments have to be radiocarbon dated. Dating each segment in a core is cost prohibitive, so only a selected number of segments can be used. If the soil cores were not deep enough or the soils too mixed to represent the timeframe of interest, that sampling site can be lost from the study. Sample size is also limited by the processing and counting time in the laboratory. It typically took a whole day to extract the phytoliths from two samples and 1-2 days to dry. Counting the phytoliths and/or charcoal required an average of 2 hours per slide. Similarities in extraction weight were the quickest way to determine if the cores from the same site were usable in this study. However, counting phytoliths and comparing assemblages for patterns is the best (and most time consuming) way to decide if the soil stratigraphy has been stable over the period of interest. Past and present soil disturbance is by far the greatest limitation to interpretation.

Future research

Even with the limitations discussed above, I believe the methods developed here hold great promise. There is, of course much more work that can and should be done in this regard. I have briefly outlined some ideas here in three areas that I think should be explored next: modern analogue studies, multi-proxy data combinations, and fire history chronosequences.

Both the multiple core and detailed core analysis presented in this dissertation suggest that the soils in these two ecosystem types can be stable and well stratified enough to explore more questions about vegetation change over the past 200 years as well as into the Little Ice Age. Our interpretations were aided by the modern analogue studies completed by researchers in other regions of the American West. However, there are differences between the Columbia Basin and the Great Basin ecosystems soils, plant communities and climate. Therefore, modern analogue studies comparing current vegetation to soil phytolith assemblages directly under them would be very useful for better interpretation of the historic assemblages that are recovered in the Great Basin. In addition, these modern analogues could be investigated with various climate variables using ordination analysis.

Another area of future research that would add strength to the ability to interpret soil phytolith assemblages would be through multi-proxy combinations. Phytoliths have been successfully paired with pollen studies and microscopic charcoal in lacustrine sediments. There are fairly protected sampling locations around caves and rock outcrops where all three proxies (phytoliths, pollen and microscopic charcoal) could be combined to provide a more complete picture of vegetation change and the impacts of fire and humans. Soil phytolith analysis could also be coupled with packrat midden analysis. Packrat middens are known to provide good historical and palaeoecological data about the presence and absence of tree species (like pinyon and juniper) that phytoliths will not be able to offer.

Finally, the potential is there for more development and understanding of burned phytoliths and microscopic charcoal in terrestrial sediments. Our modern analogue study

showed recognizable differences between burned and unburned sites. It would be useful to carry through with these modern analogue and taphonomy studies at a number of locations where there were known fires to see if the signal of the historic fire is visible in the soil profile. With varying dates since the last fire, it would also be useful to examine how long that signal is recognizable in the soil profile. More work should be done to explore fire and taphonomy of phytoliths with fire at sites with low slopes and relatively stable soils.

Significance of this research

The work presented in this dissertation demonstrates how important and revealing the human archive is for understanding ecosystem change and function. In addition, my work is the first time that soil phytolith analysis has been tested and employed as a method for inferring vegetation and disturbance regime changes in these ecosystem types, in continuous sampling of soil sediments and over this time scale. The applications of the human and biological archive methods developed in this research will be beneficial for understanding sagebrush steppe and pinyon-juniper woodlands, two widespread and highly threatened systems in the Intermountain West. They can be adapted to examine a variety of questions in other systems in future research. Therefore, this research contributes significantly to the advancement of the methods in historical ecology and the field of ecology as a whole.

APPENDIX

June 2, 2008

Lesley R. Morris
 Department of Wildland Resources
 Utah State University
lesleymorris@cc.usu.edu

Quaternary International
 Department of Geography
 Memorial University of Newfoundland
 St. John's NL A1B 3X9
 Canada

To the Editor:

I am preparing my dissertation in the Wildland Resources Department at Utah State University for completion in the summer of 2008. An article in your journal, of which I am the first author, and which will be published by your journal reports an essential part of my dissertation research. I would like permission to reprint it as a chapter in my dissertation. (Reprinting the chapter may necessitate some revision.) Please note that USU sends dissertations to Bell & Howell Dissertation Services to be made available for reproduction.

I will include an acknowledgment to the article on the first page of the chapter, as shown below. Copyright and permission information will be included in a special appendix. If you would like a different acknowledgment, please let me know. Please indicate your approval of this request by signing in the space provided, and attach any other form necessary to confirm permission. If you charge a reprint fee for use of an article by the author, please indicate that as well.

If you have any questions, please send me an e-mail message at the above address. Thank you for your assistance.

Sincerely,

Lesley Morris

I hereby give permission to Lesley R. Morris to reprint the requested article in her dissertation with the following acknowledgment:

Lesley R. Morris, Neil E. West, Fred A. Baker, Helga Van Miegroet, Ronald J. Ryel. Developing an approach for using the soil phytolith record to infer vegetation and disturbance regime changes over the past 200 years. *Quaternary International* (2007), doi:10.1016/j.quaint.2007.08.040

Signed _____

Date _____

Fee _____

Jim Catto
 2 June 08
 0

June 13, 2008

Lesley R. Morris
Department of Wildland Resources
Utah State University
lesleymorris@cc.usu.edu

Helga Van Miegroet, Professor
Department of Wildland Resources
Utah State University
Logan, UT 84322-5230

Dear Dr. Van Miegroet,

I am preparing my dissertation in the Wildland Resources Department at Utah State University for completion in the summer of 2008. I would like your permission to reprint the article we co-authored from Quaternary International as a chapter in my dissertation. Please note that USU sends dissertations to Bell & Howell Dissertation Services to be made available for reproduction.

I will include an acknowledgment to the article on the first page of the chapter, as shown below. This permission letter will be included in a special appendix. If you would like a different acknowledgment, please let me know. Please indicate your approval of this request by signing in the space provided, and attach any other form necessary to confirm permission.

If you have any questions, please send me an e-mail message at the above address. Thank you for your assistance.

Sincerely,

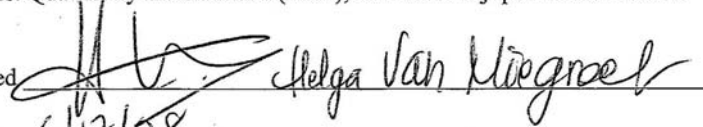
Lesley Morris

I hereby give permission to Lesley R. Morris to reprint the requested article in her dissertation with the following acknowledgment:

Lesley R. Morris, Neil E. West, Fred A. Baker, Helga Van Miegroet, Ronald J. Ryel. Developing an approach for using the soil phytolith record to infer vegetation and disturbance regime changes over the past 200 years. Quaternary International (2007), doi:10.1016/j.quaint.2007.08.040

Signed

Date


6/17/08

CURRICULUM VITAE

Lesley Argo Morris
(June 2008)

EDUCATION:

Master of Science, Policy and Management, December 2001
Department of Environmental Studies, University of Nevada, Las Vegas, Nevada.
Thesis – Challenges for the New West: Economic Impacts of Wilderness in Nevada's Rural Counties

Bachelor of Arts, Political Science, December 1995
Department of Political Science, University of New Mexico, Albuquerque, New Mexico.
Minor - Psychology Focus - Environmental Studies

TEACHING EXPERIENCE:

Co-Instructor, Utah State University, Logan, UT, Spring 2007

- * Initiated new course with Ron Ryel, Ph.D., "Special Topics: Historical Ecology"
- * Designed curriculum, lectured and directed reading discussions for 12 graduate and undergraduate students

Teaching Assistant, Utah State University, Logan, UT, Spring 2005

- * Lectured, led study/review sessions, maintained class website and library reserve readings, and graded exams with Neil West, Ph.D. for the undergraduate course "Wildland Ecosystems".

Guest Lecturer, Department of Wildland Resources, Utah State University, Logan, UT, Fall 2006

- * Lectured for Helga Van Miegroet, Ph.D. on "The use of phytoliths in soil science and historical ecology" for a graduate/undergraduate course "Wildland Soils".

Graduate Assistant, University of Nevada, Las Vegas, 1999 to 2002

- * Prepared lecture outlines, presentations and web page resources for David Hassenzahl, Ph.D. in undergraduate course "Humans and the Environment".
- * Prepared exams, graded exams and assisted students for George Busenberg, Ph.D. in undergraduate course "Humans and the Environment".

PROFESSIONAL EXPERIENCE:

Historical Ecologist, Bio-West, Inc. 2003-2004

- * Interviewed long time residents of the Meadow Valley Wash in Southeastern Nevada to assess baseline ecological conditions for an environmental consulting firm.

PROFESSIONAL EXPERIENCE CONTINUED:

Meadow Valley Wash Conservation Planning Team Member, The Nature Conservancy, 2002 – 2003

- * Participated in conservation planning workshops hosted by the Nature Conservancy

Research Assistant, University of Nevada, Las Vegas, Summer 2002

- * Reviewed archival documents and conducted interviews of key personnel at various National Parks for an environmental history project concerning fire policy in the National Park Service for Principal Investigator, Hal Rothman, Ph.D.

Noxious Weed Inventory Assistant, Environmental Careers Organization, Caliente, Nevada, Summer 2001

- * Planned, coordinated and implemented a noxious weed mapping project for approximately 500,000 acres of public land in the Ely District of the Bureau of Land Management in southeastern Nevada.
- * Created maps of noxious weed populations using ESRI Arc View and Pathfinder software

GRANTS:

- * National Science Foundation (Co-PI), Doctoral Dissertation Improvement Grant, June 2007.
- * Ecology Center Graduate Stipend, Utah State University, July –December 2007,
- * Ecology Center Graduate Research Support Award, Utah State University, July 2007.
- * National Park Service (Co-PI), Challenge Cost Share Program Grant, July 2006 – February 2008.
- * National Park Service (Co-PI), Challenge Cost Share Program Grant, July 2004 – March 2006.
- * National Park Service (Co-PI), Research and Map Fire History Grant, July 2004- June 2006.
- * Ecology Center Fellowship, Utah State University, July 2004-June 2005.
- * Ecology Center Fellowship, Utah State University, July 2005-June 2006.
- * Ecology Center Graduate Stipend, October 2005-June 2006.
- * S.J. and Jessie E. Quinney Ph.D. Fellowship, College of Natural Resources, Utah State University, Fall 2002-2004.

SCHOLARSHIPS AND AWARDS:

- * Utah State University School of Graduate Studies Dissertation Fellowship, 2007-2008.
- * Best Speaker Award, 2nd Place, Utah State University 10th Annual Graduate Research Symposium, 2007.
- * Utah State University Graduate Student Senate Travel Fund Award, 2006.
- * Terry Lynn Steel Award, 2005.

SCHOLARSHIPS AND AWARDS CONTINUED:

- * Sigma Xi Honor Society, 2004.
- * Utah State University Honor Roll, 2002-2005.
- * Gary Smith Scholarship, College of Natural Resources, Utah State University, 2003-2004.
- * Phi Kappa Phi Honor Society, 2001.
- * Outstanding Service Award, Bureau of Land Management, Ely District, Summer 2001.
- * Graduate Research and Training Assistantship, University of Nevada, Las Vegas, Summer 2000.

PUBLICATIONS:

Morris, L.R., West, N.E., Baker, F.A., Van Miegroet, H., Ryel, R.J. (In press) Developing an approach for using the phytolith record to infer vegetation and disturbance regime change over the past 200 years. Proceedings of the 6th International Meeting on Phytolith Research. Quaternary International.

<http://dx.doi.org/10.1016/j.quaint.2007.08.040>

Morris, L.R. (In press) Using emigrant diaries to examine historic environmental conditions along the California Trail in the City of Rocks National Reserve, Idaho. Overland Journal.

Morris, L.R. (In press) The Changing California Trail: a journey in repeat photography in the City of Rocks National Reserve, Idaho. Overland Journal.

Morris, L. 2006a. Ecological history of the City of Rocks National Reserve, Part I: the human archive. Report prepared for the City of Rocks National Reserve, National Park Service Pacific Northwest Region, 107 p.

<http://www.nps.gov/ciro/naturescience/naturalfeaturesandecosystems.htm>

Morris, L. 2006b. Fire history of the City of Rocks National Reserve from 1926 to 2005. Report prepared for the City of Rocks National Reserve, National Park Service Pacific Northwest Region, 20 p. <http://www.nps.gov/ciro/parkmgmt/firemanagement.htm>

Rigas, M.L., Hassenzahl, D.M. and **L. Argo** 2002. Population Extremes, pp. 5-17. In: Nevada Environmental Issues, D. Charlet (Ed.), Kendall-Hunt Publishing Co: Dubuque, IA.